The Role of Embodiment in Life and Cognition (open question 6)

The only cognitive systems we know which are not alive, are artificial ones. Moreover those artificial cognitive systems have serious limitations when dealing with the uncertainties of the real world. Apart from theoretical considerations this fact suggests that a 'fit' artificial cognitive system should be, to a certain extent and, in a sense, also 'alive'. Recently Chaitin, [1], proposed a 'meta-biology' foundation for the study of life. He essentially proposes to see life as a result of the evolution of natural programs, 'a random walk in program space'. Evolution of life is seen as evolution (gradient-based optimization) in the 'program space'. From this point of view, it looks clearer the similarity between 'natural programs' for life and (more recent?) natural programs for cognition. After all, technological evolution of artificial programs, too, started from basic functionalities and is now moving towards 'intelligent' systems development. For these and other reasons, Chaitin's model is inspiring. A supplemental reason of interest is given by the fact that we can analyze the role of embodiment for life and cognition with similar conceptual tools.
We argue, building on Chaitin's proposal, that evolution might be a random walk in the *embodied program* space.

The idea that life could be a form of 'natural programming' is corroborated by a number of ideas and results, which have been reported in the latest years.
A DNA computer can be regarded as a kind of Turing machine , [9], by enabling a wide set of arbitrary artificial chemistries , [8]. Thus it can provide the 'coding platform' for complex behaviours and simple cognitive systems. It has been recently shown that it also allows to implement perceptrons, [7].
However, there are many reasons in favour of the so-called 'morphological computation'. For example, the MIT passive biped walker by exploiting the limit cycles in its mechanical dynamics can achieve much more energy efficiency, comparable's to human walking, than its fully actuated counterparts, and what is maybe even more inspiring, with a very simple control program (essentially providing an impulse at every gait to compensate the energy losses). Human (and passive walkers') walking can be seen as a 'controlled fall' exploiting gravity to get energy. The dual function (physical actuation and sensing, and information processing) of proteins can be regarded as a similar process. We may interpret these phenomena by saying that, in nature, 'information processing' is very often outsourced to the agents dynamics, [4, 5, 6].
As a consequence, we should regard the 'programs' of the program space where the evolutionary random walk occurs, as *embodied programs*, where part of the information is coded into 'standard' DNA and protein program codes, more messy maybe, but conceptually very similar to human computer codes, and another part of the 'program code' is embedded into the physical dynamics of the agent itself and of its interaction with the environment.
There are a number of challenging issues, as we need methods to quantify and model how this information processing occurs, luckily there have been some attempts to quantify morphological computations, which may help to this purpose, [10, 11, 12, 13].We need models of the integration of morphological programming into the natu-

ral programs, which will also show some forms of programming more similar to that envisioned by Chaitin.
If we, as suggested above, look at life as a random walk in the*embodied* program space and we start, for example, from an embodied version of the minimalistic mathematical living form proposed by Chaitin, we may define the set of properties of a minimum set living system that should in turn prove to be a subset of a minimum set cognitive system.
It could be discussed whether or not all living systems should be considered as 'cognitive systems'. In this context 'cognitive systems' is empirically referred to the subset of living systems, which are capable of behaviours that could be interpreted by a human observer as symbolic-like representations and planning. Similarly the living systems could be seen as a subset of embodied information processing systems, as not all the information processing systems are 'alive'.
Living beings and natural cognitive system, are themselves the outcome of a cumbersome and undirected process of stratification of new features and capabilities, and are inherently very difficult to reverse engineer due to their extreme complexity, duplication of functions, heterogenesis, and even useless features that a given organism has kept just for historical reasons.
Theoretical modelling and the synthetical methodology may prove of fundamental importance. The theoretical models can be very difficult to prove in the overly complex, existing living organisms, especially in their current, early stage of development. The synthesis of artificial systems, with the given characteristics suggested by theoretical models, could in many cases be the only way to prove or disprove a scientific model in both life and cognition.

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