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Semiotic Approach to Behaviour Patterns Emerging From Complex Systems

Bachelor Thesis

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Author’s declaration

I declare that current thesis is result of my individual work and that it has not been presented for defending any academic degree by anyone else.

03.05.2004 Kaupo Toom

Contents

Subject

Semiotic approach to behaviour patterns emerging from complex systems.

Problem

Too many studies of behaviour patterns of complex systems are bound to their statistical measurement and narrow causal inheritance. This thesis tries to give few examples of more thorough approaches to this field.

Goals

1. Determine suitable aspects of complex systems to be approached.
2. Present an idea of semiotic approach.
3. Give few examples of alternative approaches.

Main terms

All ideas presented in this thesis revolve around four terms mainly. These are: complex systems, emergence, behaviour patterns and semiotic approach.

Sources

Books of modelling and dynamics of complex systems, academic researches, scientific articles and my instructor, of course, have been used as guides and sources of information for writing this thesis.

Methods utilized

This thesis was brought to light by utilizing following methods:

1. Set up of goals.
2. Gathering of potentially appropriate literature.
3. Filtering out data matching to goals.
4. Analysis of core data
5. Roundup of core data into readable form

Structure of the thesis

Current thesis is made up of two main parts. The first part gives some insight on pith of complex systems. Description of main properties of complex systems and several common examples of complex systems are provided there. Few examples of what the complexity is and how it is related to structure of a complex system are presented. And, of course, explanation of emergence of behaviour and behaviour patterns in complex systems is given.

All areas mentioned above are closely related to second part of the thesis which is made up of two logical parts itself. The first logical part of it is devoted to overall semiotic analysis of complex systems and structural semiotic analysis of behaviour patterns and their emergence from complex systems. Second logical part of it is composed of several alternative semiotic approaches which are more or less modified to make them exploitable for current field.

To be precise:

1. The broad semiotic analysis sustains in correlation of elements of complex systems theory to elements of theory of semiotics. Explanation of how exactly semiotic approach to complex systems and to behaviour patterns emerging from them is possible and what it is composed of.
2. First of the alternative approaches is named "example of a semiotic approach", is an example of analysis of behaviour patterns in relation to themselves, to the class of patterns they represent and in relation to its human interpreter.
3. Second of the alternative approaches, "information processing", which is a method that using one of the semiotic models represents one possibility for analysis of emergence of meaning out of raw data which has three usages in context of this thesis: first, it represents a way for gathering data about phenomenons of interest in a system studied; second, it represents a broad view of a possible pattern of emergence of meaning in complex systems; third, it gives a good overview of the idea of semiotic layers which provides a sound tool for studying very different aspects of any phenomena, in this case – behaviour patterns.

4. Third of the alternative approaches, “semiotic approach to communication”, is a thorough reductional analysis of communication act, very suitable for analysis of behaviour patterns.
5. Fourth of the alternative approaches, “qualitative semiotic approach”, is a thorough method for analysing existing complex systems and behaviour patterns in them using semiotic theories, which can also be applied for building complex systems.

Introduction

There are probably not too many cases where creators or examiners of complex systems do not want to get a hold of things happening to system under study. Questions like *how will the system act under certain circumstances*, *how behaviours of the system are related to its structure* and *what are the impacts of future modifications or of environmental changes to systems behaviour* are keen to find an answer. Sometimes structural analysis[1] of the system proves itself as a provider of awaited answers, sometimes (for AI related systems mainly[2]) more complex utilities are brought to light.

Author considers semiotic approach to behaviour patterns emerging from complex systems to be a good idea because semiotics is a rather mature science with some very good methods for studying different phenomenas and semiotics and the theory of complex systems have quite a few things in common[3].

In following chapters explanations for *what the complex systems and behaviour patterns are* and *what the semiotic approach exactly is* are given.

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[1] Definition for „structural analysis“ is provided in chapter „2.1 Structural Semiotic Approach“.
[2] Authors individual experience.
[3] Explanations with examples can be found in chapter „2.1 Structural Semiotic Approach“.

1 Complex Systems

The field of science traditionally has no concept of values or evaluation.

Yaneer Bar-Yam

Abstract

Complex systems (CS) can be regarded as something that their name sounds like - they are systems that are complex (to study and measure). The theory of CS is believed to be something that helps people dealing with CS to study them. In some cases maybe even understand them. [2] [3]

Some people (author of this thesis included) tend to think that crossing and opposing different theories to each other will probably help us understand each of them a little better, as Yaneer [3] put it – "transferring ideas from different areas leads to new results." Theory of CS intercepts with numerous theories of other fields (physics, sociology, semiotics) and thus is potentially broadly usable. For example "developing the tools to address questions about the dynamics of human civilisation is appropriate within the study of complex systems. [3]"

"Many of the systems that surround us are complex. The goal of understanding their properties motivates much if not all of science inquiry. Despite the great complexity and variety of systems, universal laws and phenomena are essential to our inquiry and to our understanding. The idea that all matter is formed out of the same building blocks (atoms and their constituent particles) is one of the original concepts of science." [3]

"All scientific endeavours are based, to a greater or lesser degree, on the existence of universality, which manifests itself in diverse ways. In this context, the study of complex systems as a new endeavour strives to increase our ability to understand the universality that arises when systems are highly complex." [3]

Still CS cannot be defined in any solid manner. CS are comparable to a point in space - it cannot be defined, but it can be described through its properties.

CS are mesoscopic phenomenons – study of systems with too many parts would lead to exploitation of tools of conventional thermodynamics, then again, study of systems having only few parts is not in scope of this thesis even if they have considerable amount of complex interactions between them. Since description of CS as "systems having not too many nor few parts" is rather discursive, the fact that most CS studied are purposive (they have some reasonable meaning) should be mentioned.

One way to see CS would be approaching them as "something existing on pseudo quasi aprioristic structural layers as endless variations and combinations of phenomenons of physical intensive finitism (being part of the "concept of physical integroinfinitism" which is part of "physical separative hierarchism" which is part of the "thesis of physical intensive infinitism" [4]).

1.1 The Field of Complex Systems

One definition of the word "complex" is: "consisting of interconnected or interwoven parts". It is believed that properties of CS are closely related to their parts. [2] [3] But then again, simple systems are also formed out of parts. Yaneer [3] uses terms "interconnected" and "interwoven" to distinct simple systems from complex ones. In simple systems reductionism can be used in order to understand how the system works as a whole. In complex systems, studying behaviour of the parts would lead to nothing. The behaviour of the parts, their relations to other parts and how they act together to form the behaviour of the whole must be taken into consideration. "It is because we cannot describe the whole without describing each part, and because each part must be described in relation to other parts, that complex systems are difficult to understand[4]." [3]

[4] This is relevant to another definition of "complex": "not easy to understand or analyse". [3]

“The field of study of complex systems holds that the dynamics of complex systems are founded on universal principles that may be used to describe disparate problems ranging from particle physics to the economics of societies”. [3] “A corollary is that transferring ideas and results from investigators in hitherto disparate areas will cross-fertilise and lead to important new results.” [3]

Author with several other people [2] [3] does not expect it to be possible to provide a succinct definition of a complex dynamical systems. Instead it is productive to give examples of such systems and thus provide the elements of their description.

System can be considered to be complex if large amounts of interrelated and interdependent parts assure performance of complex functions by the system has to be taken into consideration when studying the system. [1][2][3] However, even a few parts can behave in complex way (but we are interested of systems that contain more than a few parts) and if there are too many parts (there is usually a limit to the number of parts we are interested in), even if they are strongly interacting, the properties of the system become the domain of conventional thermodynamics [3]. Another characteristic of most complex dynamical systems is that they are in some sense purposive, which means that the dynamics of the system has a definable objective or function, that there is some sense in which the systems are engineered [3]. This topic can also be viewed as systems self-organisation or organisation by design [3].

How does the study of complex systems in general pertain to the detailed efforts devoted to the study of particular complex systems? In this regard on must be careful to acknowledge that there is always a dichotomy between universality and specificity.
A study of universal principles does not replace detailed description of particular complex systems. However, universal principles and tools guide and simplify our inquiries into the study of specifics. For the study of complex systems, universal simplifications are particularly important. Sometimes universal principles are intuitively appreciated without being explicitly stated. However, a careful articulation of such principles can enable us to approach particular systems with a systematic guidance that is often absent in the study of complex systems. [3]

1.2 Examples

Large phone network [1], airport with its personnel and customers (planes, people) [2], governments with their regulations and different layers [3] and the human body from psychological perspective are few examples of complex systems.

Examples of simple systems being contrast to complex systems are a binary switch, spinning wheel [3], an orbiting planet [3].

1.3 Central Properties of Complex Systems

Identification of commonalities between objects and phenomenons of complex systems is second recommended step after beginning to describe complex systems [3]. List of some characteristics of complex systems with measures or attributes assigned to them might be a good idea for first method of classification or description [3].

Elements (and their number)
Interactions (and their strength)
Formation/Operation (and their time scales)
Diversity/Variability
Environment (and its demands)
Activity(ies) (and its [their] objective[s])

Such list is a first step toward quantification properties of complex systems. Quantitative measurement of last three items of that list requires certain methods for counting which is one of the central issues quantitative complexity [3]. Examples of methods for measuring complexity of complex systems are given in chapters 1.5.1 and 1.5.2.

1.4 Behaviour Patterns and Emergence

In next few chapters explanations with examples for *what behaviours and their patterns are*, *what do they sustain of* and *how do they come into being* are given.

1.4.1 Behaviours, patterns, behaviour patterns

Dictionary's [10] response[5] for word **behaviour**[6] is:

1. anything that an organism does involving action and response to stimulation;
2. the response of an individual, group, or species to its environment;
3. the way in which something functions or operates.

Dictionary's [10] response[7] for word **pattern**[8] is:

1. a form or model proposed for imitation;
2. something designed or used as a model for making things (a dressmaker's pattern);
3. a natural or chance configuration (frost pattern, the pattern of events);
4. a reliable sample of traits, acts, tendencies, or other observable characteristics of a person, group, or institution (behaviour pattern);
5. a discernible coherent system based on the intended interrelationship of component parts;
6. frequent or widespread incidence.

Authors defines behaviour pattern as *systematic response (reaction, output) of an entity to certain outside stimulation (input)*. Dynamics of heartbeat [26], shopping habits of elder people [29], chafing of guppies [27], motions of autistic children [28] are few examples of behaviour patterns. Even though patterns refer to repetition the integral part of patterns is the fact that they are never repeated exactly. Closer studies done in that field can be found in the theory of chaos with examples of *Lorenz*

[5] Original output of the dictionary was altered by author in order to present meanings more suitable for purpose of this thesis.
[6] Alteration of Middle English behavour, from behaven.
[7] Original output of the dictionary was altered by author in order to present meanings more suitable for purpose of this thesis.
[8] Comes from Middle English patron, from Middle French, from Medieval Latin patronus.

attractor [30], *Gaston Maurice Julia "Julia set" and Benoit Mandelbrot "Mandelbrot set"* [30] which refer to the idea of *strange attractors* [30]. Closer overview of how behaviours emerge is given next in chapters 1.4.1 and 1.4.2. More technical explanation for what makes them so complex is given after that in chapter 1.5.

1.4.2 Local Emergence

"The field of complex systems are built on fundamental concepts – emergence, complexity." [3] The most profound problem that the study of complex systems faces is the determination of cause, form and time of emergence of complex collective behaviours (inflicted by large number of simple atoms). [3] The problem can be approached first by developing an understanding of the term 'emergence'. [3] Collective behaviour is contained in the behaviour of the parts if they are studied in the context in which they are found. It can be explained further by studying emergent properties that illustrate the difference between local emergence – where collective behaviour appears in a small part of the system – and global emergence – where the collective behaviour pertains to the system as a whole. [2] [3]

"We can speak about emergence when we consider a collection of elements and the properties of the collective behaviour of these elements. In conventional physics, the main arena for the study of such properties is thermodynamics and statistical mechanics." [3] To illustrate this Yaneer [3] used an example of a gas of particles which has two emergent properties – pressure and temperature. "The reason they are emergent is that they do not naturally arise out of the description of an individual particle." [3] Generally particles are described by specification of their position and velocity [3]. "Pressure and temperature become relevant only when we have many particles together." [3] Both, the pressure and temperature can be called local emergent properties because the way they are emergent is very limited [3]. "The pressure and temperature is a local property of the gas." [3] (Same) Pressure and temperature can be defined and measured when a very small sample of a gas is taken away from the rest [3]. "Such properties, called intensive in physics, are local emergent properties. Other examples from physics of locally emergent behaviour are collective modes of excitation such as sound waves, or light propagation in a medium.

Phase transition (e.g., solid to liquid) also represent a collective dynamics that is visible on a macroscopic scale, but can be seen in a microscopic sample as well.” [3]

Formation of water from atoms of hydrogen and oxygen can be taken as example of local emergent property to [3]. “The properties of water are not apparent in the properties of gasses of oxygen or hydrogen. Neither does an isolated water molecule reveal most properties of water. However, a microscopic amount of water is sufficient.” [3]

1.4.3 Global Emergence

The study of complex systems is particularly interested in global emergent properties [3] since such properties depend on the entire system. One reason why global emergence is not well appreciated or understood comes from the effort their mathematical treatment requires. Hopfield’s[9] network also known as an attractor network can be considered as the classic analysis of global emergent behaviour [3].

“The analogy to a neural network is useful in order to be concrete and relate this model to known concepts. However, this is more generally a model of any system formed from simple elements whose states are correlated.” [3] But if all elements are correlated in a simple way local emergent behaviour is the outcome [2] [3]. Therefore a model must be sufficiently rich in order to capture the phenomenon of global emergent behaviour [2] [3].

“The Hopfield network has simple binary elements that are either ON or OFF. The binary elements are an abstraction of the firing or quiescent state of neurons. The elements interact with each other to create correlations in the firing patterns. The interactions represent the role of synapses in a neural network. The network can work as memory. Given a set of pre-selected patterns, it is possible to set the interactions so that these patterns are self-consistent states of the network – the network is stable when it is in these firing patterns. Even if we change some of the neurons, the original patterns will be recovered. This is an associative memory.” [3]

[9] Hopfield network – associative memory in a simple model of neural networks

In neural network memory the content of storage location is specified [3] instead of assigning an address to each storage location, which is the way computer memory works. In latter case one needs to know the exact address to access the information stored in a particular location. But even more important disparity between computer memory and the network is the fact that in a computer memory a particular bit of information is stored in a particular switch in contrast to network which does not have its memory in a neuron, but in the synapses [3]. In the Hopfield model, there are synapses between each neuron and every other neuron [3]. If a small part of the network is removed, then the number of synapses that a neuron is left with in this small part is only a small fraction of the number of synapses it started with, when looking at the properties of the network [3]. When a small part of the network, which had more than a few patterns store, is cut out, the network loses its ability to remember any of the patterns, even the part which would be represented by the neurons contained in this part [3]. Emergent properties are characterised by behaviours of that type. Emergent properties cannot be studied by physically taking a system apart and looking at the parts (reductionism) [2] [3] [22]. “They can, however, be studied by looking at each of the parts in the context of the system as a whole [2] [22].”[3]

In the section of local emergent properties it was suggested, that taking a small part out of a large system causes little change in the properties of the small part, or the properties of the large part [3] in contrast to a system having global emergent properties, where the behaviour of the small part is different in isolation than when it is part of the larger system [3]. It is possible to identify a system that has a global emergent property (being formed out of interdependent parts), if one considers system as a whole, rather as thinking of it as a small part of another system [3]. Therefore it is possible to characterise complex systems through the effect of removal of part of the system [3]. There are two natural possibilities [3]. Either the properties of the part are affected and the rest is not affected or the properties of the rest are affected by removal of the part [3]. The latter system has a collective behaviour that is dependent on the behaviour of all of its parts which can be studied further when it is connected to a quantitative measure of complexity [3].

1.5 Complexity

There are several ways for complexity to emerge. It is apparent that parts of a complex system are often complex systems themselves [2] [3], which means that the complex behaviour of the system can emerge from the complexity of their parts [2] [3]. Another possibility is called emergent complexity, which can be found in systems composed of simple parts where the collective behaviour is complex [2] [3]. “The idea of emergent complexity is that the behaviours of many simple parts interact in such a way that the behaviour of the whole is complex.” [3][10]

There is also a possibility for a system composed of complex parts where the collective behaviour is simple [3]. This behaviour is called emergent simplicity [3]. Yaneer [3] used an example of an orbiting planet to illustrate this. It was because the behaviour of, for example, the Earth is quite simple despite of the many complex systems upon it. That example illustrated the possibility for the collective systems to have behaviours at a different scale than their parts. “On the smaller scale the system may behave in a complex way, but on the larger scale all the complex details may not be relevant.” [3]

As mentioned in the emergence section, the second approach to the study of complex systems begins from an understanding of the relationship of systems to their parts [3]. “A complex system is a system formed out of many components whose behaviour is emergent, that is, the behaviour of the system cannot be simply inferred from the behaviour of its components [2]. The amount of information necessary to describe the behaviour of such a system is a measure of its complexity [2].” [3] Other words, the complexity depends on the layer of detail required in the description [2] [3]. This drives one to quantitative definition of complexity. Quantitative definition of complex systems provides one with more precise definition of complexity and with tools for both, measuring complexity of a system and comparing layers of complexity of several different systems. As mentioned above, complexity is the amount of information necessary to describe a system [2] [3] (according to information theory

[10] „Elements are those parts of a complex system that may be considered simple when describing the behaviour of the whole.” [3]

and computational theory – other words statistical physics and computer science). "However, in order to arrive at a consistent definition, care must be taken to specify the layer of detail provided in the description." [3] One of the main questions related to quantitative aspects of complexity is therefore - how is it bound to emergence – emergent complexity and emergent simplicity. "[…] why information-based complexity is related to the description of elements, and how their behaviour gives rise to the collective complexity of the whole system?" [3]

1.5.1 Measuring complexity I

For specifying a state in which a system with many possible states exactly is, one needs actual number of all possible states. If one uses binary digits (bits) for this and the number of states is called Omega, then the number of bits of information required is

$I = \log_2(\text{Omega})$ (1.5.1.1)

Specifying the systems state means that all states must be enumerated which requires as many numbers as there are states [3]. "[…] the number of states of the representation must be the same as the number of states of the system." [3] Since for a string of N bits there are 2^N possible states

$\text{Omega} = 2^N$ (1.5.1.2)

which implies that N is the same as I above [3].

For a microstate of a physical system, where positions and momenta of each of the particles is to be specified, this can be recognised as proportional to the entropy of the system [3], which can be defined as

$S = k \ln(\text{Omega}) = k \ln(2)\, I$ (1.5.1.3) where $k = 1.38 \times 10^{-23}$ Joule/^{o}Kelvin is the Bolzmann constant which is relevant to conventional choice of units [3]. Entropies of order 10 bits per atom are typical when using measured entropies [3]. The reason k is so small is that the quantities of matter typically considered are in units of Avogadro's number (moles) and the number of bits per mole is 6.02×10^{23} bits [3].

"The positions and momenta of particles are real numbers whose specification might require infinitely many bits. Why isn't the information necessary to specify the microstate of a system infinite?" [3] By the theory of quantum physics microscopic states are indistinguishable unless they differ by a discrete amount in position and momentum – a quantum difference given by Planck's constant h [3]. It also indicates that particles like nuclei or atoms in their ground state are uniquely specified by this state, and are indistinguishable from each other [3]. "There is no additional information necessary to specify their internal structure. Under standard conditions, essentially all nuclei are in their lowest energy state." [3]

1.5.2 Measuring Complexity II

In practice, complexity of the system often relates to choosing appropriate system [2]. Other words, after considering factors like effectiveness, firmness etc, and discovering that several systems have same qualities, usually the more complex is chosen [2].

One rather primitive [2] but thorough and proven method in practice sustains in considering that the viewed system is composed of n types of elements. For every type of elements their complexity is appointed (intuitively, basing on gathered experience) using some measurable scale [2]. Let us mark the complexity of element of type i through s_i. And let us view systems composed of n type of elements only.

The complexity s of a system sustaining of elements with complexity of s_i, $i = 1, 2, \ldots, n$, will be marked as

$$s = \sum_{i=1}^{n} s_i k_i$$

(1.5.2.1)

where k_i is the number of elements of type i, being parts of the system viewed [2].

This approach has approved itself in many practices despite its primitive pith (measure s does not reckon with complexity of system functions and characterizes its structure in a rather narrow manner without considering interdependence of elements) [2].

In order to reckon little more with systems structure formula 2.13 has to be made to depend on amount of connections between elements of the system [2]. One way for doing that would be next. It is obvious that amount of N elements of the system is equal to

$$\sum_{i=1}^{n} k_i$$

(1.5.2.2)

Maximum amount of connections between elements equals to $N (N - 1)$. Let us mark the real amount of connections utilised in the system as M^*.

The size

$$\alpha = M^* / N (N - 1)$$

(1.5.2.3)

characterises approximate amount of utilised connections.

Therefore the complexity of the system can be characterised as

$$s = (1 + v\alpha) \sum_{i=1}^{n} s_i k_i$$

(1.5.2.4)

where v is the coefficient which takes the complexity of connections into consideration with the complexity of the elements of the system.

2 Semiotic Approach

Abstract

Author chose semiotics as the most suitable field with various tailorable methods for studying complex systems and behaviour patterns emerging from them. Within next several chapters definitions for most important terms, concepts of semiotics and several modified methods for analysis of behaviour patterns shall be provided.

Questions like why it is a good idea to use semiotic approach for studying behaviour patterns or complex systems are answered.

2.1 Structural Semiotic Approach

2.1.1 Semiotics

Etymology of the word *semiotics* starts from Greek words *semioticos* – observant of signs, *semeiousthai* – to interpret signs, *semeion* sign and *sema* – sign [10].

There are several officially recognized definitions for word *semiotics*. Like *a philosophical theory of the functions of signs and symbols* [8] or *a general philosophical theory of signs and symbols that deals especially with their function in both artificially constucted and natural languages and comprises syntactics, semantics and pragmatics* [10].

Mihhail Lotman [20] proposes usage of semantics only. Other words, that semiotics is a study of signs and sign systems and that semiotics is interested of semantic mechanisms only. Of what *is* the meaning and *how* is it bound with a sign. Semiotics is not interested either in causal connections between things or causal connections between the sign and its meaning (questions like *why* the connection occurs etc).

Kevin C. Desouza proposes that domain of semiotics can be divided into the study of the following: *syntactics*, dealing with relationships or linkages between various components; *semantics*, concerned with putting the relationships in context and perspective; and *pragmatics* that garners meaning and insight from relationships within the context of the first two sections. [7]

Author of this thesis regards *semiotics* as study of signs, their meanings and relationships between signs and their meanings. As for domain of semiotics, author of this thesis would add two more layers to those proposed by Desouza. These would be *physical* and *empirical* aspects of signs, their meanings and their relationships. More substantial explanation for what was meant by *physical*, *empirical*, *syntactic*, *semantic* or *pragmatic* layers will be given in chapter Information Processing.

2.1.2 Semiotic Approach

If something is semiotic then it means that this something is *relating to semiotics* (e.g. *semiotic analysis*) [8].

To *approach* means *to draw closer or nearer* to something, *to make advances to especially in order to create a desired result.*

From point of view of widely recognised J. Lotman semiotic approach would probably be synthesis of concept of *semiosphere*[11] and ideas Pierce and Saussure. For Gunther Kress in his socio-semiotic works semiotic approach would probably sustain in determination and further study of motivational relationship between a sign and its signifier.

For author broad definition of semiotic approach sustains in studying different phenomenons through utilisation of semiotic theories (*semiosphere, umwelt*[12]) and ideas (*semiotic layers*) and through interpreting any object studied in semiotic context.

[11] Idea presented by J. Lotman which states that semiosphere is the ultimate semiotic system embedding all other systems.

[12] Idea presented by baron Jackob von Uexküll which states that every selfaware entity has its own individual set (room) of meanings called Umwelt – own world.

Word *studying* is regarded as *analysis* in scope of this thesis. Its definitions follow:

1. An investigation of the component parts of a whole [8][9];
2. The abstract separation of a whole into its constituent parts for study [8][9];
3. Tracing of things to their source, and resolving of knowledge into its original principles [9];
4. Qualitative or quantitative study of objects or phenomenons.

As seen in given definitions, author regards study as analysis by reductionism. Either if it is reduction of parameters (of object of interest) into qualitative (what) and quantitative (how much) aspects or it is just reduction of something into smaller recognisable logical or physical parts or it is reduction of phenomenons by their properties onto semiotic layers, it is still reductionism.

As stated in chapters 1.2 and 1.3, behaviour of the whole system cannot be understood by analysing its parts only. Which can be interpreted as "one cannot always benefit from analysis by reduction because it may not give the one all those answers he or she is looking for". But it is point of view of author that the lack does not always come from method of analysis, but its inappropriate use. Why should anyone try to study complex phenomenons of complex systems by just looking at few elements of the system? If method of analysis is applicable for both, whole systems and their parts, equally, and one is interested in the parts, the system and phenomenons that emerge from co-operation (and inter-connectedness or inter-relatedness) of the parts (or their groups) and influence somehow existence of the system, one should use that possibility in implementation of that method to all object mentioned above.

This is where the theory of complex hierarchical systems comes in. It is believed, that from standpoint of theory of complex hierarchical systems[13] parts of complex systems can be complex systems themselves and complex systems can act as parts for another systems[14]. Anything can be studied when implementing proper methods, therefore, all on needs to know is what to look for and how to study it. Both those things (what to study, how to study) will be presented flowingly.

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[13] First mentioned in chapter 1.4

[14] For both, complex and simple systems. Discussed in chapter 1.4.

Since behaviour patterns were phenomenons that occurred in systems and emerged from different forms of co-existence of parts (and/or groups of parts) of those systems and by that affecting forms of existence of those systems[15], author proposes to utilise semiotic approach against next objects and phenomenons: *system*, *part* (or groups of parts) of a system, (regular) acts of *behaviour* of the system and its parts. Basically, it is a form of structural analysis[16], in this case, done with semiotic approach.

2.1.2.1 System

is the whole structure which behaviour is of interest. From point of view of cultural semiotics (which has three main objects of interest - text, culture and semiosphere [20]) complex systems can be regarded as complex structured entities which elements react to different input texts with output texts (variables, commands, noise). These, in turn, can be interpreted by both, elements themselves and outside evaluators of the system, in contexts of systems culture (rules – algorithms, inner logic of the system) which (behaviour of parts of the system or the whole system) in turn can be interpreted by outside evaluators in all possible ways of interpretation available for them in semiosphere.

That kind of approach can be beneficial because this way, it is stated, that there are several logical layers or fields in the system studied, which behaviour can have all kinds of interpretations by the elements of the system and by systems outside evaluators. Simple and sound in here it gets a bit more sophisticated touch in chapter "Semiotic Approach to Communication." Guidance for modelling complex systems (using semiotic approach) in manner to get them behave the way they are expected to, is presented in chapter "Qualitative Semiotic Approach."

2.1.2.2 Parts and groups of parts

(further mentioned as agents) are directly responsible for systems behaviour. From semiotics point of view, agents of complex systems are objects that possess Umwelt

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[15] Chapter 1.4.

[16] Stuctural analysis is a study of systems which sustains in defining the system itself, defining its elements, relationships between those elements [2] [3]. In case of this thesis - defining charts of those relationships, other words – patterns, too. As Yaneer [3] put it "A specific system is selected and each of the parts as well as their interactions are identified and described. Subsequently, the objective is to show how the behaviour of the whole emerges from them."

and are able to give outputs to perceived inputs (variables, commands, noise). Agents are interpreters which can manipulate with data on different semiotic layers. But agents cannot manipulate with any data on layers they are not designated to interpret. Considering with that is rather convenient, because it makes it easier for analysts or builders of complex systems to reckon with cultural, technical, other words – communicational aspects of agents. And communication (reaction – outputs to inputs) is what behaviour is all about. Counting with semiotic aspects of agents helps one to determine whether that agent can make out in certain cultural context (certain system or part of a system), whether it can interpret data on semantic, pragmatic or even social layer. Or how good is that agent in exchange of data on physical, empirical or syntactic layer. Of course those questions have to deal with aspects of conformity and congruity of either the agent, group of agents and their environment and some answers to those questions can be found in following chapters.

2.1.2.3 Behaviours and behaviour patterns

are acts of reaction of systems or their parts to perceived inputs. Common semiotic example of behaviour pattern can be found in theory of semiosis, which states that the act of interpretation of something (the act of semiosis) sustains in “a process of translation, which makes a copy of a text, suitable to replace the original text in some situations, but which is also so different from the original text that the original cannot be used (either spatially, or temporally, or due to the differences in text-carrier or language) for the same functions.” [24] It must be mentioned again that thorough analysis of preceding ideas is presented in chapter “Semiotic Approach to Communication.”

When building a complex system with certain behaviour patterns or analysing patterns of existing system, it must be determined where that pattern is expected to emerge (in context of the whole system). After that, it would be appropriate to determine what this pattern should consist of. Semiotic equivalent of pattern is a sign. Common semiotic definition of the word sign is “regularity”. As Cliff Joslyn put it [23] (sign is) “a deterministic, functional regularity or stability in a system, also sometimes called a sign-function.” Since sign is usually a part of some text, it can be said that pattern is a part of some other larger piece of meaningful or meaningless data (text). And that piece of data (text) is usually a part of another larger dataset of meanings – the language.

One can benefit from that knowledge by adding it methods for studying different aspects sign, text and language. Rather thorough overview of emergence of meaning and analysis of existing data (by using theory of semiotic layers) can be found in chapter "Information processing." One of ideas presented there sustains in fractioning parts of behaviour patterns onto semiotic layers in order to study their most different (physical, morphological etc) aspects.

2.1.2.4 Emergence of behaviour patterns

(which is discussed in context of theory of complex systems in chapter 1.4) is designed or self-emerging phenomena in systems which has usually one purpose – self-preservation through adaptation. Example of semiotic approach to it can be found in theory of autopoiesis [25] which characterises systems which either maintain their defining organization throughout a history of environmental perturbation and structural change or regenerate their components in the course of their operation.

The most profound questions about emergence of behaviour patterns are related to how, why and when those patterns emerge and how the process of emergence can be controlled in order to either induce or to constrict certain behaviours. Author proposes that utilisation of the theory of semiotic layers is appropriate at this point. It seems sensible to assume that processes occurring on higher semiotic layers are closely related to those on lower ones. Therefore study of how manipulation with processes on lower layers can impact on those on higher layers should be considered. Presentation of methods for statistical studies of behaviour patterns in complex systems is not in scope of this thesis, however, ideas of how different semiotic layers and processes on them are related to each other can be found in chapter "Information Processing."

2.2 Example of a Semiotic Approach

When looking for a rather light and, from analytical point of view, broadly exploitable method for semiotic approach author stumbled upon Eleonora Bilotta´s and Pietro Pantano´s method [16], which was originally meant for analysing icons in graphical user interface (GUI). It consisted of three basic steps with sub-steps related to semantics and hermeneutics. The surprising feature of this model is the broad area its additional sub-steps or layers cover. Its ten sub-steps range from perceptual analysis to psychological profiling and classification.

Main difference of this approach from others derives from its exploitative range. Every step of interpretation and classification is viewed as through a different point of view - the object (behaviour pattern), from object to system, from system to object.

There are two ways for exploiting original approach. The first one would consist in renaming *icon* to *behaviour pattern* and trying to interpret the whole research model, as it would have been originally meant for analysis of behaviour patterns. The second one would consist in presentation of original model with comments to its potential exploitation in the field of research of behaviour patterns in complex systems. Since the second approach is beneficial in two ways by giving one the overview of the original model plus an interpretation of its potential exploitation the author will use the latter.

Originally, the model for approach looked like that:

1) The icon is analysed in relation to itself
2) The icon is analysed in relation to the object it represents
3) The icon is analysed in relation to the human interpreter

In the context of this thesis the preceding model could be presented as:

1) Behaviour pattern is analysed in relation to itself
2) Behaviour pattern is analysed in relation to the behaviour class it represents
3) Behaviour pattern is analysed in relation to the human interpreter

The second step of this modified model could be a reason for confusion, probably, as it states that "the behaviour pattern is analysed in relation to the behaviour it represents". In this context phrase "behaviour pattern" acts as a piece of information or individual object, which is being analysed, and as a class of objects which is being represented by that piece of information or individual object also.

From the system analysts' point of view, it is easier to interpret same approach as:

1) An object analysed as a system itself
2) An object analysed in relation to another system
3) A system analysed in relation to object (another system)

When dividing those three steps into sub-steps one gets a result which was originally presented as next: "The first step is carried out through a *perceptual*, *formal* and *gestalt* analysis. The second step […] is carried out through *hermeneutic*, *semantic*, *functional*, and *communicative* analysis. The third step is carried out through a *cognitive*, *experiential*, *emotional* analysis […]."[16] Altogether there are ten aspects or attributes to determine and identify.

The perceptual analysis was originally performed through utilisation of aspects of Selfridges's [8] [16] theory of characteristics. According to Selfridge "the elaboration of visual material is organised in a hierarchical way, with a first layer that verifies the presence, in the input, of various characteristics; and with a second layer which activates specified recognition analysers, particular to those specific characteristics." [16] In the behaviour patterns research one could potentially use both parts of the perceptual analysis and the formal analysis with gestalt analysis, which will be later in this thesis identified as a physical or morphological semiotic layer.

From the general systems theory (GST) point of view, the perceptual analysis part dealing with verification of presence of input of various characteristics can be regarded as verification of the input signal to a receptor system. Part of the activation of input signals recognition analysers can be utilised in its original form.

Formal analysis sustains in dividing the object into "basic elements of visual communication, considering the underlying structures like dot, line, direction, hue, texture, shape, scale, dimension and motion."[16] "These structures let us to divide an icon into its components parts; while gestalt analysis allows one to put these parts together again, arriving at the re-construction of the whole icon, in a process that is not derived from the sum of the single structures, but is a constructive process of the mind." [16]

These sub-steps can be interpreted as a part of analysis on the physical layer. Their aim can be regarded (by GST) as identification of individual parts of which the whole behaviour pattern is formed.

"The second step, which refers to the object the icon represents […]" [16] – in our case to the class of behaviours (or conventional or non-conventional meanings) the behaviour pattern refers to – "[…] is carried out through hermeneutic, semantic, functional and communicative analysis." [16]

"Hermeneutic analysis considers the interpretation of icons into the socio-cultural context in which they can be found or utilised. This analysis "emphasises those areas of human experience where individual interpretation and intuitive understanding play a central role." [16] This part of analysis can be interpreted as a derivative of structural and syntactical analysis. Its original purpose is useful in its basic form for its practical utilisation in study of behaviour patterns.

"Semantic analysis deals with the relation of an icon (and of an object) to all the meanings it carries, defining not only the areas the object refers to (a network of meanings), but also the possibility of creating a shared-universe of conventional meanings, which can be utilised by a group of users in that particular domain [1] [16]." Same approach can be utilised exactly, if word *icon* gets replaced with *behaviour pattern* and put in the context of complex systems theory.

The *functional and communicative analysis* was originally meant for determining different alternatives of behaviour when using specific GUIs. All possible modes and functions of GUIs were listed and analysed in this step. When studying behaviour patterns in CS, this step of analysis can be used as a part of analyses in systems structural analyses on physical, morphological and syntactic layer. But instead of execution of this step after semantic analysis author of this thesis prefers and recommends its utilisation as one of the first steps of semiotic approach. The analysis would consist in determining different (sub) behaviour patterns utilised in interaction with specific elements of a system (e.g. functions, meanings).

"The third step is carried out through a cognitive analysis of the mechanisms the user utilises when he/she is interacting with the interface and with a set of functions, meanings, behaviours that an icon allows. Learning does not depend on the retention of an iconís formal structure, but on the user's ability to create (given certain conditions) behaviours that satisfy his own aims. It is therefore necessary to establish: a) the user's experience of the icon in that particular context; b) what his emotional responses in relation to that icon are; c) what his aims are (pragmatics) and d) the user's psychological profile." [16] This step has potential usage on higher layers of analysis when studying objects behaviour patterns certain aspects from another system perspective. Aim of this analysis would be study of definite inter-actors influences to another system (affecting systems behaviour patterns) being in inter-dependent relations with it. But since basic elements of CS can be extremely simple, there is always a chance that it is impossible to assign any properties from those layers of analyses to them. Therefore, any practical utilisation of analyses of the third step depends on definitions given to the researchable elements or groups of elements.

As a conclusion for a review of this method it can be said that it had all basic layers of semiotic research and that in modified form it can be used for studying behaviour patterns in complex systems.

2.3 Information Processing

In order for semiotic approach to behaviour patterns to take place, one must have some kind of data to analyse. That data can be gathered by utilization of information processing method using semiotic model. Information processing using semiotic model represents one possibility for analysis of emergence of meaning out of raw data which has three usages in context of this thesis: first, it represents a way for gathering data about phenomenons of interest in a system studied; second, it represents a broad view of a possible pattern of emergence of meaning in complex systems; third, it gives a good overview of the idea of *semiotic layers* which provides a sound tool for studying very different aspects of any phenomena, in this case – behaviour patterns.

Semiotic layers are something one can utilize for building a multilayer framework of a system or for studying existing system using a fine scale analysis. Semiotic layers help one to diagnose important root problems related system quality[17] [18], like communication issues for example[18] [12].

Semiotic layers can be divided into two groups in order to reveal the technical versus the social aspects division. "Physics, empirics and syntactics, taken together, constitute a domain where technical and formal methods are adequate. Semantics, pragmatics, and the social domain can hardly be explored if those methods are used exclusively and without modification." [12] Thus, whilst one may attempt to confine ones thinking about the computerized parts of information systems within a limited framework of formal concepts, one will find difficulties if he/she aims at finding a similarly productive solution for the semantic, pragmatic and social domain [12].

All these layers are relevant when discussing and setting up or analyzing a framework of systems concepts [12]. "Sometimes, a term may be used at one or a few layers only. The terms 'bit' or 'byte' for example are mainly used at the empirical layer. More often however, a term is used at several or even all of these layers. A typical example of such a multilayer-related term is 'message'. One can talk about the

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[17] Examples are given in chapter „Semiotic Approach to Quality."

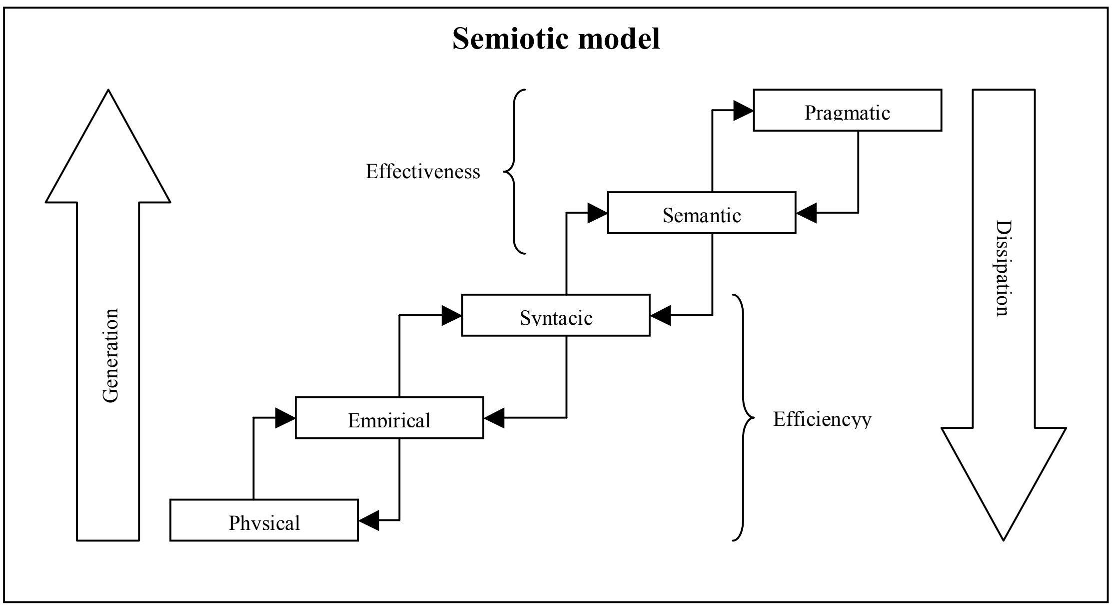
[18] Examples are given in chapters „Semiotic Approach to Communication" and „Semiotic Approach to Quality."

physical appearance of a message, about its entropy, about its syntax and semantics, as well as about its pragmatics in a social context. At each layer, the notion of ‘message’ will inevitably bear a different meaning.” [12] “The problem is that people, when uttering those multilayer-related terms, frequently fail to mention the layer or layers they are focusing on, which may result in severe misunderstanding.” [12]

One of the most thorough and known approach to semiotic layers is provided by Ronald Stamper [18] with method called ‘semiotic ladder’. It consists of six layers, which are physical, empirical, syntactic, semantic, pragmatic and social, which can be interpreted as systems structural aspects, dynamic aspects, syntax, semantics, objective and organization for example [18].

Another similar model was provided by Desouza and Tobin Hensgen [19], which was originally meant for studying information generation and dissipation through five semiotic layers, and which is presented below with some modifications to it.

Aim of the method is information filtering from raw data to actionable information, which sustains of three steps through five (semiotic) layers. On each layer data is *gathered*, *filtered* and *sent to higher layers* until actionable information is derived. The process is potentially iterational, which means, that high-layer actionable data may provide new raw data, which then can be processed through same layers for derivation of new actionable information.



2.3.1 Physical[19] layer

consists of gathering generative data, which means that data being gathered is general and potentially unnecessary [19]; actions on physical layer represent a start in data collection which might be primal guide to some information. "Not all data will sprout useful information. Organisations identify the type of data to collect by flagging any source that fits rather broad, though established, parameters." [19]

Stress is on the physical appearance, the media and amount of data available. Concerns are related to objects and agents at a rudimentary stage [7]. "At this layer, it's more critical to begin the process in step with the semiotic model than to become weighed down overanalysing the types of data to collect." [19] The lack of any co-ordinated scheme can result in improper channelling of gathered data.

Each object is analysed in isolation and an agent's activity is considered as in isolation [21]. Analysis layer is restricted to individual acts executed by an agent [21]. "At the *physical* layer, focus is on the quantity, rather than the quality, of data. As the data filters upward in the semiotic model it quickly becomes more focused." [19]

2.3.2 Empirical[20] layer

consists of first-layer data analysis [19]. "At the *empirical* layer, investigators have broadly filtered data, but not critically evaluated it. This appraisal should validate usefulness and give weight to the significance of the collected data, as well as determine whether synthesis is likely to provide information. This process assigns a value to data." [19]

Data is on *empirical* layer when each bit of data represents a raw observation and one conclusion, based on other empirical data sources coming from one place [19]. At this junction one is concerned with grouping "like" knowledge objects and agents [21].

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[19] Comes from Middle English *phisicale* – medical, from Medieval Latin *physicalis* – from Latin *physica*. [10] Physical: having a substance or material existense, perceptible especially through the senses. [10]

[20] Empirical: capable of being verified or disproved by observation or experiment [10]; received through the senses either directly or through extensions [13].

This may be referred to as categorisation [21]. Statistical properties of similar object for example [7]. The entropy, variety and equation encountered [7]. Patterns, codes, efficiency [11]. "A key task in the processing of objects and agents at this layer is summarisation." [21] The layer of summarisation is dependent of needs and design of the system [21]. "The higher the layer of summarisation, the less detail we have on individual transactions. The lower the layer of summarisation, the more details we have, but this approach uses more storage resources." [21] It is at this layer that one garners the first information that may be used to initiate some actions, however, information is not knowledge and to initiate any real action at this layer is premature [21].

2.3.3 Syntactic[21] layer

consists from relational interpretation of data [19]. Failures in usage of data occur not because data is not collected; rather, there are failures to put it together properly [19]. "The *syntactic* layer is a crucial stage in which investigators have purposefully synthesised collected data to uncover the possible and meaningful relationships among data from divergent sources. At this layer, deductive processes establish a virtual reality upon which to base preliminary decision-making." [19] The focus is on deriving complex or high-order information by assimilating and linking objects and agents from the physical or empirical layers [21]. The primary concern is structuring individual items into meaningful sets; common tasks include ensuring referential integrity and defining relationships, according to some syntax [21]. Stress is on language, structure and logic used [12]. Records, protocols, files [12]. Objects and agents observed at the physical and empirical layers are generally interdependent and interrelated [21]. Consequently, detecting patterns and relationships will help one predicting potential activities [21].

Not properly channelled available information along semiotic model can lead to intransigent activities because of the inability to react or respond to it [19].

[21] Comes from Latin *syntacticus*, from Greek *syntaktikos* – arranging together, from *syntassein* [10]. Syntactic: Of, or relating to, or according to the rules of syntax [8] or construction [9]. Syntax: the way in which linguistic elements are put together to form constituents or meaningful utterances [13]; a connected or orderly system [8], harmonious arrangement of parts or elements [10], a number of things joined together [9]. Syntactics: a branch of semiotics that deals with the formal relations between signs or expressions, is abstraction of their signification and their interpreters [10].

2.3.4 Semantics[22] layer

consists of measuring systems uncertainty. Semantics, the next-to-last layer of the semiotic model, derives higher-layer meaning from information. It can be thought of as pre-emptive, rather than reactive, information in that if the investigators act on information efficiently, decision-makers can act pre-emptively rather than wait for the information-based, calculated act to materialise and then react to it. Semantics can be considered to be similar to the concept of entropy (degree of uncertainty); the value of information here is in its surprise factor. Channels carrying the information experience noise, like all channels, but it must be considered that they contain elements of certainty associated with the information also. Elements in the state of positive certainty must be considered first. [19]

Semantics call for an encapsulation of knowledge objects in some frame of "reality" or systemic context. [21] "The semantic layer helps achieve this goal, through careful analysis of the components of the relationship in the appropriate global or system context. This requires the study of relationships among the objects, their associations, and the role of the system as a whole." [21] The meaning and validity of what is expressed [12]. Thorough analysis of the components of relationships in appropriate system context [12]. Propositions, signification, denotations, intended/interpreted meanings [12]. An important role at this layer is played by viewing relationships in context of system's definition. "The system boundary will determine whether an object and its relationships are 'inclusive' or 'exclusive'. At the semantic layer, knowledge objects are 'captured' in terms associated with the perception of the reality of the moment." [21]

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[22] Comes from Greek *semantikos* – significant, from *semainein* – to signify/mean, from *sema* – sign/token [10]. Semantics: The study of meanings, the historical and psychological study and the classification of changes in the signification of words or forms viewed as factors in linguistic development [10]; a branch of semiotics dealing with relations between signs and what they refer to, including theories of denotation, extension, naming and truth [10]; the meaning or relationship of meanings of a sign or set of signs [10].

2.3.5 Pragmatics[23] layer

: actionable information. Plausible actions are a function of the semiotic model at the pragmatics layer. One objective of this layer includes the action of debriefing members associated with each layer as to effect (success or failure) of their contribution to the ultimate decision(s) for action. [19]

At the pragmatics layer, the cumulative information gained through use of the model provides the basis for action by decision makers [21]. Stress is on the intentions, responsibilities and consequences behind the data [12]. Communication – conversations, negotiations, speech acts, comprehension [12]. On this layer, every piece of knowledge gathered from previous layers is synthesised, and reaction to that knowledge is required [21]. Responses may include acting directly and/or dissipation of information gained from any of the layers [21]. “It is likely advantageous to ‘recycle’ the information gleaned and start the semiotic process a second time to filter information further. A second run is more sensitive to timing and redundancy, i.e., information that is picked up the second time is likely more valuable because it validates earlier information while at the same time some things picked up the first time may be discarded as not useful and do not clutter this second run with noise.” [21]

On the figure above, the conclusion of the semiotic cycle is on the left side because after generation you have dissipation. As people take action, they uncover other information. Using this new information, the cycle begins again, moving through the five steps to formulate new actions. [19]

Ultimately, the model should modify the behaviour of personnel involved at various layers of the model’s generation side. “The change will arise from information use or non-use.” [19]

[23] Comes from Latin *pragmaticus* – skilled in law or business, from Greek *pragmatikos*, from *pragmat-*, *pragma* - deed, from *prassein* - to do [10]. Pragmatic: related to matters of practical affairs [8]; guided by practical experience and observation rather than theory [8].

2.4 Semiotic Approach to Communication

Analysis of communication[24] gives one an understanding of how something provides some kind of output to some kind of input. Other words, some entity's reaction to some kind of input which is the basis of behaviour – reaction to something. Communication analysis can be beneficial in quite a few ways. Model of communication can represent not only one entity's reaction to some other entity's output, but it represents pattern of communication between groups of entities as well as different systems. There would not be complex systems and thus no behaviour patterns either, if there were no interconnectedness e.g. communication between elements of the system and between elements and the system embedding them.

Semiotic approach to communication provided here can be considered as an inside-out version of Claude Shannon's and Warren Weaver's model of communication, which was preceded by Harold Lasswell's 1948 model of communication process [8][17][22].

It is usable to know potential communication mechanisms between interacting inter-dependent parts of systems in order to study behaviour patterns in them.

If we are to deal with multi-agent systems, answers must be provided for questions like:

- What knowledge and capabilities such systems may have?
- How to find out what exactly such systems understand?
- "What constraints pertain to a particular agent?
- Which activities lie within its scope and which do not?" [5]

Answers to these questions sustain in developing an understanding of the abilities of agents to communicate and reason [5]. "To do this, we need an architecture, which reveals the significant components of the agent with respect to its abilities to interact." [5]

[24] Communication: an act or instance of transmitting [10]; a process by which information is exchanged between individuals through a common system of symbols, signs, or behaviour [10].

When trying to find modelling methods for such architectures, author stumbled upon a functional model of interacting systems [5] with a semiotic touch to it. It is made for studying communication in human-computer interaction (HCI), computer supported co-operative work (CSCW) and artificial intelligence (AI). Other words – multiple inter-acting systems consisting of humans, intelligent agents or ´dumb devices´.

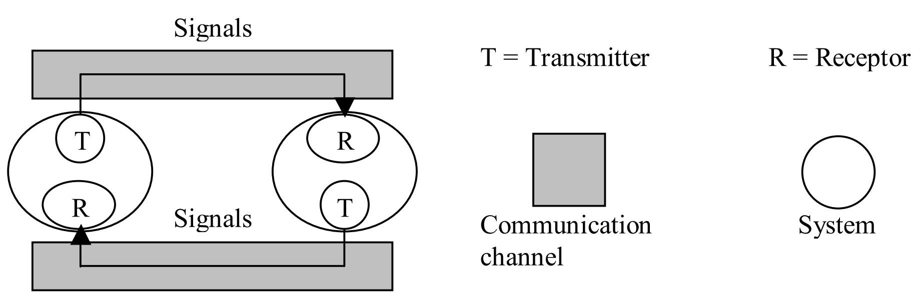
David Benyon [5] provides "the basis of a theory of interaction within which communication can be understood and capabilities of systems to communicate are brought to the foreground." It sustains in providing theoretical model for system-system interaction and study of that interaction at finer detail. It consists of two main parts, an overview of interaction and a detailed view of interaction. The latter is divided into four sub-parts: the receptor, deriving semantics, information and knowledge, transmission.

2.4.1 Interaction

Interaction between any two systems involves the physical exchange of signals which are the 'elementary particles', the basic units of interaction [5].

"Signals are units of transmission (at some layer of abstraction), which travel through a communication channel […]." [5] In order to send signals, system requires transmitter function and in order to receive signals, it requires receptor function [5].

Figure 1. General model of system-system interaction



Apart from simple systems exchanging signals interactions concerned with CSCW, HCI and DAI usually involve exchange of meanings carried by signals. “Meaning may be defined as the relationships, which exist between some signals and existing knowledge. If those relationships are not present, meaning will be absent.” [5] Meaning of some signals for a recipient system can be interpreted as the ‘selective function’ which those signals have on the system’s knowledge [5].

“Two other definitions are relevant. Information is the value added, or ‘surprise value’, arising from the receipt of some signals. Information is to do with things which were unknown, or which could not be known before the information was derived.” [5] In this case one should not be concerned with syntactic information, which is the subject of information theory, but with semantic aspects of the data [5]. Knowledge is a representation, which may be viewed as a network of beliefs and propositions, possessed by a system [5]. “Semantic information, then, is defined as ‘an increment of knowledge’ [5] – an enhancement of the network of beliefs and propositions. Information about X is obtained by a system, if the receipt of signals enriches the system’s representation of X.” [5]

“If systems only interact by exchanging signals, then how does a system derive any information or meaning from this exchange?” [5] David [5] answers this by looking inside a system, which has received some signals. As shown in figure 2, there are three major processes one can identify, which are necessary if information is to be obtained from those signals [5].

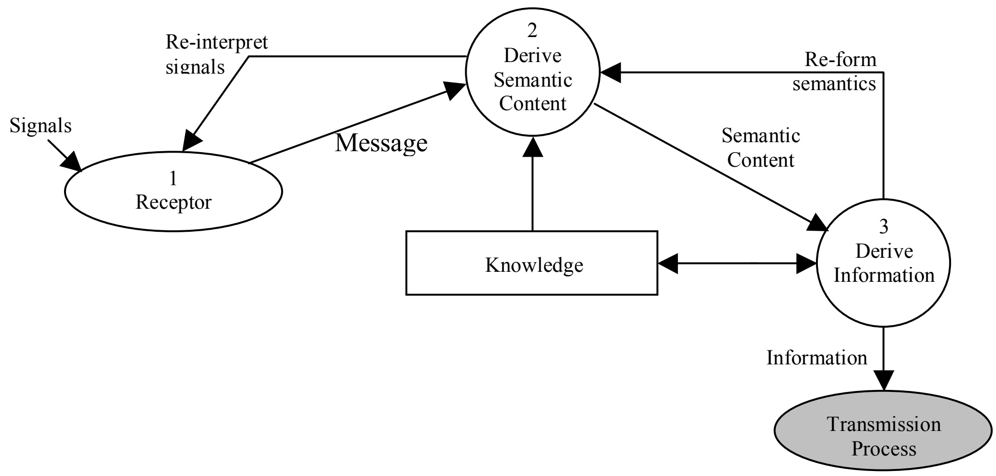
Raw signals received by the receptor process (process 1) are transformed into a structured set of signals, called message [5]. Number of algorithms, rules, heuristics and other operators embedded in this message along with existing, stored representations (knowledge) in addition to the contents of signals are employed in the process [5]. When talking about representations, one should not forget that conventional theories about representation are rather primitively false [6].

Making (again) use of existing knowledge, the “derive semantic contents” process (process 2) transforms the message into a representation of the semantic contents of the message [5]. Reformation of the message may be necessary at this point and in order for this to occur signals may be passed back to process 1 [5].

Semantic content of the message is derived by process 3 and the store of knowledge is being updated [5]. If information cannot be derived from the semantics of the message, the message may be sent back to process 2, where the semantics are then being re-formulated [5].

Next, each of these parts of the functional architecture is given a closer look. To be clear, David [5] mentions that, of course, not all systems possess all these functions. By examining the functions at a finer detail, roles of each part of the architecture can be seen and, hence, identify the abilities of different systems.

Figure 2. Main processes involved in receiving and interpreting signals



2.4.2 Interaction in more detail

"Signals are units of transmission. They travel along a channel between the source and the destination system." [5]. "Individually signals do not mean anything; they do not signify. Signals exist in time and space and have characteristics associated with these dimensions […]. Signals may be considered binary signals in that they exist or they do not exist." [5]

The transmission of signals requires some structure to be observed and if this structure is not as anticipated, the signals may be taken to signify something other than what was intended. [5]

When signals are received and interpreted, they may become signs i.e. they may signify something else. In order to signify something, a signal must be placed into a context of a system of signification, which links the purely syntactic expression of the signal(s) to a semantic system. Meaning may be derived from this relationship. It is this relationship – between the signal(s) and the things signified – which is a sign. [5]

Here David [5] brings up Eco, who emphasises, that it is the relationship, which is the sign, by saying, that a sign is always a sign-function. Also following Eco, one may use the term sign-vehicle for the syntactic part of the sign (i.e. for the signals, once they are associated with a semantic system) and sign content for the semantic part of the sign. Symbol is used by a number of authors to indicate things, which the receiving system 'understands' – i.e. the sign contents. A symbol is the conceptual side of a sign. [5]

Following and interpreting Eco (who bases his model on Hjelmeselv), David [5] defines the

- signifier (or sign-vehicle), which is the signals, when placed in a relationship with a system of signification
- signified (or sign content), which is the (conceptual) entity associated with a signifier, when put in relationship with a system of signification
- sign (or sign-function), which is the relationship between the signifier and the signified

Both, the sign-vehicle and the sign content, have a substance representing what each is and various different forms, or representations. A signal is the substance of the sign's expression. The term 'symbol' is reserved for the substance of the sign content.

2.4.2.1 The receptor

The receptor is the mechanism, which receives the signals and produces a coherent structured set of signals (a message) [5]. Hence, it is most important that the receptor is tuned to the form of the sign's expression, i.e. that it can receive the signals [5], an appropriate class of signals on appropriate layer. The sensitivity of the system to the signals is a feature of the receptor. Also, the receptor has to actively process and organise the signals it receives [5]. "The receptor has to be sensitive enough, yet robust enough, to deal with difficulties and noise." [5]

In context of the model presented here (figure 3, see below), the receptors are passive in respect to the signals they can receive. Issues related to system focusing attention or active seeking of signals from surrounding environment, may be attributed to some higher layers of functioning, which organise and direct the receptors available, by either tuning them or making them more or less sensitive [5].

On figure 3 David [5] illustrates, conceptually, the operation of the receptor function. Same type of diagram has already been used as figure 2. David [5] called such diagrams 'sign-flow diagrams' following the notion of data-flow diagrams. "Sign-flow diagrams describe the type of signs, which are communicated between the functions (or systems) illustrated by the circles. Boxes show the knowledge stores, which are logically necessary for the function to do its work. The labels used on sign-flow diagrams are themselves sign-vehicles." [5] Labels must be bound to some system of signification, in order to derive any meaning from them [5]. Their description is a necessary part of diagrams. "A particularly useful feature of the sign-flow (or data-flow) diagrams is that of hierarchy." [5] Processes numbered 1.1, 1.2, etc. are finer grained description of the process 1 in figure 2. All sign-vehicles shown flowing into or out of a process, are presented at appropriate layers [5].

Figure 3 may be interpreted as follows.

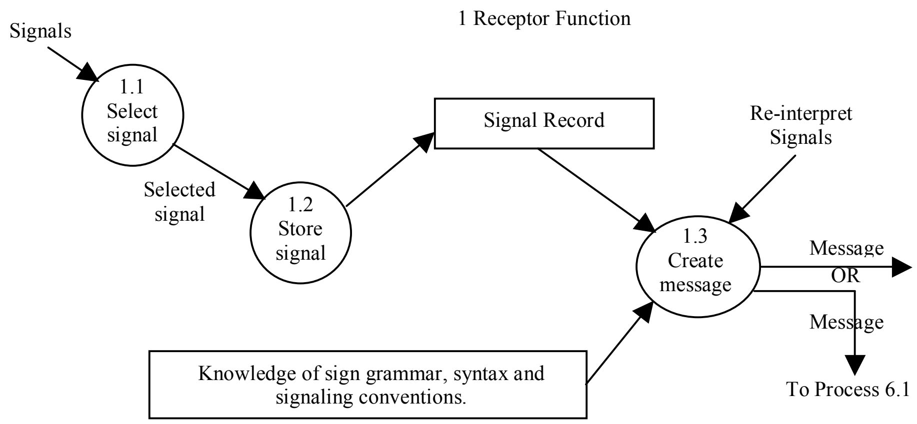
1.1 Receptor is set to sense signals. It is tuned to the type and intensity of certain signals and their position in time and space. The receptor has to separate signals from noise [5].

1.2 Then selected signals are stored in some short-term memory or buffer, called the Signal Record [5]. Signal record must be short-term, because its purpose is simply to enable the message to be created [5]. Capacity of system's Signal Record (both, in terms of the number of signals, which it can hold, and the length of time, before the representation decays) is an important determinant of its ability to create messages from signals [5].

1.3 In create message process signals are formed into a message, which is a coherent, structured set of signals. It provides enough structure for the next stage of the interaction (figure 4). Systems ('dumb', syntactic systems) incapable of communication send message directly to the transmission process (figure 7). For structuring signals properly "create message" needs to access a syntactic system." [5]

Processes (1.1) and (1.2) do not need access to the syntactic system [5]. "The select process (1.1) is physically tuned to receive a certain type of signal and to distinguish between a signals and not a signals. The Store Signal process (1.2) physically stores the signals and absence of signals until its memory (Signal Record) is full, or until the stored signals decay (are 'forgotten')." [5] Capabilities of systems to select data and store it are 'hard-wired' and, therefore, must be physically bounded [5]. On the other hand, the "create message process (1.3), is potentially able to formulate many messages from a single store of signals depending on its knowledge of signalling conventions and grammar and its ability to access and manipulate them. If "derive semantic contents" (process 2) cannot interpret the message, then "create message" may be required to do that [5].

Figure 3. The functioning of a receptor



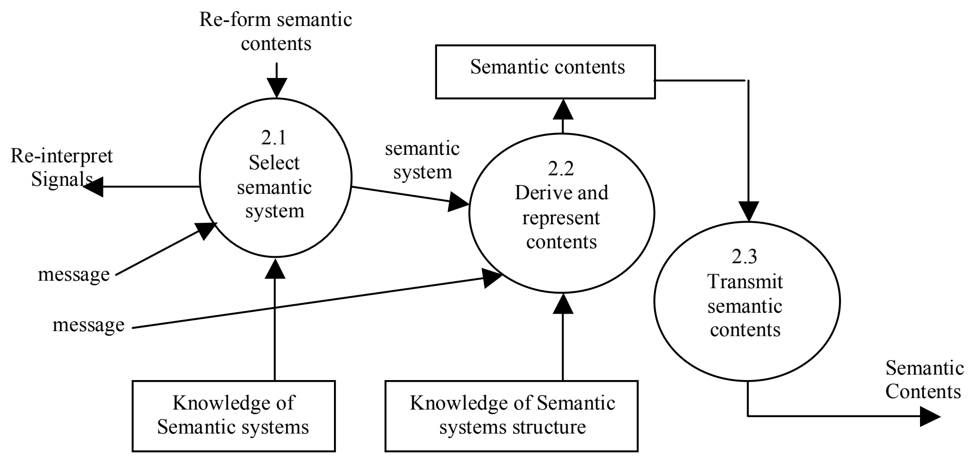
- signals – the elementary units of communication
- selected signal – the signals, which the system is capable of receiving
- message – a structured set of signals
- re-interpret signals – the message returned along with contents indicating why it could not be interpreted [5]

2.4.2.2 Deriving Semantics

"Meaning does not simply reside in the message. It has to be derived in relation to previous knowledge. Once the system knows, what is being referred to (signified), it has obtained the semantic contents of the message." [5]

Figure 4 represents that idea in more detail. Select semantic system (process 2.1) is responsible for selecting suitable system of signification for interpretation of incoming messages [5]. Selected semantic system along with the message is then passed to process 2.2, so that the semantic contents can be derived [5]. If semantic content has to be re-formed it is passed back by process 3 (figure 2) and new semantic system may be required [5]. Message is then analysed by process 2.2, in order to

Figure 4. Deriving semantic content



determine its semantic content and stored in some form in system memory called ‘semantic content’ [5]. Subsequently process 2.3 transmits suitable content to “derive information” process [5].

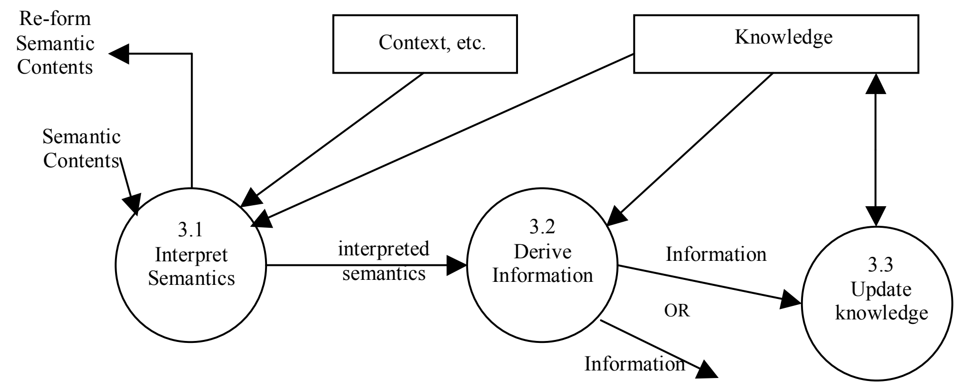
- message – a structured set of signals
- re-interpret signals – the message returned along with contents indicating why it could not be interpreted.
- semantic system – description of the semantic system selected
- semantic content – the content of the sign. The result of applying the semantic system structure to the message
- re-form semantic contents – semantic contents along with contents indicating why it could not be interpreted [5]

2.4.2.3 Information and knowledge

Although concept of sign being related to meaning of message has been understood, the system has yet to deal with that meaning. Systems ability to derive semantic information from the semantic contents of the message depends on:

- its ability to interpret the semantic content of the message,
- its ability to integrate the semantics of the message so it can be interpreted using existing knowledge [5].

Figure 5. Deriving information



- semantic content – the content of the sign. The result of applying the semantic system structure to the message
- re-form semantic content – semantic contents along with contents indicating why they could not be interpreted.
- interpreted semantics – the result of associating the semantic contents with current context and stored knowledge
- information – new knowledge. The result of associating the interpreted semantics with existing stored knowledge.

Process 3.1 illustrates the mechanism of deriving information from semantic content of message. Semantics are interpreted in relation to system's current state of knowledge and the context of the interaction and then passed forth to process 3.2 [5].

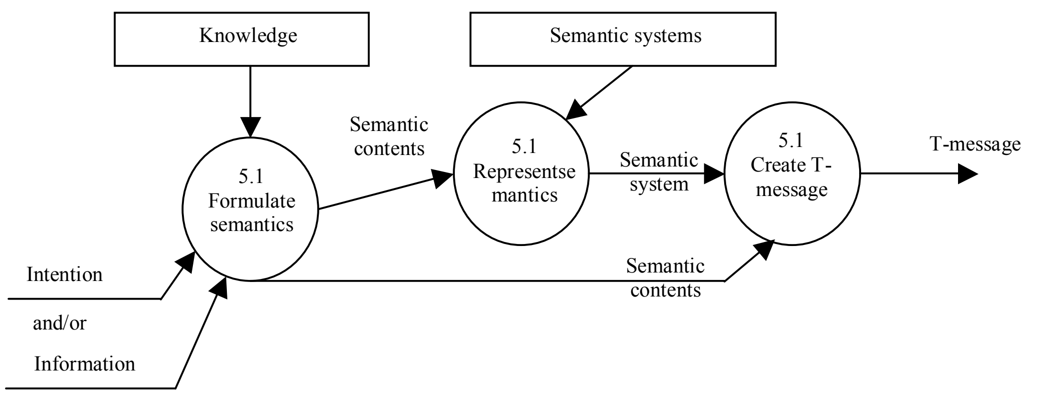
If interpretation of semantics fails, the semantic content, along with some indication of the problem, is passed back to process 2 (figure 2) [5]. "Information is derived through process 3.2 in relation to existing knowledge. Some systems will have the ability to update the content and/or structure of their knowledge store in the light of this information (process 3.3). Other systems will not have this capability and the information will flow directly to the transmission process." [5]

2.4.2.4 Transmission

After receiving signals and deriving semantics and information from them another set of signals are to be transmitted [5]. To a large extend mechanism for transmission of signals can be seen as the reverse of the receiving process. However, the fact that there are three ways to trigger the process of transmission of signals, must be recognised [5].

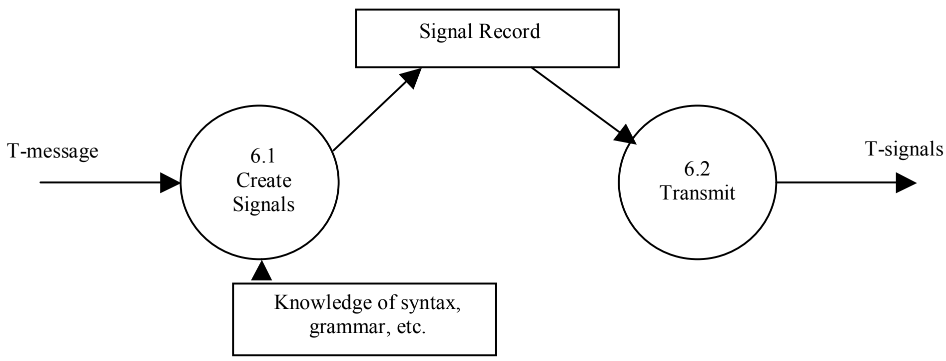
- information – new knowledge. The result of associating the interpreted semantics with existing stored knowledge.
- intention – the intention to transmit a message
- T-message – a structured set of signals (called T-message to distinguish it from message)
- semantic system – description of the semantic system selected
- knowledge – representation of possible semantic systems + general knowledge

Figure 6. Create T-message



"Process 3.2 (figure 5) shows that the information derived, may be used either to update a knowledge store (process 3.3) or it may act as a trigger mechanism for the transmission of signals. In this case, it flows directly to process 5.1 (figure 6)." [5] Semantics of the message are formulated, considering the range of semantic systems which are available, which is to be issued [5]. "These semantic contents are used by process 5.2 (figure 6) to select an appropriate system of signification." [5] Many issues concerned with the pragmatics of sign production are being considered in these processes. Semantic system must be chosen considering its appropriateness for intended recipient, context of the interaction and semantic content of the message [5]. Semantic system and output semantics are brought together in process 5.3 and structured set of signals to be transmitted (T-message) is created [5].

Figure 7. Transmission



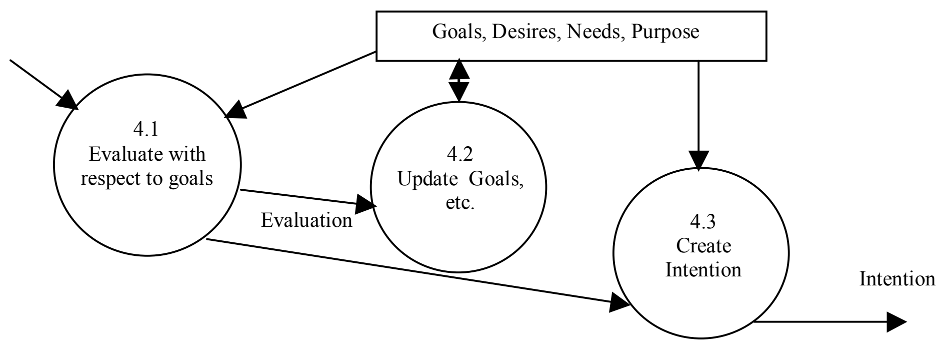
T-message – a structured set of signals (called T-message to distinguish it from message)
T-signals – the elementary particles of communication (called T-signals to distinguish them from Signals)

"A less sophisticated system may pass a message directly from process 1.3 […] to process 6.1. In such a system, there is no question of dealing with semantics. The system responds to an input by creating an output." [5]

Some systems store information and use it to formulate output on the basis of explicit goals (desired system states) [5]. Information is used to evaluate the current situation with respect to the system's goals (process 4.1, figure 8) and to update goals in the light of new knowledge (process 4.2) in these systems [5]. System's goals and new data are used to create an intention to transmit a message, which is processed (process 5.1, figure 6) to produce the semantic contents [5].

David thought that in general, information systems will have access to more methods of formulating semantic contents than other systems [5]. After formation of the semantic content, processing continues as automatic monitoring of the system [5]. Presented on figure 6 process 5.1 is concerned with evaluating alternative semantic systems – for formulating appropriate semantics and process 5.2 selects the appropriate semantic structure, allowing the semantics to be encoded [5].

Figure 8. Create intention



- Information – new knowledge. The result of associating the interpreted semantics with existing stored knowledge.
- Evaluation – a measure of how well current goals are being achieved
- Intention – the intention to transmit a message

David [5] considered it to be important to remind oneself that focus of this model is on the mechanisms of the receipt and production of signals. "There are many considerations involved in the process of sign production to do with selecting appropriate semantic systems, formulating the content of signs, choosing a medium for transmission, how the pragmatics of the signs are considered and so on." [5] He regarded these as vital considerations, but since they do not affect the functional architecture of interacting systems, they can be left out from this model. "They do, however, affect what types of knowledge a system must possess. For example, for transmission, an agent should ideally have a model of the agents with which it is communicating, for without this knowledge it may select to transmit signals which the intended system is incapable of receiving." [5] In current model, knowledge related to sign production has to be available to process 5.1 and 5.2. The process of creation of T-message on figure 6 is bound to semantics and pragmatics. And transmit process presented on figure 7, deals with syntactic aspects only [5].

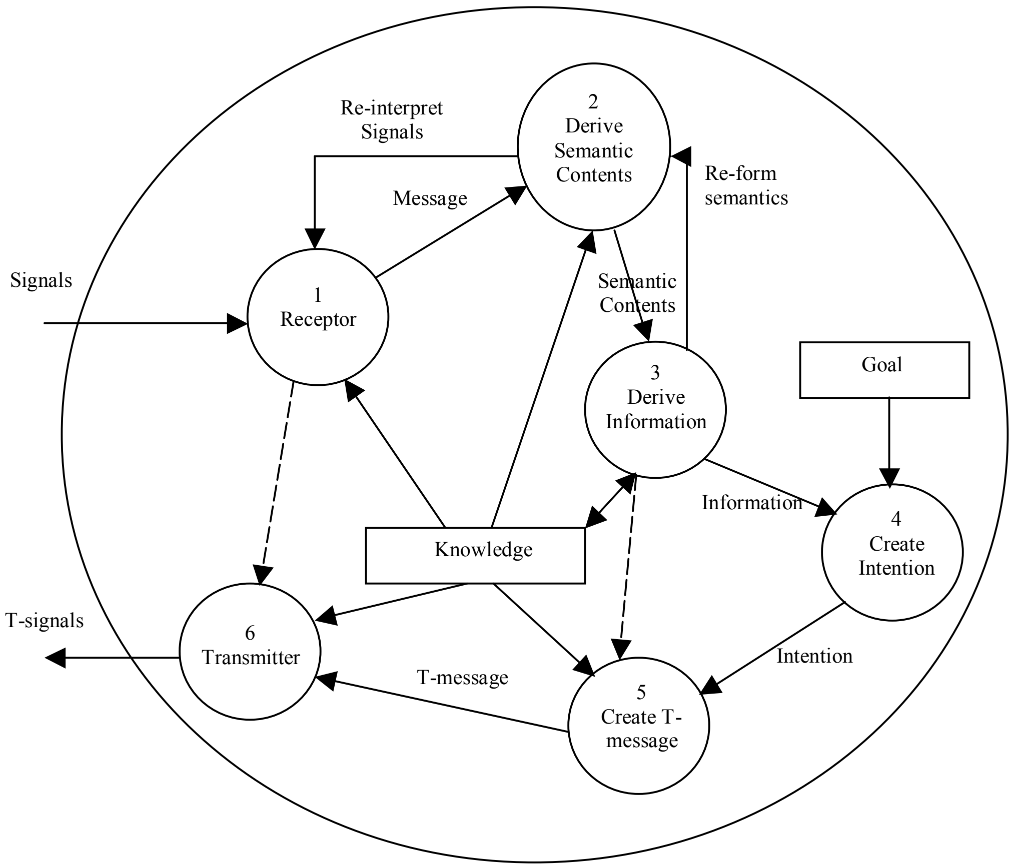
Finally, full representation of receipt and transmission of signals for interacting systems is provided as figure 9, where dotted lines illustrate alternative paths from receipt to transmission for less sophisticated systems. In syntactic systems receptors are linked directly to transmitters, in "information processing systems" process 3 links directly to process 5 [5].

Strength of any architecture or model sustains in its explanatory power, its usefulness for studying agent-based systems. As David put it [5] - dealing with questions regarding to utilisability forces designers and users to be explicit about the scope and subtlety of the representations employed in their systems.

For any agent following questions can be asked:

- "what signals are detectable?
- what is the size and decay rate of the signal record?
- what knowledge does it possess of sign grammar, syntax and signalling conventions?
- what is the system's ability to create messages from signals?
- what semantic systems does the system have to access to and what semantic systems does it know it has access to?
- what abilities does it have to derive and represent semantic contents?
- what ability does it have to represent the context of the interaction?
- can it update its knowledge store?
- can it derive information?
- what goals, motivations and purpose are represented in the system and to what extend can these be used in the system's reasoning?
- can the system update its goals?" [5]

Figure 9. General architecture of an interacting system



Previous questions can be answered if agents are described in terms of current model. Agents can be interrogated if tools for displaying representations are provided. Actions of agents can be explained by using these representations [5].

David [5] considers previous approach to be orthogonal to many architectures proposed for DAI and agent-based systems, because it focuses on the processes and structures which are necessary for communication between systems [5]. "It is a general architecture which can be applied equally well to humans, to simple devices and to computer systems." [5]

Previous model can be applied at many different layers of abstraction. It accepts that all interaction is "physically grounded", yet also shows that signals can only be understood in terms of symbols (as produced by the interaction of signals and the semantic systems, which are available to that system) [5]. Describing systems from this semiotic, interacting systems viewpoint makes explicit signals which system can receive, transmit and interpret [5]. Shows whether system can generate meaning and the degree to which the system is autonomous [5].

2.5 Qualitative Semiotic Approach

Aim of this chapter is to introduce, interpret and modify, for potential utilisation in studying behaviour patterns in complex systems, one of the most thorough semiotic approaches author of this thesis has studied yet. It was originally developed for evaluating quality aspects in requirements engineering (for modelling information systems generally) using semiotic layers [7]. Since information systems reflect subjectively suitable patterns for organising information flows in complex systems, it is regarded by author, that model for analysis of information systems generally is potentially modifiable for analysis related to topics studied in this thesis. More specifically - it can be used for studying single behaviour patterns, certain (type of) behaviour patterns (in the whole system, of the whole system) and for behaviour patterns of a part of the system.

Since the approach was meant for specifying requirements to the system, it can help one to map the observable behaviours of the existing system(s). Map of observable behaviours helps to determine main parts of the system and interactions between them. Latter are the phenomenon of the interest and data related to those interactions help to manipulate with them.

Originally, semiotic aspects of John's [7] work were presented as semiotic qualities, in order to better comprehend, they are presented as semiotic layers (embedding theories of semiotic quality evaluation methods) in this work. There is one deviation from this approach in part of semantics, where besides the semantic layer the semantic quality relative to the primary domain, pre-existing context and purpose context will be presented also.

As mentioned earlier, its background derives from requirements specification, which sustains in:

- Specifying what a system is to do, not how (which is design)
- Looking at the externally observable behaviour of the system
- Documentation (typically) in form of graphical models and structured text including both functional and non-functional requirements
    - Security
    - Dependability

- Usability
- Performance
- Maintainability
- Portability

Properties of the requirements specification are next:

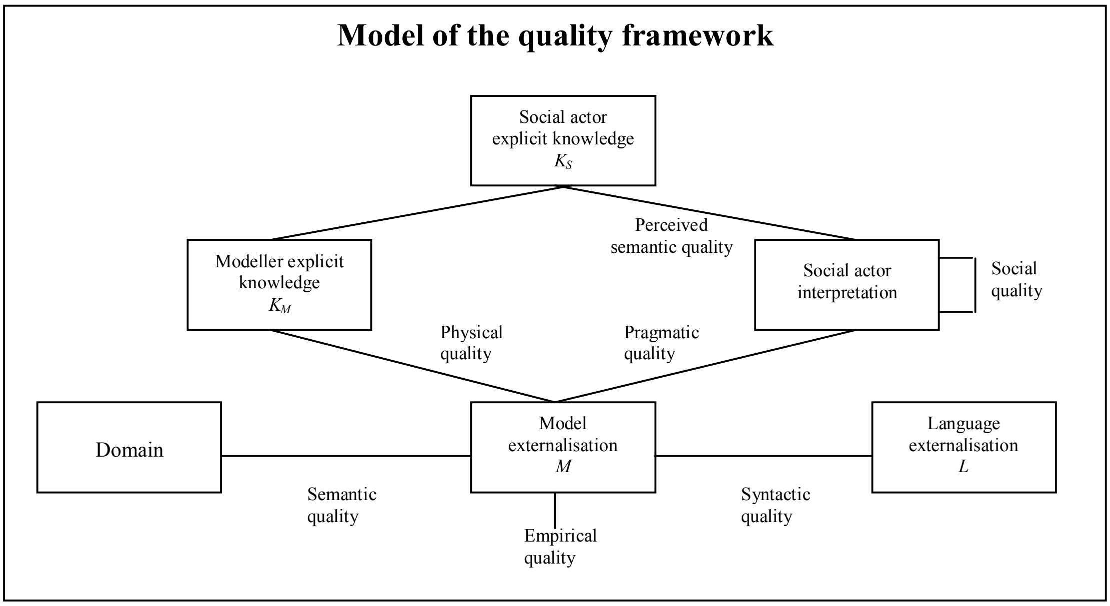
- Unambiguous
- Complete
- Correct
- Understandable
- Verifiable
- Internally consistent
- Externally consistent
- Achievable
- Concise
- Precise
- Design-independent
- Traceable
- Modifiable
- Electronically stored
- Annotated by relative importance
- Annotated by relative stability
- Annotated by version
- Not redundant
- At right layer of detail
- Cross-referenced
- Reusable
- Traced
- Organised

2.5.1 Model of quality framework

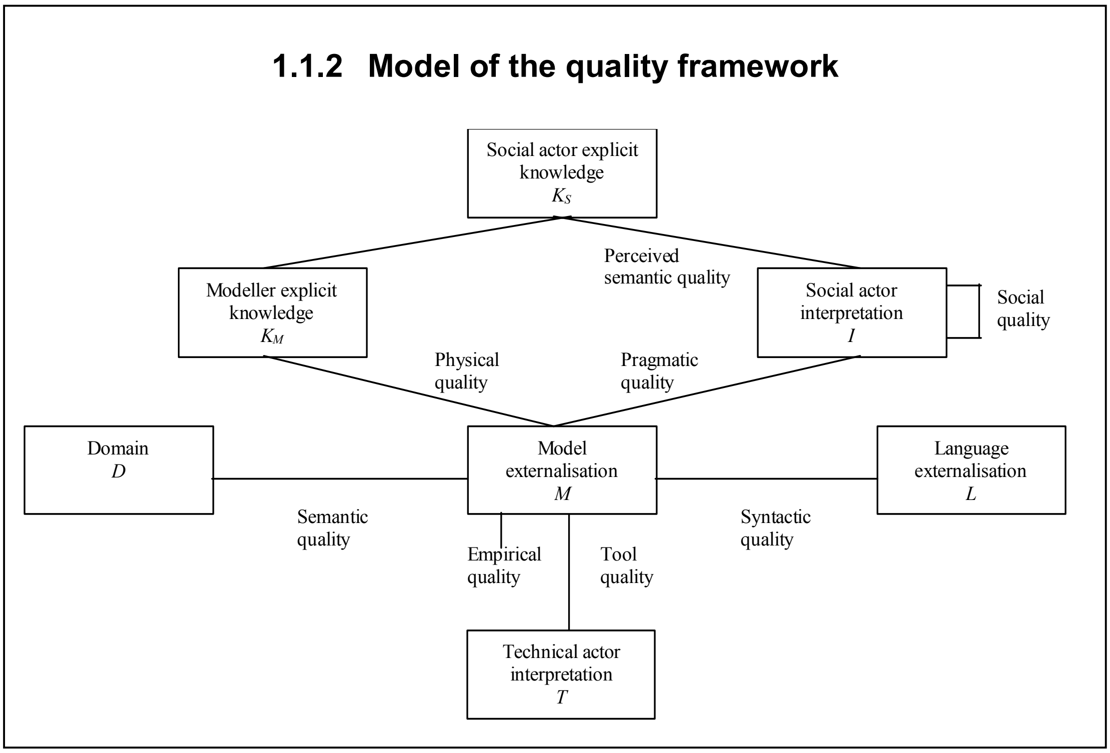
Next steps elucidate, for what and how a quality framework is modelled:

- For (information systems) models in general
- Differentiate quality layers of a model in a way that coincide with the semiotic layers
- Quality layers related
- Differentiate between quality goals and means to support these goals
- Set-oriented definitions of the quality layers

Model of the quality framework shows connections and associations between interactive and inter-dependent parts and fields (other words – data and its function) of the approach and their relations through semiotic layers presented as qualities (filters) in this figure.



This version of the model of the quality framework shows same inter-actors with additional “hard layer” this time.



2.5.1.1 Language quality

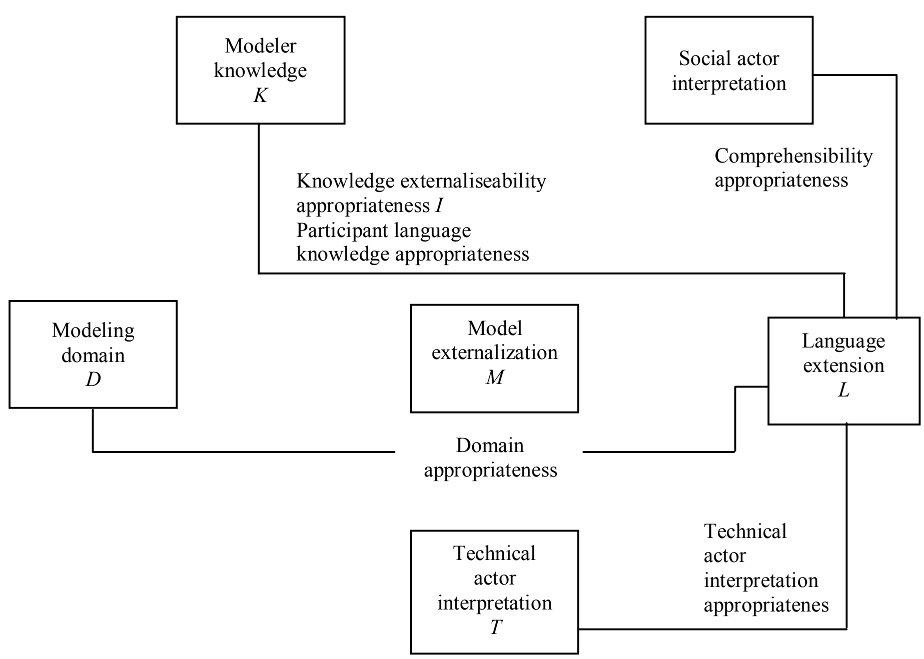
Definition and evaluation of these (inter-system) language quality elements gives one the values of quality aspects related to field of usage of languages (encodings) in and between environments and inter-actors of a system.

- Domain appropriateness
- Participant language knowledge appropriateness
- Knowledge externaliseability appropriateness
- Comprehensibility appropriateness
- Technical actor interpretation appropriateness

- Conceptual basis: Meta-model
- External representation: Notation

The figure illustrating language quality relative to the quality framework shows one the areas where language quality and quality framework coincide.

Language quality relative to the quality framework



2.5.2 The domain of requirements specification

- Primary domain: - *e.g. requirements to a system in the banking domain*
- Pre-existing context: Constraints on the model because of earlier base-lined models – *e.g. Business requirements: We are to provide self-service to our customers for managing changes to their own accounts*
- Purpose context: Constraints due to the fact that the model is to be the basis of a technical implementation – *e.g. the service must be available over internet using standard web-browsers in 3 month*

2.5.3 Physical Layer

The semiotic part of the approach begins with semiotic analysis of the aspects of elements on *physical layer* of complex systems. Data gained by evaluating physical quality aspects on the physical layer of a system provides one with information regarded to elements of electronic storage in the system.

Physical quality:

- Externalisation: $K_{M\,(D)} \setminus M = \emptyset$
  - Language quality aspects
    - Domain appropriateness
    - Participant language knowledge appropriateness
    - Knowledge externaliseability appropriateness
  - Language extensions

- Internaliseability
  - Persistence
  - Availability
  - Repository functionality

2.5.4 Empirical layer

Empirical quality deals with something one can call understandability aspects.

- Empirical quality of a model is about
  - Ergonomics
  - Graph and document layout
  - Readability

- Language quality
  - Comprehensibility appropriateness
  - Expressive economy

- Modelling activities
  - (Automatic) graph-layout, readability index for textual models, evaluating the use of colour etc.

2.5.5 Syntactic layer

Syntactical quality can be regarded as grammatical rules of systems encodings.

- Syntactic correctness: $M \setminus L = \emptyset$
- Two types of errors
  - Syntactic invalidity
  - Syntactic incompleteness

- Language quality
  - Formal syntax

- Modelling activities
  - Error prevention

- Error detection
- Error correction

2.5.6 Semantic layer

Semantic quality can be exploited as a method for evaluation of correctness of interpretation of data.

- Goal
  - Validity: $M \setminus D = \emptyset$
  - Completeness: $D \setminus M = \emptyset$

- Language quality
  - Formal (mathematical) semantics, analysability

- Modelling activities
  - Model testing (consistency checking)
  - Model reuse
  - Driving questions

Semantic quality relative to the primary domain

- Complete (= complete)
- Correct (= valid)
- Internal consistency (valid + complete)
- Precise
  - Use of numerical quantities (vs. completeness)
  - Granularity vs. completeness and validity

Semantic quality relative to pre-existing context

- Traced (Complete)
- Externally consistent (Complete + valid)

Semantic quality relative to purpose context

- Annotated by priority (completeness)
- Annotated by stability (completeness)
- Annotated by version (completeness)
- Traceable (completeness)
- Verifiable (completeness)
- Achievable (validity)
- Design-independent (validity)
- Unambiguous (completeness and validity)
- Other means
    - Modifiability, non-redundant, use of formal languages, 'proof-of-concept' prototyping, preliminary design and test-modelling

2.5.7 Pragmatic layer

Pragmatic quality is related to domains as: Executeability, interpretability, basis for prototyping, organised, cross-referenced.

- Goal: Comprehension (I=M)
- Language quality
    - Operational semantics, executeability
- Other modelling activities: Inspection, visualisation, filtering, explanation generation, simulation, animation, report generation

2.5.8 Social layer

Social quality lets one to evaluate system inter-actions on social layer.

- Goal: Agreement
- Language properties: Possible to express inconsistencies

- Modelling activities:
  - Model integration
  - Conflict resolution

Summary

Author chose *systems as whole*, *parts and groups of parts of systems*, *behaviours and behaviour patterns* and *emergence of behaviour patterns* as suitable objects of complex systems to be approached semiotically.

Basic idea of semiotic approach sustained in structural semiotic analysis (chapter 2.1) of objects of complex systems and their relationships with references to more complex methods of analysis presented fully in following chapters.

Other examples of semiotic approach sustained in analysis of behaviour patterns in relation to themselves, to the class of behaviours they represented and to their human interpreter (chapter 2.2); presentation of one possible pattern of emergence of meaning out of raw data utilising theory of semiotic layers (chapter 2.3); analysis of mechanism of some entity's reaction to outside inputs which is the basis of behaviour (chapter 2.4); qualitative semiotic analysis of existing systems or requirements of a system to be built (chapter 2.5).

Conclusions and suggestions

Semiotics is a very good tool for studying behaviour patterns in complex systems. One would certainly benefit from exploring it.

Author suggests that when trying to study the field of complex systems and utilising semiotic ideas and theories while doing it, one should give closer look not only to theory of complex systems and semiotics, but to theory of chaos, to ideas of thermodynamics, to general psychology and to general sociology also.

Eestikeelne kokkuvõte

Autor valis semiootilise lähenemise objektideks keerulised süsteemid tervikuna, keeruliste süsteemide osad ning osade grupid, süsteemi ja selle osade käitumise ning käitumismustrid koos käitumismustrite esilekerkimisprotsessiga.

Semiootilise lähenemise (peatükk 2.1) põhiidee seisnes keeruliste süsteemide osade ning osadevaheliste seoste semiootilises struktuuranalüüsis ning mõningates spetsiifilise kallakuga reduktsionistlikes analüüsivõtetes.

Semiootilise lähenemise spetsiifilise kallakuga reduktionistlikud analüüsivõtted seisnesid käitumismustrite võrdluses iseenda, oma käitumismustrite klassiga ning võrdluses käitumismustrite interpreteerijatega (peatükk 2.2); semiootiliste kihtide teooriat rakendades tähenduste tekke ühe võimaliku versiooni esitamises (peatükk 2.3); kommunikatsioonimehanismide semiootilises uurimises käitumismustrite kontekstis (peatükk 2.4); olemasolevate või planeeritavate keeruliste süsteemide kvalitatiivses semiootilises analüüsis (peatükk 2.5).

Peamised järeldused ja soovitused

Semiootika on suurepärane vahend keeruliste süsteemide ning neis toimuvate nähtuste uurimiseks.

Autor arvab, et antud valdkonna uurimisel osutub peale semiootika ning keeruliste süsteemide uurimise kasulikuks ka kaoseteooria, termodünaamika, üldpsühholoogia ning üldsotsioloogia uurimine.

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