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Human-like Perception for Psychoanalytically Inspired Reasoning Units

Perceptual Information Processing Concepts Realized in the ARSi12 Framework Implementation

DISSERTATION

zur Erlangung des akademischen Grades

Doktor der technischen Wissenschaften

by

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Erklärung zur Verfassung der Arbeit

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Abstract

Artificial perception architectures deal with problems that the human mental apparatus flawlessly solves. The benefit in human perception lies in the combination of information from various sensory sources, with previously experienced perceptual memories in order to condense a multimodal and subjectively consistent view of the world. Insights of human-like functionalities in perception extend the possibilities of cognitive architectures. However, a holistic view on human perception and cognition in technical artificial agent architectures is yet to be investigated.

This work describes a bionically inspired framework of perception in a control unit for an embodied software agent architecture. The focus is on the realization of neuro-psychoanalytic concepts for processing mental perceptual data. This approach, new to Artificial Intelligence, allows the design of perceptual functionalities inspired by the human mental apparatus in a cognitive agent architecture.

The existing decision unit is extended in a top-down modeling approach by investigating the perception-action cycle and the resulting adaptions are implemented in the embodied agent computational software framework ARSi12. The resulting model shows how data from a multimodal sensory system is condensed into mental data structures, how they are associated with knowledge of the individual agent and how this information is processed to decision making.

Use cases are used to evaluate the agent abilities inside the multi-agent artificial life simulator ARSin world, developed as a test platform to evaluate the functional model and decision unit.

Kurzfassung

Architekturen künstlicher Wahrnehmung befassen sich mit Problemen, die das menschliche Gehirn problemlos löst. Der Vorteil der menschlichen Wahrnehmung liegt in der Kombination von Informationen aus verschiedenen sensorischen Quellen mit zuvor erlebten Wahrnehmungs-Erinnerungen, die eine multimodale und subjektiv konsistente Sicht auf die Welt generieren. Erkenntnisse aus Funktionalitäten in menschlicher Wahrnehmung erweitern die Möglichkeiten kognitiver Architekturen. Allerdings muss eine ganzheitliche Sicht auf die menschliche Wahrnehmung und Kognition in technischen künstlichen Agenten-Architekturen noch untersucht werden.

Diese Arbeit beschreibt ein bionisch inspiriertes Framework der Wahrnehmung, in einer Kontrollarchitektur für körperbasierte Software-Agenten. Der Fokus liegt auf der Realisierung von neuro-psychoanalytischen Konzepten für die Verarbeitung von mentalen Wahrnehmungs-Daten. Dieser neue Ansatz für Künstliche Intelligenz ermöglicht die Modellierung von Wahrnehmungs-Funktionalitäten, inspiriert durch den menschlichen psychischen Apparat in einer kognitiven Agenten-Architektur.

Die bestehende Kontrollarchitektur wurde in einem Top-Down-Modellierungsverfahren durch die Untersuchung des Wahrnehmungs-Aktionen-Zyklusses erweitert und die daraus resultierenden Anpassungen sind in dem körperbasierten Agenten-Framework ARSi12 implementiert. Das resultierende Modell zeigt, wie Daten aus einem multimodalen sensorischen System in mentale Datenstrukturen verdichtet sowie mit Wissen der einzelnen Agenten assoziiert wird und wie diese Informationen zur Entscheidungsfindung beitragen.

Use Cases werden verwendet, um die Fähigkeiten der Agenten innerhalb der Artificial-Life Multi-Agenten-Simulation ARSin world zu bewerten, die als Testplattform entwickelt wurde, um das Funktionsmodell und die Entscheidungsfindungs-Einheit zu evaluieren.

Contents

Abbreviations

ACT-R	Adaptive Components of Thought-Rational
AGI	Artificial General Intelligence
AI	Artificial Intelligence
ALCOVE	Attention Learning COVEring map
A-Life	Artificial Life
ALIVE	Artificial Life Interactive Video Environment
APPLE	APProximately ALcove
ARS	Artificial Recognition System
ARSi12	ARS implementation number 12 (v38j)
ARS-PA	ARS-PsychoAnalysis
ARS-PC	ARS-PerCeption
BASE	Building Automation System for Safety and Energy Efficiency
BDI	Believe-Desire-Intention
BICA	Biologically Inspired Cognitive Architecture
CAAT	Cognitive Agent Architecture and Theory
CogAff	Cognition and Affect
CS	Cognitive Science
DeSTIN	Deep SpatioTemporal Inference Network
DM	Drive Mesh
EPIC	Executive Process Interactive Control
GCM	Generalized Context Model
GWT	Global Workspace Theory
IBCA	Integrated Biologically-based Cognitive Architecture
LIDA	Learning Intelligent Distribution Agent
MAS	Multi-agent System
MASON	Multi-Agent Simulator Of Neighborhoods… or Networks… or something…
NPSA	Neuro-Psychoanalysis Society
PAM	Perceptive Awareness Model
RCS	Real-time Control System
SEAL	Smart Environment for Assisted Living
SENSE	Smart Embedded Network of Sensing Entities
SmaKi	Smart Kitchen
SOAR	State, Operator And Result
SUSTAIN	Supervised and Unsupervised Stratified Adaptive Incremental Network
TP	Thing Presentation
TPM	Thing Presentation Mesh
UML	Unified Modeling Language
WP	Word Presentation
WPM	Word Presentation Mesh
XML	Extensible Markup Language

CHAPTER 1

1. Introduction

At every instant the human mind is capable of perceiving a great amount of information from the environment. The cognitive processes of perception and decision making of the human mind handle huge amounts of data and still react in real-time to the environment.

To cope with the rising demands of building automation, Dietrich [Diet00] and his research team at the Institute of Computer Technologies introduced a bionic[1] approach to the field. Especially the areas of data processing and interpretation lacked solutions capable of dealing with the ever-growing amount of data. The introduced biologically-inspired concepts for field bus networks [Diet00, p.43, DiSa00, p.7] showed a new way to deal with the problems. The model is inspired by Freudian psychoanalysis, ten years later within the same research group, a new bionically inspired model for decision making in autonomous embodied agents was introduced [Lang10]. The goal is to find solutions for technical problems, by learning from the cognitive processes of the human mind. Decision making is highly influenced by different types of perception. This thesis introduces a perception framework for the autonomous agents based on neuro-psychoanalytical[2] findings.

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[1] The term bionic comes from the Greek word bios, meaning life, and is used to describe where nature is examined to take inspiration from in order to solve other e.g. technical problems.

[2] Neuro-Psychoanalytic Society (NPSA) is the movement within neuroscience and psychoanalysis to combine the insights of both disciplines for a better understanding of mind and brain [3].

1.1 Into the Field of Machine Perception

Intelligent control, inspired by biological principles, has increased the understanding and capabilities of complex automation processes. The elaborated solutions are a step in the right direction in understanding complex systems for customized applications. However, research in this field has yet to provide a solution for the problems arising with autonomous systems operating in real-world applications. To be situated in a complex world, generates the demand of perceiving this world. Processing this huge amount of incoming data is a complex task that all artificial systems lack an overall solution. An expectation gap between the envisioned artificial autonomous systems and the currently realizable systems has developed. This gap has arisen as a result of AI, Robotics and Automation Systems falling short on their promise to provide intelligent and effective solutions for highly dynamic real environments.

To use an example, a robot equipped with a state-of-the-art perception and decision-making system is not capable of bringing me a cup of coffee from the institutes' kitchen, as described later in this chapter.

A system getting near on fulfilling the above task would be bulky, expensive and inflexible - thus, could not be used in any other kitchen in the world - and would still require a human operator to watch over it. Given the example, the question arises: Is it possible to span the expectation gap with today's technology? Is it possible to overcome the problems we are facing by using the same methods we used in the past? Or do we need a different kind of thinking, when we try to reproduce the same level of intelligence and interaction that humans show?

Various research groups are taking promising steps towards fulfilling this expectation gap (e. g. [AnLe03, p.36, SoSo09, p.5]). Yet no architecture seems to address all problems arising when trying to build a truly intelligent system for a real environment. The partial fulfillment of complex tasks brings us nearer to understanding the isolated task, but drags us nowhere nearer in understanding the whole process involved in human-like intelligence and acting in the world.

According to [ThBr95, p.1], robots – as any other artificial system – face some obstacles that prevent the widespread use of those systems. They lack the ability to generalize to a variety of tasks, leaving the challenging task of reprogramming and specializing on the next task to the operator of the system. Another problem we face is that artificial systems cannot adapt to their environment. They lack the ability to operate in unfamiliar situations for which they have not been developed. This leaves operation of such systems in real-world environments as the most complex task. The third boundary we face is the poor error recovery of artificial systems. Handling of new environmental conditions or tasks anticipated by the real world, often lead to unexpected states for which they have not explicitly been programmed [ThBr95, p.1].

Great achievements facing those problems have been produced when we look back at the development of AI and ‘intelligent’ systems. Despite the progress in different research fields we still face huge restrictions in describing and developing solutions for the problems above. As Norbert Wiener – one of the founders of intelligent systems research – stated that interscientific work [Wien65, p.8] is the source for solving problems, and so we need to make a closer look at other scientific disciplines and integrate their results in the process of finding new solutions for the problems we face.

Technical systems are growing in complexity, as they have to handle an increasing amount of sensor data [DiZu08]. This is particularly true with systems and thus sensors becoming interconnected. This cannot easily be handled by systems using traditional approaches. Current technologies are facing bottlenecks and limits. Classic approaches to computer systems are no longer able to handle and interpret the rising number of sensor nodes and data. This is especially true with building automation where the amount of sensor nodes within a building increased from several thousand to more than five hundred thousand nodes [Diet00] and [DFZB09]. A problem current technologies and models face. Another problem is shown by [Russ03, p.12]. He states, that current building automation systems are reactive systems. Reactive systems cannot cope with unfamiliar or unforeseen situations.

Humans perceive a huge amount of information from the environment at every instant and only a fraction of this information is processed [RLPW07, p.1] and used to create a model of the surroundings for further decisions. Artificial perception systems need to process the data in a similar way as they are also faced with redundant information from their sensor systems. More sophisticated methods of extraction of specific features coming from the perceptual data flow are needed to limit the incoming information. Moreover, the needs of the user as well as the specific layout of sensor systems and the purpose to the user of the recognized perceptual object have to be considered in the perceptual process. The problems which arise when designing biological inspired perceptual systems have led to significant efforts dedicated to the design of perceptual models that mimic the structure and functionality of human perception [RLPW07, p.2].

A need for new solutions in the field of building automation, intelligent systems and perception arises. The new solutions need to take the three major problems into account. They need to cope with unfamiliar situations, especially in a real world environment. They need to be able to generalize to a variety of tasks to lose the high impact of the operator of the system. The third is the need for more stable systems capable of dealing with unexpected errors. To the general problems another problem regarding perception should be added. The need of a system to associate perceived symbolic information with possible actions for informed decisions.

The complexity in these problems cannot easily be handled with traditional technological approaches. It is necessary to look for new solutions to the problems. A promising approach to the problems is by using bionic models. By learning from nature we can extract models and solutions for the complex tasks we are facing [DiZu08, pp.12–16]. Following the bionic approach, first concepts were realized within the project SmaKi (Smart Kitchen) [FDDR01, Russ03], at the Institute of Computer Technology at the Vienna University of Technology. After the first bionic approaches (see Section 2.5 for details), a novel approach was formulated by Brainin et al. [BDKP04] by using neurobiology, psychology and psychoanalysis for system design. The work on previous systems and the introduction of the interdisciplinary approach formed the foundations for the project ARS (Artificial Recognition System). The main purpose of ARS is to generate a functional model of the human mental apparatus based on findings in Psychoanalysis. The target applications are autonomous agents populating a simulated –Artificial Life – world, and beyond. More on the ARS project and existing preliminary work can be found in Section 2.5.

1.2 Problem Statement

Artificial systems are often specialized on a specific task. The core element of the project ARS is to not specialize on specific action but to research a general model which is capable of or more general problem solving. The task of perception in this general model is to provide the decision unit with information from the world and bodily states. The human perceptual system processes only a fragment of sensorial information (e. g. *"… makes assumptions to fill in details outside of the focus of attention"* [Ward10, p.126]) and still provides the decision-unit with a stable impression of the environment. With the help of an example in this section, several considerations are formulated that guide the work on the sketched topic. In the example, it is shown how perception can be influenced by other factors than the physical sensing of the world. By deriving research questions out of the example, the focus of this thesis is presented in detail and the problem statement implicitly sketched by the previous sections is made explicit. The motivation as well as the research considerations are pointed out. In this chapter the above is summarized into the task of this work, how this is achieved and possible realizations are given.

1.2.1 Motivation

The ARS project is modeling the mental apparatus as a whole. This includes all areas the human individual is capable of:

- From perceiving the environment to recreating subjective experiences of the perceived.
- From looting the right demands out of the endless stream of information coming in, to find the right wishes for the individual.
- From deciding for the most prominent wishes to find a plan to fulfill them and finally.
- From planning the execution to actually shaping the physical world to satisfy them.

Not all problems regarding the above capabilities of the human mental apparatus are solved yet, but a lot of work has been done regarding decision making [Lang10, pp.49–64], information representation [Zeil10, pp.80–88] and modeling the whole human mental apparatus in a functional model (e.g. [DBZM09, DeZL07, DFZB09, DiBr10, DTMZ09]).

The concepts and findings described above use concepts from psychoanalytical metapsychology to model and implement a computational framework. The main goal – applications for building automation – is still a primary focus, but to test the implications of the resulting model the target platform has shifted to an embodied autonomous multi-agent simulation. The concepts and findings can still be translated to building automation, with respect to the different 'body' used [LBVD09]. The main research focus is on the decision making part as this is the most complex system in the human mental apparatus. In order to understand how we humans come to a specific decision, it is mandatory to have a look to the whole system. A decision is based on internal needs of the body, external perception, how this percepts are interpreted, what experiences the individual has learned in the past and finally what decisions would be possible in the real world.

Using the ARS model for decision making, the aim of this thesis is to show the detailed path of a percept from the beginning to the end and to develop methods for extracting meaningful information out of the perceived information stream. The use of a simulation to bring the model to test has its advantages: parts of the model that would mean a great effort dealing with can be postponed for later. The same functionality can be achieved by using a shortcut in the simulation, to focus on the more relevant parts right now. The focus on decision making lead to a simplified framework for the gain of information out of perceptions. In order to implement the model in a real-world application e.g. a robot it is necessary to bring the spotlight back to the perception part, where the project once originated.

To summarize, the scientific motivation for this work is the following:

By using concepts based on neuro-psychoanalysis the aim of the project is to create an autonomous decision unit capable of informed acting in a real-world environment. By using this model in connection with a comprehensive perception model it is - for the first time - possible to model and simulate the interaction of perceptual information gathering and psychoanalytic inspired decision making. This work connects the models of perception based on neuroscientific findings to the functional model derived by psychoanalytical metapsychology. At last, this work is a step further in implementing the model in a real-world application e.g. a robot or building automation application.

1.2.2 Problem Description Based on Examples

In the following several considerations are formulated on the above sketched topic. They are formulated by following an example that makes the need for them clear. The defined basic assumptions and considerations are used throughout the thesis and guide through the modeling process.

Coffee in the Kitchen

Inspired by the work of [Russ03], this example uses the idea of the SmaKi and extends it by looking at a process so easily happening every day in the institute's kitchen.

Assuming we have a situated autonomous agent – a robotic device – capable of moving around and interacting in a kitchen, just like any human could do. The kitchen itself is a normal kitchen: an entrance door, a water sink, a cupboard full of plates and mugs, a refrigerator and of course a semi-automatic coffee-machine. A typical scenario occurring around the kitchen every morning could look like this:

A human individual as well as a robot are given the task to get some coffee. The individual is approaching the kitchen, where the kitchen is, is clear by the fact that the sign next to the door says so. Although any member of the institute knows the entrance to the kitchen it happens that the wrong door is used, because the adjacent doors look the same.

This error is due to the fact that the perceptual system of the human brain is actually only perceiving a fraction [WuCM12, p.14] of the environment. The rest is subjectively added by memories and knowledge of the individual [Dama00, p.184, Solm02, pp.153–156]. This is necessary to filter the huge amount of information not needed for the decision, in this case what door to use. Sometimes this can lead to misinterpretations, but most of the time it is necessary to filter the posters on the wall next to the door, the patina and scratches of the door itself, the detailed color of the doorknob and so on to summarize to higher order information. The information needed here is: which one is the door to the kitchen and how to open it.

Statement 1: Perception is generated not passively perceived.

The individual approaches the right door, the decision is based on reading the sign or by activated knowledge of past scenes with the same aim. At the door the next tasks arrives: How to open it?

We are not born with the ability to open doors. As most of the interaction in the environment, also this simple task is learned. This physical interaction with the environment is bound to the fact that we are physical beings acting with our physical body. When performing an action in the environment we remember the appropriate action and prepare the body for the task [Solm02, p.27]. These predictions also add to the perceptual process of extracting meaningful information out of the incoming stream of percepts.

Statement 2: Perception is not just perceiving sensor data, it is also forecasting the actions that can be done.

Another ability of the mental apparatus is the classification of information into a semantically organized tree of data. There is not just one type of doorknob in the world. Every existing type can be recognized and the according perceptual knowledge and action knowledge is adjusted to any new type we get to know.

Statement 3: Perceptual knowledge is semantically organized together with action knowledge and can adapt to new information.

The kitchen door is opened. The individual approaches into the room and orients itself.

Orientation to a new room takes up to 30 seconds [LaMR99]. In this time the individual is projecting the knowledge about other rooms, kitchens in this example, to the actual situation. This functionality enables us to use maps, landmarks and navigation aspects, so that we can find our way in unfamiliar new territory.

Statement 4: Actual state, learned knowledge and evaluation of percepts are strong influences on the perception process.

In the example the protagonist is entering the kitchen in order to get a cup of coffee. But let's assume the individual can't remember why it came here. The question is why did it come here? After a few seconds and opening the senses to the impacts of the room the answer arises: I want a coffee!

Either the coffee machine came into sight, or the smell of previous coffee brewing found its way through decision making. In fact it is a combination of both or even more senses. Vision is the main sense for humans, but the influences of others are joined for a multimodal image. The other senses complete the picture of possible actions. But we are not driven by external perception alone. The needs of the body have to be taken into account represented as drives generated in the mental apparatus. Various inputs are formed by different mental functions into a wish of the individual and possible actions to fulfill it.

Statement 5: The influence of multimodal senses is essential for perception and decision making where unimodal perception is ambiguous.

Statement 6: Perception is a highly integrated process. Gathering data from external sensors, the needs of the internal systems of the body and subjective memory activation of past events cannot be separated from each other and influence one other. A look at the whole system is needed in order to model perception.

The individual takes a mug from the cupboard, faces the coffee machine, places the mug where it should be and presses the button for a coffee.

To get coffee, the information is needed that this is a liquid, liquids need a container to be put in. This knowledge is learned and we don't think about it. Some individuals may not even think about the process at all. The scenario is abstracted, and the next step in this scenario demands a mug for the coffee.

Statement 7: Scenario information adds to the perception process and active perception for objects in the scenario is influencing the process. Perception is an active not passive process.

The machine responds to the button but not with the expected action. Something is wrong. The individual searches for clues and finds the answer: No water in the tank. After searching for the water tank and filling it with water from the sink (the right hand automatically opens the right faucet for the cold water without looking at it), the process concludes again and is finished with a cup of hot coffee.

Either the individual knows that water is essential to the coffee brewing scenario or the information perceived from the machine leads to an intermission of the original scenario and a whole sub scenario is added. The process with the right hand is automated and only adoptions of the sensor-motoric feedback are necessary to conclude the process.

Statement 8: Perception can be divided in automated processes*[3] *and processes needing attention, indicating unconscious and conscious processing of perceptual data.

The scenario ends with the desired outcome for the individual. On its way out the individual passes the robot that is still standing there and figuring out what door to open and how.

This simple example raises questions and describes the enormous functionality the perceptual systems are capable of. The problems arising when trying to model this functionality will be discussed in this thesis.

Additional Statements

Robotics, cognitive science and AI are working on perception and provide the community with different frameworks for agents. The approaches are using statistical or symbolic concepts and implementations. Some researchers use insights in neurology or biology or investigate the human decision-making and perceptual systems themselves. They use descriptions of cognitive processes in

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[3] Automated processes can be further divided into reflexes, routine actions and unconscious actions. The focus on this thesis is on unconscious processes.

order to project them into the technical realizations. Cognitive architectures in the past combined different theories from several scientific areas and failed to close the expectation gap we are facing now. The project ARS however is working on a unitary model of the human cognitive processes. The unified psychoanalytical theory the project is using serves as a topmost layer. Together with psychoanalytic advisors, functional descriptions of the layers below are generated and serve as specifications for the top layer for implementation.

This thesis relies on the unitary model and the functional descriptions of the psychoanalytic advisors and extends the model with a detailed view on the perceptual processes. New concepts and functionalities are discussed with the international advisor-team to make sure to avoid conceptual flaws. This leads to the last two and most important statements and basic premises, crucial for the following work:

Statement 9: Neuro-psychoanalytical theory and especially psychoanalytical metapsychology provides a unitary functional description on the human's perception and decision-making process.

For the interdisciplinary work a clear methodology for the modeling approach is used.

Statement 10: To ensure the necessary integrity of the implementations and in order to verify and integrate the model, a strict top-down approach will be used in design of the model.

The considerations formulated above guide the following work and sketch the topic. The ten statements define basic assumptions and conditions. The first two statements indicate that perception is an active process not a passive one. The next three statements focus on the data basis the perceptual system of the brain uses to enrich the raw perceived information, mainly memory and experience. Statements five to eight focus on how perceptual data is processed and what influences occur in the process. The last two statements deal with the used approach in this thesis.

The Statements above show how the human mental apparatus goes from desire to planning and fulfillment of actions by using memory and perception as the main source of input. The same stays true when dealing with cognitive architectures for autonomous embodied agents. A holistic and complete concept of the mental apparatus is needed to model all influences to the process of perception. The very nature of the human mental apparatus is that especially memory and the influences to it on the path to a conscious perception have a deep impact on the outcome. The above statements are a minimum set focused on the topic of perception in the human mental apparatus. In order to design the perceptual framework of this thesis the other parts of the model of the project ARS are essential and interdependency as such will be discussed in the following chapters in detail.

1.2.3 The Focus of this Work and the Basic Assumptions

The basic assumptions and conditions formulated in the last chapter define the general requirements and implications for a psychoanalytic inspired perception framework. The aim for this thesis can be condensed to:

The focus of this thesis lies on the perception- and the decision-making cycle and the interaction between those two systems. The main task is to transform concepts of neuro-psychoanalysis into a *technical feasible model of the perceptual system and integrate it into the functional decision making model of the project ARS. The model will be evaluated in an autonomous multi-agent A-life simulation by extending the embodied situated agent with the psychoanalytic perception framework.*

Although the main focus is on perception, the whole second topographical model by Freud has to be looked at as far as influences to perception appeal. The holistic view during the modeling-process is a paradigm of the project and thus this also stays true for extending the perception part. As a result the modules and interfaces of the whole model of the mental apparatus have to be dealt with. The modules of the Super-Ego and decision-making are sketched briefly. Also the descriptions of the bodily functions involved in drive generation are only touched as far as influences to the perception generation dictate importance.

The model of the project ARS, as well as the work on this thesis use neuro-psychoanalysis as a foundation. Psychoanalysis itself and Neurology is out of scope of this thesis. Where needed the concepts of the interdisciplinary sciences are examined to explain the technical feasibility of the model herein. In order to implement the model several simplifications on the body and sensor parts had to be made. A realistic simulation of a human body is out of scope of this thesis and would derive from the focus of perceptual information processing. The introduced system works similar to a realistic body whit the benefit of portability to other applications as far as the interfaces allow it. Nevertheless, the system is rich enough to provide sensorial input to test the theories within this thesis.

Evaluation of the model is done in a test-bed inspired by A-life simulations. Inside this test bed the world is designed to meet the research needs. A use case is defined for every experiment that includes start situations, conditions and desired outcome. The basic premise of the project ARS is that the inspected agent has the psyche of a normal human adult. The age is set to 30 years and thus the memory is prepared for every object the world has in it. Learning of new objects is out of scope of the project as of now and is also not considered in this thesis (only mentioned in future work as far as perceptional memory goes).

1.2.4 Bridging the Interdisciplinary Theories

One of the aims of interdisciplinary research in the project ARS, in which the author of this thesis is working in, is the development of a technical-psychoanalytic formalization. A formalization inspired by an axiomatic system. Therefore the psychoanalytic metapsychology is reduced to statements that are said to be non-contradicting within the psychoanalytic theory. These axioms are propositions that are not proved or demonstrated but considered to be self-evident. Their truth is taken for granted and they serve as a starting point for deducing and inferring other (theory dependent) truths.

Freud for example was compelled to borrow the vocabulary of the language as it existed, but in order to yield the meanings and insights he meant it to communicate he had to distort and extend it. Hence a completely new language gradually crystallized in Freud’s hermeneutics of human epistemology [LaPo73]. For the work on the technical functional model terms from neuroscience, psychoanalysis and especially neuro-psychoanalysis had to be grounded to the same meaning and thus creating a shared language for engineers and psychoanalytic advisors.

Throughout this thesis, terms and definitions coming from the different research areas are pointed out and where necessary, the formalization of terms is clarified. A group of definitions can especially be found in the Sections 2.5 and 3.1.

1.3 What This Work is Not About

This thesis follows the unitary modeling approach of the project ARS. The perception model described here is highly integrated in the decision model as described in Section 2.5.2. Further details on the model of the decision unit can be found in [Lang10]. A detailed description on the information representation part of the model can be found in [Zeil10]. A focus on the drive and the Id parts of the model can be found in [Deut11].

In this thesis the decision making processes of the functional model is only described to make clear where the interaction to perception is taking place. It is needed to clarify where the perceptual information is processed to and how it influences later decision making processes. It is shown how perceptual information is saved and organized, how they are used in the process but not how the information is processed in the functions of the decision unit if not necessary for the explanation. A look on every process of the human mental apparatus would go beyond the scope of this thesis but can be achieved by studying the other major publications of the project ARS. The suggested further readings are mentioned in the according Sections 2.5.2 and 2.5.1 of the next chapter.

The functional model is derived from findings in psychoanalysis. Although psychoanalysis is a foundation of the project, psychoanalysis itself is out of scope for this thesis. The concepts used are only introduced where required for technical feasibility and to understand the derived definitions. The same stays true for neurological, physiological and anatomical findings where excerpts of the theories are used to ground the inspiration taken of the human body and mental apparatus.

1.4 Methodological Approach

The project ARS follows a new approach. The reasons why can be found in the next Section by pointing out why old approaches have been abandoned and the advantages leading to the new approach. The use of psychoanalysis leads to common objections as stated by [Deut11, p.5]. A summary of those objections is discussed in the following Section. The use of interdisciplinary theories required a clear methodical approach as pointed out by [Deut11, p.6]. A revised and extended design process can be found in the Section following.

1.4.1 Modeling Approach

The use of bionic approaches for the development of technical models has proved to be successful in the past. The field of bionic influenced models is wide spread but unfortunately especially in AI the use of other sciences is often bound to development of task models instead of process models. Especially when using terms from human sciences as inspiration one has to be careful. Many AI projects were and are still labeling mechanics that have nothing to do with the original concept. The term emotion for example [Slom04, p.128] is often taken from various fields like psychology, behaviorism, neurology and psychoanalysis as well as other definitions (exemplary projects from [Brea02]). As stated by [Deut11, p.2] usually the theory that fits best to the task at hand is taken without attention whether the underlying assumptions are consistent. Deutsch [Deut11, pp.3–4] further states five failures commonly made when dealing with other sciences as influence to AI models:

Misunderstanding what terms and concepts provided by human sciences are: Terms in human sciences are often used not to describe the thing itself but describe in short a model. They are already abstractions made in other sciences in several layers apart from the inspected subject. In order to use the term one has to investigate and understand how other researchers abstracted the concept and not use the simplistic view on these sketches (e.g. [Slom01, p.178]).

Integration of these concepts into control systems: The example here is if the concept of memory is taken from psychology and then integrated into a cognitive architecture (e.g. Ho et al. [HoDN03] and [Broo91a]) several problems arise because the used architecture is not grounded in the same theories and thus several problems arise while integrating them.

Neglect of possible information overload in interdisciplinary projects: Researchers are confronted with different knowledge bases, methods and terminology [LePf02, p.70] when working outside their scientific community. Personal cooperation with scientist of the field of interest is needed.

Mixture of systems that have e.g. emotion and systems that show emotional behavior: Having an emotional expression is different to labeling some behavior that is interpreted by a human observer (e.g. Breazeal in [Brea01, p.584]).

Stating that a system can feel something: Mental states are subjective experiences [Solm02, p.xiii], it is wrong to state that a system feels something [Lori08, p.4]. It is only possible to implement mechanisms identified to be necessary for a mental state to – up to some extent – believe that the agent experiences a certain fleeing [Deut11, p.3].

The history of AI can, as stated by Palensky et al., divided into four generations. They are symbolic AI, statistical AI, embodied AI and emotional AI [PBTD08, Zeil10, p.5].

The bottom-up methodology used by a wide range of the AI research projects can be best defined as: *“The functionality of existing modules are enhanced piece-wise in order to gain a new system”* [DFZB09, p.419]. In order to solve complex problems not manageable [Zeil10, p.5] by using a bottom-up approach, engineers use the top-down approach which is defined by Dietrich et al. as: *“Top-down design refers to a design method that starts its design process with the problem to be solved or the task to be committed. The designer tries to identify the necessary functionality in order to overcome the problem. This functionality is then further subdivided until existing solutions can perform subtasks”* [DFZB09, p.429]. As stated by Dietrich et al [DiZu08, pp.12–17], a 5th generation of AI is needed to focus on common issues and avoid mistakes repeated in the history of AI. The ARS project proposes the 5th generation of AI as a possible path for progress.

The need for a top-down methodology as well as the use of a holistic model for the new approach derives from the insight that handling complex models is not manageable with a bottom-up approach

[Deut11, p.56]. The project ARS uses a bionic approach, for modeling the information processing of the human mind, that addresses the lacks of conventional systems in AI. After evaluation, the most promising theory of the human mind – neuro-psychoanalysis – is used for the project. It is used for the project because it is the only [Deut11, p.4] model that describes the mind in a holistic and unitary fashion. Also the requirement of the top-down approach is given by psychoanalysis by Sigmund Freud and his approach to research the human psyche. Using psychoanalysis the ARS project developed a functional model of the human mind that follows a generative approach as it describes the functions which describe behavior instead of building a behavior model [Scha12, p.5]. For the development of the functional model the first- and the second topographical model of the human mind by Sigmund Freud [Freu33, p.77, Solm02, p.99] are used. Freud distinct the human mind in conscious and unconscious processes and divides it in three abstract functional units *Id, Ego and Super-Ego*. With this as a starting point finer descriptions of modules have been generated in conjunction with our team of psychoanalytic advisors for every layer of the mental apparatus. A detailed description of the functional model can be found in Section 2.5.1. Especially the construction of the unconscious processes of the human mind is neglected by conventional AI [Scha12, p.5], as more focus was given to the rational process of the mind and logic. A focus on the unconscious process is but necessary, as a majority of processes are not based on the structured and logical methods of the secondary process [Kahn11, p.46, Scha12, p.5]. A more detailed description on the functional model and the theories used can be found in Section 2.5.2.

The approach fits into cognitive science as described by Gardner [Gard85, p.37]. Cognitive science can be described as one of the following six sciences: psychology, AI, linguistics, anthropology and neuroscience. Gardner pairs several sciences with strong interdisciplinary ties such as AI and neuroscience and some paring like AI and philosophy are weakly tied. In the project ARS the focus is on the triangle (see Gardner's hexagon [Gard85, p.37]) AI, neuroscience and psychology (especially psychoanalysis). According to Deutsch, this approach complies with the Artificial General Intelligence (AGI) approach (subset of AI). AGI aims at the general nature of human 'intelligence' [WaGo06, p.1], although a precise definition for AGI is not existent [Deut11, p.8]. AGI is used for development of models which support the ideas of creating human-level 'intelligence' by including at least a cognition cycle memory and learning.

According to Deutsch [Deut11, p.9] the ARS project can be seen as a member of the AGI projects [2], when comparing it to the (soft) requirements, with some limitations:

- The concept of learning is postponed until the functional model is implemented in the static form.
- In psychoanalysis there is no general definition of 'intelligence' only a general architecture how the human mind works, what can be translated as such.
- The open view other AGI-architectures share is not developed enough and thus makes it hard to compare as the implementation is still in construction.

A model following a holistic approach with the human mind das archetype cannot be reduced to a simple set of performance measures [DKPM11, p.3]. First it has to be proven that the design follows human-like behavior. Psychoanalysis is used for this step as the statistical approach shows a distinction between normal and abnormal human behavior. A standardized test-bed, like a multi-agent simulation is then used for performance evaluation. No standardized comparison platform exists for AGI, thus an evaluation of single models (e.g. [BeWa09, Bull08]) and comparison between approaches (e.g. [CoSu04, FGSW06]) is performed. Comparison between architectures is done narratively, single architecture tests are hand-crafted for this purpose. For standardized comparison of AGI control architectures requirements are: *"An interface which decouples the control architecture from the simulator, pre-defined tasks to which the agents are exposed to, possibilities to probe the internal states of the agents to provide more information for the manual review of its performance afterwards, a world which complexity meets the one of the to be evaluated models"* [DKPM11, p.1].

For the ARS project three different approaches to model evaluation can be used: test cases, use cases and psychological tests (more details on this topic see [DKPM11, p.3]). The ARS project has used test-cases and use cases up till now. The psychological tests follow for evaluation of believable human behavior (see Chapter 5 for more details).

The common ground all architectures share is the tasks they are exposed to. This makes the evaluation and comparison possible. The formulation of hypotheses and piecewise evaluation via use cases ensures the systematic approach and quality of the design [WBDK10, p.1].

Several use cases – textual descriptions of desired observable behavior with defined preconditions [DKPM11, p.3] – are defined for the project ARS (e.g. [Kohl08, pp.40–41]), where they are defined as a sequence of interactions between two agents (or the agent and the environment) with desired results in agent's behavior. *"The mere function of these use cases is to define a framework to enable evaluation and comparison of agents and their behavior in the simulation"* [DKPM11, p.5].

1.4.2 Modeling Process and Evaluation

From the descriptions supplied by psychoanalytic theories, functional descriptions and requirements are deduced using the top-down design approach. In consultation with the neuro-psychoanalytic advisors the originating model is refined until a technical implementation is possible. In order to model the framework, based on neuro-psychoanalytic findings, terms and definitions like perception, recognition and sensation have to be defined and elaborated in the interdisciplinary context. A model then is implemented that can associate current perceptions to memorized knowledge and thus form recognitions in the process. In order to do this a detailed analysis of the transported data on every layer in the model is necessary. The possibilities of the implemented perception framework are then tested by use cases and comparing recognition to other frameworks.

In the project ARS, in which the author of this thesis is incorporated, the problem of AI to mix incompatible theories is taken very serious. From the beginning interdisciplinary experts have been and are still part of the project and are integrated in the modeling process as well as in scientific publishing. In the beginning project meetings with our advisors were held every two months (publications: e. g. [BDKP04]). Since 2007 one or two psychoanalysts are employed in the project. This was done to intensify the modeling process and overcome the interdisciplinary challenge-tasks, as not only language but also the scientific processes are sometimes widely contradicting [DFZB09, pp.36–37, LBPV07, p.70].

In the project ARS we use a modeling process consisting of several steps. It is a repetitive algorithm with an initial step. Figure 1-1 shows a revised version of the process as shown by Deutsch [Deut11, p.6] with two additional steps for evaluation of use cases. The approach is, as stated by Deutsch, comparable to a scientific loop proposed by Franklin [Fran97, p.507] called Cognitive Agent Architecture and Theory (CAAT). The original process consists of seven steps and its main purpose is the development of intelligent autonomous agents. Reviewing the original process proposed by Franklin, the ARS modeling process has been enhanced by steps for creation of testable predictions (use cases) and implementation in the test-bed (simulation) as seen in Figure 1-1.

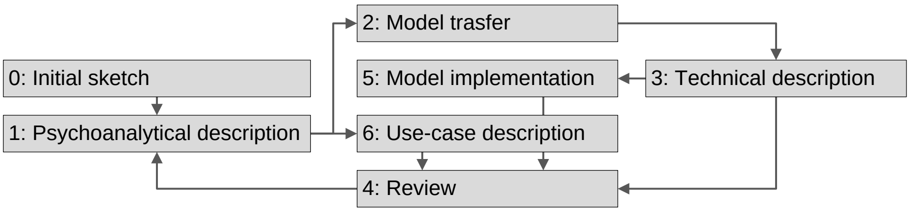

Figure 1-1: Revised modeling process of project ARS

0. Requirement analysis and rough sketch of the model made by psychoanalysts and engineers.
1. Description and extension of the initial sketch by psychoanalysts in their own language. The requirements for use cases for testable predictions are described by psychoanalysts.
2. Transformation of the descriptions into an intermediate model done by psychoanalysts and engineers.
3. Interfaces and the model itself are described by engineers in their language and form the descriptions for the functional model.
4. Knowledge gained from use case experiments and reviews of the functional model are used to rework the model to remove inconsistencies.
5. The model implementation is done by engineers parallel to the reviewing process.
6. After the implementation the reviewed use case descriptions are taken to design and carry out performance evaluations which influence the reviewing process in the next loop.

For the perception framework itself the evaluation is done via use cases describing tasks for the agents. In every use case given by psychoanalysis the perception part is highlighted and examined. Variations in the simulation lead to different use case scenarios which handle the different mechanics of the perception framework in different ways. For the framework itself use cases or scenarios were added that show details of the implementation where the psychoanalytic use case itself was not sufficient from an engineering perspective (the changes are reviewed with the psychoanalytic experts). In the simulation the performance evaluation was used by integrating the object knowledge of the simulator and the results of the model were then compared to the actual objects that had to be identified. This leads to objective comparison of the recognition tasks and supports the evaluation process.

Psychoanalytic theories are very detailed for the task they have at hand. But especially for perception not every mental function is described in a resolution fine enough for implementation. At this point theories from neuro-psychoanalysis are used in conjunction with the function model and with the help of experts in the field collaborating with the project ARS. Especially the works of Solms, Damasio, Wiest and Fodor (e. g. [Dama00, DFZB09, Solm02, Wies09]) enhance the view of the mental apparatus and make it possible to close the gap between understanding of neurology and psychoanalysis. Parts of this thesis even go further in the scientific fields of psychophysics and medical engineering, where the author of this thesis has a degree in.

CHAPTER 2

2. State of the Art

The increasing amounts of data that technical applications have to process make it necessary to find new approaches in modern information technology. Since the beginning of research in the area of AI this issue is one of the key aspects. The main elements of a model for artificial agents are perception, decision making, planning and action processing. Modern AI systems focus on the bionic approach by mimicking human cognitive abilities to perform general intelligent actions. The ability to sense and give the information gathered meaning is the most important task and main topic of this thesis. Interpretation of the world, or what sensors receive from the environment, is not trivial task. To reproduce the human perceptual system the mechanics and functionalities behind it have to be understood. Human perception is information processing and thus we need to understand how the information is processed and how the huge amount of data is condensed into meaningful symbolic information forge-driven processing [Styl05, p.12]. This distinction is central to understand the relationships between sensory processing, attention, perception, memory, recognition and sensation.

In the following different approaches in modeling the human perceptual process are discussed and categorized, keeping the focus on the perception part of the different models and how the findings of different sciences are used in technical perceptual systems. In Chapter 1 the next generation of AI, AGI was discussed. The following chapter focuses on the requirements for the topic of this thesis. In the first section the influences of embodiment and emotions to AI are discussed. The cooperation of the field of engineering and neuro-psychoanalysis is analyzed, in this context influences to the ARS model are discussed as well as the findings of R. Pfeifer, S. Turkle, M. Solms and A. Damasio. The discussion focuses on the information processing principles of the autonomous agent architectures. Next principles of human perception are discussed, again with focus on the information processing principles. The last section focuses on the modeling and implementation techniques used in the ARS model so far.

2.1 General Principles

Over the last three decades, research in AI has gone through several important paradigm shifts. Intelligence and cognition were perceived in a very logic and rule system way with the brain as archetype of a central processing system. The main mechanisms behind AI models were highly successful in dealing with very specific problems, especially to problems where the context could be made fully explicit. This led to very successful problem-solving architectures with limited environments they could be used in.

Problems that cannot be defined in an explicit and rational way, like the task of getting a cup of coffee from any kitchen in the world, these methods were not able to deal with. This led to the understanding, especially in the new research area of AGI, that problem-solving based on logic and rule system is only a small part a human-like 'intelligent' architecture have to encompass [Capd10, p.7]. To understand how living beings make sense of their environment and act accordingly requires taking into account:

- What they can do with their environment (*affordances of the environment*).
- How their physical properties can interact with their environment (*embodiment of the individual*).
- How possibilities are evaluated (*emotional and logic evaluation*).

Below, the role that *affordances*, *embodiment* and *emotions* play in AGI are discussed and are analyzed related to the concept building the ARS model.

2.1.1 Embodiment

When designing a human-like 'intelligent' autonomous agent it is not sufficient to look at the center of intelligence, the brain, alone. The connections between brain, body and environment are of fundamental importance, especially for information processing and perception. The importance of the connection to the body is best given by the quote from Pfeifer and Schleier:

"Intelligence cannot merely exist in the form of an abstract algorithm but requires a physical instantiation, a body" [PfSc99, p.649].

The key argument for perception is that the interaction, between the brain, body and the environment, shapes the sensory input and information processing [Send09, p.23]. In other words, the structure of the information processing system is modeled by the dynamic coupling between brain, body and environment in an embodied system.

Aside the fact that embodiment is widely discussed in the fields of cognitive science and especially in neuroscience, the concept has a great impact on the development of architectures for autonomous agents and robots. A broad definition of embodiment referring to it as the ability of robots was first given by Brooks:

"… have bodies and experience the worlds directly – their actions are part of a dynamic with the world, and the actions have immediate feedback on the robots' own sensations[4]*"* [Broo91a, p.1227]

Brooks focused on the system-environment interaction [Broo86, pp.14–23] in the mid-80's and introduced the so called subsumption architecture later. This architecture is based on the theory that intelligence emerges from several sub-components by interacting with the environment [Broo91b, p.3].

The term embodiment exists in different notions, thus Ziemke divided them into six categories [Ziem03, p.2]:

- Structural coupling between agent and environment with no restriction regarding physical or non-physical bodies.
- Historical embodiment resulting from a history of structural coupling where competence with the environment was gained by the agent.
- Physical embodiment that requires a physical body which excludes non-physical bodies like software agents.
- Organismoid (organism-like) embodiment refers to organisms like body forms and includes every living organisms from animals to robots.
- Organismic embodiment of autopoietic[5], living systems limits embodiment to organisms only.
- Social embodiment that defines social interaction social information processing.

The agents used for the perception system in the ARS project would qualify as orgasmoid embodied [Deut11, p.35] when including software agents into embodiment. In the next Sections the issues of physical and virtual embodiment regarding software agents are discussed.

In Figure 2-1 a simple view of an embodied agent is given by Russel and Norvig. Their definition of an intelligent agent [RuNo03, pp.32–54] develops from simple interaction to more and more complex views.

The same approach and a useful categorization is done by Chiel and Beer in [ChBe97]. Their categorization integrates interaction between the nervous system (brain), the body and the environment. The nervous system in this categorization is regarded as the central processing unit.

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[4] The term 'sensation' used differently by Brooks in this context, see Section 3.1 for a detailed definition of the term in this thesis.

[5] Autopoietic, is a term introduced by biologists Humberto Maturana and Francisco Varela [Matu80] for living systems that maintain themselves.

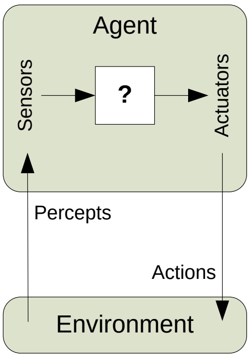

Figure 2-1: Notions of embodied agents [RuNo03, p.33]

A more and more complex view is then developed by the authors on the interaction between that central processing unit that uses environmental inputs and its internal state to plan future actions, and then generates motor commands to execute its plans.

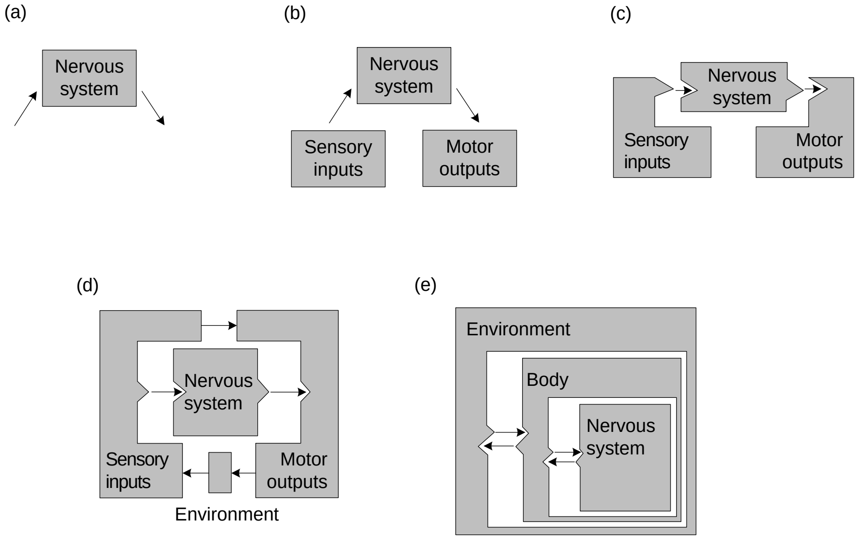

Figure 2-2: Interaction between environment, body and the nervous system [ChBe97, p.554]

In the simplest view shown in Figure 2-2 (a) the nervous system is assumed as the central role in the generation of adaptive behavior. In Figure 2-2 (b) the concepts is extended due to the fact that many sensory inputs are preprocessed by a separate system and outputs are transformed by separate systems of the body as well. The systems are still separate and only inputs and respectively outputs are processed to and from the nervous system. In Figure 2-2 (c), the co-evolution and co-development of the nervous system is taken into account and that the body led to extensive matching and complementarity between the sensory- and motor-systems. The matching and complementarity between the two systems is indicated by the projecting triangular regions. The next step of development in Figure 2-2 (d) the nervous system is also affected by feedback. Some of the feedback is coming from the motor outputs, some feedback is coming from the environment. The influence from the environment is processed through sensory inputs which influence on the other hand motor actuator directly. In the most complex view in Figure 2-2 (e) the nervous system is embedded within a body which is embedded in the environment. All three are rich, complicated, highly structures dynamical systems with a bi-directional communication between them and a direct coupling with one another. The adaptive behavior that emerges from the interactions of all three systems and behaviors that might emerge cannot be properties only of one of the coupled systems.

Applying the category of Figure 2-2 (e) to a model of the human mind and perception, the body and world have to be of fitting complexity. This paradigm stays true when taking the psychoanalytically described human mind, as archetype for building the model [Deut11, p.36]. The view is also supported by the findings of Pfeifer and Bongrad in [PfBo07]:

"… that one of the aspects of the principle of ecological balance is that the complexity levels of sensory, motor, and neural systems should match." [PfBo07, p.161]

When modeling a perceptual system around the complex view of Figure 2-2 (e), the implications above are taken into account and extended with details about perception and other findings of neuro-psychoanalysis.

The prototype implementation is realized in an artificial life simulation with embodied agents. In the following section the possibilities of using embodiment in a virtual environment is discussed.

2.1.2 Virtual Embodiment

Interaction of an agent with the world is the core element of embodiment. In [Deut11, p.36] a list of four demands to complete agents, the objects of study in this thesis, is given:

- Autonomous: they have to be independent of external control.
- Embodied: they have to exist as a physical entity in the real world.
- Situated: all information about the environment has to be gained from its own perspective through its own sensory system.
- Self-sufficient: they have to have the ability to maintain all their necessary resources by themselves. In this way they can truly operate independently in a real world setup.

These demands to cognitive agents lead with the list of essential properties [PfBo07, pp.95–96] to a list of design principles for embodied cognitive agents which can be found in [Deut11, pp.36–38]. The first essential property is of utmost importance regarding virtual embodiment in situated worlds:

"They are subject to the laws of physics: Each real world agent (artificial or biological) is subject to the laws of physics. When it moves it has to overcome friction, gravitation, etc." [Deut11, p.38, PfBo07, p.95].

This raises a problem: If embodiment is only possible when agents interact in a physical world, then can embodiment applied to virtual/simulated world? Brooks grounds the problem by stating that *"… to build a system that is intelligent it is necessary to have its representations grounded in the physical world"* [Broo90, p.5]. From this point of view even the notion of virtual embodiment may sounds like a contradiction in terms. It also implies that for the demands of embodiment to be fulfilled a physical body has to be provided.

To conclude, Pfeifer and Bongard [PfSc99, p.91]: *"… unlike virtual worlds, the real world challenges an agent in various ways"*. The real world…

- …requires time to extract information from it;
- …extraction of information is always partial and error prone;
- …is not neatly divisible into discrete states;
- …requires agents operating in it to do several things at once;
- …and finally the real world changes of its own accord, not only in response to agent action.

So, the *"real world is challenging and 'messy'"* [PfBo07, p.92].

The work of Kushmerik provides a more open view on embodiment where he claims that physical requirements can be replaced by computational ones by sets of simplifications [Kush97, p.233], although one has to be aware that simplifications in a virtual world hinder understanding of model and behavior in full extent [PfBo07, pp.78–81].

The reason why embodiment is important to a psychoanalytically inspired control architecture and perception framework is discussed in the next Sections.

2.1.3 Artificial Sensor Systems

In human-inspired agents, interaction with the environment takes up a large part of the models. Also interaction between agents is highly important especially for cognitive inspired agents. Interaction with the environment is possible through awareness of the environment, this awareness is achieved through an agent's perceptual system [HeGA05, p.2]. Agents with a perceptual system following this paradigm are embedded, through internal representations of the world and of themselves, in the environment they interact with. This is also a paradigm of embodiment (situatedness) which was presented in Section 2.1.2. When following this paradigm then an agent who perceives an object inside a virtual world and has an internal representation of the object, then the agent will be aware of the object.

The term awareness is used slightly different in various sciences and a detailed view of the term from psychoanalysis and psychophysics is given in Section 2.2.4. From the embodied cognitive agent view awareness is defined by Dourish and Belotti [DoBe92]. They define awareness as *"… an understanding of the activities of others which provides a context for your own activity"* [DoBe92, p.1]. To give the agent the capability to experience the environment awareness is important but the above definition implies a broader definition of the term to 'social awareness' which includes interaction with several other functions of the human psyche.

Artificial sensor systems for perception are built in different ways to fulfill various aims and features of the agent systems. Following [HeGA05, p.363] most artificial sensor systems can be implemented in different ways.

Focused on processing of sensory input with a simplified decision unit to process the perceptions, or focused on the agent's decision unit (mostly cognitive inspired control architectures) where the perception process is less important. Simulated agents have been modeled with different aims in mind depending on what they were designed for.

Sensor systems can be implemented in different ways. Some focus on introducing sensory inputs as artificial creatures. The artificial fishes of Tu and Terzopoulos [TeTG94] or the animated dog of Blumberg [Blum97] are examples of the approach. The prescribed artificial fishes introduce a vision-based perception for fishes. The new paradigm introduced for vision research consists of artificial animals, situated in a virtual world based on a physics simulation. The simulated virtual animals possess an active perception system and can autonomously control their eye movement. On the actuator side they are equipped with autonomous muscle-actuated bodies. The virtual fishes emulate the motion, behavior and appearance of real fishes. They are capable of 'recognizing'[6] objects and navigation guided by perception.

The other example mentioned is the ALIVE (Artificial Life Interactive Video Environment) system created by Blumberg [MDBP93]. The autonomous dog is placed in an artificial 3D environment and equipped with synthetic vision to fulfill its main goals: satisfy internal motivations and obey the user. Interesting in this approach is the use of internal values which indicates the note of the homeostasis concept.

Both approaches mimic biological animal perception systems and base their perception algorithms on 2D visual image processing in order to build a system for robotic applications. The fundamental idea of the biological-inspired approach is a simplified motivation and perception system to achieve a level of autonomous behavior in their field of living.

Another approach is to use virtual sensors, like visual, auditory, tactile or olfactory sensors. This approach has already been used to model specific human perceptual behavior [Thal95, p.2], for example handling object, sensorimotor coupling and guided locomotion. This approach focuses on the gathering information in various forms about the dynamic environment. Some systems claim to create a sense of awareness but fail to transform their findings to real world applications. In order to achieve natural sensorimotor behavior and perception it is not sufficient to model the abilities of the sensor system but also the limitations [HeAn02, p.6] which formed the system in real life (such as attention mechanisms which help to cope with computation resource limitations).

When the focus is on the cognitive architecture then other capabilities of the system than perception have more weight. Abilities like learning, decision making and planning are in the focal point of modeling. In architecture COGNET [WaRH98, p.8] for example the role of perception is to transfer data of the environment to the cognitive processor. A sensor can query all the objects within its range and relay the information to the perceptual cycle. A moderation entity balances the limited perceptual bandwidths and the decay of perceptions. Another instance of the cognition-first approach is ACT-R [AnLe03]. The most important assumption of ACT-R is that human knowledge can be divided into two kinds of representations: declarative and procedural. Declarative knowledge is represented in the form of chunks, which represent individual properties of representations. In the

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[6] The term recognition is misleadingly used, as it is by definition consciously experiencing of perceptions by means of past memories and no evidence for this functionality was found in the model of artificial fishes.

perceptual-motor modules these chunks are created and held accessible (buffered) for the memory modules.

The project LIDA [FRDM07] makes use of interaction of dominant and non-dominant content following the Global Workspace Theory. Stimuli from internal and external sensors are processed by the sensor-memory module. In the perceptual-associative-memory module meaning is attached through association and the current percept and previous still existing percepts are combined to higher-level percepts. The forwarded percepts then compete with other codelets for dominance. LIDA is based primarily on neurology and psychology, but especially the concept of codelets lack a description of their theoretical origin and how they operate in detail [Deut11, p.20].

The mentioned architectures are only short examples of the cognitive process focused approach. Most of the presented models focus on parts of perception (as i.e. attention) but not on a holistic approach to cognitive perception and information processing. In Section 2.3 models are reviewed following the second paradigm where the cognitive process is in focus. In the next section the connection between action and perception is discussed in the context of perception frameworks.

2.1.4 Perception and Action

The in Figure 2-1 (page 20) used simple view of an embodied agent can also be titled as another paradigm in embodied cognition: the perception-action loop of an agent. The same paradigm is used by other sciences, for example by psychophysics, and is called the perceptual process cycle [Gold07, p.5] that will be discussed later in this chapter.

It is defined as perceptions that are sensed and the resulting information is the base for the decision process which results in actions taken by the agent in the environment, these actions can potentially be fed back into the perception process and thus influences the next decisions and actions. Embodied self-sustained agents constantly run through this process over time. The cycle is also defined as the *"… continuous circular flow of information between itself (the organism) and its environment"* [Fust06, p.130].

This process can also be seen as a loop between perception and action with a two-sided mediation: by the environment for the external part and by decision making on the internal part [Capd10, p.8]. The process described does recall descriptions of control theory, and indeed it can be seen as such. In fact the resemblance of concepts and methods of engineered control systems and that the same concepts and methods could be applied to biological control systems lead to the *Perceptual Control Theory* by William T. Powers in the field of Psychology [PoCM60]. The theory differs from classic engineering control theory insofar as the reference variable for each control loop, which is set by a controller external to the system normally, is set from within the system. This follows the concept of internal stimuli in the embodied agent that acts as a controller. This results in actions to put the environment into a specific state, with feedback from internal and external sensor systems and improve the equilibrium of the whole system.

The concept behind this is also called homeostasis and is known to be a crucial aspect of every living being. Homeostasis was defined by Claude Bernard [Bern65] and later by Walter Bradford

Cannon [Cann39]. Typically the concept refers to the internal milieu of living organisms and the dynamic equilibrium adjustments necessary to make homeostasis possible.

“Homeostasis is the ability of a system to actively control the value of some internal variables (e.g. level of sugar in blood, temperature, etc…) despite the environmental perturbations that the system encounters” [Capd10, p.8].

The discussed concepts stays true in the science of biology but was later used by other sciences and not latest used by S. Freud [Freu15a, p.122] to explain how homeostasis affects human behavior and why we make decisions. The detailed concepts and how S. Freud used them will be discussed later in this chapter.

Above the general principles for agent architectures were presented in the context of human-like perception. In the following section the principles of human-like information processing for perception are discussed in detail as a foundation for the functional model. The insights in this section also give an overview of interdisciplinary work on perception models which creates the connection between different models of perception under the light of the perception-action model.

2.2 Foundations of Human-Like Perception

Theories of the human brain and mind form the basis of the technical models used in the ARS project. This section describes how perception is performed in the human brain and how the perceptual information is processed by the human mind to give the percept meaning. The models used are based on theories by the neurocientists, psychoanalysts and neuro-psychoanalysts Mark Solms [Solm02], Aleksandr Romanovich Luria[7], António Rosa Damásio [Dama00], Sigmund Freud [Freu20], as well as the theories of other experts in the field of human perception.

In this Section general physiological, neurological and psychoanalytical principles and theories that build the conceptual tools for the modeling and implementation of the perception system in this thesis are summarized. More details on specific topics in perception and information processing can be found in Section 2.4.

The human brain and mind are two parts of the human information processing and decision making entity. Both parts are interposed between the inner world, the homeostatic demands of the body and the outer world, the perception of the external environment. The main functionality of both entities is to moderate between internal and external demands. According to Solms [Solm02, p.28] the inner world refers to functions like respiration, digestion, temperature control and the like, which is routed via the limbic system and hypothalamus to the cortex. The interface to the outer world is through the sensory and motor apparatus of the body.

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[7] In this work the English transcription Aleksandr Romanovich Luria is used; the transliteration is Aleksandr Romanoviè Lurija [Luri73]

2.2.1 Information Processing

There seems to be little to explain about perception from a subjective standpoint. For us perception of the world is direct, immediate and effortless and while we experience perception there is no hint on complex processes going on in our brain. The simplicity of perception is supported by the fact that the human perceptual system almost always if flawless and accurate. Even more fascinating is the fact that our perception seem to exactly match the perceptions of others, when we compare them. This gives us the impression that perceptual information is out there in the world and not constructed in our head.

Yet the brain and mental apparatus construct the perceptions of the world around us by a huge mass of neurons performing complex processes. The amount of neurons devoted to perceptual and especially visual processing hint at the complexity of the involved processes [LeKr94]. The second indication is that, despite the large successes in computational perception, computer scientists have not yet succeeded to build a general purpose perceptual system with the same capabilities of the human brain. There have been great successes in solving relative confined problems of perception models like [Huan05, p.48]. Clinical studies from brain experts like A. Damasio and M. Solms of individuals that suffer brain damages in the areas of the brain responsible for different perception tasks, show great deficits and sometimes very specific failures to perceptual tasks [Dama00, p.196, Solm02, p.222] helping identifying the mechanics of perception in the brain. In this examples it is also stated how experience and emotional state influence the way the human brain and mind processes perceptions [Math09, pp.3–4].

The Simple Information Processing Approach

In Figure 2-3, a version of the early information-processing approach can be seen. In this oversimplified model a stimulus from the environment causes various cognitive processing. These processes finally produce the required output and thus a response, or action to the stimulus.

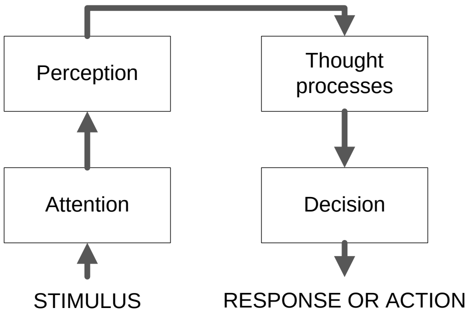

Figure 2-3: Simplified model of the information-processing approach [Eyse05, p.2]

Every part of processing is directly affected by the stimulus from the underneath processing block. This form of processing is known as *bottom-up processing*. This approach to perception has been abandoned because it ignores processing influenced by the individual's knowledge and expectations rater then the stimulus itself [Eyse05, p.2]. The missing form of processing is called *top-down* *processing* and as stated by Eysenck and other researchers in the field of perception: most human perceptual processing involves a mixture of both forms of processing.

Perception-Action Cycle

A more complete model of the perceptual process can be seen in Figure 2-4. In this model the processing steps are arranged in a cycle to emphasize the fact that the process of perception is dynamic, continually changing and constantly gets feedback through the environment. In the following the stages of the perceptual process are explained. Detailed explanations on the used terms can be found in Section 3.1.3.

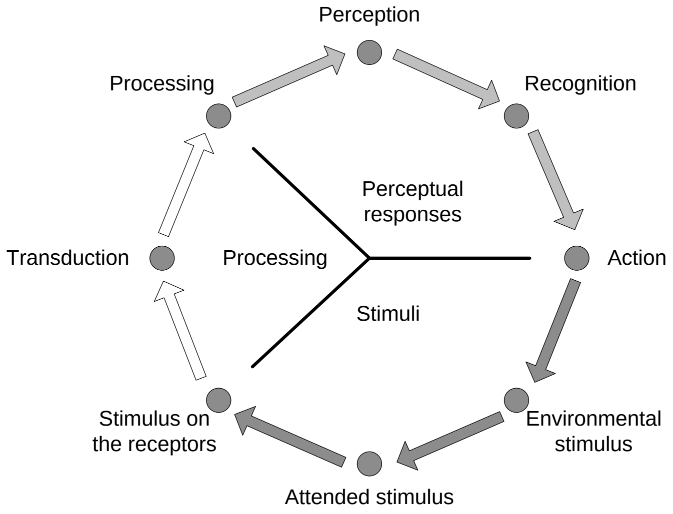

Figure 2-4: The perceptual process cycle based on [Gold07, p.5]

- **Environmental and Attended Stimuli –** The things in the environment that can potentially be perceived can be summarized as the environmental stimuli. As stated by [Gold07, p.6] the amount of information that can be perceived is limited and thus the human perceptual process needs to focus on specific environmental stimuli. When this focused stimuli is the center of attention it becomes the attended stimulus.
- **Stimulus on the Receptors** – In this step of the model, the external stimulus of the environment is transformed to an abstracted image and becomes the input for the various perceptual receptors (e.g. photoreceptors of the eye).
- **Transduction** – The external stimulus is transformed into electrochemical signals. The term transduction is defined as the conveyance from one form of energy[8] into another form of energy [Gold07, p.6].

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[8] In psychoanalysis the term energy is often misused but in this context it is used in the transformation from values of e.g. electromagnetic energy in form of light reflected by objects to electrical energy processed by the photoreceptors as Goldstein is working in the field of psychophysics. (The psychoanalytic term is scheduled for revision in the project ARS, in this thesis the term *intensity* is used for a clear distinction to the technical term energy.)

- **Processing** – The electrical signals from the receptors activate neurons, which in turn activate neural networks and the signal undergoes neural processing.
- **Perception** – Perception, in the most general meaning of the term is sensory processing [Styl05, p.7]. In the context of this model the perception stage is the first step to conscious experience of the sensed stimuli.
- **Recognition** – Recognition is defined as the human ability to place a perceived object into a category [Gold07, p.7]. In Section 3.1.3 the term will be revisited and explained in more detail.
- **Action** – Is the process of translating planned actions into motor activities. This step is the final process and the goal of the whole perceptual processing cycle and actively controls the perceptual input. The dynamic changes that occur through the perceptual processes and the changes to the environment throughout processing is the reason the steps are arranged in a cycle.[9]
- **Knowledge** – The term knowledge is widely used in this model. It is used to name any information that the perceiver brings to a situation [Gold07, p.8]. Different types of knowledge are used in every step that has access to it. More information on knowledge can be found in the following sections.

Embodiment is one of the key concepts in the perception-action cycle. The cycle can also be defined as interplay between actions performed by the perceiving individual on the environment and the resulting percepts it get through its sensors. These percepts can potentially feedback into the decision process and lead into actions changing the body and environment of the individual. The loop between perception and action which is mediated by the environment for the external part of the loop, and by the decisions of the individual for the internal part [Capd10, p.8]. The individual is embodied in the perception-action cycle.

The purpose of any perceived object inside the perception-action cycle is to provide the possibility of actions for the individual. To understand how living individuals make sense of their surrounding – the environment – in order to act, requires to take into account what they can do with their environment [Capd10, p.7]. From the perceived object point of view this means what kind of interaction they offer the perceiving individual. This is one of the key notions of embodiment but takes the ‘body’ and interaction possibilities of the perceived objects into account. Within the perception-action cycle this shows the reciprocal relationship of the knowledge about the environment [PFKI07, p.1] directing actions and perceptions in the recognition process.

The key aspect is that perception is limited by the abilities of the embodied individual and the capacities of the environment. This concept was described by Gibson [Gibs79] and labeled with the term *affordances*.

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[9] It should be noted that the simplified model of the cycle as presented here is describing action responses for every perceptual input. In psychoanalytic theory not every perceptual input is required to have an immediate action. In fact most of the inputs are filtered or not directly processed by the decision unit.

"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment" [Gibs79, p.127].

These theories led to a new perspective for the research in perception and especially in machine perception. In AI this concept is called embodied and situated [VaTR93]. In this concept the actual environment is taken into account for the process of perception, or more detailed in the perception and recognition steps of the perception-action cycle. The theory of affordances will be revisited in Chapter 3 as one of the concepts to the proposed perception model.

The notion of perception inside a closed loop with the physical world on one side and the mental world on the other side leads to a clear technical model which can be explored and implemented by introducing techniques from AI [Bruc07, KlPN07, p.7] or even introducing mathematical vector analysis [Capd10, p.18] to the loop. What all scientific explorations have in common are the following assumptions:

- The perceiving individual is part of a larger environment-individual system.
- The perception-action cycle consists of several discrete states.
- Every state proposes a defined functionality and an affiliation to parts of the environment, body, brain (and mental apparatus)
- The states of the loop follow a path from low-level sensor information to information of higher quality for the individual.
- Knowledge about the environment is a key element in perceptual processing.

The introduction of knowledge to the functionality of perception is one of the key elements to perceptual processing. Information about past experiences quantifies and enriches the possibilities of future actions by introducing predictive information to perception. In technical applications this functionality is often introduced as statistical measures to quantify information structures [ABDG08, p.330] without a clear understanding how human individuals gain experiences and where inside the perception-action cycle this information is used for perception. The concept of *predictive information* [ABDG08] takes these mechanisms and extends it with the concept of certain knowledge for the lower steps of the perception-action cycle in an information theoretic approach.

2.2.2 Sensory Information Processing

Sensory information from the physical world has to be detected, encoded, forwarded to the brain and translated into a 'language' [Styl05, p.29] that the brain can understand. The information path is started by stimulation of a sense organ by a physical object. Encoding of sensorial features of the object is the task of specialized neural regions. The information is forwarded to the brain for further encoding, interpretation and recognition. On the path the information becomes a conscious experience of the environment. This path from physical experience to a psychological one was the heart of the question [Styl05, p.29] of experimental psychology in the 19th century. The findings led to detailed insights how sensory information is encoded in the first stages of neural processing.

Neural Hierarchical Processing

In the nervous system of the brain, information is forwarded by electric signals, passed from cell to cell (neurons) through the system. The key components are the cell body which contains mechanisms to keep the cell alive, the dendrites which branch out from the cell body to receive incoming impulses and the axon which transfers the impulses from the body to other nerve cells. Between one neuron and the dendrite of another neuron a so called synapse passes the impulse along by releasing neurotransmitter chemicals.

Environmental information in different forms is transduced (or converted) by specialized sensor cells. They receive a particular form of energy and convert them to neural electrical signals. These electrical signals are then processed in the corresponding neural structures of the brain.

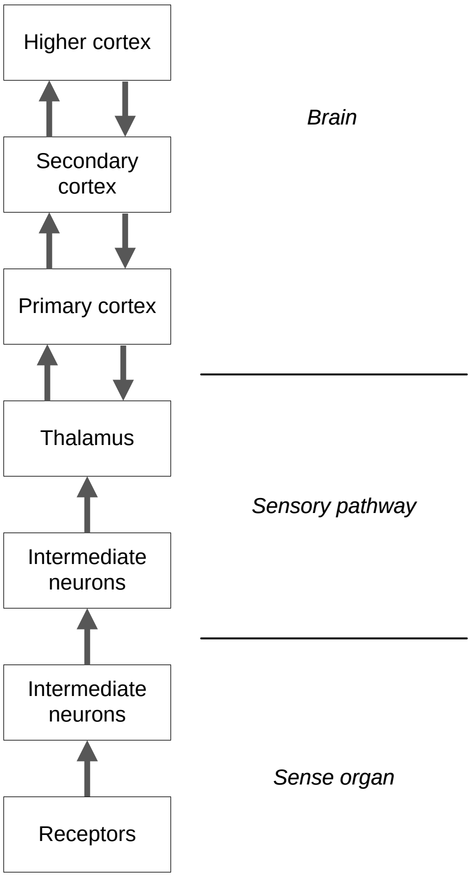

Figure 2-5: Hierarchical stages of sensory processing in the brain [Math09, p.14]

Figure 2-5 summarizes the successive hierarchical stages characteristic of sensory processing through the neural structure of the brain. The arrows indicate the direction of flow of the neural signals and show functional information paths that resemble the information flow in the perception-action cycle.

From transduction of the environmental information to processing in the higher cortex, signal information from each cortex is passed through different layers of synapses to higher levels of neural processing. In each stage of processing the information is processed and modified. The information is undergoing a transformation in each stage passing through the processing stages. The provided information is refined and condensed, useful information is selected, less useful is lost [Math09, p.14].

The signal flow, indicated by the arrows in Figure 2-5 identifies the flow of neural signals. In this model the signal flow is unidirectional up to the thalamus and bidirectional thereafter. The type of information flow that can be derived from this model is a straight bottom-up approach to information gathering. The hierarchical stages model will be revised in the next Section with a deeper look on the perceptual information processing.

Sensory Active Perception

The signal flow indicated by the neural hierarchical processing model indicates that one stage reacts on the outcome of the last stage. The serial processing of the model shows that the perception process is passive. But perception is more than just passive reception of information. Perception is an active process. *"Perception is active, not passive. It is exploratory, not merely receptive"* [Gibs58, p.43]. The alternative view to perception proposed seeks to analyze stimuli which excite the individual, not the sensor. Explaining perception in terms of active processes exploring the environment is proposed by the framework by [Gibs79], it further proposes that perception is used for getting information about said environment for need fulfillment purposes not being a mere passive responder to physical stimuli of the receptors.

Multisensory Processing in Perception

Separate information paths in the human brain are specialized for every modality. The different sensory modalities for audio, vision, smell, taste and somatosensory information extract information for further processing. Research in cognitive science shows that in fact, information is shared across modalities to enhance the results. Environmental objects usually are multisensory and multimodal presentations speed up reaction time to unimodal presentations [Math09, p.384]. Evidence from multiple mechanics show that information between modalities interact with each other. In cross-modal cuing for example visual detection is enhanced by auditory information. The McGurk[10] effect shows that for example speech sound is influenced by lip movement seen. Whether these effects occur in neural processing or in symbolic form is out of the scope of this thesis but the mechanics show the need for multi-sensory interaction in the perceptual process.

Binding Problem

Information paths in perception do not work isolated. They interact with each other in order to form multimodal percepts for object recognition. How theses information paths can interact is the fundamental question of the so called binding problem. The binding problem is not limited to

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[10] The McGurk effect [McMa76] is one evidence for multisensory processing in cognitive science, for more effects see [Math09, p.384]

perception alone but is concerned in other forms of human information processing for information across space, time and ideas [Veli08, p.38]. Binding in perception is of special interest because information about the features of every object in the external world goes to disparate areas of the brain, is processed differently and the outcome is still a multimodal view of the same object. Human individuals solve the binding problem in the brain, which merges information from disparate brain areas [Jasw10, p.15]. The introduction of neuro-symbolic networks by Velik [Veli08] (see Section 2.4.2 for details) solves the problem for symbolic processing in the functional model of the mental apparatus of the project ARS. For the implementation in the artificial life simulation temporal binding (binding by synchrony) is sufficient.

Low Level Object Feature Extraction

Feature extraction of perceptual information especially in vision is out of the scope of this thesis as the focus is on processing of symbolic information in the mental apparatus. The contents in this chapter are introduced to close the perception-action cycle. Figure 2-6 shows the three stages of visual processing (as example of the most important form of feature extraction) from local image properties to representations of shapes to object representations prepared for recognition tasks.

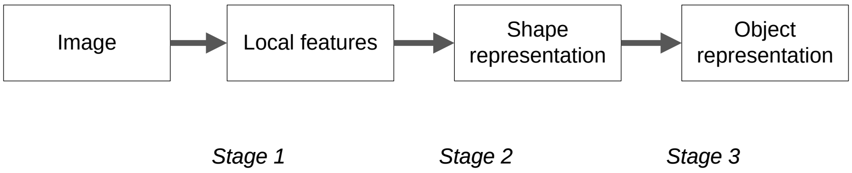

Figure 2-6: Tree stages of visual processing based on [Math09, p.275]

Local features are extracted in stage one which resembles mainly object appearance of edges, color, texture. In the second stage Gestalt laws [Gold07, pp.97–106] describe how image elements are grouped together on attributes such as proximity, similarity, common fate to name the most important ones. Texture analysis, symbolic grouping and common motion are the main mechanics used for shape segmentation. In the object representation stage information about objects is used to recognize objects as belonging to a class of objects. This stage will be reviewed in the Section about perceptual symbol generation (see Section 2.4)

2.2.3 Hierarchical Information Processing

In the previous sections several mechanics and functionalities of sensory stimuli of the environment were given. The environmental stimulation causes several activation paths to work from the sense organ to specific areas in the brain. Accepting that neural activity has a causal link to consciousness and psyche, this stimulation causes an individual perceptual experience. The representation of the outer world is translated into a personal perceptional observation. Perception is the formation from particular brain patterns to representations of the outside world. This representation of the outside world is built by different stages of neural processing before the information is passed to the conscious entity of the mental apparatus. Representations are generated alongside stages of sensorial and mental levels, the stages of perception correspond with levels of object representation [Wies09, p.98].

A neural state of the brain represents information about the environment as well as a symbol represents a specific neural state for a perceived object. Representation is *"… the Idea that the state of one physical system can correspond to the state of another physical system, each state in one system has a corresponding state in the other"* [Math09, p.20].

At this stage of information processing the perceptual information can be split as two forms of representations: analog representations and symbolic representations:

Analog representation: Values in a system vary proportionally with the values in another system. Patterns of external stimulation are reflected by patterns of internal activity. E.g. patterns of light or dark of the photoreceptor cells can be measured as distinct activity patters in the respective sensor areas. This activity is encoded in a particular net of activity (called population coding in neurological literature).

Symbolic representation: Symbols in one system act as tokens for the state in another measurement system for translation into another domain.

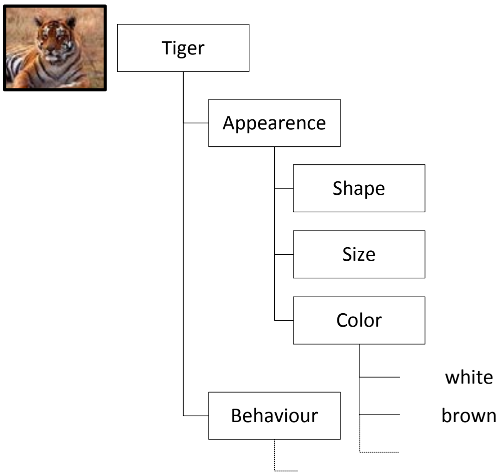

Figure 2-7: Pictorial and symbolic representations example

In this view of the perceptual system, the perceptions of the environment are represented by an abstract set of symbols, with each symbol being a representation of a particular object or property of an object. The shape assertion given as seen in Figure 2-7 is a symbolic label for the given shape. *"In the brain the assertion is encoded as a labeled line*[11] *, this represents a specific neural pathway that is only active in the presence of its triggering stimulus"* [Math09, p.22].

In neuro-psychoanalysis the fact that the brain and the mental apparatus are part of the same model is represented in this context by the fact that information is processed from analog representations to symbolic information. In psychoanalysis the term object-representations is used in conjunction of

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[11] Labeled Line: *"A general principle of sensory processing, according to which a perceptual attribute or label is uniquely specific by activity in an restricted set of neurons"* [Math09, p.22].

conscious and unconscious representations of perception objects. Later this concept resulted in the term presentations in their specialized forms thing- and word-presentations (see more on psychoanalytic data structures in Section 3.1.2).

The concept of computation[12] can be seen alongside the concept of representation. The concept is described in great detail in [ChSe92, p.61] and can be summarized as *"the manipulation of quantities or symbols according to a set of formal rules"* [Math09, p.23]. The perceptual quantities e.g. brightness or perceptual symbols like an object property can be described as a computational process. The idea behind this concept is to mimic the idea that perceptual processing is a form of computation as it is done by modern computers. The comparison to a computer in this concept is in the sense that both perform a manipulation of quantities and symbols according to a set of rules and algorithms.

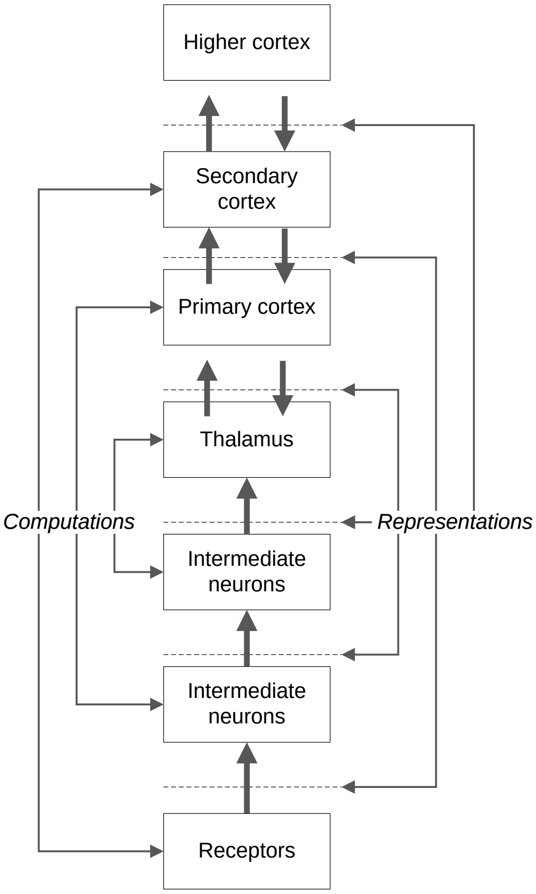

Figure 2-8: Representation and computation in relation to the hierarchical processing scheme introduced in Figure 2-5 [Math09, p.23]

Perceptual systems can be seen as representational systems, where the brain states represent the outside world. Through different neural processing stages perceptual analysis is processed through a

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[12] *Computation* is not to be confused with the engineering term it only mimics the term, it is used to describe the functions that manipulate information into another form of information.

series of representations. At every processing stage the representation is transformed by a computational operation. The outcome is passed on to the next stage as seen in Figure 2-8. Depending on the form of the representation (analog or symbolic) the nature of computation is different. Analog computing is the creation and manipulation of sensorial quantities according to a set of rules (allocated in the scientific field of signal processing and image recognition), for example finding the edge of an object. This computation is done by cortical cells in the brain. Creation and manipulation of symbols according to a set of rules is involved in symbolic computing and includes mechanics of test of equality, comparison and combination of symbols to higher forms of information. This form of computation is often used for higher-level perceptual representations and object identification. This is the same form of processing stated as binding of neuro-symbolic information as defined by Velik in [Veli08, p.73] and represents the mechanic of translation of sensorial information to symbols for processing in the mental apparatus. In the Figure 2-8 arrows pointing upwards in the sequence from bottom (Receptors) to the top (Cortex) indicate a *bottom-up information flow* or processing where information is 'computed'[13] to higher forms of information. The arrows pointing down indicate a *top-down information flow* from higher levels of processing, to lower ones by using representations[14]. Both types of processing are necessary to generate perceptions. Bottom-up processing is stimulus (sensorial input) driven and top-down processing is said to be conceptually (existing knowledge) driven [Styl05, p.18].

The above Sections in summary indicate that information represented in analog stimulus information shifts to a symbolic representation for further processing in the perceptual functional blocks. A similar sequence of processes can be seen in the perception-action cycle in Figure 2-4.

2.2.4 Perceptual Information Processing

Taking agent embodiment (as in Figure 2-1) into account the perception-action cycle can be seen as a *"loop between perception and action which is mediated by the environment for the external part of the loop, and by the controller of the agent for the internal part"* [Capd10, p.8]. This perspective is related to the classic control theory which is also describing different feedback mechanisms. In the above chapters the concept of homeostasis has been described which act as an internal feedback or control task of the agent. In order to keep a specific equilibrium the embodied agent has to bring the environment in a specific state, in this case he acts as a controller. This approach is strongly reminiscent of Shannon's [Shan48] information theory[15]. In fact a clear information flow and communication channels can be described. This approach was used by Klyubin [KlPN07] and described with Bayesian graphs in mind. The same approach is used by Capdepuy [Capd10, p.11].

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[13] Computation is used by Mather [Math09] to summarize all forms of mechanics where information is collected and associated.

[14] Representations are used by Mather [Math09] to indicate information 'computed' by bottom-up processes which is represented to the other processes as top-down influence.

[15] This was already considered by Gibson [Gibs79] but not committed to, as he could not see environment and agent as sender and listener.

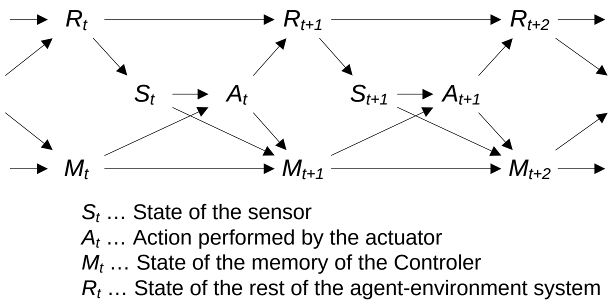

Figure 2-9: Perception-action loop as Bayesian network by [KlPN07, p.9]

Klyubin [KlPN07] described the perception-action loop of embodied agents as a Bayesian network as seen in Figure 2-9. To apply the formalism of information theory the quantities involved are represented as random variables. In [KlPN07, p.9] they represent sensors S, actuators A, environmental state R, agent memory state M and time steps. In this diagram action A_t is picked based on given sensor state S_t (which is obtained by the state of rest of the agent-environment R_t) and memory state M_t (R_{t+1} is given by R_t and A_t etc.). This architecture can best be described in a causal Bayesian graph which shows the probabilistic relationships between variables [Capd10, p.14]. This allows a compact and transparent joint distribution of collections of variables [TiPB99, p.10] while staying true to Pearls concept of causal effect which introduces a notion of information flow that quantifies the amount of information that is transmitted between nodes of graphs [KlPN07]. The concept of information flow is studied in great detail in [ABDG08, p.2, Capd10, p.17ff, KlPN07, p.7].

Following approach of Capdepuy, where perception is formulated in the information-theoretic approach, we can formulate a generic model of perception. The model of the perception-action cycle as seen in Section 2.2.1 is the basic starting point. Based on this simple model and with information-theory in mind a model of perceptual information processing is formulated. A general definition of the process is given by Chenney, he defines *"… perception of agents*[16] *as a process of interaction with the environment to collect and exchange information about the environment and the agent itself"* [HeAn02, p.3]. Chenney also classifies perception as active sensing, passive sensing and feedback sensing[17].

Passive and Active Perception

The perception process of any system (human or artificial) can be considered in two parts: active and passive. *Passive perception* is the process where the incoming data from the sensor or sense only receives information. The system the sensor belongs to does not provide any feedback. The incoming information is organized, fused together and analyzed in order to represent information about the environment. The information can be considered as an *"environmental picture"* [LoLW04, p.145]. This image of the surrounding is processed in various components of the system with the aim

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[16] Agents, are autonomous software agents in this notion from Chenney, it stays true for all forms of agents.

[17] Chenney refers to low level sensor-motor feedback loops which are not the focus of this thesis.

to provide the system with a continuous stream of perception information. This form of perception is also known as the bottom-up information path of perception. The sensor systems as the different components on the way are not provided with any feedback.

Active perception on the other hand describes mechanisms that have the ability to make corrections to the process of passive perception and provides the process with feedback from other parts of the perception system. Active perception may be used to redirect specific sensing modules or to adjust specific setting [LoLW04, p.144] and has the ability to make corrections with respect to the aims or goals of the system. The phrase *"we do not just see, we look"* [Bajc88, RLPW07, p.448] explains active perception best. There are different feedback mechanisms in perception systems like attention, priming, categorization, common coding to name just a few. Some of the mechanisms are reviewed in the next chapter in detail. Active perception is also known as top-down influences to the information processing processes active in the perception system. The influences often not only have the origin inside the perception system itself but are coming from other systems. With the model of the basic interaction of agent and environment in mind (as seen in Figure 2-1), it can be extended to combine the basic perspective of interaction with the human inspired merging of perceptual information with memory capabilities. Loutfi et.al divide the basic cycle into four sub processes that identify the main processing activities [LoLW04, p.142]:

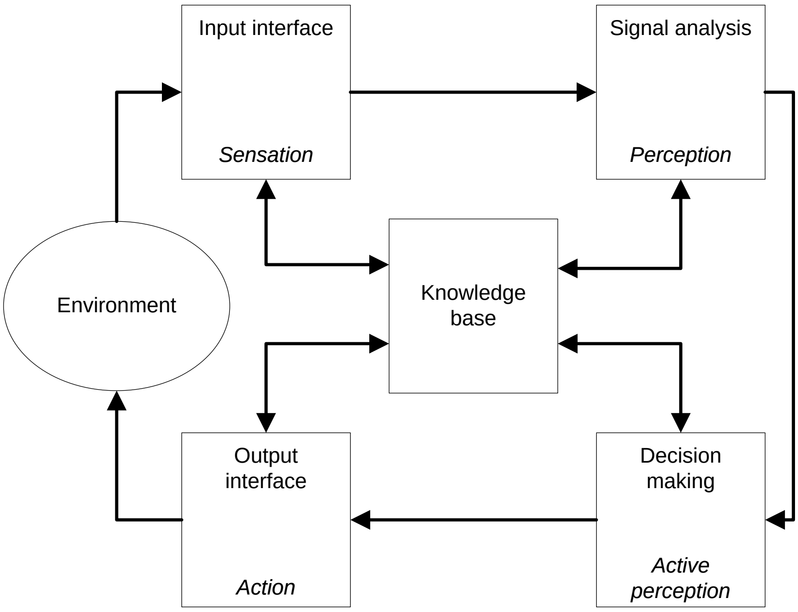

Figure 2-10: Feedbacks in an active perception system by [LoLW04, p.142]

- *Input interface*: The here used term sensation refers to the sensational process by which different sensor information is preprocessed for further analysis. This process is described with similarities to human sensation as described in Section 2.2.2. This process ensures the ability to connect the rest of the system to dynamic changing sensor information in the environment.
- *Signal analysis*: In this sub process the perceptual input is organized in an image of the environment and enriched with knowledge of the agent. This resembles to the perception

and recognition processes of human perception and creates a multimodal environmental image the agent can perceive.

- *Decision making*: This sub process handles the decision making of the system. The term active perception refers to the functionality of actively controlling where the perception systems will focus next (see attention mechanisms later in this chapter).
- *Output interface*: The output interface describes the planned activities of the system and their communication to the environment.

The here shown model also includes comparison to the human perceptual system and can be seen as a simple view of the perception-action cycle as shown in Section 2.2.1 reduced for an active perception model of artificial agents.

The top-down and bottom-up approach to perceptual information processing can be adopted when building an active perception system, as described by Bajcsy [Bajc88].

Top-Down and Bottom-Up Information Processing

The human perception and cognitive system have to deal with certain limitations and have adapted to those or found an improved path for their tasks. The amount of information from the environment exceeds the processing abilities of human and artificial systems and in fact only a small fraction of sensory information can be processed and forwarded to the cognitive systems [KiVH05, p.1] In the human realm functionalities like spatial attention let us cope with the sensory stimuli we are facing [KiVH05, p.2]. In cognitive psychology the fact that the information flow between perception and cognition is bidirectional (top-down and bottom-up) has long been recognized [Pete03, Shan05, p.107]. Computational models of perception in the field of machine vision generally also fall into those two camps. A great emphasis was placed on top-down techniques e.g. [Walt75] and bottom-up processing like [Marr82]. The need for a bidirectional flow of information has always been acknowledged [Shan05, p.107].

In cognitive science has long been a controversy how close the cognitive processes are linked to perception. One extreme is the view of building larger structures from retinal to sensorial features which form an image of the environment in the cognitive structures. The other faction of scientists accept the hierarchical construction but state that without knowledge there is no image so nothing can be perceived that was not in the memory (knowledge base). In this regard perception is formulating a hypothetical image of the world beforehand and is then only checking the sensorial data for verification. Especially in vision research the popularity of these views has swung around not only in dominant schools of psychology but also in fields like neuroscience, artificial intelligence, psychophysics etc. [Pyly99, p.342].

In AI and especially in the field of computer vision the goal is to design a system that is capable to identify objects in the environment. The first approaches followed a data-driven (bottom-up) approach and led to systems like the Perceptron by Rosenblatt [Rose62]. From there various improvements in computer vision led to object and scene analysis but with edge and feature analysis as the primary source of identification. The idea of local guiding for edge-finding from knowledge of the scene marks the beginning of knowledge (top-down) based vision systems [Pyly99, p.345]. In addition to local image features the view of context dependent influences was highlighted by insights from [Shir75, Wins74]. Freuder [Freu86] even proposed a system where specialized knowledge is influencing every level of processing in a perceptual system. Even stronger is the claim of Riseman and Hanson stating that "*… it appears that human vision is fundamentally organized to exploit the use of contextual knowledge and expectations in the organization of visual primitives ... thus the inclusion of knowledge-driven processes at some level in the image interpretation task, where there is still a great degree of ambiguity in the organization of the visual primitives, appears inevitable*" [Pyly99, p.346, RiHa87, p.286].

From this point the so called 'knowledge-based' approach in computer vision is conceded to be essential to develop high performance systems [Pyly99, p.346]. The use of stored knowledge makes recognition of objects more reliable, especially with ambiguous or incomplete, voluminous sensorial information. This knowledge-driven approach led to actual systems like [DaCL09, DTLT03, LCDM08, MCFF11]. All the mentioned systems follow the basic knowledge-driven approach in various forms and implement specific parts of perceptual information processing to solve their tasks. Amazing results have been forged but the lack of a unified holistic approach ho human information processing, where perception is only a small part, limit the possibilities to perform well in real human environments.

Neuroscience and the hierarchical organization [Solm02, p.221, Wies09, p.99] of visual pathways encourage the hierarchical and bottom-up driven approaches of visual (and in conjunction also the other senses) processing. Top-down effects shown in neuro-physiological and psychophysical theories originate in the visual cortex itself as mapped out by Fellemann & Van Essen [FeXM97]. Two major forms of modulation are shown. First a modulation associated with focal attention from the environment (exogenous) or from cognitive sources (endogenous). Second a modulation originating in motor systems (which led to the models of sensor-motor control) [Pyly99, p.347]. One of the more general views of activation influences in the perception system has been demonstrated by studies of Kosslyn [Koss94]. Even more experimental findings, for example by Humphreys and [HuRi87, p.104] show an important differentiation of the perceptual system in perceptual and recognition processes (as stated in detail in the perception-action cycle in previous Sections). The findings state that for the recognition task, stored knowledge has to be intact and this in conjunction shows that recognition requires the matching of perceptual information against stored memories, whereas perceptual representation in this distinction can be solely driven by stimulus information that is unaffected by contextual knowledge [Pyly99, p.348].

In summary, the findings show that it is clear that other cognitive processes have influence on lower-level perceptual processes: "*… the precise nature of the interplay between cognition and perception is controversial … that such interplay exists is less so*" [Shan05, p.131].

The distinction in bottom-up and top-down information processing approaches led to a detailed view on information processing. Top-down approaches, as already seen, often use knowledge or expectations to guide the process of percept building. Bottom-up approaches put pieces of data together until an image of the environment evolves. One of the masterminds of bottom-up approaches was J. J. Gibson [Gibs79] with his theory of direct perception. He also invented the model of affordances. In his theory the main concept is that the real environment provides sufficient contextual information for the human perceptual system[18] to directly perceive the objects. Affordances in his theory refer to aspects of objects or environment that allow the perceiver certain forms of interaction. His approach is often referred as ‘ecological’ because of the emphasis between individual and environment and the perception system balancing the needs of the two. Actual theories of perception argue that perception is an active process as seen in the last chapter and thus bottom-up and top-down processes are involved. Nevertheless several strong theories for bottom-up processing have been developed:

In *template-matching*, recognition of objects is performed by a comparison of the representations to templates stored in memory. One problem of this theory is that object recognition has to be possible regardless of perspective. In order to be able to recognize objects regardless of perspective, every view of an object has to be stored, suggesting for every view of every object a template is stored, which would lead to an immense amount of templates stored in memory.

A more advanced theory, originating in the template theory is based on *prototype matching*. Instead of checking the perceptional input against a library of objects it is compared to a stored prototype. The prototype is an average of the object, a match is done by family resemblance. The prototype theory will be reviewed as categorization task in the next Section.

The next bottom-up approach is *feature-matching*. In this theory the visual patterns are decomposed into a set of critical features which are compared to features stored in memory.

In summary it is clear to say that perception is an active task and bottom-up mechanics, like sensor fusion, are working in cooperation with top-down mechanics as a feedback mechanism to *“… not only maximize useful information, but also to minimize useless information”* [Shan05, p.109].

Perceptual Symbolization and Object Recognition

Top-down and bottom-up approaches can be interpreted as the perceptual process of building a model of the world. In the bottom-up approach, the construction is based on sensory input and the model is the result of perception. In the top-down process the starting point for building such a model is based on prior knowledge (i.e. information from memory).

The significance of memory to the perception process (especially vision) was already recognized by Helmholz and resulted in the term ‘unconscious inference’ [Frit07, Helm85]. Here the need for assumptions based on previous experience is expressed to compete with incomplete sensor data. The significance of prior knowledge to perception is emphasized in his theory. According to the top-down approach by [Metz09, pp.72–77] the brain constructs a transparent model of the world and this construction happens actively and unconscious. The process of construction is not recognized but we accept the subjective model of the world it produces. Model-building is followed by several top-down approaches for perception via prediction [Bar09]. Memory based information is used to predict which objects or situations to expect. These memories are triggered by actively associating representations. The similarities used for the associated content may be perceptual, conceptual, functional or driven by mechanics of awareness and attention. Additionally also the embodied

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[18] Gibson’s focus is on the human visual perception system.

approach should be noted here, that *“… internal states such as meta-cognition and affect constitute sources of knowledge no less important than external experience”* [Bars08, p.620].

Awareness and Attention in Perceptual Processing

The ability to be aware of what is happening around us and to connect that information with meaning for ourselves is summarized by the term situational awareness [Ends95]. According to Endsley, a situation is *“… the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”* [Ends95, p.36]. Endsley summarizes his findings into three functional blocks of situational awareness in terms of its role in the overall decision-making:

- Level 1– *perception of the elements in the environment:*
  To perceive the status, attributes, and dynamics of relevant elements in the environment is the first task in achieving situational.
- Level 2– *comprehension of the current situation:*
  Beyond being aware of the elements in environment, in the second level the task is in understanding the significance of those elements in reflection of the actual individual goals. In decision-making a holistic picture of the environment is built with significance information about objects and situations.
- Level 3– *projection of future status:*
  Projection of future situations is the highest level of situational awareness. It is achieved through knowledge of the status and dynamics of situations. Allocation of future statuses comparing it with the individual’s goals is used as one aspect of decision making.

These three blocks show the necessity of the different information paths to work together. The top-down, goal-driven and bottom-up, data-driven models of perceptual information processing working together are vital mechanisms that support situational awareness [SoSo09, p.144]. In top-down models processing goals or the intention of the perceiver focus on what elements in the environment attention should go. This affects the direction of attention, what information is processed and what level of detail the information has. This results in perception becoming a process where information is actively gathered from the environment. In bottom-up models, attention is driven by the environment itself. The processing of data is based on its inherent perceptual characteristics [SoSo09, p.144].

The roles of situational awareness and how they can be applied to agent modeling is summarized in Figure 2-11.

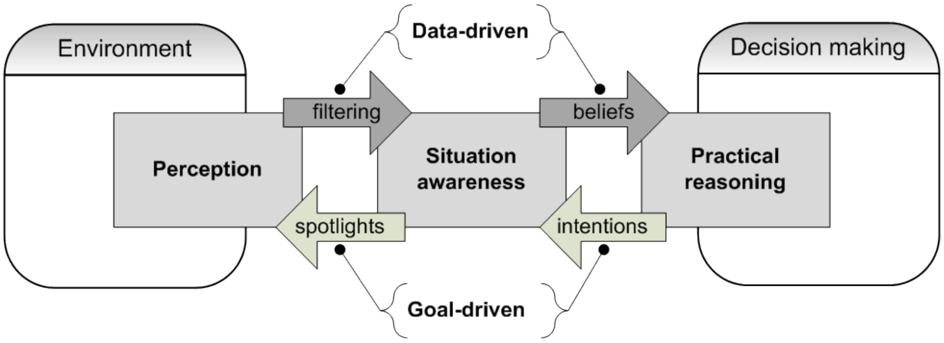

Figure 2-11: The roles of situational awareness in agent systems based on [SoSo09, p.144] in a BDI model

The background of the proposed influence is grounded in agent modeling based on models of BDI (Believe Desire Intention). The Figure shows the ability to incorporate reactive or bottom-up (data-driven) to deliberative or top-down (goal-driven in this model) processes. It shows a cycle from data perceived by sensors, where awareness can act as a filter for information required for goal attainment, to decision making and the feedback to perception through situation awareness mechanisms.

The above notions show, that it is central [PiRB08, p.422] to study the mechanics of attention in information processing of cognitive architectures. The first indication of necessity is from the notion that processing capabilities are limited whereas computational demands of processing are huge [PiRB08, p.423] (especially in visual inputs). The second reason for attention mechanics lies in the fact that not every environmental information is equally relevant to the perceiver (relevance computation is where the most agent architectures lack a detailed model). Another factor why attention is necessary is the use in one of the solutions in the binding problem (see Section 2.2.2). According to Pisapia [PiRB08, pp.423–424] there is a common ground in cognitive theories that in visual (as example) perception attention is a core component, attention focusing is a combination of bottom-up and top-down mechanics and that directing attention is achieved by means of top-down processes to specific features in the environment.

In a memory driven model the same mechanics are applied to the top-down approach of perception via prediction [Bar09]. In this specialization of the attention mechanic, information from the memory is used to predict which situations or objects are to be expected [Scha12, p.10] by triggering activation of associated memory representations.

In the section above the interdisciplinary models of perception and their basic mechanics were presented. The focus on information processing in human-like models and the influences to perception shows the basic principles a perception model has to follow. The presented mechanics are important to the way information is processed in a holistic model of perception. In the following section technical models of perception are discussed especially models in AI agent architectures.

2.3 Applied Human-Like Perception

If we accept that the brain is an information processing device then we can also accept that the perceptual system can be emulated by using computers. The sensory input can be measured and thus be represented by mathematical terms. The responses of the brain, the patterns of neural activity can also be expressed by mathematical terms. As both input and output can be expressed mathematically researchers have attempted to develop formal mathematical rules to describe and implement emulations of the brain processing perceptual inputs. Some attempts [Gurn07] use large neural networks to solve the processing tasks. Others use functional descriptions in layered control architectures [Slom00, p.6] or connectionist approaches and Bayesian networks as seen later in this chapter. In this chapter a comparison of technical and other models used in perception and decision making is given with respect to the different approaches, application domains and terms.

2.3.1 Foundational Architecture Frameworks

According to [Fran06, p.48] an agent in a cognitive architecture has to perform cognitive cycles in an infinite loop. The cognitive cycle resembles to the perception-action cycle and is a sequence of sensing, processing and acting [Deut11, p.16]. Franklin describes a basic architecture with the minimum model in [Fran06] (where the emphasis is on learning but also shows the most foundational architecture for AGI). Figure 2-12 shows the foundational architecture.

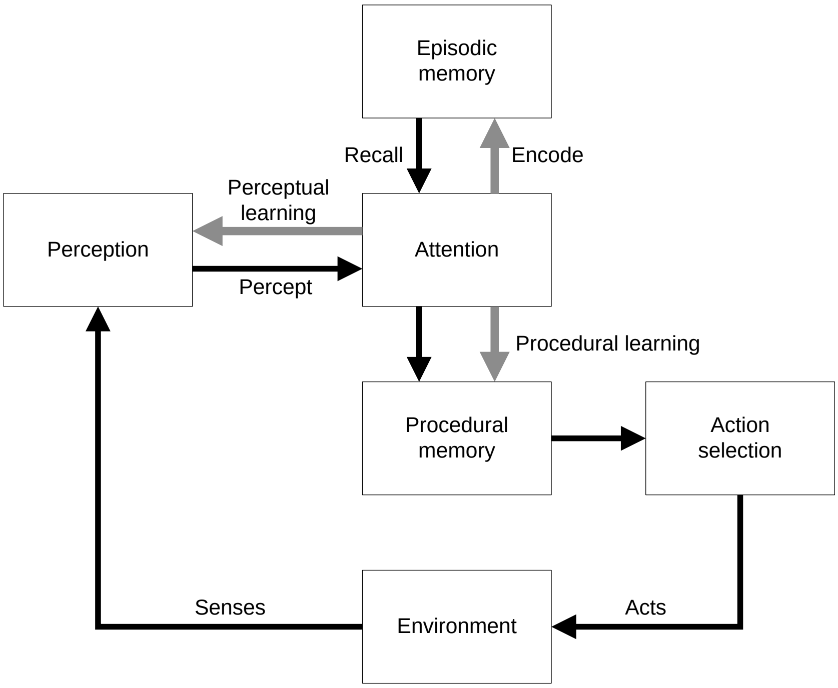

Figure 2-12: A foundational architecture for AGI [Fran06, p.44]

Perception is used to evaluate and sense incoming sensor data (assign meaning). *Attention* is used to connect information built by *Percepts* and recalled from *Episodic memory*, where information about previous experiences is stored. The module is also responsible for decision making and decides what information is passed to *Procedural memory* to associate fitting actions. *Action selection* makes the final decision for actions in the environment. In this model also learning mechanisms [Fran06, p.44] are noted which are out of scope of this thesis.

The mapping of this basic architecture by [Fran06, p.47] to architectures like Cognition and Affect (CogAff) [Slom00, p.6], Global Workspace Theory (GWT) [Baar93] and Learning Intelligent Distribution Agent (LIDA) [Fran06] is used in the next Section to compare various AGI projects with emphasis on the perceptual process in those frameworks.

2.3.2 Artificial General Intelligence Architectures in Perception

Cognitive architectures in AGI and especially Biologically Inspired Cognitive Architectures [4]. also known as BICTAs[19] have a common target: *"attempt to achieve brain like functionalities via emulating the brain's high-level architectures"* [GLAG10, p.1]. Duch [DuOP08, p.2] made an attempt to simplify the taxonomy for cognitive architectures for comparison. He divides the approaches into three main paradigms: symbolic, emergent and hybrid as seen in Figure 2-13.

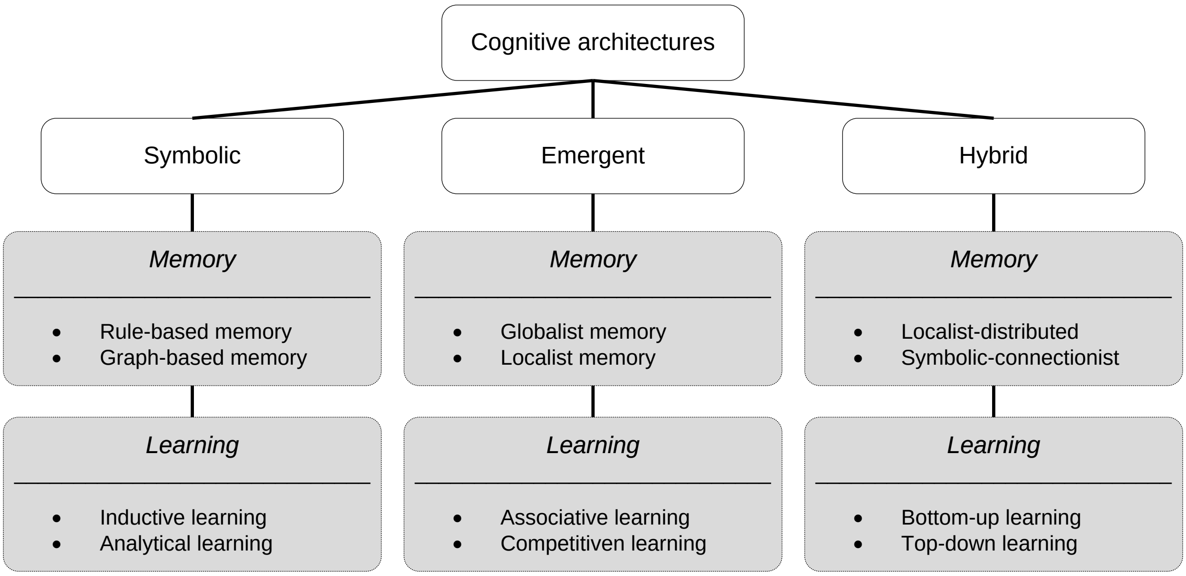

Figure 2-13: Duch's taxonomy of cognitive architectures [DuOP08, p.3]

He further proposes two key design properties for every cognitive architecture, which are memory and learning. As learning is out of scope of this thesis the according classification is only given for completeness of the taxonomy.

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[19] The term BICTA is commonplace since the 2005 DARPA funding program and is used to emphasize cognitive architectures with biological inspiration but to distinguish architectures with direct inspiration from the brain to architectures based on models of the mind [GLAG10, p.1].

Symbolic Paradigm Architectures

High-level symbols or declarative knowledge in a classical AI top-down approach is the focus in architectures using the symbolic paradigm. The notion here is that the mind exists mainly to manipulate symbols that represent the outside world or states within [GLAG10, p.2]. They rely on memory architectures for centralized control over perception and decision making.

SOAR (State, Operator And Result) [LaNR87] is a model for general intelligence in a rule-based cognitive architecture. Physical symbols are approximated in a knowledge-based system which stores its knowledge in production rules that act as operators in the problem space. The problem space is represented as a set of states, which represent the task to be solved. The focus is on processing large rule sets in planning, problem solving and natural language comprehension [DuOP08, p.4]. Perception and action are linked in SOAR as perceptual-motor systems and perceptions are mediated by encoding (and decoding) productions between high-level structures used by the cognitive system and low-level structures used by motor and perception subsystems. Perception in SOAR works parallel to the decision cycle and thus allows solving of asynchronous perceptual inputs.

ACT-R (Adaptive Components of Thought-Rational) [AnLe03] defines procedural and declarative knowledge in a symbolic system. Procedural knowledge is the form of if-then rules similar to classical expert systems, so called production rules. Declarative knowledge is in the form of ‘chunks’ formed by combination of previous rules. As the original ACT-R model has no model of perception, EPIC (Executive Process Interactive Control) enriches it with several interconnected processes aiming in capturing perceptual and motor activities by means of parallel working processes. Operation is done in symbolically coded features rather than raw sensor data [GLAG10, p.2]. EPIC has also been connected to SOAR, as it is an independent cognitive architecture focusing on modeling human behavior, and has been applied to air traffic control simulation [RoCE01].

Emergent Paradigm Architectures

Emergent cognitive architectures follow a ideas of connectionism [RuMC86] and use activation signals through networks of processing units, that interact with each other by changing internal states in bottom-up processes for emerging, self-organizing properties. Relations to brain-like processes are rather distant [DuOP08, p.5], the architectures are designed to simulate neural networks or aspects of brain functions.

IBCA (Integrated Biologically-based Cognitive Architecture) is an architecture that has a focus on distributed and automatic notions of information processing in the brain [OrBC99]. The focus is on various human psychological and psycholinguistic behaviors especially in the posterior- and frontal-cortex and the hippocampus of the human brain. The architecture is divided in three main modules according to the three above noted brain regions. In the three modules the focus is on: sensory-motor, multi-modal hierarchical processing; localist organization in conjunction with working memory to create representations; and sparse, conjunctive, globalist organization with interactive contribution of all modules to given representations. Current implementations are limited to leaning weight parameters of the used Artificial Neural Networks (ANN) but not the network structure itself

[DuOP08, p.6]. Psychological or psycholinguistic experiments can be explained by using such architecture, but reasoning tasks are out of scope of IBCA.

In DeSTIN (Deep SpatioTemporal Inference Network) [ArRC09] hierarchical spatiotemperal networks are used for unsupervised classification of perceptual inputs (so far visual and auditory). It creates structures for categories of objects and actions. DeSTIN was planned to gradually extend from perception to a complete system of humanoid robot control. The practical work of the architecture focusses on auditory and visual processing and is used in other architectures like CogPrime as a perception and action layer.

Hybrid Paradigm Architectures

Hybrid architectures result from the promising combination of the strengths of symbolic and emergent paradigms for developing more complete frameworks for cognition [SuAl97] and perception. Symbolic architectures have strengths in realizing the information processes of high-level cognitive functions however the major issue [DuOP08, p.7] is in the formulation of symbolic entities from low-level sensor information. A solution to this issue is the architecture proposed by Velik, the neuro-symbolic network [Veli08]. The long list of hybrid approaches as for example listed by the BICA (Biologically Inspired Cognitive Architecture) society website [4] consists of CLARION, CogPrime, DUAL, HTM, LIDA, Pogamut and Polyscheme to name a few important ones. The two most important ones are given here in detail with addition of neuro-symbolic networks as example from research within the ARS project.

LIDA (The Learning Intelligent Distribution Agent) [FRDM07] has two aims: a conceptual one and a computational framework. The engineering aim [FrPa06, p.2] is to implement a framework for intelligent autonomous software agents by using ideas from the Global Workspace Theory (GWT) by Baar [BaFr09]. The conceptual aim is to provide a *"cognitive theory of everything"* [FrPa06, p.4]. The main processing is done in a cognitive cycle, a set of steps integrating various forms of memory and intelligent processing [GLAG10, p.7] in a closed processing loop. The project incorporates scientific findings from neurology, psychology and cognitive science but not with the aim of a coherent model. Another aim of the project is mapping and evaluation of other projects into the cognitive cycle.

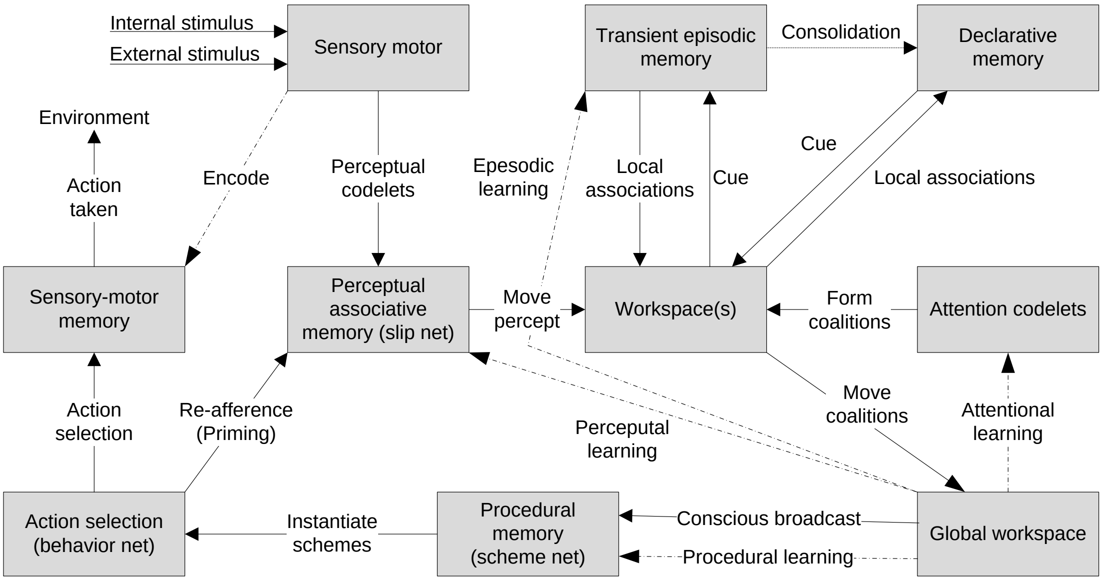

Figure 2-14: The LIDA cognitive cycle [BaFr09, p.26]

The LIDA agent processes the cycle [FRDM07, p.3] (Figure 2-14) by perceiving internal and external stimuli through the sensor motor module into a resulting percept codelet. In the perceptual associative memory module past and current percepts are combined to higher level percepts. The workspace module information from episodic memory, perceptions and associations from the declarative memory are merged to cues which are stored in the long term memory. Cues compete for dominance guided by mechanics of attention from the module attention codelets. Next follows interaction in the global workspace to create a model of the current situation of the agent. In interaction with procedural memory appropriate responses for the dominant cue is evoked. The action selection module binds non dominant content to resources and the corresponding action is executed in the action selection module and through sensor-motor memory on the internal or external environment.

The OpenCog (Open Cognition) Prime project originates in a theory called PsyNet [Goer06, p.452] and can be roughly compared with the above discussed LIDA [GoPe08, p.2]. OpenCog Prime is an open source implementation of the Novamente [Goer09, p.1] architecture. The architecture's assumption is that the human mind is made of patterns [GoPe07, p.80] represented by Atoms. So called MindAgents operate on these Atoms. Input to the architecture is via text I/O and sensorial processing responsible for sensations[20] and perceptual schemata. Atoms are processed from the perceptual memory to a central processing module – the central active memory – where the central Mind Database is connected and goals, feelings, cognitive schemata and declarative knowledge is stores and processed. From this central memory module evolution of new knowledge and relation building to existing knowledge is processed by means of pattern mining. Genetic algorithms and evolutionary learning, which is also influenced directly by sensorial processing, is used to adapt

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[20] In this case the term sensation is used as a sensorial input from various modalities in the form of attribute value pairs recorded from the virtual-world implementation AGISim.

schemata. In the framework a scheduler is executing every agent and they perform tasks based on their stored atoms. The main goal is in a framework for cognition, language and virtual agent control [GLAG10, p.7] but a focus is also in collaborative learning [GoPe08, p.2] and practical applications in gene analysis [LoGP04, p.60].

Albus [Albu99] shows in his 4D[21]/RCS (Real-time Control System) architecture that models developed for artificial systems can be applied for biological inspired systems. In his work he proposes five elementary axioms to model functional elements of an intelligent system (with the human mind as archetype), such as perception, behavior generation, value judgment and world modeling [Albu99, p.1] which is also his first axiom. In his second axiom he proposes that 'intelligent' systems are supported by a priori and dynamic information about the world stored in a knowledge base. In the third axiom he proposes that the knowledge base and the functional elements can be implemented by interconnected computational modules, forming nodes in a control system architecture (see Figure 2-15 for the functional elements in the RCS reference architecture).

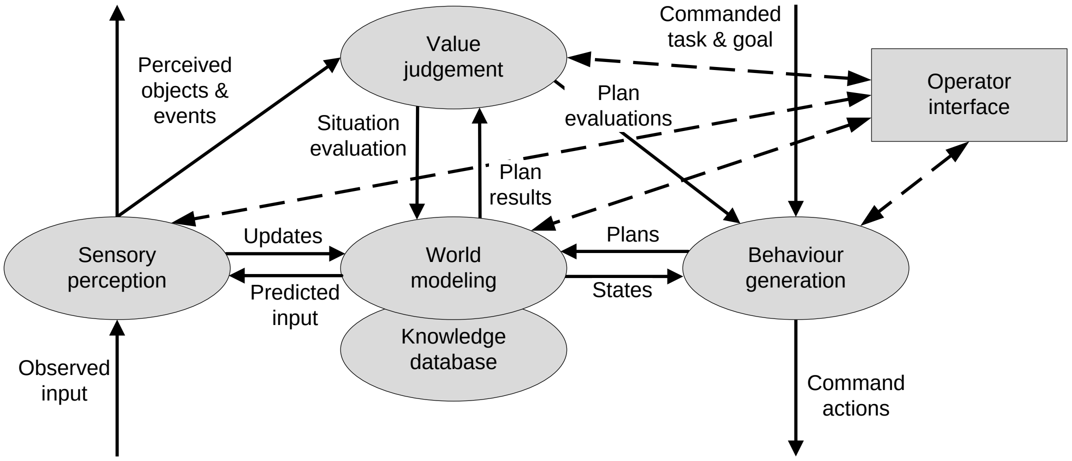

Figure 2-15: Functional elements (nodes) of the RCS reference model architecture [Albu99, p.7]

The fourth axiom is about using organization in hierarchical layering[22] to manage the complexity of 'intelligent' systems. The approach uses lower level nodes with a narrower scope and shorter time horizons and higher level nodes with longer time horizons and a broader scope. The last axiom deals with complexity of real world environments. The proposed solution to finite computational resources is focusing of attention where the system is able to focus resources on what is important. What is important is set through behavioral goals and perceptual generated expectations. This statement can be correlated to active perception, where relevant information is collected depending on the goal, but the RCS architecture omits the subjective behavior of goals and knowledge a model abstracted from the human mind must contain.

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[21] 4D is a reference to the 4D approach to dynamic vision by Ernst Dickmanns developed for control of autonomous vehicles [Albu10, p.1520] in addition to the RCS reference model architecture.

[22] This results in military-like hierarchical structure as developed for the Army Research Laboratory Demo III in [Albu10, p.1524].

In the RCS (Figure 2-15) model, the module behavior generation is responsible for planning, control and execution of actions. This module is provided by world modeling which is responsible for storing and retrieving knowledge and pretending future states. The module sensor perception filters, detects, recognizes and interprets from observed input (in the 4D implementation this comes from cameras, radar accelerometers etc. for autonomous vehicle control) and updates the module world modeling. The three noted modules are supported by a knowledge base and the module value judgment for computing cost, benefit, importance and uncertainty for data in the other tree modules which results in evaluated plans, situations and objects. Each of the modules may have an operator interface with no biological analog [Albu99, p.7] for human operators to insert commands, override or modify system behavior (as well as maintenance and debugging).

Neuro-Symbolic Network

The base functionality of the human psyche is based on interaction neurons in the brain. As the examination of the relationship between brain and psyche is not yet fully understood and unclear the functionality is best described on a symbolic level. The transition from neural to symbolic processing as described by Velik [Veli08] is called neuro-symbolization. Velik is basing on neuroscientific literature such as [Luri73] and on a three layer approach. The first layer extracts features from unimodal sensor information which are merged in the second layer to sub-unimodal symbols (which resembles of simple object information). In the third layer multimodal symbols are created by fusion of symbols in the lower levels to a multimodal perception. More on the topic of sensor to neuro-symbols can be found in Section 2.4.2.

2.3.3 Neuro-Psychoanalysis Meets Artificial Intelligence

In interdisciplinary approaches, control systems inspired by psychoanalysis are rarely found. Various researchers have tried to extract essences of psychoanalytic theories to form technical models. The project ARS transfers the whole holistic model of psychoanalysis for the first time [Zeil10, p.20] to use it in a computer scientific model.

Turkle proposes a new alliance between AI and psychoanalysis to benefit from each other. According to her, both have different aims but many overlapping concepts especially when it comes to descriptions of internal objects. This especially comes true for subjective self-reflection [Turk89, p.244] and subjectivity mechanics. Internal objects would be the concepts of memory traces, mental representations, introjections, identifications and inner structures such as the Super-Ego (for details on Freud’s Super-Ego see Section 2.5.1). The subjectivity described by Turkle only deals with conscious processes, but in fact main parts of psychoanalysis deal with unconscious information and mechanics. This is especially pointed out for attention where the focus is only on processes the individual is able to reflect on. According to Turkle two approaches in AI are promising coincidences for the psychoanalytic object relational approach [Turk89, p.247]: agent oriented programming (she notes the possibility of an implementation in a multi-agent architecture) and connectionist emergent AI (see the distinction of BICA in the Section above). She further states that information processing in AI is not feasible for a model of the human mind [Turk89, p.252] as it is not flexible enough in the rule-based behavior of AI systems. This is where emergent AI could be used, as knowledge is not stored there in rules but in relations between agents, which appears similar to connectionist approaches in artificial neural networks. For perception her introduction of the ‘perceptron’[23] as one form of an agent is especially interesting. Perceptrons are matched in a bottom-up approach and Turkle states that networks of perceptrons can resemble the theory of object relations. The work done by Turke does not result in a technical model it, is mere a mapping between different theories without the use of functional descriptions existing in psychoanalysis.

A true interdisciplinary dialog between cognitive science and psychoanalysis can be seen in the work of Leuziger-Bohleber and Pfeifer [LePf06]. Especially their work in the use of memory as a function working in all cognitive functionalities has to be pointed out [LePf02, p.3]. They state true subjectivity by using embodied connections and memories in the architecture as well as objective features coming from sensor-motor coupling based on neural patterns. There is no engineering implementation yet, but the theoretical work influences projects like ARS due to the challenges noted in interdisciplinary work. Due to their work with neurologists and psychoanalysts the model building process has a high impact on the project ARS and can be used for new scientific insights.

The work of Buller [Bull09] and his architecture Volitron shows another interdisciplinary project with implementation. The work on psychodynamics by Freud is used for control units for software agents [Bull02, pp.17–20] based on physical tension and defense mechanisms. The agents explore their surroundings, actions are triggered by tensions and filtered by defense mechanics. In [Bull05, pp.72–73] he states ten assumptions for psychodynamic agents. The agent must be operating for his own pleasure whereas pleasure is the reduction of a tension that is created by several tension sources from body and brain. High tension means increased unpleasure for the agent. The highest tensions fight to be fulfilled and are thus suppressing others. Actions in the environment are reflected through other agents and in case of a positive judgment stand for another source of pleasure. Even though the architecture Volitron is not fully implemented yet the parts that are implemented are successfully tested. The psychoanalytic concepts used still need a critical examination by interdisciplinary experts.

The first notion of the idea of the project ARS was given by Dietrich in [DiSa00, pp.343–350] by introducing a new paradigm for building automation. The ongoing work resulted in the notion of a 5th generation of AI [DiZu08, pp.12–17], which in core proposes a hierarchical processing of information and a decision unit based on findings in psychoanalysis. The foundation of the project was laid by Fuertes in 2003 [Fuer03] and the Perceptive Awareness Model (PAM) as well as by Russ [Russ03] and the model for situation recognition for proactive action. Both models act as a foundation for the perception branch or the project ARS called ARS-PC (PerCeption) which resulted in the works of [Bruc07, Burg07, PrLD05, VLBD08]. The other branch of the project called ARS-PA (PsychoAnalysis) resulted in the works of Rösener [Roes07] and Palensky [Pale08] and laid the cornerstone for the functional model as it is today. The two branches are merged now in one holistic functional model of the mind in the project ARS. The research in ARS-PA showed that modeling design paradigms were not fulfilled [Zeil10, p.24]. With insights on interdisciplinary work and a refined modeling process the first functional model was published in [DFZB09, pp.56–64] and [ZDML08, pp.259–264] and resulted in the model versions ARSi09 to ARSi11 published in

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[23] A predecessor of emergent AI actually first introduced by Rosenblatt in [Rose62].

[Deut11, Lang10, Zeil10] (the latest model iteration published is reviewed in Section 2.5). The preliminary results of project ARS are a foundation for the work in this thesis.

In psychoanalysis the connection between body and psyche is described as interplay between bodily and mental states that influence each other. Psychoanalysis is used as a therapy, which evolved a research method and lead to a theoretical framework called metapsychology, where a functional model of the mental apparatus is described. Information structures and functions for the mental apparatus are described. However when it comes to descriptions of bodily parts of information as well as higher (conscious) forms of information (e.g. scenarios) psychoanalysis reaches its limit in this issue [Zeil10, p.58]. Here researchers from neuro-psychoanalysis like Solms [Solm02] and neuroscientists like Damasio [Dama00] tie up to it and complete the concepts around the interdisciplinary work between the fields of psychoanalysis and neuroscience.

The discussed models of perception in AI show great detail in separate parts of perceptual processing. There are no models present with a holistic approach to perception and decision making in a human-like control architecture which led to the initialization of the ARS project. The ARS architecture incorporates the findings of the presented foundational agent architectures but also incorporates a new view by introducing the concept of psychoanalysis. In the following section the generation of symbols and perceptual data structures is discussed which represent the starting point for the development of the associative data structures used in the perception model.

2.4 Perceptual Symbol Generation

Perception as described above is a combination of bottom-up processes with raw sensor data as starting point and top-down processes where prior knowledge is the main influence. The whole process of perception is there to provide the mental apparatus with a model of the world with as much detail and information needed to base decisions on it (this notion alone indicates a feedback mechanism between perception- and decision-mechanisms). In a top-down approach building a model of the world is dependent on previous experiences (knowledge) stored in memory. The model of the world is constructed and sensor data is actually used to complete the model and approve the construction to the real world. Sensors in a bottom-up approach construct perception from sensory data and create a model of the world as a result. Since the creation of the world is based on prior knowledge, top-down processes emphasize the role of subjective memory for perception. The construction of the model happens actively and unconscious [Metz09, pp.72–77, Scha12, p.10]. The constructed model of the world is recognized but the process itself is not, it says unconscious. The built model consist of past experiences associated with each other and the current environmental perception, it is used in a top-down approach to predict [Bar09, p.1238] the objects or scenes to expect from incoming perception. In the following the above briefly described mechanics for perception are investigated in detail.

2.4.1 Perceptual Categorization and Classification

As perception processes are connected to the memory, the human mental apparatus is able to recognize[24] objects as ones that were perceived before. As a result we cannot only tell what object we are faced with but also what kind of object it is and what other memories are associated with it. This distinguishes the perceptual task into two parts namely identification and categorization. Identification is about finding similarity in physical features of an object. For categorization the human mental apparatus must generalize across physically different objects [PaGa04, p.291] and decide about an object's kind. To be more precise the task is perceptual object categorization because inside a cognitive architecture identified and categorized objects are the base for decisions. Another premise is that after the symbolization task (see Section 2.4.2) sensory information (stimulus) is represented in a symbolic form. As stated by Palmeri [PaGa04, p.292] object recognition researchers and perceptual categorization researchers should not see their sciences as modules where categorization is started as perception ends, the two processes must be studied concurrently to create holistic experiences [Bars99, p.582].

Computational models for object identification (or recognition) and models for perceptual categorization focus on different stages in perceptual processing. Detailed descriptions of the format of object representations are typically the emphasis in identification models, with less detail on how categorization is generated. On the other hand is the focus for categorization models in the impact on decision making with simplified object representations [PaGa04, p.292]. In fact category recognition and conceptualization reflect the possibility to use categorization in a reasoning or comparison process for object identification [Scha12, p.11].

In a computational model for a cognitive architecture a memory based approach is used for the comparison and recognition processes. This emphasizes the focus on memory based categorization approaches in this thesis. In a cognitive agent architecture similarity based processes rely on object representations stored in memory (see Section 3.1.2 for details). Kruschke describes in [Krus08, p.269] three basic parts for every computational model for categorization:

- A clear description of the format and content how internal categorical knowledge is represented.
- A description of the process how a stimulus is matched and classified to knowledge.
- A process description how, based on matching and classification process, a category is selected and responded.

Kruschke further proposes a categorization of models according to the type of knowledge (content and format) stored in the knowledge base into models using: exemplars, prototypes, boundaries, rules and theories [Krus08, p.269].

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[24] The term recognition is often used in perception architectures when memory is attached. In fact it is misleading because it indicates some form of cognition which is not modeled by most of the perception architectures.

Foundational Models

The models have a clear distinction between categories built by summaries of its contents or by individual exemplars. A member of the first group is rule-models. A rule defines the members of a category by specifying necessary and sufficient features for category membership [Krus08, p.270]. Through the definitions in the rules, membership of every object to a specific category is laid out. The problem arises as stated by [Murp02, p.16] that it is very difficult to specify the necessary and sufficient features and not every object has a clear distinction to be in one or another category. This rule based approach led to finding typical members of a category and finally ended in the prototype approach explained below. Boundary models on the other hand do not describe the contents of a group but instead go the other way by describing the boundaries between categories [Murp02, p.271]. There is a connection to rule-based models as also rules are created as conditions for necessary and sufficient features. The distinction is that unlike in rule models not the insiders of the category are described but mere the boundaries between them. Theory models for categorization introduce knowledge of the world an individual has into categorization. The approach is based on the notion that individuals have theories (knowledge) about the world which they use to categorize objects [Murp02, p.271]. This approach is close to the rule models but expands it by formalizations of previous knowledge an individual has. The basic idea behind a theory lies in the fact that individuals cannot consider all observations and all possible parts of observations [HeBo00, p.164] for forming a new category, instead category forming is guided by already learned background knowledge (theoretical knowledge).

Prototype Models

The prototype approach goes back to the psychologist Eleanor Rosch [RoMe75] who studied naming of color perception and founded the family resemblance hypothesis that items show typicality if they have common features in their category and do not share features common to other categories [Murp02, p.35]. In addition, not all category members have to share one attribute that identifies them. Attributes are by definition subjective characteristics that individuals associate to objects. This family resemblance is the base for the today so called prototype theory.

Prototype models share an analogy to exemplar models (see below), but a summary representation (the prototype) of the instances in a category is stored instead of storing every instance perceived of an object [Krus08, p.270]. A prototype could also be derived from the most frequent instances or a combination of the most frequent features. The most frequently used definition for a prototype is as summary representative of the category that describes the category as a whole, instead of a single ideal member as the best example [Murp02, p.42]. The whole notion of prototypicallity is behind the idea to use one member exemplarily. Typicality itself explains the degree of coherence inside a category, makes integration of new instances to a category possible and ensures flexibility for the categories.

Under the hood of typicality each instance’s feature is weighted by the number of objects it is a member of in relation to the number of members where it is not a member. This gives an impact to features appearing frequent in a category. As a result the weights for each feature of an object are summarized and give a typicality score for every category [Murp02, p.35]. The weights indicate typical features which are common in one category and uncommon in another category and how ‘typical’ the object is for a category.

One addition to typicality was made by Barsalou [Bars85] in adding three measurable variables: central tendency, frequency of instantiation and ideals [Murp02, p.35]. Central tendency mimics the findings of family resemblance but only includes within-category resemblance. Frequency of instantiation is the frequency with which an object is categorized as member, extending the simple frequency of occurrence with occurrence of being member of the category. Ideal reflects the degree to which each object fits the primary goal of each category. The ideal is a subjective selected dimension to reflect the degree to which an object fulfills the main goal of a category.

Objects in categories are represented by features. Each feature on this feature list that matches the stimulus weights the object higher in the category. This leaves the problem with discretization of values which the prototype theory seems to be lacking [Murp02, p.43]. A new object to be categorized is weighted for every feature on the category list and loses value for every feature not represented by the stimulus. After all weights are calculated membership is calculated if the score for the new object is above a critical value, the categorization criterion. This mechanic makes sure that the more highly weighted features an object has, the more likely it is to be identified as a category member [Murp02, p.44].

A critique to the feature list approach is that no relationships between features of a category are created above the weight calculations. The introduction of schemata to the theory enhances the feature list by adding structured representations that divide the features into dimensions [Murp02, p.47]. This leads to representations of features in simple forms of rules (an indication for rule based models) and extend the capabilities of category learning.

Exemplar Models

In exemplar models every stimulus is compared to the stored exemplars (every distinct occurrence of a stimulus already categorized). A set of stored exemplars of a category represents that category. The stimulus is not checked against a summary representation but similarity of the stimulus is determined to all known exemplars [Krus08, p.270].

Similarity of a new stimulus has to be calculated to place it in a category as in the prototype model. The calculation incorporates the number of exemplars similar to the category and the degree of similarity for categorization. Unlike the adaptive similarity calculation in prototype models, exemplar models use a multiplicative rule. First in this rule is the identification of shared and different items. For each feature importance of the similarity to the dimension has to be defined. Second for the mismatching features, an importance value has to be defined as well. In order to do this factors have to be quantified (typically from 0 to 1 [Murp02, p.52]). Finally the scores for each feature are multiplied resulting in an overall similarity score for the stimulus to the exemplar. After calculating similarity scores for each exemplar, the stimulus is categorized to the category of the exemplar with the highest score. The multiplicative nature of the calculation leads to the typicality notion, that it is best to be similar to a few items instead of have a lower similarity to a lot of items, also: *“Typical items would be categorized faster than atypical ones”* [Murp02, p.50].

Dominant exemplar models in categorization center on the Generalized Context Model (GCM) [Noso86], which is a formal generalization of the context model of Medin and Schaffer [MeSc78]. Similarity calculation and category membership for exemplar models is explained by using the GCM as it is the most dominant one [Krus08, p.273]. The GCM categorization process consists of three steps [Murp02, p.66]:

- Calculation of the distance from the exemplar of the stimulus to all the other stored exemplars.
- Scaling of the distance metric by weighting close similarity higher than moderate similarity.
- Decision of the category membership by comparison of similarities to categories.

In GCM's stimuli are points in a multidimensional space, formally exemplar x has value x_i on dimension i. A dimension may be a feature or an adaption of features. Similarity calculation between two exemplars (x and y) is computed in two steps: first the distance d between x and y is calculated before the similarity $s(x,y)$ can be determined. The first step, the calculation of the distance d is given by the following equation [Krus08, p.273]:

$$d(x,y) = \sum_i \alpha_i * |x_i - y_i| \tag{2.1}$$

In Equation (2.1) α_i is a weight (attention) to the dimension, a free parameter calculated from the exemplars (between values of 0 to 1) and indicating the impact of the dimension. For each dimension i the absolute difference between the two exemplars is calculated and then added up to a total distance (weighted by attention).

After the distance, similarity is computed by an exponentially decaying function in Equation (2.2). The exponential form of the equation is based on experiments that show evidence that *"behavioral similarity between items is an exponentially decreasing function of their psychological distance"* [Murp02, p.68, Shep87, p.1319]. The similarity calculation is represented by the following formula [Krus08, p.274]:

$$s(x,y) = \exp(-c * d(x,y)) \tag{2.2}$$

In the GCM the distance is calculated for every dimension and the similarity on stimulus level. The scaling parameter c represents this scaling effect in distance for the spread of similarity. With high values of c, similarity drops off more with distance, meaning that for a stimulus to be compared to an exemplar the similarity has to be very high. The value is estimated through training data.

After similarity calculation, a category membership is computed on the basis of similarity from the stimulus to category exemplars and what exemplars are most frequently present. Here the equation for the original GCM model is given [Murp02, p.69]:

$$p(R, y) = \frac{\sum_{x \in R} s(x, y)}{\sum_{K} \sum_{k \in K} s(k, y)} \tag{2.3}$$

Equation (2.3) calculates the probability $p(R, y)$ weight for the stimulus y to be placed into category R with consideration of the summarization of the other categories K.

The attention weights α_i in Equation (2.1) are estimations. Kruschke introduced in his ALCOVE (Attention Learning COVEring map) model a learning algorithm for the attention weights as described in [Krus08, p.275]. In summary, the GCM is a powerful and influential [Murp02, p.71] categorization model. In the models, stimuli are represented as points on a multidimensional interval-scaled dimension space other scales are not considered. Also the similarity is calculated by using the differences between dimensions not the commonalities. Thus extensions to categorizations models try to improve category representations in a more flexible way. SUSTAIN (Supervised and Unsupervised Stratified Adaptive Incremental Network) [LoMG04] for example follows a more flexible path of category representation which can act as an exemplar or a prototype. APPLE (APProximately ALcove) by [Krus93] follows a continuously scaled dimension approach and stimuli is affected by the number of matching dimensions, even for identical stimuli [Krus08, p.278].

In the project ARS representations of objects and rules of the primary process (see Section 2.5.1) imply a similarity-based model for categorization. An even more hybrid approach has to be considered when dealing with subjective data as described in psychoanalysis. The knowledge and rule based models imply a logic based processing which indicates secondary process processing. This is also base for language generation to form logical rules but as the focus in this thesis is on the primary process the categorization processes focus on symbolic processing based in the primary process rules.

2.4.2 Sensor Signals to Neuro-symbols

The work of the project ARS is divided into two areas as described in Section 2.5, where also the ARS-PA (*PsychoAnalysis*) modules, dealing with the decision unit itself, is described. The other area of the project has its focus on perception (ARS-PC; *PerCeption*). Here the main work is on how sensor signals are merged into symbols that are then forwarded to the decision unit of ARS-PA. The main challenge is in merging and filtering incoming data.

Zucker (né Pratl) introduces in [Prat06, p.33] processing of sensor signals in a model with hierarchical structures. The structure is based on findings in neuroscience, psychology and psychoanalysis. The hierarchical model [Prat06, pp.30–35] consists of three layers of symbols as resembled in Figure 2-16. The three symbol layers consist of microsymbols, snapshot symbols and representation symbols. Higher levels of symbols represent more (higher quality) information.

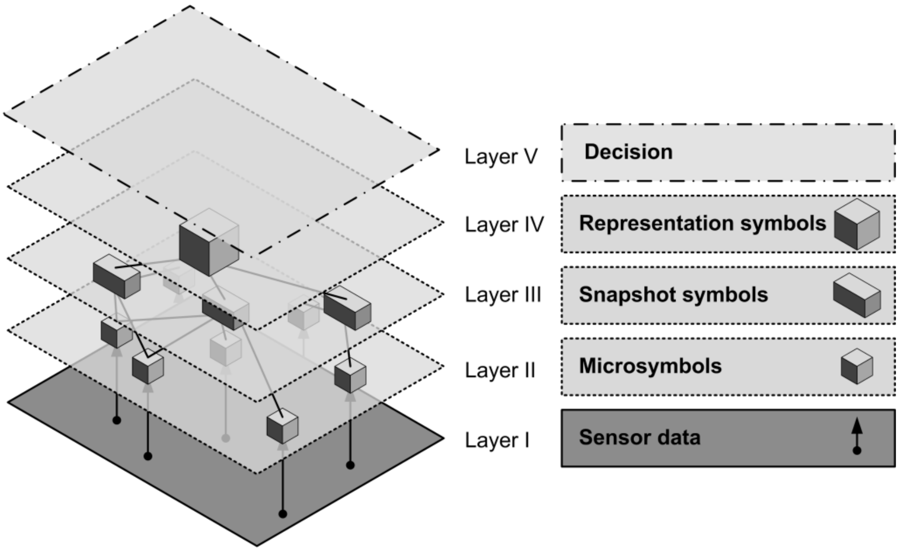

Figure 2-16: Levels of symbolization based on [Prat06, p.31] with the hierarchical layer structure of ARS-PC as stated by [Zeil10, p.44]

Figure 2-16 shows the hierarchical layers of symbols in conjunction with the layers of the ARS-PC model. It also shows the corresponding symbol types and their interconnection throughout the layer structure. Sensors data resided in layer I creates microsymbols in layer II by means of discretization [Prat06, p.32] of raw data. Microsymbols represent event-like data and characteristic features in sensor information. Groups of microsymbols are the base of the creation of a snapshot symbol (layer III). These symbols represent perceptions of objects in the world at one point in time and all snapshot symbols represent the systems perception of the environment. Micro- and snapshot symbols are formed due to changes in internal or external states. They form the representation of the world, the representation symbols in layer IV. Representation symbols represent the knowledge of the system and exist for longer time periods. They represent knowledge of the world and information formed by snapshot symbols. Information connected on all three layers of symbols form the representation of a specific scenario which is used in the additional layer V representing the decision layer of ARS-PC.

Burgstaller et al. [BLPV07, pp.1033–1038] extended the scenario recognition model and introduced basic and complex emotions to the model. The extended recognition model was used for example in an extension of the SmaKi test-platform for detection of safety-critical situations (see Section 2.5 for more information about the project SmaKi). Based on the work of Burgstaller et al. and Zucker (nè Pratl) a model for human-like perception was presented by Velik [VLBD08, pp.657–662]. Her model is based on neuroscientific and neuro-psychological findings and combines symbolic perceptual processing with the theory of neural networks [Zeil10, p.44]. In her model, neuro-symbols process symbolic and neural information [Veli08, p.50] in network structures called neuro-symbolic networks. By means of sensor fusion information is processed by neuro-symbols which have properties as well as a specific perceptual meaning in a hierarchical layer structure.

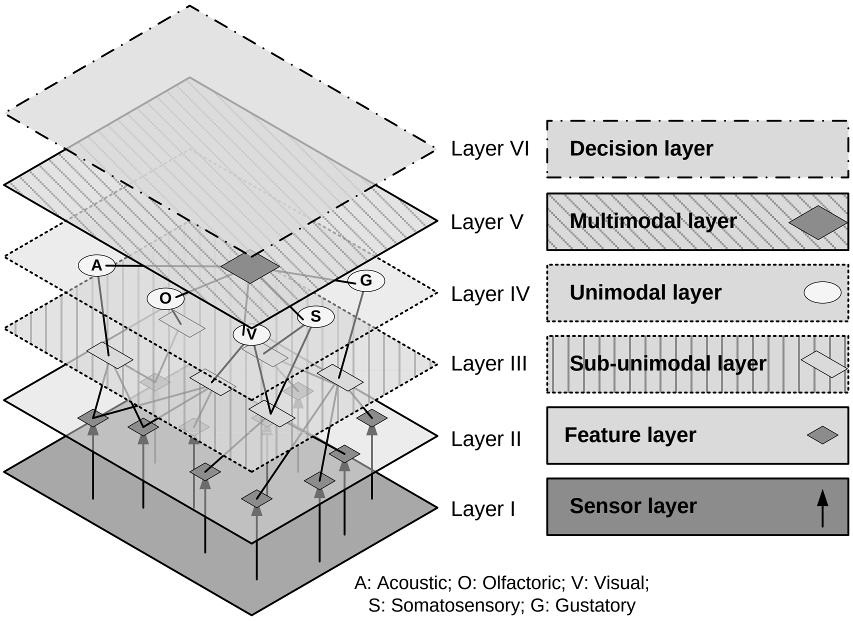

Figure 2-17: Neuro-symbolic processing based on [Zeil10, p.45] with the hierarchical layer structure as defined in [Veli08, p.67]

The layers as seen in Figure 2-17 are differentiated into the sensor value layer, feature symbol layer, sub-unimodal symbol layer, unimodal symbol layer and the multimodal symbol layer. The layer structure mimics the cerebral organization of the human brain as archetype [VLBD08, p.660]. The model introduces learning by neuro-symbol activation and a bidirectional information flow between the layers for knowledge influence. A connection to knowledge of the decision-unit as influence to the network is an unsolved issue but an ongoing work in the project ARS. The focus in neuro-symbolic networks is in perception of the environment for applications like the project SmaKi (see Section 2.5). Perception of internal, bodily values is addressed but not discussed in detail [VLBD08, p.661].

Raw sensor information, as seen in Figure 2-17, is incoming through layer I and processed into feature symbols in layer II. According to Velik [Veli08, p.67] the layer structure is inspired by the human cortex. Layer I and layer II represent processing in the primary cortex and layer II and layer IV processing in the secondary cortex. Multimodal symbols of the layer V represent mechanisms of the tertiary cortex. According to the structure in Figure 2-16, a final layer (layer VI) representing processing in the decision unit is added to Symbolic information in the sub-unimodal layer is merged from feature symbols, representing an information path from one perceptual modality but possibly from different sensors, to sub-unimodal symbols. Unimodal symbols represent the combined state of one sensor modality. On the next layer (layer IV) unimodal symbols are combined to multimodal representations which then activate scenarios and are used as input for the ARS decision unit.

After the introduction to the history and origins of the ARS model the functional model itself is discussed in the next section in detail. The presented model describes the mechanics out of scope of this thesis as the focus is on the perception model. The processing of data inside the model is presented to follow the decision making and action generation mechanics which will be used in the resulting ARSi12 framework.

2.5 Artificial Recognition System

Automation systems that can deal with complex situations was and still is the motivation of the project ARS. Applying classic AI approaches to the immense data, that result out of sensor and actuators in real life applications, may lead to systems that are unable to extract the important features [PrPa05, p.56]. From the various approaches nature has developed to cope with immense amount of data, the human mental apparatus is one of them. An appropriate model for the human information processing capabilities is given by neuro-psychoanalysis, which is used by the project ARS. Neuro-psychoanalysis merges insights from psychoanalysis with the insights of neurology and the background or neurobiology. The resulting models, which are gained in a holistic top-down approach, are appropriate for the application in cognitive architectures [Deut11, p.4] and implementation in autonomous agents.

Project Origins

More than ten years ago the projects ARS started with the invited talk by Dietrich [Diet00] and has developed a strong basis for bionic approaches and modeling since. Coming from building automation and following a bionic approach, at the Institute of Computer Technology at the Vienna University of Technology the first installation was done in the project SmaKi (SmartKitchen) [Fuer03, Russ03]. The SmaKi - the institutes' kitchen - was equipped with different types of sensors and actuators, merely as an implementation platform for different bionic approaches. Following the Idea of Perceptive Awareness the first implementation was done by Gerhard Russ and Clara-Tamarit Fuertes [Russ03]. Perceptive Awareness describes the functionality of control systems to be able to perceive and recognize situations and react accordingly [FDDR01, SoRF00]. In [Russ03] and [Fuer03] an approach is used that covers the recognition of the perceived situations and selection of the proper responses in front of them. The SmaKi was able to detect different scenarios and assign those scenarios to different individuals acting in the room. The information was extracted by different sensor groups, such as tactile floor sensors, motion detectors and light barriers. The system was capable of distinguishing a visitor going for a cup of coffee from a child coming too close to an active, hot stove top. Following the self-learning scenario recognition approach the first systems SENSE (Smart Embedded Network of Sensing Entities) and SEAL (Smart Environment for Assisted Living) were implemented. The next step was to adapt the system to prolong independent living for elderly people in their own flat [Bruc07, p.39]; this was done within the project BASE (Building Automation System for Safety and Energy efficiency).

The work on these systems formed the foundations for the project ARS (Artificial Recognition System). The foundation of the ARS project lies in the work of perceptual awareness. As stated above the systems have to deal with real world systems and with recognizing situations and action within them [DKMR04, pp.93, 94]. The first model of symbolization was inspired by neuroscientific findings and introduced in [PrPa05, p.58]. Three layers of symbolization symbols — microsymbols, snapshot symbols and representation symbols [Prat06, p.31ff] — were used to represent the different information representations. The data in the system was represented in three symbolization layers Figure 2-18. Each layer takes the information from the layer beneath and processes them to a higher order of symbols which go from micro symbols (equivalent to a sensor), to snapshot symbols (incorporation of multiple micro symbols to represent short scenarios) and finally to representation symbols (which represent history of longer episodes of the person in projects like in project SmaKi). See Section 2.4.2 for more details on the subject of symbolization in the project ARS.

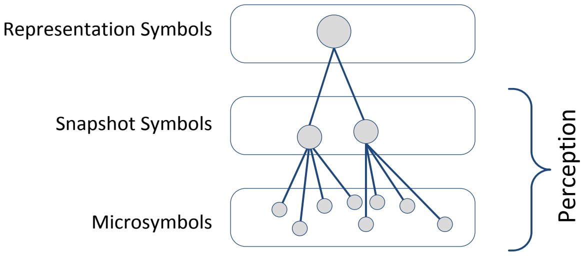

Figure 2-18: Levels of symbolization [Prat06, p.33]

In [Burg07, pp.16, 52] a layered perception model and a basic emotional system is added as evaluation system for the perception and thus further neuro-psychoanalytical findings were added to the project.

The multi-level sensor fusion was further developed in a another approach by Velik called neuro-symbolization [Veli08]. The work of neuro-psychologist Luria and his three-layer perception model [Luri73] was used to elaborate the development of representation symbols out of sensor symbols. With [Veli08] another perceptual symbolization layer was added to the project. A new model using multi-modal neuro-symbolic awareness [Veli08, p.51] was introduced. This layer depicts the neural as well as symbolic information processing of the brain and thus represents even the highest layer of neuroscientific concepts. This was done by introducing different modalities of human perception and a feedback between different layers into the system. It resulted in the novel concept of neuro-symbolic networks which incorporate the mechanics of human neural and symbolic processing.

The problem with interpretation of immense amount of data prevailed and the need of alternative approaches was pointed out ([DKMR04, p.93, RHBP04, p.349]). The novel approach of using psychoanalysis in AI was first sketched by Pratl and Palensky by the use of the first approach in [PPDB05]and [PrPa05]. The first approach resulted in a cycles and feedback mechanisms of human information processing which a rich internal model of drives and basic emotions based on the basic emotion system by Panksepp [Pank98, p.52] as seen in Figure 2-19.

Perception collects data from the world and is not directly forwarded to the decision system but processed by so called pre-decision. Perception from the body invokes emotions and drives and results in either reactive actions if too strong, or the emotionally evaluated scenarios detected are transferred to decision making where based on this scenarios and the emotional state decisions of actions are made. Perceptions are transformed into symbols by using memory and matching previous experienced scenarios. Basic emotions (e.g. seeking system, fear system) and the bodily state is used to generate complex emotions (e.g. joy, disappointment, hope) and processed in higher cognitive functions. How the emotional system can be implemented is described by Burgstaller et al.

[BLPV07, Burg07] and is an important part of the ARS project in this first model. The cycle of information processing as describe in Figure 2-19 and in more detail described in [PaPC09, pp.197–216] has been developed.

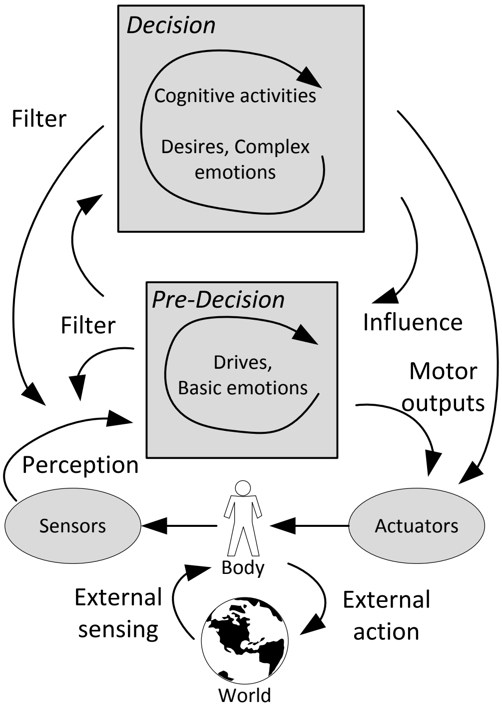

Figure 2-19: Old ARS model overview [PaPC09, p.200]

To the perceptual concepts, additional concepts for evaluating the sensory information were developed and resulted in a functional model for decision making based on the human mental apparatus. Following a top-down approach, different models of the human mental apparatuses cognitive processes influenced the model. Neuro-psychoanalysis and psychoanalysis were a vital influence. Following the project's paradigm, the model was created in close cooperation with experts in the field. The first models were introduced by [Roes07, p.72] and [Pale08], and were compatible with the symbolization model by [Prat06]. The symbolic information generated by [Prat06, p.31] was used as input for the framework and for the model of the human mental apparatus based on psychoanalytical concepts

The above described concepts were put together to create the first final model of project ARS as seen in [PaPC09, p.202]. The described model introduced an interdisciplinary approach to human information processing. As stated by [DFZB09, p.53] the used terminology raised a problem as the different interdisciplinary models use different wording and concept. The incomparableness of the used concepts led to a full functional investigation of the human mental apparatus based on findings in psychoanalysis and a new functional model was developed.

The successors [Lang10, p.88], [Zeil10, p.102] and [Deut11, p.116] of the above implementation further improved the functional description and model of the system following the strict top-down approach and concepts of metapsychology. In [Lang10, pp.49–64] the decision unit for the autonomous agent is introduced, whereas in [Zeil10, pp.80–88] the focus is on the information representation layer. [Deut11, pp.79–85] addresses the drives system and the revised version of the decision unit. The models will be discussed in more detail in Section 2.5.1 and Chapter 3.

Implementation of the First Model

The first test bed to evaluate the above described model was developed by Deutsch et al. [DeZL07, pp.1021–1026] and named Bubble Family Game (BFG). The simulator was developed in Java and AnyLogic and was built to evaluate not a single agent but teams of agents of the same kind. The design focus of the agents and use cases is on social interaction between team-members. The agents (which are called Bubbles) are interacting in the A-Life simulator to avoid danger and cooperate for food consumption. The experiments performed e.g. in [Roes07, pp.118–123] were used to state survivability of the agents and the functionality of the first model.

2.5.1 The Functional Model of Project ARS

As sketched in the chapter above preliminary work has been created. This work in this thesis is embedded in the project ARS and publications and innovations have been done in the last ten years. The latest work is done in the functional model of the human mental apparatus and several iterations of the model have been worked on in conjunction with our psychoanalytic advisors.

The first iteration, the version ARSi09 was described by Lang in [Lang10]. The implementation of the model focused on the decision-making and embodiment theories of the agents. Information processing between the psychic instances Id, Ego and Super-Ego was described in detail and the first implementation in a multi-agent simulation framework was introduced.

The second major publication of the functional model of project ARS by Zeilinger [Zeil10] emphasizes in the information representation of psychoanalytic data types. The version of the implementation was named ARSi10 and introduced details about information representation management. Activation and retrieval of stored data structures as well as a detailed view on memory was the focus in this iteration of the model.

The latest iteration of the functional model by Deutsch [Deut11] introduced a focused view on Freud’s Id and its interaction with the body. The distribution of drives inside the cognitive architecture as well as a strong connection to AGI was introduced.

In the following Sections the functional model is summarized in the so called track-view of the functional model and references for detailed investigation are given before the innovations to the newest iteration of the functional model are given in the next chapter.

Interdisciplinary Approach

Findings in psychoanalysis or even neuro-psychoanalysis are hardly used in AI research. Some suggestions how to use a connection between engineering and psychoanalysis exist [Turk89] but are not commonly used. However there is are wide spread uses of terms like ‘emotion’ without proper knowledge of the scientific fields that define those terms (e.g. [CoMC05, GoNH09]). Theories and terms are often mixed together from different not comparable theories.

In the project ARS, advisors specialized in the field are used to overcome this problem. The design of the functional model is worked on in a strict top-down design approach as described below. In this approach the model of the psychoanalytic theory is transferred into a functional technical model before it can be implemented. In order to describe the full functional model it is reduced to certain information paths, so called tracks. The interfaces and details about the modules are found in the corresponding publications as pointed out in the next Sections. The tracks represent a collection of functional blocks and the corresponding interfaces between tracks are described in detail.

Top-Down Design

Thinking in hierarchical layers or in distributed systems comes natural for computer engineers. Also the general definition of a computer as a system transferring, saving and manipulation information is still valid. The neurologist Lurija organizes the human brain in three layers [Luri73]. In the project ARS the layer structure of the brain, which is familiar to computer engineers is compared to the layer structure of mental apparatus in the design process.

The brain manipulates information to manage the needs of the human body and the mental functions are nothing else then another description of the underlying hardware (neural networks). Similarity between the underlying models is gained by comparing the overall architectures of both systems. The same layered approach that is used for designing computers can be used to model the mental apparatus.

Former attempts to define and understand the principles of the human brain in AI used a bottom-up-approach. First the lower neurological layers were defined and then the behavior out of this base should emerge [MuPB11, p.3]. In the project ARS the design of the mental apparatus is done in a top-down approach by starting to define behavior of higher functional blocks before simulation and emulation of the human mental apparatus as a whole can be executed.

The model is designed by using a hierarchical model which is a technique widely used by engineers. Abstract layers show a more detailed view of the previous one. In the project ARS five layers of granularity are used with the addition of the track-layer which is a summary of functional modules of the 1st level of granularity for improved explanation of the whole model.

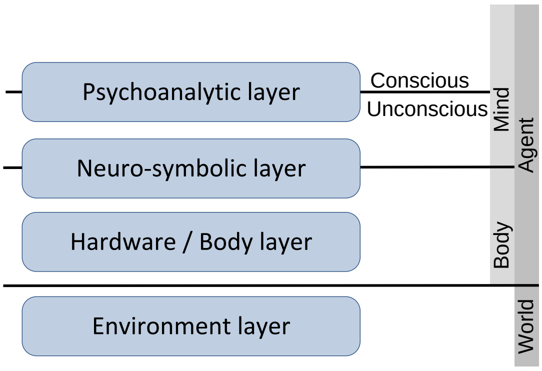

Figure 2-20: Hierarchical layer definition

The approach to design these layers follows a top-down approach and when one layer is defined the next layer is created by the functional demands of the layer above and the need of finer granularity in the functional descriptions. The design is not started from the neurological layer but from the highest definitions of the mental apparatus. The starting points are the conscious and unconscious[25] operations as described by psychoanalysis. For the lower layer findings of neuro-psychoanalysis and neurology are connected.

The functional requirements from psychoanalysis describing the higher layers make a definition of the interfaces of the lower layers possible. The same requirements are used for the lower layers and make the interconnection of the layer in between possible. Figure 2-20 shows the hierarchical layers and the model space between which is filled in the modeling process described above. Details on the modeling process of the functional model can be found in [Zeil10, p.63].

Foundations of Metapsychology in the Functional Model

The design process introduced the models as described in [Deut11, Lang10, Zeil10] using the second topographical model. The model in the 4th topological layer (Figure 2-21) is the result of the first step of granulation from the overall model by Freud (5th topological layer).

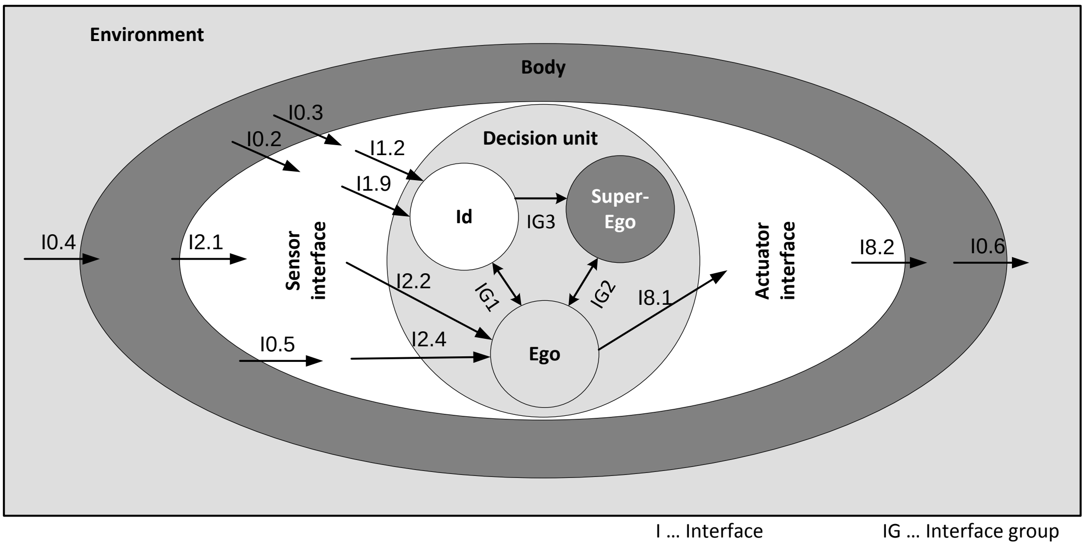

Figure 2-21: Decision unit, 4th& 5th topological layer based on Freud's 2nd topographical model

The Decision unit receives information about the environment via interface I0.4 and I2.1 and bodily information is passed via interfaces I0.2, I0.3 and I0.5. The interfaces I1.2, I 2.2, I2.4, I1.9 and I8.1 mark the information flow between outer and inner world via the sensor interface and the actuator interface. The interface I8.2 and I0.6 resemble the connection between the inner world and the environment for action execution. The decision unit in Figure 2-21 represents the mental apparatus in technical terms with the information flow between outer and inner world. The mental apparatus itself mediates between three main instances (the Id, Ego, and Super-Ego complex) and the

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[25] More on the terms unconscious/conscious and their corresponding terms primary/secondary process can be found in Section 3.1.1.

requirements coming from them. The first instance, the Id, generates the drive demands triggered by bodily needs or an imbalance in the internal homeostasis. The second instance, the Ego is responsible for the reality demand combining knowledge about reality and the possibilities, constraints and subjective consequences of outer perceptions. The third instance builds the demands of the Super-Ego. That demands are coming from social and cultural rules as well as believes. The interface groups (IG), IG1 to IG3 in Figure 2-21, represent the described information flow between the instances, as described by Zeilinger in [Zeil10, p.63].

Id

The Id is the psychic entity that holds unconscious data like repressed contents as well as bodily needs. The needs are represented in the form of drive representations [Deut11, p.81] and affects and the functions work according to the pleasure principle [LaPo73, p.181] which demands instantaneous satisfaction of all demands. The Id is acting according to primary process principles and deals with unconscious information. Detailed information about drives and the functions of the Id can be found in [Deut11, pp.79–85].

Super-Ego

The Super-Ego is responsible for management of restrictions or internalized rules and acts as an antagonist to the Id. The internalized rules bind actions requested by the Id to *“socio-culturally acceptable behavior”* [DBZM09, p.5]. The conflict between demands of the Super-Ego and demands coming from drive representations triggers defense mechanisms and can act as a filter mechanism for unconscious information before actions are taken. A discussion of the aspects of the Super-Ego can be found in [DTMZ09].

Ego

The demands from Id and Super-Ego and reality are mediated in the Ego. The conditions of outer world are considered by the reality principle [Solm06] which converts drive demands according to reality of the environment. Psychic content is organized according to the secondary process principles and thus has the possibility to become conscious but some functions of the ego are part of the primary process and their content stays unconscious. Besides the mediation functionality between the outer and the inner world, other functions like evaluation of actions, decision making and parts of focus of attention are based in the Ego. The functions of the Ego with functional sub-divisions are discussed in detail in [Lang10, pp.66–76].

Introduction to Psychoanalytic Data Structures

Information inside the functional model is processed in several forms. The layer where symbolic data is processed consists of multimodal neuro-symbolic networks. The information is processed in so-called neuro-symbols [Veli08, p.49]. Neuro-symbols are activated through neuro-symbolic networks and stand for perceptual stimuli. In the mental apparatus itself, the most fundamental data structure is the memory trace which is a term originating in the psychoanalytic theory by S. Freud [Freu33, p.75]. A memory trace is a record of an experience of the mental apparatus [LaPo73, p.446]. Based on these basic definitions, data types were defined for information processing in the functional model.

A perceived image is a neural (or neuro-symbolic) snapshot of perceptions from the body or world without subjective rating. Then the information is forwarded to the mental apparatus it is translated into thing presentations (TPs). TPs consist of a memory trace with subjective rating, the quota of affect. As TPs stand for one object several TPs can form a template image which creates a group of information but still for a small frame in time or region. In the first modules of the mental apparatus TPs are matched against previously experienced and stored template images. TPs and template images are not bound to logical relations [Freu15b, p.186]. Connection between data structures is achieved by association. TPs are connected by TP associations, which are non-directed connections between two presentations. Every association has an association weight to represent the connection strength which was created during learning of the presentations or repeated activation from memory. Learning is postponed at this stage of the implementation thus presentations and associations are created by engineers in conjunction with psychoanalytic advisors.

In the secondary process of the mental apparatus logical and long-term processing is possible [MWBM11, p.3]. The main data structure in this part of the model is the word presentations (WPs). WPs are attached to TP in the conversion process. The connections between these data structures can be directed and are called WP associations. They connect two WPs and have an associated weight as well as an association type, which represents several possible forms of logical or content associations.

Temporal processing in the secondary process is represented by acts. Acts consist of at least three template images (with the corresponding TPs) [MWBM11, p.4]. Two of the template images with corresponding WPs are connected with a temporal WP association. The two template images are then connected with another one in a hierarchical WP association representing the act itself.

Data structures in the primary process are grounded in symbolic or even sensor value information and presentations in a unstructured way. Secondary process data structures represent logic, ontologies and presentations for planning. More details in the data types of the implementation can be found in Section 3.1.2 and in [Zeil10, p.58].

Third to First Topological Layer

In the modeling process the 4th topological layer is sub-divided to the 2rd layer by analyzing functionality of the three instances Id, Ego and Super-Ego (see [Zeil10, pp.67–72] for details). For the Id and sub-modules are identified for the management of drives and affects as well as for management of repressed content. In the Ego functionalities for the management of perceptual interfaces are identified. The Ego acts as a psychic mediator between Id and Super-Ego modules and has to be investigated further for the role of mediation of demands from the Id and rules from the Super-Ego. In Super-Ego itself parts of the module have the ability to become conscious thus this module is split into a Super-Ego for the primary process and one for the secondary process (with functionalities according to the specifications of the two processes).

In the 3rd layer the modules are even divided further where a split is necessary. In this layer some of the descriptions are already sufficient [Zeil10, p.70] to name them with the final module names of the full functional model as they will not be split further. For every of the above named functional blocks sub-modules are worked out and connected to the according modules via named and identified interfaces. The separation of the Super-Ego is finished in the last layer and not revised further.

In the final iteration to the 1st topological layer some modules have already reached the finest granularity for the functional model. The Ego must be refined further and this is done by a close look to management of memory traces from perception and drive objects as well as modules for conversion from primary process data structures to secondary process data structures (see below for details on psychoanalytic data structures). The result in this iteration is the functional model as seen in the version of ARSi11 in Figure 2-22. The functional model in this version consists of 44 function modules and 49 interfaces [Deut11, p.86] between them. Each module is assigned the according instances of the mental apparatus based on psychoanalytic findings (represented by colors in Figure 2-22). In this model the overall layer architecture as stated in Figure 2-21 is added. The naming and numbering of the modules follow a clear concept. Modules are labeled with an E and followed by a number which is increased for every new module. Module labels are not reused when a change marks the need of a split of a module. Interfaces are labeled with I and followed by two numbers separated by a dot. The first number represents the layer the interface is situated in and the second number is increased for every interface but also not reused. In Figure 2-22 the original functional model is enhanced by information processing tracks for clear descriptions of the modules.

2.5.2 Functional Model ARSi11 – Track View

Based on this top-design approach several iterations of the functional model have been developed. Figure 2-22 shows the ARSi11 [Deut11, p.87] version of the functional model with the simplified track view used in this thesis added to model. Details about the specific modules can be found in [Deut11, pp.86–107].

In the functional model, drive tension from the internal and external world influences the mental apparatus. Perceptual sensor data from the world as well as bodily information form the body exterior (bodily sensation) represents the outer world. This raw sensor data is neuro-symbolized and represents the external perception in the environment perception and body perception track. Physiological imbalance is also neuro-symbolized and triggers the generation of a drive-tension which is a mental representation of a bodily need. These tracks consisting of the sexual drives track and the self-preservation drives track together with the two perception tracks represent the border of information incoming to the mental apparatus. At first the information is processes as unconscious data represented as TPs. Information is passed through the defense mechanisms, where the information is filtered and has the ability to become conscious and are therefore converted to the secondary process. TPs are connected here with the according WPs. Thus, presentations can be ordered logically (the task of the secondary process) and processed by further modules. Decision making is then taking the translated information to form action plans and the result is passed to actuator control for execution.

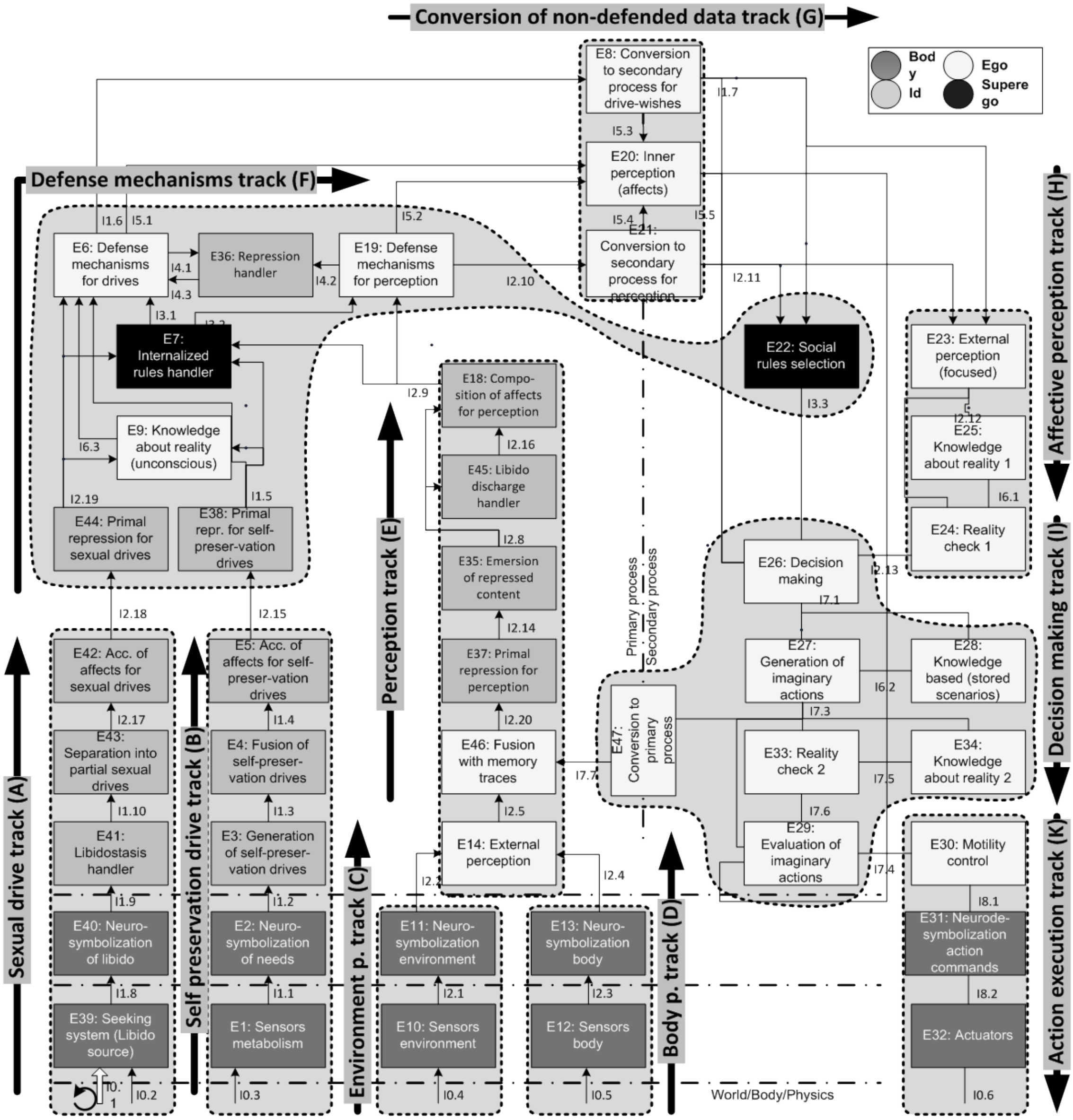

Figure 2-22: Functional view of the ARS model version ARSi11 [Deut11, p.79] with simplified drive track overlay

Environmental Perception Track (C), Body Perception Track (D) and Perception Track (E)

Environmental perception track (C) is formed by modules E10 and E11. The *Body perception track* (D) by modules E12 and E13 and *Perception track* (E) consists of modules E14, E46, E37, E35 and E18.

The body is split into three main tracks for processing sensor information from the environment and bodily needs and one for processing actuator commands (see *Action processing track* (K)). Body and world information provided by the sensor system (containing vision, acoustic or tactile information) is collected and translated into symbolic information for further processing. Information about the body not included in homeostasis (processed by the *Self-preservation drives track* (B)), for example pain or position of joints of the locomotor system. Both information paths are translated into psychoanalytic data (in the form of thin presentations) and forwarded to the *Perception track* (E). In this track perceived data is compared with known objects and scenes and missing information is complemented by activating memory patterns. In this track repressed content from the *Defense mechanisms track* (F) is associated with actual perceptions is possible. Finally the perceptions are attached with remembered tension in the form of affects (quota of affect). A detailed view and innovations on the perception track is found in the next chapter.

Sexual Drives Track (A) and Self-preservation Drives Track (B)

The *Sexual drives track* (A) is built by modules E39, E40, E41, E43 and E42. The S*elf-preservation drives track* (B) consists of modules E1, E2 E3, E4 and E5.

The two drive tracks are the *Sexual drives track* (A) and the *self-preservation drives track* (B). The S*sexual drives track* (A) contains drives created by an inner somatic source (libido source or seeking system) which results in a tension used as a basic motivational incentive for the agents to search for sensory sensations. The sexual drives are not to be confused with reproduction it can be compared to Panksepp's seeking system [Pank98, pp.144–163]. Details on the sexual drives can be found in [Deut11, pp.79–103]. The information is translated into drive structures and passed on in the same manner as the self-preservation drives as described below but with sources and object according to the sexual drives contents.

The S*elf-preservation drives track* (B), takes information from homeostatic body systems and translates them into psychic content. If any homeostatic value is out of balance this information is transmitted into the modules for drive generation and the values are translated into drive structures. The drive structures contain information about the source, aim, object and tension of the drive. The received structures are processed and the tension is attached as affects (quota of affect) to the TPs representing the drives.

The information from the drive tracks is merged with perception information to a mental image which represents the current situation as perceived by the agent and forwarded to the *Defense mechanism track* (F).

Defense Mechanisms Track (F)

The *Defense mechanisms track* (F) consists of the modules E44, E38, E9, E7, E6, E36, E19 and E22.

In this version of the functional model he module E22 is in the secondary process. The innovations of this thesis (see next chapter) show the affiliation to the defense mechanisms and thus this module is already placed in the *Defense mechanisms track* (F).

Superego rules are used in the defense mechanisms track to filter incoming data in the D*efense mechanisms track* (F). The basic function in this track is to transform the incoming information in three possible ways: passing of the information to conversion to the secondary process, parts of the contents have to be changed before conversion or the whole information is repressed and sent to the repressed content storage for later processing.

Conversion of Non-defended Data Track (G)

Modules E8, E20 and E21 build the *Conversion of non-defended data track* (G).

Information in the primary process is only accessible in the form of TPs and quota of affect. In the C*onversion of non-defended data track* (G) the incoming TPs are associated with WP. WPs can be processed by logic in decision making and be used to order them in temporal time frames. The information passed is perception in the form or recognized object and situations, drive-wishes with information about the desired object and a translated desire (related to the tension of the quota of affect) and information about the inner perception (which represents the current mood to some extent). The later concept has been refactored of the mechanics of emotions and feelings as stated in Chapter 3.

Affective Perception Track (H)

This track is built by modules E23, E25 and E24.

In the *Affective perception track* (H), perceptual information is first focused on ‘important’ things (by ordering external perception according to drive wishes). Then the ordered information is forwarded to reality check which with help of knowledge sorts out unrealistic drive wished and impossible perceptions. This is actually a two-step check and the second stage is done for situations and objects in the actual plan of decision making.

Decision Making Track (I)

The *Decision making track* (I) consist of the modules E26, E27, E28, E33, E34, E29 and E47.

The task of decision making is to combine the information from the other tracks and generate plans for actions to fulfill the most important or most promising wishes of the primary process. The intermediate plans are checked by the second step of reality check and finally result in a set of actions, a plan to be fulfilled by actions taken similar situations.

The module E47 in the *Decision making track* (I), forwards imaginary actions to the *Perception track* (E) before they are executed and thus imaginary. The secondary process information is spitted from the primary process information and the resulting TPs can be used to enhance perception quality (as described in Section 3.4 and in [MWBM11]) or can be subject of imagination.

Action Execution Track (K)

The *Action execution track* (K) is formed by modules E30, E31 and E32.

In the *Action execution track* (K) the planned actions are split into actions that can be performed by the locomotor system. The resulting commands are executed by the body and the changed body/world is perceived by the sensors through the environment.

In the last chapter the development of the ARS model as well as other models for agent architectures and perception were discussed. The psychoanalytic principles cover the recognition of perception data up to the functional description of principles of the human mental apparatus. In the models the strict distinction between functional descriptions and the actual data flow has been taken which is an engineering requirement the psychoanalytic concepts struggle with and thus an hurdle when creating the functional model. The discussed ARS model present a foundation for the conversion to a technical framework. The incorporation of the perception-action cycle model as well as the important modules for the cycle are discussed in the next chapter. Upcoming questions like the mapping between sensor data and psychoanalytic data structures are solved as well as the design of the perception track which incorporates the agent architecture with a process for recognizing objects by using their sensory features as well as stored memory structures. The implementation of the resulting model is discussed in Chapter 4, where also the tools are presented to evaluate the model which leads to the results discussed in Chapter 5.

CHAPTER 3

3. Concept and Model of the Perceptual System

Below, the concept and model of the proposed perceptual system is discussed. The system is based on the interdisciplinary work between engineers and psychoanalytic scientists as described in Chapter 2. This chapter focuses on the perception generation inside the model and how the model of the perception-action loop was developed from psychoanalytic concepts to a technical model for the generation of perceptual data structures. Resultant questions are the conversion of perception data to data structures used in the functional model and how they are processed throughout the model. The activation, retrieval and manipulation of data structures throughout the model is discussed in detail.

3.1 General Concepts

Below the psychoanalytic terms used in this thesis are discussed with respect to their use in the perceptual model. For more detailed explanations of concepts not directly used in perception referenced extended literature is given, as here only the concepts needed for the perception system are discussed.

3.1.1 Psychoanalytic Concepts and Technical Definitions

One advantage of using psychoanalysis for modeling the mental apparatus is the provision of an abstract concept for memory structures. This leads to a model of information representation as presented by [Zeil10, p.9] und [DBMW13, pp.42–48]. The most basic form of information presentation is the memory trace (see below) representing memories in the mental apparatus. On top of this data structures are defended according to the needs of the cognitive architecture and psychoanalytic theories. In addition to the functional descriptions in the last chapter for the 2nd topographical model by S. Freud [Freu23], a clear distinction for the information processed in the functions is needed. For more details on information representation inside the ARS architecture and the information management system see [Zeil10, pp.48–60].

Primary Process

In psychoanalysis the processing of information inside the mental apparatus is divided into two encoding mechanisms: the primary process and the secondary process. Functionalities can be grouped in one of the two processes as well as basic structures of information. In the primary process TPs are processes as well as affects following the pleasure principle [Solm02, p.100]. In the primary process data structures including logic or chronological order are not processed. Contradicting information is not filtered but processed parallel and the emphasis is on the demands of the drives.

Secondary Process

Conflicting or contradicting information must be processed and cleared in the secondary process. Information from the primary process is associated with WPs and structured by using temporal, local and logical associations. Information is processed according to the reality principle [Solm09, p.118] which requires logical structures on top of WPs like acts and scenarios.

Memory

The basic concept of information representation inside the ARS architecture was developed by Zeilinger in [ZeLM09] and is shown in Figure 3-1. Modules in the cognitive architecture are accessing information through this information representation module by means of searching, storage and computing.

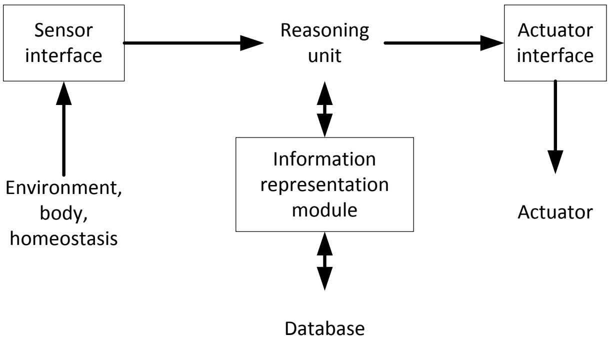

Figure 3-1: Information representation module [ZePK10, p.710]

The information representation module adds a horizontal layer to the functional model where every module from Id, Ego and Superego can access the memory. The addition of the information representation module makes the implemented architecture independent [ZePK10, p.710] from the used storage technology and thus makes it flexible for future adaptations.

3.1.2 Psychoanalytic Inspired Data Types

Processing of information in the psychoanalytic inspired functional model is divided in two main areas. In the primary process data structures consisting of symbolic information represented as TPs are processes whereas in the secondary process more logical structured data structures the WPs are processed. The focus on this thesis is in perceptual processing in the primary process where a majority of functions for perception are. The primary process is often unvalued in classic approaches to AI where the focus is on logic-dependent theories. Logic based computation resides in the secondary process part of the model and is discussed to close the perception-action cycle in the model. A detailed few on the atomic data structures of the project ARS can be found in [DBMW13, pp.42–46] and [Zeil10, pp.53–61].

Memory Trace

The most basic form of information as it is represented in the memory is the *memory trace* [LaPo73, p.138]. The memory trace is the psychophysiological specification of the concept of memories represented in the psyche [DFZB09, p.424]. The memory traces represent a pattern of events stored in the memory which can be activated and associated for processing in the mental apparatus. The memory trace is a record in the memory of the mental apparatus and is stored there in relation to other traces. The memory trace is the basic pattern how psychic data structures are represented but not a data structure itself.

Perceptual Image

The perceptual image (or percept) is representing a mental impression of objects or scenes perceived by the senses. Percepts are the summary of perceptual symbolic data and are used in psychoanalytic literature in all areas of processing. The technical specification of the percept as the data structure perceptual image inside the mental apparatus gives a more detailed view and a clear distinction of processing areas inside the functional model. Incoming perceptual information in the form of symbols is translated to TPs, summarized as perceptual images and used to activate memory structures (in the form of TP meshes, see composed data structures later in this Section). If the match is not successful new thing presentation meshes (TPMs) are generated out of the percepts and can be stored for further processing.

Thing Presentation

Presentations are cathexes of memory traces that evolve out of them when they are activated but must not be mistaken for them [Freu15b, p.178]. A *thing presentation* (TP) is the presentation of a thing and is processed in the primary process. In the technical definition it is the unconscious representation of an object or scene. The TPs follow the rules of the primary process and thus are not structured or associated in logical relations but with associations using similarity and co-occurrence. TPs are the most basic form of data structures and represent for example one feature of an object or the object itself. The full representation of an object is built by several TPs associated to a group or mesh as discussed below.

Word Presentation

A *word presentation* (WP) is the equivalent of a TP in the secondary process as defined by [DFZB09, p.429]. It describes an object by using a set of symbols, which consists of verbal expressions for the most time. A WP is a merge of a group of TPs to one symbol. The logical and temporal associations possible with WPs make the constructions of scenes and acts possible as described below.

Quota of Affect

According to psychoanalysis, the term *affect* describes the quantitative component of a drive, the intensity of a drive demand [LaPo73, p.37]. In the technical model it represents a quantitative measure of the bodily homeostatic unbalance represented in the functional model and this quantitative measure is called *quota of affect*. The term *affect* is associated in psychoanalytic literature with the terms pleasure and unpleasure [Freu98a, p.410]. In the technical translation the term pleasure is defined as the reduction of *quota of affect* what in turn is identifying the drive demand’s intensity [Zeil10, p.51]. For a more detailed explanation on the term affect used inside the definition of a drive see [Deut11, p.79]. In the technical definition the term *quota of affect* is used for a clear unification as the amount of intensity associated with a drive.

Composed Data Structures

The psychoanalytically inspired data structures can be divided in atomic data structures [Zeil10, p.50] as described above and into composed data structures. Atomic data structures, like the TP, are associated to each other to build meshes by weighted associations. Associations inside the model can be divided into intrinsic and extrinsic associations. Intrinsic associations are connections between data structures that define the data structure itself. Extrinsic associations are representing subjective connections in the memory formed by experience. These associations do not define the described entity but are attached during processing or by activating scenes from memory.

The most basic composed data structure is the *thing presentation mesh* (TPM), which acts as the elementary form of representation of information in the primary process. Associations in this form according to psychoanalysis are not directed and represent the weighted connection between object representations and their properties. On top of the TPM exists a WP for processing in the secondary process associated to represent the connection between those two processes. WPs itself can also be associated with each other to form a *word presentation mesh* (WPM), which is the equivalent of a TPM for the secondary process. This second type of association between TPs or TPMs forms semantically arrangements for further processing in the form of acts or scenarios as described in [Lang10, p.99].

Another composed data structure is the *perceived image*, which is a snapshot of perceived and recognized objects in a short timeframe. It consists of meshes of data structures forming the actual perception. The *template image* on the other hand is a perceived image extracted from the memory of the agent. The template image can consist of generalized associations to classify perceived scenes or properties in the images.

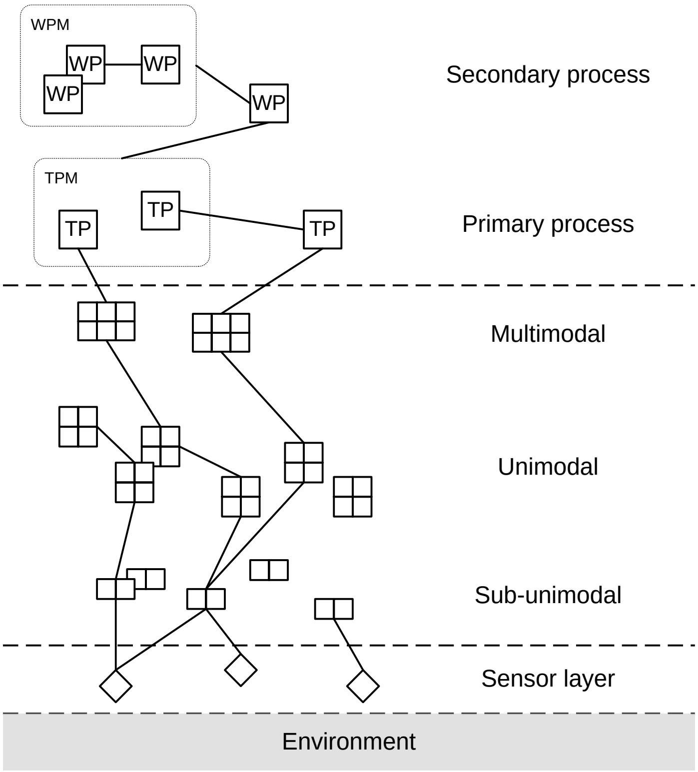

Figure 3-2: Summary of composed data structured

TPMs can be associated with each other by using primary associations reflecting similarity or temporal links to co-occurring objects in perception. This group of TPMs is also called percept or object-TPMs and represent perception of objects inside the model.

The last for of specialized composed data structures is the *drive mesh* (DM). As already described, a drive is the psychic representation of a bodily need and the drive mesh represents the parts a drive is constructed by. First the origin of the drive is represented by the drive source, the organ creating the bodily tension. Second part is the aim of the drive, showing the intention of the drive which is always to reduce the bodily tension to reach balance. There may be different paths leading to this ultimate goal by reaching intermediate goals which leads to partial satisfaction of the drive. These two parts of the drive are the most rigid ones but the third component is interchangeable by the functions in the primary process. The third part is the object of the drive that is the target through which the TP is able to reach its aim. The object can also be a part of the body itself. This is learned through satisfaction or predefined through instinct but can heavily change due to the mechanics in the primary process.

3.1.3 General Definitions in the Perception-Action Cycle

In order to match the functionalities of perception in a cognitive model a deep understanding of the used terms is necessary. This is especially important because the following terms are often [Egmo03, p.137, LaPo73, sec.vii, Sand85, p.178] used with a different meaning in the interdisciplinary sciences as major theorist use terms in their particular way. The core science for modeling in this thesis is neuro-psychoanalysis and the upcoming functionalities are matched in a common ground to the action perception cycle as seen in Figure 3-3. Further unification of the functionalities can be found in Chapter 3. In the following the German terms are added where needed as translation into English and retranslation to German caused several misunderstandings especially in psychoanalytic literature.

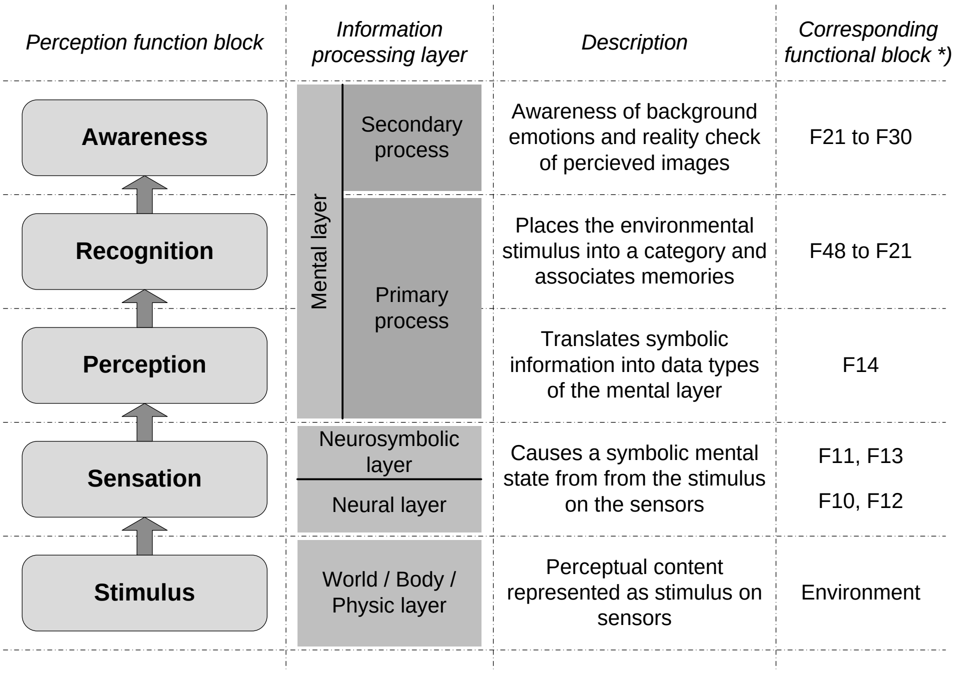

Figure 3-3: Perceptual information flow and categorization of used terms
*) The corresponding functional blocks refer to the model description in Sections 3.2 and 3.3

Stimulus

The stimulus[26] is divided in three parts. The environmental stimulus consists of all physical information in the environment that can potentially be perceived. The attended stimulus describes part of the environment that is perceived by making it the center of attention. The stimulus on the sensors is the information detected by the specific sensor ready for transformation and further processing.

Sensation

Sensation[27] is commonly used to describe the subjective experience resulting when a sense organ is stimulated. This would include the whole process to conscious experience. This is misleading as the actual function of this process is the passive part of perception. It is the passive process of bringing sensorial information (stimuli) from the outside world into the brain. The process is passive in the

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[26] Stimulus refers to the German translation: ‘Sinnesreiz’

[27] Sensation refers to the German translation: ‘Sinneswahrnehmung’

sense that no engagement by mental processes is included. The information is conditioned for further processing. Later in this thesis this process refers to the first layer of symbolic processing.

Perception

The term perception is often used to describe the whole process from sensor information to conscious experience of environmental data. Throughout this thesis the term *perceptional process* is used when the process in entirety is meant. The functional block perception itself is responsible or translation of neural states into information packages ready for organization in the unconscious parts of the mental apparatus. This is an active process in contrast to sensation and indicates the use of knowledge to some extent. The most generic definition of perception is to describe it as sensory processing with perceptual experience as the final output of perceptual processing [Styl05, p.7].

Recognition

Recognition[28] is the ability of the human mental apparatus to place an environmental stimulus into a category. This categorization process is, according to psychoanalysis, an unconscious act but involves the use of memory to compare the stimulus. The term has the word cognition in fact the data from this process only has the possibility to become conscious and is often used misleadingly.

Awareness

Awareness describes the process of perceiving (converting) previously preconscious perceptual data. Inside the model this stage is described as the secondary process perception of emotions in the primary process. Humans are only subtly aware of background feelings (emotions) but are able to report instantly on its quality [Dama94, p.150].

Subjectivity

Perception can only be measured up to some extent. This is due to the fact that an individual describing a perceptual experience is describing a personal subjective experience. It is difficult to explain a subjective perception but more so the recognition is also dependent on earlier experiences [RLPW07, p.447]. The physiological part of subjectivity is due to the adaption of the sensor system to certain stimuli. They can be trained by experience and adapt to current situations to provide the perceptual system with a constant stream of information within the allowed parameters and granularity. In the stages of perception where object information is categorized for further processing subjective experience is used in the categorization process. As seen in the mechanic of priming activated perceptions also influence the categorization process in the following perceptions processes. The final influence of subjectivity can be seen when perceptions are processed by the unconscious and conscious parts of the mental apparatus. There especially evaluations of past experiences are used to define desired actions for decision-making and how actual situations and objects are experienced. Common ground on the topic is that subjectivity is based on the experience the individual has gained and is used in the perceptual process. Without a proper understanding how

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[28] Recognition refers to the German translation: ‘Wiedererkennen’

this experiences are created and used in the recognition process, a cognitive architecture cannot make use of memory as an influence to the perceptual process.

The psychoanalytic concepts and data structures presented in the section above represent the base for the overall model of perception used in the following sections. Especially the introduction of composed data structures or data meshes is important as their weighted associations represent the main mechanic by which a stimulus is matched to searched exemplars. In the following section these basic principles are used to build the functional model for perception generation inside the ARS framework.

3.2 Perception Generation in the Perceptual Process Cycle Model

The main functionality of the mental apparatus in conjunction with brain and body is to summarize and bring together information about the environment. The purpose of this functionality is to provide the mental apparatus with object- and scenario-recognition for orientation in the environment. A second functionality is to prepare the decision unit for actions to fulfill the needs of the body and mental apparatus. From the functional point of view several questions arise for the modeling process: Where the sub processes are working according to the distinction of body brain and mental apparatus? What functions interact with the functional model and where is information passed between the sub processes? What responsibilities fall into the different functions and how do they carry them out? What types of information are processed and how is the memory interconnected in the process? In this Section the functional model of the project ARS (Section 3.3) is reviewed and supplemented with focus on perception.

The Sub Processes According to the Distinction of Body, Brain and Mental Apparatus

The above taken distinction in body, brain and mental apparatus is directed by the main task of perception, the interpretation of a sensorial stimulus. The approach is grounded in the distinction of the perceptual process in three layers done in neuro-psychoanalysis [Luri73, Wies09, ZiGG08]. The approach is also guided by the diversion of perceptual sensation in identification and interpretation of the distal stimulus (the actual sensation of the object in the environment) and information coming from the proximal stimulus (the sensation of the perceiver), which resulted in the three step model (as described in Section 2.2).

The model [ZiGG08, p.110] is adopted for this thesis and enhanced with a full functional view that connects the mental apparatus of the project ARS. Figure 3-4 shows the three steps model of perception inspired by Zimbardo. The figure sketches the transformation process of incoming information from environment on the steps of the sensorial processes (Sensation) the Perceptual Organization step and the Identification / Recognition step. According to Zimbardo [ZiGG08, p.169] the complete system of perception is interconnected by bidirectional running processes of information flow, as seen in Figure 3-4. When the perceptual representation is gained by available information from sensorial input, this is called bottom-up processing (information flow). When the perceptual representation is affected by expectation, knowledge or other higher aspects of memory it is called top-down processing (information flow). The importance of the top-down and bottom-up information processing will be discussed in detail in the following Sections.

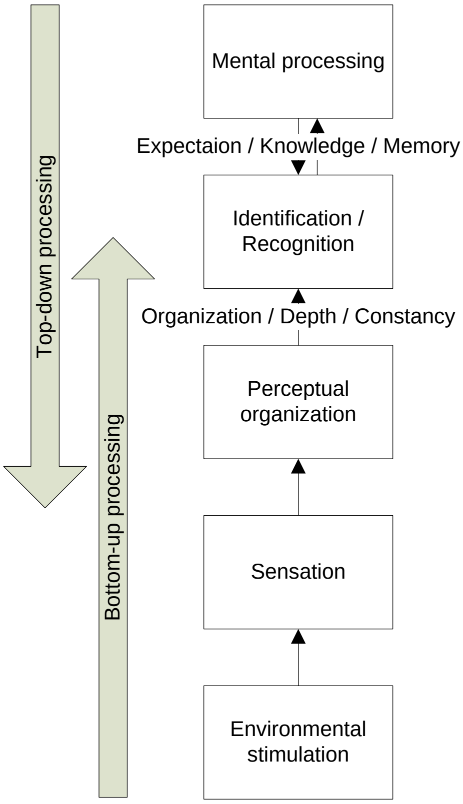

Figure 3-4: Three steps of perception based on [ZiGG08, p.110]

At this stage of the model it is only important to state that mental processes provide the perceptual process as a top-down source and the stimulus from the environment is a source for perception in bottom-up direction. Both systems influence the whole process of perception.

The integrative nature of the described processes lead to the notion that perception can in fact not be seen as set of well-delimited functional blocks as, e.g. shown by Goldstein. Goldstein states [Gold07, p.8] that perception is a sequence of differentiated steps which is beginning with the stimulus at the sense organ, transfer to the recognition processes in the brain and ends with subjective perception and action generation. It is further stated that this view would not suffocate the systemic nature of perception. This critique brings forth the need to extend the three-step model by looking deeper into the functionalities and especially extend it with the functionalities around action generation. The following model is constructed according to process as described in Section 2.5 and widely followed by AGI modeling. As two premises of the top-down design approach these basic designs steps are followed in the upcoming sections:

1. Stepwise refinement from the topmost abstract view by dividing into sub modules according to their functionality.

2. Interconnections that show information exchange, the interfaces between modules, are described with their content and data type.

First the model has to be extended to show the layers of the whole functional model it will result in. Figure 3-5 shows the basic structure of topmost functional blocks in the 5th topological layer of the project ARS, based on Freud's second topographical model [Freu23] even more simplified from the original model in Section 2.5.1.

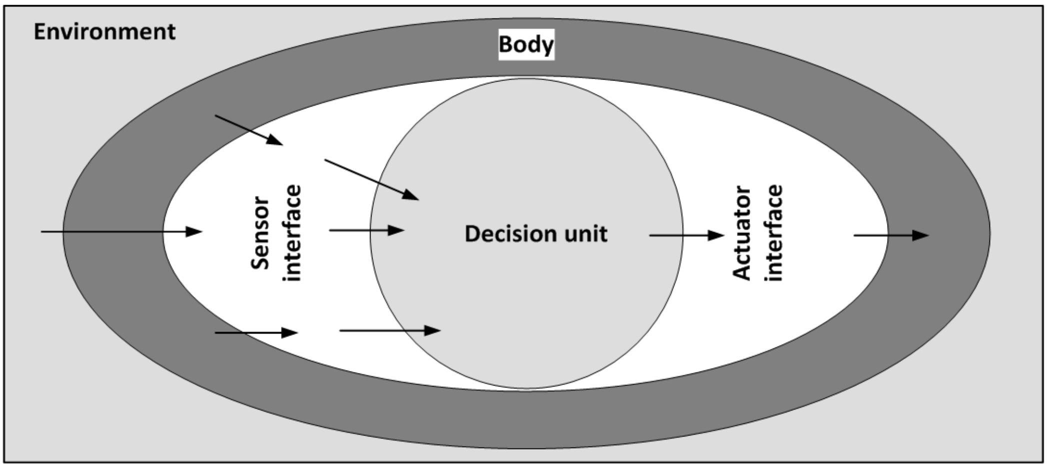

Figure 3-5: Information flow in the 5th topological layer of project ARS [Zeil10, p.62]

The Figure 3-6 and the Figure 3-7 show the addition of the mental-processes layer to the three steps model (seen in Figure 3-4), a preliminary step to identify the functionalities of the three steps model for the mental apparatus and to map the model with the functional blocks in the 5th topological layer.

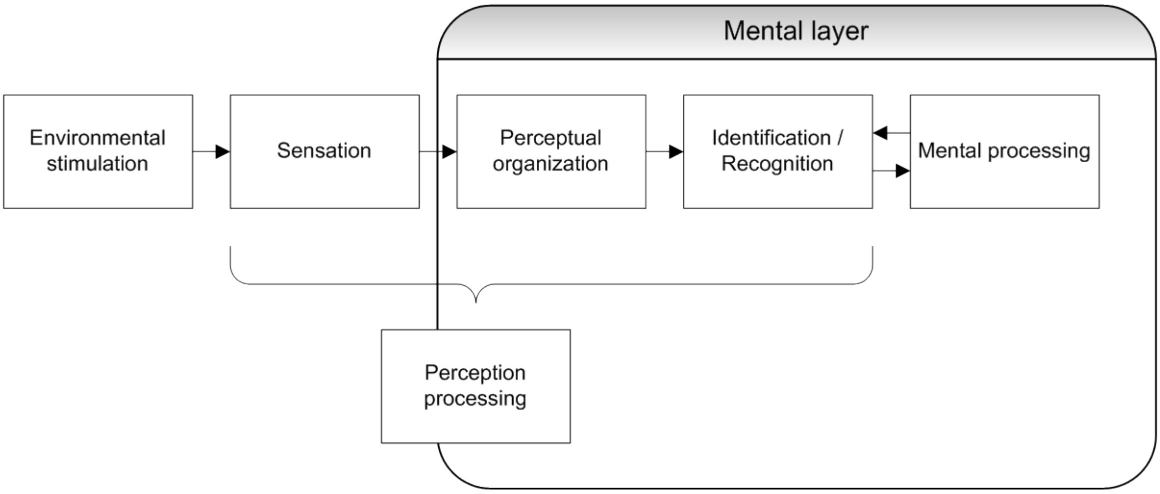

Figure 3-6: Grouping of the three-step model

The insight that actions influence the perceptual process makes it necessary to add them into the functional model as seen in Figure 3-7. The necessity comes from the perceptual process as described by Goldstein [Gold07, pp.5–9] and in Section 2.2.1. The figure also shows the conversion from a set of high level functional blocks towards a functional model showing the detailed processes. The dashed arrows show the information flow inside the model and are only temporal for the sake of model building. Inside the mental apparatus parts of the processes identification, recognition and sensation are summarized as *Perception processing* which is partially a member of the mental layer.

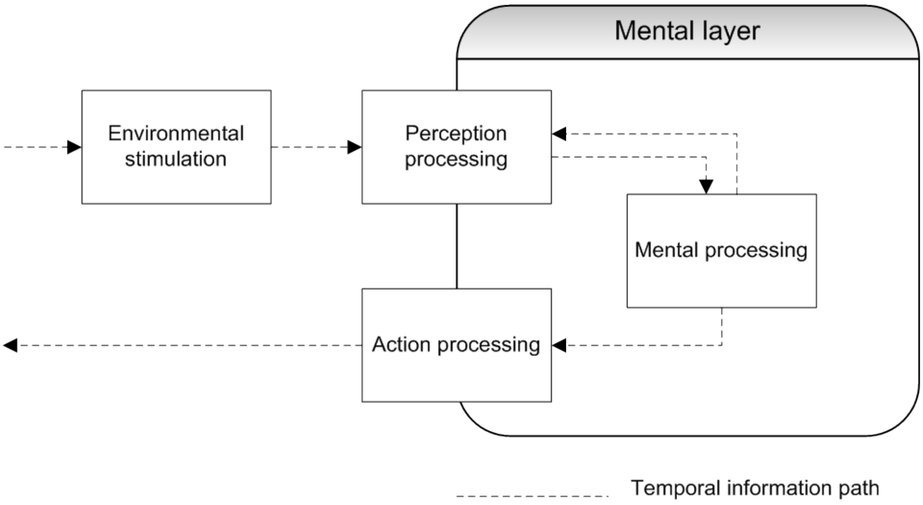

Figure 3-7: Intermediate modeling step with addition of action processing

By adding the functional requirements of actions the need to show the layer of the environment arises. In Figure 3-8 the environment is added as a connection between sensorial stimulus and action processing.

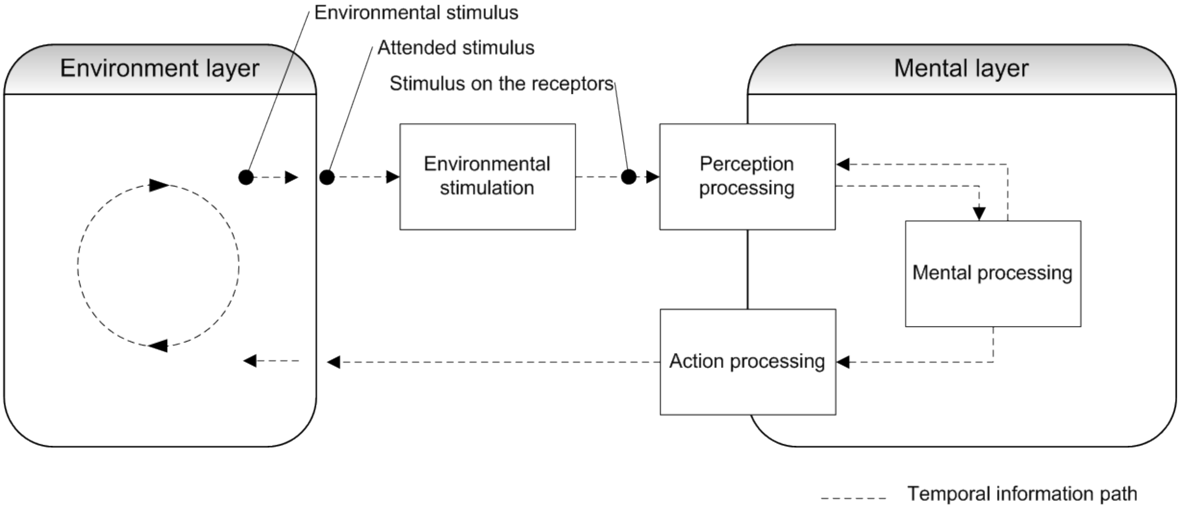

Figure 3-8: Introduction of the Environment layer in the modeling process

Figure 3-8 shows the addition of the environment and the closing of the perceptional cycle in the functional model. With the introduction of the environment to the model special attention has to be brought on the path from the *Environmental stimulus* to *Attended stimulus* and *Stimulus on the* *receptors*. The *Environmental stimulus* is everything that could be potentially received by the observer. It represents the physical entity created by the environment and stands for the totality of the perceptual data available. The human mental apparatus cannot perceive everything and thus has to focus on parts of the perceptual information - this is called the *Attended stimulus*. The *Attended stimulus* is influenced by attention and is guided by processes we will see later in this chapter. The *Stimulus on the receptors* is the actual physical information of the environment that penetrates the receptors of the according sense organ and creates input for *Perception processing*.

As it can be seen the processes *Environmental stimulation* and action belong to another. The connection is represented by introducing the body/brain layer at this stage of the model and can be seen in Figure 3-9, which is also the most simplified but complete model of the perceptual process cycle.

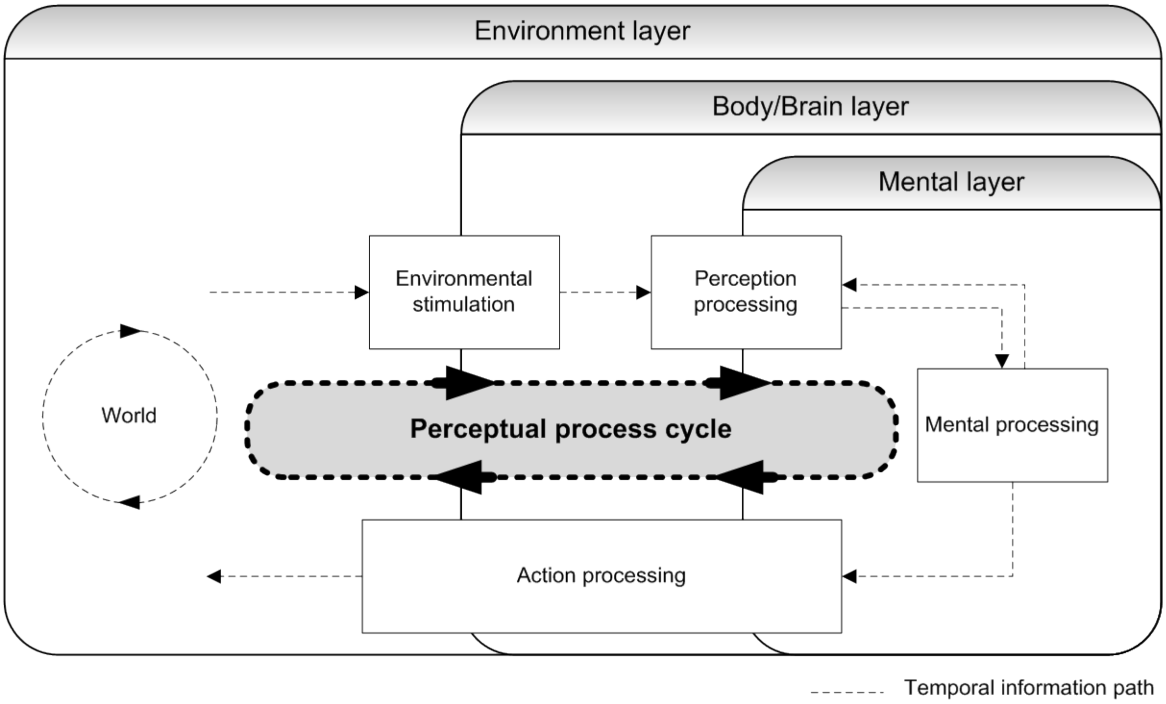

Figure 3-9: Top-down view of the Perceptual process cycle model

This concludes the simplification of the perceptual cycle coming from neurology and psychoanalysis. The model is not at a state where it can be matched to the ARS functional model of the decision unit in the form of the 5th topological layer as shown in Figure 3-5 as well as in Section 2.5. In the next steps this simplified but complete model of the perceptual cycle is enhanced with higher levels of granularity to match the findings of this thesis. The process follows the same methodology as described in Section 2.5 where the ARS decision unit is described in detail.

Interaction with the Functional Model and Information Flow Between the Sub Processes

With insights in biophysics and neurology the model shown in Figure 3-8 is then enhanced by processes that transform the physical stimuli coming from the environment to information that can be processes by the mental processes.

The previously grouped modules as seen in Figure 3-6 can now be reintroduced as seen in Figure 3-10. The module *Sensation* is also broken down into previously identified sub processes in this Figure. The new modules are *Stimulus on receptors, Transduction* and *Neural processing*. *Stimulus on receptors* represents the actual sensual organ the physical information is processed by. *Transduction* is the process of transforming from one form of energy into another form of energy, which is in this case from physical information that stimulates the sensor to electrical signals in the human brain. *Neural processing* is the module where in the human brain several processes of organization are done before perception becomes part of the mental apparatus. The processes *Perceptual organization* and *Identification / Recognition* are parts of the previous module *Perception processing* that resides inside the mental apparatus and belong to the mental layer of the model. *Perceptual organization* has the task to organize the sensorial information into a coherent stream of perception. Another assignment of this module is to translate the incoming information into a percept, which is the psychic construct that is further processed in the mental apparatus. These modules stay grouped under the new functional block *Perception processing* until the granulation of the other layers is finished while *Sensation* is now split from the mental layer and moved to the body/brain layer.

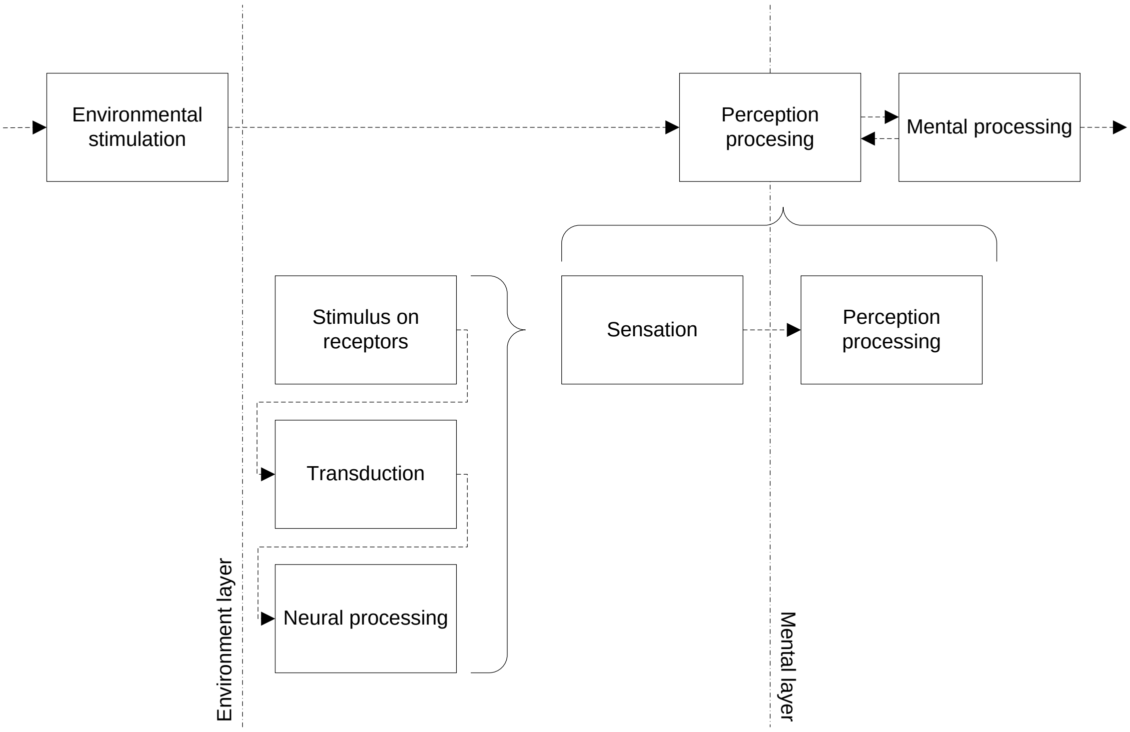

Figure 3-10: Modular decomposition of the perceptual processing module

The module *Action processing* has to be divided into the functions of the different layers later as seen below. *Action processing* is preparing actions coming from the decision unit in the mental apparatus, and the bodily part is actually executing the planned actions. The model of the Perceptual process cycle is redrawn to face the recent changes in subdividing the modules as shown in Figure 3-11. As this view of the model is the most finely graduated form of the modules regarding the layers of environment and body/brain, the interfaces are now numbered. The interface names are independent from the ARS decision unit as introduced in Section 2.5 and will be matched to the functional view later in this chapter.

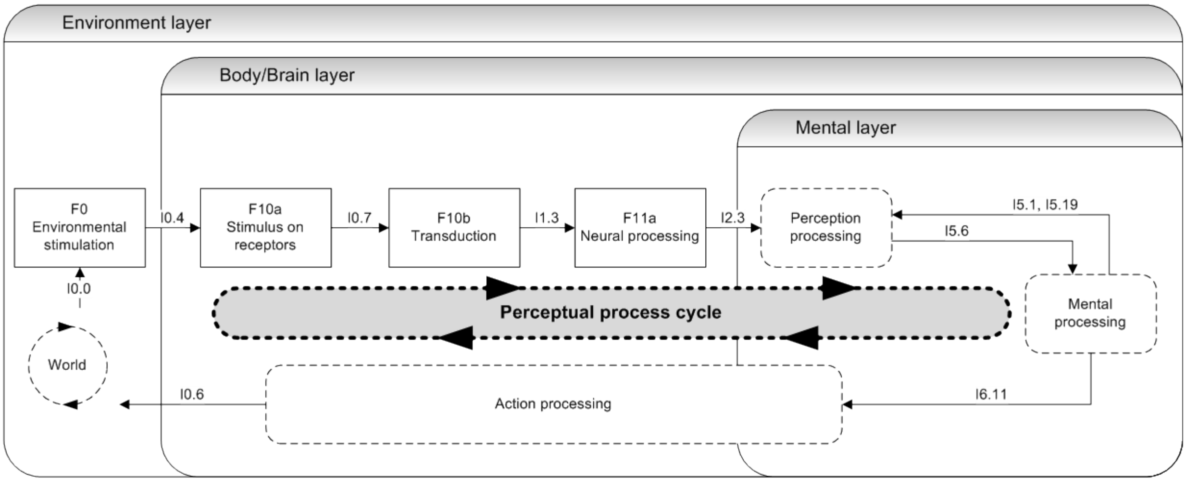

Figure 3-11: Functional view of the Perceptual process cycle at the level of the first topological layer

The Environmental Layer contains the physical entities that can be perceived by the autonomous agent. *Environmental stimulation* (F0) represents the receiving of the environmental stimulus, which is all physical information that is available from the environment through interface I0.0. The module is only introduced for the sake of completeness of the model as it is not influenced by the agent itself but only by environmental physics. The module *Stimulus on receptors* (F10a) receives the attended stimulus (part of the physical information that the sensors are focused on) and represents the border to the Body/Brain layer. Here environmental information about the visual, olfactory, acoustic, gustatory and somatosensory (details for the somatosensory perception follow in the Sections below) are transferred via I0.4. Module F10b handles the *Transduction* from one form of data to another, here the modal sensory information is converted into symbolic information that can be processed by the next modules. The information is processed in module F11a, where neuro-symbols are generated for processing in the mental layer, by following the approach as discussed in Section 2.4.2. Interface I1.3 transfers the symbolic information to *Neural processing* (F11a) where associations between the symbols are created according to the principles discussed in Section 3.1. Interface I2.3 represents the transition into the mental layer and transports associated information about the perceived objects, it also handles the connection between the body and the decision unit. *Perception processing* is responsible for the translation into data types of the decision unit and further processing like identification and recognition of perceived objects in the agent’s memory. The latest module marks the connection to the mental processes of the decision unit as and is subject of integration into the functional model of the decision unit as discussed below. The modules building *Action processing* with the corresponding interfaces I0.6, I6.11 are part of *Action execution track* as seen in the track view in Section 2.5.2.

Interface	From	To	Content	Data type
I0.0	Environment	F0	Physical object information	Raw physical data
I0.4	F0	F10a	Attended stimulus	Raw data
I0.6	Action proc.	Environment	Actuator commands	Raw data
I0.7	F10a	F10b	Stimulus on receptors	Sensor data
I1.3	F10b	F11a	Object information	Feature symbols
I2.3	F11a	Perception proc.	Environmental state	Neuro-symbols
I5.1, I5.19	Mental proc.	Perception proc.	Feedback from mental processes	TPM, WPM
I5.6	Perception proc.	Mental proc.	Identified and associated objects	TPM
I6.11	Mental proc.	Action proc.	Actuator command parameters	Raw data

Table 3-1: Interfaces for Environment / Body / Brain / Mental layer
(proc. … processing)

Table 3-1 gives an overview of the interfaces that are listed in Figure 3-11. It shows how the modules of the Perceptual process cycle fit in the overall functional model. It forms the interface between the environment and the decision unit which resides in the mental layer. The connection to the functions of the decision unit is discussed next.

Integration of the Perceptual Cycle in the Mental Layer of the Functional Model

In order to describe the model in conjunction with the functional model of the project ARS the model as seen in Figure 3-11 has to be diverted even further. Figure 3-12 shows how the functions of the Perceptual process cycle are mapped to the layers they reside in. The resulting layers are mapped to the information flow of the 5th topological layer as seen in Figure 3-5.

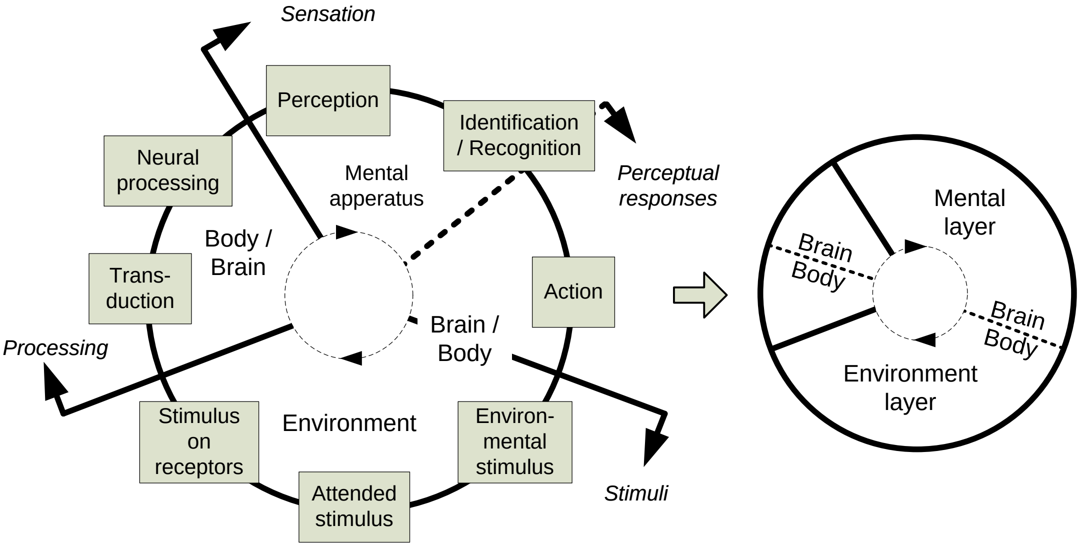

Figure 3-12: Top-down view of the Perceptual process cycle

The processes already identified for the mental layer have to be mapped to the mental apparatus of the functional model as seen below. Figure 3-12 also shows an association between the functions residing in the body and the brain. The Body/Brain layer is divided by introducing the concept of neuro-symbolic processing as described in Section 2.4.2 into a Neural layer and a Neuro-symbolic layer. The Neural layer represents the connection of the environment via sensors to neural data. The Neuro-symbolic layer represents the transformation of sensorial data to symbolic data for further processing inside the model. This step includes the introduction of the new module *Neuro-symbolic Processing* (F11b) in conjunction with the module *Neural Preprocessing* (F11a) in Figure 3-11 to represent the changes. This concludes the analysis of the perception path for external perception of the sense organs.

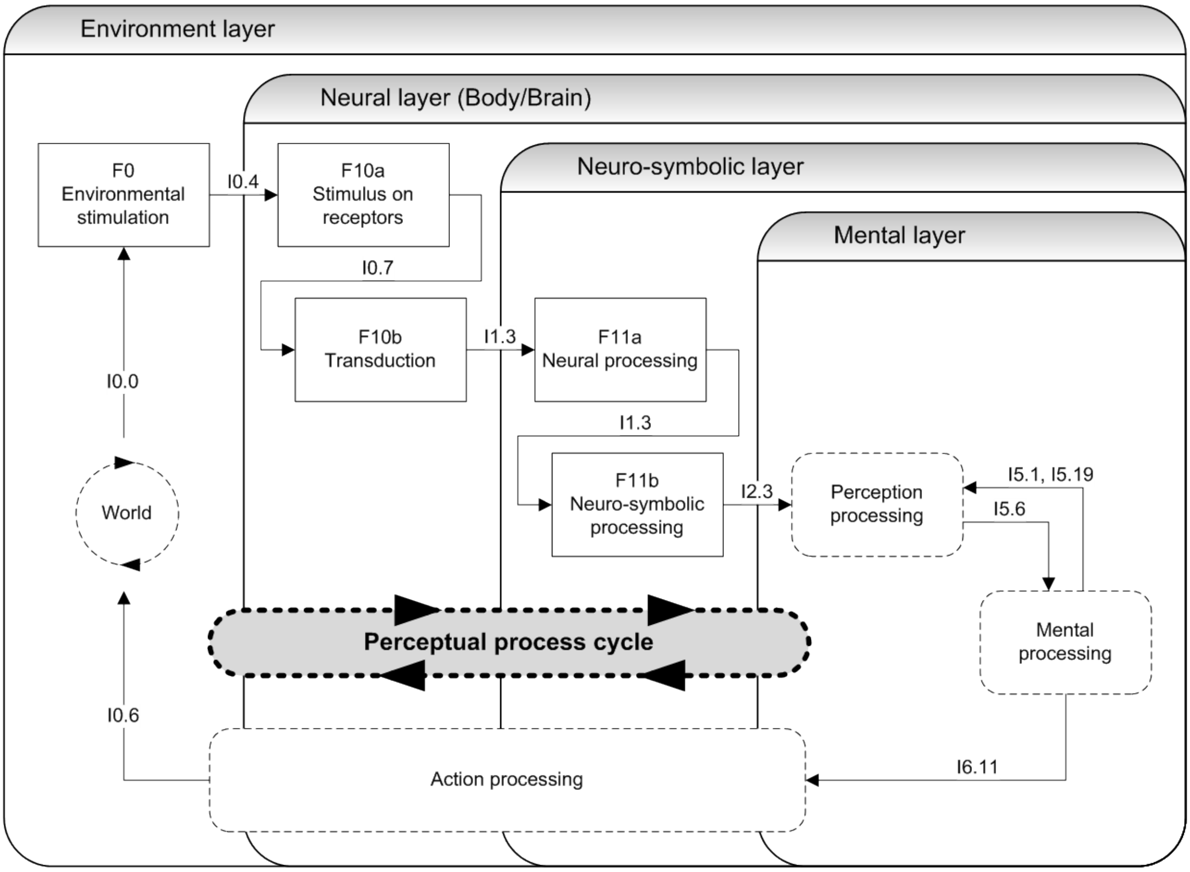

Figure 3-13: Introduction of neuro-symbolic processing

Bodily Perception and Environmental Perception

Bodily perception is different from perception of the metabolism (Self-preservation drives track (T2), Figure 3-14). Environmental perception is accountable for visual, olfactory, acoustic, gustatory and somatosensory perception for the detection of stimuli of the environment. For psychoanalysis the bodily state itself is of importance as influence to the mental state and the creation of self-perception. This requires a clear distinction into environmental and bodily perception. The information in this path has the possibility to become conscious after processing in the mental layer. The sensorial information of the metabolism on the other hand (see Figure 3-14, Self-preservation drives Track (T2)) cannot become conscious and only transports information about the state of bodily organs. To represent the diversion between sensor information from the environment, sensor information from the body and sensor information from bodily organs (metabolism) the information flow is divided into three parts. Body and sensor information tracks are integrated into the Perceptual process cycle in Figure 3-14.

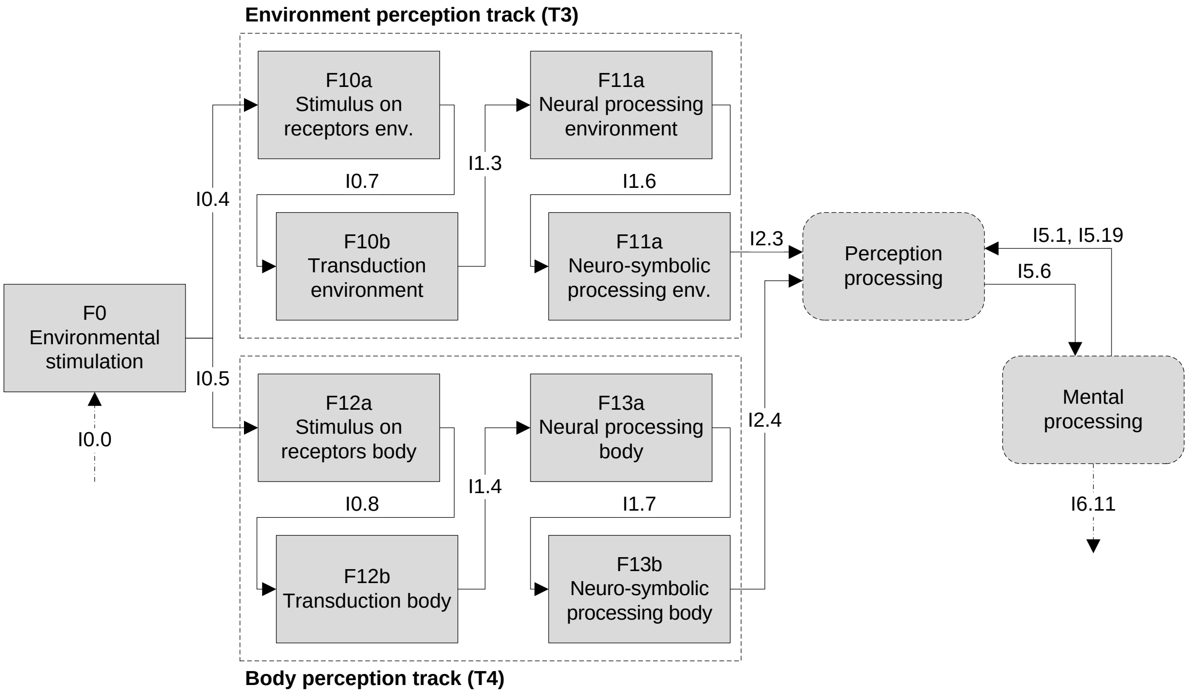

Figure 3-14: Addition of bodily perception to the perceptual process cycle

A detailed description of the modules in Figure 3-14 is given in the next section where *Perception processing* is subdivided to the finest granularity of the model.

3.2.1 Subdivision of the First Topological Layer of the Perception Track

The granularity of the modules in the first topological layer is sub-divided into further modules to match the insights from the Perception process cycle and allow descriptions in a granularity ready for implementation. The *Perception processing* module is divided (see Figure 3-15) into *External perception* (F14) and *Memory traces for perception* (F46).

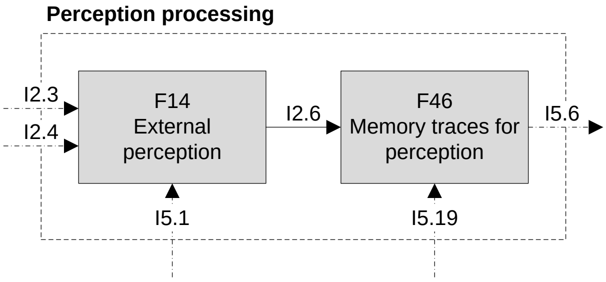

Figure 3-15: Top-down view of perception processing

External Perception – F14

Module F14 joins sensorial information from body and environment and processes the provided data. Neuro-symbolic content is transformed into primary process data (TP). This makes identification of percepts in the memory and further processing possible. The generated TPs are associated among each other according to their temporal vicinity to form TPMs. The TPMs are then used for identification and categorization processes. In the later the output of the drive track is used for drive object categorization.

Memory Traces for Perception – F46

TPs at this stage represent the information identified about objects in the field of perception. Module F46 then activates the identified TPs in the memory and associates them with previous experienced memory traces. Object perception is completed with previously stored information and enriched with information strongly associated to the objects. Expectations in the form of TPs coming from the secondary process are used to enhance the recognition of meshes and are associated in the process.

Subdivision of the Functional Modules

The perception track as described above has three main functions in the functional model:

- Conversion of sensorial data into symbolic data.
- Conversion into psychic data structures for further processing.
- Categorization and identification of psychic information in conjunction with the agent's memory.

Figure 3-16 to Figure 3-18 shows the three steps inside the functional model with the according types of information representation in a detailed view of the perception track (Table 3-2 to Table 3-5 shows the corresponding interfaces). This diversion into three subparts of the functional modules is used to represent the three steps of data processing and where the influences (interfaces I5.1 and I5.19) are processed in the model.

The module F14 is divided into the functions *conversion*, *identification* and *categorization*. The conversion sub function translates symbolic information from the environment or body into psychic data structures. TPs and TMPs are generated from the perceived symbols and correlated by temporal and spatial binding. The TPMs are processed to the identification functions where the perceptual input is prepared for comparison with already experienced and stored objects from the memory. The rules in the primary process require the categorization process to be comparison instead of reasoning [Scha12, p.37]. Thus the exemplar model approach is used for low-level object representation in this part of the model. Category criteria used are similar to topics as described by S. Freud [Freu98b, p.290] and are similarity based which is used in the search space for associating with previously experienced memories.

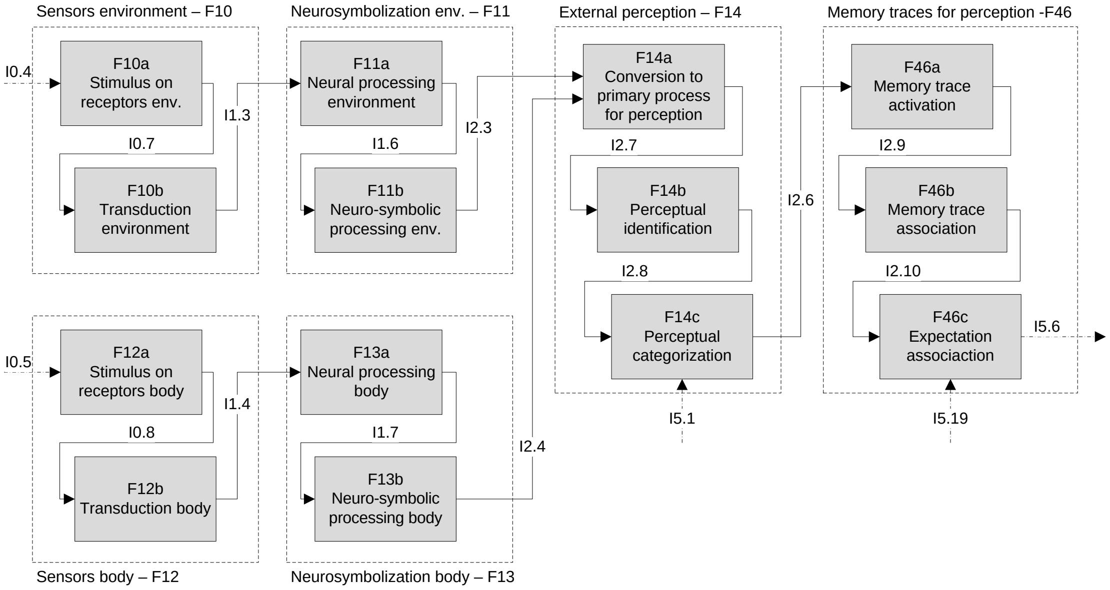

Figure 3-16: Functional view of the Perception track, part one

In Module F14c the interface I5.1 is used as influence in the categorization process and is one example how this multi-criteria categorization model can be influenced. The interface incorporates current drive information from the drive track in the form of drive meshes for drive object categorization. In the psychoanalytic model the drive has a high impact on several parts of the data processing. The main task of a drive is to search a target for fulfillment and one possibility is to take it from the current perception. This means the perceived objects have to be categorized as possible targets for suitability for one of the agent's bodily needs. In this process the drive category, which is defined by the drive source and the drive component, is added to the entity by searching other entities that satisfied the drives in memory. Drive categories also inherit the intensity the drive was satisfied with, adding a graded perspective which object might satisfy the drive best. The result of drive object categorization is the association of the perceived object with drives from the drive track in the same drive categories. The quota of affect of these drives influences the categorization process and thus gives certain objects importance or meaning to the agent.

In the subdivisions of the Module F46 the collection of sensor properties that build up the TPMs representing perceived objects (object-TPMs) are associated with memory traces. The entity properties are used as search criteria inside the memory mesh. Additional to this step all drive meshes for the search results are also activated and associated for further processing. The drive meshes have the remembered quota of affect associated with them.

The bodily perceptual information itself is handled in a different manner in this part of the perception track. Data from the body perception track represents information about the body that the agent may be able to process in the secondary process. In conjunction to the bodily/homeostatic data in the drive track which can only be experienced directly. To bind the bodily information together the entity (TP) SELF is generated. On top of that this entity is used to bind information about the agent itself activated from memory as well as emotions or actions (which are added in later in the model).

Interface	From	To	Content	Data type
I0.7	F10a	F10b	Environment sensor stimulus	Raw sensor data
I0.8	F12a	F12b	Body sensor stimulus	Raw sensor data
I1.3	F10b	F11a	Transducted env. stimulus	Raw sensor data
I1.4	F12b	F123a	Transducted body stimulus	Raw sensor data
I1.6	F11a	F11b	Environmental state	Featuresymbols
I1.7	F13a	F13b	Bodily state	Featuresymbols
I2.3	F11b	F14a	Environmental state	Neuro-symbols
I2.4	F13b	F14a	Bodily state	Neuro-symbols
I2.6	F14c	F46a	Categorized perception objects	TPM list
I2.7	F14a	F14b	Converted env. and body state	TP list
I2.8	F14b	F14c	Extracted objects	TMP list
I2.9	F46a	F46b	Connected memory traces	TMP list & affect
I2.10	F46b	F46c	Memory traces associated	TMP list & affect

Table 3-3: Interfaces perception track, part one

The second part of the perception track further processes the perceived TMPs representing entities. In Figure 3-17 rest of the modules of the perception track are shown.

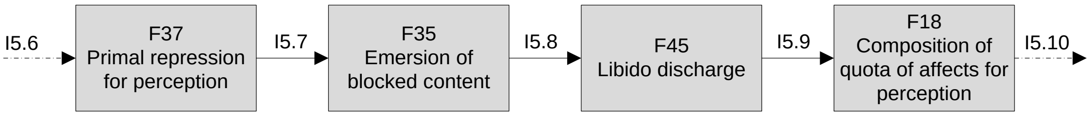

Figure 3-17: Functional view of the Perception track, part two

Primal repressed objects or images in the primal repression storage can be associated in the module F37. In this process quota of affects from primal repressed memories can affect the perceived objects and thus change the subjective evaluation. Primal repressed content is not allowed to pass the defense mechanisms in the defense mechanisms track but the association is necessary to find the primal object that satisfied the corresponding drive first and best. These objects are added to perception as they are always the origin for drive object categorization. Primal repression and defense mechanisms are out of scope of this thesis, for more information see [DBMW13, p.77].

The module F35 is responsible for emersion of blocked perceptual content or drive meshes. When the defense mechanisms block entities from perception or from usage as drive object or the drive mesh itself they land in a blocked content container. The module has access to this container and by definition, every content has the urge to emerge and associate itself to current content until the originating homeostatic imbalance is satisfied or the content is processed otherwise (for example by the psychic process of dreaming, which is not part of this thesis). The repressed content is associated either by using similarity matching for entities or by using quota of affect and drive content type associations.

In the module F45 libido discharge is calculated. F45 communicates with module F41 from the *Sexual drive track* (T1) via the libido buffer. Perceptions are compared with memory if they are eligible for libido discharge and reduce the libido buffer if so. This reduction produces pleasure by perceiving object according to the 'urge to see'[29] [Freu15c, p.81].

The last module in the perception track is module F18, which is responsible of calculation of the quota of affects for perceptual objects. After several modules have associated content to the TPMs representing perceived objects the value of quota of affect is calculated by looking up the mesh and summing up the corresponding quota of affect values thus presenting the top object with the possible pleasure gain for further processing.

Table 3-4 shows the interfaces discussed in this part of the perception track.

Interface	From	To	Content	Data type
I5.7	F37	F35	Perception and repressed content	TPM list
I5.8	F35	F45	Perception and blocked content	TPM list
I5.9	F45	F18	Perc. before affect recalculation	TPM list

Table 3-4 Interfaces perception track, part two

The drive track and the perception track forward data to the defense mechanisms as described in [DBMW13, pp.81–88] and in Section 2.5.2. The modules F21, F20 and F8, as seen in Figure 3-18 and Table 3-5, are responsible for conversion from TPs in the primary process to WPs in the secondary process and are part of the conversion track.

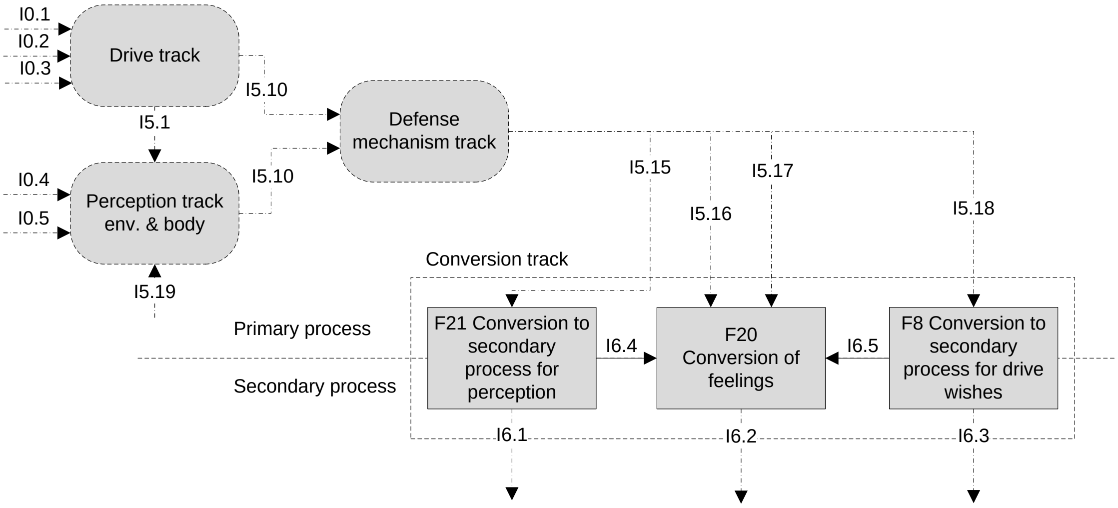

Figure 3-18: Functional view of the Perception track, part three

The WPs activated from memory are associated with the corresponding TPMs. In the module F8 TPs and quota of affects are translated to drive wishes (in the form of WPMs). F21 transforms the perceptual stream of objects into according WPs for processing in the secondary process. In F20 emotions (see [DBMW13, p.87]) are converted to feelings. The interesting concepts for perception in this conversion are discussed later in this chapter.

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[29] Translation of the German term 'Schautrieb'

Interface	From	To	Content	Data type
I6.4	F21	F20	Perceptual data	WPM list
I6.5	F8	F20	Homeostatic state	WPM list

Table 3-5: Interfaces perception track, part three

The last step shown in Figure 3-19 concludes the subdivision of the functional model and closes the Perceptual process cycle as discussed above. Details on the decision making process can be found in great detail in [DBMW13, p.89], as the focus in this thesis is on perception important functions in the selection and action process are pointed out.

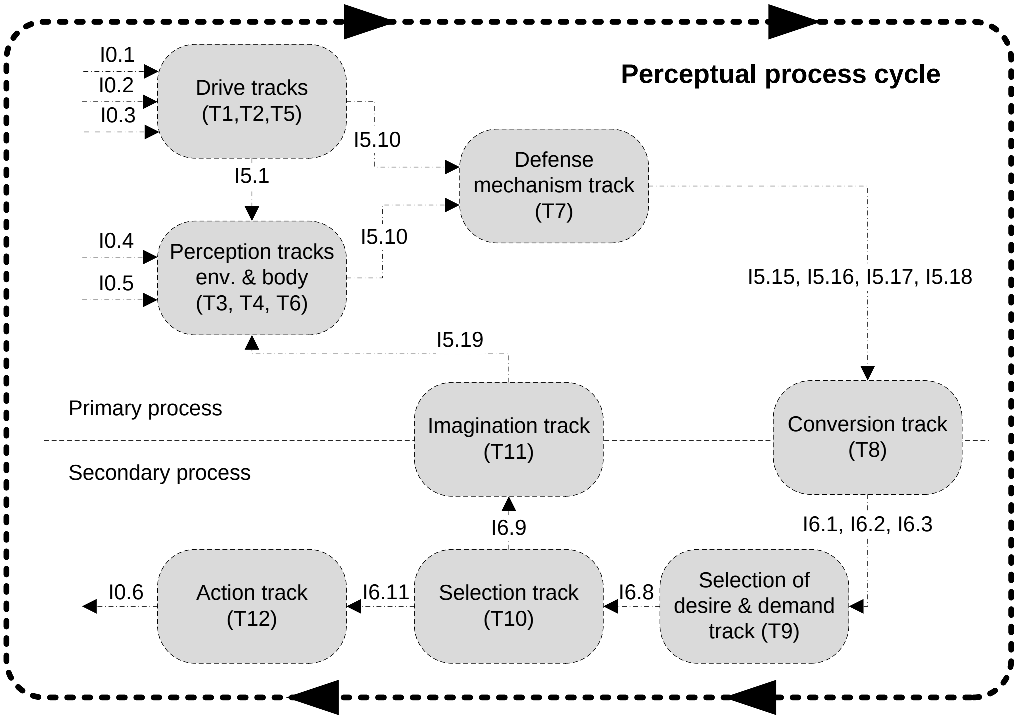

Figure 3-19: Functional view of the Perception track, part four
(Track numbers according to Figure 2-20)

Perceptual and drive information is passed forward to the selection tracks where first the desire with the strongest quota of affect is selected. The selected desire is processed through reality check where the desired object is searched in the current perception and run through a knowledge test for feasibility. In the selection track scenarios are generated for the desire by planning with the objects in the perception view. From these scenarios imaginary actions are generated, evaluated and the resulting actions are executed through the action track which results in action commands processed in the environment. These actions influencing the environment and the perception of the next loop close the perceptual cycle.

Actions can address perception directly which results in focus of attention actions or indirectly by expressing bodily feedbacks from emotions which affects the sensors attached to the body (see below for details).

Another influence of importance for the perception process is the imagination track. Imaginary action generated while planning translated back into thin presentation meshes and forwarded through interface I5.19 to the perception track. The imaginary data is used to activate memory content for the next processing of the model. This ensures that next time objects can be found in the categorization and identification process more quickly.

In the following section the perception model is matched to the ARS decision unit in the track-view of the functional model. The innovations to the ARS model are pointed out and the section ends with the full functional model of the ARSi12 framework presented in this thesis.

3.3 Functional Model of the Artificial Recognition System Decision Unit

After the details the development of the perception cycle in the ARS model the overall model of the ARSi12 framework are shown in Section 3.2.1. This track view of the functional model is a simplified version of the fourth level of the functional model which can be found in [DBMW13, p.97].

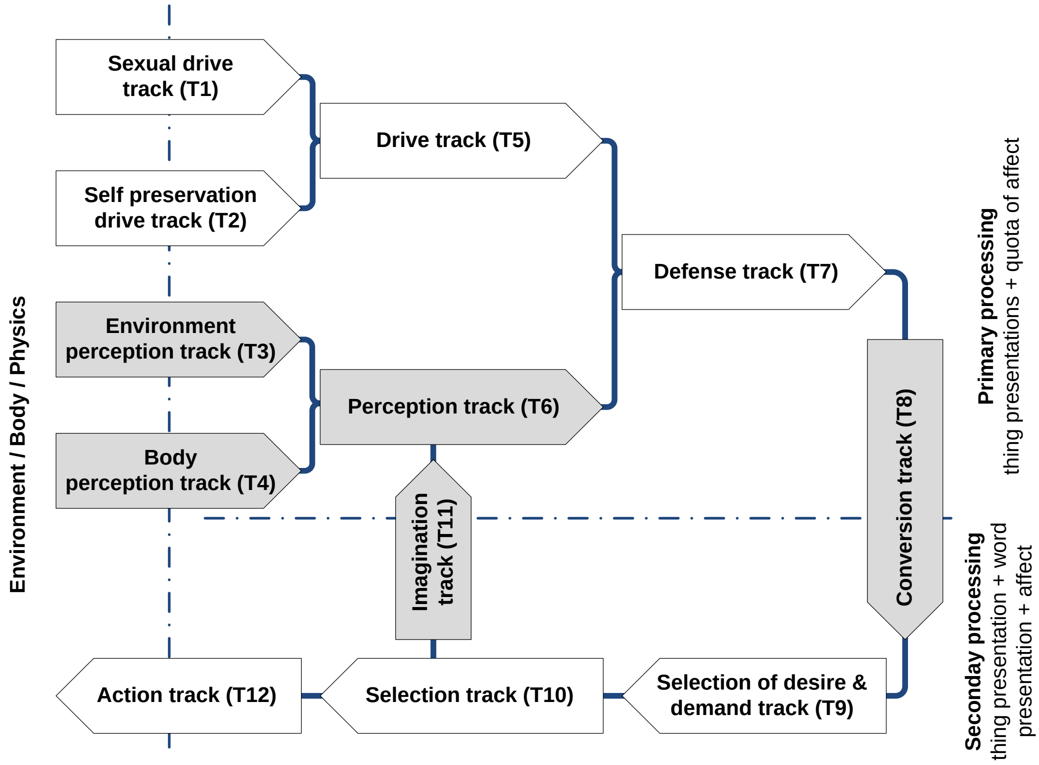

Figure 3-20: Track view of the ARS model version ARSi12

Figure 3-20 shows the ARSi12 version of the functional model. As a detailed discussion of the functional model is out of scope of this thesis, only the changes in regard of the track view seen in Figure 2-22 in Chapter 2.5 are given here. Detailed explanations about the modules relevant for the perception cycle have been discussed in the chapter above.

For this thesis the tracks, which are highlighted in Figure 3-20, are particularly relevant for perception generation, namely the Environment perception track (T3), Body perception track (T4), Perception track (T6), Conversion track (T8) and the Imagination track (T11).

Track view version		Description
ARSI11	ARSI12	
Sexual drive track (A)	Sexual drive track (T1)	See description of changes in next Section
Self preservation drive track (B)	Self preservation drive track (T2)	See description of changes in next Section
Environment perception track (C)	Environment perception track (T3)	Subdivision of modules according to the Perception Process Cycle
Body perception track (D)	Body perception track (T4)	Subdivision of modules according to the Perception Process Cycle
-	Drive track (T5)	Modules in tracks A and B have been unified and formed the new track T5
Perception track (E)	Perception track (T6)	Subdivision of modules according to the Perception Process Cycle
Defense mechanisms track (F)	Defense mechanisms track (T7)	See description of changes in next Section
Conversion of non-defended data track (G)	Conversion of non-defended data track (T8)	No changes in version ARSi12
Affective perception track (H)	Selection of desire & demand track (T9)	Renamed, for details see [DBMW13, p.88]
Decision making track (I)	Selection track (T10)	Renamed, for details see [DBMW13, p.92]
-	Imagination track (T11)	The module F47 from track I was integrated into a new track
Action execution track (K)	Action track (T12)	Renamed, for details see [DBMW13, p.95]

Table 3-6: Summary of changes to the functional model in version ARSi12

Table 3-6 shows a summary of the changes in the functional model from version ARSi11 [Deut11, p.87] (see Figure 2-22 in Section 2.5.2 of this thesis for the ARSi11 functional model with the additional track view) to the version ARSi12 developed in this thesis. The tracks have been numbered according to the naming scheme of the project ARS and renamed for clarification and faster explanation.

Summary Description of the Track View

In summary the track view in Figure 3-20 describes a closed loop between the environment and the psychic data processing inside the mental apparatus.

The functional model is influenced by the drive tension of the internal and perception of the external world. The outer world is represented as perceptual sensor data through the *Environment perception track (T3)* and from sensor information from the body in the *Body perception track (T4)*. This raw data is neuro-symbolized and composes the external perception information processed in the *Perception track (T6)*. The inner homeostasis generated by physiological imbalance is also neuro-symbolized and triggers the generation of a drive tension in the *Self preservation drive track (T2)*. In the *Sexual drive track (T1)* drives influenced by the seeking system [Deut11, pp.83–85] are generated and merged in the *Drive track (T5)*. The drive is the first mental representation of a need and is represented in the model as a drive mesh composed of TPs representing the aim, source and object of the drive. The drive content is transported to the defense mechanisms in the *Defense track (T7)*. Here, the moral rules and threats coming from the Super-Ego are weighted against the inner demands and it is decided if and in what form a drive content can be handled further or repressed. The repressed contents stay in the Id and wait to be associated with other content for another try against the defense mechanisms. Drive contents passing the defense mechanisms have the ability to become conscious and are therefore converted to the secondary process. In the *Conversion track (T8)* TPs are connected with the according WP. Thus, presentations can be ordered logically (the task of the secondary process) and processed by further tracks.

The drive demand generates a drive tension and if possible, this tension creates a conscious WP originating the wish for an action which is transferred to the *Selection of desire & demand track (T9)* where the most desired wishes are selected for execution. Perception information is available as TPMs in the perceptual stream and as drive object associated to drives. In the conversion WPs are associated to the perceptions and are presented to the selection processes for evaluating the wishes demanded by the primary process. This information is used to decide how and if the wish that is generated from the drive content is processed and fulfilled. In the *Selection track (T10)* plans an imaginary actions are generated for the drive demands. The imaginary actions are forwarded to the *Imagination track (T11)* for pre-activation of memory traces for the next perception processing and to the *Action track (T12)* where action plans are generated from the imaginary actions. The different plans are evaluated and verified by the reality-check module. After evaluation and decision the resulting plan is executed by neuro-desymbolization of the information to physical motor control of the body.

3.3.1 Innovations to the Functional Model

In Section 2.5.2 the preliminary work created for the project ARS has been sketched. The first version of the functional model was created in 2008 and constantly changed. Innovations introduced by this thesis based on the simplified track view of the functional model were already introduced in Table 3-6. The innovations of the perception tracks are based on the argumentation given in Section 3.2 and described in great detail as they are the focus of this thesis. The resulting final functional model can be seen in Figure 3-21.

The tracks A and B have been uniformed after the Modules E43 and E4 and form the new *Drive track (T5)*. Additionally an information path from track T5 to the *Perception track (T6)* was introduced as feedback mechanisms for perception generation.

The modules for defense mechanisms have been reworked and incorporated into track T8. Details on defense mechanisms can be found in [GeBr12] and [DBMW13, pp.80–83] as they are out of focus for this thesis.

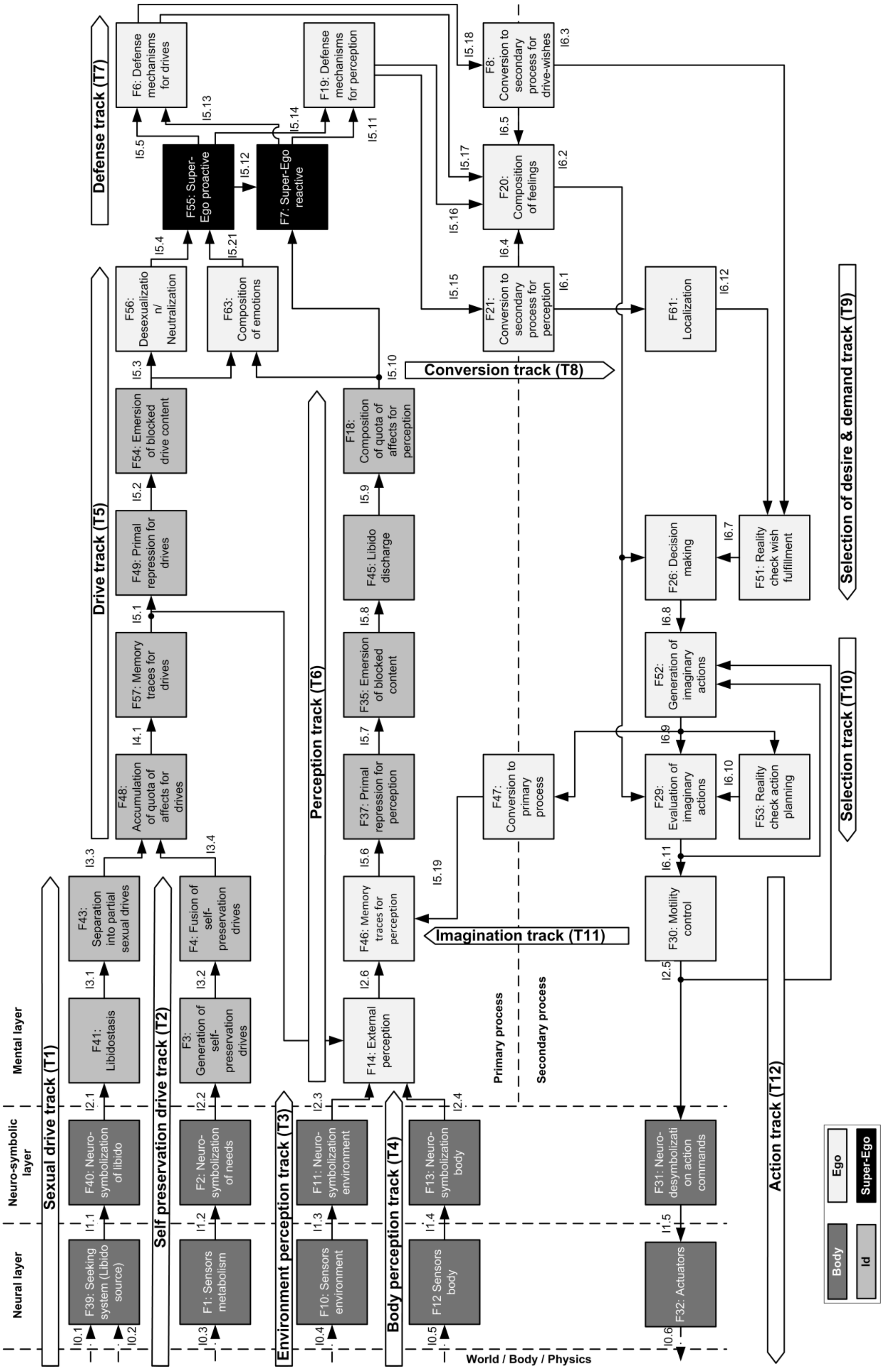

Figure 3-21: Functional model of ARSi12

The tracks in the secondary process have been renamed according to Table 3-6 to emphasize the underlying functionalities. Additionally, the module F47 was divided from the decision making track and incorporated into the new track T11, which describes the functionality of feedback by imagination to the perception and memory association processes.

The naming convention of the functional modules has also been reworked by renaming all modules from E to F.

The final functional model as seen in Figure 3-21 is built of 41 modules and shows the finest granularity of the functional model. The modules of the Perceptual process cycle are highlighted and described in Section 3.2. The rest of the modules are described in great detail in [DBMW13, pp.49–96] as only the modules influencing the perception process are described in this thesis.

The above presented model is the full functional model of the ARSi12 framework. The details how objects are recognized and the similarity values for the activated exemplars remains open. The generation of perceptual symbols and how they are influenced by different parts of the model is the topic of the next section. The calculation of appearance recognition is discussed as well impact points where data is manipulated along the perception-action cycle model.

3.4 Perceptual Symbol Generation

The main function of the above described model is processing data from various internal and external sources. The perceptual process is highly integrated in the model of the mental apparatus and has to interact with the functions of the cognitive architecture. In the following the main influences to the perceptual symbol generation process are investigated.

Perceptual data inside the model is processed in three main stages. First the sensor data from the different modalities are preprocessed and symbolic data for every modality is created. In the second step this symbolic information from the environment is associated with previously experienced memory. The third main stage consists of processing inside the functional model where different mechanics alter the incoming information before it is processed in the decision making modules.

3.4.1 Memory Association and Activation

As described in Section 3.1.2, the atomic data structures are combined to information meshes by associations to one another. Associations between data structures can be formed and disbanded during processing in the functional model. In addition, previously experienced and stored data structures can be retrieved from memory by means of search through the information representation layer as described in [Zeil10, pp.80–87] and associated in several modules of the functional model. Associations in the primary process should not be mistaken as logic implying relations. They are formed based on the content of perception other mechanics allowed in the primary process. In the secondary process, where connections between WPs are formed, the associations can be directed and used for representation of logic and structured knowledge. Associations regarding the technical model are grouped into different classes describing the nature of the connection or how the association was created. Associations are, as described earlier, weighted connections which emphasize the importance of the connected data structure to the mesh according to the classification of the association. The classifications are created by distinguishing associations through the following characteristics:

- The similarity of attributes between objects (perceived or activated from memory).
- Temporal co-occurrence during processing (or as stored while experienced).
- Spatial occurrence of objects through perception.
- Categorization knowledge from WPMs.
- Intrinsic data structure definitions.

One example where a composed data structure is defined by intrinsic associations defining the data structure itself is the Drive Mesh (DM). The DM represents the psychoanalytic concept of a drive. It is composed of a drive source, a drive object and a drive aim. The composed data structure is built by intrinsic drive mesh associations, e.g. a drive object association is connecting the DM to a TP representing an object the drive can be satisfied with, as represented in Figure 3-22.

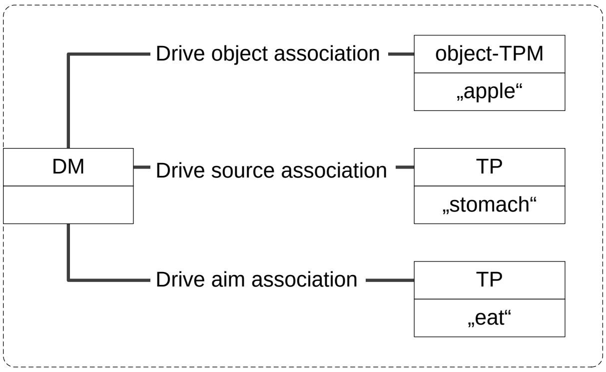

Figure 3-22: Drive mesh intrinsic associations

The drive mesh is generated as a representation of a bodily need, thus the generated DM has the quota of affect added reflecting a value for the drive tension in the associated drive source. The quota of affect value not only represents the current tension of the drive but also the possible drive satisfaction by reducing the drive tension with the drive object in the action provided by the drive aim. When a DM is activated from memory then the stored quota of affect represents the degree the according bodily need was satisfied by using the associated drive aim in previous incidences. This concept comes into play when drive objects influence the perception process as part of drive object categorization.

3.4.2 Influences to Perceptual Symbol Generation

TPs in the primary process are used to represent drives in the specialized form of DMs as well as data types for external perception in the psyche. In DMs, as described above, they originate from homeostatic imbalance in the body and specify the different parts of the DM (e.g. the drive object). TPs in the perception tracks of the model evolve out of neuro-symbols as described in Section 2.4.2.

Sensor information is passed to the decision unit as unimodal and multimodal symbols gathered from the different external sensors of the body. Perceived objects are represented by their physical occurrences of the different sensor modalities. Unimodal symbols are directly mapped to TPs whereas multimodal symbols combine different sensor modalities and are mapped to meshes of TPs (TPMs). As perceived objects mostly exclusively consist of more than one attribute represented by a TP, they are always represented as TPMs throughout the examined solution. For simplicity reasons perceived objects in this thesis are often combined as one TPM (e.g. as seen above the drive object *TPM:"apple"*) where the TPM itself stands for the root node of the TPM. This is also necessary to display the data structure in models and implementation as in the primary process no words have been associated to the TPM yet but they still have to be displayed in text-driven development language (*TMP:"apple"* actually does not represent the word apple but a symbol representing an apple).

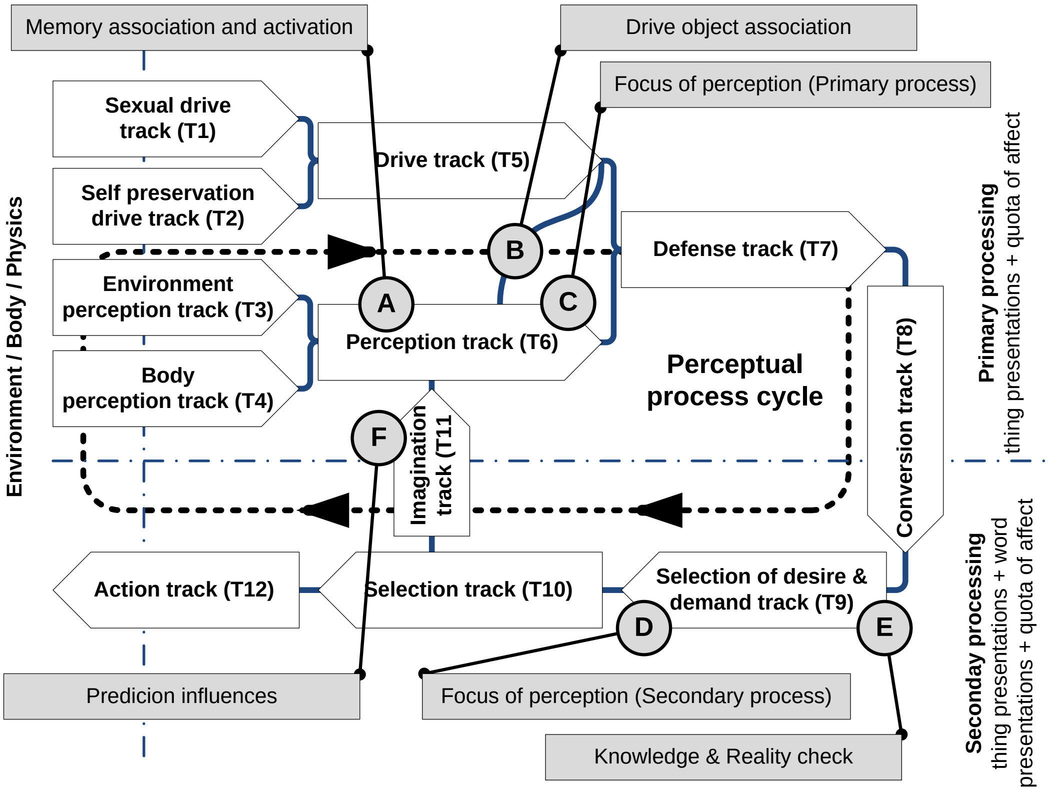

Figure 3-23: Influences to perception generation in the perception cycle (with influence points A to F as described in Section 3.4.2 on the following pages)

Figure 3-23 shows the track view of the functional model with additional main influences to the perception process. Activation and association of memory structures was described in the last Section (influence point A), the other influences are described below. Before focusing on the details of the influences, the path of perception data structures in the track-view model is reviewed.

As seen in Figure 3-23 there are four main tracks that are used as input to the decision unit. In the *Self preservation drive track (T2)* homeostatic state generated by the body generates the DMs as described above. In the *Sexual drive track (T1)* inner psychic imbalances generate DMs as described in [Deut11, p.81].

It is a point of discussion to provide feedback from bodily sources to the drives generated in the *Sexual drive track (T1)*. It is not foreseen in the neural and neuro-symbolic layers yet and therefore not discussed in the proposed model.

In the *Environment perception track (T3)* sensory representations of external objects are processed in the form of TMPs in the proposed perception cycle as described in Section 3.2. The *Body perception track (T4)* represents somatosensory modalities which are part of the environmental and body sensations. To distinguish the information from external sensations of objects, the SELF-objects is introduced to the model. The SELF-object represents root information about the agent itself, especially bodily self-perception and is generated as a TP in module F14, where external and somatosensory sensations are translated into atomic data structures. All somatosensory sensations are associated to the TP:SELF-object and thus generating a TPM which is forwarded to the decision unit. The usage of this root object, as it is a very specific object and its use beyond rooting somatosensory perception is a point of discussion for future iterations of the functional model.

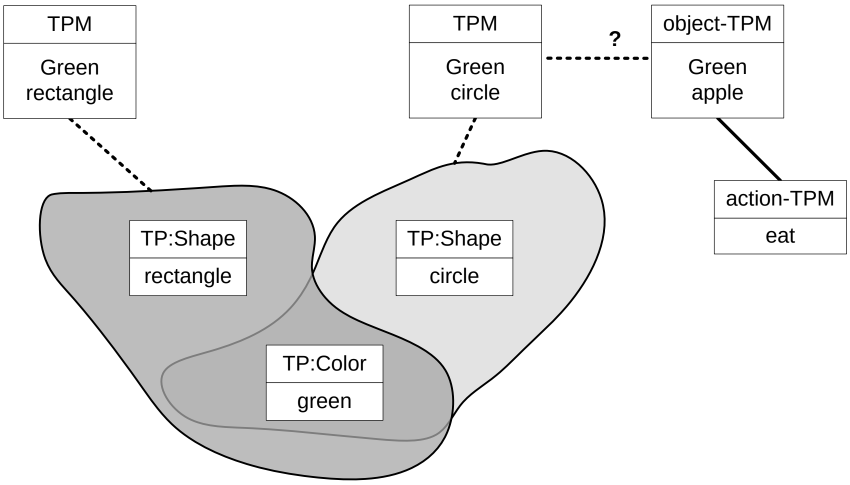

Figure 3-24: TPM attribute association example (The association labeled with ‘?’ represents a possible match to an activated object-TPM)

The external sensations of objects form perceptual images which represent the perceived environmental state. In the described process of perception these perceptual images are compared with stored template images that are stored in memory and represent previously experienced sensations that are retrieved and activated from the database. The weighted associations are used in case of matching input information according to the described types of associations. Figure 3-24 shows an example of the use of attribute associations to construct two objects. In this case weighted association between the TPMs and the TPs containing the attributes are shown. This dependence of attributes assures that various objects from memory are triggered by one attribute (color in this example). These associations of attributes defining an object are again intrinsic associations defining the object. Beyond these defining associations experiences with the stored objects can be used for perception mechanics or planning later in the decision unit.

Focus of Attention

Attention mechanics inside the functional model are divided into mechanics in the primary process and the secondary process[30] (influence points C and D in Figure 3-23). Before the actions of the decision unit to move to the desired objects and fulfill the planned actions can be executed the decision unit has the option, or in fact the action possibility, to move the field of view in the direction of the planned object. This is done to face the object before movement but also to actively improve the perceptual input by focusing on the object. This 'looking at' action is also used to identify obstacles and refine the executed plans. This active planning of focus is only possible in the secondary process as the desired objects and plans are available for active steering of the perceptual field. As the visual field is the main sensory source this visual field is used as the main vocal point.

Apart from this proactive part of attention focus, where perception is actively guided, there is also a reactive focus of attention which mechanics reside in the primary process. Psychoanalytic data structures in the primary process are mainly driven by values of quota of affect. This value is an indicator for the intensity of the data structure. For a drive mesh this directly resembles to the homeostatic imbalance of the drive source. For objects in perception also exist a possible quota of affect which is retrieved from previous experiences in memory and represents a possible satisfaction with the object (this is used as feedback mechanism as described later in this Section). For objects in perception exist also another form of intensity which is reactively introduced into the model through the sensor system. This intensity is called saliency and represents the intensity of one object feature. Examples for these values are the brightness of an object, or the loudness. For every modality exists a value that stands out relative to its neighbor experiences and is used to focus the limited perceptual resources to the most pertinent sensor values. Saliency typically arises from contrast between two values or groups of values but for the examined solution normalized values inside the simulation are used to show the underlying concept. This saliency values compete against quota of affect values from drive objects and possible drive object for attention which adds another layer to reactive behavior to the model.

Primary Process Feedback

The first influence is indicated by prediction in point F in Figure 3-23. The generation of predicted or imagined objects is described in the next section. In the primary process the imagined objects from the last pass of the functional model are used to activate memory structures of possible perceived objects. This way the objects don't have to be searched and associated through attributes of objects but are reused if the perceived attributes match the perception from the *Environment perception track (T3)*. The described mechanic makes recognition of already recognized objects from the last pass of the model faster but also has the possibility of false associations if the predicted or imagined objects are close to the attributes of the perceived ones. Failures and advantages to this mechanic are discussed by using examples in the next chapter.

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[30] Additional mechanics in the neural layer are foreseen as stated by researchers in the field of neurology but as the neural and Neuro-symbolic layer are missing, the possibility for feedback mechanics right now this is a point for future discussion.

Another influence mechanic is indicated by influence point B in Figure 3-23, the drive object association. In the *Drive track (T5)* not only the drives are computed but also possible drive objects are selected which would satisfy the drive best according to experiences store in the memory. In the subjective approach to categorizing a perceptual input as a possible drive object the most relevant question to the primary process is what objects are suitable as drive object. The most important factors for categorizing are the stimulus representations of the perceived objects and the representations of the categories of drives to decide category membership. Such a model where category membership is decided on multiple categorization criteria is called an exemplar model. During the process a decision is made if the presented exemplar (a perceived object in the form of a TPM with associated perceptual attributes) matches the drive category (which is represented by the combination of the drive source and drive component associated to objects in the memory as a DM). This indicates that DMs created by active drives activate possible objects in the memory what would match the according drive category. These pre-activated objects are matched to the perceived object and the best match is associated to the drive (see next chapter for examples in the examined solution). In this regard the described mechanic leads to the recognition of an perceived stimulus as an object by emphasizing the objects meaning for the bodily needs of the agent and thus possible failures in association, as examined in the examples in the next chapter, but also accelerating the recognition process by narrowing the possible search space of objects to the agent’s needs.

Secondary Process Feedback

After perception information is processed through the primary process WPs are associated to it in the *Conversion track (T8)*. These WPs represent words previously experienced to the corresponding TPMs that represent objects from environment. The recognized objects are used in the decision unit for planning and action selection in the functional model. A plan in the model is a sequence of scenarios the agent expects to perceive in the future with the desired outcome selected through the demands of the drives with associated drive objects. This creates expected situations with objects in them for future passes of the functional model. These expectations are fed back to the primary process through the *Imagination track (T11)* and translated back to TPs only containing information about objects. These objects can also be imagined objects as part of a recalled scenario from memory. The TPMs pre-activate and associate memory structures which are used in the next cycle of the perception functions and speed up the retrieval process from memory. This is a form of situational knowledge influencing the whole process (influence point F in Figure 3-23).

In the primary process itself, where rules of logic do not apply, perceived objects from the environment cannot be distinguished from imagined objects from the previous iterations. Here two mechanics highlighted by the influence point E in Figure 3-23 apply. The first one is knowledge about reality where learned knowledge about objects and the current situation the agent itself is in have to match. If the result is impossible by means of stored knowledge the perceived objects are most likely not really present but imagined and actions for further investigation of the object in question are necessary or they are noted as imagined objects for the next planning steps. The second mechanic is checking if objects are actual physical objects. Perceived objects have additional information attached to them generated by saliency values of the different sensor modalities. These values indicate the objects as grounded in physical objects and thus pass the reality check indicated in influence point E.

3.4.3 Perceptual Categorization and Activation

In the previous sections the conceptual requirements for activation and categorization of perceptual input are analyzed and their impact on the perceptual cycle is shown. Next, the model of perceptual activation is shown and their fulfillment in the activation-based ARS system is presented. The input and output of the perception track is defined as well as the exemplar based categorization process.

Before presenting the model, a reminder is given on the basic terms that have been defined. A stimulus is a perceived object and as it represented in a symbolic form the input to the model is called a *stimulus symbol*. The terms are interchangeable and the latter is used to distinguish it from other data structures used in the model. *Associations* between data structures are always of a specific type and weighted. In the images this information is neglected to improve readability where this information is unnecessary. When a TPM is used to represent a perceived object it is called an *object-TPM* for clarity but it is not a special type of TPM. An *exemplar* is an object-TPM that has been stored previously and is called *exemplar-TPM* again for clarity reasons. In the primary process there exist no words for the object-TPMs, they are only represented by their symbolic form in the framework. Names of objects in the form of WPMs are added in the conversion process to the secondary process. To improve the readability of model images the names of the object-TPMs are added in hyphens to make them addressable in the text.

Exemplar Representations

As described in Section 2.4.1 exemplars are stored object-TPMs which is built of the TPM itself and associated TPs defining the exemplar. TPMs itself can be associated with other data structures such as drive meshes which make them a possible drive object in this specific context. In the current state of the framework it is not possible to retrieve two TPMs with identical TP-associations. For categorization of TPMs as drive objects this would not add additional information as the possible drive satisfaction and thus categorization is not dependent on the agent’s context and is the same in different situations[31]. Exemplars and thus object-TPMs in the primary process have to follow the pleasure principle and thus are possible candidates as drive objects. Because in the current version of the ARS framework learning is excluded the associated possible drive satisfaction is defined by our psychoanalytic advisors for the given situation and use case.

In exemplar-based models the objects to perceive are categorized by comparing them to previously stored exemplars which are already categorized (e.g. by learning mechanisms or predefined by experts as in the ARS project). The degree of similarity in such models is a sufficient criterion to determine membership from the stimulus (perceived objects). The degree of similarity is enhanced by various influences to find the most appropriate candidate from the stored exemplars. This degree of appropriateness of the stimulus’ category membership reflects how appropriate the exemplars

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[31] The situation the agent is currently in is not considered yet in the framework but is a necessary addition for future iterations of the ARS model.

category is when categorizing the stimulus. The goal of the model is to determine the graded category membership for the stimulus and use the one with the highest category appropriateness value as the subjective result of the recognition process in the perception track.

Premise of the memory structure in the project ARS is that the agent is only represented with objects he already knows but they may have ambiguous features according to the selected use cases. In this case the most appropriate exemplars are used. In this thesis various mechanics to alter this result are described to address the high uncertainty with the simple categorization process in the first modules of the perception track. Identified objects with high uncertainty proposed by the primary process can also be revised by the reasoning and reality-check functions in the secondary process or by focusing mechanics which can result in actions for higher perceptual feature density.

In summary, the stimulus is categorized by using objects categorization and weighted with an category appropriateness value. Composition of the stimulus' category is determined by subjective information of the stored exemplars and the result is valuated as a subjective recognized object (object-TPM).

Activation Based Categorization

Main factor of the activation process is to find the most appropriate exemplar to base further processing of the model on. Various influences, for example coming from expectations as described in the last Section, may impact the decision for the exemplar. In order to integrate the influencing exemplars impact criteria are defined for each influence. For exemplars coming from expectations this value is generated by the expectation grade of the activated scenario feed backed from the secondary process (*Imagination track (T11)*). The activated exemplars are taken into account to determine the appropriateness of the exemplars.

Main influence for the perception path is the perceptual similarity of the exemplars activated by the stimulus. The stimulus symbols are resulting from the Neuro-symbolic layer and are the only objective influence to perception. The other influences result from activation of already evaluated data structures and represent a subjective influence inside the functional model of the mental apparatus.

Objective similarity categorization is calculated by comparing the features of the stimulus with every feature of the exemplar. This is a disadvantageous strategy for exemplar based perception models as it would not be possible for a large amount of exemplars. The advantage of the associative memory structure of the ARS agent lies in a reduction of possible exemplars by reducing the search space to only significant exemplars for the categorization task. A TP, and thus the representation of a feature, exists only once in the stored data structures but can be associated to multiple objects represented by object-TPMs. By using only TPs representing the objective stimulus the search space can be reduced to relevant possible exemplars only. In the current framework implementation visual symbolic features do not represent qualities. Other modalities receive certain qualities in the form of uncertainty if the represented feature can be associated to the stimulus. In the visual modality only absence or presence of the feature can be taken into account which results in a binary quantification of the features. The lack of quantification of features for the calculation of the perceptual similarity is currently not required due to the low number of possible object and features. On the exemplar side of the similarity calculation selective quantity of features is represented by weights reflecting the significance of a feature to the object. These weights are taken into account for the calculation of the similarity criterion and impact the overall grade the exemplar is associated with in the process. The represented weights are created for every situation in the current framework implementation as the ARS agent resembles a thirty year old person[32], but a learning mechanism to build and update these weights is advised for future iterations of the functional model.

Subjective influences in the functional model of the mental apparatus can come from various sources throughout the processing in the model. The impact from expected drive objects for example result from the experience of the agent with bodily needs and expected objects that can satisfy the need. As already described the value representing the demand of the bodily need of the agent is represented by the quota of affect associated during generation of DMs in the drive track. The quota of affect is used as an expectation weight for the associated 'best' (according to experience from memory) drive object. The activated and associated candidates for exemplars influence the perceptual process where the appropriateness of the exemplars from objective sources is calculated and thus are weighted to limit the influence by subjective criterion according to the influence.

The purpose of multiple influences to the exemplar categorization process is to determine the appropriateness of the selected exemplars. Multiple influences reduce the uncertainty and in the case of the described subjective influences represent the method of top-down perception.

Similarity Activation Process

As already described above, exemplars are activated by the presented features of the stimulus and the stored features of the exemplar. The aggregation of multiple activations of the different modalities leads to an overall activation value of an exemplar. The overall activation values of the different information paths are then used to determine the most appropriate exemplar which is then chosen as the perceived, or even more precisely, the recognized perception object (for the difference of recognition and perception see Section 3.1.3).

To determine the appropriateness of the exemplar the criterion's activation sources are defined, calculated for every modality in the activation function and aggregated for every modality with the criterion weights in mind. In the associative memory structure the agent uses an activation based similarity calculation to determine the activation value of an exemplar. Unlike conventional exemplar models not all exemplars have to be considered but only those who are similar to the stimulus which reduces the search space significantly.

The first step is the conversion of the stimulus to psychic data structures as seen in Figure 3-25. This is done by creating TPs for the features of every stimulus.

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[32] According to psychoanalysis a thirty year old individual has an almost complete set of object representations in the memory.

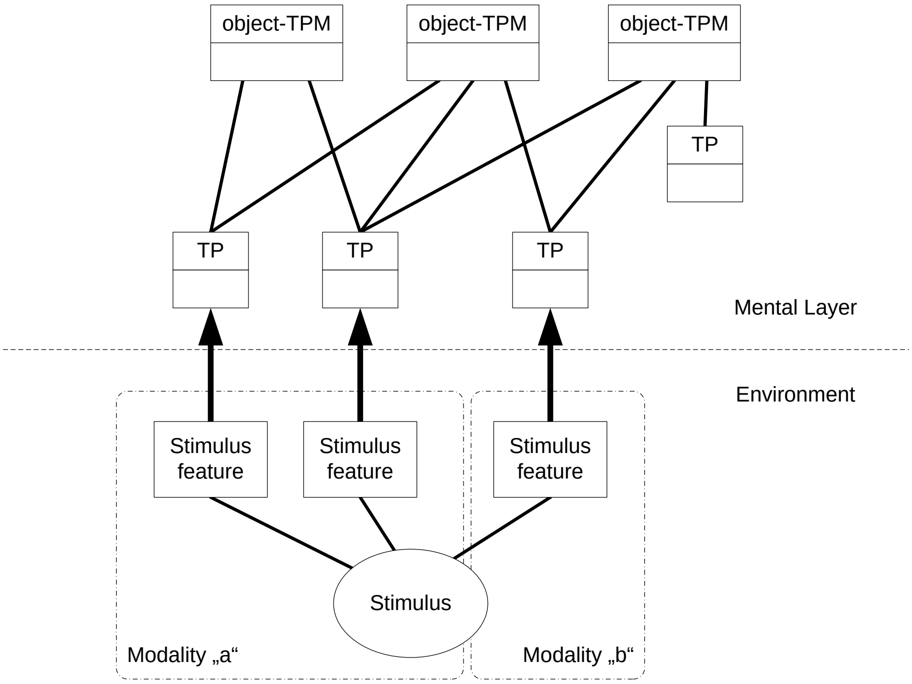

Figure 3-25: Similarity activation association example

At this stage (in module F14) the proposed data structures are temporary and created for exemplar identification only. The TPs the stimulus created are then used to activate similar TPs in the agent memory through the Information Representation Framework [Zeil10, pp.48–60]. The activated TPs themselves activate associated TPMs representing stored object-TPMs which act as possible exemplars in the similarity calculation process. Exemplars are represented by their feature TPs and associated with a feature weight reflecting the impact of a feature.

To reflect the impact of features every feature of the stimulus has to be compared to the features of the exemplar. The resulting similarity activation value s_i (3.1) represents how much of the possible similarity the exemplar is fulfilled. High weights of features from exemplars should have a higher impact on the similarity activation value therefore the values are weighted by feature weights of the exemplars as seen in the function (3.2).

$$s_i = \frac{w_i}{v_i} \tag{3.1}$$

s_i … similarity activation value of the activation source i, with $s_i = 1$ if $s_i > 1$

w_i … association weight of the exemplar i

v_i … association weight of the TP according to stimulus i

The calculated activation value a (3.2) is then formed as the weighted average of the similarity activation values:

$$a = \frac{\sum_{i=1}^{n} w_i * v_i * s_i}{a_{max}} \tag{3.2}$$

a … activation value of the exemplar

n … number of stimulus TPs

With a_{max} being the sum of all possible weights of the exemplar being evaluated:

$$a_{max} = \sum_{i=1}^{n} w_i \tag{3.3}$$

w_i … association weight of the exemplar i

n … number of stimulus TPs

The maximum value a_{max} as stated in (3.3) represents binary activation of due to the usage of a nominal scale in features in the visual field as described above. In the visual field the in case of on activation the similarity activation value is 1. In other modalities the respective weights of the stimulus, which represent uncertainty of the sensory symbol, are taken into account. Due to consideration of weighted features and the normalization of s_i the summed weighted similarity activation values are related to the maximal value of the activation value a.

The direction of the procedure that is comparing exemplars and stimuli in this activation-based categorization is the stimulus as it is driven by features (of the stimulus). Values of a of 1 would indicate the activation of an exemplar by all features. In this case exemplars with additional features would lead to a full match and a false identification of the exemplar. The approach to fulfill the requirement of the framework that an object is represented by a full set of features is to use change the direction and use the exemplar as a starting point for the identification process. In this case the stimulus is searched in the known exemplars. The usage of association weights of exemplars w_i for the a_{max} calculation in (3.3) is the result of this approach. As described this leads to possible missing features on the other end of the similarity calculation (in this approach the stimulus). To represent the missing stimulus feature in the activation value a_{max} has to be adapted. The maximum activation value as stated in (3.4) represents a combination of exemplar weights and missing stimulus weights. This approach also represents the subjective nature of the primary process where stored information about exemplars is preferred as a starting point for the identification direction.

$$a_{max} = \sum_{i=1}^{n} w_i + \sum_{j=1}^{m} vj \tag{3.4}$$

m … number of stimulus features not represented by the exemplar

n … number of stimulus features from exemplars

w_i … association weight of the exemplar i

vj … association weight of the stimulus where $i \in m$ and m being the difference of stimulus features and exemplar features

As described above, every modality has a different certainty attached to it representing the visual modality as the leading one in the human perceptual system. To reflect the agents subjective certainty of using a modality the activation values the proposed addition to the activation function is to aggregate the activation values per modality and introduce a modality criterion. The aggregation then reflects the impact to every criterion to the overall value activation value of the exemplar. This leads to the determination of the criterions impact on the stimulus to activate the appropriate exemplar. Particularly this leads to the case that an exemplar has a high activation value from one modality but the criterion has a low impact on the aggregated value. This mechanic can even be expanded to give high impact to similarity activation as a whole in contrast to the other influence and make the perception process more objective then subjective. These criterions can be used to balance the top-down and bottom-up influences described earlier and the exact values are subject to further investigation in the simulation[33]. The determination of the criterion impact leads to the following weighted function of the aggregated activation values:

$$a_{aggr} = \frac{\sum_{i=1}^{n} a_i * c_i}{\sum_{i=1}^{n} a_i} \tag{3.5}$$

a_{aggr} … aggregated activation value of the exemplar

a_i … activation value of the criterion i

c_i … criterion activation value of criterion i

n … number of criteria

The proposed criterion for modalities is dependent on a balanced number of features throughout the modalities. The impact of several matching features from one modality could influence the exemplar selection less than a low number of features matched from another modality. This leads to an addition of the aggregated value to dynamic factors for the number of features present which is suspect of future work after investigation of the resulting scenarios.

In summary, the similarity activation value is used to determine the most appropriate exemplar for further processing in the functional model. It also represents a value of certainty of the used criterions which can be used for further actions and calculations outside the perception track.

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[33] In the current implementation of the ARS framework an addition of personality parameters for every agent has been introduced. They are not subject of this thesis but the described balance between objective and subjective perception is proposed to one of these parameters.

Saliency Perception

For every modality the agent can perceive there is one value that is used for saliency calculation. For visual sensors this is attached to the brightness value of objects. The olfactory modality has the intensity of the detected smell attached to this value. In the current implementation of the framework this value is not used in exemplar identification apart from the feature of the modality itself. The value is used to indicate how high the perceptual impact of one object is regarding the perceptual ‘importance’ (saliency) of the modality.

The saliency value of a stimulus is associated to object-TPMs like other perceptual features but is used in the perception track to guide focus of attention mechanics according to the arousal reaction described in psychoanalysis. In the current implementation the values indicate associations which are evaluated with a negative effect to the agent. In future iterations of the model the subjective valuation of high saliency values can be used for positive interpretations. For example, a high saliency in the olfactory modality could be evaluated as a strong pleasant smell (e.g. from a flower) instead of just a strong smell indicating the need for focusing the attention on it.

In the scope of the ARS implementation the global scale for all association weights is [0,1]. Hence all values have to be normalized with respect to the global scale. For the implementation of this thesis values over 0.7 were chosen as the border for high saliency values where the agent is intended to react. As this value is bound to the conceptual content and personal attributes (personality parameters) of the agent it is a candidate for further investigation in the simulation.

In this chapter, the development of the model in a top-down design process has been done. By incorporating the conceptual interdisciplinary description a technical feasible model is generated to the point where the calculation of similarity values for appearance recognition could be developed. The resulting model uses associated memory structures and the concept of exemplars for perceptual symbol generation which results in recognized objects the ARSini agent can use to base decision upon. In Chapter 5 the model is evaluated by using use cases the agent has to perform in and the resulting calculation values are inspected by using the tools shown in Section 4.2.2

The considerations in Section 2.1 and 2.3 imply the use of simulation of models, especially of an artificial life simulation to verify the model described in Chapter 3. This follows the requirements from the described interdisciplinary research for environment to body to decision unit feedbacks. Chapter 4 discusses the multi-agent simulation environment, the implementation of the functional model and the modules of the proposed model of the perception-action cycle.

CHAPTER 4

4. Platform and Framework Implementation

Chapter 3 introduces concept and model of the perception-action cycle to the ARS decision unit framework. For the development and evaluation of the model inside the embodied software agents called ARSins an artificial life simulation is used. It provides a platform for the different parts of the decision unit and the functional model implementation. The implementation of the model is realized in virtual, embodied agents. Inside this virtual world the agents are faced in several scenarios with different object to perceive and react to.

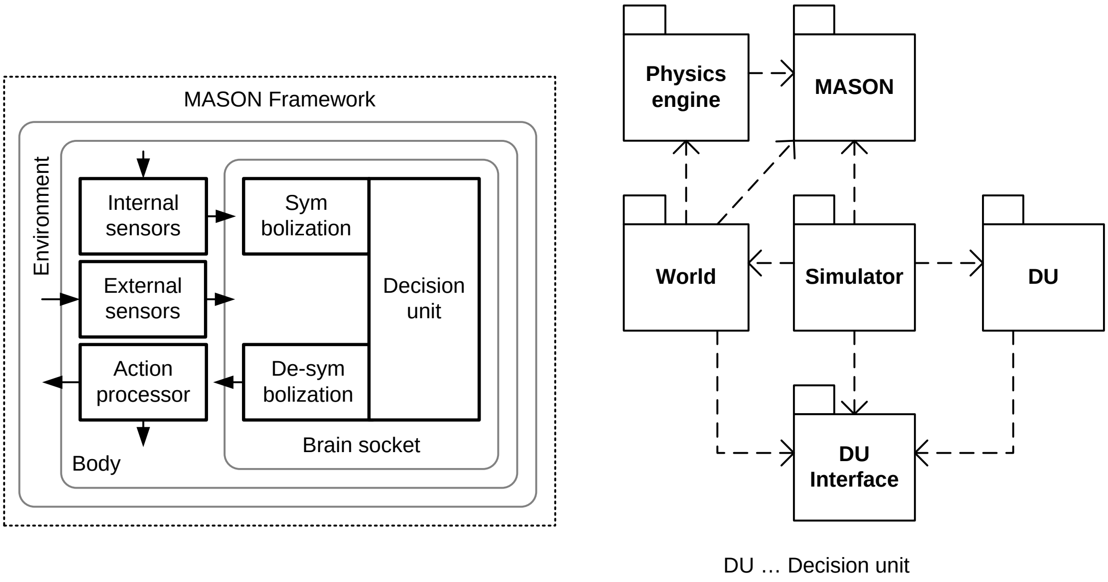
In the first section, the artificial life simulation environment itself as well as the agent is discussed. Next, the design of the simulation framework is described. This includes the decision unit sequence as well as the tools used to investigate and evaluate the agent's inner workings during runtime. This chapter is concluded with the implementation of the data structures the simulation can contain. The revised implementation of the functional model and the coupled perception-action cycle framework are merged and labeled as ARSi12, the ARS framework implementation number 12.

4.1 Simulation Platform ARSin World and Embodied Software Agents

The purpose of the simulation framework ARSin world is to provide a simulation test-bed for different decision units and in particular the implementation based on the functional model. The tests performed in the simulation consist of situations with available resources, different object and agents according to the use cases where the agents are tested in. At the end of the simulation, or even within if the use case describes it, it should be possible to evaluate the shown agent behavior. With the tools at hand it is even possible to go beyond and investigate the inner workings of the agents that led to the decisions the behavior is based on.

4.1.1 Concept

The purpose of the simulator is to create an environment where different types of agents are put to test by exposing them to different scenarios. In order to remain flexibility for the scenarios the environment has to be capable of consisting different object and other agents besides the ARSin agent. The objects range from inanimate objects like walls and different other obstacles to animate objects which have different levels of autonomy. A special group of objects named energy sources are there to provide the agents with a constant source of food by consuming them. They provide different sets of nutrition and can range from less complex control architectures (like plants) to implementations with reactive architectures used by animal-like objects. All objects have various ranges of interaction possibilities with the special type of agent implementation, the ARSin agent, there the functional model of the project ARS is implemented as control architecture. Their main parts consist of the decision unit itself and a body with various sensors, actuators and internal mechanics (see Figure 4-1(a)).



(a) Embodied agent structure (b) Project structure

Figure 4-1: Modular structure of the embodied agent and project structure

These main parts are interchangeable through an interface implementation which makes the evaluation of different control architectures possible. The body represents the interface between the simulated world and the decision unit of the agent. ARSi12 is realized in a multi-agent system based on the development toolkit MASON [5] in the Java programming language. The decision for the use of MASON is the orientation towards a simulation of large numbers of agents and the resulting performance. MASON is also very flexible due to the Java-based design and thus not only provides a platform for rapid prototyping but integrates well with the framework developed in the ARS project (Figure 4-1(b) shows the overall project structure of the implementation). Additionally a rigid body physics engine is provided for two dimensional environments which enables the environment with a feedback of objects needed by the implementation. All agents and objects in the simulated world are represented in two dimensions which is preferred to simplify the interaction process during evaluation of the control architecture. MASON itself provides a 3-dimensional visualization but in order to extend the ARSin framework to three dimensions a more sophisticated physics engine and visualization engine[34] are available. The interaction possibilities with the two-dimensional visualization provided by MASON are extended (inspectors) to provide monitoring of the agent's behavior, inner working and attributes. With the described inspecting tools also the associated data structures can be observed during runtime.

In the upcoming sections, the implementation of the framework is represented by using Unified Modeling Language (UML) sequence and class diagrams. UML is standardized as a modeling language by the International Organization for Standardization and International Electrotechnical Commission in the ISO/IEC 19501[35] standard.

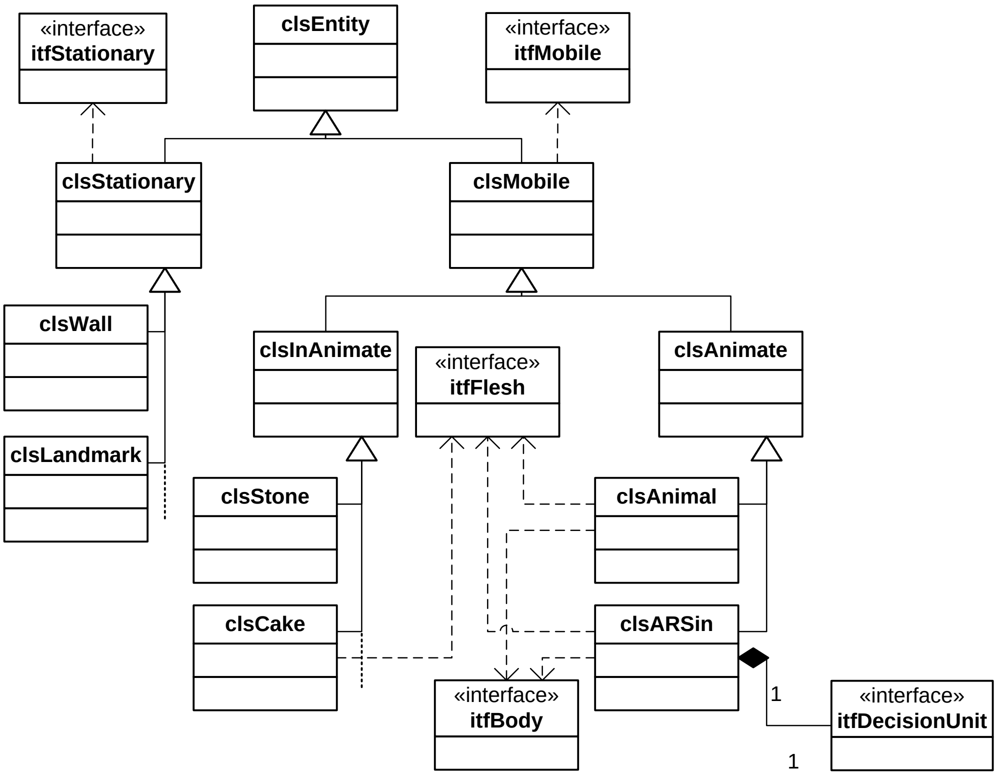


Figure 4-2: Entity hierarchy of the ARSin framework

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[34] For the ARSin framework an interface to the free 3D-Engine UNREAL [6] was developed but the interaction of sensor and actuator systems need more investigation and a reliable interface.

[35] ISO/IEC 19501:2005, Information technology — Open Distributed Processing — Unified Modeling Language (UML) Version 1.4.2

Figure 4-2 shows that every object in the simulation is designed as a specialization of the *clsEntity* class. The physics engine itself knows two types of objects stationary and mobile. Stationary objects like *clsWall* and *clsLandmark* have infinite weights, thus not movable in the simulation, and are introduced to speed up the calculation process of the physics engine. These elements are implementations of *clsStationary* which is a specialization of the stationary classes of the physics engine. Each stationary entity implements the interface *<<interface>> itfStationary* through *clsStationary* for the physics engine to react accordingly. Mobile entities in the other hand are movable in the physics engine and have to implement *<<interface>> itfMobile* through *clsMobile*. Specializations of the mobile tree of entities are again split into *clsAnimate* and *clsInAnimate*. Inanimate objects cannot move themselves but can be moved around according to physics by other objects in the simulation. Into this category fall objects like stones, plants and various other energy sources and obstacles for the agents. Animate objects are designed to be able to move around by themselves and thus have to implement the *<<interface>> itfDecisionUnit* which provides the framework to implement different control architectures. Simplified reactive decision units are used for the specializations *clsAnimal* and the ARS functional model implementation is used by *clsARSin*. Entities which are planned to be consumed have to implement the *<<interface>> itfFlesh* which provides the consumer with actions where nutrients are forwarded. Agents also have to implement the *<<interface>> itfBody* which is in the case of *clsAnimal* a simplified body for reactive decision units and all ARSin agents have to implement a complete body represented by *clsComplexBody*.

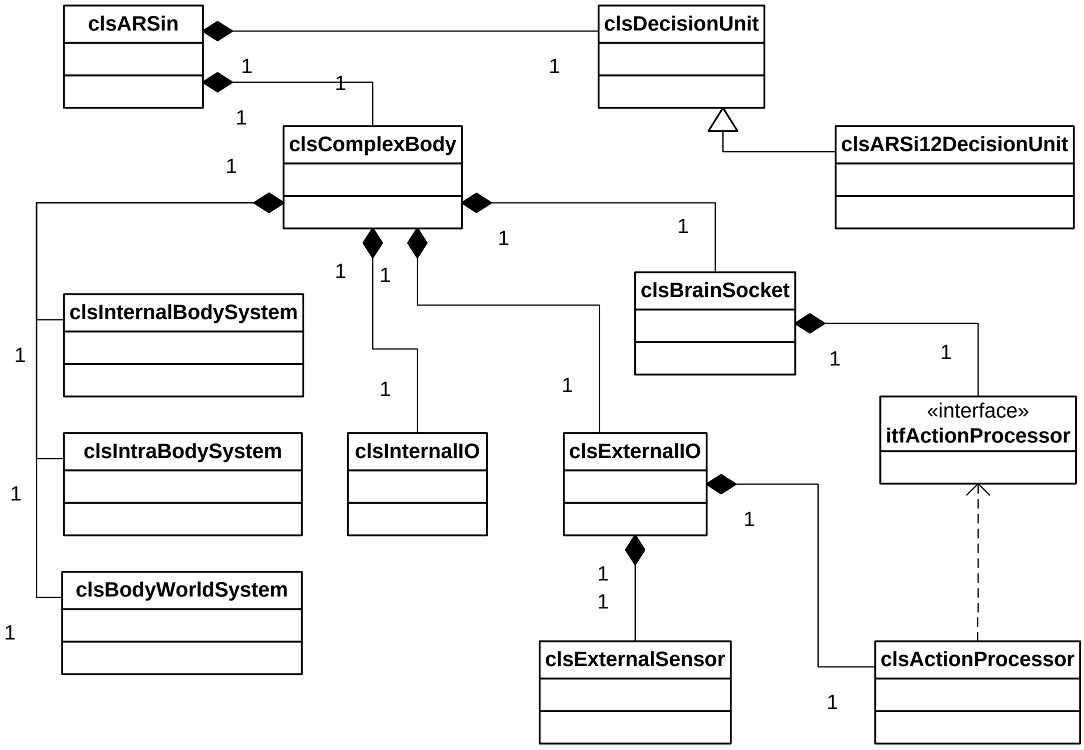


Figure 4-3: Class structure of the ARSi12 agent

Figure 4-3 shows the class diagram for the ARSi12 agent implementation. As stated above, every agent contains one body and one *clsDecisionUnit*. The agent containing the ARS functional model decision unit implements the *clsARSi12DecisionUnit* and the *clsComplexBody*. The *clsComplexBody* itself introduces internal (*clsInternalIO*) and external (*clsExternalIO*) interaction. The *clsExternalIO* is divided into a communication platform for environmental sensors (*clsExternalSensor*) and an action processor (*clsActionProcessor*) which is used through the *clsBrainSocket* to execute actuator commands of the decision unit. The body itself if represented by a set of internal systems (*clsInternalSystem*) and intra-body systems (*clsIntraBodySystem*) which implement internal messaging systems of the body and systems for bodily conditions like health, stamina and multiple stomach systems. These internal systems control the bodily state of the agent and are one source of the drive system. The class *clsBrainSocket* is the interface and communication class between the body and the decision unit. Through this class the decision units and bodies are interchangeable for the simulation and thus it allows the evaluation of different implementations. The brain socket transfers sensory information from the body, where internal and external sensor systems detect values from the physical environment or the internal body mechanics, and action information from the decision unit which is processed through the actuators on the body or environment. Perceived sensory information are forwarded through the functional modules F1, F10 and F12 (see Section 3.3) to the *Self preservation drive track (T2)*, the *Environmental perception track (T3)* and the *Body perception track (T4)*.

In the ARSin simulation framework as shown in Figure 4-4 every entity is processed in various phases. Entities are registered in the event scheduler of the simulation framework in the startup of the simulation and all phases are processed in every simulator step. The step is divided into four sub-steps (phases):

- Phase one – *update*
- Phase two – *sense*
- Phase three – *process*
- Phase four – *execution*

In phase one – *update* – the internal systems of the body of every *clsEntity* are calculated and updated. In this phase state changes resulting from the interaction of the different internal systems of the agent are executed. Entities without a complex body also receive the update step where internal mechanisms of the corresponding bodies are executed. After that the second phase – *sense* – is initialized. In this phase all entities with sensor systems update their environmental information by accessing data from the world detected by their various sensors. The ARSin agent polls the internal and external interfaces represented by the classes *clsInternalIO* and *clsExternalIO* to receive environmental and homeostatic (bodily) data. In phase three – *process* – entities call their decision unit to process the incoming information. In the case of the ARSin agent *clsBrainSocket*, the connection between the body and the decision unit, calls every module of the functional model to process the data from the previous module. Before the processing the method *applySensorData()* (Figure 4-4) is called to process the sensor information to the input interfaces of the functional model. After the processing phase of every agent is finished the resulting actions have to be forwarded to the body in the fourth phase – *execution* – which results in a state change of the world.

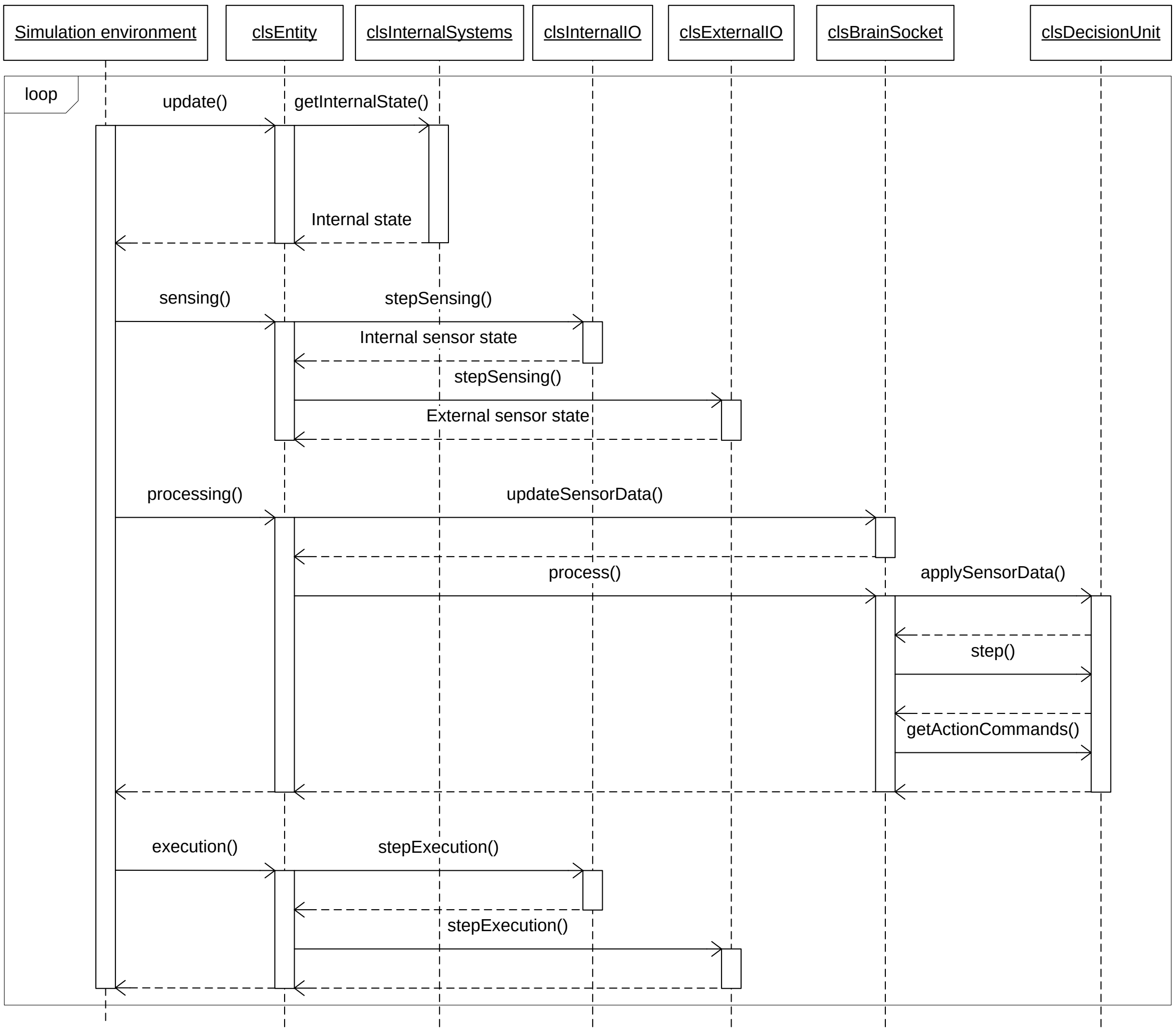


Figure 4-4: Simulation cycle sequence diagram

The step of the simulation has been divided to provide every agent with the same state of the environment before the processing phase begins and not to have false sensor information of the environment impact in the processing of the functional model. As many entities do not implement a processing phase, which is the processing-intensive phase of the simulation, because they do not need a decision unit the diversion into these sub-phases does not slow down the simulation. On the other hand the design decision to make every animate entity implement the steps poses a possibility for simple state changes (e.g. visual representation in the simulator if an energy source is partly consumed).

In summary, the ARSin agent consists of internal and external systems providing the agents decision unit with data to process. The interface to the decision unit is *clsBrainSocket* which manages the transformation from the sensors and actuators of the body to the decision unit. The received information is interpreted in symbolic form and converted to psychoanalytic inspired data structures which are then processed by the decision unit as described in Section 4.2.

After the initial overview of the ARSin simulation the agent processing the functional model, the ARSin agent is described in more detail in the next section.

4.1.2 ARSin Agent

As discussed in the previous section the decision unit of the ARSin agent requires perceived information about the internal (homeostatic) and external state. This represents information about the body and the environment. The agent's body passes this information through the *clsBrainSocket*, the intermediate class between body and decision unit, from the equipped sensor system. In the external sensor system multiple sensors for the different modalities can be registered. The system can handle visual, tactile, olfactory and gustatory stimuli to perceive the environment. An extension to the acoustic sensor modality is intended and but not part of this thesis.

The specification of the agent is inspired by the human body which uses different forms of information messaging systems to pass bodily states. The state of the ARSin agent is formed by body condition levels from several internal systems, slow messengers and fast messengers. Fast messengers are used to transfer bodily sensations without time loss during the steps of the simulation. They implement a direct source of origin which can be linked to the current position of actuators as well as direct stimuli originated from organs. This system can be matched to the nervous system of real life forms. The slow messenger system implies the characteristics of hormones and represents values that change over time in the simulator. Together with the body condition systems which display the state of the stamina system, health system, body integrity and several nutrition systems. All those systems are centralized in the internal systems of the *clsComplexBody* as shown in Figure 4-3. All internal systems are bound to an internal energy consumption system which reflects an influence between one another. For example, every action performed by the agent consumes a certain amount of internal energy as well as possible direct influences to the stamina system. Consumed nutrients on the other side raise the energy levels through a digestion mechanism as well as indirectly the health system and body integrity. These complex internal bodily systems form the homeostasis of the body and in order to remain balance in the system the ARSin agent has to perform actions in the environment. This internal information of the body is introduced to the model itself by translating them into multiple drives in the drive tracks.

To detect the internal homeostatic values the following internal sensors are equipped to the *clsComplexBody*: *fast messenger*, *slow messenger*, *stomach*, *health*, *stamina*, *temperature* and *stomach tension*.

The external sensor system of the agent is equipped with different modalities. Figure 4-5 shows the implementation where every modality is divided into detection areas. For the visual field the sensor range is divided into three areas to represent distances in the simulation and give the possibility to limit the features the agent can detect further away.

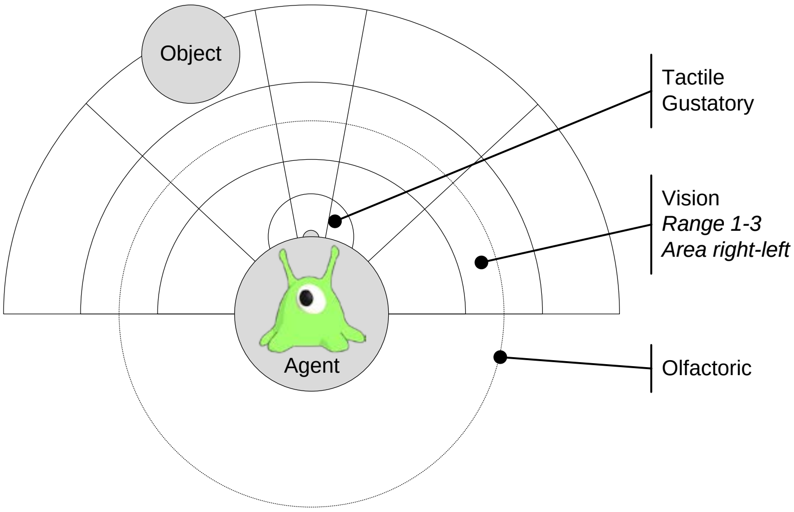


Figure 4-5: Agent external sensor system

Gustatory modalities are dependent on a direct interaction of the agent with nearby objects in the simulation. They can only be detected in the so called eatable area in front of the agent (Figure 4-5). The tactile modality is dependent on the interaction of objects with the body itself, represented by the close area around the agent in Figure 4-5. For the visual modality the above mentioned ranges and areas were introduced to divers the detected features of objects. Detectable objects in the model are represented by a composition of features from different modalities. The object represented in Figure 4-5 is in the most distant range (Range 3) of the visual field. Dependent on the sensor ranges the agent can only receive visual information about the object and due to the range features can be reduced. When the agent reduces distance to the object it is possible to perceive more information about the object, represented by additional sensor characteristics, which leads to a higher density of features and in conclusion to higher activation values of the exemplars loaded for detection. In order to mimic natural characteristics of vision and to add more complex perceptual scenarios the granularity of feature detection in the vision ranges was introduced. The features detected are dependent on the distance to the object and thus the range to the agent. With this mechanic the visual information about an object can range from rudimentary characteristics like shape and color to possible detailed features like texture (an extension to additional features is intended but not intended and but not part of this thesis). With the represented external and internal sensor systems various action plans for scenarios can be generated to investigate the functional model. In summary, the external sensor system of the agent consists of the following external sensors:

Vision: This external sensor detects objects within the three ranges of the visual field. The information decreases with distance to the object and is the primary source of the perception system in the current implementation.

Bump (Tactile): The force the physics engine calculates when another object hits one of the body parts is calculated. The calculated forces are dependent on the masses of the object and their speed. The sensor information itself is translated into a pain like information if it reaches a certain threshold.

Eatable Area (Gustatory): Objects in the small area in front of the agent can be eaten. The sensor itself only returns the available object but not if they actually can be eaten as this information is dependent on the experience of the agent itself.

Olfactory: Olfactory information about other objects depends on their possibility to emit odors. The result of the olfactory sensor alone does not give information about the exact number of present objects, nor does it give exact position. This is dependent on the link to visual sensor data.

An extension to add acoustic sensor values is intended but not part of the current implementation. The sensor system itself (see Section 4.2.1) is designed for easy expendability to make this addition possible in future iterations of the framework.

The basic functionality of the ARSin agent is to provide an entity which offers internal systems, internal and external sensor systems and actuators for world interaction. This provides a platform to test various architectures and the mechanics of the implementation of the functional model. The overall process is to detect and interpret data from internal and external sensors, provide the decision unit with information to process and execute the planned actions.

Every action that is executed through the actuator system consumes internal energy of the body. Internal energy consumption was introduced to resemble the consummation of nutrition’s of the human archetype. The actions that can be performed by the agent exist in different versions to represent intensities which result in different energy demands. A detailed examination of the actuator system and the corresponding actions can be found in [Doen09]. The basic actions of the agent are: *move forward*, *turn (right/left)*, *eat*, *bite* and *seek*.

The represented actions are also accessible for implementations of the *clsAnimal* (see Figure 4-2). Next to these actions which allow the execution of basic scenarios, additional actions were introduced to the ARSin agent. They incorporate advanced interaction with objects in the world as well as the possibility to interact with other agents of the type ARSin. The additional interaction actions are: *sleep*, *excrete*, *facial expression*, *body color*, *pick up*, *drop*, *say* and *kiss*.

The above presented actions and internal systems make the agent capable of social interaction with other agents and represent the extensibility of the framework to new features requested for scenarios in the future. To investigate the inner workings of the system and measure the internal values so called inspection systems are added which are the subject of Section 4.2.2. Before that the implementation of the decision unit is introduced in the next section as well as details of the sensor system.

4.2 ARSi12 Framework Implementation

In the design of the framework implementation each module has a corresponding class. Every decision unit module extends the base class of all modules *clsModuleBase* which forces the implementation of the methods *receive()*, *process()* and *send()*. As seen in Figure 4-4 the simulation is divided into phases and every decision unit is called once every step in the *process()* phase. The processor of the decision unit (*clsProcessor*) then this processing step is forwarded to every module in a predefined sequence from module F01 to F32.

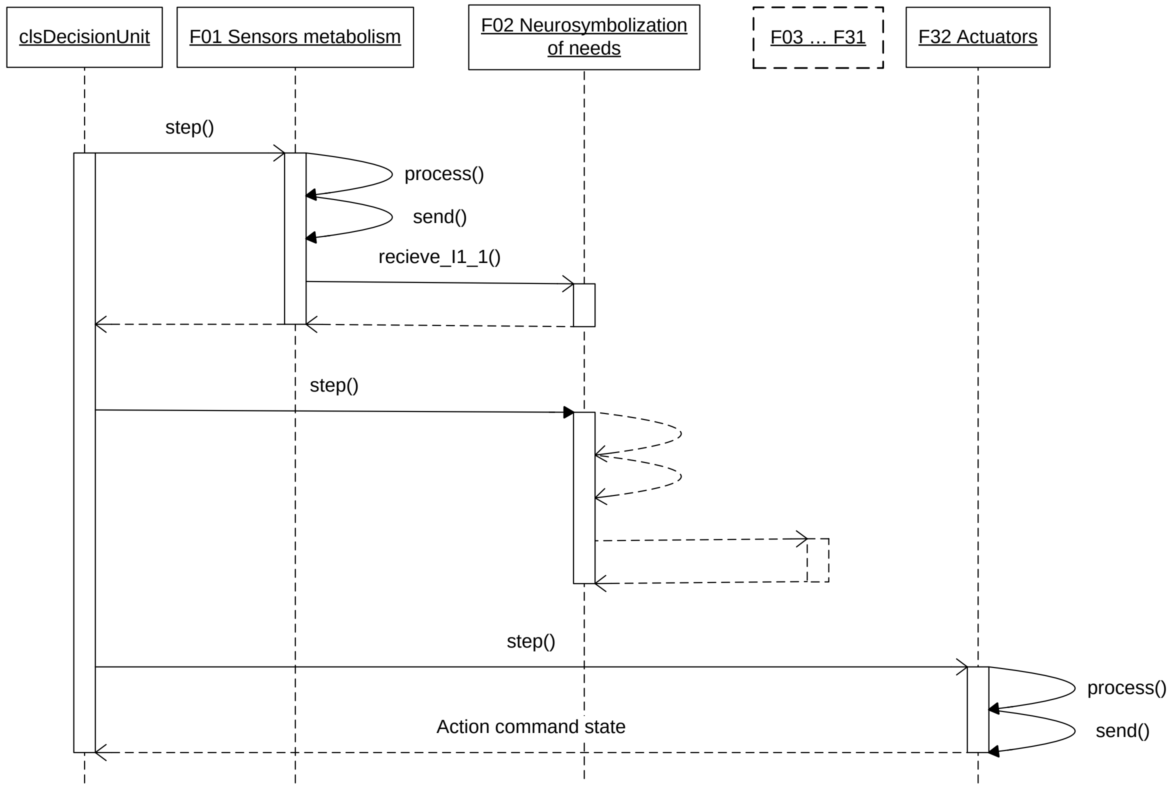


Figure 4-6: Module calls of the decision unit in one step

In the sequence diagram Figure 4-6 the call of every module is sketched. Every module then runs through the three methods *receive()*, *process()* and *send()*. The *process()* method manipulates the incoming data according to the functionality of the module and the output data is then forwarded to the output interfaces of the next module in the processing order. This done by calling the *receive()* method of the adjacent module which then stores the data structures internally for processing. For development reasons there exist three versions of the *process()* method which can be set in configuration for each module. This helps to examine changes to modules before they are set hot for the whole development team. The nomenclature presented in Figure 4-6 for the *receive()* methods follows the interface number between modules where the first number represent the layer the module is in and the second one is a running number for every interface the module has a connection to.

As stated above the *clsProcessor* calls the classes of the modules F01 to F32 in a predefined order. Table 4-1 shows the processing sequence with their corresponding tracks. The listed classes are the implementations of the modules as seen in Figure 3-21 with the corresponding tracks as discussed in Table 3-6 in Section 3.3.

#	Classes in processor sequence	Track	#	Classes in processor sequence	Track
1.	F01_SensorsMetabolism	T2	22.	F18_CompositionOfAffects-ForPerception	T6
2.	F02_NeurosymbolizationOfNeeds	T2	23.	F63_CompositionOfEmotions	T5
3.	F10_SensorsEnvironment	T3	24.	F56_Desexualization_Neutralization	T5
4.	F11_NeuroSymbolizationEnvironment	T3	25.	F55_SuperEgoProactive	T7
5.	F12_SensorsBody	T4	26.	F07_SuperEgoReactive	T7
6.	F13_NeuroSymbolizationBody	T4	27.	F06_DefenseMechanismsFor-Drives	T7
7.	F39_SeekingSystem_LibidoSource	T1	28.	F19_DefenseMechanismsFor-Perception	T7
8.	F40_NeurosymbolizationOfLibido	T1	29.	F08_ConversionToSecondary-ProcessForDriveWishes	T8
9.	F03_GenerationOfSelfPreservation-Drives	T2	30.	F21_ConversionToSecondaryProcessForPerception	T8
10.	F04_FusionOfSelfPreservation-Drives	T2	31.	F20_CompositionOfFeelings	T8
11.	F41_Libidostasis	T1	32.	F61_Localization	T9
12.	F43_SeparationIntoPartialSexual-Drives	T1	33.	F23_ExternalPerception_focused	T9
13.	F48_AccumulationOfQuotaOfAffects-ForDrives	T5	34.	F51_RealityCheckWishFulfillment	T9
14.	F57_MemoryTracesForDrives	T5	35.	F26_DecisionMaking	T10
15.	F14_ExternalPerception	T6	36.	F52_GenerationOfImaginaryActions	T10
16.	F46_MemoryTracesForPerception	T6	37.	F47_ConversionToPrimaryProcess	T11
17.	F37_PrimalRepressionForPerception	T6	38.	F53_RealityCheckActionPlanning	T10
18.	F49_PrimalRepressionForDrives	T5	39.	F29_EvaluationOfImaginaryActions	T10
19.	F54_EmersionOfBlocked-DriveContent	T5	40.	F30_MotilityControl	T12
20.	F35_EmersionOfBlockedContent	T6	41.	F31_NeuroDeSymbolizationAction-Commands	T12
21.	F45_LibidoDischarge	T6	42.	F32_Actuators	T12

Table 4-1: Class *clsProcessor* sequence with assigened tracks

It can be seen that the processing sequence does not follow the order of the track view as the tracks are only introduced for simplification and explanatory reasons. The order follows the sequence of the functional model as shown in Figure 3-21.

4.2.1 Sensor System

Besides the interfaces between the decision unit modules, the interfaces between the agents, decision unit and the sensor system must be discussed. As seen in Figure 4-3, the *clsARSin* agent has a connection to class *clsBrainSocket* which provides the interface between information of the simulation world and the used decision unit. Through the class *clsBrainSocket* sensor information is forwarded as input into the internal and external perception tracks. The base classes for these two information paths are *clsExternalIO* and *clsInternalIO*.

This structure separates the information processing, which is performed in the decision unit itself and the gathering of sensor data which is actually the function of the used body of the *clsARSin* agent. The class diagram in Figure 4-3 only shows the class *clsComplexBody*, which is the implementation the ARSin agent uses. The body itself has a base class *clsBaseBody* as seen in Figure 4-7 where all possible body implementations have the possibility to use the sensor system functionalities. This design decision was made to provide agents without the need of a complex body with internal systems like *clsAnimal*, with the possibility to reuse the sensor system developed for the more complex *clsARSin* agents.

In the following the structure of the sensor system itself is described. Figure 4-7 shows the inheritance structure of all classes used in the sensor system. The full use of the sensor system (as seen in Figure 4-7) and all classes can only be seen in the implementation of *clsARSin* agents with *clsComplexBody* bodies. For every used agent the used internal and external sensors can be defined and thus the class structure can look different for e.g. *clsAnimal* agents. All sensors are derived from the class *clsSensorActuatorBase*, a pattern often used in the design of the simulation framework. As discussed above ARSin agents have the possibility of a complex internal system in conjunction to the complex external world of the simulation. There are two different kinds of sensors: internal and external. The base classes for them are *clsSensorExt* and *clsSensorInt*. The internal sensors collect information from the internal body systems which are represented in Figure 4-7 by the base class of all bodies. These sensors fetch the information from internal systems like the stamina system, temperature system, health system and different stomach systems. The sensors itself are merely used as getters for the internal body states as the normalization of values is performed in the first modules of the decision unit.

The most of the external sensors in the implementation have a certain range and a field of view, as it can be seen in Figure 4-5 in Section 4.1.2. In order to detect sensor information the collision detection of the physics engine is used. Every sensor has a physical implementation of its field of view which is attached to the body of the agent and moves with it. When this physical sensor segment collides with another physical object the collision data is detected and processed by the specific sensor implementation of the various modalities. This physical sensor segment is represented by the class *clsSensorRangeObj2D* which the agent can have multiple instance of depending on the sensor implementation. In the case of the visual modality with different ranges this sensor segment is actually a ring segment which is represented by the class *clsSensorRingSegment* and designed flexible enough to be reused for every modality with different requests for field of views. This class is then the base class for the implementation of every module namely *clsSensorBump*, *clsSensorVision*, *clsSensorManipulateArea*, *clsSensorOlfactory* and *clsSensorEatableArea*. The exception to this design is the class *clsSensorTactile* which detects the forces working on the body itself and thus does not need a separate physical sensor entity. It is debatable that the data collected is actually bodily information and thus has to be assigned to the internal sensors but as discussed in Section 3.3 the external perception track is divided in the *Environment perception track (T3)* and the *Body perception track (T4)* and this data is forwarded to the bodily path of external perception as it does not represent homeostatic data. Figure 4-7 in this case, is also slightly simplified as there can exist a sensor implementation for every body part comparable to *clsSensorTactile*.

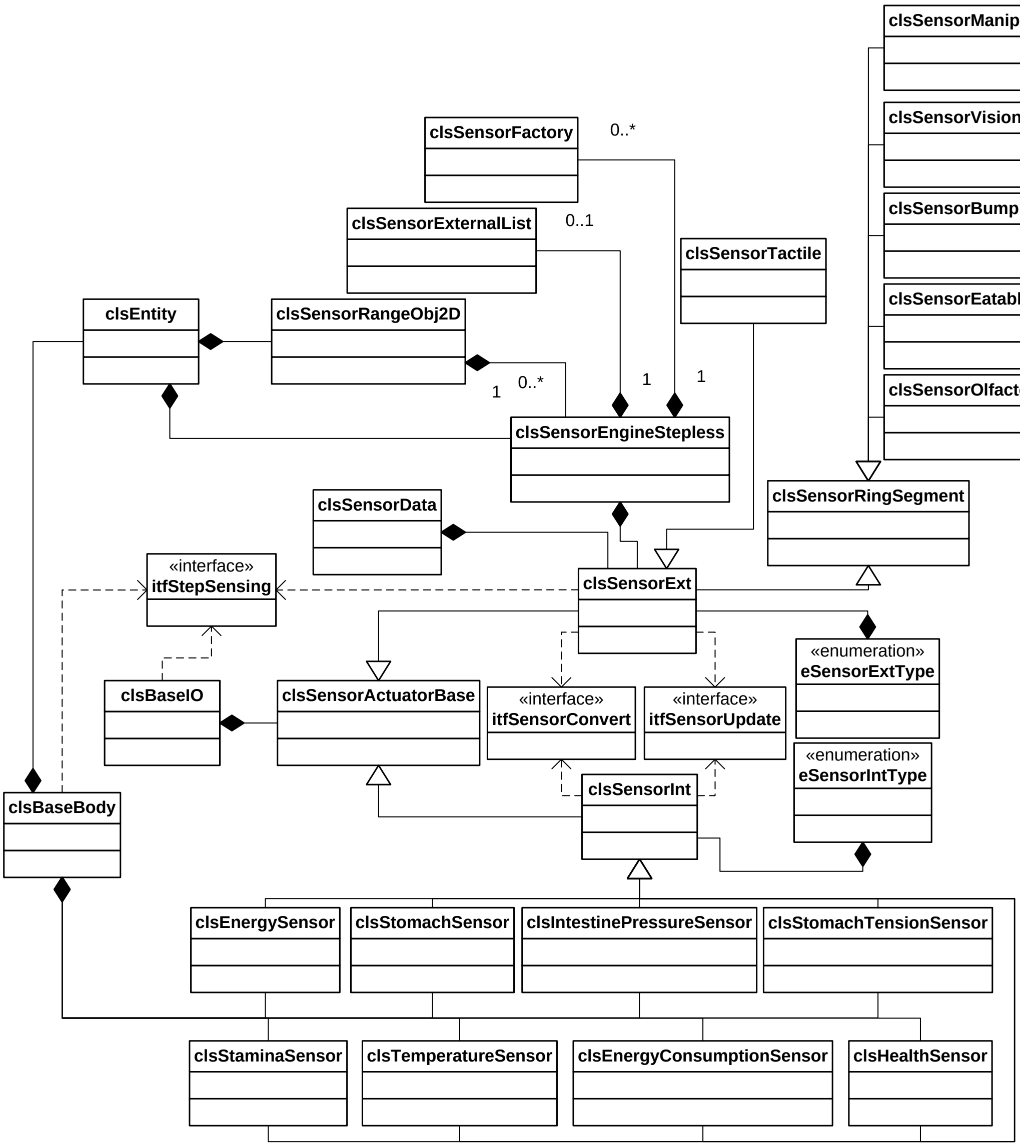


Figure 4-7: Sensor system class diagram (Compositions without multiplicity values noted are 1..1)

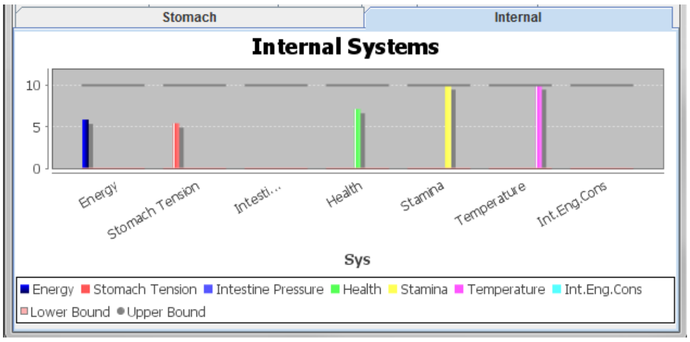
Because an agent can have multiple sensors *clsSensorEngineStepless* is used to group the sensor representations. This class passes all sensor data with the information about the sensor type, represented by the <<*enumeration*>>*eSensorExtType*, through the body of the *clsEntity* to the *clsBrainSocket*. The data of all sensors is requested in the *sensing()* phase (see Section 4.2) which calls *stepSensing()* of *clsExternalIO* represented in Figure 4-7 by the class *clsBaseIO* and the interface *<<<interface>>itfStepSensing*. The sensors themselves have to implement update and conversion methods requested by the interfaces *<<interface>>itfSensorConvert* and *<<interface>>itfSensorUpdate* which is demanded by the base class of all external sensors *clsSensorExt*.

4.2.2 Data Collection Systems

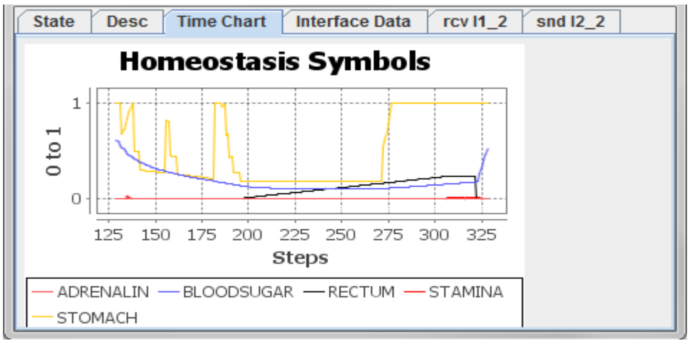
In order to inspect the inner workings of the model during runtime of the simulation several, so called, inspectors where introduced. With these inspectors several states of the agents can be viewed and recorded for later analysis. To display data structures the agent is processing a graph inspector was introduced. In every module of the functional model implementation the current state can be displayed to show the processing of data throughout one simulation step. The following shows examples of these inspectors and explanations what they show.

Body State Inspectors

The bodily states displayed in the example screenshot in Figure 4-8(a) show the summary of various internal systems like health, stamina stomach tension etc. as they can be represented by a single value.



(a) Internal Systems example (Intesti… Intestine Pressure, Int.Eng.Cons … Internal Energy Consumption)



(b) Homeostatic Symbols time chart

Figure 4-8: Internal system inspector examples

The values itself are normalized to values from 0 to 1 but for clearer visualization the values are multiplied by ten in this inspector for the y-axis. Figure 4-8(b) shows the results of several homeostatic values in a time diagram for the simulation steps 0 to 325. The values in this example represent the state of the module F02 (*Neurosymbolization of needs*) processed in every step with additional bodily states converted by the respective module. The data shown in this figure represents an example of the values possible to be detected by the inspectors.

Additional inspectors can be activated to show the values of the messaging systems, the nutrients in the stomach, energy consumption of the internal systems in addition to the state of every module of the functional model implementation.

Inspectors for Perception

Figure 4-9 shows how the associative data structures inside the framework implementation are represented during runtime. The graph inspectors are used to probe the state of the various modules of the implementation of the decision unit. They represent memory meshes (composed data structures as discussed in Section 3.1.2) as they are present in the current processing step. They can display incoming sensor information, activated exemplars, associated drive meshes and all possible memory structures processed in the functional model implementation. The inspector implementation is removed to a separate project for reusability in the whole ARSin world simulation. In every module an additional inspector-tab is created for every receiving and sensing node of the interfaces between modules, the graph inspector itself then cycles through the meshes and display the according data structure.

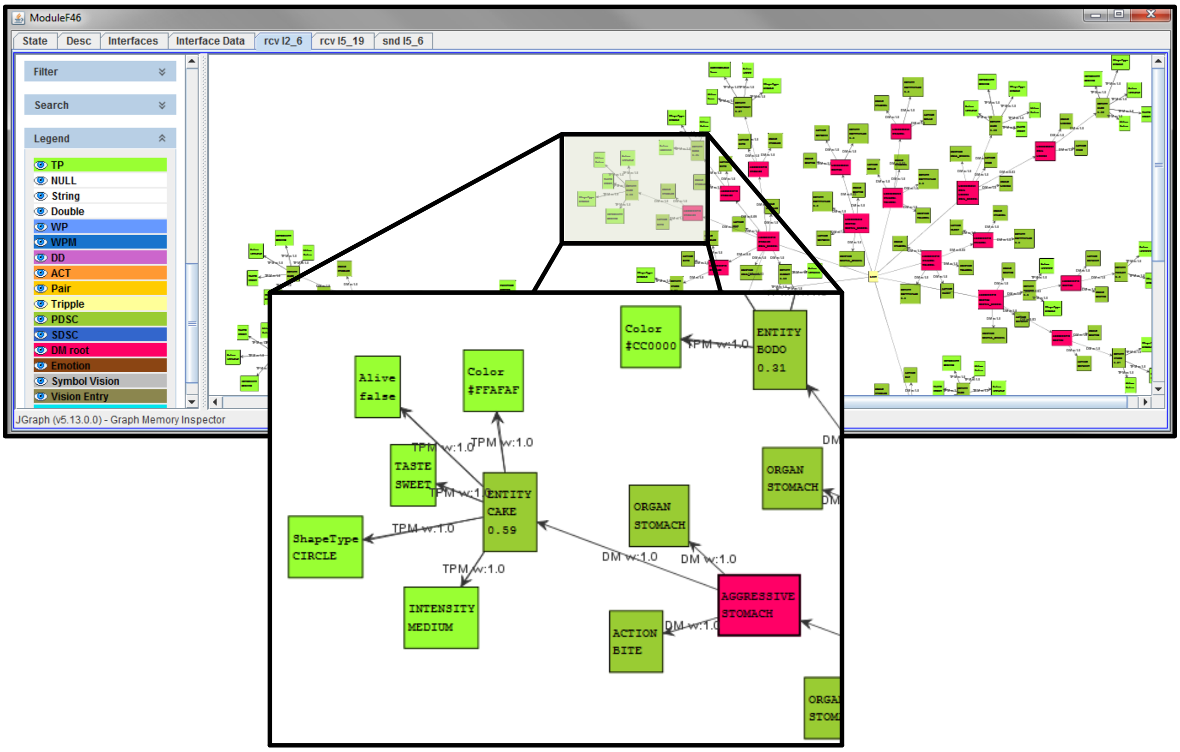


Figure 4-9: Perception inspector graph example

In Figure 4-9 an example from module F46 (*Memory traces for perception*) is show. The inspector shows the data structures received by the module and all associated and activated meshes. In the magnification the root node of a Drive Mesh (STOMACH) can be seen with an associated object-TPM (CAKE) and its TPs. The associations itself represent their type (e.g. the DM notation stands for Drive Mesh Association) and weight but the weights. The real weights of the associations are not represented in the graph inspector but an extension to show them is being developed as it can be seen in Figure 4-9 (all weighs are displayed as 1.0 for the current implementation of the graph inspector). In Chapter 5 the graphs representing perception information are redrawn for clarity and additional information, like the actual weights of the data structure associations or the type of data structure which is represented in Figure 4-9 by using different colors.

The presented ARSin world simulation framework meets the requirements to test different control architectures and especially the implementation of the functional model of the ARSin agent. It provides an environment to evaluate the presented model with the focus on perception as defined in Chapter 3.

In Chapter 5, use cases to verify the ARSi12 framework are introduced. In the performed use cases critical points of the model are identified with impact to the proposed model implementation. The focus on the presented simulations is on perception generation but as the purpose of the decision unit itself is to provide the agent with actions to survive in the simulated world the impact of perception to the overall decision making process is investigated.

First, it must be proven that the proposed structure of data in this associative memory model provides the possibility to create action plans in the decision unit from a stimulus of sensor data. In the decision unit the mechanics of primary and secondary data structures in their different abstraction levels is of the primary interest. The same stays true for the perception system where the mapping from raw sensor data to primary data structures marks the transaction from the world and body layers to the mental layer. The mapping from secondary data structures to actuator commands is not the primary focus of this thesis but in order to close the proposed action-perception cycle the feedback from the agent to the environment is also examined.

The second major impact to perception generation lies in the use of predefined knowledge to recognize exemplars. These subjectively generated abstractions of world objects are then used to base decisions on. As learning is excluded from the current system, system engineers in conjunction with our psychoanalytic experts must define the data structures and rules for the selection process. In the design of the data structures the inner workings of the model are looted out and show improvements for future iterations of the model. In the examination process learning mechanisms inside the associated memory structures are investigated for future work.

In the examination the impact of mechanics to the decision unit other than perceptual influences is only discussed as reference to the overall functional model. As planning is excluded in this examination, the decision unit only reacts to internal and external input from the sensors and it is investigated how the specification of plans, acts and scenarios allows activation or inhibition of perceptual data in the perception process.

The simulation and examination of all of these points is part of the analysis in Chapter 5.

CHAPTER 5

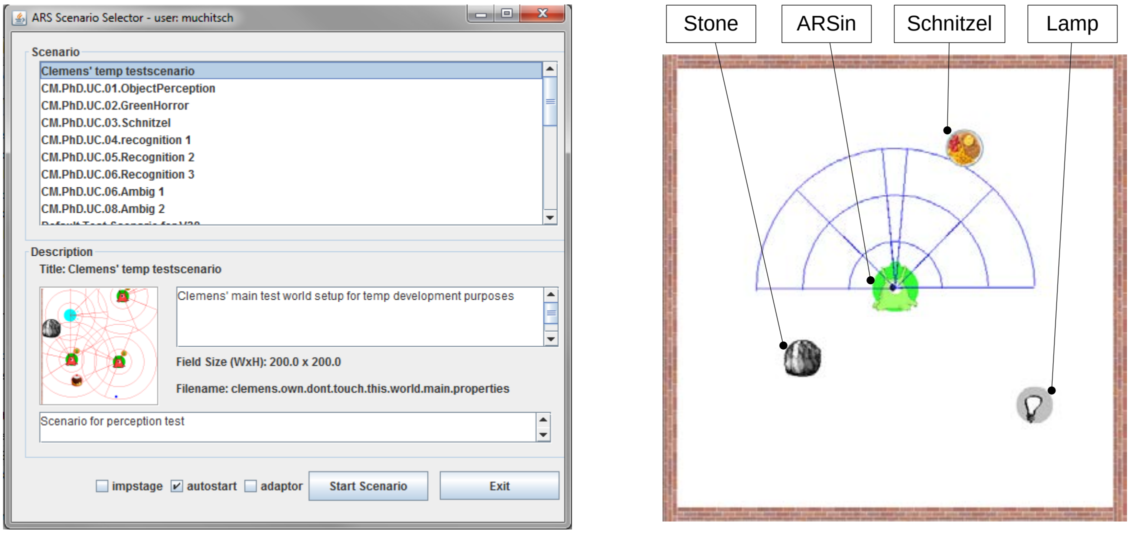
5. Evaluation and Results

In Chapter 3, the technical specification of the final functional model with focus on perceptual processing is developed and discussed. As stated in Chapter 1, the evaluation of a perception framework using an associative memory structure cannot be decoupled from the decision unit layer as the functionality is interconnected with the subjective weighting process of the whole functional model in certain points (see Section 3.4.2). In order to evaluate the concepts introduced and discussed in Section 3.2, it must be shown how the gap between a sensory stimulus and resulting actions can be closed by the Action Perception Cycle. Due to the basic research character of this work this evaluation has to be done by proving the concepts step by step of each module of interest by following the data structures and their changes in the model. The impact on the whole model is discussed by using use case 1 and the alterations of the scenario described in it. In Chapter 3 and 4 the generation of perception data is discussed in theory. Below, the model is tested inside the developed simulation framework by integrating an embodied software agent (as described in Section 4.1) into an artificial life simulation and investigating the behavior of the system and inner workings of the model. Finally, the implemented model is integrated into other simulation as well as real robotic platforms and the investigations are discussed.

5.1 Simulation Setup

The ARSin world simulation framework as discussed in Section 4.2 provides a world setup for the experiments described. The agent is placed in this multi-agent framework, into an environment that assigns tasks to it. The environment itself is based on a physics engine that grounds all objects in it to physical laws. The physics engine itself cannot replace realistic conditions but it provides a first step to testing the behavior of the agents in a physical environment in certain situations. Especially for perception, the interaction of sensors, actuators and the body itself requires a body-world interaction which is provided by the simplified physics laws in the simulation framework. Within the ARSin world, the functionality of the ARSi12 perception system is verified in various scenarios.

Figure 5-1(a) shows the scenario editor where the different scenarios being tested can be selected and modified. A simple world setup is shown in **Figure 5-1**(b). The elements present are the ARSin agent with the visualization of his sensor ranges, various objects to interact with and a solid impenetrable wall surrounding the simulation area.



Clemens' temp testscenario
CM.PhD.UC.01.ObjectPerception
CM.PhD.UC.02.GreenHorror
CM.PhD.UC.03.Schnitzel
CM.PhD.UC.04.recognition 1
CM.PhD.UC.05.Recognition 2
CM.PhD.UC.06.Recognition 3
CM.PhD.UC.06.Ambig 1
CM.PhD.UC.08.Ambig 2

Title: Clemens' temp testscenario

Clemens' main test world setup for temp development purposes

Field Size (WxH): 200.0 x 200.0

Filename: clemens.own.dont.touch.this.world.main.properties

Scenario for perception test

(a) Scenario editor (b) Simulation environment

Figure 5-1: Simulation setup

The ARSin agent (see Section 4.1.2) contains the ARS decision unit and is confronted with various objects, configured by the simulation scenario, to confront the agent with various perceptual and decision making tasks. Each entity of the simulation has a wide range of parameters customizable to the simulation as well as memory entries the agent has access to. In the following a list of basic elements of the setup as seen in **Figure 5-1**(b) is given:

- **Schnitzel** – This represents an edible entity and is derived from the class *clsMobileEntity*. It implements the <<*interface*>>*Flesh* which provides interaction methods eat and bite. When edible entities are partly consumed they are represented as such inside the simulation and removed if totally consumed. The Schnitzel consists of several nutrition types as well as a stomach-oriented desire fulfillment association inside the memory structures of the agent.

- **Stone** – Stones are of type *clsMobileEntity* as well and thus mobile in the simulation but also inanimate entities which do not provide interfaces to be eaten. Attempts to do eat or bite Stones can result in pain as well as moving into a stone with higher force (which is dependent on weight and speed ratios between the two objects).

- **Wall** – Walls are stationary entities which have no possibilities of interaction or movement except for the same impact mechanics as for example stones have.

- **ARSin** – This is the *clsARSin* agent itself as discussed in Section 4.1.2 with the psychoanalytic inspired decision unit applied to it. The agent itself is embodied in this simulated world and actively perceives his surroundings through his sensor systems represented in **Figure 5-1**(b).
- **Lamp** – This entity is derived from the animate type. The lamp is designed with simple internal states which changes the appearance of the object and thus provides interactive mechanics for the perceptual process. In this case the lamp is turned on and off according to an adjustable scheme providing a blinking object.

Additionally several edible objects for interaction have been introduced which provide a variety to scenarios especially for perception tasks. For each entity a set of properties exists which make them highly customizable for the simulation tasks. After the translation of these world properties in the first layers of the sensor system they are symbolized and from there on named stimulus features.

Inside the simulation framework several use cases can be evaluated with focus in different mechanics inside the whole functional model. For this thesis only use cases for perception are of potential interest for this evaluation. These use cases are defined below and their results are discussed.

5.2 Use Case Definitions

The perception-action cycle is evaluated by use cases and different scenarios of these use cases. Every use case presented implicitly tests the functionality of the perception system, as it is a vital system to the whole decision unit, and the interaction with other parts of the functional model. The use cases are used to define criteria that have to be fulfilled as well as the world setup which evaluates how the implemented model recognizes perceived objects. The agent uses the experience with similar objects from the knowledge base to fulfill the perception tasks. In Use case 1 the basic perceptual task as well as the reaction of the agent's decision unit is explored. In the different scenarios following this use case, categorization and interpretation of the various perceived stimulus data is evaluated by changing the agent's experience and influencing internal factors. The scenarios show how uncertain and ambiguous perceptual input is processed in the model.

As the use cases focus on the perceptual tasks no high-level social interaction between agents or cooperation is introduced. The focus is on the interaction between the sensor, actuator and decision unit systems in perceptual tasks. At this stage the basic functionalities of the perception system must be evaluated in order to give input to other parts of the functional model dealing with objectives like navigation or decision making and planning.

In the following the overall perception-action cycle is discussed step by step by using the use case designed for testing the reaction to one edible object. It provides insights how the different tracks work together, with focus on the *Perception track (T6)* and how the agent performs appearance recognition of the object.

5.2.1 Use Case 1 – Perception Cycle Step by Step

In this use case the agent perceives an edible object, a schnitzel in the starting scenario. The hierarchical way of information processing must be verified through the model. The setup includes two objects, an energy source of some kind and the ARSin agent itself, as seen in Figure 5-2 and in the use case scenario setup in Table 5-1.

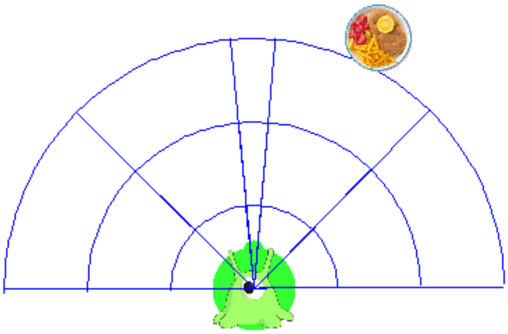


Figure 5-2: Simulation setup Use case 1

The agent is set in the middle of this figure and the energy source schnitzel is on the top right to it. The circles around the agent symbolize the sensor ranges. The agent is started with low values in the bodily stomach system which creates the demand to consume energy sources. The primary task of this use case is to deal with this demand through means of perception and action. The basic set of actions the agent is provided with are turning and moving as well as actions that can manipulate objects like eat. The agent searches actively in the environment to fulfill the internal demands by using the object he perceives in the environment.

Stimulus	Schnitzel		
Stimulus features	TP:Color=brown (1.0), TP:Shape=circle (1.0)		
Activated memory structures	Schnitzel, Cake		
Exemplar features association weights in different experiments	Exemplar	Color	Shape
	Schnitzel	1.0	0.8
	Cake	0.5	0.9

Table 5-1: Starting conditions for the basic scenario in Use case 1

The first action triggered is a seeking sequence in case no energy source can be perceived. Seeking is a randomized call of the moving and turning actions which results in moving forward first. Figure 5-3 shows the possible energy source in the visual field of view of the agent. After the object is detected and identified the corresponding current position of the object is used for movement actions and results in eating the energy source.

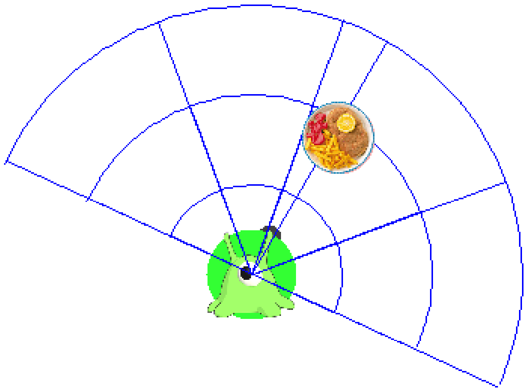


Figure 5-3: Simulation state after agent movement (The black orientation marker visualizes the forward motion of the agent.)

Figure 5-4 shows the internal sensor information of the body of the agent which represents the homeostatic state detected from its blood sugar, stomach tension, internal energy consumption and health status. The initial setting of the use case leads to high unbalance of the stomach oriented homeostatic values which are mapped into drive meshes (DM) as seen in Figure 5-4. These data structures are generated in the drive track and indicate the origin of an internal requirement the decision unit has to deal with. In Figure 5-4 the associated data of the DMs labeled AGRESSIVE and LIBIDINOUS is shown. As discussed in Section 3.4.1 each DM consists of a drive source (which represents the source, organ and orifice, of origin of the DM), a drive aim (resembling the action the DM is aimed at), a drive object (which marks the object that fulfilled the aim best according to activated memory structures) and an affect (which represents the intensity of the internal demand). This process is discussed in detail by Deutsch and Lang [Deut11, Lang10]. For perception the important fact is that the drive track already associated objects (cake and carrot in the screenshot in Figure 5-4) from memory which is demanded to be perceived which leads to drive object priming mechanics as discussed earlier.

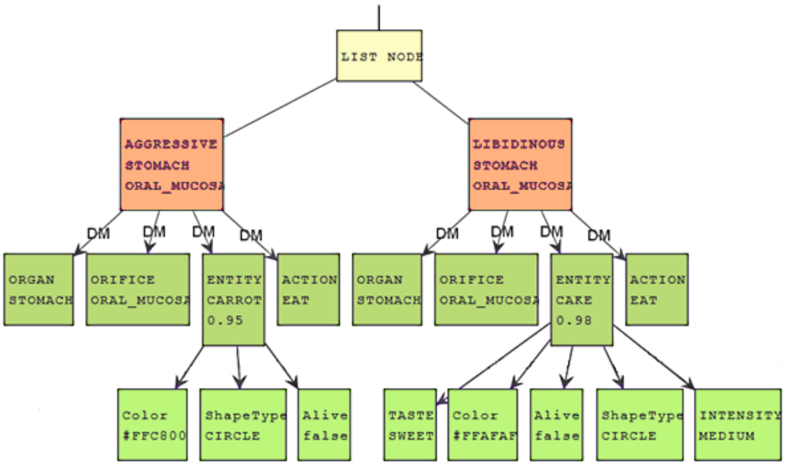


Figure 5-4: Homeostatic (DM) data screenshot of the inspector in the Drive track (T5)

The object in the environment is the so called stimulus and is represented by a set of features detected by the external sensors. The features are dependent on the sensor modality detecting the stimulus and represent for example color and shape information in the visual modality.

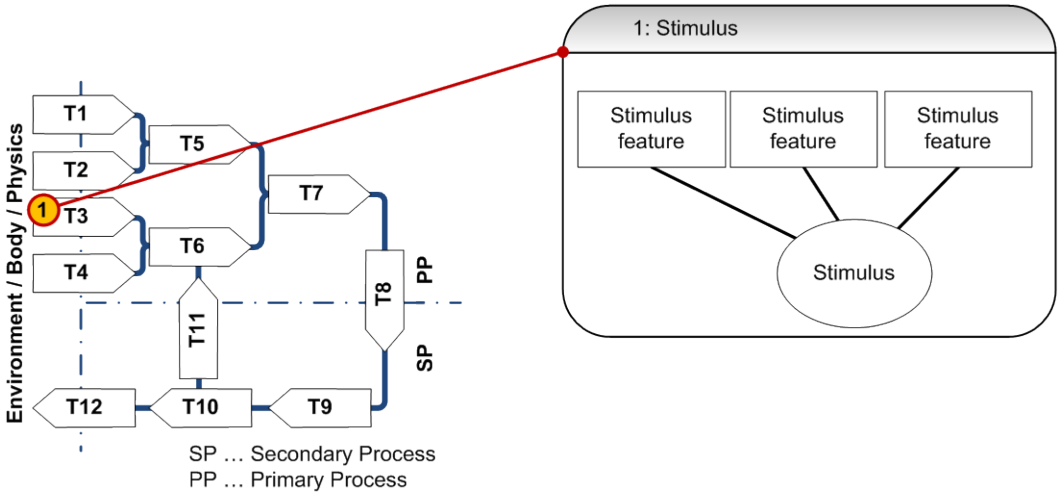


Figure 5-5: Stimulus data represented in the track view of the model

Figure 5-5 shows the track view of the model and the stimulus of the perceivable object in range of the agent's visual field. The stimulus is represented by a set of attributes, or features, which are detected by the various sensor modalities available for the agent. These features are translated into symbols in the *Environment perception track (T3)*.

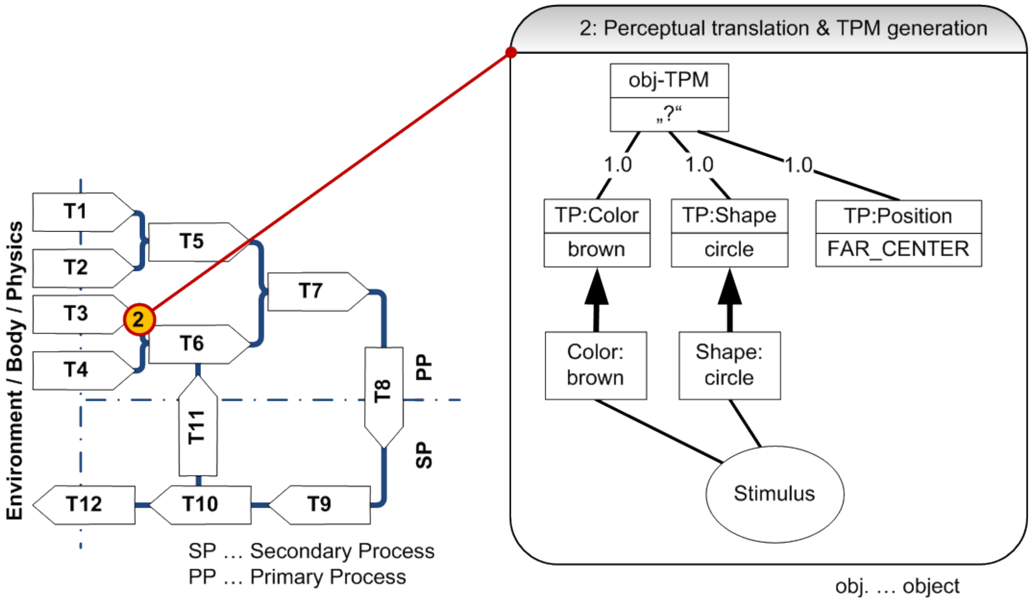


Figure 5-6: Feature representation at the input of the Perception track (T6)

After the *Environment perception track (T3)* the stimulus features are converted into TPs and a TPM representing the stimulus object, the object-TPM, as seen in Figure 5-6. In this step the identity of the object is unknown which is why the identity number is set to "-1" and the name is set to "?" which represents that the object is not compared to a stored object in memory. The visual features of this ENTITY object are represented by the TP:Shape circle and the TP:Color brown (with the underlying RGB values). This object-TPM is forwarded to the *Perception track (T6)*.

In Figure 5-7 the comparison process of the object-TPM (the representation of the schnitzel object) to knowledge representations (exemplars) is shown. Through the sensor system not only feature data is associated to the object but also additional information from the detection process itself like the location of the object inside the sensor ranges. This additional information does not represent the object itself and represents dynamic data dependent on the environment state. This data is not stored for every object as the exemplars only hold data representing them. The data is important for decision making later and thus the static features and the dynamic information has to be separated first which is the task of the first modules of the *Perception track (T6)*.

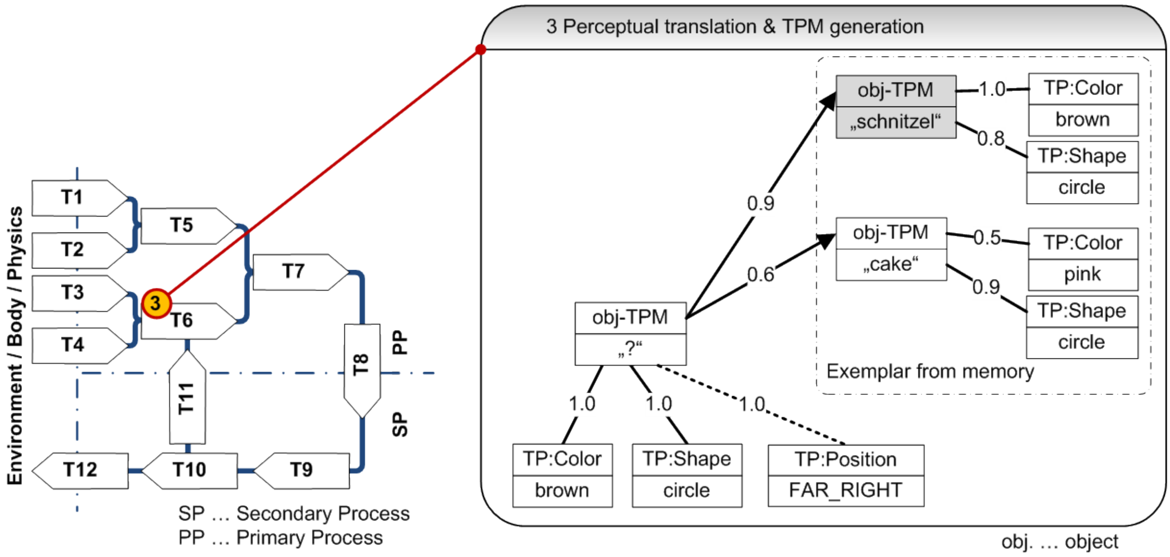


Figure 5-7: Exemplar comparison representation in the model track view

The task of the perception system is to perceive and recognize objects and associate them with memory structures for decision making. Figure 5-8 shows the functional modules and the interfaces of the *Perception track (T6)*. The six modules are External perception (F14), Memory traces for perception (F46), Primal repression for perception (F37), Emersion of blocked content (F35), Libido discharge (F45) and Composition of quota of affects for perception (F18). The modules F14 and F46 have two functional sub-blocks as discussed in Section 3.2 and interfaces to the *Drive track (T5)* and the *Imagination track (T10)*. Module F14 receives stimuli data in the form of object-TPMs from the Environment perception track (T3) and bodily sensor input from the Body perception track (T4)[36].

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[36] Processing of body perception data is not part of this thesis and thus not discussed in detail.

Module F18 forwards the processed perceptual information to the *Defense track (T7)* and further to the decision making modules.

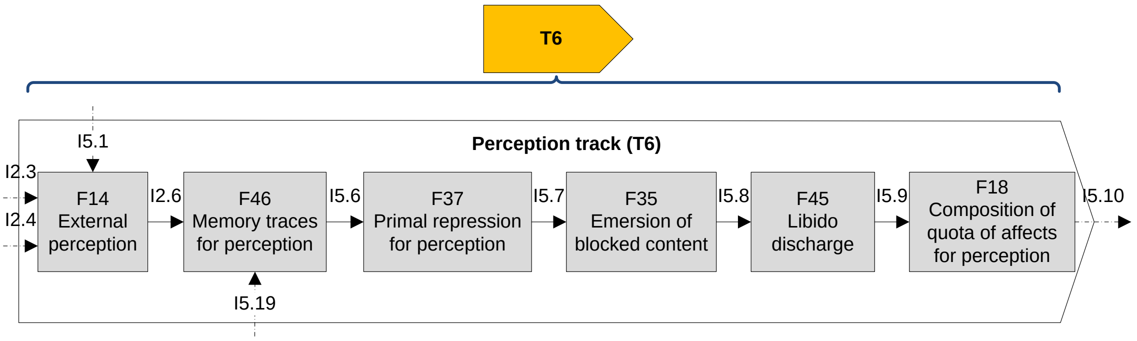

Figure 5-8: Modules of the final functional model – Perception track (T6)

Module F14 receives the raw sensor information from the stimulus objects. In this simple use case it receives one object with color and shape information with additional data like the position of the object inside the visual field of view (only visual sensor information is passed in thus use case). From the external body sensors data about the body itself is also passed through and immediately attached to a new TPM:SELF for later use in the functional model. The features, the perceived physical attributes of the object are converted into TPs with an unnamed TPM to represent the object itself. This temporary object is forwarded to the knowledge representation framework as a search parameter. The input object is compared by using stored data structures which creates a list of possible matches, the list of exemplars. Each required feature of the stimulus is weighted against each exemplar with the particular association weights of the exemplars.

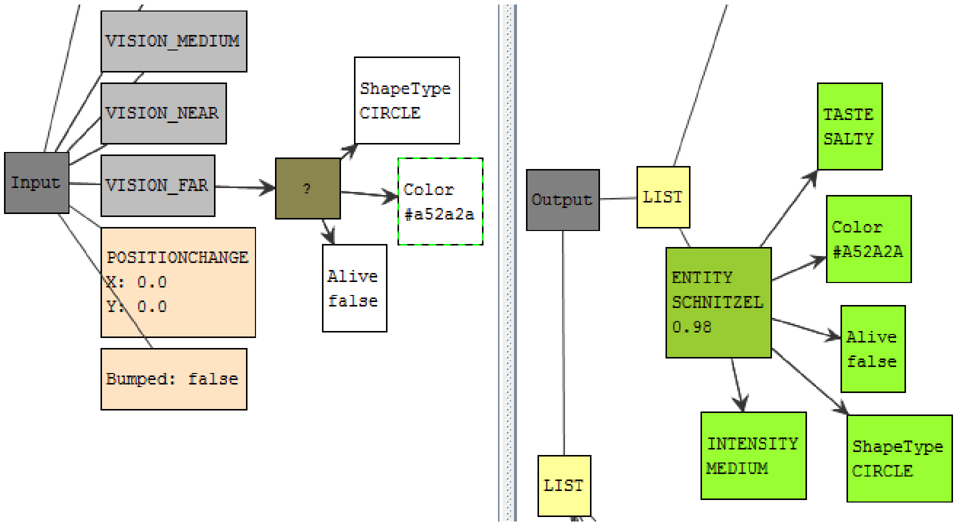

Figure 5-9: Module F14 inspector screenshot input and output of the module

The values of this appearance calculation process are noted for every exemplar and the list is sorted afterwards by their similarity factors. The best match is selected and the unknown stimulus becomes the matching exemplar. In this case the TPM:”schnitzel” matches the stimulus best and is forwarded to F46 as seen in the screenshot in Figure 5-9.

The next module in line is module F46. The recognized object is received and in this module additional information from the stored data structures is activated and associated. This adds previously stored data to the object-TPM. Especially DMs are activated and associated which gives additional possibilities of evaluation of the objects. In module F37 primal repressed content is filtered. Currently this module is not active as no content list of repression object for perception is given by the psychoanalytic advisors. Module F35 associates object-TPMs from the blocked content storage to the list of perceived objects. In this storage objects, previously blocked by defense mechanism filters can become available again for the perception track is their associated affect is high. These objects are candidates to be blocked again in the *Defense track (T7)* but as defense mechanisms are out of scope of this thesis they are not discussed here. The list of recognized object if the forwarded to module F45 where libido discharge for perception is calculated. The agent can generate lust by reducing the tension or affect of a drive. Since the introduction of sexual drives to the model by Deutsch [Deut11, pp.79–85] the perceptual system can reduce the so called libido-value by using the mechanic of the scopophilic drive[37] for every object in the visual field of the agent. This value is calculated and forwarded to module F41 in the next step of the simulation. In the final step of the perception track the collected affects of all perceived objects is calculated and attacked to the root objects, the object-TPMs.

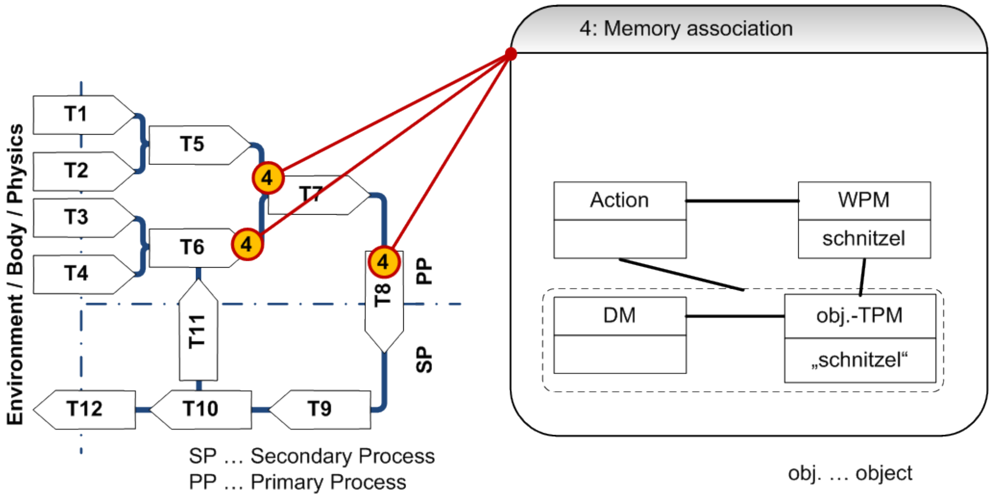

Figure 5-10: Resulting data structures of the Perception track (T6) with additional drive and word presentation data associated

The result of the *Perception track (T6)* is sketched in Figure 5-10. In this image the underlying associated data structures, like the feature TPs, are removed for clarity but they are still associated at this point. From the *Drive track (T5)* the internal homeostatic imbalances represented by drives are also forwarded and both data paths are further processed in the *Defense track (T7)* where filter mechanisms are applied to the data.

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[37] Scopophilic drive refers to the German translation: Schautrieb

Additionally in the *Conversion track (T8)*, where the data from the primary process is translated to the secondary process, template images (TI) are generated for every perceived object with its additional data like the object location. A TI of the current environmental state is composed and secondary data structures (WPMs) are generated from the primary data structures (TPMs). As defined previously fir ARSi12 only one association between primary and secondary data structures is allowed, hence only one match is returned from the information representation system.

The resulting data structures are forwarded to the secondary process where they are ordered by the intensities of their affective state. The next step, the goal deliberation or selection of desire track is processed. This process is discussed in detail by Lang [LKZD10, pp.107–111]. In summary, the desires and demands represent a homeostatic need that has to be fulfilled by the decision making process. For his use case the highest demand is to refill the imbalance in the stomach system. The resulting DMs and TIs are used to find a matching object to satisfy the demand with it. If no object would be present the objects activated by the DMs would, as they are only imagined and not present in the environment, invoke a seeking sequence for these objects making the agent move around in his environment in search for those objects. In this stage of the use case and adequate object is detected and the desired action-object data structures are forwarded to the decision unit modules. The Decision making process decides on the demands which would fulfill the most intensity reduction and the information management searches for acts matching the goal state of this demand. The plan to achieve this goal state is generated by the act’s preconditions, which results in movement actions towards the object and finally in the act EAT, as seen in Figure 5-11, which reaches the goal state of that act.

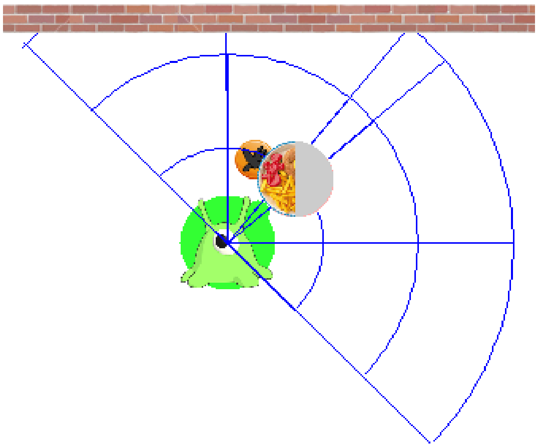


Figure 5-11: Simulation state after agent eating action (The round marker above the agent visualizes the eating action.)

The generated action sequence is submitted to the *Action track (T12)* where the actions of the agent are executed. The generated preconditions and objects inside a plan are forwarded as feedback to the perception track for additional detection possibilities and influences. The action sequence is converted into commands for the actuator control processor the agent which changes the environmental state and closes the perception-action cycle.

Use case 1 shows the feasibility of the realization of the whole perception-action cycle concept in the ARSi12 functional model structure. The external sensor data are converted into primary process data structures and represent perceived objects. After the exemplar search in the stored data structures the similarity of every exemplar loaded is calculated and the object is recognized as the best match. This could lead to ambiguous similarity parameters which will be examined in detail in the following scenarios. The recognized objects are then associated with secondary process data structures and used to define acts for decision making and planning. The resulting actions change the environmental state and close the cycle through the environment. The agent is capable to fulfill the desires and demands of the body by interaction with the environment. With the perception-action cycle inside the functional model the ARSi12 framework is able to provide a full control and feedback mechanism for autonomous agents. The framework further incorporates neuro-psychoanalytic inspired data structures and processing along the cycle and describes the various influences to the whole perception, recognition and action generation process.

5.2.2 Use Case 1 – Perception Scenarios

In the following scenarios the parameters of the basic use case 1 are changed to show influences to the similarity recognition process. Changes to bodily needs, the weights of the stimulus, the number of features present and weights to the associated data structures of the exemplars influence the similarity values and lead to the following scenarios. Table 5-2 shows the parameter changes that generate the alternative scenarios.

Scenario	*Description*
Use case 1, Scenario 1	Appearance recognition and impact of association weights In this scenario different association weights in the memory structures of the agent and their impact to exemplar selection is explored
Use case 1, Scenario 2	Appearance recognition, missing features A feature present at the stimulus has impact on the overall similarity calculation. In this scenario the possibilities to features present but not expected by the exemplar is shown
Use case 1, Scenario 3	Appearance recognition, ambiguous objects When two exemplars have the same association weight ambiguity occurs. In this scenario the outcome of the calculation and the results for the agent are discussed.
Use case 1, Scenario 4	Appearance recognition, modality impact Modalities have an impact criterion associated and the results for appearance recognition are discussed in this scenario.

Table 5-2: Use case 1 – scenario descriptions

The similarity values for every scenario the primary conditions that lead to the different values and the resulting impact on exemplar selection are shown for every scenario. Figures showing the according data structures are presented as well as simulation screenshots to depict the behind processes.

Focus of the simulation is on appearance recognition and the use of associated data structures from the knowledge base. The number of features used significantly changes the impact every feature has to the appearance recognition process thus some restrictions are made to the available number of features. To evaluate the model behind the similarity calculation process in an exemplary but still comprehensible form, two to three features are sufficient. When not explicitly noted the weights of associations are valued with 1. In the first three scenarios impact factors of modalities are irrelevant and remain unused.

Scenario 1 – Appearance Recognition and Impact of Association Weights

Simulation with different association weights of the data structures used for exemplar activation show the impact of features to the appearance recognition process. Additional influences like the impact of DMs or expectations are not taken into consideration at this point. As the premise is that the agents do not have to perceive objects unknown to them, the impact of stimulus features for categorization of exemplars exceeds the ambiguity in this scenario. The impact of different association weights to the similarity calculation process is the purpose of this scenario. Other influences in such a scenario are not sufficient for object identification as it can be seen in the following scenarios. According to psychoanalysis the quota of affect of perceived objects has a maximum value of 0.9 as only ‘primal objects’, the first impression of an experienced object, can reach values of 1. As these object are not currently considered (see the discussion of module F37 in the use case description above) values of 0.9 are the maximum values that can be reached for quota of affect.

In this scenario only visual features of one object are considered with different possible memory structures to show the impact of association weights. In this scenario the agent perceives a green apple as seem in Figure 5-12. After the green apple exemplar is activated amongst other possible exemplars it is weighted and all exemplars are ranked according to their overall appearance weights.

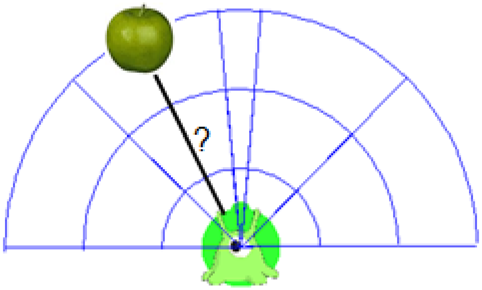


Figure 5-12: Use case 1, scenario 1 setup

The conditions for the different weights are summarized in Table 5-3 and the resulting association weights are shown in Table 5-4. Association weights in these tables are displayed in parentheses after the feature.

Stimulus	Green apple						
Stimulus features	TP:Color=green (1.0), TP:Shape=circle (1.0)						
Activated memory structures	Green apple, cake						
Exemplar features association weights in different experiments	Exemplar	Color			Shape		
		(a)	(b)	(c)	(a)	(b)	(c)
	Green apple	1.0	0.7	0.7	0.8	0.9	0.8
	Cake	0.5	0.4	0.4	0.9	0.9	0.9

Table 5-3: Starting conditions for scenario 1 and experiments (a) to (c)

The simple appearance recognition task was tested by using different association weights in the experimental setup (a) to (c). In the first experiment weights to the two features of the green apple are set relative high, especially for the color. In the second experiment the impact of the color is reduced for both the apple and the cake which results in a lower similarity value for the green apple but still the highest exemplar. Figure 5-13 shows the resulting data structures exemplary for the use case, scenario 1, experiment (a). Figure 5-14 shows the resulting data structures in an inspector-screenshot of the simulation. For the cake the weight for the color is reduced, the impact of the shape to the cake increases and results in a higher value than before.

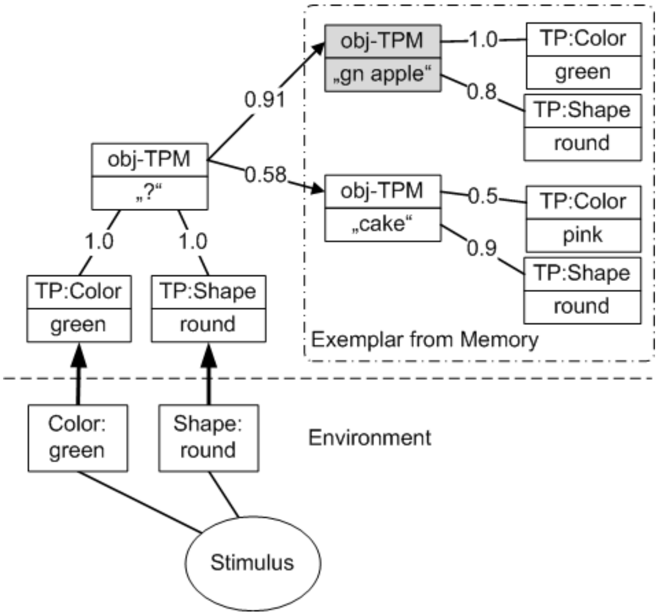
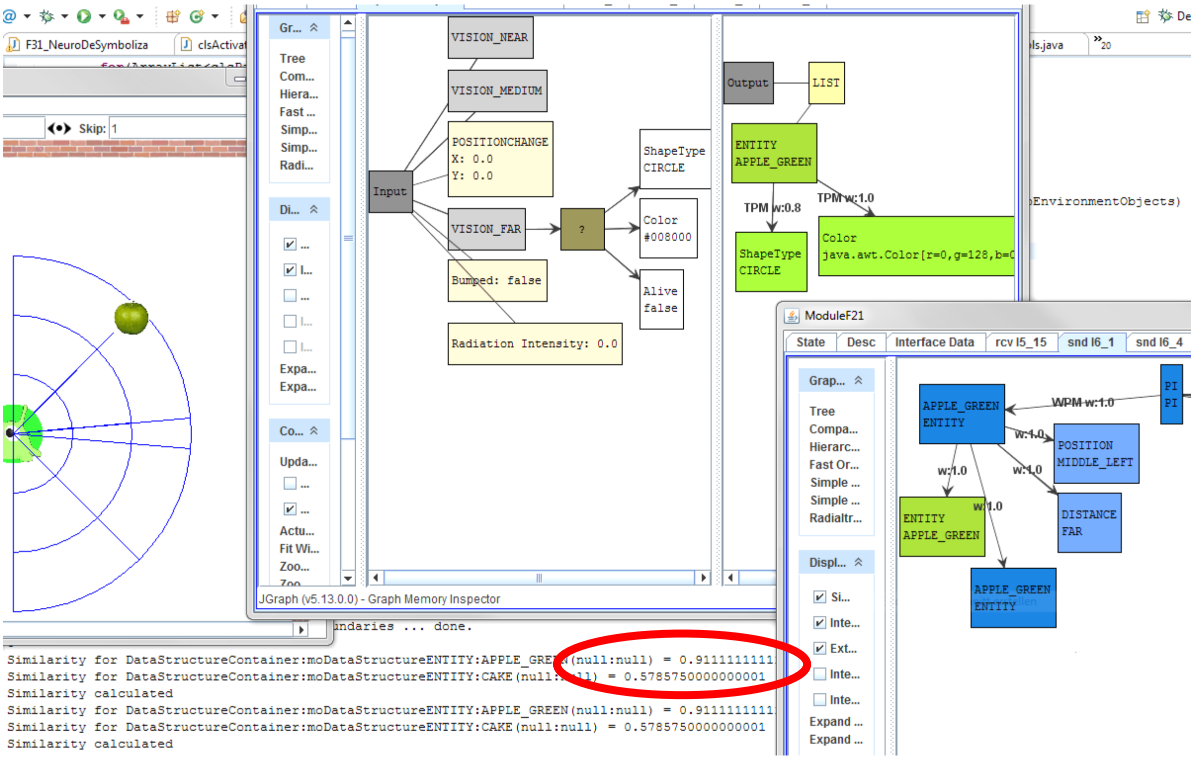


Figure 5-13: Scenario 1 resulting data structures for (a) (gn … green)



```
ndaries ... done.

Similarity for DataStructureContainer:moDataStructureENTITY:APPLE_GREEN(null:null) = 0.9111111111
Similarity for DataStructureContainer:moDataStructureENTITY:CAKE(null:null) = 0.5785750000000001
Similarity calculated
Similarity for DataStructureContainer:moDataStructureENTITY:APPLE_GREEN(null:null) = 0.9111111111
Similarity for DataStructureContainer:moDataStructureENTITY:CAKE(null:null) = 0.5785750000000001
Similarity calculated
```

Figure 5-14: Screenshot inspector data for scenario 1 (a)

In this screenshot on the left the simulation of the ARSin agent with the stimulus object can be seen. In the center of the screen inspector data from module F14 shows the input (left) and the output (right) data structures. On the right side the selected exemplar APPLE_GREEN can be seen with the associated and weighted data mesh. The inspector window on the lower right shows the resulting WPM of module F21 where secondary process data structures are associated. The lower part of the screenshot shows the similarity calculation values of the APPLE_GREEN and CAKE exemplars (highlighted in red).

The same relationship to association weights and the resulting similarity values can be seen when the weight of the shape is changed as in experiment (c). Here the results show that the green apple is close to being removed as the topmost best match in this scenario. It also shows the flexibility to the associative memory structures and that the similarity values are dependent on subjectively weighted memory entries.

Similarity values	Green apple	Cake
Experiment (a)	0.91	0.58
Experiment (b)	0.75	0.62
Experiment (c)	0.45	0.35

Table 5-4: Scenario 1 results

The experiments show that high feature association weights give higher impacts to the appearance of objects. They are more ‘expected’ by the memory to be perceived and thus give high negative impact to the similarity values when they are missing. To balance the impact of one missing feature the perception of these objects are tested in scenario 2.

Scenario 2 – Appearance Recognition, Missing Features

As already mentioned, the ARSin agent can only perceive objects known in memory structures. The same perception mechanics have to apply when additional features are presented to the similarity calculation process. In such a case the agent has additional information from the stimulus present which has a high impact on the resulting similarity values as this scenario applies. The same exemplars as in scenario 1 exist in the agent memory as Figure 5-15 and the starting conditions in Table 5-5 shows.

Stimulus	Green apple with one additional feature		
Stimulus features	TP:Color=green (1.0), TP:Shape=circle (1.0), TP:Size=small (1.0)		
Activated memory structures	Green apple, cake		
Exemplar features association weights	Exemplar	Color	Shape
	Green apple	0.7	0.8
	Cake	0.4	0.9

Table 5-5: Starting conditions for scenario 2

The agent expects to perceive objects of type green apple or cake with only two features associated and thus the impact of the third missing feature of the stimulus has a high impact on the similarity values.

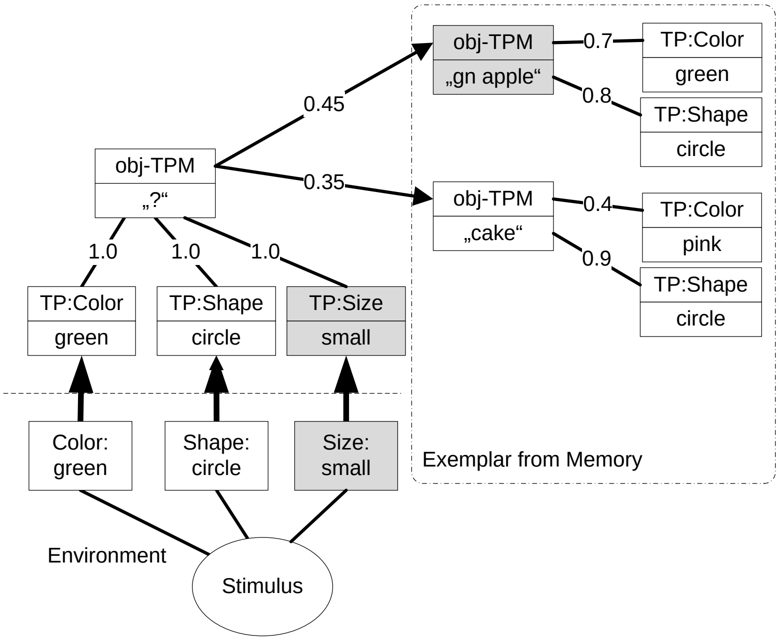


Figure 5-15: Scenario 2, resulting data structures

The association values are set to the same weights as in experiment (b) of scenario 1 where the resulting similarity values were 0.75 for the green apple exemplar and 0.62 for the cake exemplar.

Similarity values	Green apple	Cake
Scenario 2	0.45	0.35

Table 5-6: Scenario 2 results

The results, as seen in Table 5-6 show that the values for the green apple are lowered to 0.45 and to 0.35 for the cake exemplar. The results of the scenario 2 show that features missing from the stimulus in the exemplars have an impact on the similarity value calculation and the subjective certainty in choosing exemplars is lowered.

Scenario 3 – Appearance Recognition, Ambiguous Objects

It has been stated that the ARSin agent can only perceive object known to it. To be more precise only objects can be matched if those exist in the associative memory structures of the agent's memory. When a stimulus is to be perceived that has the same features as multiple exemplars this creates ambiguity in the similarity values for those exemplars. In the following scenario the limits of appearance recognition based on similarity of features is explored. As the selection of the exemplar is based on a best match the mechanics of the perception path always select one exemplar. Right now as the list of exemplars is sorted by similarity values and the first one is selected even if there are more than one best result. The selection process is bound to return at least one solution for the recognition process. This mechanic shows the limit of the implementation for certain scenarios as it is right now and gives insights for further investigations.

Stimulus	Green apple				
Stimulus features	TP:Color=green (1.0), TP:Shape=circle (1.0)				
Activated memory structures	Green apple, green sprout				
Exemplar features association weights in different experiments	Exemplar	Color		Shape	
		(a)	(b)	(a)	(b)
	Green apple	0.7	0.7	0.8	0.8
	Green sprout	0.7	0.7	0.8	0.7

Table 5-7: Starting conditions for scenario 3

For this scenario (see Table 5-7) an object matching the same features of the green apple has been introduced, the green brussels sprout. For perceiving the green apple two exemplars with ambiguous features exist in the agent's memory. In experiment (a) they get the same association values which results in the same similarity values, as seen in Table 5-8.

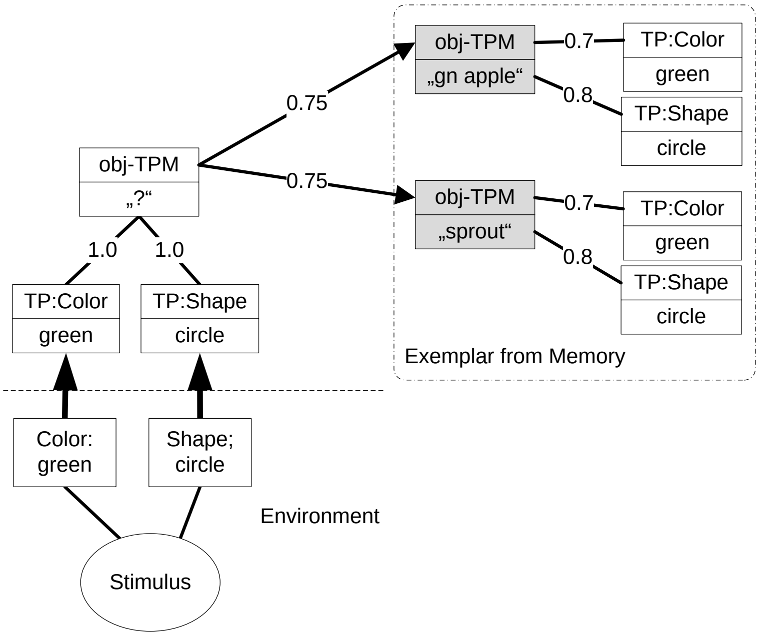


Figure 5-16: Scenario 3, experiment (a) resulting data structures

For experiment (b) the association values have been slightly changed to reproduce the impact of association weights as seen in scenario 2. The results here show that the impact of one feature weight changed by 0.1 lowers the similarity by 0.05 which is expected by the fact of two features present.

Similarity values	Green apple	Sprout
Experiment (a)	0.75	0.75
Experiment (b)	0.75	0.70

Table 5-8: Scenario 3 results

The agent in this scenario needs additional information to reduce the ambiguous results from the similarity calculation values. This is reached by the various described influences as described in Section 3.4.2. The most important mechanic here is that the agent needs more information about the object which can be reached by focusing on the object (see below), which can increase the number or quality of features present in the perceptual field. The same result is achieved by the decision unit when the focus is on one object and the actions to move closer to the object are executed.

Scenario 4 – Appearance Recognition, Modality Impact

For the scenarios discussed previously the association weights of features of the stimulus itself have been set to 1.0. This is true for the visual modality as features in the field of view can be matched with high certainty to one object. When other modalities are added the additional information, especially with multiple stimulus objects present, cannot be associated to an object directly. In this scenario the limits and impact of association weights for the stimulus itself are explored by adding features from another modality as proposed by the introduction of the modality criterion in Section 3.4.3.

Table 5-9 shows the setup for scenario 4. The use case is extended by adding smell features through the olfactory modality. In the first experiment (a) the green apple and the sprout are placed in the visual field and olfactory field of the agent. The additional feature is only present from the apple stimulus.

Stimulus	Green apple, green sprout						
Stimulus features	TP:Color=green (1.0), TP:Shape=circle (1.0), TP:Smell=sweet (0.5)						
Activated memory structures	Green apple, green sprout						
Exemplar features association weights in different experiments	Exemplar	Color		Shape		Smell	
		(a)	(b)	(a)	(b)	(a)	(b)
	Green apple	0.7	0.7	0.8	0.8	0.9	0.9
	Green sprout	0.7	0.7	0.8	0.8	-	-
Modality criteria activation value	Visual = 1.0, olfactory = 0.75						

Table 5-9: Starting conditions for scenario 4

While the agent’s environment has changed in comparison to the other use cases the basic aim has not. It is still the aim of the agent to reduce homeostatic imbalance by identifying an appropriate exemplar. In this case there are two possible energy sources available but as seen in scenario 3 the visual features present the agent with ambiguous similarity values. The purpose of experiment (a) is to introduce another modality to the process and stimulus feature weights to the calculation. In contrast to the visual features which are weighted with 1.0 the smell is added with 0.5 as there are two possible objects the feature can come from and the perception of odor cannot be assigned to one stimulus alone. The uncertainty of the stimulus feature is represented by the weight it is associated with. The stimulus processed is the green apple, the sprout acts as a modality distraction in this setup this is represented in Figure 5-17 by adding the second stimulus with dotted lines.

The impact to the stimulus and the resulting TPs can be seen in Figure 5-17. In the similarity value calculation the collection of the visual features and the olfactory features have to be separated as their summary has to be weighted separately for every modality.

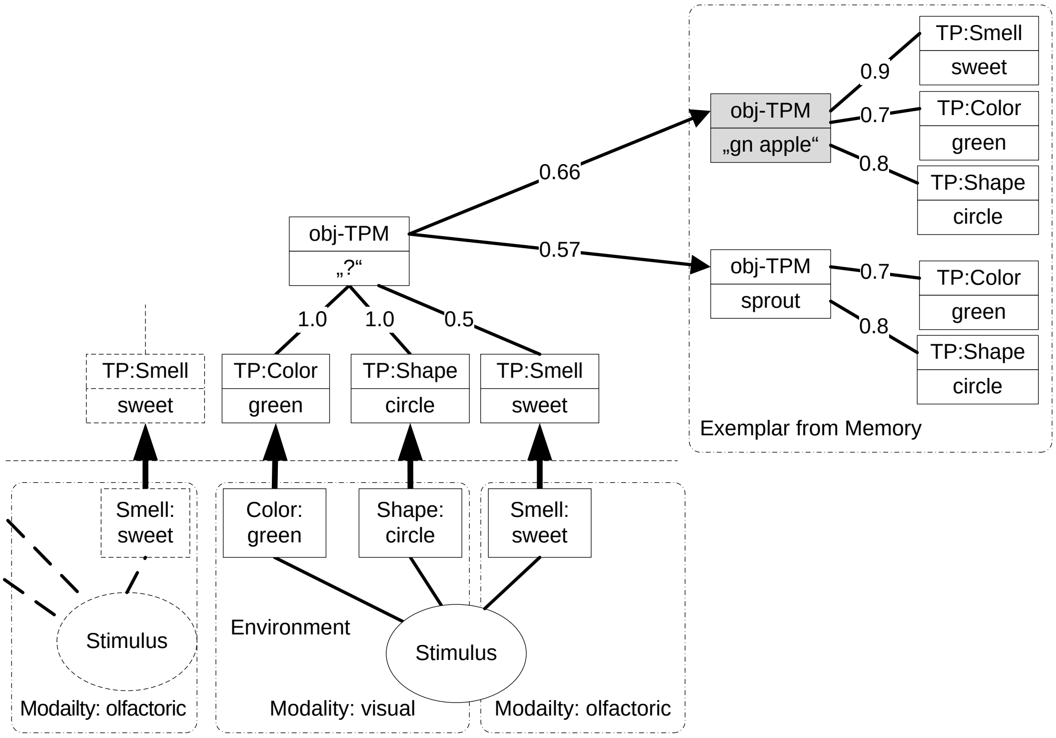


Figure 5-17: Scenario 4, experiment (a) resulting data structures
(second stimulus added with dotted lines)

The resulting weights are displayed in Table 5-10. The calculation in experiment (a) is without modality criterion which results in the green apple being the best match with 0.66. The sprout reaches a value of 0.57 as the smell feature is not expected. The uncertainty of the added smell feature is taken into account which reduced the similarity value from scenario 3 for these exemplars.

Similarity values	Green apple	Sprout
Experiment (a)	0.66	0.57
Experiment (b)	0.90	0.57

Table 5-10: Scenario 4 results

In experiment (b) the modality criterion of 0.75 increases the results for the green apple exemplar as modalities are calculated separately and the match of the olfactory feature is taken into account.

The value for the sprout does not change as the olfactory feature is not expected and thus does not increase the outcome. This shows the impact of modality parameters if the exemplar is calculated separately for every modality.

5.3 ARS on the NAO Platform

Another experiment to extend the capabilities ARS framework is described in this section. It includes the first implementation of the framework into a real world application [DBZL11]. The aim of this experiment was to show the feasibility of using the ARS control unit in a real world humanoid robot robotic platform, the NAO by Aldebaraan Robotics [1] in this case. First the applicability of using the robot body as input for the bodily needs (Drive track) was evaluated. The ARSin World framework is specifically designed to decouple environment and body from the core decision unit. This was created to compare different body and decision unit implementations to another inside the same environment simulation, respectively interface different kinds of bodies with these decision units. The decoupled interfaces allowed the connection to the real robotic body and the test of the decision unit on the NAO robot.

The robot itself is controlled by the framework NAOQi which provides high level access to motion and movement controls as well as direct access to all sensors and actuators. To test the implementations before the real world test the simulation framework Webots is used (see Figure 5-18).

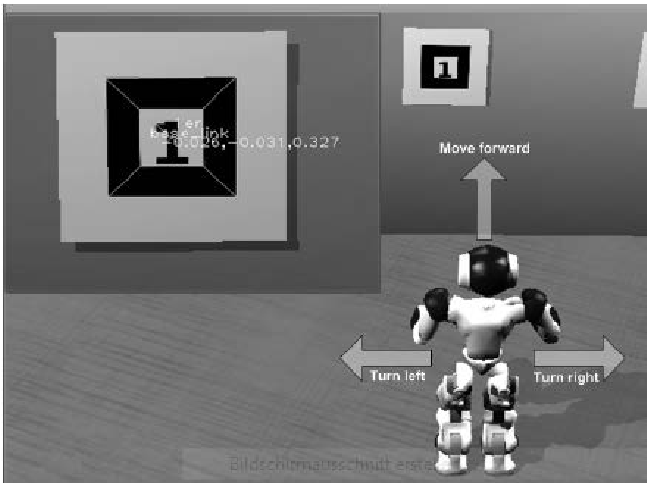


Figure 5-18: NAO Webots simulation [DBZL11]

For the experiment performed [DBZL11] the ARSin agent body was replaced by a Python-proxy. The proxy was used to provide interfaces to the *clsARSin* agent as other body implementations. This path was chosen to limit the changes to the decision unit itself. The simulated world was replaced by the real world and to bypass the object recognition problem, as the purpose of the experiment was to test the body integration, markers were used to represent object for the robot to react to. The visual sensor ranges were translated into the visual field the agent normally has so the changes to the perception track of the decision unit could be small.

The system was configured to match the setup of Use case 1, where the aim of the agent is to overcome bodily imbalance by interacting with the surrounding environment. Next to the Webots simulation the applicability of the cognitive framework was tested on the real NAO. The results show the first realization of a decision unit inspired by psychoanalysis on a humanoid robotic platform and thus the first real world application. The robot was successful to accomplish the same results as described in Use case 1 above within a laboratory environment.

The experiments show a comparable behavior to the one observed in the simulation when the differences between biped locomotion and two wheeled locomotion are neglected. For future work the rich internal system demanded by the ARS framework has to be recreated for the biped robot to form a real world interaction between body and decision unit with feedback through the environment. For this the high-level sensor command API of the robot has to interact with the lower layers of the functional model.

5.4 Discussion

Extension to the psychoanalytic inspired technical model of the human mental apparatus, especially the perception system of the decision unit, was approached by using a top-down design process. Step by step interdisciplinary concepts were transferred into technical feasible terms. The resulting perception-action cycle model describes the information flow of the perception system distinct from its control functions. In the results this step by step approach was reused to give insights how the implementation of the model affects the perception data in the perception process.

The results are generated by using use cases in a proof-of-concept approach where the implementation is evaluated by using scenarios which address the functionalities that are investigated. First, the perception-action cycle and the resulting data structures are discussed for the focus of this thesis, the perception track, as well as the whole cycle of the decision unit. Step by step the function of each module having an impact to the perception process is explained in a single object recognition scenario. It is analyzed what changes to the data is made within the functional module as well as what resulting data is forwarded to the next module.

The following use cases explore the mechanics of the appearance recognition process by evaluating the results in different scenarios. In the ARSi12 model a clear distinction between stored knowledge and functional modules is made. In the use cases this underlying theory is observed by inspecting the input and output data of the functional modules in differentiation to the functional descriptions of the modules.

The results of the use cases showed that the implementation of ARSi12 covers the conversion, perception and recognition of sensor data up to the execution of actions based on the perceived environment of the agent. They show that the implementation works according to the developed model and that the modules interact with the existing systems of the simulator along the perception process. The proposed model introduces associative data structures that match the requirements from sensor features to knowledge representations and meshes of perception data that are used for planning in the decision unit. The clear distinction between primary and secondary data structures shows the possibilities of data manipulation to logical relations as proposed by the model. This differentiation makes low level sensor feature manipulation possible with regard to the primary process while in the secondary process the associative data structures can be optimized to logical relations for planning and scenario recognition. The implementation of association weights in conjunction with different types of associations between data structures leaves options for optimization and other concepts for future iterations of the functional model.

The described appearance recognition and possible influences to the process adds stability to the object recognition process to potentially conflicting perception tasks. The provision of conflicting data structures is an important aspect to the model as further development can extend the knowledge base without breaking the recognition process.

The performed experiments are one step of the modeling process as described in Section 1.4.2. The review of the gained insights of the implementation of the model in conjunction with the psychoanalytic experts will be taken into account for the next iteration of the model. In this regard the density of the functionality for modules F14 and F46 has to be reviewed as they essentially process inputs from different parts of the model. It should be considered if these two modules need to be split into separate modules. This would also improve the clarity of the implementation inside the modules.

The last section of this chapter describes the first application of the functional model to a real world robotic platform. Up to some extent it was possible to show that the decision unit itself can be used in the real world robot NAO. The limits of the robotic body have to be overcome by introducing a rich simulated body with feedback to the robot itself and the perception system as well as the actuator system needs a framework to translate the data of the model to full extent.

To conclude, the introduced concepts of the ARSi12 implementation proved useful. The framework represents the first implementation that realizes principles of human-like perceptual information processing in a technical functional model. The implemented framework allows extension of the model by future findings and leaves space for improvement of performance. The interdisciplinary work resulted in a fusion of the ARS decision unit and psychoanalytically inspired perceptual data structures in a cycle model describing the interaction of data from sensor features to actions.

CHAPTER 6

6. Conclusion and Outlook

In a top-down modeling process the goal of improving and extending the ARS functional model was reached especially for the perception system of the decision unit. The interdisciplinary concepts were investigated and transferred step by step into a technical functional model. The resulting ARSi12 framework incorporates perception mechanics and influences to the perceptual information flow distinct from its control functions to the ARS control unit which is based on psychoanalytic concepts. In this chapter, after the conclusion and discussion of the introductions of the ARSi12 framework to the functional model, future tasks are worked out as well as perspectives for project.

6.1 Discussion of the Key Results

Interpretation and transfer of theories between different scientific disciplines is challenging but common for research work in the area of AI. Incorporation of bionic or neuroscientific concepts to AI in a general purpose control system is one of the attributes of the young scientific field of AGI. Research in that specialized field of AI offers benefits in obtaining another point of view to an existing problem by learning from another science discipline. The biggest problem of researcher lies in the incorporation of models where they are not experts in the field without proper feedback and understanding of the other concepts. This challenge is even bigger when engineers are faced with a part of science where another form of scientific language is spoken. Without the expertise in the field a correct implementation cannot be achieved. This is especially true for psychoanalytic theory.

In the project ARS the challenge is faced by incorporating experts in the field of psychoanalysis in the development team, which helps to avoid inconsistencies in the translation process of the original theory. Another key aspect is that the theory translation and modeling part of the project is clearly separated from the simulation implementation. The presented framework ARSi12 was developed following these guidelines and modeling process.

The presented architecture is based on results generated by previous dissertations in the project ARS (e.g. [Deut11, Lang10, Pale08, Veli08, Zeil10]). This provides the model in this thesis with a clear concept of psychoanalytic theories like drives, bodily homeostasis, planning and information processing for decision making in the primary and secondary process.

Based on the role of drives and the body, the influences to the perception process in the functional model were investigated and incorporated in the resulting perception-action model. The presented model is derived step by step from the basic concepts provided by psychoanalysis and grounded in interdisciplinary work of neuro-psychoanalysis. From the identified basic perception-action loop model which makes the connection even to other sciences like neurology possible and intermediate model was developed with the psychoanalytic functional model as basis. New and updated concepts to the intermediate model were presented which lead to the next iteration of the modeling process in a top-down approach. The resulting model is the final functional model of the perception-action loop incorporated in the full functional model of the mental apparatus.

The implementation of the model results in the ARSi12 framework which is realized as an artificial life simulation with multiple virtual embodied autonomous agents acting in a world with simulated physics. In this test-tool use cases based on definition of the psychoanalytic advisors are created to expose the agents with an environment they have to react to. By analysis of the behavior and inspecting the reasons behind the behavior insights on the model can be extracted to refine the model and prove the underlying concepts. Key results are shown by exposing the agents with objects to perceive in different scenarios which show the inner workings of the model.

Finally an alternative implementation or extended implementation of the functional model to the field of robotics is realized to prove the flexibility of the framework and investigate future improvements for the next model and implementation cycle.

6.2 Recapitulation of the Research Considerations

In Section 1.2.2 research considerations or statements were formulated. These statements are revisited after reviewing the results of this thesis along with additional insights to research gained by this work.

The first two statements deal with the assumption that perception is an active process. In the light of the model based on psychoanalysis this assumption holds true. The interdisciplinary research on perception discussed in this thesis shows the model of a cycle between the decision unit of an agent and the environment itself. The various influences to perceptual data identified in this thesis further support the active interaction of the whole functional model to the perceptual process. Although the stimulus from the environment is the starting point for appearance recognition of objects subjective influences like learned knowledge or need of the body have great influences to the outcome of the recognition process.

In this thesis, the use of associated data structures shows how adaptive this form of knowledge representation is even for future improvements, as discussed in the next section. These data structures are individually developed in real life and even if learning mechanisms are not part of the model right now the possible individual parameters possible for the ARSin agent show how flexible the perception process is for the different use cases that were tested. It was also shown that the individual state of the body is a strong subjective influence and even can distort the results of appearance recognition up to some extent.

What the results show is that the different mechanics of a psychoanalytic inspired decision unit cannot be looked at separately as they influence each other and a look at the whole system is needed to model the perceptual process. This is especially true for the separation into primary and secondary processing. The different rules and mechanics of those two processing parts of the mental layer have to be incorporated in to modeling and implementation of the function module inside them, but when it comes to decisions and actions based on perceptions the whole process cycle has to be investigated.

The feasibility of the translation of psychoanalytical concepts to a technical model has already been proven by pervious dissertations in the project ARS. The proposed model in this thesis was approached in a top-down modeling process following the modeling process of the project ARS and this process has been continued until the functional description of each single module could be implemented by an engineer. This process showed points of improvement to the model where the descriptions have not yet reached the desired granularity as discussed further in the next section.

The results in this thesis were reached by the execution of use cases in an artificial-life simulation. This simulation platform proved to be a good platform to evaluate the outcome of every module in the model implementation as well as a setup to expose the ARSin agents in different scenarios where interaction with multiple objects is possible. In this thesis it is shown that for the agent itself it makes no difference if perceptual information is coming from the simulation itself or other applications even a real robotic platform. The agent itself subjectively recognizes objects according to the parameters and knowledge he has access to without differentiating where the sensor information is coming from. In this regard the extension of research into the topic of believable agents will be the next step for the ARS project.

The human mental apparatus with based on psychoanalysis has to incorporate the mechanics of drives and affects. Perception is an integrative part of the mental apparatus and thus these concepts interplay with the model of perception. A human like decision unit without a model of the mental apparatus is not possible. A model of human like perception without this model is also not possible. Thus the interaction between the perception model inside the model of the mental apparatus is an important part executed this thesis.

The work on this thesis showed that without a layer between the mental apparatus and the environment that incorporates symbolic translation perception in real world applications would not be possible. This neuro-symbolization layer, even though theoretically described by Velik [Veli08], remains an open research issue carried out by the ARS project. In order to integrate the ARS model into possible multiple real world applications the proposed concepts in this thesis have to be taken into account for the neuro-symbolic layer realization.

The model proposed in this thesis is designed to be extensible for future work and to match models from different sciences to the perception-action cycle. The prototype implementation is designed to be extendable for other applications, sensor systems or simulation environments. A prototype implementation like this uses a general approach to be extendable and is not optimized for processing speed. The focus is on a clear implementation of the functional model with capabilities to inspect the inner workings of the model during runtime. It presents the base for future improvements of the model and performance in the upcoming iterations or the framework.

The model and implementation presented in this thesis showed the requirements to perception in the whole cycle from sensor values to decision making and resulting actions. Special attention was turned on the feedback mechanisms between the different parts of the functional model to the perception framework. The ARSi12 framework is a base for future research works in the ARS project and perception mechanics in the model.

6.3 Future Research Work

The aim to create a technical model of the perception to action process inside the bionically inspired decision unit is reached with this thesis. The ARSi12 framework as a prototype implementation represents possible tasks for future research work. These topics are summarized below and represent focus points for the next stage of the project ARS.

Feedback from the Functional Model to Feature Extraction

Up to now the feature extraction[38] of incoming perceptual stimuli in the perception framework is a one-way process. With the introduction of multiple modalities and other sensor systems in the future the certainty for a feature to be attached to an object can become ambiguous. Future work in this topic could be done by defining a feedback loop between the mental layer of the functional model and the layer closer to the body to enable recursion which can be used in body perception. In the same loop data from the exemplar selection process could be fed back to feature extraction. In this way a missing modality (or feature) present at the selected exemplar would be used to influence the feature extraction process in the next cycle. Features that could not be matched in the first cycle could be candidates for the next loop. In this process a similarity criterion to the stimulus itself could be introduced which would improve performance and recognition stability over multiple steps.

Use Saliency for Investigation Actions

High salience in the olfactory modality is not directed right now if not matched with the visual modality on the same object. This leaves the agent with ambiguous feature weights for the recognition process which lowers the exemplar appearance values. In order to improve the perception process, actions to investigate low association weighted stimuli would be needed. Intensity values are uniform right now throughout the perceptual field of the respective sensor so in

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[38] The term feature extraction is used to represent the perceptual process of extracting attributes from an object for further processing.

order to make object-investigation actions possible the vicinity to an object has to have an impact to the intensity. This can be reached by introducing several segments of perception like in the visual sensor to other sensor modalities. Also the perceptual input before an object is recognized has to be saved in a perceptual memory or the intensity values of a feature have to be associated to the resulting TPMs for comparison between simulation steps.

Feedback Track for Emotional Reactions on the Body

The insights of the use cases showed the possibility for a feedback path to the body. This data path shows could be used for emotional reactions in the framework. In addition to these reactions on the body psychoanalysts propose some reaction on the sensor and actuator system as well. The same proposed feedback path could be used to alter the sensor system. This would make it possible to influence the perception process by a mental state and make described mechanics like the tunnel vision possible. The introduction of this mechanic can be used to explore these feedbacks to the perception process.

Use a Criterion to set the Subjectivity or Objectivity Perceived Objects

In Section 3.4.3 the introduction of a criterion to set if the agent is recognizing object more objectively was discussed. In the ARS model and implementation the addition of personality parameters for every agent is planned to set several values which can impact the behavior of the agent or how data is processed in the functional modules. By setting a minimum value where the agent is able to select an exemplar it can be examined what the agent has to do if no exemplar could be selected below this threshold. The proposed mechanic would make the agent aware of objects in the secondary process which have not been recognized and result in investigation actions and can be the first step to perceptual learning mechanisms. In order to implement such a mechanic the side effects to exemplar activation have to be investigated further. In the same set of personality parameters if the impact to different modalities would be introduced this would create the possibility to make one agent rely on a specific modality over another one.

Integration of Psychic Intensity to the Appearance Recognition Process

Psychic intensity is a value derived from the mental activity of the decision unit and is used in several parts of the model to limit the calculation time of one module to free resources for others. For the perception process psychic intensity is right now only used to limit the number of exemplars returned by the search mechanisms to reflect limited resources for the perception process. The intensity value could also be introduced as one criteria of the similarity activation function by introducing a best guess mechanic. In that way already identified object-TPMs feed backed from expectations would get higher meaning as they do not consume this intensity value again and make the perception process rely on previously recognized objects. This would reflect the mechanic described in psychoanalysis that human perception is lethargic when it comes to new objects from perception when the energy is needed elsewhere. To do this the proposed mechanic has to be added to the exemplar rating process by introducing a psychic intensity criterion in the activation value function.

Spreading Activation of Memory Data Structures

In the current implementation exemplars are only searched and matched by their direct association of features. Conjunctions and disjunctions of secondary process data structures are already implicitly integrated through different types of associations. Through features or logic associations object TPMs are already associated one to another. In addition these associations could be used to activate other exemplars in the vicinity of the object searched through features. Future work on this topic should be done in combination of the spreading activation mechanic which uses intensity values to activate other objects of the memory mesh structure. These objects can then be used to match exemplars which might not use all features the stimulus expects but could overcome ambiguity by identifying a group of objects which the stimulus is similar to. This can also be used as input to a learning mechanism where a new object is identified by his similarity to a group.

Introduction of Partial Feature Match

For ARSi12, presented features of a stimulus are binary matched. If an object feature matches the exact stimulus feature the similarity is calculated. But features in the real world often do not match binary as the image of the object can be distorted or the feature could not be matched to a feature type. For ARSi12 this binary shortcut to the simulation was introduced. This is possible for the simulation as the required data can be detected with high certainty. However in order to integrate the ARS model in a real world application, as the experimental setup with the robotic platform NAO showed, partial feature matches have to be introduced to the model. The proposed first concept is that for example oval shapes are to some extent also round shapes and thus could be associated to a stimulus but with lowered certainty. These values have then to be calculated in the appearance recognition process by incorporating this feature match factor. This higher granularity in conjunction with the described spreading activation process and grouping of features can become an advantage for the recognition process especially when aiming for real robotic applications.

Learning of Drive Satisfaction

The feedback of drive satisfaction in the ARS model is through the body alone. This leaves the agent without the possibility to reflect if using an action on an object actually had the impact proposed by the data structures. In order to introduce a feedback or learning mechanism for drive satisfaction the planned action with the object aimed at has to be present in the primary process. The proposed solution is to use the data fed back to the primary process through module F47 as one input and the actual drive satisfaction as the second one to match the actual satisfaction with the proposed one and change the association weights accordingly. Another possible soloution is to use the input from the body perception track to identify what actions have been executed, match them with the recognized object and use this again as a feedback mechanism for chancing the proposed affect values in the stored DM structures.

Somatosensory Feedback to Decision Making

During the work in this thesis the SELF object was introduced as the single instance representing information about the agent itself. The association of data from the body perception track is not optimized regarding the outcome of associated data structures and the use of them throughout the model. The advantages or disadvantages by using the data collected under the SELF object have to be evaluated further before identification of executed bodily actions can be associated to it. Another extension would be to store the SELF object in a temporal storage and not create it new for every simulation step as this would make it possible to detect changes to the body and detect actions the body is executing. Hence a temporal storage has to be introduced as buffer for the upcoming simulation steps. After this extension to the model is implemented the SELF object can contain somatosensory feedback about the agent's bodily vicinity which then can be used in decision making for planning and goal selection. In order to achieve this implementation the body perception system also has to be extended by additional sensors that provide the perception systems with data to recognize the action or somatosensory state (e.g. movement, eating, proprioception) the body executes or is in.

Defense Mechanisms for Perception

Defense mechanisms have a high impact to the decisions the agent takes and the objects it can perceive. For the implementation in this thesis defense mechanisms were not included. This is not because defense mechanisms are not intended. They are implemented to a certain extent and were deactivated to simplify the decision making process after object have been recognized as they are not the focus of this thesis. The defense mechanisms also partly affect how perceived objects are filtered after they were associated as drive objects and thus the impact to perception has to be finalized when the defense mechanisms are finished. They are not used in the appearance recognition process so this topic was left open for further investigation.

In summary, ARSi12 framework incorporates the perception-action cycle as modeled therefore the aim of this work is accomplished. The above discussed tasks aim at further research in the ARS project as well as preparations for extension of the perception model in future iterations. The next section discusses the future outlook of the ARS project and model as well as possible areas of application.

6.4 Outlook

The implemented simulation prototype acts as a test application for the functional model and is used to evaluate the behavior of the decision unit and agents in the simulation for psychoanalytical inspired use cases. The project itself originated from building automation and the challenge of evaluating the input of multiple sensor and actuator values. A possible application of the system lies in scenario detection for sensible areas like airports.

By mirroring the human perceptual process, any application using this framework, could provide the human user of that application with more target-oriented information. This would ease the interaction between humans and computers. It would also enhance the human capability to gather meaningful information by providing the user with previously narrowed possibilities. In the ever growing and overwhelming amount of sensorial inputs, a human user could come to decision faster and would not miss necessary information. Understanding the actions of humans in these scenarios for prediction of behavior would help to secure and comfort in these applications.

The information-gathering process can also be used in any software application to extract meaning out of a perceived data stream. Simulated individuals perceiving the incoming data could make the information gathered more realistic. The ARS project models individuals with past experiences to extract meaningful information. The same approach can be used in any information gathering process. An informed human can often extract a higher grade of useful information for a specific situation. By reproducing the same process any system faced with thousands of chunks of undirected data can provide a higher grade of information. This would be useful for any real life situation where the sheer amount of sensorial data is overwhelming for human and artificial observers.

A complete different type of possible realization is to use the ARS model on a humanoid robotic platform. The humanoid robot NAO was successfully used in an experiment, to evaluate if the robot can be connected to the decision-unit. However as seen in the experiment, the improvements made for the ARS framework for a connection to this robotic platform have to go beyond the combination of a sensor system to a decision unit. The framework has to provide interaction possibilities and not a decision unit independent from the perception system. The successor to the robotic platform NAO the humanoid robot Romeo will be used at the institute in the near future. The possibilities for physical interaction and programming this robot provides will reduce the hurdle the experiment with the NAO showed. The first step would be to create an interface between the sensorial and actuator systems the robot provides with the possibility for immediate feedback for motion control and for bodily needs translated into a virtual internal body simulation provided by the ARS framework. In our experiments the decision unit and framework was processed outside the robotic hardware due to resource limitations of the platform. The next generation can provide enough processing power to integrate the framework in the robot and extend the interaction of the robot with the environment. The research of the project shows that the different parts of the framework cannot work separated from each other, they are highly integrated and the same level of interaction stays true for the transformation to a robotic platform. Feedback and information channels the human original has developed, like slow and fast messenger systems as developed in the ARS framework, could be the key to connect the different parts of the robot framework. The possibility of interaction with a robot in conjunction with the here proposed learning mechanisms show a bright path for the future of the ARS framework.

Interpretation of the inner workings of an architecture inspired by psychoanalysis shows another difficulty due to the complexity of stored knowledge and subjectivity of associated data structures. In order to interpret the outcome of various parts of these models different methods have to be used to reason the behavior of such human like inspired systems. A possible solution is to design a personality for the system which indicates a certain behavior in specific use cases designed by psychoanalysts to predict intermediate and future behavior of such system in other scenarios.

The upmost challenge for the project members is the integration of the SELF-object in every aspect of the functional model. As pointed out throughout this thesis this object is the root node for knowledge about the agent itself, actual world knowledge and composed by past experiences. This object is an indicator for the personality of the agent as but is also used in various aspects of the model. For perception this root node is the point of concentration for bodily perception data. Bodily perception data is collected by various senses and has the possibility to become conscious, in conjunction to data of the metabolism used for drive generation. In the current state of the framework and simulation data like the position of the extremities or the position of the head is not of immediate importance but it will be especially for any robotic platform. The position of the head of the agent could be used for additional focus of attention mechanics and thus will be viable information in the decision making process. The SELF-object is also entitled to hold the very last experiences with the environment of the agent and thus could serve as a new form of short term memory for perception. Data there would act as the collection of objects the agent has perceived and with the additional information about the external body itself can also hold the information about object not in the field of view anymore. For orientation and decision making processes this would present additional possibilities for the agent.

The framework presented shows the realization of a functional model developed in conjunction with an interdisciplinary team of researchers. For me it represents the first step of a full model of human decision making in all aspects of the human mind and body. As a cognitive framework it goes beyond cognition itself and incorporates bodily feedback as well as other aspects, which in the future will provide us with a holistic model of the machine we call human being.

The presented artificial life simulation is an intermediate step before switching to other applications. Still a lot of research has to be done as even the consistent model provided by psychoanalysis shows further research questions when it faces a technical realization. In this thesis future tasks to close these gaps in the functional model are provided by matching the functional model to the perception-action cycle model which is referred in interdisciplinary research and thus grounding the model to other sciences.

This work extends the ARS decision unit by introducing a psychoanalytic inspired functional model of perceptual information processing. It is still a long way to go before the control architecture based on psychoanalysis is finished. This thesis hopefully helps the ARS project to get closer to this goal.

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Education

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1998 – 2002	Study of Electronics, University of Applied Sciences Technikum Wien
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Since 2010	Member of the Doctoral College on Computational Perception

Professional Experience

2001 – 2002	ZELED – LED information system for traffic (Design, Software and Hardware implementation) at Zelisko GmbH
2002 – 2007	Design and implementation of software and project management at ACE - Neue Informationstechnologien GmbH
2007 – 2009	Presales, Microsoft CRM & Sharepoint-Consulting, Projectmanagement at Kapsch BusinessCom

Publications

Clemens Muchitsch has written 7 peer reviewed publications in the context of the project ARS for the fields of artificial intelligence, perception, cognitive science and robotics.