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A SET OF COMPONENT TYPES AS A SUBSTRATE FOR INTELLIGENT SYSTEMS

Abstract. Advances in AI are weakening the ability to distinguish biological from artificial intelligence based on external criteria, of which the Turing test is most famous. The development of internal criteria would enable comparison of intelligent systems at the level of their internal organization and substructure. The article proposes such a criterion based on the definition of a substrate as a set of component types. A number of basic concepts are refined, such as component, subassembly, organization. A new concept of complexion is introduced, meaning a set of conditions that realize the system in its physical form and operation. The proposed formulation of the definition of substrate is methodologically grounded on set theory and aims to unify the understanding of the concept of substrate in the fields of technical sciences and philosophy.

Keywords: philosophy of mind, intelligent systems, artificial, biological, physical substrate, internal criterion.

1. Introduction

Subsequent generations of AI systems can carry out all the narrowly defined tasks set before them. The sheer narrowness of the tasks could be the last hint for the artificiality of a system until AGI emerges for which no superficial criterion will be convincing anymore. With the progress of AI, the hardware develops as well, and it is reasonable to ask how close artificial systems come to human brain. Can we already talk about categorical affinity, or will only appearance of AGI implemented in hardware different then computer begin to make both systems kindred? To properly answer this question, it is necessary to use an inward criterion that will allow us to compare different cognitive organizations and structures.

The Turing Test, most famous criterion, can be described as fully external, because it is based solely on comparing the utterances of different systems (Turing 1950). This test, visited many times (Proudfoot

& Copeland 2000, Hernandez-Orallo 2000), has a flaw described best by Searle (1980): it does not detect whether the system actually operates on internal states or only efficiently manipulates the utterances. Among the alternative approaches to assessing the working of a system, there is a search for a quality called "connectivity" (Turnbull et al. 2018, p. 2). It is an approach distinguishing structural and functional connectivity as well as looking for fundamental units. Another strategy of explanation, going even deeper, is called neo-mechanistic (Levy, Bechtel 2013). Bich (2021) summarizes it as follows:

> The other strategy is the new mechanistic one, which aims to provide a causal explanation of how the individual parts of the systems, or the parts of one or several subsystems, functionally operate and interact within autonomous systems to realize specific phenomena. (p. 12)

The problem of proper approach to complex systems dates back to Ludwig von Bertalanffy. To oppose the classical, analytical approach in which "isolable causal traits" were sought, he was one of the first to propose the "holistic", systemic approach (Bertalanffy 1968, pp. 18–19). In the former, the whole is the sum of the parts, and it is necessary for the parts to be independent of each other. In the latter, the relations between the parts mean that the phenomena appearing in the work of the system can only be explained by treating the system as "wholeness". Von Bertalanffy points out that both strategies bring benefits where applying them is justified.

Even more daring is the approach proposed within a field of synthetic biology (Damiano, Stano 2023, p. 374), in which the study of engineered and implemented physical structures reproducing the "natural" organization of living systems will provide direct comparisons. To quote Langton (1989):

> A properly organized set of artificial primitives carrying out the same functional roles as the bio-molecules in natural living systems will support a process that will be "alive" in the same way that natural organisms are alive. Artificial Life will therefore be genuine life – it will simply be made of different stuff than the life that has evolved here on Earth. (p. 69)

Notice the term "stuff" referring to the specificity of the physical realization of an organism. Philosophy uses the term substrate, refering to physical bedding, denoting a technical device in the case of an artificial system, and neural tissue in the case of a biological organism. However, there is no single definition of a substrate. What is emphasized concerns the need to provide appropriate organization for various parts made from various materials (Stacewicz 2010, p. 112). The term substrate often appears in a pair of words as "physical substrate", for example: "The idea is that mental states can supervene on any of a broad class of physical substrates (Bostrom 2003, p. 2)." There is a reference to both the material and the structure that is built from it. The word "substrate" is used because of its neutrality in terms of connoting where the physical form of a given structure comes from. This origin can be indicated with an appropriate adjective: artificial substrate (computer, machine) or natural substrate (biological neural tissue).

The origin is probably the most obvious criterion when comparing intelligent systems as we know them. Among the fundamental differences between biological and artificial intelligence are also: basic structure, speed, connectivity and communication, updatability and scalability, efficiency in energy consumption (Korteling et al. 2021, p. 5). What could the criteria for detecting these differences look like? Developing criteria is a topic for another paper, in this article I will focus on the definition of the substrate, which could support such dvelopment. To do this, I will assume that the substrate must include everything that in the system comes from its physical implementation, as opposed to what comes from its internal organization.

To show this difference, I will use the example of three devices: a pocket calculator, a home computer, and a computer system with a hardware random number generator, such as AlphaRNG (https://tectrolabs.com/alpharng/). These three devices differ in the phenomenon of providing truly random results. A simple calculator does not have a randomness function. A home computer can provide a sequence of seemingly random numbers, but usually this function is implemented by using a sequence of random numbers stored in memory, so it is not a process of actual random work; the algorithm that implements it is called Pseudo Random Number Generator (PRNG). The third device is the only one that realizes the phenomenon of true randomness in the thermodynamic sense. This happens by connecting the system to what is called a source of chaos, or a source of entropy. In the case of the aforementioned AlphaRNG, the source of randomness is two independent circuits based on avalanche breakdown effect in reversed-biased Zener diodes. Comparing these three devices allows to notice an important feature of the systems they run. The first two will not exhibit thermodynamically chaotic operation, but the third will, and this phenomenon will not come from the relations between its parts (organization), but from the properties of one of its components. In other words, the activity of a single component will be the source of a phenomenon displayed by the whole system.

Physical phenomena as such do not appear as actions in the system, they manifest by the actions of components. If so, the set of all actions of components will include everything that can happen in the system due to physical phenomena. Since the actions of components are known (and sometimes there may be many of them), listing all types of components will simultaneously combine the entire set of possible elementary actions in the system. The analysis of the system would rely on searching for phenomena that can be traced to physical processes of one of the types of its components. Thus, the criterion for comparing systems in terms of their physical realization would be based on the comparison of their substrates.

As von Bertalanffy wrote: "[systems] assembled from components originating in heterogeneons technologies (Bertalanffy 1968, p. 4)", I propose to separate notions of components, subassemblies, devices, matters or substances between the concept of substrate and the field of technology. The concept of substrate would include only elements as components of the system, and the field of technology would describe specific physical realization of its devices. In this paper, I will try to show that defining the components of a system fully determines the conditions of its physical realization.

2. The discrepancy

The word "substrate" comes from the Latin *substrātus*, meaning in philosophy "substance considered as that in which attributes and accidents inhere" (Collins English Dictionary, 2014). Substrate in technical sciences means the basis on which technological processes are carried out (for example: Knick et al. [2017], Karade et al. [2024]). In semiconductor technology, it refers to the so-called wafer, i.e. a slice of silicon crystal. In terms of its function, it is a solid layer with specific chemical properties. Differences in individual substrates result from the properties of the material they are made of, which is why it is often identified with the material. In neuroscience, on the other hand, substrate means a set of brain structures underlying a specific behavior or mental state (for example: Bar-On et al. [2003], Li et al. [2014]). In this sense, the concept of a neuronal substrate is close to the concept of a neuronal correlate; they sometimes appear interchangeably. As can be seen, sometimes the substrate means a material, and sometimes a structure. The discrepancy between the understanding of the concept of substrate in various sciences, and its use sometimes in a narrow and sometimes in a broad sense, incline to consider several issues:

• The technical characteristics of the substrate: flat and hard, chemically reactive, semi-conductive – do not say anything about the features of the system. The neurological characteristics: location, organization, anatomy, do not refer to the material at all. Since the referents are different, these concepts are unhelpful from an interdisciplinary perspective.

• If the concept of substrate is equivalent to the concept of material, then it is empty as a separate category. When asking about the possibility of a given material becoming a substrate, there are no grounds for formulating an answer. For example, Sharp Corporation produced the Z80 microprocessor on a glass wafer (Lee et al. 2003), and Intel Corporation demonstrated prototypes of processors made on glass to enable further component densification for AI applications (Intel Corporation 2023). Is it possible to point out the differences between a glass plate and nervous tissue within the "substrate" category? Or point out the features that both materials have, such that they can constitute the basis for intelligent systems?

• The hypothesis of substrate independence supports the thesis of functionalism, which treats the organization of the system as a set of states and functions of transitions between them (Putnam 1975, p. 434). The problem is that the organization of switching depends on the components that perform this switching. Since the component features do not belong to the substrate category, I think the methodological relationship between the organization in the system and the implementation of the system is disrupted.

• The lack of methodological dependence results in an unfortunate transfer of concepts between dissimilar categories. For example, the term "neural network" comes from the category of physical organization of structure and is used within the category of software. The term is used illustratively, not reflecting the reality of the process it describes. The program modeling the operation of the network is not implemented on a network basis, it is a serial multiplication of matrix elements (Bridgelall 2024, p. 89).

Below I will review the statements of several authors (keeping the original spelling to show what words and phrases are used).

David Chalmers: "(...) the brain's abstract causal organization, an organization that might be realized in many different physical substrates" (Chalmers 1995, s. 1).

Nick Bostrom: "(...) mental states can supervene on any of a broad class of physical substrates. Provided a system implements the right sort of computational structures and processes, it can be associated with conscious experiences. It is not an essential property of consciousness that it is implemented on carbon-based biological neural networks inside a cranium: silicon-based processors inside a computer could in principle do the trick as well" (Bostrom 2003, s. 2).

Marcin Miłkowski: "(...) we may safely abstract away from certain physical properties as long as the logical causal powers are still retained (...)" (Miłkowski 2016).

Paweł Stacewicz: "So if (...) we manage to recognize the internal structure of the mind and the program according to which the mind works, we will be able to duplicate its operation using downright any material (not only protein, but also silicon, copper, wood, etc.)" (Stacewicz 2010, p. 112).

Robert Poczobut: "If mental states can be understood by analogy to the states of a Turing machine (as computational states characterized purely syntactically), then we should not impose any material restrictions on the manner of their physical implementation" (Poczobut 2015, p. 245).

All the quoted statements locate the requirement for the organization of the physical substrate at the level of the computational structure in the system. Below the level of computational structure is everything that can be replaced (manufactured in different technology) without altering the organization of this structure (this is essentially the interpretation of the principle of substrate independence). I notice that the computational structure itself is not included in the notion of a substrate. One cannot say "computer substrate" or "microprocessor substrate" because a computer or a microprocessor are computational structures. Therefore, the appropriate formulation of a substrate for a computer system is "a substrate of logic gates" or "a substrate of logic functions". This term is consistent with the fact that a computer system uses binary information, i.e., information on which logic functions operate. Due to the lack of inclusion of the level of computational structure in the notion of a substrate by the above-mentioned authors they need to always add a stipulation about arranging the substrate in accordance with this structure.

3. Definition of a substrate

On the basis of integrated information theory, an attempt was made to define the physical substrate of consciousness: "A set of elements in a state that satisfies all the postulates of IIT constitutes the PSC (Physical Substrate of Consciousness) (Tononi et al. 2016, p. 3)". However, this is not a definition of the concept of substrate itself, but a definition of a group of elements for which the concept of substrate is used. In this definition, the substrate corresponds to the concept of a neuronal correlate. Another definition is formulated by Cassimatis, for the cognitive substrate: "[The] set of earlier mechanisms (...), in addition to the new mechanisms that adapt them for use to new domains, are sufficient to achieve human-level intelligence in all domains (Cassimatis 2006, p. 46). He notes that complex cognitive processes can be reduced to elementary activities. These include reasoning about time, space, being a part, categories, causality, uncertainty, beliefs and desires. Their set, which can be constantly expanded, would be the cognitive substrate. Therefore, he does not indicate the basic components, but basic procedures or – as he calls them – mechanisms. Cassimatis (2006) uses frazes like: "relatively small set of computational problems (p. 46)" or "a modest set of primitives (p. 47)".

I propose to define a substrate as a set of component types. The concept of a set of types comes from engineering, where every design begins with bringing up a catalogue of components (obvious example is electronics). The authors mentioned above, when describing the physical implementation, use a set of types intuitively. A review of the literature shows that this intuition is present even when the set of types is not explicitly named. An example is Alan Turing, who, when defining an unorganized intelligent machine, described it as composed of standard components of one type (Turing 1948, p. 9). This type of component is a NAND gate, so the set of types would be single-element, although the implementation of the system using only this type of component encounters problems; see discussion in (Copeland; Proudfoot, 1996).

Why a set of types and not a set of all components? Each type of component contributes some physical process, so duplicating types does not contribute anything qualitatively new. Furthermore, the set is unordered. The unorderliness within the set of components is a clear separation of the sources of the phenomena in the system, emphasizing that all relations between components belong to the category of organization, not substrate.

Therefore, I formulate the definition of substrate as follows:

> Definition 1
>
> **A substrate is a set of all types of components performing elementary functions in a given system.**

A component is the lowest organizational element in the system structure, i.e., the one whose internal structure already belongs to the level of the physical bedding. In a digital system, the basic component is a logic gate (not a transistor), in a neuronal system the component is a neuron. The definition of the substrate proposed here is based on the type of an individual component so that its function can be linked with a single subassembly.

A subassembly I understand as a physical implementation of a given component. Sometimes it is a complex device, sometimes a simple part. Technical subassemblies implementing the same function can be manufactured in different technologies; for semiconductors they are called logic families: ECL, TTL, CMOS (Maini 2007). For biological systems, a subassembly would be a single neuron cell.

An elementary function is an interaction between elementary components that can be recognized within a system (Bertalanffy 1968, s. 44). An element is the basic component of a system because its internal structure and operations are not visible at the level of the system.

A system is "a complexes of elements in interaction to which ceirtan system laws can be applied (Bertalanffy 1945)".

The definition of the substrate of consciousness mentioned before (Tononi et al. 2016) refers to entire functional clusters, and the elementary function of such a cluster is elementary experience. In the definition of a cognitive substrate (Cassimatis 2006), an elementary function corresponds to an elementary mechanism of reasoning in the system. Both definitions locate the substrate elements at the level of the computational structure (or even above). In the conceptual grid presented here, these elements would include dozens, if not hundreds or thousands of components.

Referring to formulations locating the concept of substrate at the level of matter, for example by Tegmark (2017), one may point out that formulating a definition that directly refers to carbon or silicon, semiconductors or neurotransmitters, transistors, or synapses, etc. better suits the needs of philosophical discourse. However, all these indications can be found at one of the levels below the component level. The material properties must somehow be realized in the system, and this happens through the functions of the component. The property of silicon dioxide to form a semiconductor is revealed by the switching function of the transistor. Additionally, moving the material to the level of technology provides proper context for discussing its features. If carbon is mentioned, it is in the context of organic chemistry, and if silicon is mentioned, it is in the context of semi conductivity, etc.

The phrase "set of types of logic gates" does not seem close to the phrase "characteristics of the physical substrate", the latter so broadly present in discussions about intelligent systems. However, specifying the logic function of the gate and what it will be connected to in the structure is all an engineer needs to construct a device implementing it, therefore entirely setting physical bedding (the rest of the knowledge comes from the field of technology used in each case). The juxtaposition of above phrases and finding parallels between them is where the interdisciplinary discourse can benefit.

4. Why component?

Chalmers, writing about the functional organization in the system, used the term "component" (Chalmers 1995, p. 1). The feature of a component is that replacing it with another one, made in a different physical form, but maintaining the same organizational dependencies, does not change the structure of the system. It is organizationally (in the system structure) invisible. It is this possibility, of making a change at the bedding level without changing the organization, that lies at the heart of the principle of substrate independence.

The function of a component is to transform what it receives as input into a specific form of what the system expects as its output. The component performs its function in the system structure by implementing a physical process (processes) that reflects the nature of this transformation. In other words, there is a correspondence between the dependencies of the course of physical quantities during the implementation of a physical process in the physical structure of the component and the dependencies between what the system "sees" as the input and output of the component. This is how information is processed. The function of a component is a mathematical idealization of the course of physical processes within it.

Since a component is built in such a way that it introduces a certain action into the system, there is a correspondence between this action and the physical process that realizes it. This relation has features of isomorphism, as Kazimierz Ajdukiewicz defines it (Ajdukiewicz 1975, p. 252). Bourbaki's definition of isomorphism points to this feature as "preserving" the structure (Corry 2004, p. 319). An example is the implementation of a logical gate in a digital system – a set of transistors switches electrical signals exactly according to the logical function it realizes, so the structure of logical relations and the structure of signal switching are isomorphic to each other. When formulating the concept of a substrate of consciousness, Tononi et al. (2016) stated that: "(...) every property of the experience must correspond to a property of the conceptual structure and vice versa (p. 3)". This "vice versa" is indeed an isomorphism.

Isomorphism between a component and a subassembly is clearly seen in the integrated circuits industry, where the definition of a function is sufficient to determine what will be physically manufactured. Designing integrated circuits is not done by drawing gates but using hardware description languages like Verilog. The description of the logical relationships between the components allows to arrange the entire technological process of integrated circuit fabrication. Description of the functional organization of components is also a method of programming FPGA microchips, although "programming" is not an accurate term in this case, "configuring the circuit" would be more appropriate. Isomorphism makes reverse engineering possible. Analysis of the circuit on the silicon dye allows for mapping the components and their functional organization.

5. Description of a substrate in notation of set theory

To illustrate how the notation of set theory can be utilized to describe various substrates, I will use the example of a simple arithmetic and logical system, a network of simplified neurons and a substrate in which cells change the number of synapses over time.

Both a single-element set of NAND gate and a three-element set of AND, OR and NOT gates can be a substrate of a binary arithmetic-logic system, because a given computational structure operating in binary logic can be composed of these three types of gates and transformed into a circuit which uses only one type of gate, NAND.

Using mathematical notation, a substrate of component types can be represented as:

$$S_{i\_types} = \{c_{type_1}, c_{type_2}, \ldots, c_{type_i}\}.$$

A logic gate as a component can be described as:

$$g_{binary\text{-}function} : A^{in} \to R^{out},$$

wherein:

$g_{binary\text{-}function}$ – means a logic gate with a given function,
A^{in} – means the input argument space,
R^{out} – means the output result space.

For a NAND gate, the component characteristics will be as follows:

$$g_{NAND} : \{0,1\}^2 \to \{0,1\}^1.$$

This expression means that the component implements a NAND function with two input lines that can accept values 0 and 1, while the results of the component's operation, also with a value of 0 or 1, can appear on one output line.

A substrate composed solely of NAND gates (the one that Turing (1950) proposed for building his unorganized intelligent machine) can therefore be described as:

$$S_{onlyNAND} = \left\{ g_{NAND} : \{0,1\}^2 \to \{0,1\}^1 \right\}.$$

or in short:

$$S_{onlyNAND} = \{g_{NAND}\}.$$

A substrate composed of AND, OR and NOT gates would be given by:

$$S_{AND\_OR\_NOT} = \{g_{AND}, g_{OR}, g_{NOT}\}.$$

Formulas for individual logic gates (the marking of the first power is usually omitted):

$$g_{AND} : \{0,1\}^2 \to \{0,1\}$$

$$g_{OR} : \{0,1\}^2 \to \{0,1\}$$

$$g_{NOT} : \{0,1\} \to \{0,1\}$$

There is only one input for the NOT gate, so the set of arguments appears in the first power.

It may also happen that the circuit will be organized in such a way that it will be necessary to use an unusual gate such as an AND gate with many inputs. To take into account the number of inputs, the notation of such a gate would look like this:

$$g_{n.AND} : \{0,1\}^n \to \{0,1\}$$

And an example of a substrate in which there are, among others, two types of AND gates:

$$S_{many\_types\_gates} = \{g_{2.AND}, g_{8.AND}, g_{OR}, g_{NOT}\}$$

indicating the presence of an AND gate with two inputs and an AND gate with eight inputs. For typical gates, the number of inputs can usually be omitted. However, there may be a component with a different number of inputs and outputs:

$$g_{n.function.m} : \{0,1\}^n \to \{0,1\}^m$$

In this notation, n inputs and m outputs can assume the states 0 or 1. In the subscript of the component designation, for readability of the notation, the number of inputs is given on the left side of the function name, and the number of outputs on the right side.

The proposed notation can also be used to describe a substrate of a neuronal structure. Let us assume for simplicity that all the components of this structure are of one type of neuron, so the substrate is a single element set:

$$S_{one\_type\_neuron} = \{c_{neuron}\}$$

This neuron is an element with many inputs and one output. Inputs can be excitatory or inhibitory, which can be denoted as -1 and 1:

$$c_{s.neuron} : \{-1, 1\}^s \to \{-1, 1\}$$

The number of inputs is the number of synapses, so the power is marked with the symbol s. A neuron may have several hundred or several thousand synapses; it is estimated that a Purkinje cell in the rat cerebellum may have up to 175,000 synapses (Napper, Harvey 1988). Assuming 175,000 inputs and one axon, the substrate for a network composed exclusively of this type of cells would be described as:

$$S_{only\_Purkinje} = \left\{c_{175,000.neuron} : \{-1, 1\}^{175,000} \to \{-1, 1\}\right\}$$

If we want to take into account the synaptogenesis, understanded as constantly creating new connections by modifying number of synapses, the neuron description needs to include the time domain. We can write then:

$$c_{cell} : \{-1, 1\}^{s(t)} \to \{-1, 1\}$$

which would describe a cell in which the number of synapses is a function of time, $s(t)$.

6. Why set theory?

The set of components is basic to systems theory, which further uses set theory to axiomatize general formal properties of systems, closed and open ones (Mesarovic, 1964). Mesarovic and Takahara (1989) in their introduction to Abstract Systems Theory (AST) define a system as a relation on a set of objects: "$S \subset \times\{V_i, i \in I\}$ (p. 12)". Lin (1987) extends this notion, instead of one relation, there is a set of relations: "A is a system if and only if A is an ordered pair (M,F), where M is the set of all objects in the system A, and F is the set of some relations among the elements (or objects) in M. M and F are termed as the object set and relation set of A, respectively (p. 96)." Systems theory deals with the relations between components within the organization of a system. Based on sets of objects and sets of relations between objects, Lin (1987) lists the properties of systems: partial systems, relations between systems, composition and decomposition of systems or capability of systems to reproduce certain outputs.

The definition of substrate supplemented with the notation proposed in this paper, can form the basis of a separate theory of substrates that would deal with operations on a set of components and relations between sets of components. For example, the concept of **inclusion** can be utilized, to notice that the **set** of all types of logic gates contains a **subset** of one NAND gate, or the concept of **classes**, to notice that the set of all types of logic gates contains elements belonging to one **class**.

An example of the use of the proposed notation can be the phenomenon of thermodynamic randomness mentioned in the introduction. Assuming that in a certain digital system the arithmetic-logical unit consists of three types of gates AND, OR and NOT and that the system has a component (device) generating thermodynamic chaos RND, system can be represented by its substrate as:

$$S_{arithmetic\_and\_chaos} = \{g_{AND}, g_{OR}, g_{NOT}, d_{RND}, \}$$

If we were to ask about determinism in the system, the answer would usually take the form of a longer verbal description, or perhaps formulas from the language of physics. The proposed notation aims to provide philosophy with its own tool for providing an answer to this type of question. To "examine" the system, it is enough to examine its substrate defined in proposed way. Looking at individual elements in terms of the entropy-generating properties, it is clear that such a component is present and there is only one. We can approach it from the other side, grouping into a subset all the components whose activities are fully deterministic, we will get the notation:

$$S_{arithmetic\_and\_chaos} = \{\{g_{AND}, g_{OR}, g_{NOT}\}, d_{RND}, \}$$

$$S_{arithmetic\_and\_chaos} = \{G_{deterministic}, d_{RND}, \}$$

meaning that the system contains a fully deterministic subsystem and one thermodynamically chaotic component. The example is trivial, but it shows that the language is adequate and that the properties of the system are possible to capture in the description of its substrate.

7. Dependence of a structure on components

The stipulation that it is necessary to map the functional organization to be able to map processes follows every formulation of the principle of substrate independence. Consequently (usually not emphasized) it is also necessary to map the components appropriate for this organization. A given combinatorial task can be implemented using AND, OR and NOT gates connected within proper circuit (organization). If we want to implement this task using only NAND gates, the arrangement of paths connecting them will be different. An important conclusion follows this observation: given task can be realized by systems of different substrates, but each change of the type of a component must be followed by a change in the organization that compensates for different component functions. In other words, a **structure (functional organization) depends on the types of components it is composed of**. Two identical substrates (sets of component types) can be used to arrange different structures, but two identical structures has to be made from the same substrates.

For a given code written in Verilog, based on a certain type of substrate, changing only the type of available gates (changing only what has been denoted as the substrate referent) will result in the need to reformulate the code, which shows that the structure will follow the type of the component. This is another reason why a set of types was used not the number of components, to define a substrate.

8. Complexion

Physically realized intelligent systems have many types of components, not all of them are responsible for information processing. I introduce the concept of complexion to show important issues in the practical implementation of intelligent systems.

The word "complexion" comes from Latin *complexiō* referring to "one's bodily characteristics" and describes the general nature or character of something (Collins English Dictionary, n.d.). I call a system complexion a set of elements and conditions that realize the system in its physical form and proper functioning. In other words, it is the material and organizational constitution of the system. This concept is based on the recognition of the fact that various information systems clearly differ in their forms, and each of them is defined by an extensive list of requirements that must be fully met for the system to come into existence and work. Therefore, either a whole group of conditions is met or a system does not become operational. The complexion consists of everything that needs to be organized, built, connected, initiated, powered, and set up until programming or receiving data begins. Setting a clear boundary between complexion and information in the system is possible because it is possible to run an information processing system without information. Basically, it is the difference between hardware and software. Complexion is what does not change in the system when carrying out various tasks, it is the source of universality.

Complexion is a broader concept than architecture. For example, a computer complexion may be organized in a von Neumann or a Harvard architecture. A system may have one or many processors, it may have different types of memory – these features differentiate within a given complexion. If talking about the number of microprocessors makes technical sense within one group (computers) but does not make sense within another group (biological cell systems), this clearly indicates a fundamental separation of these groups. The concept of complexion allows us to notice that microprocessor systems also need quartz resonators to operate, and quantum computers need temperatures close to absolute zero. Complexion is a broader concept than substrate. I would describe the difference between them as follows: a substrate is a physical bedding, and a complexion is a set of conditions for its use. If the system can be in different states (system components can enter distinguished states), then complexion is what enables the controlled physical transitions between these states.

Using Chalmers' formulation (Chalmers 1995, p. 1), I will define a structure as a system with a functional organization. The concept of structure therefore includes a set of components and their mutual dependencies. The concept of structure is very general and can be used in various areas and levels of system characteristics. Computer architecture is a structure, but a memory module or a microprocessor are also separate structures. At this point I will distinguish two main structures: the one that covers the entire organization of the system, so it is the structure of the complexion (it would include buttons on the computer keyboard or the already mentioned quartz resonator, i.e. components other than logic gates), and the computational structure, i.e. including only those elements that are directly responsible for information processing (computations).

The scope of the substrate definition can be designated depending on what part of the system needs to be characterized. The broadest circumscription of the system is defined by the concept of complexion, so the definition of the substrate of the entire system is:

Definition 2

A substrate of a system is a set of all types of components performing elementary functions within its complexion.

In such a case, the substrate for a typical computer, in addition to the computational elements, would also include: a resonator, analog-to-digital converter or key in an input device. If we were to describe a substrate of information processing structures only, we could refere to components of an integrated circuit (a microprocessor). These components would define what is computationally possible in the system, while Definition 2 would describe how the system physically implements those computations.

9. Summary and future work

Atomic or holistic strategies in the epistemology of complex systems are not sufficient to grasp all the phenomena present in the operation of intelligent systems. The neo-mechanistic strategy in philosophy aims to distinguish which phenomenon originates from system's organization ("wholeness", in von Bertalanffy words) and which from functions of its components. The scale and diversity of intelligent systems and the engineering method of designing them require proper conceptual tools to describe origins of their features. In the paper some of the ideas were proposed:

- A concept of a criterion based on a searching in the behaviour of a system a phenomena that can be traced to physical processes of one of the types of its components.
- A definition of a substrate as a set of component types.
- A recognition of isomorphism between a component and it subassembly.
- Utilization of language of set theory to describe properties of substrates.
- A proposition to develop a substrates theory which would formalize operations on a given set of components as well as relationships between different sets of components.
- A recognition of dependence of structure on components.
- A concept of complexion which denotes everything that needs to be organized, built, connected, initiated, powered, and set up until information processing could begin.

The utility of internal criteria is in identifying qualitative differences between systems, originating from the properties of their components. The internal criterion can also allow to distinguish the real phenomenon from its simulation, by looking for the lowest element discriminated at the level of system organization and comparing it with the form of elements creating the simulated system. If there is no physical correspondence between the elements of the modeled system and the elements of the device implementing a given process, it is strong premise for a conclusion, that it is simulated.

Other system features resulting from the properties of the components include:

- Plasticity. The presence of neurons capable of creating new projections will show that the system has the ability to develop by the mechanism of synaptogenesis.
- Hybridity. If the set includes both digital and analog elements, the system is hybrid in the sense of computational technology. If there are both biological and non-biological elements in the set, the system is hybrid as a cyborg.
- Randomness. If there are no elements in the substrate in which random physical processes occur, the system cannot generate truly random results.

Defining a substrate by reference to a set of component types can also be useful for the philosophy of computer science. The concept of hardware could thus gain a tool for an in-depth analysis of its structural and technical variety.

Future work will aim to: develop the above mentioned idea of a criterion into proper methodological tool, use the proposed notation to describe real devices which intelligent systems run on (especially digital computer) and establish a theory of substrates with a goal of helping interdisciplinary discourse in particular between philosophy and engineering sciences.

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