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Computing with Nature †

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Abstract: Natural and morphological forms of computing have diverse conceptualizations. This paper presents an alternative view on morphological computing based on a slightly generalized form of a Turing machine in which one-way action of head on tape is replaced by mutual interaction. This generalized (symmetric) Turing machine can serve as a component of a multi-level complex computing system in much closer analogy to living objects which tend to form systems of very high level of complexity (with levels starting at molecular level, through cellular one to organismal level, or possibly to the level of population or eco-system.

Keywords: morphological computation; natural computation; hierarchic information systems; interactive computation; dynamics of information

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1. Introduction

Unconventional forms of computation (i.e., computation essentially different from and not reducible to the computation described by the theoretical model of an a-machine introduced by Alan Turing in his famous 1936 paper [1]) generated emotions comparable with those in discussions of life after life. In both cases the central concept of heated disputes, computation or life, remains vague. Also, in both cases the source of strongest contention is in the mystery of consciousness, especially in the context of the question about the role of natural processes and mechanisms responsible for its phenomenal experience. Questions of the type "Is the Brain a Digital Computer?"[2] stimulated hot discussions in the 1990's, but they are no more in the center of attention not because they were answered, but it is now not so clear what computer is and what exactly is the role of the brain in cognition.

Fortunately the time of definite answers to indefinite questions and their furious defense seems to be over. This is why so important are maybe less ambitious, but more clearly formulated research programs focused on problems which when answered can help in dealing with the ultimate questions.

One of the fields of this type of research and accompanying it philosophical reflection is a question about the relationship between computing and natural processes. We have to accept the need for rather intuitive understanding of the expression "natural processes" and "computing", the concepts whose understanding is rather a goal of the study, not a point of departure. The noun "nature" and adjective "natural" are subjects of many controversies and attempts to answer them open entire field of inquiry, which due to the restricted format of the present short paper is excluded from consideration. The same applies to "computing" which more and more frequently is discussed in the context of "hypercomputing" [3] or "unconventional computing". Thus, the idea of "natural computing" involves double difficulty, but this does not diminish its attractiveness for research and reflection. Sometimes, when computing is understood in conventional way (modeled by Turing machine or automaton) and the focus is on its implementation in living organisms the reference to natural computing seems perfectly justified [4,5].

Research on natural computing is already very diverse. Two main directions are in some sense leading in the opposite directions. One direction explores processes in nature, especially in living objects or their populations which can be used to implement conventional forms of computation or which exhibit behavior which can be interpreted as such computation. Advanced forms of such research have for instance objectives of the development of molecular or cellular robotics [6,7]. The other direction is to search for processes in nature which can provide examples of unconventional forms of computation, for instance reversible computation [8–10]. The directions are opposite in the sense that one assumes already existing conventional model of computation and looks up for their implementation in nature, the other explores nature in the search for new forms of computation.

Morphological computing (in its diverse ways of understanding) is at the cross-section of these two directions. Its diverse forms have in common interest in morphological characteristics of the computing systems. Thus, we can consider computing understood as transformation of acellular slime mould *Physarum polycephalum* within the wide spectrum of morphological patterns in response to changes in environment [4]. But the concept of morphological computation has consequences and applications in much broader context, for instance when human "extended or embodied cognition" is considered in its natural form of organismal morphology. It becomes increasingly clear that the attempts to understand cognition are hindered by the simplifying idealization expressed by the simile of a "brain in the vat".

My own approach to naturalization of computation presented here is different, possibly more abstract and motivated rather by more general reflection on both natural processes and on computation without the assumption that either one has more primary status. Probably the closest affinity in my research interests is with the studies carried out by Kenichi Morita on reversible computing [10]. My original research questions were derived from the observations on similarities and differences between theoretical computing devices such as a Turing machine and actual physical systems studied in physical sciences [11]. Some of these questions were as follows:

1. Why conventional computation is irreversible, while processes of simple physical systems are always reversible? Irreversibility (breaking time-reversal symmetry) is coming with increased complexity and is manifested in systems far from equilibrium. If the Turing machine computing operates at the lowest level of complexity, why is it irreversible?
2. Reflection on implementations of computation in natural or physical systems is usually expressed in terms of causality. However, the concept of causality is absent in formalisms of physical theories. It is more a (doubtful) philosophical concept used in interpretation of physical theories or just a convenient expression to describe components of a system ("The revolution of Earth around Sun is caused by gravitational force of the mass of Sun"—the obvious physical nonsense as Earth is not revolving around Sun). The questioning of the cause as physical concept goes back at least to Bertrand Russells essay from 1917: "All philosophers, of every school, imagine that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word 'cause' never occurs…" [12]. Naturalized computation should be described in terms of interaction not cause.
3. More careful reflection on the way Turing derived the description of his a-machine shows that the description involves some arbitrary elements probably coming from the original vision of the "human computer" performing calculation. There is no reason to insist that the entire content of the instructions has to be located in one central place with primary control function (head) and that the head has to have more active role in the computation than the tape.
4. Natural systems are typically of a complex hierarchical architecture. Natural computation should be generalized to make multilevel simultaneous computation possible.

This paper is devoted to the study of consequences of these questions.

2. Another Form of Morphological Computing

Conventional computing with a Turing machine can be described in the following way:

Slight modification (generalization) makes the machine (s-machine) symmetric in the sense that the roles of the head and tape are equivalent and that the action of the head on tape is replaced by the interaction of the head and tape. It is a generalization, because when we make a non-physical assumption that only head is acting on tape, we return to the conventional Turing a-machine described at Figure 1.

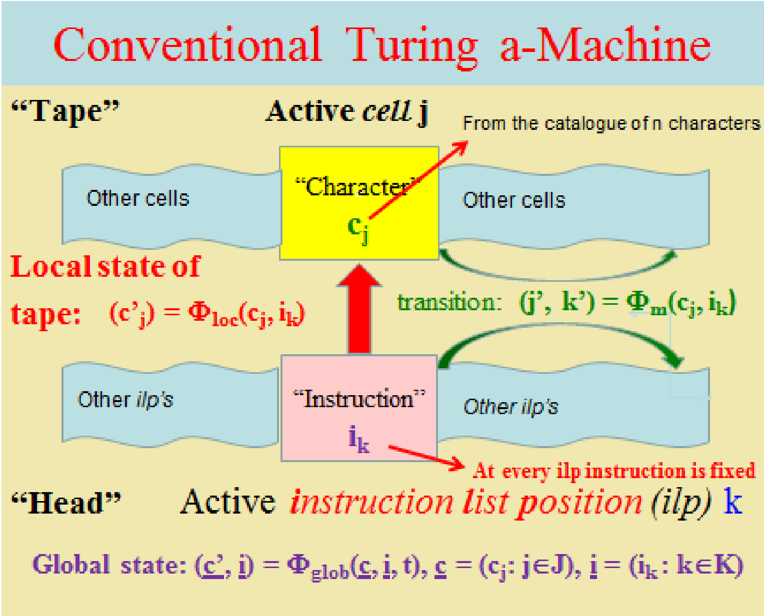

Figure 1. Conventional computation with Turing's a-machine, but with modified morphological characteristics of the system [11].

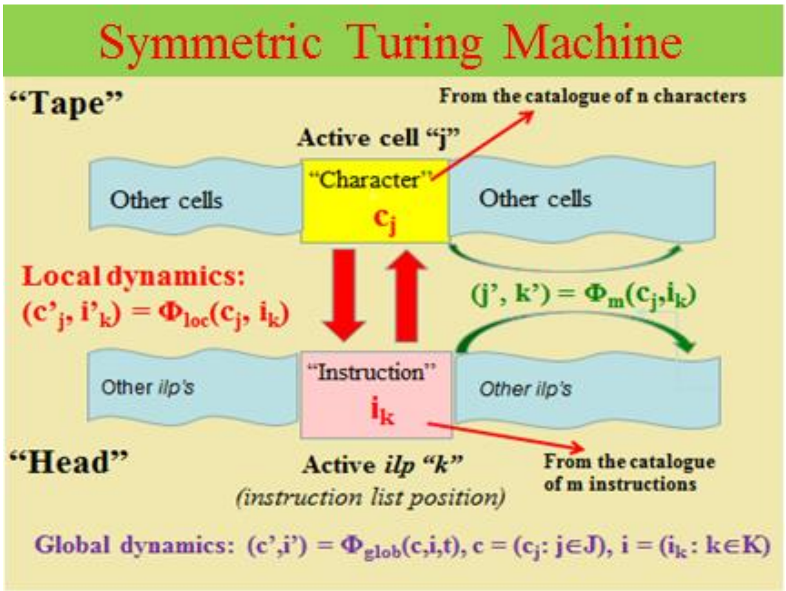

Figure 2. Symmetric Turing machine in which head and tape are interacting and the distinction in the names of these components is purely conventional [11].

Compounding of computational systems is based on the fact that at each level we can distinguish to levels in the information system: global (e.g., structure or configuration of characters on the tape) and local (e.g., selection of a character for a particular cell.

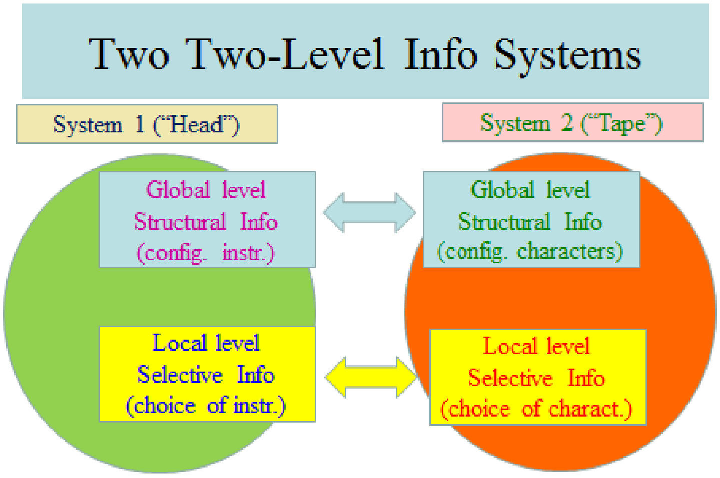

Figure 3. "Simple" computing system (s-machine).

Now we can consider a compound computational system in which head of one level can be a tape of another ("lower" level) and tape of this level can be a head of another level.

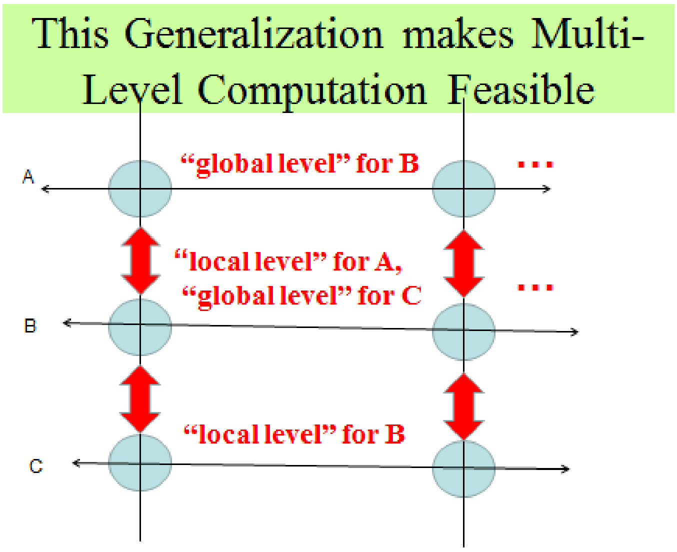

Figure 3. Compound computing system of hierarchical, vertical architecture.

Conflicts of Interest: The author declares no conflict of interest.

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