Generative Representations for Automated Design of Robots

Compact representations circumvent the computational obstacle to complexity.

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A method of automated design of complex, modular robots involves an evolutionary process in which generative representations of designs are used. The term “generative representations” as used here signifies, loosely, representations that consist of or include algorithms, computer programs, and the like, wherein encoded designs can reuse elements of their encoding and thereby evolve toward greater complexity.

Automated design of robots through synthetic evolutionary processes has already been demonstrated, but it is not clear whether genetically inspired search algorithms can yield designs that are sufficiently complex for practical engineering. The ultimate success of such algorithms as tools for automation of design depends on the scaling properties of representations of designs. A non-generative representation (one in which each element of the encoded design is used at most once in translating to the design) scales linearly with the number of elements. Search algorithms that use non-generative representations quickly become intractable (search times vary approximately exponentially with numbers of design elements), and thus are not amenable to scaling to complex designs.

Generative representations are compact representations and were devised as means to circumvent the above-mentioned fundamental restriction on scalability. In the present method, a robot is defined by a compact programmatic form (its generative representation) and the evolutionary variation takes place on this form. The evolutionary process is an iterative one, wherein each cycle consists of the following steps:

1. Generative representations are generated in an evolutionary subprocess.
2. Each generative representation is a program that, when compiled, produces an assembly procedure.
3. In a computational simulation, a constructor executes an assembly procedure to generate a robot.
4. A physical-simulation program tests the fact that when $V_{\text{bias}}$ is set at the value for maximum extinction, equal-magnitude positive and negative pulses applied to the electro-optical crystal produce equal output light pulses.

In a modulation system designed and operated according to this method (see Figure 2), the modulating pulses are converted to alternating polarity, a small portion of optical output power is sampled by a photodetector, the photodetector output is multiplied by a sample of the alternating-polarity modulating signal, and the product is integrated over time to obtain an error signal. When $V_{\text{bias}}$ is not at the optimum, maximum-extinction value, there is either an overshoot or an undershoot in the output light pulse, such that the integral signal amounts to an error signal that is proportional, in both magnitude and sign, to the difference between the actual and optimum values of $V_{\text{bias}}$. The integral signal is amplified and added to a DC offset voltage, and the sum fed to a bias control input terminal to drive the modulator toward optimum bias. Normally, the DC offset voltage would be set initially at a maximum-extinction point.

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the performance of a simulated constructed robot, evaluating the performance according to a fitness criterion to yield a figure of merit that is fed back into the evolutionary subprocess of the next iteration.

In comparison with prior approaches to automated evolutionary design of robots, the use of generative representations offers two advantages: First, a generative representation enables the reuse of components in regular and hierarchical ways and thereby serves a systematic means of creating more complex modules out of simpler ones. Second, the evolved generative representation may capture intrinsic properties of the design problem, so that variations in the representations move through the design space more effectively than do equivalent variations in a non-generative representation.

This method has been demonstrated by using it to design some robots that move, variously, by walking, rolling, or sliding. Some of the robots were built (see figure). Although these robots are very simple, in comparison with robots designed by humans, their structures are more regular, modular, hierarchical, and complex than are those of evolved designs of comparable functionality synthesized by use of nongenerative representations.

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