Theoretical Approaches to Systems

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Contents

Abstract

This diplomarbeit is about general system theory. It provides a brief overview over system theory in chapter 1. The term system will be explained and an insight is provided regarding the application and expectations towards it. Chapter 2 provides a variety of system theoretical works. Eight system theories were selected, from engineering, biology, psychology, linguistics, sociology and economy. The aim is to provide an overview. The works are not analysed in depth or criticised. The focus was on width more than depth. A short summary and comparison of the eight works is provided. It is by no means very exhaustive. Chapter 3 introduces a mathematically formalised general system. It is influenced by David Lewis' concept of possible worlds. The formalisation aims at providing a vocabulary for rigorous descriptions and explications. Chapter 4 is an application of system theory. It describes the flow of information in human communication. It was done in close collaboration with the AG RVS during AG meetings. It is based on an idea of Avinanta Tarigan who was researching communicational structures.

Chapter 1

A Brief Introduction to System Theory

1.1 Systems and System Theory

Some things in life we term systems. Systems need not have to have much in common with other things termed systems. At least not at first sight. There exists a many kinds of systems: living systems, monetary systems, weapon systems, political systems, computer systems, nervous systems, number systems, metric systems. I could go on for pages and pages.

The encyclopedia *Der Große Brockhaus* describes the term system

1. "ganzheitl. Zusammenhang von Dingen, Vorgängen, Teilen."
2. "auf allg. Grundsätze zurückgeführtes Lehrgebäude einer Wissenschaft."
3. "Plan, Ordnung, Aufbau (z.B. wirtschaftl., polit., botan.S.,Rechts-S.)"
4. "**Systematik**, die Kunst der ganzheitl-planmässigen Ordnung oder Darstellung"

A definition of a system is given in [Hall and Fagan, 1956], where a system is "an aggregation of objects and relations between objects and their properties".

In a multitude of sciences specific systems can be found. Molecular systems in physics, ecological systems in biology, cognitive systems in cognitive sciences, economic systems in business studies, mathematical systems. All systems have in common that there are elements interacting and standing in relation with each other. Interactions and relations are the structuring mechanisms of systems. General System Theory can provide insight into general structuring mechanisms. The simplest form being mathematical graph theory which basic parts are nodes and edges. The nodes would represent the elements and the edges would represent relations and interactions.

In [Bertalanffy, 1969] the use of a general system theory is seen as a prospect for disciplinary glue. With scientific disciplines providing system views many disciplines could be easily integrated into a interdisciplinary framework. Working in the overlap of a number of disciplines could be performed much easier. There would be no need for a interdisciplinary exchange of vocabulary that could only be applied to the specific overlap in question. Beyond this Bertalanffy expresses the hope to foster interdisciplinary education. If the principles of a general system theory were understood knowledge about specific systems could be acquired much more easily. If this would be the case then system theory would be a all-encompassing super-science. But this is not the case. Instead a wide range of specialised system theories has emerged. They are not only meant for interdisciplinary research but often serve as basis for argumentation, description and justification within their scientific fields.

Let's take computer science for example. The ability to abstract, model and describe is necessary for successful engineering of software. The models of a software's environment are not restricted to only one or two fields. Often computer software interfaces with a number of very different systems: machinery, human operators, other computers, sensors, etc.

It is often noted (e.g. [Ladkin, 2000], [Leveson, 1995], [Laprie et al., 1992]) that the key to reliable software lies in good specification. How can good specification be achieved? Mathematical rigour is needed to provide proof that software meets specifications and requirements. A formal method brings explicitness, descriptiveness and objectivity. The systems in question will have to be formally modelled.

1.2 Formal and Non-Formal Systems

Most system theories introduced below are non-formal. But that does not necessarily mean that they could not be used for formal modelling, description and explication. The non-formal systems provide a layer on top of the formal systems. The non-formal systems provide the semantics. They can be "mounted" on top of formal systems.

Chapter 2

System Theoretical Approaches in Different Scientific Disciplines

The comparison will be done with focus on breadth rather than depth. A deep insight into all theories of all authors compared cannot be gained. Of central interest are the building blocks and structures of the theories.

2.1 For each example theory the following will be described

1. The author: name, occupation
2. The work: title, year of publication, scientific/disciplinary context
3. Object of the work: function/aim of the work, topic and object of consideration
4. Composition of Systems under consideration: Elements, Relations, Borders between Systems, Generation/Creation
5. Emergent Properties of Systems under consideration

The works chosen are

"General System Theory" by Ludwig Avon Bertalanffy: Bertalanffy was among the first to give an elaborate vision of a general theory of systems.

“Menschliche Kommunikation” by Paul Waltzlawick, Janet H. Beavinand Don D. Jackson: Watzlawick et al. combined psychological and linguistic aspects of communication. They applied a system theory of communicational systems incorporating an interdisciplinary approach of psycho-linguistics.

“Living Systems” by James Grier Miller: Miller can be regarded as the one to implement Bertalanffy’s vision of a general system theory. Miller constructed a very comprehensive ontology of living systems in the way proposed by Bertalanffy.

“Das Unternehmen als kybernetisches System” by Johann Jirasek Jirasek described a cybernetical approach to business and administrative management.

“Kommunikation” by Hans Strohner Strohner aims at providing a work book for both qualitative and quantitative linguistics. He emphasises the integration and mutual dependability of both aspects.

“Einführung in die Systemtheorie” by Niklas Luhmann Luhmann built one of the most popular and comprehensive system theories in social science. He did not only elaborate the theory, but also published many works where he used his theory to examine social phenomena.

“Foundations of Social Theory” by James Samuel Coleman Coleman, too, developed a theory of social systems. In contrast to Luhmann he chose a very different path. He not only examines the structuring and mechanics that form social systems. He incorporates a quasi-psychological view on the individual. Similar to Strohner he emphasises an integrated approach of qualitative and qualitative methods.

“Causal System Analysis” by Peter B. Ladkin Ladkin built a formal method for analysing (mostly physical) system. The term system had to be formalised for the method to be fully formal and rigorous. Ladkin emphasises the advantages of formal methods over non-formal methods.

2.2 [Bertalanffy, 1969], General

Ludwig von Bertalanffy was Professor for Theoretical Biology at the University of Alberta, Canada from 1961 to 1968. In 1968 he first published "General System Theory" and one year later the revised edition[1]. The work is a summation of scientific papers already published by him earlier. Only one introductory chapter has been written for the book originally ([Bertalanffy, 1969], Acknowledgements, p. xi).

Note: Because the title of the book and the topic of the book are termed the same the following distinction will be done:

General System Theory *will be the term used to denote the book written by Ludwig von Bertalanffy*

General Theory of Systems *will be the term used to denote the concept that is described in the book*

Bertalanffy introduced the general theory of systems. Seeing the growing specialisation in the scientific disciplines he argued that scientists are "encapsulated in their private universe" ([Bertalanffy, 1969], Chapter 2, p. 30). Bertalanffy observes that "similar problems and conceptions have evolved in many different fields" ([Bertalanffy, 1969], Chapter 2, p.30). Following this thought it seems appropriate to search for connections and correlations in scientific disciplines. Bertalanffy assumes that "there exist models, principles, and laws that apply to generalised systems" ([Bertalanffy, 1969], Chapter 2, p. 32). This is the motivation for the development of a "theory , not of systems of a more or less special kind, but of universal principles applying to systems in general" ([Bertalanffy, 1969], Chapter 2, p. 32).

2.2.1 Function/Aim of "General System Theory"

Bertalanffy gives his views on a part of the evolution of science. He sees an opportunity in the research of parallels, analogies and similarities that occur in different, seemingly unconnected, scientific disciplines. To properly approach such interdisciplinary phenomena there is need for meta-scientific means of analysis. Giving an introduction of his vision for such a meta-scientific approach and providing various examples from different disciplines Bertalanffy describes a general system theory, its applicability and justification.

[1]The latter was used by me

2.2.2 The Object of Consideration: General Theory of Systems

According to Bertalanffy the general theory of systems "subject matter is the formulation of principles that are all valid for "systems" in general, whatever the nature of their component elements and the relations of "forces" between them"([Bertalanffy, 1969], Chapter 2, p. 37). The major aims are:[2]

1. There is a general tendency towards integration in the various sciences, natural and social.
2. Such integration seems to be centred in a general theory of systems.
3. Such theory may be an important means for aiming at exact theory in the nonphysical fields of science.
4. Developing unifying principles running "vertically" through the universe of the individual sciences, this theory brings us nearer to the goal of the unity of science.
5. This can lead to a much-needed integration on scientific education.

Bertalanffys illustrates his proposal for a unifying meta-science with various examples taken from different disciplines.

- mathematics
- biology
- chemistry
- psychology and psychiatry
- cybernetics

For all disciplines the constituting elements and relations are given to illustrate the applicability of a general theory of systems. By applying such a theory to various fields that are very different from each other Bertalanffy illustrates what he termed in his list of aims "vertical". The general theory of systems may be used as an all-embracing language for science in general.

[2]taken directly form [Bertalanffy, 1969], Chapter 2, p. 38

2.3 [Watzlawick et al., 1969], Psychology and Linguistics

Paul Watzlawick, Ph. D.

Paul Watzlawick was born 1921 in Villach, Austria. He studied philosophy and philology at the University Venice, Italy, and became a psychotherapist at the C. G. Jung Institute in Zürich, Switzerland. 1957 he received a call to the University of El Salvador. 1960 he did research at the Mental Research Institute at Paolo Alto and became professor for psychotherapy at Stanford University, USA; in 1976.

et al.

Unfortunately I was unable to research biographical information on co-authors Janet H. Beavin and Don D. Jackson. Scanning the internet all sites containing their names were references to "Menschliche Kommunikaiton". Since this work is not about giving biographical information the search had to stop at some point.

2.3.1 Function/Aim of "Menschliche Kommunikation - Formen, Störungem, Paradoxien"

"Menschliche Kommunikation" aims at analysing and describing forms of human communication. It focuses on the pragmatic level of communication and at communicational behaviour. Watzlawick et al. give a hypothesis of communicational systems based on general system theory. They explicitly state that they are trying to apply theoretical concepts of Ludwig von Bertalanffy ([Watzlawick et al., 1969], Chapter 4, p. 123) and Hall and Fagan ([Watzlawick et al., 1969], Chapter 4, p 124). To exemplify their approach of communicational systems Watzlawick et al. provide illustrative material in the form of a communicational analysis of a theatre scene ([Watzlawick et al., 1969], Chapter 5).

2.3.2 The Object of Consideration: A Psychological Theory of Communication

Communication (treated in "Menschliche Kommunikation") occurs between humans. On the pragmatic level, the one focused on, communication is more than exchange of information. Communicational action and interaction are the main interest. With a refined concept of a communicational system theory any form of communication should be at least describable, if not analysable. Especially non-standard forms of communication as encountered in psychotherapy can be described, understood and eventually treated. The work aims at integrating a view of the communicating human psyche and communicational relationships between people.

2.3.3 The Composition of Systems under Consideration

Watzlawick et al. use a definition found in [Hall and Fagan, 1956]
A system is "an aggregate of objects and relations between objects and their properties".
The objects in a communicational context are people engaging in communicational interaction. Communicational partners have properties. These properties are their communicational behaviour. Internal psychic properties are not taken into account, though they may be a major factor in influencing communicational properties.

Relations in this system are human interrelations of communicational partners. Relations between communicational partners are established by themselves. But the perception of a common relation may deviate for different partners.

So established communicational systems are open systems. They are in constant interaction with their environment or setting. Communication never happens only between people. It is always embedded in context and situational perception of its partakers.

Watzlawick et al. give a list of properties of open systems in general and communicational systems in particular:

Wholeness

A system can be regarded as a whole. Even though, as stated above, it is an aggregate of objects, relations and properties. The property of wholeness is crucial to a system to be regarded as one. Without wholeness the would-be system would merely be the "sum of its parts". Wholeness is what makes the difference.

Over Summation

Over summation is very closely related to wholeness. If objects and systems aggregate over summation leads to the added value and establishes wholeness for the system. The minor changes to objects, properties or relations inside the system can cause major changes is the systems properties or behaviour.

Feedback

Feedback is the ability of systems to perceive the effect of influencing the environment. This leads to a loop in information flow. The environment is influenced, the effect is perceived, the effect is assessed, influence-taking is triggered.

Equifinality

Equifinality describes the ability of a system to achieve a goal state via different ways. Many initial states of a system can lead to the desired goal.

According to ([Bertalanffy, 1962], p. 7) the structure of a system if much more influent on the possible goal states than its initial state.

2.3.4 Emergence

Watzlawick et al. focus on inter-human communication. Nevertheless they are aware of higher level communicational systems and believe in the applicability of the theory for those, too. When analysing communication between single individuals emergence is still a major factor. Especially in psychotherapy. Each individual is a member in one or more communicational systems. As stated above the effect of over summation may easily lead to changes of system properties when only minor changes occur inside the system. In therapy the change in communicational and social behaviour of the patient has effect on the systems he is a member of. While helping the patient the systems have to be maintained in a healthy state, too.

The effect of system members on emergent properties has to be understood and taken into consideration.

2.4 [Miller 1978], Biology

James Grier Miller was professor for biology at the University of Louisville from 1973 to 1980. He coined the phrase "Behavioural Science" ([Miller 1978], Preface, p. xv) and together with his wife started a journal that went by that name. In 1975 he published "Living Systems" to introduce what he calls a "General Theory of Living Systems" ([Miller 1978], Chapter 1, p. 1). The work was inspired by the proposals on a general systems theory done by Bertalanffy ([Miller 1978], Preface, p. xvi). Miller formed and introduced a system theory specialised on the description and analysis of living matter, e.g. cells, organs, organisms, organisations. The work belongs to the essentials of theoretical biology.

2.4.1 Function/Aim of "Living Systems"

Biology is split into sub-disciplines, e.g. cytology, neurobiology, behaviour research. All sub-disciplines research biological fields of interest. All these fields produce results and findings but seldom these can be easily transformed to be usable by another sub-discipline. In that way biology suffers from the same disciplinary gaps as can be observed for science in general. As Bertalanffy proposed to use a general systems theory to build bridges between different scientific disciplines, Miller builds a specialised theory to bring together the parts of biology. He wants to build a "commonly accepted language, systematic theories, and basic laws to organise the huge volume of research findings and bridge the gaps of our knowledge" ([Miller 1978], Chapter 1, p. 5).

2.4.2 The Object of Consideration: General Theory of Living Systems

"General systems theory is a set of related definitions, assumptions, and propositions which deal with reality as an integrated hierarchy of organisations of matter and energy. General living systems theory is concerned with a subset of all systems, the living ones" ([Miller 1978], Chapter 2, p. 9).

Millers idea of a general theory of living systems is to develop a theory closely related to that of general systems (see [Bertalanffy, 1969]. The specialisations made are

- Only physically existing systems are considered. There is no need for purely abstract or logico-mathematical systems. This does not include abstractions from real systems.

- The systems have to be living. Because this constraint is set up before the formulation of the theory consensus of what a living system is is presumed. The definition of a living system does not come from the theory itself.

Miller classifies the systems under consideration as following ([Miller 1978], Table of Contents, p. vii)

- The Cell. Cells come in two variants. Free-living cells, so called "microorganisms" ([Miller 1978], Chapter 6, p. 203), and cells that are part of organs. ([Miller 1978], Chapter 6, p. 203).

- The Organ. Accumulations of cells can form organs. Organs can be seen as parts of organisms, but unlike (free-living) cells are not capable of living independently. Organs serve definite functions inside organisms. Examples for organs are the brain, the heart, the bones or the skin of an animal. Where the animal would be the organism binding the organs together. ([Miller 1978], Chapter 7, p. 315)

- The Organism. The term is used with its "usual biological sense" ([Miller 1978], Chapter 8, p. 361). Examples for organisms are all animals and plants. ([Miller 1978], Chapter 8, p. 361)

- The Group. "A group is a set of single organisms, commonly called members, which, over a period of time or multiple interrupted periods, relate to one another face-to-face" ([Miller 1978], Chapter 9, p. 515). Examples for groups are families, tribes, packs or swarms. Social groups are included by the term, too. Groups of friends, relatives or colleagues for example. ([Miller 1978], Chapter 9, p. 515)

- The Organisation. Organisations can (but must not) be constituted of groups, though they naturally develop inside an organisation. Organisations main traits are the existence of "multiechelon deciders" ([Miller 1978], Chapter 10, p. 595). Organisations are lead by members in order to be able to perform as one. The differentiation betweem kinds of action, communication and decision to be taken by an organisation leads to the assignment of agents (groups or individuals) to perform these tasks. ([Miller 1978], Chapter 10, p. 595)

- The Society. Societies are formed of individuals , groups and organisations. Societies are bound together by territorial location and kinship. Societies create organisations for securing the existence and safety of a society and its parts. Nations, federal states as well as primitive people form societies. ([Miller 1978], Chapter 11, p. 747)

- The Supranational System. A supranational system is composed of at least two societies. These engage in concerted behaviour by creating super-national instances for decision making, communication between members and concerted action. Examples for supranational systems are military (NATO, Warsaw Pact States) and economic alliances (European Union, G8). Supranational systems are not systems whose parts exist in different nations. These are termed "transnational". ([Miller 1978], Chapter 12, p. 903)

2.4.3 Composition of Systems under Consideration

All kinds of systems described by Miller are presented in a uniform way. Miller introduces a scheme to describe components and actions of and inside systems. ´Miller calls them "Basic Concepts" ([Miller 1978], Chapter 2, p. 9).

Space and Time

Since Miller is only interested in physically existent systems physical space and time have to be considered. Apart from that conceptual and abstracted space can be taken into consideration. ([Miller 1978], Chapter 2, p. 9)

Matter and Energy

"*Matter* is anything which has mass [...] and occupies physical space. *Energy* [...] is defined in physics as the ability to do work" ([Miller 1978], Chapter 2, p. 11)

Information

The term information is used in its technical sense introduced by [Hartley, 1928] and further developed by [Shannon, 1948]

System

Miller states that the most general definition would be: "A *system* is a set of interacting units with relationships among them" ([Miller 1978], Chapter 2, p. 16) Miller lists the ontology of his idea of a system. The ontology is used by Miller throughout his book to uniformly describe definite systems. I will give a list of the ontological parts. For a in depth discussion see ([Miller 1978], Chapter 2, pp. 16).

- Units
- Relationships

- The Observer
- Variable
- Indicator
- Function
- Parameter
- The State of a conceptual System
- Formal Identity

Additionally Miller gives classifications for systems he uses.

- Living and non-living systems
- Totipotential and partipotential systems
- Fully and partial functioning systems

Structure

"The *structure* of a system is the arrangement of its subsystems and components in three-dimensional space at a given moment of time" ([Miller 1978], Chapter 2, p. 22).

Process "All change over time of matter-energy or information in a system is *process*." ([Miller 1978], Chapter 2, p. 23).

Type

if similarities in characteristics of systems can be observed these can be "classed together as a *type*" ([Miller 1978], Chapter 2, p. 24).

Level

Systems can be used as parts of other systems. In that case there is a hierarchy of systems. The place in this hierarchy called the *level* of the system. Most of the time the levels are given distinct names, e.g. the molecular level, the microscopic level, the macroscopic level.

Echelon

With *Echelon* Miller means the "chain of command" ([Miller 1978], Chapter 2, p. 29) across system borders and across different levels of systems. All systems whose structure have distinct deciders that can instruct performers to act have echelons. ([Miller 1978], Chapter 2, p. 29)

Suprasystem

The system A that is a part of a system B has B as its *suprasystem*. ([Miller 1978], chapter 2, p. 29)

Subsystem

The system A that is part of a system B is system B's *subsystem*. ([Miller 1978, **?**, **?**]

Transmission

The term sums up the transfer of information and matter-energy across system borders. Commonly divides into *input, throughput and output*. ([Miller 1978], Chapter2, p. 34)

Steady State

Steady states are system states that lie within a defined state space. They are only *steady* with respect to the definition of that space.

Millers given description of a system ontology is not restricted to living systems. Though Miller only uses it for living ones. The ontology given on systems is used throughout his book to present the diverse forms of living systems given above. All can be described using this scheme, from the cell to the super-national organisation.

2.4.4 Emergence

Miller focuses only on living systems. He created a hierarchy and with each hierarchy new forms of life and its organisation can be found. All of them using the properties of their respective subsystems. This way each level of living system has own means of reproduction, energy-matter and information transmission, growth, evolution, (self-)structuring or adaptive ability.

Millers approach, from cell to super-national organisation, seems natural. It bears similarities to the effort that "unification of science has been seen in the reduction of all sciences to physics, the final resolution of all phenomena into physical events" ([Bertalanffy, 1969], Chapter 2, p. 48). Bertalanffy criticised this effort as too mechanistic and put his general system theory as an alternative. Miller's cross-section of living systems gives a good view on how these systems are linked together. But the emergent properties of all system levels need special approaches.

Miller only examined the constitution of systems regarding the use of subsystems as building parts. He named the emergent properties of the new systems and then went on to construct a concept of a new, bigger system.

2.5 [Jirasek, 1968], Economy

Dr. Dipl. Ing. Johann Jirasek published this work as his doctoral thesis. Originally being an engineeri he achieved the grade "Doktor der Betriebswirtschaftslehre".

2.5.1 Function/Aim of "Das Unternehmen - ein kybernetisches System"

Jirasek aims at introducing cybernetical terms and ways of thinking to the field of economics, especially for corporate management. He sees his audience especially among the executive personnel of business and administration. According to Jirasek the understanding and application of cybernetic principles will enhance the chances for successful corporate action ([Jirasek, 1968], Vorwort, p. 8).

2.5.2 The Object of Consideration: Cybernetics in Corporate Management

Jirasek regards cybernetics to be the science of measuring and controlling. With a cybernetic approach to measuring corporate conditions and a profound understanding of economic mechanisms controlling the company will be more efficient.

Both, measuring and controlling, have to be done on two different levels. The corporate structure level and the corporate action level. On the structure level the object is the composition of the company. With changes made in the composition of the company more efficiency and effectiveness is aimed for. This is commonly known as rationalisation. Rationalisation is seen as adapting to the environmental condition the company is in. On the action level the aim is to control information-, money- and goods-flow and human resources. The company's actions should lead to a most beneficial revenue. This includes e.g. business strategies, buy/sell/trade, corporate action, price determination, legal action.

2.5.3 The Composition of Systems under Consideration

In Jirasek's examination of the "Unternehmen als Regelungssystem" ([Jirasek, 1968], Chapter 2, pp.30), the three aspects of a company are

1. "Der systemtheoretische Aspekt"

2. “Der regelungstechnishce Aspekt”

3. “Der informationstheoretische Aspekt”

([Jirasek, 1968], Chapter 2, p. 30)

Business as a system describes the ontology of a company. The measuring aspect assumes flows of information, money and goods between the business's parts as well as to and from the business. These flows have to be observed by measurement devices. The information aspect (not to be confused with the information flow mentioned above) deals with the processing of the data acquired and the issuing of commands to parts of the company to be controlled.

The company's behaviour can be observes internally and provides the bast for decision taking. After decision taking commands flow back into the company and can be monitored for effect. The company has established a feedback loop and can adapt itself to achieve set goals.

2.5.4 Emergence

Not mentioned.

2.6 [Strohner, 2001], Linguistics - Communication Theory

Hans Strohner is professor at the department of linguistics and literature at the University of Bielefeld. He wrote “Kommunikation” based on his lectures at the university. The book was published in 2001 and is meant as an introduction to cognitive basics of communication theory as well as a guide for practice ([Strohner, 2001], Vorwort, p. 7). Strohner emphasises his use of systems theory in the analysis of communication principles.

2.6.1 Function/Aim of “Kommunikation”

Strohner wants to provide students in the field of communication theory with

- a historic time-line of communication theory ([Strohner, 2001], Chapter 1, p. 23),
- an introduction to academic foundations of communication theory([Strohner, 2001], Chapter 1, p. 11),
- an introduction to qualitative and quantitative methods used([Strohner, 2001], Chapter 3, p. 47),
- examples for the appliance of communication theory in different communicational contexts ([Strohner, 2001], Part 2, p. 57).

2.6.2 The Object of Consideration: Communication Theory

Strohner’s book is divided into two parts. The first part is about conceptions and basics. The second part deals with the appliance of these conceptions in different, selected communicational environments.

Basics

Strohner defines communication as cognitive interaction ([Strohner, 2001], Chapter 2, p. 34). All communicational actors are by definition cognitive, information processing systems. Strohner refers to biological ecosystem theory ([Strohner, 2001], Chapter 2, p. 44) to be sufficient for overcoming all deficiencies of past theories. He develops his theory of communication analogous to the ecosystem theory and speaks of “Kommunikative Ökosysteme” ([Strohner, 2001], Chapter 2, p. 44).

Strohner emphasises the ability of the systemic approach

- to be able to sufficiently describe and differentiate between information (to be transmitted), interaction (action by communication) and situation (context). All these forming the “Verarbeitungsdimension” ([Strohner, 2001], Chapter 2, p. 45),
- to take into consideration the dynamics of communication,
- and to take into consideration the evolutionary aspects of communication.

([Strohner, 2001], Chapter 2, p. 45)

Applications

Strohner classifies communication into categories. A communicational act need not be solely placed into only one of these categories. More may be involved. The categories are

interpersonal communication

This is done between individuals. All individuals representing only themselves and all interaction and information can easily be attributed to an individual. Examples for special forms of interpersonal communication are inside the family, between man and woman and between younger and elder people([Strohner, 2001], Chapter 4, p.59).

organisational communication

This is done between groups of individuals who share a common interest. Groups can be formal (companies, clubs) or informal (friends, mobs). Communication with and between organisations is done via interpersonal communication. Organisations have (formal or informal) means of information processing, decision taking and interaction. Members of the organisation split the organisational work and serve as spokes people or decision makers. The inability of the organisation to perform like a collective whole needs creation of channels of communication via interpersonal, representational communication. Examples of special forms of organisational communication are inside and between companies, communication inside military structures and diplomatic communication ([Strohner, 2001], Chapter 5, p. 83)

public communication

Public communication is performed when the addressee is not a specific target. Communication is done via means of broadcasting (commonly referred to as "the media"). It may not seem obvious but this does not mean that public communication has to be one way. Although not immediately accessible the public processes the information received and feeds it back to it's origin via numerous channels. Examples for special forms of public communication are television, radio and newspapers (differ in medium) as well as political communication, advertisements, so called public discussion (differ in function) ([Strohner, 2001], Chapter 6, p. 83).

inter cultural communication

This categorisation is not consistent with the three aforementioned. It adds a new dimension. Inter cultural communication can occur in interpersonal, organisational and public communication. This form of communication focuses strongly on the situation the communication takes place in. Actors from mutually different cultural and social backgrounds experience difficulties in understanding each other. This may be the case although none have any deficiencies in their abilities and are successful inside their respective cultural context. The ability to put oneself in the others position is diminished by the crossing of social and cultural borders ([Strohner, 2001], Chapter 7, p. 139).

2.6.3 The Composition of Systems under Consideration

As mentioned above Strohner sees several interrelated parts that make up a communication setting.

Information

Information is transmitted between communicational partners. Information is transmitted physically (through several media) and links together communicational partners. Although Strohner differentiates between interpersonal, organisational and public communication the individual always needs physical access to transmitted information.

interaction

By exchanging and interpreting (or processing) information communicational partners can perform actions. This is referred to as the pragmatic dimension of communication, often described in terms of speech acts [Searle, 1969].

Situation

The situation should ideally be viewed containing all contextual aspects of communication. The contextual aspects[3] given by Strohner are

- time
- space
- knowledge and history
- personality
- emotion
- social and cultural background
- partner perception

Strohner describes all four categories of communication (see above) by explicating the kind of information and the way it is transmitted, the interactions taking place and the situation the communication takes place in.

2.6.4 Emergence

Strohner is more interested in classifying communicational parts and analysing their interrelations. Emergence is not considered. Although, like [Miller 1978], Strohner makes the same step of getting from the individual to a organisation. Strohner in not interested in the emergence or creation organisational communication from the individual level communication.

[3]presumably there are more to be found

2.7 [Luhmann, 2002], Social Science

Niklas Luhmann was born 1927 in Lüneburg and dies 1998 in Oerlinghausen. He achieved the 2. Staatsexamen in law in 1950 and graduated in social sciences 1961 in Harvard. After his dissertation and state doctorate 1966 in Münster he was called to the University of Bielefeld to become professor in social sciences. Luhmann's lifetime achievement is his theory of society.

2.7.1 Function/Aim of "Einführung in die Systemtheorie"

Luhmann's main aim was to create a general theory of social systems. The theory was not meant for specific systems or actual systems. Of course all examples and applications deal with actual systems. But even with major changes in social systems Luhmann's general theory will still hold.

Luhmann's theory of social systems claims to be universal and sufficient for all social reality ([Berghaus, 2003], Chapter 3, p.25).

2.7.2 The Object of Consideration: A General Theory of Society

Luhmann's focus is the construction of a universal and all social reality encompassing theory of systems. All social phenomena will be describable and analysable using the theory. With the theory in place one of Luhmann's main interests is the analysis of mass media communication and social risk, using his theory.

In order to provide a consistent theory Luhmann puts much effort into the justification of several mechanics that are applied within the theory. Communication ([Berghaus, 2003], Chapter 6, pp. 67), "Autopoiesis" ([Berghaus, 2003], Chapter 4, pp46), "Operative Geschlossenheit" ([Berghaus, 2003], Chapter 4, pp. 51) and system-environment-difference ([Berghaus, 2003], Chapter 4, pp. 38) are among the principles used in the theory. For each Luhmann gives a very detailed version of *his* interpretation. Which is fundamental for the creation of *his* theory.

2.7.3 The Composition of Systems under Consideration

Systems in Luhmann's sense have to be "autopoietisch", operate via communication, "operativ geschlossen", "umweltoffen" and able to differentiate.

Autopoiesis

Autopoiesis is the ability of systems to create their own kind. Systems of one kind can create systems of their kind. No other system of another kind can create such a system. E.g. life can only be created by life, social systems can only be created by social systems. According to Luhmann a non-autopoietical system is not a system (in his sense). It is noteworthy that a human being is not a social system, but a person is. A human being is a biological system. A person is "created"[4] by educating persons.

Operation via Communication

In Luhmann's systems everything is done by communication. This is especially relevant for creation and disbanding of social systems and for social action. Communication is considered to be continuing perpetually with endless chains of responses to previous communication.

Operative geschlossenheit

The concept of operative geschlossenheit is closely related to communication and autopoiesis. In terms of social systems all social actions originate from or aim at other social systems. There cannot be non-social systems that operate on social systems or vice versa.

Ability to Differentiate

Systems have to be able (a) differentiate between them self and the environment. (b) Systems have to differentiate between things perceived in the environment according to their function. E.g. law systems differentiate between legal states, business systems differentiate between economic states.

A Working Theory

Luhmann used his established theory himself. Among his numerous publications most deal with "Gesellschaft"[5]. Luhmann investigates the functions of social systems, their influence on each other and why there is a need for a social system's function in "Gesellschaft".

[4]admittedly in a *very* broad interpretation of the word

[5]most notably *Die Gesellschaft der Gesellschaft*, Suhrkamp, 1997

2.7.4 Emergence

Luhmann is going into much detail describing how social systems are created and disbanded. The creation of a system always establishes a systems function. If the function is no longer desired a system disbands. Partaking social systems in the creation process of a social system find the need for the created social system. The creating systems have a clear perspective of the new systems added value. Emergence is a product of the imagination and organisational/communicational abilities of social systems.

2.8 [Coleman, 1990], Sociology

James Samuel Coleman was professor of sociology at the university of Chicago from 1973 to 1995. He published "Foundations of Social Theory" was published in 1990.

2.8.1 Function/Aim of "Foundations of Social Theory"

Coleman wanted to create a social scientific approach that takes into account social group behaviour and individual social behaviour. Most phenomena in human society are researched at the individuum-level. Then these are accumulated and viewed statistically.

Coleman emphasises the transition between macro- and micro levels of social organisation. The higher (macro) levels cannot be solely regarded as statistics or as accumulated individual (micro) behaviour. The structures of organisation of individuals is cannot be accounted for by statistical/quantitative methods alone.

Coleman begins with defining basics of individual behaviour and interaction. From this basis behaviour of higher level groups can be derived. These can be further grouped to even higher (and so on) levels. The mechanisms have to be reversible. High level behaviour must be ascribed to lower level behaviour. This transition from micro level to and from macro level is crucial to Coleman's theory.

2.8.2 The Object of Consideration: Theory of Social Systems

Coleman aims to provide an "in principle" explanation of social behaviour. Because he does not consider his work to be psychological ([Coleman, 1990], Chapter 1, p. 1) a (relatively) simple model of individual behaviour must suffice. Social behaviour is to be considered behaviour of large social systems with many actors and many other contributing parts. In structuring these parts and actors in a model of social behaviour and action phenomena can be explained using the model. Whether the model has sufficient descriptive or even predictive power remains to be seen. Coleman's approach tries to incorporate quantitative as well as qualitative methods. The quantitative part (theory building) will focus on providing the description and prediction. The qualitative part (statistical evaluation) will either reinforce the model or lead to its revision.

2.8.3 The Composition of Systems under Consideration

The composition of Coleman's model of social systems can be divided in two parts. Coleman starts out at the individual level, with simple relations, etc. From this on, the bottom-most level, higher levels of social systems can be constructed.

The individuum-level

For the individual actor level the model consists of the following elements,

- **actor:** a single person
- **action:** an actors operation of influencing his-her environment
- **interest:** according to an actor's goals he-she acts to achieve gains in resources, relations, control or rights
- **resource:** anything that can be of value to an actor
- **control (over resources):** the ability to perform actions arbitrarily (to a certain degree) with a resource
- **(legal) rights (of actors):** the (social/legal) permission or denial to act in a certain way described/defined by the right[6]
- **relation :** associations between one or more actors

On the individual level actors are single persons, who engage in social action. Social action can be attributed to the actor's interest in resources, rights, relations and control. All actions are aimed at to achieve a goal, short term or long term.

Resources can be distinct objects of value, the ability to work, information or anything an actor could attribute value to. One or more actors can exert control over distinct resources. The uni- or multilateral transfer of resources or control over such is the simplest form of trading. Actors exchange resources or control to increase their personal gain. This is only possible because different actors attribute different value to different resources. The actor's interest in a resource will determine its value to the actor.

[6]rights include duties

In more complex trading rights can be granted and taken (by authority) to actors. In some cases actors may also have the right to exchange rights, e.g. the right to control a resource.

Relations between actors, resources and rights are many. Examples between actors are family relations, friendship relations, business partner relations. Relations between resources and actors are relations of ownership (not to be confused with control), legal contract relations.

The super-individuum level

On a higher level that the individuum level actors can be different from single persons. Still all actors will consist of individuals on the bottom-most level. People will form groups of different degrees of organisation in order to pursue common purposes, e.g. families, corporations, nations, political parties, clubs. Other actors are groups that did not form on purpose and have next to no structure, but nevertheless can be regarded as a group due to common characteristics or similar types of behaviour, e.g. traffic, mobs, super-national community.

All these different actors can engage in social behaviour the same way the individuum can. For each high-level actor all actions are performed on the lowest level by an individuum (an agent) being in charge of a part of the groups actions.

Actors can belong to very many different groups even with conflicting interests and purposes. The individuum can assume certain roles inside a group.

The Macro-to-Micro and Micro-to-Macro Transition

When social behaviour or phenomena have to be explained the observations made can be described using the models ontology. Then the question arises "Why did this happen?".

A groups behaviour is a direct result of the concerted behaviour of the groups subgroups. Ultimately one will arrive at the individuum-level. This is the *Macro-to-Micro transition* going from the top-level group down to the individual.

When individuals from groups they engage in concerted action, the group will have a degree of organisation to perform effectively and efficient. Only if the kind of organisation, common goals and use of resources are taken into account group behaviour can be analysed. Moving upwards from the individual through diverse layers of (sub-)groups will lead to the top group.

This is the *Micro-to-Macro Transition* explaining the behaviour of complex social phenomena.

2.8.4 Emergence

Emergence and Coleman's *Macro-to-Micro and Micro-to-Macro Transition* are closely related. The transition method's aim is to take into account the emerging properties of groups to explain the behaviour of the next-higher group.

2.9 [Ladkin, 2000], Engineering

Excerpt from [RVS, 2002]

"Peter B. Ladkin is Professor of Computer Networks and Distributed Systems at the University of Bielefeld in Germany, and Visiting Professor at Middlesex University in London. His research specialises in specification, verification and failure analysis methods for complex heterogeneous systems, and distributed systems in general, specialized recently in issues with aeronautical systems. Apart from that, he has worked on constraint satisfaction problems and temporal reasoning, and also written on the logical justification for system engineering practice. He is especially keen on applied formal and informal logic, particularly temporal reasoning, and social and ethical issues and consequences of ubiquitous computing.

During the 1980's, he worked at SRI International's Computer Science Lab and the Kestrel Institute as well as consulting, and taught at various universities in the San Francisco Bay Area. In the 1990's, he has visited the Universities of Hamburg, Berne, Stirling and Nancy, as well as IBM's Almaden Research Center in San Jose, the Telecommunications Lab of INRS in Montreal, and INRIA Lorraine in Nancy. He founded the British company Causalis Limited for performing complex systems analysis. Current collaborators are Leslie Lamport at Digital Equipment Corporation's Systems Research Center in Palo Alto, California, Stefan Leue at the University of Waterloo in Ontario, Barbara Simons of the ACM, and Harold Thimbleby at Middlesex University in London."

2.9.1 Function/Aim of "Causal System Analysis"

"Causal System Analysis" aims to provide a method used for investigating causal relations and dependencies in physical or logical systems. With the methods Causal System Analysis (CSA) and Why-Because Analysis (WBA) Ladkin provides a methodology explaining, describing and investigating causal relations that may influence (CSA) or have influenced (WBA) events or occurrences (the book speaks of "events" in general and of "incidents" and "accidents" in particular).

2.9.2 The Object of Consideration: Analysis with CSA and WBA

WBA and CSA are formal methods. As noted in ([Ladkin, 2000], Preface, p. iii) and ([Ladkin, 2000], Chapter 3, pp.47) and illustrated by ([Ladkin, 1996]), formal methods have several advantages over non-formal methods of analysis:

- With the definition of an appropriate formal semantics formal correctness ensures semantic correctness. The verification of correctness can be done (in principle) by anyone. A hight level of objectivity is achieved.

- Closely related to the above mentioned point: The human factor in analysis is reduced. Personal experiences, values and the like do not influence (or to a considerably lesser extent) the analysis

- Explicitness is facilitated. Ambiguity is reduced.

- Explicitness fosters a high degree of precision.

The method is based on concepts developed by David Lewis (described in [Lewis, 1986]). Lewis approach to causality and counterfactuals belongs to the core of Ladkin's justification of WBA and CSA.

Since the objects of interest in CSA and WBA are systems and since CSA and WBA are formal methods there has to be a formal explanation/definition of systems. The definition of systems is given with regard to their suitability for building the analysis.

2.9.3 The Composition of Systems under Consideration

Ladkin constructs an abstract system in order to establish a general formal frame work for the objects of interest (that are to be analysed). The frame work established is suitable for physical systems as well for conceptual or logico-mathematical systems. Ladkin mentions two points in defining a system ontology for analysis:

- "there are provably complete forms of formal reasoning about these structures; and

- one can describe any "real world" situation adequately using these structures"

([Ladkin, 2000], Chapter 3, p. 58).

A system is described to "contain *objects* which engage in *behaviour*". Objects not belonging to a system, but influencing the system belong to the "*environment*". Everything outside the system or its environment belongs to the "*world*". The "*system boundary"* separates the system from the environment and world ([Ladkin, 2000], Chapter 3, pp. 50).

Ladkin distinguishes between teleological and non-teleological systems. The work focuses on the teleological systems mostly ([Ladkin, 2000], Chapter 3, p. 52).

Objects denote "*anything which may be the value of a quantifier*". Additionally fluents are introduced to denote "*things which take values over time*" ([Ladkin, 2000], Chapter 3, p. 53). Objects and fluents inhabit the system world. Systems are (in principle arbitrary) aggregates of system. Of course in the analysis of real world systems the aggregation of objects and fluents to systems is determined by their real world counterparts.

These systems and their objects engage in behaviour. Behaviour is understood to be "*how the properties of an object and its relations with other objects change over time*". This leads to the question what "*change*" means in this context. A complete assignment of objects, properties and relations may be true at one point in time. At another point in time it is no longer true, but an other assignment is true. This is considered "*change over time*". The complete assignment at a given time is termed a systems "*state* ([Ladkin, 2000], Chapter 3, p 53, 54).

If one state of an object or system follows an other an event has occurred. A series of events is termed a "process". States can be measured (by appropriate measuring functions) and a (semi-ordered) state space can be established.

2.9.4 Emergence

Since the ontology of systems given by Ladkin is meant for "real world" descriptions emergence is not a concern in the ontology itself. If a CSA or a WBA (examples can be found in [Ladkin, 2000], Chapters 7, 8, 9, 13, 23, and 24) is looked at (in forms of a Causal Influence Diagram ([Ladkin, 2000], Chapter 9, pp. 128) or a Why-Because Graph ([Ladkin, 2000], Chapter 25, p. 423)) the graphs show the causal influences on the event analysed. It belongs to the formal semantics that had one event (denoted by a node in the graph) had not happened the top event (denoted by the top node) had not happened. Ladkin speaks of the counterfactual test ([Ladkin, 2000], Chapter 14, pp.208) In system theory objects are structured to form systems to gain an added value. [Watzlawick et al., 1969] speaks of over summation. If components form a system by over summation[7] minor changes on parts (may) lead to major changes for the system. The principle of the counterfactual test used in CSA and WBA is a definite illustration of this effect.

[7] If they don't then the "system" is merely the "sum of its parts".

2.10 Summary

2.10.1 In what way has System Theory been used differently by the authors?

the ways of using a system theory can be categorised into three groups.

1. Theories explaining the structuring principles and working mechanics in systems under consideration.
2. Theories providing an ontology for further examination of the topic under consideration.
3. Theories on the principles of general systems.

Bertalanffy is the only one of the list of authors who belongs to the third category. All others belong to some degree to the first and to the second. Exceptions are Strohner and Jirasek who both only belong to the second category. Both give system theoretical and cybernetical reasons for their approach. But non are investigating the structuring principles of the systems under consideration.

2.10.2 Where are points of contact between the disciplines?

Some of the authors, but Bertalanffy especially, emphasise the interdisciplinary potential of system theory. Watzlawick for example put this into action by giving an interdisciplinary approach of communicational systems. Both linguistics and psychology are included in the approach. Though Watzlawick et al. do not incorporate two different systems to work together, there is no problem of linking linguistic and psychological terminology and concepts into a working whole.

2.10.3 Emergent Properties of Systems

One of the key interests in system theory is the generation of added value (or emergent properties) by structuring objects to systems. There are many hints to systems being "more than the sum of their parts". But a very through and in depth explanation on the mechanics of emergent properties can only be found in [Coleman, 1990]. Coleman introduces the concept of "macro-to-micro transition"[8]. When examining a social phenomenon Coleman not

[8] and the "micro-to-macro transition"

only takes into account the systems involved and their interrelations. With regard to the phenomenon in question the system will be analysed from top to bottom (macro to micro) to identify the parts contributing to the phenomenon. Then the system will be analysed from bottom to top (micro to macro) to determine the mechanics involved with the phenomenon.

Chapter 3

Formalising a General System

This ontology for a general formal system is derived from the concept of the *possible worlds semantic*, by David Lewis. David Lewis uses it to illustrate the concepts of causality and counterfactuals in [Lewis, 1986].

Whenever possible only set theory and logic has been used in formalising. Even if it is laborious in some places I decided to keep the construction mechanism[1] as simple as possible.

3.1 What is a General Formal System for?

Starting from the idea of formalising and categorising system behaviour a formal system world had to be established first. It can serve as a vocabulary to define system behaviour with formal strictness. There are attempts to disambiguate system behaviour, found for example in [Laprie et al., 1992], but are not done on a logico-mathematical basis.

3.2 Semantics and Designers

The designer of a system has to apply semantics to the formalism given. If done correctly the formalism can be examined to gain new insights on the semantic level. For each application of the general formal system there may be more than one suitable semantic interpretation. It is the designers task to choose the one best suited (e.g. choose the right level of abstraction, denote formal semantics to elements, systems, relations and properties)

For elements, systems, properties and relations there may always be innumerable trivial ones that will only hinder in establishing a working system

[1] not the constructed formalism

definition. As noted in [Hall and Fagan, 1956] care has to be taken to always consider the problem to be solved. In the long run the ability of the designer will strongly influence the usability of the system established.

3.3 A General Formal System

3.3.1 Element

Elements are the conceptional smallest parts in our ontology. For every design there has to be a lowest level of things participating.

$\mathscr{E}$ is the set of elements e. e is atomic.

3.3.2 Attribute

Attributes denote elements' or systems' characteristics. They are purely qualitative, meaning that the quantitative specificity will be denoted otherwise (see Values and Value Space)

$\mathscr{A}$ is the set of all attributes a. a is atomic.

3.3.3 Value Space

Value spaces are associated to attributes. They provide the potential for qualitative specificity.The actual value provides the current characteristic. The value space for each attribute has to be defined accordingly.

$\mathscr{V}_a$ is the value space associated with the attribute $a \in \mathscr{A}$.

3.3.4 Value

$v_a \in \mathscr{V}_a$ is the value associated with the attribute $a \in \mathscr{A}$.

3.3.5 Properties

Properties are attribute-value pairs. They can be related (see below for relations) to systems and elements to denote their characteristics.

$\mathscr{P}$ is the collection of all properties $p := (a, v_a)$
where:

$$a \in \mathscr{A}$$

$$v_a \in \mathscr{V}_a$$

3.3.6 Relations

Relations are *the* organisational force. They do not only provide means of structuring of systems and elements. They also provide the means for associating systems and elements with properties. Systems and elements do not *have* properties, but are related to them. Relations can exist between any number of systems, elements and/or properties.

$\mathscr{R}$ is the set of all relations $r := \{E, S, P\}$
where:

$$E \subset \mathscr{E}$$

$$S \subset \mathscr{S}$$

$$P \subset \mathscr{P}$$

Short forms:

$$\begin{array}{lll} e \vdash r & \text{for} & r = \{E, S, P\}, e \in E \\ s \vdash r & \text{for} & r = \{E, S, P\}, s \in S \\ p \vdash r & \text{for} & r = \{E, S, P\}, p \in P \end{array}$$

3.3.7 System

Systems are aggregations of elements, relations and (sub-)systems. But no subsystem can be a supersystem's supersystem. If we draw all sub-super-relations between systems we must end up having drawn a directed tree-graph. See below for a in depth discussion on the terms subsystem and supersystem.

$\mathscr{S}$ is the set of all systems $s_{sup} := \{E, S_{sub}, R\}$ where:

$$E \subset \mathscr{E}$$

$$S_{sub} \subset \mathscr{S}$$

$$R \subset \mathscr{R}$$

Short forms:

$$
\begin{array}{lll}
e \vdash s & \text{for} & s = \{E, S_{sub}, R\}, e \in E \\
s_{sub} \vdash s & \text{for} & s = \{E, S_{sub}, R\}, s_{sub} \in S_{sub} \\
r \vdash s & \text{for} & s = \{E, S_{sub}, R\}, r \in R
\end{array}
$$

3.3.8 Object

As a short form we will introduce the term object. If we need not distinguish between systems and elements we will refer to them as objects.

$\mathscr{O}$ is the set of all objects.

$$\mathscr{O} := \mathscr{E} \cup \mathscr{S}$$

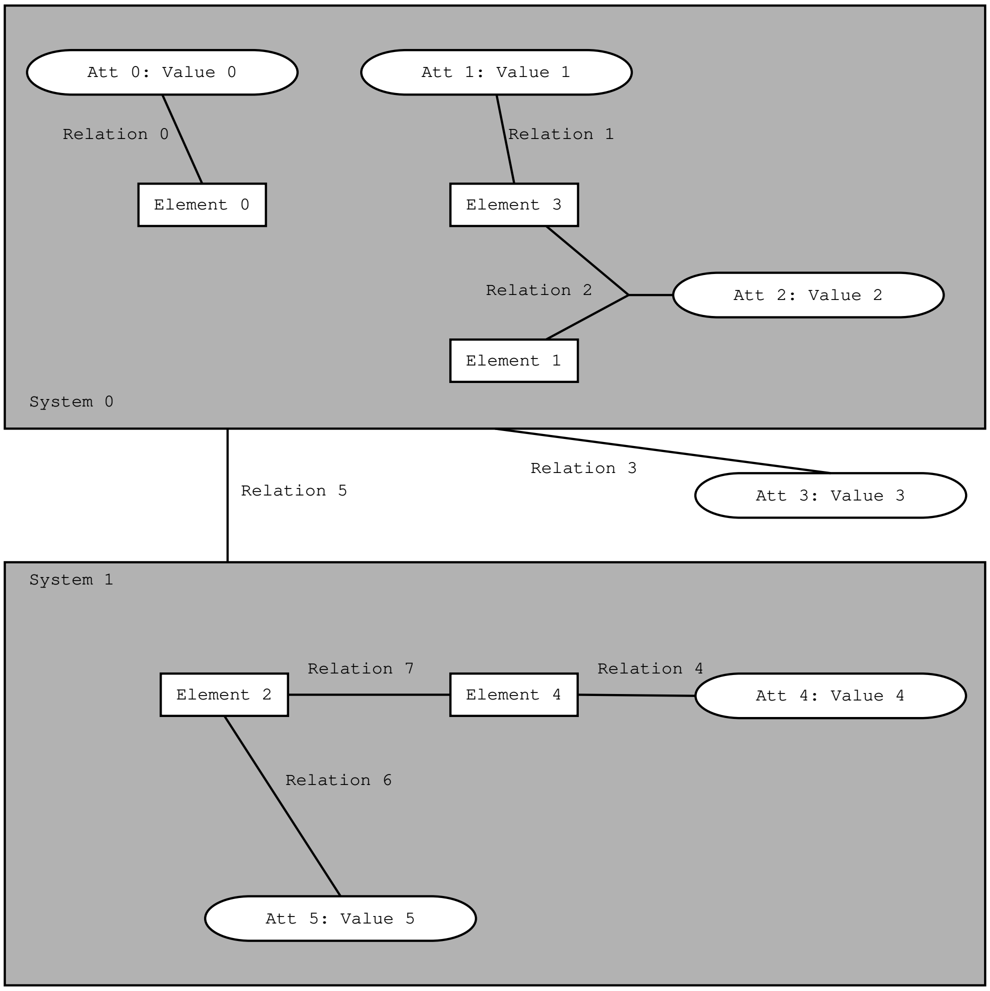

Figure 3.1: Illustration of a basic system

3.3.9 Subsystem, Supersystem and Part

We have seen that systems may contain other systems. The containing system is termed supersystem and the contained system is termed subsystem. Subsystems' subsystems (and so on) are considered to be non-direct subsystems (analogous for supersystems). We will only use the terms *non-direct* and *direct* where a distinction is of importance. Parts of systems are all subsystems, as well as all elements.

- A system s_{sub} is a direct subsystem of a system $s_{super} = (E, S, P, R)$, iff $s_{sub} \in S$.
  short: $s_{sub} \lhd s_{super}$

- A system s_{sub} is a non-direct subsystem of system s_{super}, iff $s_{sub} \lhd s_0 \lhd ... \lhd s_n \lhd s_{super}$, where $s_0, ..., s_n \in \mathscr{S}$.
  short $s_{sub} \lhd * s_{super}$

- A system s_{super} is a direct supersystem of system s_{sub}, iff $s_{sub} \lhd s_{super}$.
  short: $s_{super} \rhd s_{sub}$

- A system s_{super} is a non-direct supersystem of s_{sub}, iff $s_{super} \rhd s_0, \rhd ... \rhd s_n \rhd s_{sub}$, where $s_0, ..., s_n \in \mathscr{S}$.
  short: $s_{super} \rhd * s_{sub}$

- x is a part of a system $s = \{E, S, R\}$, iff $(x \in E) \vee (x \lhd * S)$.

3.3.10 System Border and Environment

The environment consists of elements and systems that are in contact with the system in question. If there exists a relation between two systems (or a system and an object) it belongs to its environment. System border and environment are to be defined by the designer arbitrarily.

The environment Env_s of a system s consists of all objects $\{o_0, ..., o_n\} = Env_s$ that share a relation $r_0, ..., r_m \in \mathscr{R}$ with s:

$$o_i \in \mathscr{O},\ 0 \leq i \leq n$$

$$r_k \in \mathscr{R},\ 0 \leq j \leq o$$

$$\forall o_i :\ o_i \vdash r_j\ \wedge\ s \vdash r_j$$

The system border is a conceptual and/or physical border. The border encloses all parts $p \vdash s$, but no non-parts $p_{neg} \nvdash s$.

3.3.11 Universe

The universe is an all-containing system. It represents the piece of the real or conceptual world the designer has interest in. All other systems are subsystems of the universe. There is no supersystem to the universe.

$$universe \in \mathscr{S}$$

3.3.12 Rules (static)

Rules determine a universe's structuring and the building parts contained (systems, elements, attributes, relations). Rules define restrictions on the construction of systems of a *universe*. Rules are divided into the following parts:

- a set of elements allowed in the $universe : L_E \subset \mathscr{E} := \{e_0, ..., e_n\}$
- a set of properties allowed in the $universe : L_P \subset \mathscr{P} := \{p_0, ..., p_m\}$
- a set of relations allowed in the $universe : L_R \subset \mathscr{R} := \{r_0, ..., r_l\}$
- a set of systems allowed in the $universe : L_S S \subset \mathscr{S} := \{s_0, ..., s_k\}$

3.3.13 State

A state consists of an object's relations and values of all properties related to it. The state of parts contribute to the state of their supersystem. If a system is observed over time the state of a system can be regarded as the condition the system is in at a given point in time.

$\mathscr{Z}$ is the set of all states.

object state: The state z_o of an element $o \in \mathscr{O}$

$$r_0, ..., r_n \in \mathscr{R}$$

$$z_o := \{r_0, ..., r_n\}, \ \forall r \in z_o : \ o \vdash r$$
$$state(o) : \mathscr{O} \mapsto \mathscr{Z}$$
$$state(o) = z_o$$

For short: $Z_O = \sum_{o \in O} state(o)$

3.3.14 State Transition (Event)

A change of state, respectively a transition of one state to another, occurs when one of the system's properties changes value or a relation changes. Event can be used synonymous for state transition.

$\mathscr{T}$ is the set of all state transitions $trans := (z_0, z_1), \ z_0, z_1 \in \mathscr{Z}$, where z_0 is the immediate predecessor of z_1.
short:$z_0 \rightharpoondown z_1$

3.3.15 Process

A process is a succession of state transitions.

$\mathscr{Q}$ is the set of all processes $q := (z_0, z_1, ..., z_n)$, where $\forall z_i, z_{i+1} : \; z_i \rightharpoondown z_{i+1}$ short: $z_0 \rightharpoondown *z_n$.

3.3.16 Rules (dynamic)

These rules determine restrictions on system states and transitions (see Possibility and Reachability below). They rules restrict the states elements and systems can be in and the transitions from one state into another.

- a set of all initial *universe* states.

$$Initial_{universe} = \{z_0, ..., z_n\}$$

- a set of possible transitions. A possible transition is a transition-probability pair $ptrans := (trans, n), \; trans \in \mathscr{T}, n \in \mathbb{R}$. If the universe is in a transition's starting state it is possible to transit into the corresponding end state. For all tuples with the same starting state the sum of all probabilities has to be equal or less than 1. If it is less than one no transition will be a possibility, too.

$$PTransitions_{universe} = \{ptrans_0, ..., ptrans_m\}$$

- a set of necessary transitions. A necessary transition is a transition-probability pair $ntrans := (trans, n).trans \in mathscrT, n \in \mathbb{R}$. If the universe is in a transition's starting state it is necessary to transmit into a corresponding end state. If there is a number of equal starting states a necessary transition will happen with the assigned probability. For all tuples with the same starting state the sum of all probabilities has to equal 1.

$$NTransitions_{universe} = \{ntrans_0, ..., ntrans_l\}$$

3.3.17 Equality

- Two properties are equal iff their attribute-value pairs are equal. Equality for attributes and values has to be defined according to value-space.

$$
\begin{array}{lcl}
p_0, p_1 \in \mathscr{P}\ a_0, a_1 \in \mathscr{A} & & \\
v_0 \in \mathscr{V}_{a_0}, v_1 \in \mathscr{V}_{a_1} & & \\
p_0 = (a_0, v_0), p_1 = (a_1, v1), & & \\
p_0 = p_1 & \leftrightarrow & a_0 = a_1 \\
 & \wedge & v_0 = v_1
\end{array}
$$

- Two elements are equal iff all of their related properties are equal to their respective counterparts.

$$
\begin{array}{lcl}
e_0, e_1 \in \mathscr{E}, & & \\
r_0, r_1 \in \mathscr{R}, & & \\
p_0, p_1 \in \mathscr{P}: & & \\
e_0 = e_1 & \leftrightarrow & \forall r_0, r_1 :\ e_0 \vdash r_0 \wedge e_1 \vdash r_1 \\
 & \wedge & \forall p_0 :\ p_0 \vdash r_0\ \exists p_1 :\ p_1 \vdash r_1,\ p_0 = p_1 \\
 & \wedge & \forall p_1 :\ p_1 \vdash r_1\ \exists p_0 :\ p_0 \vdash r_0,\ p_1 = p_0
\end{array}
$$

- Two relations are equal iff the elements involved are equal to their respective counterparts.

$$
\begin{array}{rl}
r_0, r_1 \in \mathscr{R} : & \forall o_0 :\ o_0 h r_0\ \exists o_1 : o_1 \vdash r_1,\ o_0 = o_1 \\
 & \wedge \forall o_1 :\ o_1 \vdash r_1\ \exists o_0 :\ o_0 \vdash r_0,\ o_0 = o_1 \\
 & \wedge \forall p_1 :\ p_1 \vdash r_1\ \exists p_0 :\ p_0 \vdash r_0,\ p_0 = p_1 \\
 & \wedge \forall p_0 :\ p_0 \vdash r_0\ \exists p_1 :\ p_1 \vdash r_1,\ p_0 = p_1
\end{array}
$$

- Two systems are equal iff all relations and parts inside the system are equal to their respective counterparts and all system properties are equal to their respective counterparts

$$
\begin{array}{rl}
s_0, s_1 \in \mathscr{S} : & \forall o_0 :\ o_0 \vdash s_0 \exists o_1 :\ o_1 \vdash s_1,\ o_0 = o_1 \\
 & \wedge \forall o_1 :\ o_1 \vdash s_1\ \exists o_0 :\ o_0 \vdash s_0,\ o_0 = o_1 \\
 & \wedge \forall r_1 :\ r_1 \vdash s_1\ \exists r_0 :\ r_0 \vdash s_0,\ r_0 = r_1 \\
 & \wedge \forall r_0 :\ r_1 \vdash s_0\ \exists r_1 :\ r_1 \vdash s_1 : r_0 = r_1 \\
 & \wedge \forall p_0 :\ p_0 \vdash s_0\ \exists p_1 :\ p_1 \vdash s_1 : p_0 = p_1 \\
 & \wedge \forall p_1 :\ p_1 \vdash s_1\ \exists p_0 :\ p_0 \vdash s_0 : p_0 = p_1
\end{array}
$$

3.3.18 Difference

$\mathscr{M}$ is the set of all measures m. Measures can be of one of the following kinds:

$$m_{property} : \mathscr{P} \mapsto \mathbb{R}$$

$$m_{relation} : \mathscr{R} \mapsto \mathbb{R}$$
$$m_{element} : \mathscr{E} \mapsto \mathbb{R}$$
$$m_{system} : \mathscr{S} \mapsto \mathbb{R}$$
$$m_{state} : \mathscr{Z} \mapsto \mathbb{R}$$

For all measures m the following applies:

- $\mathscr{X} = \mathscr{S} \vee \mathscr{X} = \mathscr{E} \vee \mathscr{X} = \mathscr{R} \vee \mathscr{X} = \mathscr{P} \vee \mathscr{X} = \mathscr{Z}$ (for convenience)
- $m(\emptyset) = 0$
- $m(X) \geq 0, \forall X \subset \mathscr{X}$
- $X_1, X_2 \subset \mathscr{X},\ X_1 \cap X_2 = \emptyset \Rightarrow m(X_1 \cup X_2) = m(X_1) + m(X_2)$
- $X_1, ..., X_n \subset \mathscr{X},\ X_i \cap X_j = \emptyset, 0 \leq i, j \leq n,\ m(\bigcup\limits_{i=1}^{\infty} X_i) = \sum_{i=1}^{\infty} m(X_i)$

3.3.19 State Space and Distance

The state space is multi-dimensional and states do not always only differ in quantity but also in quality[2]. With the introduction of state, system, element, property and relation measures the state space can be (at-least) semi-ordered. With the right measuring functions a total-order may even be established[3]. The difference quantised by the measure is the distance in state space between two states.

$dist(z_0, z_1) := \|m(z_0) - m(z_1)\|$, where $z_0, z_1 \in \mathscr{Z}, m(z_0), m(z_1) \in \mathscr{M}$

3.3.20 Stability

A stable object stays within the boundary of a stability condition. The stability condition defines a centre of stability, a measure to quantify the distance between the centre and the actual state and a maximum distance for the actual state to be stable.

$\mathscr{C}$ is the of all conditions $c := (z_{center}, dist(z_{center}, z_{current}), n_{maximum\ difference})$. $z_{center} \in \mathscr{Z}$ defines the *absolute* stable state of an object. $dist(z_{center}, z_{current})$ is the distance between the centre and the actual/current state. $n_{maximum\ difference}$ denotes the maximum difference between the centre state and the actual state for an object still to be stable (or within a stable area).

[2]which makes determining dimensionality rather tough

[3]Through "Gödelisierung" for example. Even though this may be questionable, semantically spoken

3.3.21 Possibility

The rules for state transitions define the possibilities of change in the state of a *universe*. There may be states that are possible states (legal states according to rules), but are not necessarily reachable (see below). For different initial states of the same *universe* possible-but-unreachable states may vary.

3.3.22 Reachability

The rules for state transitions define for each state z_0 a set of legal transitions to other states $z_1, ...z_n$. Those states are immediately reachable from z_0 since there is only one transition needed. If a process (a number legal of transitions) is needed to transit from z_{start} to z_{end}. z_{end} is reachable from z_{start}.

3.3.23 Classes, Instances and Inheritance

There are associations[4] between systems (and elements) with regard to equal (or equal-enough) structure and characteristics. Classes and instances are concepts widely used in software engineering (e.g. in programming languages like C++ or Java, or as means of modelling in UML or ER) as well as in biological animal and plant categorisation (e.g. species, families), among others.

There are two types of associations:

- class membership
- inheritance associations between classes

3.3.24 Element Classes and Instance

$\mathscr{C}_{element}$ is the set of all element classes. An element class $C_e \in \mathscr{C}_{element}$ is a set of unary functions, we will term them criteria, $c_e : \mathscr{E} \mapsto \{true, false\}$. An element $e \in \mathscr{E}$ belongs to a class C_e iff, $\forall c_e : \ c_e \in C_e, c_e(e) = true$.

3.3.25 System Classes and Instance

$\mathscr{C}_{system}$ is the set of all system classes. A system class $C_s \in \mathscr{C}_{system}$ is a set of criteria, $c_s : \mathscr{S} \mapsto \{true, false\}$. A system $s \in \mathscr{S}$ belongs to a class C_s iff, $\forall c_s : \ c_s \in C_s, c_s(s) = true$.

[4] "associations" is used as a substitute for the intuitive meaning of "relation", since the latter term is already occupied within the formal general system

3.3.26 Relation Classes and instance

$\mathscr{C}_{relation}$ is the set of all relation classes. A relation class $C_r \in \mathscr{C}_{relation}$ is a set of criteria, $c_r : \mathscr{E} \mapsto \{true, false\}$. A relation $r \in \mathscr{R}$ belongs to a class C_r iff, $\forall c_r : \ c_r \in C_r, c_r(r) = true$.

3.3.27 Property Class and Instance

$\mathscr{C}_{property}$ is the set of all property classes. A property class $C_p \in \mathscr{C}_{property}$ is a set of criteria, $c_p : \mathscr{P} \mapsto \{true, false\}$. A property $p \in \mathscr{P}$ belongs to a class C_p iff, $\forall c_p : \ c_p \in C_p, c_p(p) = true$.

3.3.28 State Class and Instance

$\mathscr{C}_{state}$ is the set of all state classes. A state class $C_{state} \in \mathscr{C}_{state}$ is a set of criteria, $c_{state} : State \mapsto \{true, false\}$. A state $state \in States$ belongs to a class C_{state} iff, $\forall c_{state} \in C_{state}, c_{state}(state) = true$.

3.3.29 State Transition Class and Instance

$\mathscr{C}_{trans}$ is the set of all state transition classes. A state transition class $C_{trans} \in \mathscr{C}_{trans}$ is a set of criteria, $c_{trans} : Transitions \mapsto \{true, false\}$. A state transition $trans \in Transitions$ belongs to a class C_{trans} iff, $\forall c_{trans} \in C_{trans}, c_{trans}(trans) = true$.

3.3.30 Inheritance

Inheritance is a way of hierarchically aligning classes. Inheriting classes (subclasses) contain all criteria from the inheritance class (superclass). The inheritance relation is transitive: If class A is a subclass of class B and B is a subclass of C, then A is a subclass of C.

Inheritance comes on two flavours:

Single-Inheritance Single-Inheritance structures classes strictly hierarchically. The inheritance relations form directed tree graph, where the most general class is the trees root node. No class can inherit from more than one class.

Multi-Inheritance Multi-Inheritance structures classes only semi-hierarchically. The inheritance relations form a directed graph. No class can inherit from one of it's subclasses, but inheritance from more than one class is allowed.

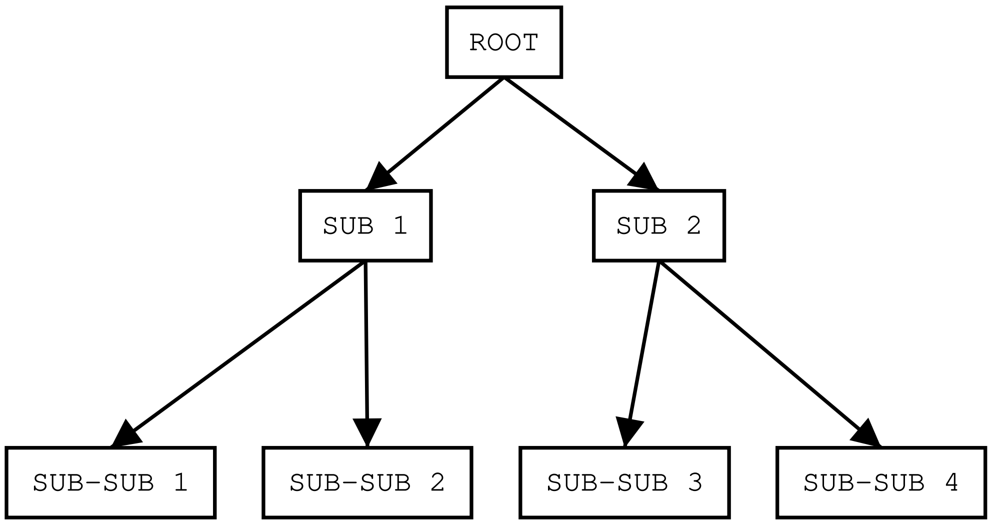

Figure 3.2: Single-Inheritance: directed tree graph

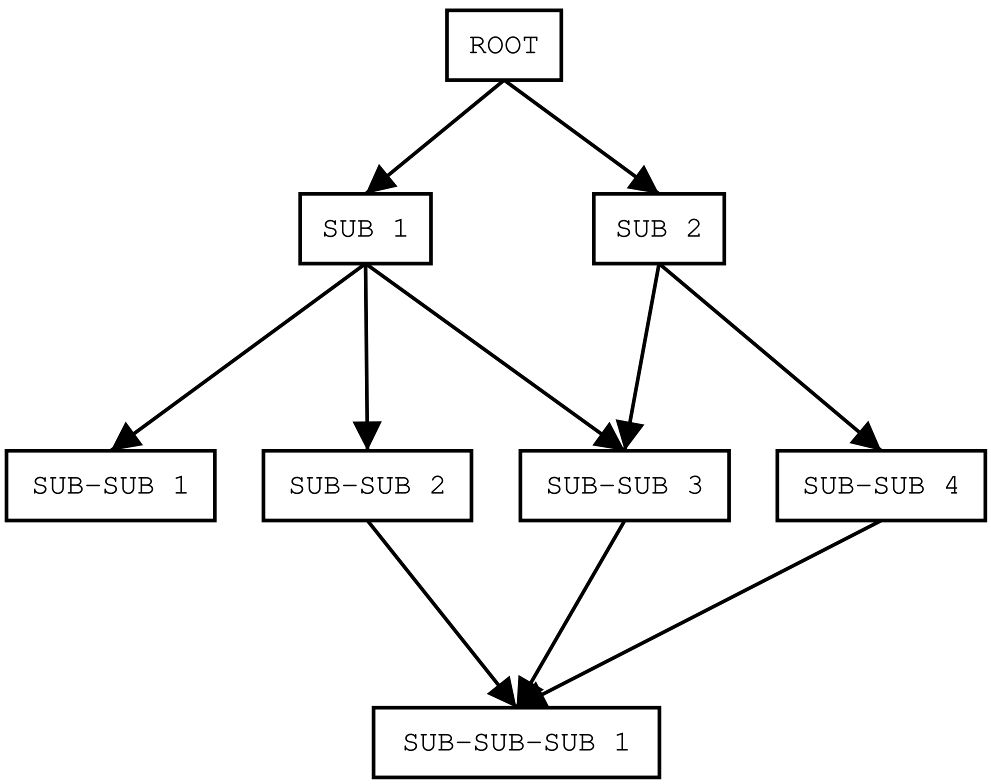

Figure 3.3: Multi-Inheritance: directed graph

3.3.31 Time

For descriptions of behaviour and processes time may be a factor of importance. If time plays a role in a *universe*, all elements will be related to a property $time := (t_{attribute}, t_{value}) \in \mathscr{P}$. The property denotes point in time.

3.3.32 Behaviour

Behaviour can be described discreetly by giving all transitions/processes in the *universe*. Linear behaviour is simply a process. Non-linear behaviour must discriminate between different processes under different (pre-)conditions.

$\mathscr{K}$ is the set of all condition-process pairs $k := (C_{state}, q), C_{state} \in \mathscr{C}_{state},\ q \in \mathscr{Q}$. q denotes the process that is performed if the system (and the environment) fits into the state class C_{state}.

$\mathscr{B}$ is the set of all behaviour b. b_s is the behaviour of a system $s \in \mathscr{S}$. It is a list of condition-process pairs. $b := (k_0, ..., k_n)$.

3.3.33 Telos

Telos (Grecian: end, border, goal) characterises systems to have purposeful behaviour (or can perform purposeful action). These systems either behave consciously or have been designed by a conscious system to imitate/simulate teleological behaviour.

To integrate Telos into the ontology we will simply assume that Telos is an element. To model a teleological system a system $s \in \mathscr{S}$ will be related to Telos: $\mathscr{R} \ni r_{Telos} := (\{Telos\}, \{s\}, \emptyset)$.

3.3.34 Interaction

Systems interact iff during the course of a transition relations involving both systems over the course of the transition change or during the course of a transition objects change their system membership. Systems may interact directly or by means of media. The media provide a way to interact with systems indirectly.

$\mathscr{I}$ is the set of all interactions. Two objects $o_0, o_1 \in \mathscr{O}$ interact iff there is a

change of relation

$$\exists r : \ r \in \mathscr{R}$$

$$\exists trans: \; trans = (z_0, z_1) \in \mathscr{T}$$

$$o_0 \vdash r \;\wedge\; o_1 \vdash r$$

$$((r \vdash z_0) \wedge (r\neg \vdash z_1)) \vee ((r\neg \vdash z_0) \wedge (r \vdash z_1))$$

or a

change of membership

$$\exists o_c: \; o_c \in \mathscr{O}$$

$$\exists trans = (z_0, z_1) \in \mathscr{T}$$

$$while\ z_0: \; (o_c \; \triangleleft * \, o_0) \;\wedge\; (o_c \; \neg \triangleleft * \, o_1)$$

$$while\ z_1: \; (o_c \; \neg \triangleright * \, o_0) \;\wedge\; (o_c \; \triangleleft * \, o_1)$$

short: $o_0 \otimes o_1$

3.3.35 Control

The controlling system has to be able to interact directly or via media with the controlled systems. The controlling system aims (purposeful action) at bringing the controlled systems into desired system states.

The controlling object o_{active} has a goal state $z_{goal} \in \mathscr{Z}$. Depending on the actual state $z_{now} \in \mathscr{Z}$ there may be a process $q = (z_{now}, ..., zgoal)$. The level of control equals the probability of instancing the process q.

Chapter 4

Information Flow Process in Human Communication

In this chapter a system of cognitive information passing is described. There is an ontology determining the participating elements and systems of the information flow process. The elements of the ontology are interacting with other elements of the ontology.

This information flow process between two communicating humans serves as an example for applied system theory. The level of abstraction is above the physiological level. The aim was to provide insight on the possibilities of a communicational deficiency in the information flow process. Where do they occur and why?

4.1 The Process

Sender and Receiver - Systems The sender's aim is the transmission of his-her own thoughts to one or more receiving parties. Both parties are able to attribute semantic and pragmatic meaning to the transmission and it's parts.

Gedankensatz - Element

- the gedankensatz is the most immediate form of knowledge representation to the sender
- the gedankensatz is created by the sender's mind or consciousness
- how it is created is not of importance

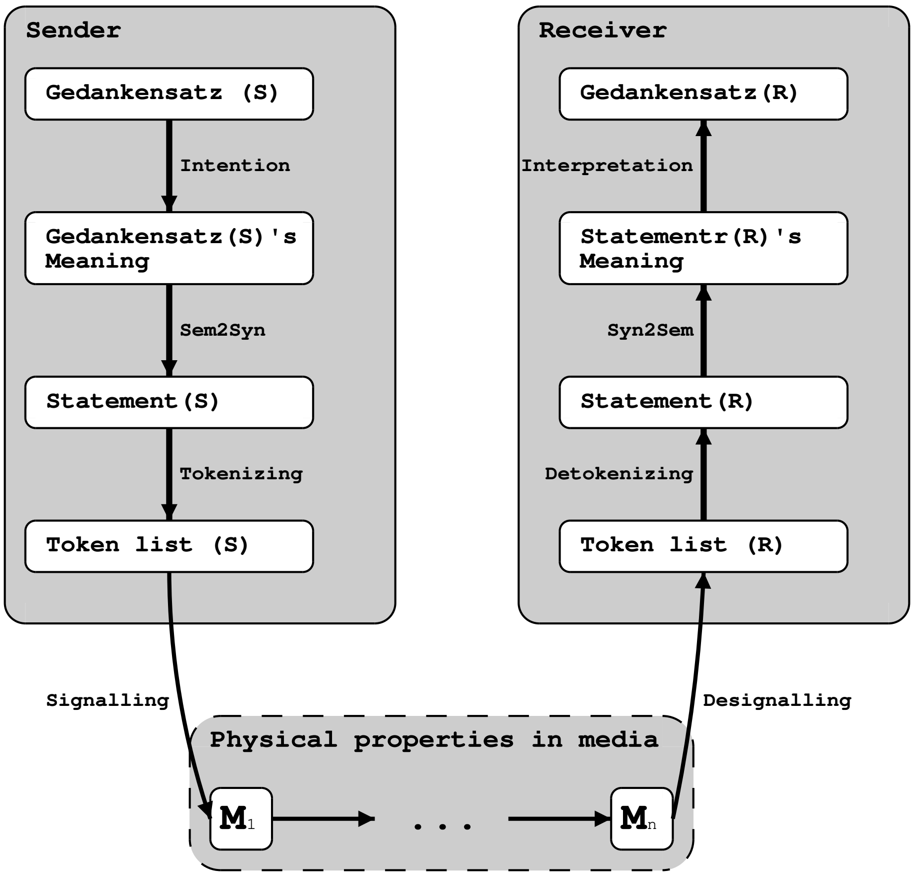

Figure 4.1: "Pipeline" model of the information flow between human communication partners

- the mind or consciousness has the ability to decide on the transmission of a gedankensatz to a selected destination
- the mind forms the intention and puts the gedankensatz into the transmission pipeline's front
- possible deficiencies: none

Intention - Function

- sender's intention to perform an action through the transmission (speech act)
- possible deficiencies: The senders knowledge of the receiver's knowledge or state of mind may be insufficient, leaving the receiver unable to comply as desired by the sender

Gedankensatz(S)' Meaning - Element

- after forming the intention an action is triggered
- the gedankensatz is being transformed into a semantic form that resembles its content
- the semantic form may deviate from the gedankensatz's content
- the sender may be aware of the possibility that the semantic representation may deviate
- possible deficiencies: the deviation may be sufficient to lead to misinterpretation of the transmission by the receiver

Transforming semantics into syntactics (Sem2Syn) - Function

- the semantic form of the content to be transmitted has to be transformed into a syntactic form
- the Sem2Syn function has to choose between several syntactic forms
- the sender chooses that form which seems most appropriate to the sender with regard to his-her knowledge of situation and audience
- the overall number of syntactical forms is limited by the senders knowledge of the language used

Statement(S) - Element

- the result of the Sem2Syn function. This form will be used for transmission.

Tokenizing - Function

- the syntactic statement is not suitable for direct transmission
- the syntactic statement has to be broken down into distinct transmittable units. This is done by the tokenizing function
- the units (tokens) do not carry information on their own

Token List(S) - Element

- the content is now available in a transmittable form, the token list

Signalling - Function

- the sender chooses one or more media for transmission
- the Token list is transformed into a command list for the sender's modulators
- the medium is manipulated by the sender's modulators
- transmission is done (roughly) token-wise

Physical properties of Media - Element

- the medium has to be accessible and manipulatable
- the transmission travels to the receiver in the form of recognisable changes in the mediums state
- possible deficiencies: The signals' way through the medium is subject to potential change through noise

Designalling - Function

- the medium has to be accessible for the receiver
- the medium's state changes are perceived by the receiver
- the receiver distinguishes potential informational state changes from others
- these are processed further and transformed into a token list
- possible deficiencies: insufficient perception/access to the medium; incapability to distinguish tokens in noisy transmission

Token list(R) - Element

- the receivers token list is a result of the signal processing function
- possible deficiencies: noisy transmissions can be understood due to sufficient redundancy, but the recovery of the content transmitted may fail

Detokenizing - Function

- the detokenizing function tries to transform the token list into a syntactic statement (that hopefully does make some sense)
- there may be more than one syntactic representation of the token list; the function has to choose one that seems most probable according to the situation
- possible deficiencies: problems in designalling can lead to problems in detokenizing. The situational awareness may detect the inadequacies of the designalling function or lead to a false syntactic interpretation

Statement (R) - Element

- syntactic form of the information gathered
- serived from the token list

Syn2Sem - Function

- this function transforms the syntactic statement into a semantic statement
- there may be many correspondences; the function has to choose one that suits the situation best, according to own knowledge/perception of situation
- possible deficiencies: inadequate choice of semantic representation

Statement(R)'s Meaning - Element

- this is the semantic representation of the information gathered

Interpretation - Function

- the Interpretation function transforms the semantic representation into a receivers meaning
- the interpretation of the semantic content (again) depends on the situation, knowledge and the receivers view of the sender

Gedankensatz(R) - Element

- a gedankensatz can be formed and assimilated by the receivers mind or consciousness; the transmission is complete
- the receivers action will be indicative to the sender whether the communication has been successful or not.
- note: even after a complete screwed up information transmission the receivers ability to judge the situation can lead to the effect desired by the sender; in some cases the existence or the perceived attempt to communicate may contain enough information for the receiver to act properly

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