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Semantics and symbol grounding in Turing machine processes

The symbol grounding problem is one of the most important questions encountered in Artificial Intelligence research. The problem is very old and repeatedly discussed.[1] It received special attention from Steven Harnad.[2] There are many articles attempting to describe the way to solve this problem.[3] Despite this, works on Artificial Intelligence still face obstacles to proper embedding of symbols of artificial systems.

The difficulty of the symbol grounding problem is that we cannot accurately determine how to depict the content of a representative element in a symbolic system – how sensory data affects the whole of symbolic representations. Likewise, we do not know how sensory

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[1] See A. Cangelosi, A. Greco, S. Harnad, *Symbol Grounding and the Symbolic Theft Hypothesis*, in: *Simulating the Evolution of Language*, ed. A. Cangelosi, D. Parisi, London 2002; S. Harnad, *The Symbol Grounding Problem*, "Physica D: Nonlinear Phenomena" 42 (1990) iss. 1, p. 335–346; K. MacDorman, *Cognitive Robotics. Grounding Symbols through Sensorimotor Integration*, "Journal of the Robotics Society of Japan" 17 (1999) no. 1, p. 20–24.

[2] See Professor *Stevan Harnad*, http://www.ecs.soton.ac.uk/people/harnad (22.11.2017).

[3] See e.g. L. Steels, *The Symbol Grounding Problem Has Been Solved, so What's Next*, "Symbols and Embodiment: Debates on Meaning and Cognition" (2008), p. 223–244; M. Taddeo, L. Floridi, *Solving the Symbol Grounding Problem: a Critical Review of Fifteen Years of Research*, "Journal of Experimental & Theoretical Artificial Intelligence" 17 (2005) iss. 4, p. 419–445.

data influences the totality of symbolic representations. The problem is related to cognitive science, but it directly influences the process of creating intelligent systems. Such systems have to relate directly to the real world in order to develop cognitive skills and thus perform intelligent tasks. Meanwhile, the existing symbolic systems (irrespective of their intelligent or autonomous actions) do not use symbols belonging to them, but ones owned by their human architects.

An artificial symbolic system is the result of a double translation of the world. Firstly, the external symbols are translated by a programmer into the language of human symbols. Secondly, they are transformed into a formal language, which can be implemented in the machine. That is exactly the issue we are dealing with in the problem of grounding. The symbols of the artificial system are not related to the world directly, but indirectly through the mind and the language of human maker. Therefore, symbols processed by the machine are semantically foreign to its system. They are not connected neither to the world nor to the internal machine environment.

The creators of the contemporary computational theory were mathematicians and logicians.[4] In their work, they did not consider physical and cognitive processes. It was much later that their successors understood there was a need to consider the problem of computation as related to the problem of the mind. For decades, the field of Artificial Intelligence has developed in a computational paradigm, which has been associated with computer science since its inception.

1. Question of computation

One of the keystones of this area remains the Church-Turing Thesis.[5] The Church-Turing Thesis states that any physical problem for which there is an effective algorithm of its solution can be solved by a Tu-

[4] The major researchers were Alonzo Church, Alan Turing, Kurt Gödel, John von Neumann.

[5] See B. J. Copeland, *The Church-Turing Thesis*, in: *The Stanford Encyclopedia of Philosophy*, ed. E. N. Zalta, https://plato.stanford.edu/entries/church-turing (28.11.2017).

ring machine. Within formal operations, all logical inferences, computations, and proofs can be made by the machine. However, there are still open questions: do living organisms "calculate" things? Are there things that are not computable in the formal sense?

Church-Turing Thesis generalization for physical system assumed that everything a physical system can do can also be done by computation. This physical Church-Turing Thesis takes two versions: weak and strong, depending on whether all physical systems are assumed to be formally equivalent to computers, or whether all physical systems are computers. This distinction provides the essential problem of computationalism – the thesis that cognition is only a form of computation. Analogously, this thesis comes in a weak and strong form. There are also alternative views on the features of computations. One of them presents a conviction that there are states not formalized yet, while the other assumes that there are states that cannot be formalized at all. It seems that in the latter case one should completely reject computationalism and assume that the Church-Turing Thesis is false. Such a solution would be trivial, because the CHT is supported inductively by the computational theory.[6] This rejection would also result, on the one hand, in abandonment of considerations concerning the nature of symbolic systems, and on the other, in renunciation of research on intelligent systems. Consequently, the assumption of equality between computations and cognition allows us to better understand the nature of both and recognize the significant differences between them. Likewise, adopting the thesis as potentially true assumes that grounding of symbols of an artificial system in the natural world is possible, and the symbol grounding problem may be solved.

In computers, the equivalent of cognitive processes are computations. Computations are the interpretation of symbol processing. Symbols are objects that are manipulated on rules based on their shapes.[7] Symbols in an artificial system are interpreted as having

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[6] See B. J. Copeland, *The Church-Turing Thesis*, *op. cit.*

[7] See S. Harnad, *Computation Is just Interpretable Symbol Manipulation; Cognition Isn't*, "Minds and Machines" 4 (1994) iss. 4, p. 379–390; A. M. Turing, *Com-*

a specific and immutable meaning. If we assume, in relation to the Church-Turing Thesis, that computations are universal, everything can be subjected to a formal interpretation. Every event, every relationship and every object of the world can be represented with symbols used by a Turing machine. However, we distinguish consistently computational processes from different kinds of things, e.g. mental states, emotions, or feelings. None of those can be implemented (so far) through symbolic systems in a computing machine. The reason is the way living organisms are grounded.

2. Meaning and grounding

Symbol grounding is strongly connected with meaning. That makes the symbol interpreted in a particular way. In an artificial system, the interpretation of the symbolic system is not directly related to the system, but rather projected onto it by a programmer.[8] The programmer is a translator, who implements his own symbols, depending on his own meaning, in the artificial system. Such a system is deprived of certain "freedom of interpretation" depended on the context or relationship in which the symbol is perceived by the interpreter. On the contrary, living organisms are grounded directly in the world and thus are significantly different from computers. They do not need an interpreter to know objects and understand relationships. The meaning of symbols is grounded in their ability to interact with the real world of objects, events, and states. Symbols they use are consistently interpreted as referring to something. They have a meaning here and now.

In formal computations performed by a Turing machine, symbol operations (read, write, move, stop) are performed on the basis of their shapes. They are syntactic operations as opposed to semantic operations, which underlie the meaning of the symbols. That is more than the form itself. Meaning does not play any role in the

puting Machinery and Intelligence, "Mind" (1950), p. 433–460.

[8] See S. Harnad, *The Symbol Grounding…*, *op. cit.*

formal definition of computations. There are symbols and ways of combining them into longer formulas, using rules of logic and mathematical principles. However, symbols themselves are devoid of semantics. On the other hand, all these manipulations are somehow significant. Symbols refer to specific actions and allow understanding of formulas. Even the shape of symbols refers to something. In the Turing machine processes, the symbol "0" means something else than an ellipse. The head reads out a symbol and performs an appropriate operation (it does not go around in circles, but moves forward or backward above the tape). Therefore, this feature of computation process contains a criterion that does not directly derive from the definition of computation,[9] but contains a premise that the symbol is interpreted during the computation. Besides, all interpretations of symbols and operations must be homologous with each other, as is the case in mathematics or logic. There must be a sense, both in its entirety and in its parts.[10] Therefore, computation of sentences is the hallmark of semantic interpretation. There is also an analogy to living organisms, which are reading the meaning.

According to a variation of Turing machines, computations appear as symbol manipulations.[11] The machine reads symbols placed on the tape in the form of images. The read head can move over the tape forward or backward,[12] it can stop, read, write or overwrite the symbols. The machine is built in such a way that reading, writing and stopping are determined by the current state and by the symbol that has been read. The state can be described as acting "read, and if it is 1, move the tape to the left and return to that state; if it is 0, stop". Turing machine is an abstract idealization of the use of a symbolic system. The computer is a concrete physical implementation of

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[9] See G. Piccinini, *Computation in Physical Systems*, in: *The Stanford Encyclopedia of Philosophy*, ed. E. N. Zalta, https://plato.stanford.edu/entries/computation-physicalsystems (28.11.2017).

[10] See J. Fodor, Z. W. Pylyshyn, *Connectionism and Cognitive Architecture: A Critical Analysis*, "Cognition" 28 (1988) iss. 1, p. 3–71.

[11] See A. Turing, *Intelligent Machinery, a Heretical Theory*, "B. Jack Copeland" (2004), p. 465.

[12] See A. M. Turing, *Computing Machinery…, op. cit.*

a symbolic system. It is a dynamic system whose states and sequences of states are interpreted objects. It is worth to point out once again that symbols processed on the basis of shapes in the system are interpreted, so one can talk about the meaning to which they refer.

3. Symbol arbitrariness

Another important feature of computations is that symbols cannot be arbitrary with regard to their interpretation. For example, the symbol "=" is manipulated on the basis of its shape, and it refers exclusively to the physical property of "equality". Nevertheless, it does not refer to the concept of equality or causality, e.g.: it cannot be interpreted as a multiple of the symbol "–". Likewise, symbols of a natural language have the same property of flexibility with respect to what they mean.[13] The relationship between the form of the sign is communicated and determined by convention or agreement. The sign "=" means that the "first part of the sentence before the symbol has the same value as the second part of the sentence after the symbol"; it is an arbitrary signal where the shape is the major value (two parallel lines); its size or color are completely unimportant.[14]

A formal system of language can be considered as a natural language, because it has a syntax that generates correct statements, and these statements are interpreted as meaningful. All formal languages are a subset of natural language.[15] This is the source of the risk of reference of computation to cognition. The arbitrariness of a symbol shape in a symbolic system causes people to use semantics to interpret computational processes. Living minds do not use a formal language to think. They need to use semantics to interpret computational processes. In the world of living organisms, this convention combines the meaning of characters with certain meanings,

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[13] See C. S. Peirce, *The Essential Peirce: Selected Philosophical Writings*, vol. 1, ed. N. Houser, Bloomington 1998.

[14] See F. De Saussure, *Nature of the Linguistic Sign*, "Course in General Linguistics" (1916), p. 65–70.

[15] See S. Harnad, *Computation Is just Interpretable…*, *op. cit.*

which may change depending on the context. Any object, event or state of affairs cannot be treated computationally, because, depending on many variables, it can be interpreted as a different symbolic description. The syntactic ambiguity is very frequent in real world. It arises from the relationship between words and the structure of a sentence. In other words, a sentence is syntactically ambiguous when a receiver can reasonably interpret one sentence as having more than one possible structure. For instance, the sign seen in streets "SLOW CHILDREN" provides evidence for several levels of underlying syntactic structure and can be interpreted as follows:

SLOW, CHILDREN. Information for drivers to slow, because there are children on the street.

SLOW CHILDREN. There are children moving very slowly.

SLOW, CHILDREN! Information for children to slow.

SLOW CHILDREN! Recommendation for a caregiver to slow children.

Can one talk about the relationship of these symbols in terms of computations? How many factors would be needed to formalize this relationship for an artificial system to be able to read the meaning of this sentence properly? In the case of semantic interpretation, the shapes of symbols are very arbitrary in relation to what is interpreted as meaning. Different logical formulas are needed to implement different descriptions of the sentence. It is required to specify the level of language description in which two separate structures may be assigned.

Turing machine operations neglect the semantic relationship between symbols and their meaning. The computations are independent of the context. The meaning of the symbol system as well as the physical composition of the device are not relevant to the computation. It is formal properties that matter, not physical ones. If physical properties had an impact on the computation, the use of a Turing machine would be pointless. Moving away from physical data is what gives a Turing machine the power to perform any computations in general. The machine does not need a few things to perform mathematical operations. This computational independence, symbol manipulation and interpretation make it possible to run any computation. Computers do what a trained one can do. We do not know all operations of the cognitive system, and computations appear as a form characteristic of the human cognitive system. The ability to perform computations is unique, and since computers can do this, it may seem that we are dealing with some kind of thinking.

4. Semantic interpretation and Turing test

Alan Turing proposed a test,[16] which assumed to recognize a machine as intelligent if a person does not distinguish the computer from another human in a conversation. The test is performed so that communication processes occur through the correspondence use of symbols. The Turing test was designed to prove that intelligence (as a fundamental feature of living beings) can be a form of computation. The valid application of symbols will allow a machine to pass the test and lead to implementation of the mind. Unfortunately, supporters of this attitude have to face the argument of the Chinese Room.[17] John Searle pointed out that any person can replace a machine in a correspondence test using a symbolic system and without understanding any single sign of language. Such a person would perform a mechanical action without using his cognitive skills. While computing is independent of implementation, it is a proof against any cognitive processes where a computer uses a particular symbol system in a deliberative way, thus disqualifying it as an intelligent machine.

It seems, however, that Searle's argument does not question the Turing test in its entirety, but only the possibility of purely symbolic communication. Thus, only alternative use of an understandable symbolic system is susceptible to the argument of the Chinese Room. We do not know how to properly define intelligent behavior,

[16] See A. M. Turing, *Computing Machinery…*, op. cit.

[17] See J. R. Searle, *Minds, Brains, and Programs*, "Behavioral and Brain Sciences" 3 (1980) iss. 3, p. 417–424.

but we know we and others exhibit it. One cannot be sure whether someone (human or machine) understands the symbols used.

Symbolic systems have the property of computing computable things. Accepting the physical version of the Church-Turing Thesis consists in assuming that such systems can do what a human can do. There is one important difference: a symbolic sequence, such as "2 + 2 = 4" or "SLOW CHILDREN", can be generated by a symbolic system, although interpretation of the latter requires reference to additional data not included in the system. The interpretation is influenced by many other factors that are additive and external to the formal symbol system. The meaning of symbols is grounded outside the system. Manipulation of symbols on the basis of shapes is not arbitrary in relation to what they mean for the interpreter. The meaning in a system is analogous to the meaning in the Chinese Room if one does not know Chinese. The sequence of symbols is irrelevant if one looks at the input and output of data in the Chinese Room. This applies to the whole process. The process itself is, however, devoid of any meaning and there is no way to ground it in the world of the machine. On the other hand, if one knows the basics of Chinese – there is a semantic interpretation. All the symbols here are fully defined, systematic, and consistent.

Here we find a critical divergence between computation and cognition. We have no idea what our thoughts are, but there is one thing we can say for sure: thoughts are significant; they are always about something. They are not only properly interpreted – they are directly thought by the subject, without any intermediary. The symbolization is based on the appropriate combination of symbols directly addressed without external interpretation or mediation.[18]

5. Robotic system and simulations

Steven Harnad discussed a solution to this problem: one Turing machine has to find its grounding in another machine, preferably

[18] See S. Harnad, The Symbol Grounding…, op. cit.

a robotic system.[19] Symbolic abilities can be grounded in the robot's ability to connect to the world through sensor and motor devices. Such a robot would have its own skills of internal interpretation of objects, events and states of affairs. They are not interpreted by an external medium because the robot itself participates in the interaction and directly interprets everything in its own way. It detonates "SLOW CHILDREN" in an analogous way a human does, taking into account the factors that give meaning to each element and the whole of this sentence. Symbol processing is semantically coherent and acquires meaning. It takes into account the context and chooses an adequate action. This ability applies to all things perceived: present and absent, material and abstract. However, there is a price one has to pay for such a symbol grounding system: it involves more than just computation. Sensorimotor transfer of signals is more than computation – even if it takes place through a formal system on the machine-machine path. The machine's architect loses access to its internal meaning. Signals transmitted this way are interpreted directly by the artificial system without human intervention. The symbol processing operations are interpreted by the machine, and they are quite different from the human cognitive processes. It can be interpreted by humans, but this is a completely opposite situation. This time the machine – through the formal language – translates symbols grounded in the world to the operator.

The weak variation of the Church-Turing Thesis is strictly formal. It can be accepted, because every physical setup is formally equivalent to a Turing machine and everything can be simulated by the computer. Here is a need to stress that no one mistakes a simulation for reality (the exception being an active subject of virtual reality). The computer simulation does not provide the actual properties of world. During operation of a helicopter simulator cockpit, one does not actually fly, but rather the program simulates a flight in simulated air. There is only experience of the form of computation. The procedure is independent of a particular implementation and it is an interpretation of computer symbol manipulation.

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19 See S. Harnad, *Computation Is just Interpretable…*, *op. cit.*

Symbols are interpreted as a helicopter cockpit, a flight, air, a person taking part in the Turing test or a robot. There are actual dynamic simulation animations of objects. A virtual object in a virtual world is only a symbol interpreted by the system. We are forced to rely on computational modeling, which is a great way to understand physical systems.

Conclusions

Any simulation supports the strong Church-Turing Thesis. Even with the ability of a well-grounded robot to simulate the qualities of cognition, we are still faced with an incomprehensible symbolic system that is completely dissimilar to the cognitive system of living organisms. The misunderstanding of the system makes it unintelligent for the perceiver. The robotic symbol grounding cannot be transferred through a sensorimotor system to create a simulation corresponding to human concepts. Someone who encounters the simulation does not understand what is happening between the input and output data. A formal language is understandable, but other data, like noise considered as distortion, remains incomprehensible. Even if one could understand it, it would be only grounding of the system as a whole, through an external mediator. The programmer could analyze it in a human way. The system itself would remain a purely symbolic system. The cognition would still be different from the computation. The cognitive artificial system may be perceived only as an action in the "mind" of the cognizant.

Thus, there exists a gap between cognition and computation, which is unlikely to be closed. The reason is the way a system grounds its symbols in the world and how the process of its interpretation unfolds. It is possible to prove there is a way of grounding symbols of an artificial system and there exists a sort of its semantic interpretation, but one cannot accept that it is similar to the activities of living organisms. It is exactly the problem of symbol grounding and the result of anthropocentric attitude that lead to fundamental problems in the study of Artificial Intelligence.

Summary

Semantics and symbol grounding in Turing machine processes

The aim of the paper is to present the underlying reason of the unsolved symbol grounding problem. The Church-Turing Thesis states that a physical problem, for which there is an algorithm of solution, can be solved by a Turing machine, but machine operations neglect the semantic relationship between symbols and their meaning. Symbols are objects that are manipulated on rules based on their shapes. The computations are independent of the context, mental states, emotions, or feelings. The symbol processing operations are interpreted by the machine in a way quite different from the cognitive processes. Cognitive activities of living organisms and computation differ from each other, because of the way they act in the real word. The result is the problem of mutual understanding of symbol grounding.

Keywords: Steven Harnad, symbolic system, semantic system, symbol grounding problem, Turing machine, Turing test, Church-Turing Thesis, artificial intelligent, cognition

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