

Practically-usable analog design using Evolutionary Algorithms ***The art of Evolutionary Design***

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My work (with co-authors) presented at HUMIES 2006 showcased four sine-wave oscillator designs which were better than the state-of-art in oscillator design and fifteen oscillators which served as alternatives to the state-of-art. Sine-wave oscillators are a fundamental building block for analog circuits and extensively used in communication (modulation/demodulation), signal processing and measurement systems (e.g., oscilloscope). All these oscillators were automatically invented by a genetic algorithm!

There has been considerable success in automatic evolutionary design. However, in many cases the evolved designs are incomprehensible, idiosyncratic and practically unusable. Evolution finds a way to bluff the fitness function or the evolved designs work only on simulation, aren't robust or are too complex to be understood, re-used or implemented practically. A way to resolve this is to restrict the solution space intelligently. In tradeoff, as the restriction on the space is increased, evolution loses the ability to innovate. The problem of circuit design poses similar challenges. To address this, we chose a nice trade-off between practical usability and design innovation. We not only evolved practically-usable oscillators, but evolution also invented new re-usable design principles.

Another issue with evolutionary design is the large search space of designs which has to be searched. In general, though the structural space is small, the parameters (real-valued) associated with the structure bloats the space manifolds. This makes evolutionary design computationally very expensive at times and infeasible in other cases. Such algorithms could then be only run on super-computer grids and are not viable as desktop solutions for design. In the present work, we use domain knowledge to facilitate an intelligent design decomposition, which brings the time for evolutionary design on a desktop PC to few hours.

To restrict our design space rationally, we let evolution work at the level of linear active and passive components. We used first-order models for active components. This relieves the design process of the idiosyncrasy of transistor non-linearity and non-ideality. It is similar to using registers, adders, summers, etc. in the design vocabulary for evolving a CPU rather than using transistors or digital gates. The choice of the right abstraction level (components and models) ensured sensible designs, while it left enough room for innovation.

The fitness function was inspired by the human design process. Human designers don't use the SPICE simulator (numerical simulator for circuits) to innovate, instead they analyze the circuit symbolically. It is well-known that the ability of doing complex tasks, intuit and use deductive logic are results of the capability of the brain to reason symbolically. I used symbolic analysis for fitness evaluation to mimic the human design process. This leads to decomposition of the design process decoupling circuit topology search and circuit component values search. It is in fact this decoupling which makes the problem tractable for the human mind and the same benefit carries over to automated

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design. The component values are constrained adequately given the structure of the symbolic equations and can be solved for deterministically. This design decomposition brings down the computational cost of automatic design of oscillators to that achievable on a desktop PC today. It is worth noticing, that use of SPICE simulation instead of symbolic analysis would have yielded a spiked search space incapacitating evolutionary search.

Inspired by a network synthesis class and encouraged by Prof. Senani, I designed the algorithm for oscillator synthesis when I was a senior in my undergraduate school. I presented my first paper about this work at The 2003 NASA/DoD Conference on Evolvable Hardware. Subsequently, I collaborated with Dr. U. Cam, Selcuk Kilinc and Varun Jain. We published more than 19 oscillators complete with simulation results in the last 4 years and discovered many new design principles.

One of our most recent paper notes, "...the second topology changes the notion of minimum-components required for realization of a variable frequency oscillator using a single active element, which should now be considered four instead of five." In yet another paper, we show that the designed oscillator requires one terminal less of the active element in comparison to previous designs, thus saving power and area. A recently created design is the lowest-component oscillator which uses only grounded capacitors and can be implemented by a single discrete IC, AD830.

The success of the project of evolutionary oscillator design can be attributed to the following decisions in putting together an evolutionary design system: a. Choice of the right abstraction level for evolutionary search, b. Effective design decomposition using domain knowledge, c. Design of a smooth fitness function for easy traversal of search space.

Reference: All related papers, video and HUMMIES presentation present at http://web.mit.edu/varun_ag/www/hc-2006.html