Evolvability: Complexity in a Chemistry Based Metabolism for an Autonomous Robot

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The Problem: In the future, complexity will be essential to a robot's remarkable ability to be perceived as alive. A fundamental question of science is: How and why did complexity arise in living systems?

Motivation: The two major forces of evolution: selection and variation, do not suffice to answer even at a high level how complexity arises. While selection, given its survival of the fittest directive, can choose between alternatives, it does not influence the generation of alternatives. Variation is the evolutionary process that generates alternatives. However, its random alteration of genetic material is counter-intuitive to promoting the growth of systems that are organized.

The source of complexity in living systems is the mapping process that occurs when a genome is transformed into a phenotype. Factors such as the "language" of DNA and the processes of transcription, and translation which interact with this "language", plus higher level mapping actions influence the phenotypic outcome. The mapping directs the complexity of a living system: its organization, the composition and functionality of its components and the interfaces between levels in a system.

How nature's genome to phenome mapping arose is an open question. It seems clear that the mapping itself must have *also* evolved. We wish to investigate how complexity arises from an evolutionary process that must inherently have an evolvable mapping process.

Previous Work: This work is related to research on artificial chemistries [2] and the evolution of control metabolisms for a robot [7]. Evolvability has been considered by biologists (e.g. [6, 3]) and in the context of evolutionary computation from both theoretical (e.g. [1]) and applied (e.g., [5]) perspectives. A new evolutionary computation paradigm called Grammatical Evolution [4] focuses on the properties of genotype to phenotype mapping.

In 2002 members of our group have prepared a combined hardware and software architecture that supports the construction of small, autonomous robots. The hardware consists of a configurable stack of PCB's comprising a network and assorted processors for behaviour direction, actuator control and sensing. The software consists of a high-level multi-threaded language supporting real-time I/O, shared variable space and inter-module messaging tailored to autonomous robot control.

Approach: We intend to build a robot and use evolutionary computation to produce different metabolisms (or other subsystems) for it. We will use the robot to examine relationship between evolved (and evolving) mappings and complexity.

Our robot will be a mobile hexapod. It will be autonomous. It will have some means of signalling to the humans in its environment the status of its internal states. It will be able to sense people and sources it can consider energy as it navigates within the working space of our lab. Improving the robot's ability to conduct its so-called life in an unstructured world (entailing survival, the metabolizing of external sources to internal energy store and expending it) will be the goal of the evolutionary process.

Impact: This robot will among the first engineered using the Creature-Language (CreaL) software environment and its associated hardware platform. It will thus act as a testbed and verification for them. To our knowledge, evolved embedded software focusing on emergent, self-organizational properties that yield life-like behavior will be novel.

Investigating *evolvability* and the role of mapping in the rise of complexity will lead to a better understanding of living systems. It may yield improved explanations of how we evolved and what else could possibly evolve and

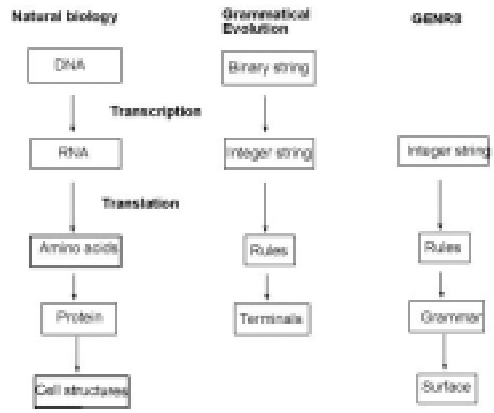

Figure 1: Block diagram of three different evolutionary mappings. In nature (left) DNA is transcribed and translated in a process resulting in cellular structure. In Grammatical evolution (middle) transcription and translation are abstracted to operate on binary and integer strings with the results being computer programs. We have designed a system called GENR8 (right)that produces grammars via its versions of translation and transcriptions so that it conducts search in representation space.

also be alive.

Future Work: This year we will build the robot and evolve one of its subsystems. In the future we can investigate evolving a different subsystem or examine how multiple subsystem's interactions can be evolved.

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