Evolutionary Optimization of Circuits

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A cheery quote to start...

"*The future for EH-based digital circuit synthesis methods looks bleak. The truth is EH-based approaches simply can't stand up to existing design methods. Evolving combinational and sequential circuitry is never going to intrigue anyone...*

Consequently it is strongly recommended that EH practitioners abandon any further work on evolving combinational or sequential circuits"

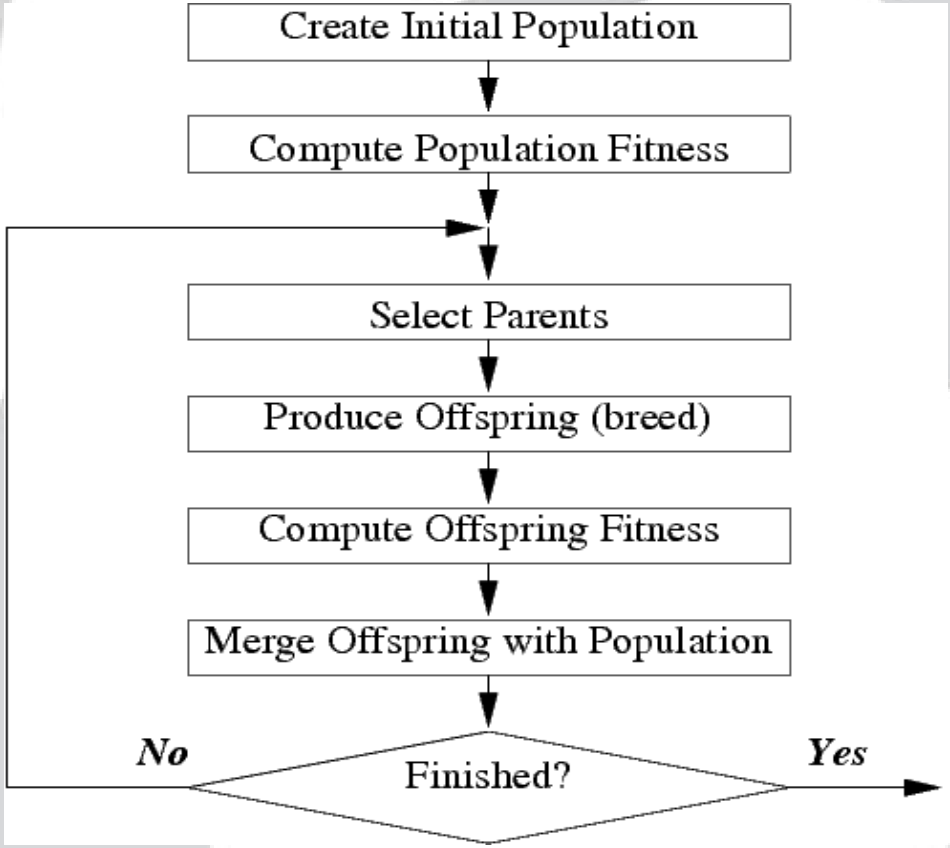
Garrison W. Greenwood, WEAH '09 (Editor-in-Chief of IEEE TEC)

What's Evolvable Hardware (EH)?

- Design of hardware by means of evolutionary computation
- Analog circuits
  - Amplifier, filters, oscillators,...
- Digital circuits
  - Sequential, combinatorial
- 'Lower-level'
  - Geometries, routing, placement, materials,...
- 'Weird stuff'
  - In-materio evolution

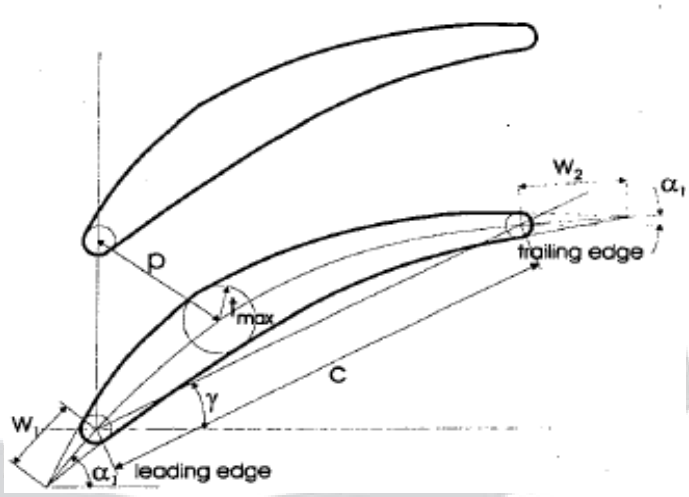
What is Evolutionary Computation ?

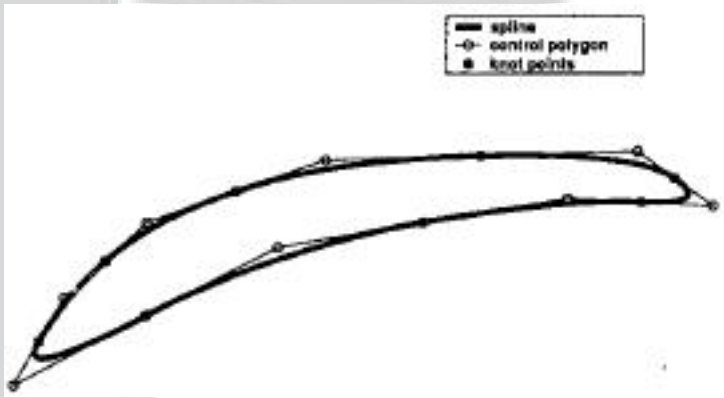
- Population based, stochastic search algorithm
- Intelligent way to do *trial-and-error*
- Survival of the fittest
- Crossover and mutation



Success in Design Optimization

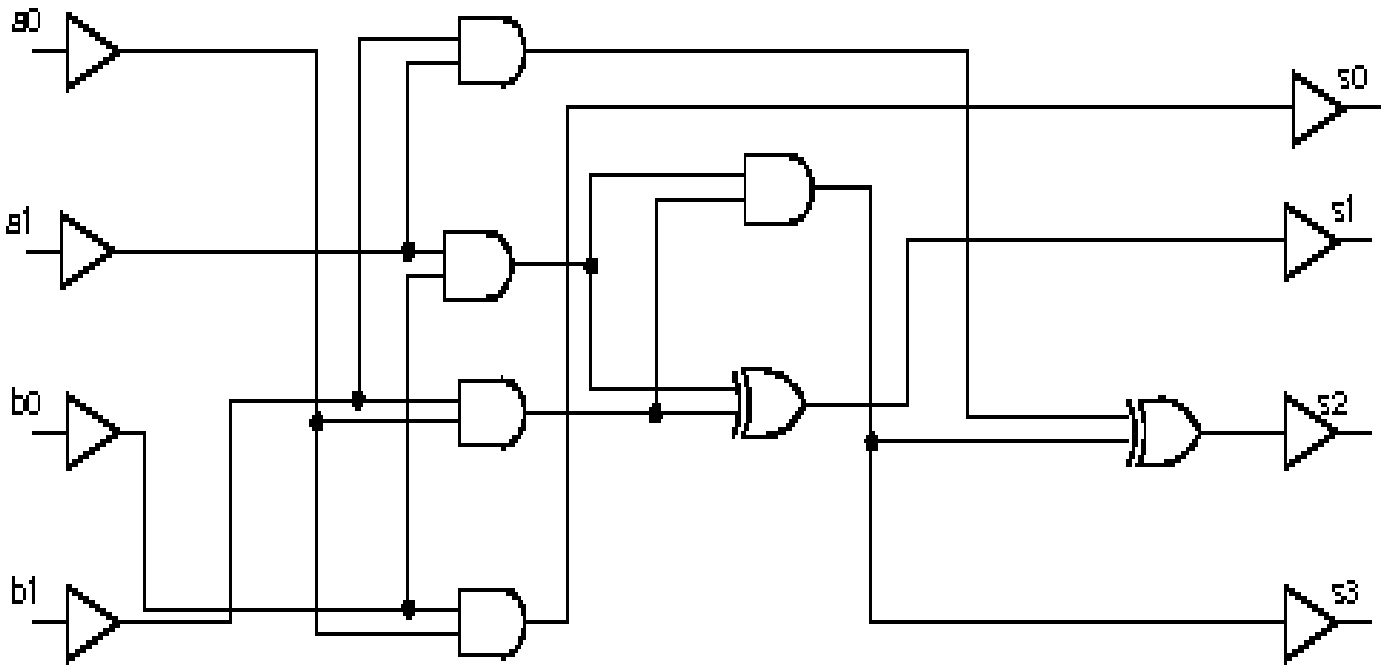
- Many human-competitive solutions
- Many patented results
- Example: turbine blade design (Honda):





Evolving Digital Circuits

- Representation example: Cartesian GP



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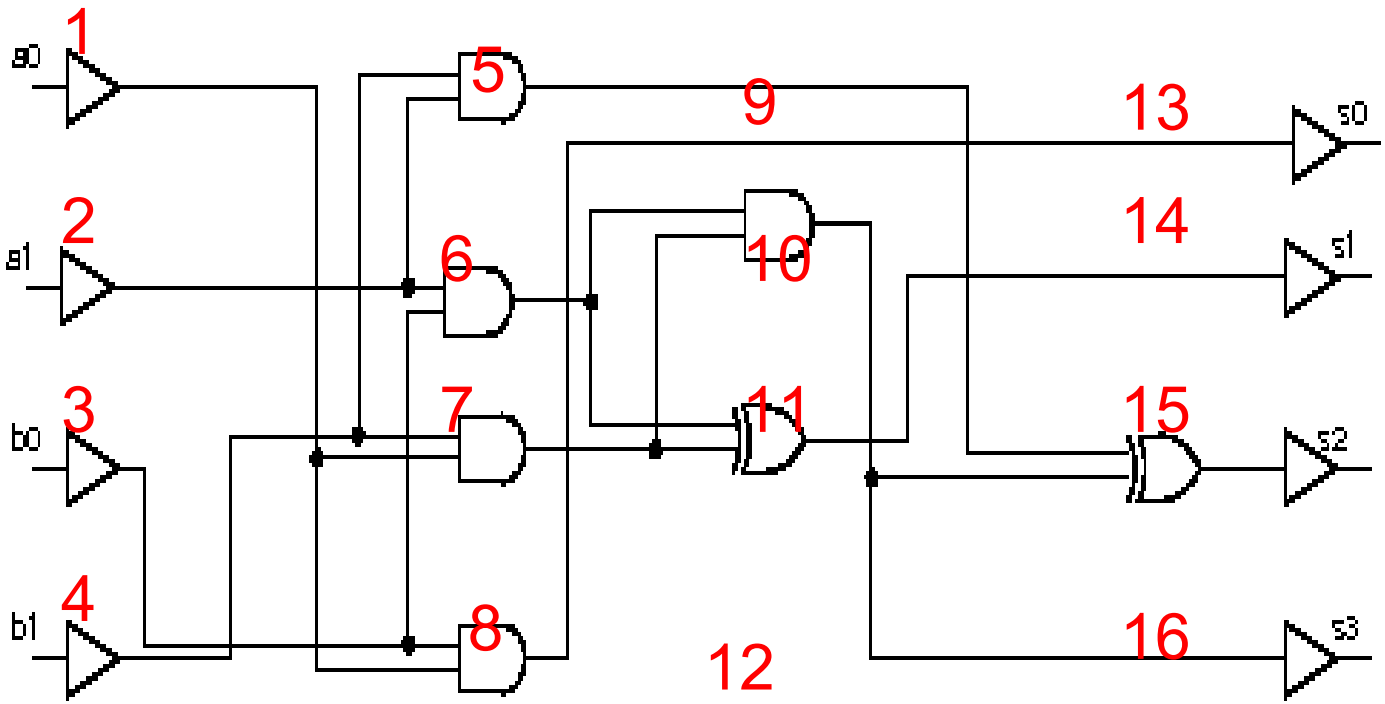


Fitness Evaluation

- Digital circuits in simulation:
  - Just try all possible inputs
  - Count how many output bits are wrong
    - (you can do that in parallel)
  - Mostly sequential logic only
  - Millions and 100s of Millions of evaluations....
- Or: on the real hardware

What can you do with it?

- Evolve 4x4 bit multipliers
- Machine learning
  - Compression engines
  - Classifiers
- Evolve Signal Processors
  - Digital filters (e.g. for low coefficient sensitivity)
  - Linear transforms

What's Wrong?

- According to Greenwood
  - EAs can't handle different levels of abstraction
  - EAs can't use pre-designed IP
  - EAs can't instantiate on-chip resources
  - EAs don't handle design constraints effectively
  - Scalability

Should I give up ?

- No way !
  - Get better
  - Find niches where the competition is even worse...

Better Fitness

- No fitness gradient – integer fitness
  - Deadly for EA performance
  - Neutral walk crucial
  - Is it even accurate?
- Can we get additional information ?
  - Are we getting closer to a correct circuit?
  - Internal states useful?
- Pseudo-Quantum gates ?
  - A little bit of 'or', a little bit of 'and'...

Better Operators

- Crossover pretty much useless
  - Can we define an intelligent crossover?
- Mutation completely random
  - Likely to destroy useful structures
  - Can we define a better mutation?
    - Functionally-neutral mutations for optimization
    - Bias towards local connections helps sometimes

Simplify the Problem

- Divide and Conquer
  - By outputs
  - By input
  - Much faster to evolve four 4-input circuits than one 6-input circuit

Growth

- Discovery of modularity
  - A human would assemble a multi-input adder from half-adders
  - An EA usually wouldn't
  - We can push EA to do this by including 'development' in the representation, and evaluating for more and more inputs

Incorporate Knowledge

- Multi-Level design, design using IP
  - Is there an *optimization* problem at higher levels?
  - Is there a fitness that I can use at higher levels?

Find Niches

- EvoComp is most competitive where there is no perfect conventional way of doing things
  - Approximations are used
  - Only part of the design space are used
  - There is room for improvement
  - Your designers require a cauldron, and a daily ration of chicken feet...

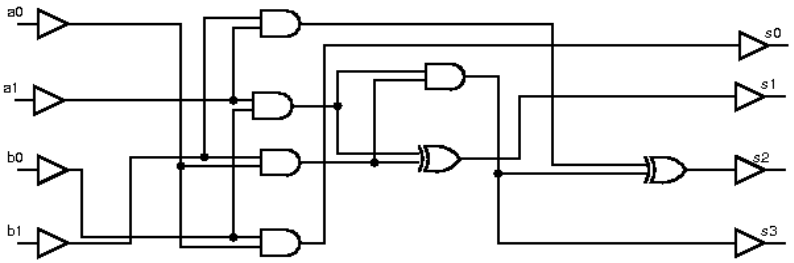
Optimization

- The smallest known instances of (simple) adders and multipliers have been generated using EH
- Multi-Objective problems
  - Exploration of tradeoff fronts (e.g. digital filters)
- Post human-design optimization

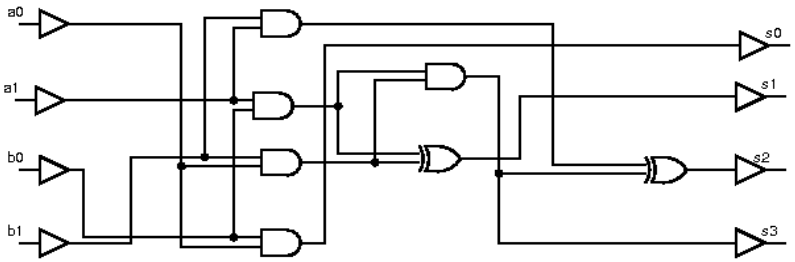
Fault-Tolerance

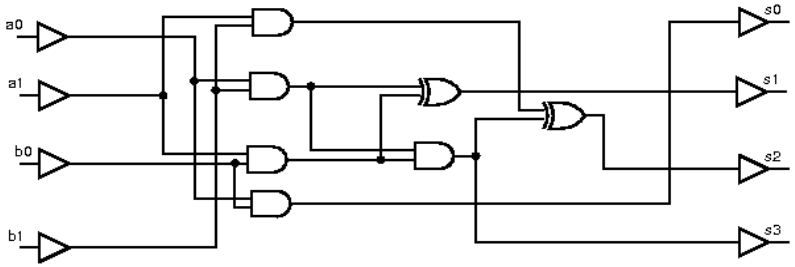
- Redundancy relies on diversity
- Is there a conventional design methodology for diversity?
  - EH can deliver diversity
  - EH can even deliver *optimized* diversity

Evolved Circuit-pairs



Human





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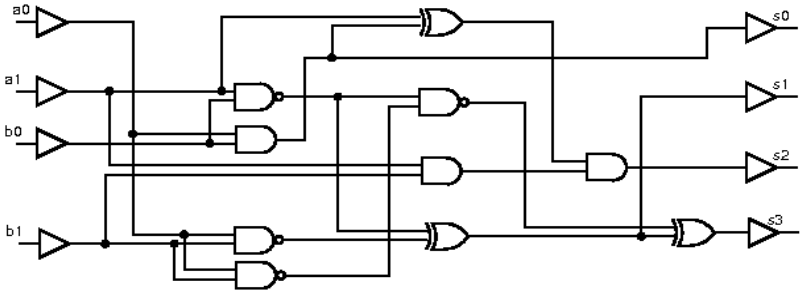
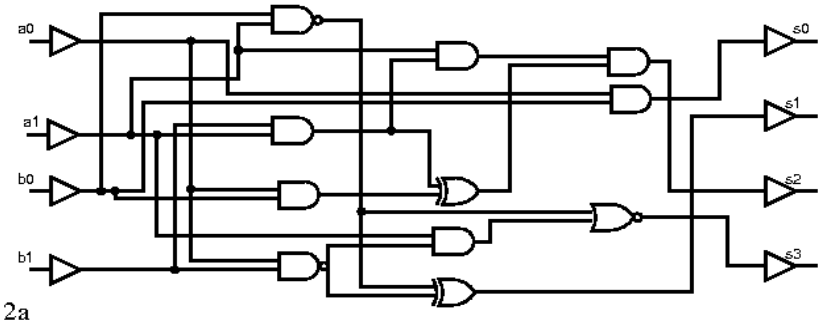
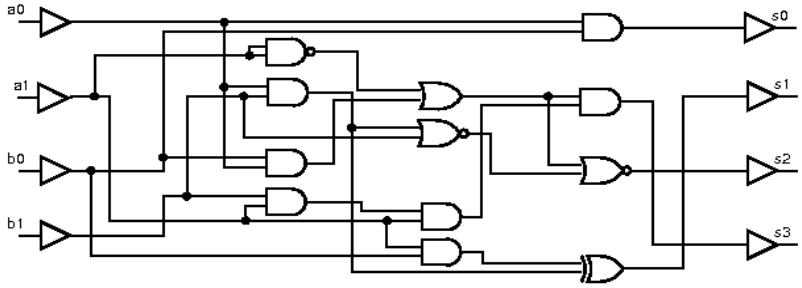


1b



2a



2b

Unusual hardware

- Adrian Thompson's frequency-discriminator-on-a-FPGA
- 'In-materio' evolution – e.g. using LCD, wetware,...
- Ternary logic?
- Quantum logic?

Repair and Callibration

- Incomplete knowledge
  - Solar Storm - Space radiation damaged FPGA – can you repair it without knowing the exact faults?
  - Production has tolerances – can you calibrate each chip to increase yields (analog) ?

EA on massively parallel hardware

- Evolutionary algorithms parallelize easily
  - Fitness evaluation in parallel
  - Island models with migration
- Potential for implementation on FPGA (done), GPU, Physics engines, …
- Depends on application/fitness function

Summary

- Not a general replacement for traditional design techniques
- Potential for use in combination with traditional design tools
- Currently best for 'unusual' applications
- Room for improvement