Trial and error-based necessary conditions for general intelligence

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Abstract

We prove that Deterministic Turing Machines whose transition function is defined in a (finite) subset of the tape's contents$^{(a)}$ have limited meta-learning capabilities, and that random variation is required for general learning.

One of the commonly accepted requisites for general intelligence is the ability of learning. Specifically, a system with general learning capabilities must be capable of modifying itself to adapt to the intended goal. In the case of Deterministic Turing Machines, a transition function defined by the contents of the tape is dynamic because it can modify itself during the operation of the machine. In other words, the Turing machine modifies the tape according to the instructions coded on the tape. Under these conditions, the process of executing one instruction is isomorphic to a single monoid action over the set of all possible tape states. By means of monoid actions, it is shown that the sequence of changes to the transition function becomes cyclic$^{(b)}$, which defeats the requisite of general self-modification.

We propose a workaround to overcome this inherent limitation in Turing machines. Nondeterministic Turing Machines behave like Turing Machines except that the action is chosen amongst a probability distribution. In the extreme case, a *random* Turing Machine selects between all the transitions with equal probability$^{(c)}$. Here, the transition function coded on the tape serves no purpose with respect to self-modification and any transition function can, in principle, be reached at the cost of making mistakes. Therefore, a general learning machine cannot be deterministic in nature, nor it can reach its goal without statistically making mistakes first. Amongst all the transition functions so produced, a mechanism of selection is required to discard those that do not fulfill the goal of the system. Consequently, general learning requires a process of trial and error on transition functions until an appropriate one is produced.

For example, the general learning system par excellence, the human brain, is well known by the amount of mistakes it makes even on mastered tasks. Also when developing, children's play involve heuristical trial and error, as well as learning to accomplish any new task. With respect to Artificial Intelligence, genetic algorithms that evolve machine code have the proposed requirement, as well as Reinforcement Learning-based algorithms. However, its inefficiency hinders the emergence of complex intelligent behaviors. A solution to this inefficiency is to provide heuristics to the stochastic process of choosing a new transition function, yet the limits imposed by the free lunch theorem. A natural system where this mechanism is found is in Darwinian Evolution. Random mutations and natural selection enable trial and error on the genetic code. Despite its inefficiency, trial and error stand at the basic procedure to produce complex life, which rises the question of whether Evolution is actually a general learning system.

Consequently, a necessary condition for a self-referencing computing device to achieve general intelligence is that it contains a true random generator.

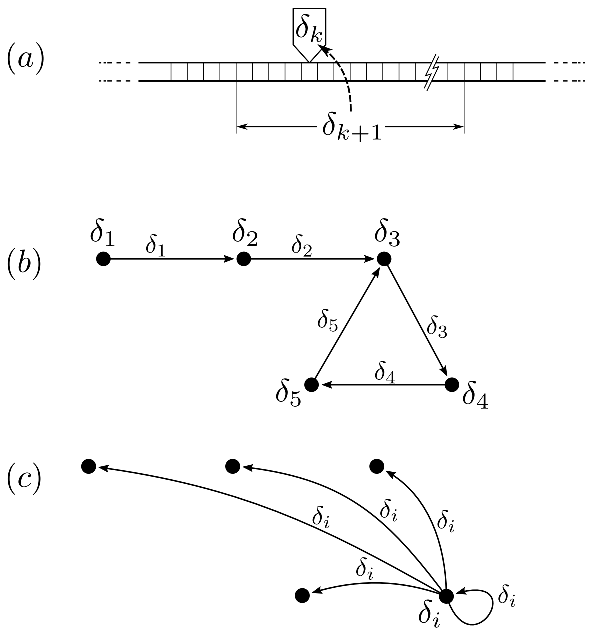

Figure 1: (a) A turing machine whose transition function δ_k is defined on the tape. (b) Meta-transition functions $\delta_k : \delta_k \longrightarrow \delta_{k+1}$ define single monoid actions, that end in cycles. (c) These cycles can be escaped by using stochastic transition functions.