A system model for the scalable construction of evolved robots

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Introduction

- Background
- Motivation

Background

- The goal of a self-sustaining system that increases in complexity by evolution has been a grand vision since von Neumann's classic work on self-replicating automata
- Such a scenario still remains well out of reach
- Recent interest in the possibility of achieving scaled down and simplified version using EC

...because

- Framing problem in terms of software based EC allows convenient narrow focus on effects of genotypic variation
- Abstracting away many difficulties such as :
  - Maintenance of identity and autonomy (McMullin)
  - Machines replicating themselves;
  - Natural selection occurring “naturally” due to relative differences in the rate of replication and survival in the world over extended time scales
  - Overall system being self-sustaining

Shortcoming

- This EC based approach has been effectively used to evolve robot controllers
- BUT given present technological capabilities the evolution of ***complete*** robots (i.e. ``body and brain'') along similar lines continues to be a problem evading convenient practical resolution.
- For EC to provide a useful simplification then...

“BIG” problem (for this paper)

- Need for a minimally constrained EC-based system that:
  - Avoids the problem of exhaustively constructing and evaluating generations of such robots, AND
  - Remains consistent with broader objectives of understanding the bottom-up development of complex functionality in evolving physical systems

Motivation

- Common theme among few previous systems implemented is to decouple the evolutionary process from construction (Lund, Jakobi, Funes, Lipson, Hornby).

- Rationale: EC could be applied offline in software so that
  - The actual physical construction of robots could be deferred till a suitable ``solution'' is evolved
  - Only robots corresponding to specific chosen “solutions” need be constructed.

“Three generations”

- **Funes**: Preliminary description of use of offline evolution with a “blueprint model” to evolve LEGO structures
- **Lipson**: Same blueprint model to evolve blueprints of sensor-less dynamic structures for locomotion over a regular flat surface.
- **Hornby**: Problems of scalability observed in previous implementations addressed using developmental encoding mechanisms by leveraging the use of repeated substructures to achieve this scaling

Difficulties

- Dominant focus has been on issues to do with EC
- Poorly characterized difficulties that have been generically labeled as “poor substrate” and “reality gap”
- Particular concern: Difficulties may be hiding issues threatening the reliability of construction with increased scalability of the robot blueprints

Motivating question

- How can the reliability of robot construction based on evolved blueprints be ensured independent of the complexity of these blueprints, given that construction errors and simulation imperfections will never be fully eliminated or accurately characterized?

Strategy here

- Blueprint model is powerful approach
- In its present form it is inadequate to address this problem
- Propose a modification of this blueprint model to address this problem

Idealized blueprint model

- Decomposition of problem of evolving robots into:
  1. Problem of generating the specifications of a robot that would have the desired behavior
  2. Problem of constructing a robot that matches these specifications.

- “Blueprint” is interface allowing specification generation and construction to be composed together

Advantages

- Larger problem of producing a robot exhibiting a desired behavior is hidden from the construction process.
- “Responsibility” shifted to problem of spec. generation
- Modular: Hides details of internal working from each other

Solution concepts

- Problem of generating specifications of a desired robot is conceived as being achievable using mathematical abstractions, models and "creativity", possibly entirely in software, without involving any construction.

- Solution concept is a natural match with the use of simulation based EC techniques.

Construction solution concept

- The solution concept for construction is a general purpose system that could reliably construct robots corresponding to any such evolved specifications, independent of their complication.
- In the ideal modular case where the sole interface between specification generation and construction is restricted to the blueprint and the internal working of each function is hidden from the other, this solution concept is tantamount to a Universal Constructor

Actual constructor

- Stance taken here:
  - Practical construction systems are always limited in capability, flexibility and reliability so the production of a robot corresponding to any given evolved specification cannot be taken for granted.
  - Construction is a significantly more costly as compared to the expenditure of computer cycles
  - Discovering construction limitations by trial and error during attempts to construct a robot based on an evolved specification needs to be minimized

Interaction across module boundaries

- One way is allowing an increased amount of principled interaction across the boundaries of these modular sub-functions.
- By “interaction”
  - Internal working of the construction system is made transparent to the specification generation system
  - Information obtained from this increased transparency is allowed to influence the process of generating the specifications

Principled interaction models in engr. systems

- Construction -> design:
  - Making models of the manufacturing processes available to the designers.
  - Using these models, particular design can be evaluated to determine (a) if it can be manufactured with the available facilities and resources, and (b) the cost of successfully manufacturing the design.
  - This approach is called Design for Constructibility

- Design -> construction:
  - If a design cannot be modified due to other constraints, then themanufacturing setup is itself often modified or enhanced to accommodate the peculiarities of the design.

Design for certifiability

- With respect to problem of reliability, need some additional considerations.
  - Being constructible does not mean errors, failures cannot occur.
  - In actual process there is a need to know: "has the goal been reached?". This is required for every blueprint independent of specification intricacy

Proposed construction model assumptions

- Fully automated:
  - Considering the problem in terms of full automation could add to the clarity of the analysis by revealing assumptions that are often unstated when there are "humans-in-the-loop".
  - Consider the construction system (whether a device or a system of interacting machines much like a factory) to be fully automated by being under programmable digital computer control.
  - Only way of interaction with the machinery is via these programs.

- Stateless construction system :
  - “Stateless” i.e. where there is no explicit mechanism to maintain the history of previous blueprints constructed including processes, outcomes and subassemblies from previous construction runs.
  - Construction based on a given blueprint is always performed right from the primitive components, rather than as modifications of a pre-constructed structure as in (>>Lund and Jakobi).