Neural networks and information interchange in buildings

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Abstract

Where do we place cables and servers for information interchange in smart buildings? This paper investigates the relationship between the organisation and structure of biological neural networks and technological networks for information interchange in buildings. The aim of this research is to identify useful organisational patterns in biological and technological networks as an approach for future network planning. This analysis compares biological and technological networks due to system behaviour, organization, environment, structure, function and form. Visionary projects will present different evolutionary stages of technical networks for information interchange in buildings. Finally two structural models of ‘complex exuberant networks’ and ‘organic backbone networks’ will be presented with a case study of the recent project R 128 by Werner Sobek.

Keywords: intelligence, neural networks, smart building control, network theory, network topology.

1 Smart buildings as ‘thinking plants’ with social behaviour?

1.1 Introduction

How intelligent are our smart buildings? Automatic doors open and close when we intend to pass through. Sensors register the presence of persons and control lighting, climate and temperature. But is this intelligence? Doors open and close even, when we are just standing near and wait. In this case we dare to doubt the door to be intelligent. So what does intelligence mean? Are there parallels between biological and technological networks for information interchange?
1.2 Intelligence as a sum of ‘higher’ qualities

Intelligence, as we know it, is inseparably related to organic life and is characterized by: exchange of substances, growth, reproduction, sensitivity, self-regulation and mobility. Mandl [12] Nourishment (exchange of substances) and reproduction are the primary aims of the system. Growth, mobility, sensitivity and self-regulation are important and necessary prerequisites (given system functions) to realize these aims. Phenomena such as complexity, self-organization, identification, compassion or sympathy are linked to intelligent life. Therefore to define intelligence is not so easy. As we were shown by the example of the automatic door, it is easier to show what is not intelligent.

“The attempt to define intelligence is more difficult, the more exact you try to define the idea.” Cruse et al. [4]

Apparently intelligence is connected with the simultaneous presence of following characteristics and capabilities: 1.) recognition of a ‘subjective environment’ (‘Merkraum’ and ‘Wirkraum’ according to Uexküll) 2.) an efficient solution to a problem, 3.) autonomy of the system, 4.) intention (aims) and focussed attention, 5.) capability to adapt and to learn, 6.) capability to decide and to judge, 7.) capability to generalize, to categorize and to predict, 8.) openness towards changes in the environment.

“… , what we consider to be life is to a very small degree defined through its outer shape, but much more in the way it behaves.” Franke [7]

To recognize a ‘subjective environment’, to possess self-consciousness and language make up what we can describe as ‘emerging’ qualities of an intelligent system. Popper [15]. These qualities are ‘higher’ capabilities. They appear unexpectedly and can not be explained by the physical structure alone. But indeed there is interaction between these ‘emerging’ qualities and the physical structure of intelligent networks. For example, the capability to adapt and to learn is bound to certain ‘dynamic engrams’ in the human brain.

“It is postulated, that this mechanism is based on a structural change, which is ‘readable’, so the code can be expressed in a neural operation of the brain” Eccles [5]

An example of this relation is the way the synapses in the human brain react with plastic modifications according to the frequency of use.

1.3 Is intelligence bound to specific network-structures?

At this point the question arises, whether these interactions are equally valid in reverse. Do physical structures imply the existence of ‘emerging’ qualities of intelligent networks, such as recognition of a ‘subjective environment’, self-
consciousness and development of language? We will try to answer this question in the final project analysis. But first let us fix the criteria of this analysis.

1.4 Levels of description and criteria of analysis

As we saw, a description of the processes in our brain is possible at two different levels of description. On the one hand as an ‘emerging’ quality (as our memories and feelings), on the other hand physically (as neural impulses in a certain space-time-pattern).

This examination is therefore divided into three different levels of description – the system layer, the structural layer and the element layer.

At the system layer ‘emerging’ qualities and ‘higher’ capabilities of networks can be described. The structural layer is dedicated to the topology and the structural qualities of networks. At the element layer we can describe physical qualities and functions of elements in a network.

The analysis follows five different criteria (A, B, C, D, E): At the element layer – the logical function (A) and the physical form (B) of elements in a network. At the structural layer – the topology (network organization) (C), and the network environment (D). At the system layer – the ‘emerging’ qualities and ‘higher’ capabilities (E) of intelligent networks.

1.5 Smart buildings as ‘thinking plants’ or as an autonomous life-form?

Will intelligent buildings build symbiotic societies in the future? Will they reproduce, grow, communicate or develop social behaviour? How will they nourish? Or will they never be much more than simple, immobile but thinking plants, reacting with different reflexes to certain irritations?

Will a ‘polite’ house close its sunshields when the neighbour-house is asleep? How will we behave towards these intelligent buildings? Will it have a right of an independent existence? Would it be murder to cut it off electricity? In that certain moment, when we are confronted with this reality, we will identify with our buildings, we may even experience empathy. At that point we should have answers to these questions.

2 Elements, structure and behaviour of intelligent buildings

The following chapter is dedicated to a general comparative study of biological and technological networks due to the five different criteria of analysis (A, B, C, D, E). In this course we will introduce the terms of ‘used’ and ‘not used elements’. We will pass through the models of ‘harmonic’ and ‘disharmonic’, ‘symmetric’ and ‘asymmetric’ networks. We will introduce ‘Milgram’s assumption’ and the terms of ‘random networks’, ‘scale-free networks’ and ‘hierarchical networks’. Finally we will derive the structural models of ‘organic backbone networks’ and ‘complex exuberant networks’. Some architectural visions will close this chapter, showing recent progress on the way to a realized ‘self-conscious’, ‘rational’ or ‘pre-rational’ intelligent building.
2.1 Construction and use of neural networks (the element layer)

The human brain consists of cells of nerves (neurons), which are connected to each other and communicate by electro-chemical signals. A neuron sends signals by a so-called axon and receives signals from other neurons by its so-called dendrites. The interface between axon and dendrites are called synapses.

In network theory widely accepted today is the model of ‘nodes’ and ‘links’. Neurons and synapses can be described as nodes, axons and dendrites as links. A so-called ‘hub’ will represent in network theory a ‘higher node’, summarizing additional higher links, so-called ‘spokes’. In a technological network we can describe tools or sets as nodes, amplifier and router as hubs. Paths for signal transfer (wired / wireless) we can describe as links or spokes.

2.1.1 Function (logical)

Complementary to physical form there is the specific function of a network. Höhl [8] This temporary organization I call the logical function of a network; it is essential for the selective use of a physical network and is projected in the so-called logical addresses of a certain tool (set). It is given that the logical address is not equal to the physical location of a certain tool (set). The relation of the number of tools (sets) in comparison to the active logical addresses gives information on the performance of the network, taking into account both used and not used elements.

Interestingly, the logical functions in biological networks are fixed during the lifespan of a system. For example the function of our hands stays the same all the way. On the contrary, logical functions often change during a lifetime of a technological network. Widely accepted today is the definition of four functional topologies: 1.) the star, 2.) the bus, 3.) the ring, 4.) the tree

2.1.2 Form (physical)

A physical network consists of a certain number of elements and links; they define the so-called ‘hardware’ of a network. Within this hardware specific technical features can be distinguished such as: 1.) capacity, 2.) size and number of elements, 3.) connectivity of a single element (number of links per element), 4.) number of used and not used elements

2.2 Network organization and environment (the structural layer)

How are biological and technological networks organized? In this context we often speak about the phenomena of self-organization and complexity. The following chapter is therefore dedicated to the organization of biological and technological networks and their specific structural models.

2.2.1 Self-organization and complexity

Like technical networks, the human nervous system is totally finished before it begins to work. “Wherever you examined neural connections, you found that they were completed in their final form, before they were used.” Eccles [5]
Today it is widely accepted, that formation and regeneration of biological neural networks is controlled by self-sustained electro-chemical processes. Technological networks on the contrary, are being planned, formed and reorganized by external influence. As in biology, we can observe a general development from simple to complex structures.

A most interesting self-sustained smart-home-project is the design of ‘Generator’ by Cedric Price. It is an elementary set of building-components and cranes. A computer simulates proposed structural changes and develops possible plans; it coordinates individual wishes and available material, collects and stimulates the proposed design-ideas and optimizes the floor plans.

The architecture of the building is not the physical form, but the computer program. “Only when the program is used the building does suppose a certain form, which changes continually.” Flusser [6]

When there is no change for a long period, the program gets ‘bored’ and changes the building on its own.

Another feature of biological and technological networks is complexity. It describes not only the quality of the topology of a certain network (such as number and kind of network connections) but also the relations to neighbouring systems and the embedding into the total organism. With this criteria we can distinguish different topologies such as ‘harmonic’ or ‘disharmonic’ networks.

2.2.2 Network-topology and structural models
As with the usual formal qualities of structure, we distinguish in biological as well as in technological networks, so-called ‘symmetric’ and ‘asymmetric’ networks [3].

Generally accepted is the suggestion that biological networks follow three different structural models – 1.) random networks, 2.) scale-free networks and 3.) hierarchical networks. Wuchty et al. [16] found that neural networks in general seem to follow the topology of scale-free networks. For example scale-free-networks differ from hierarchical networks in the way of clustering and growth.

“With the introduction of new nodes, already highly connected nodes are more favoured to be connected to the new one, than less connected nodes.” Wuchty et al. [16]

This analysis is also based on the Milgrams [13] assumption, that any two points in a network (biological or technological) can be connected over just six points in between.

2.2.3 ‘Organic backbone networks’ and ‘Complex exuberant networks’
The human nervous system has a structure in three parts. It consists of 1.) the central nervous system (brain and spinal cord), 2.) the peripheral nervous system (afferent and efferent paths for sensors and muscles) and 3.) the vegetative nervous system. The structure of the whole nervous system is ‘harmonic’ to the structure of the organism. Its organization is symmetrical and distinct from neighbouring systems. For example nerves do not penetrate the bones or the blood circuit.
Buildings are divided into two types according to their construction – massive and skeleton constructions. In each of them we will find technological networks in only two parts - 1.) central control and 2.) peripheral paths for sensors and effectors. In skeleton constructed buildings we also find distinct neighbouring systems. Paths for building technology arrange themselves ‘harmonically’ within the total building’s structure. On the contrary, paths for building technology develop more freely in massive constructed buildings. They often touch or penetrate other systems (e.g. the construction) and develop a ‘disharmonic’ structure, independent from the building’s shape.

Therefore we can distinguish two basic structural models. In skeleton constructions we will find so-called ‘organic backbone networks’, homogeneous and harmonically networks with a central ‘spinal cord’. In massive constructions we can observe so-called ‘complex exuberant networks’, a heterogeneous growing network with un-used rudiments.

2.3 Consciousness and social behaviour (the system layer)

2.3.1 ‘Rational’ and ‘pre-rational’ intelligence

Often it is maintained that different forms of intelligence will distinguish man from animal. The development of language, rational critics and a self-conscious insight are the core of this difference. Undoubtedly even animals show intelligent behaviour which is not bound to the development of language. Widely accepted today is, therefore, a difference between ‘rational’ (language-bound) and ‘pre-rational’ (non-language-bound) intelligence (Cruse et al. [4]). We can assume, that these two forms of intelligence will play a role within technological networks as well.

2.3.2 ‘Organics’, ‘Variomatic’ and ‘The Growing House’

System qualities such as exchange of substances, reproduction, growth, mobility, sensitivity and self-regulation are central qualities of biological networks. By now there are no realized buildings with these capabilities, only a few visions.

In 1960 William Katavolos [10] developed the idea for his ‘Organics’ - buildings growing from a self-catalytic chemical substance, forming caved bodies. This construction would be changeable and flexible. Its walls contain intelligent chemical tools; they clean, heat and cool the air and support the biomorph building (self-regulation). Meals are cooled and waste is absorbedchemically (exchange of substances). Spontaneously growing chairs and showers fit the wishes of the user (sensitivity). And these structures even develop social behaviour.

“In the morning they could union to suburbs; by night you can see them, like music, move on to other places, to satisfy cultural needs or to form political or social systems, which is necessary for this new life.” Katavolos [10].

At the moment Katavolos [11] is designing his ‘Liquid Villa’. He is experimenting with gas- and fluid-filled membranes for stable structures. They can float on water or serve as water-tanks in the desert.
Further examples of moveable constructions (mobility) are the ‘Parascape Structure’, the ‘NH-Pavilion’ and ‘Variomatic’ by Kas Oosterhuis [14], the ‘Walking Cities’ by Archigram [1] and the ‘Flexstrut Theatre’ by Johansen [9]. In his visions of a ‘Metamorphic Capsule’ and of the ‘Growing House’ Johansen [9] thinks even of the ability to sustain life itself. To him the solution to this capability lies in the future application of nano-technology, artificial intelligence and a ‘genomic’ construction in a kind of ‘fibrovascular system’ made of carbon fiber. All authors leave the question open, as to whether these buildings will even have self-consciousness. Buildings developing a language of their own (communication) or developing capabilities of swarm-behaviour or common breeding, are unknown today.

3 Intelligent features of R 128

According to the criteria of analysis developed in this paper, let us have a look at the recent project R 128 by Werner Sobek in Stuttgart (Blaser and Heinlein [2]).

3.1 ‘Learning’ from the inhabitant

There are some intelligent features such as microelectronic ‘learning’ to adapt the building’s behaviour to the habits of the inhabitants. Intelligent behaviour, such as self-consciousness could not be observed in this project yet.

3.2 Five ‘harmonic’ and ‘hierarchical networks’

The technological networks for building control are divided into five different networks: 1.) climate, 2.) electricity, 3.) security, 4.) sanitary, 5.) household. These five networks develop ‘harmonically’ within the total shape of the building in a symmetric ‘organic backbone network’. Interestingly, this basic structure was completed by so-called ‘optional loops’. These are circular paths in every floor, reserved for additional links and nodes. Un-used nodes and links can so easily be removed, changed or re-installed. This organization is open to functional changes in the environment.

All of these five networks have a very low complexity and present a structure in only two parts (central control and peripheral paths); their structure corresponds more to that of a ‘hierarchical network’ than a biological ‘scale-free network’. We cannot confirm Milgram’s assumption [13] that any point in a network can be connected to another over six other points. There is no detailed information available concerning the elements of the networks.

3.3 ‘Optional loops’ and future research

Now, where to place cables and servers in smart buildings? ‘Organic Backbone Networks’ with ‘Optional Loops’ turned out as a practical solution in the project R 128 by Werner Sobek. Maybe this could be an idea for other technological networks within buildings in skeleton construction?
Do biomorph networks, such as ‘Organic Backbone Networks’ provide more intelligent potential than ‘Complex Exuberant Networks’ in other smart homes (e.g. the in-haus in Duisburg)? Would a network with higher complexity (and operating due to Milgram’s assumption) support more intelligent features? Which advantages would have three-parted technological networks, equipped with a kind of self-sustained ‘vegetative nervous system’?
These might be interesting questions for future research.

References

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