

Genetic Programming and Evolving Complex Genomes



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Outline

- Complex Genomes
- Genetic Programming
- Linear Genetic Programming
- Examples
- Evolve Everything!

Complex Genomes

• Nature and EAs



Complex Genomes



Genotype

Phenotype

Fitness

Complex Genomes

• Genetic Algorithms/Evolution Strategies...



- Genetic Programming
 - John Koza, 1992
 - Extend GA/ES to anything
 - Focus on computer programs



- Internal representation
 - Binary trees
 - Specialized mutations and crossovers

- General idea: EVOLVE <u>ALL</u> THE THINGS
 - If you can *describe* a candidate solution to a problem...
 - ...and variations (e.g. mutations, crossovers)...
 - ...and you can *define a fitness function*...
 - ... EAs can explore the space of all possible solutions!
- It worked for *life on Earth*!
 - DNA is pretty complicated
 - Genome doesn't need to be just numbers





Operators: +, -, *, /, In...

Terminals: reals, ints, vars, ...

 $f(x, y) = (0.2 - x) * \ln(10 * y)$

Symbolic Regression



Symbolic Regression





Operators: +, -, *, /, In...

Terminals: reals, ints, vars, ...

 $f(x, y) = (0.2 - x) * \ln(10 * y)$



Operators: α, β, γ, ζ, λ, π, ς, ...

Terminals: δ, ε, η, θ, ρ, σ, τ, ...



• Mutation(s)



• Mutation(s)



POINT MUTATION

• Mutation(s)



POINT MUTATION

• Mutation(s)



SUBTREE MUTATION

• Mutation(s)



SUBTREE MUTATION

• Mutation(s)



• Mutation(s)



• Crossover(s)





• Crossover(s)





• Crossover(s)





Genetic Programming: Issues

- Issues
 - Bloating
 - Introns
 - Destructive recombination



Genetic Programming: Bloating

- Over the generations
 - Individuals tend to increase in size...
 - ...with no benefit on their fitness!
- Solutions
 - Penalize large trees (penalty coefficient)
 - *Fitness hole* (randomly, tournament selection on other criteria, such as size or diversity)
 - Simplify (problem-dependent)

Genetic Programming: Introns

- "Useless" parts inside individuals
 - Non-coding genome (y+1-1/1...)
 - Increase in size

- Are they REALLY useless?
 - Introns exist in natural DNA
 - "Protect" important code from destructive recombination



GP: Destructive Recombination

- Issue with crossovers
 - Important information is destroyed
 - How to choose a proper cut point?

- Heuristic crossover (problem-dependent)
- Ignore the problem (hope introns solve it)

- What are we doing?
- Blending optimization and machine learning?
 - If your candidate solution is a *model*...
 - ... then you are (arguably) doing machine learning!

• Terminology is still uncertain



Linear Genetic Programming

- Evolving linear graphs
- Used for evolving computer programs
- Backward/forward arcs interpreted as jumps





Linear Genetic Programming

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Evolving Als

- Real-time strategy (RTS)
 - Planet Wars (Google)
 - StarCraft
 - Student StarCraft AI Tournament
- Trade-off
 - ANNs are better
 - You can read GP trees



Evolving ML Workflows

• TPOT

– https://epistasislab.github.io/tpot/



Evolving Neural Networks

- Design of Artificial Neural Networks (ANNs)
 - Most are built by copying literature
 - Trial and error, human-designed
 - But can we find something better?
- Neuroevolution!
 - The concept exists since ~1995
 - Wider adoption since 2016, with success of Deep Learning (improved ANNs)

Software Testing

- Generate sequences of inputs to find bugs
 - Motorola tests mobile phones
 - Facebook tests graphical user interfaces (Sapienz)

- Fitness landscape seems impossible!
 - Few points with bugs, everything else is 0
 - Smoothing landscape with domain knowledge
 - Reward individuals that explore functions

Genetic Improvement

- Automatic correction of software bugs
- Individual: series of code modifications

- Fitness
 - A series of test cases
 - They still have to work

Comment line 52
Swap lines 3 and 22
Change variables lines 42 and 11
•••

Genetic Improvement

- But does it *really* work?
 - Aren't EAs introducing other bugs?
 - Aren't HUMANS introducing other bugs?
 - In the end, you just need to be as good as the average programmer, and you save time
 - Still experimental

Langdon, William B. Genetically Improved Software

Justyna Petke and Saemundur O. Haraldsson and Mark Harman and William B. Langdon and David R. White and John R. Woodward. **Genetic Improvement of Software: a Comprehensive Survey**

Evolve Everything



Evolve Everything: Antennas

- Design of antennas for satellite ST5 (2006)
- Lots of constraints: weight, size, efficiency...
- Genome
 - Forward (length, radius)
 - Rotate_x (angle)
 - Rotate_y (angle)
 - Rotate_z (angle)
- It worked!



Evolve Everything: Robot Movement

https://www.youtube.com/watch?v=iNL5-0 T1D0



Evolve Everything: Movement

Evolved Electrophysiological Soft Robots



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