

Automating Algorithm Design through Genetic Programming Hyper-Heuristics

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Morris, MN

What does the title mean?

- Reducing the human component in algorithm design



[https://scratch.mit.edu/
discuss/m/topic/200574/](https://scratch.mit.edu/discuss/m/topic/200574/)

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- More work at the beginning, more possibilities



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What does the title mean?

- Reducing the human component in algorithm design
- More work at the beginning, more possibilities
- Genetic programming hyper-heuristics as a method to the madness



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Outline

- 1 Background
- 2 Hyper-heuristics
- 3 Genetic Programming Variants
- 4 Autoconstruction
- 5 Summary

Outline

1 Background

- Evolutionary Computation
- Genetic Programming

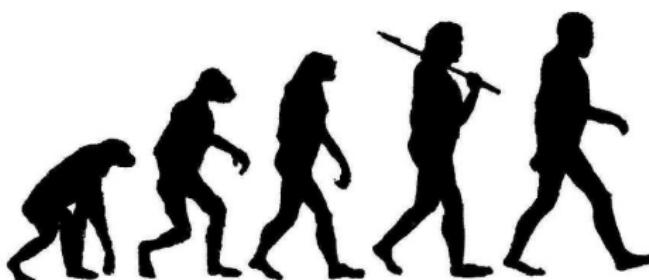
2 Hyper-heuristics

3 Genetic Programming Variants

4 Autoconstruction

5 Summary

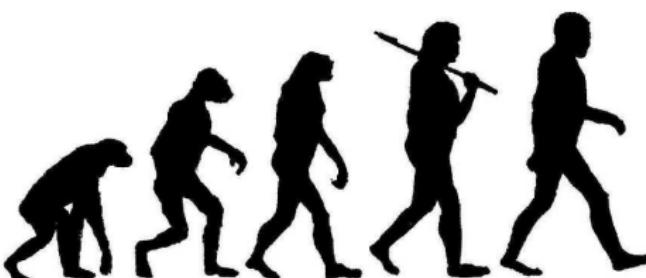
Evolutionary Computation



<https://www.spigotmc.org/attachments/evolution-jpg.137048/>

- Subfield of Artificial Intelligence

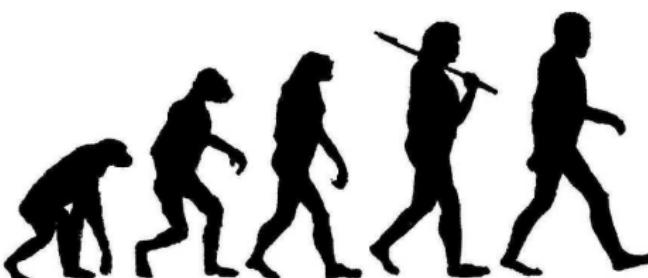
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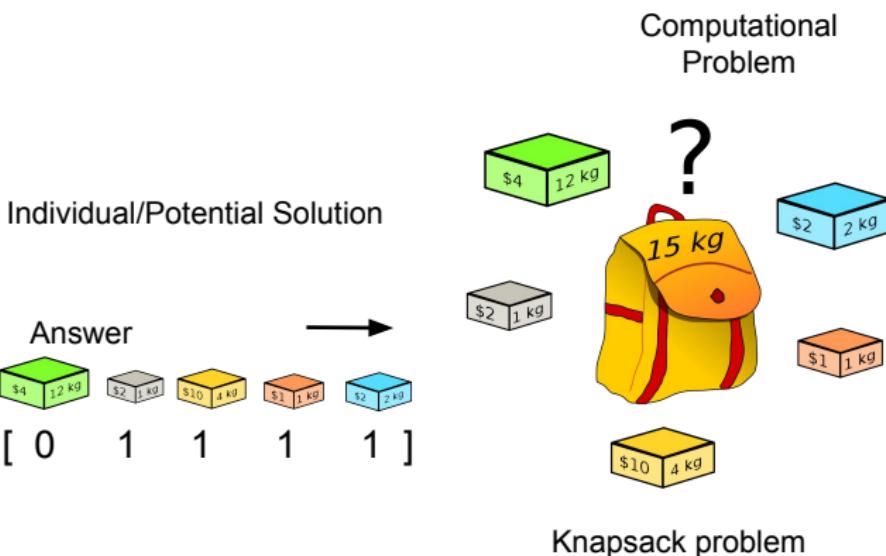
- Subfield of Artificial Intelligence
- Algorithms based on biological evolution

Evolutionary Computation



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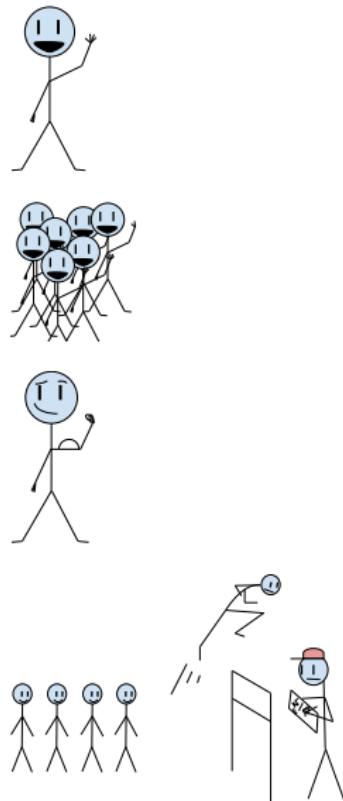
- Subfield of Artificial Intelligence
- Algorithms based on biological evolution
- Uses lots of terminology from biology, doesn't always mean same thing as term means in biology.



Based on <https://upload.wikimedia.org/wikipedia/commons/thumb/f/fd/Knapsack.svg/1200px-Knapsack.svg.png>

Evolutionary Computation – Terminology

- **Individual** – a potential solution to a problem (or set of problems)
- **Population** – a group of individuals
- **Fit** – how well suited an individual is at solving a problem
- **Fitness Test** – a set of tests to determine how fit an individual is.



Evolutionary Computation – Terminology

- **Mutation** – an insertion, deletion, or small change in the code of an individual, creating a new individual
- **Sexual reproduction** – when two or more individuals are munged together to create a new individual

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If individual A experiences a mutation to create individual B, then:

- **Parent** – Individual A



- **Child** – Individual B



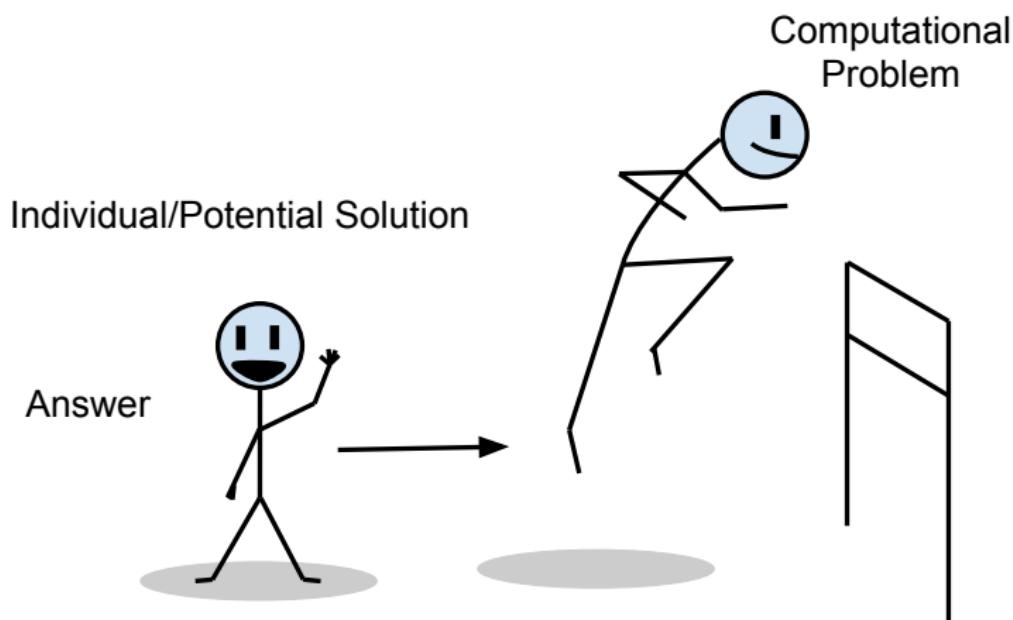
Evolutionary Computation – Terminology

- **Generation** – a population of individuals
- **Global optima** – best solution (or solutions) possible
- **Stopping point** – time limit, or generation limit.

Genetic Programming

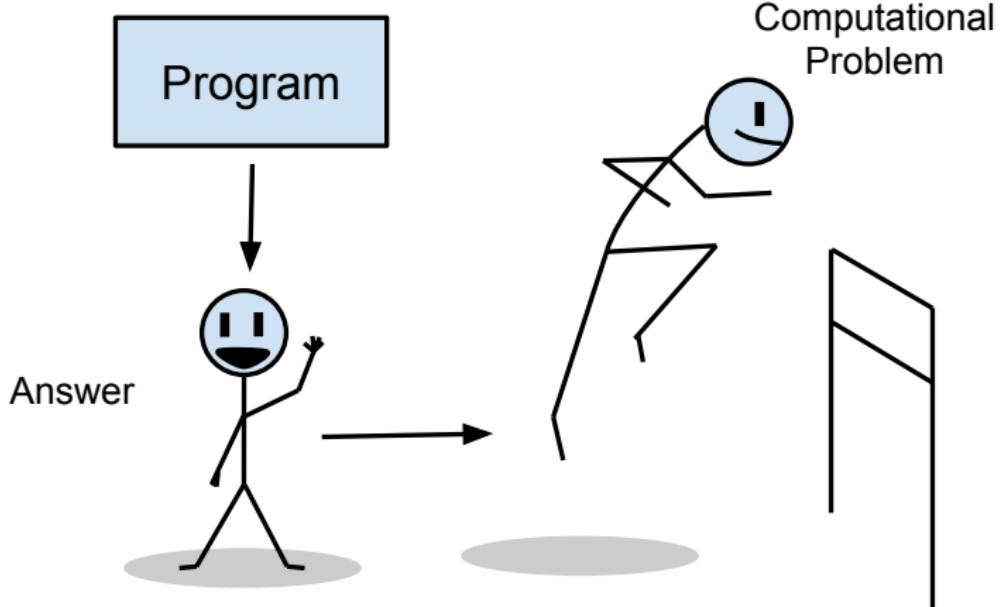
A family of algorithms in Evolutionary Computation that uses biological techniques to create programs to solve computational problems.

Genetic Programming

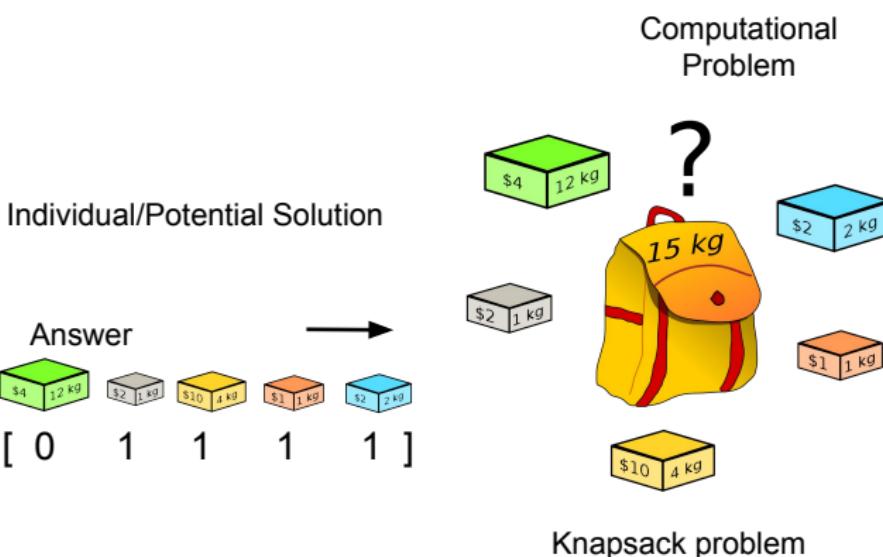


Genetic Programming

Individual/Potential Solution



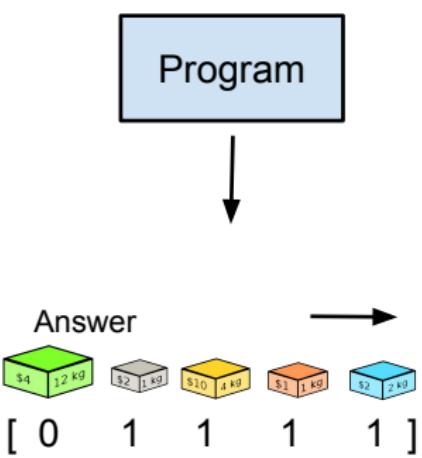
Genetic Programming



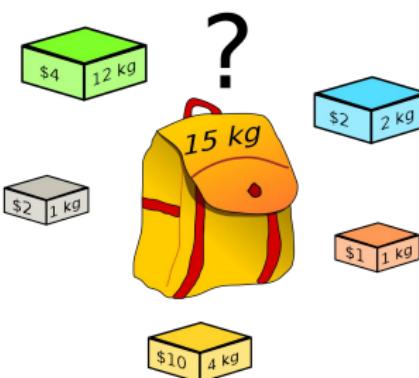
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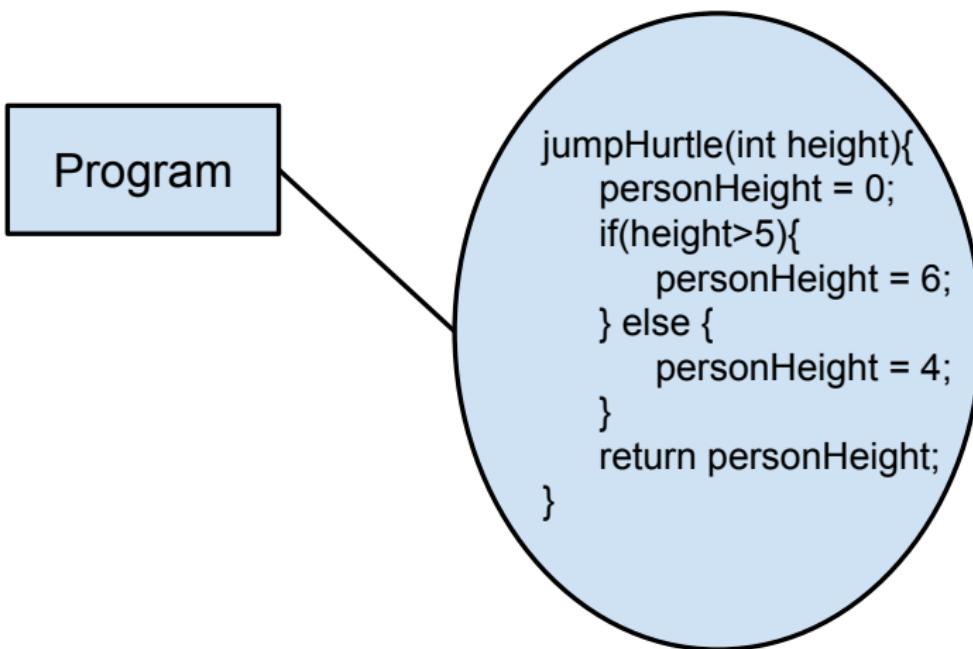


Computational Problem

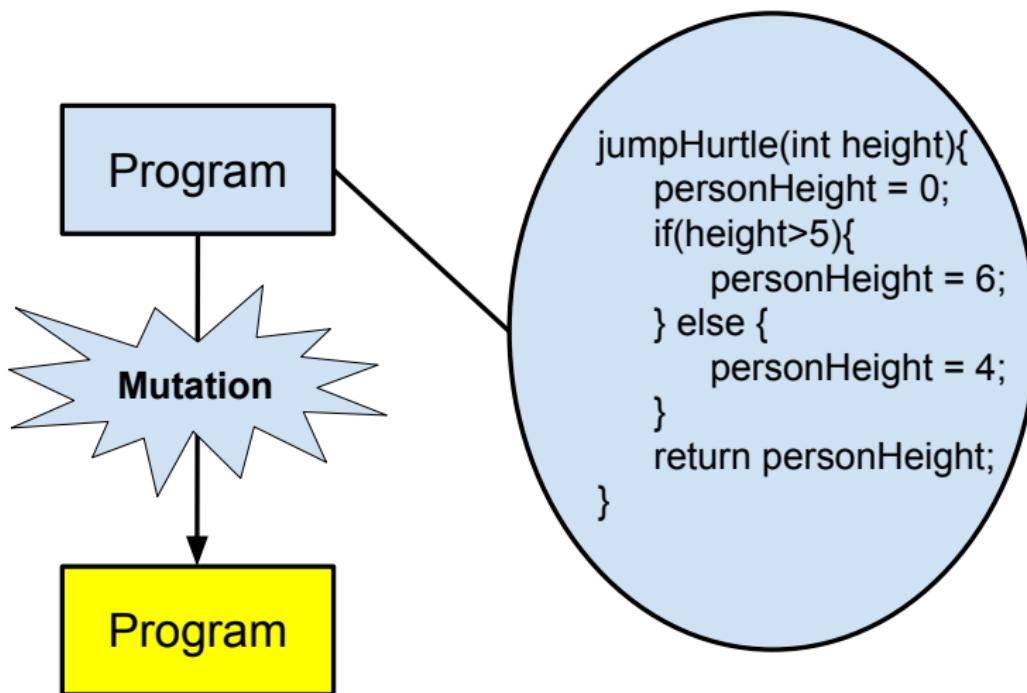


Knapsack problem

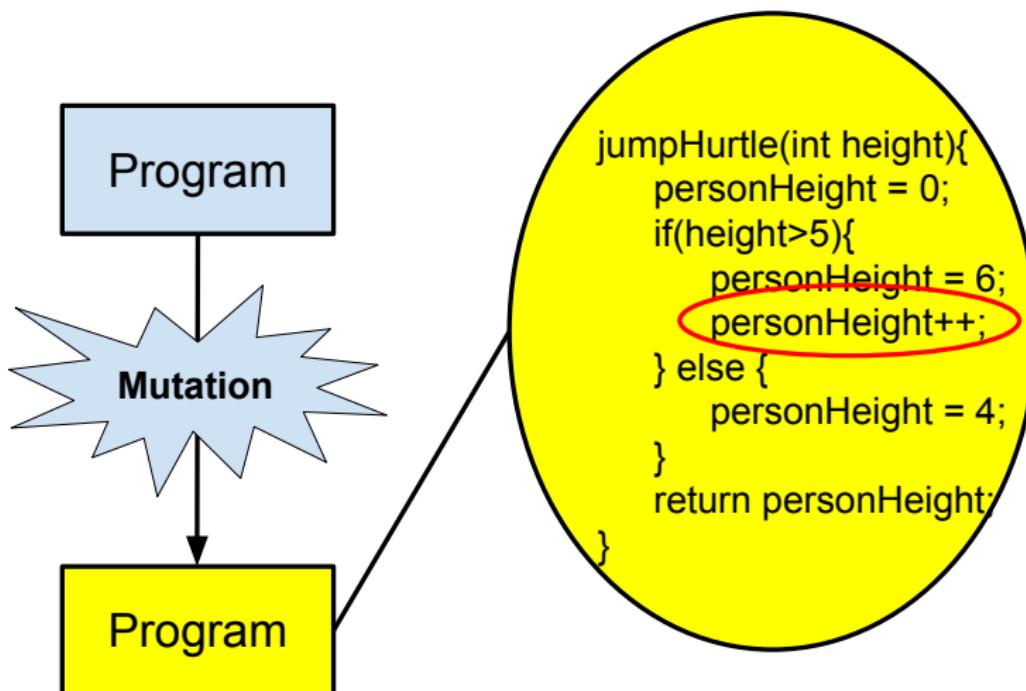
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Genetic Programming



Genetic Programming



Outline

1 Background

2 Hyper-heuristics

- Heuristics
- Hyper-heuristics

3 Genetic Programming Variants

4 Autoconstruction

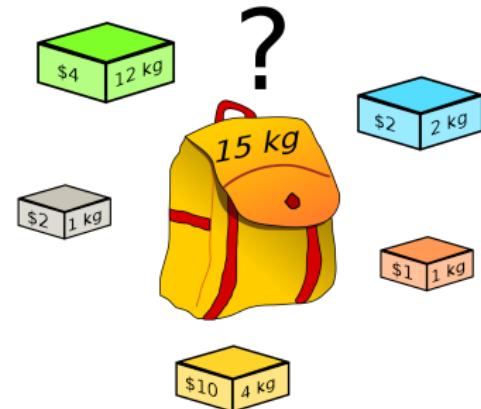
5 Summary

Heuristics

Heuristics – a function that ranks alternatives in a search algorithm at each branching step and uses that information to choose which branch to follow.

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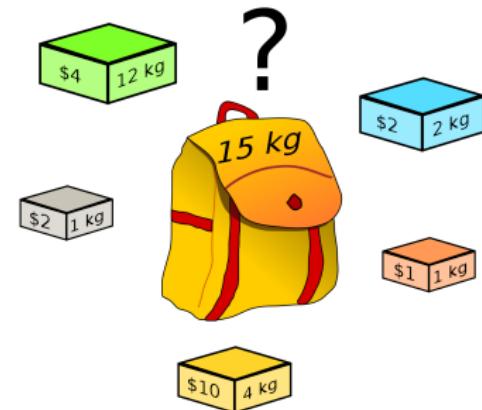


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Heuristics

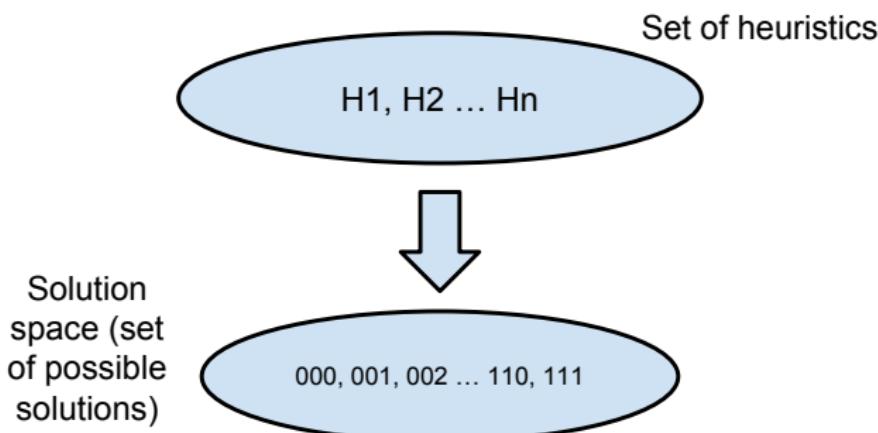
Heuristics – a function that ranks alternatives in a search algorithm at each branching step and uses that information to choose which branch to follow.

Example: “Select highest valued item and put into knapsack. If item puts knapsack overweight, select next highest value instead. Repeat until all items are gone or until the knapsack is full”



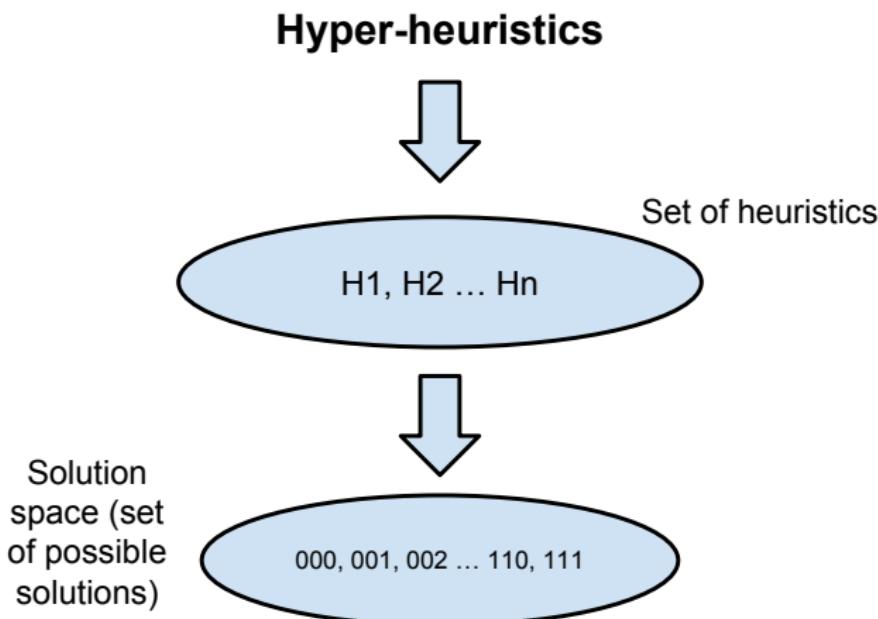
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Heuristics



Based on figures from Tauritz et al. [3]

Hyper-heuristics



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Hyper-heuristics

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Genetic programming hyper-heuristics – hyper-heuristics that use genetic programming for the process of selecting, generating, or adapting several simpler heuristics.

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2 Hyper-heuristics

3 Genetic Programming Variants

- What are they?
- Why should we care?
- Stack-based genetic programming

4 Autoconstruction

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Genetic programming variants

GP variants – variations on the structure and setup of a genetic programming system.

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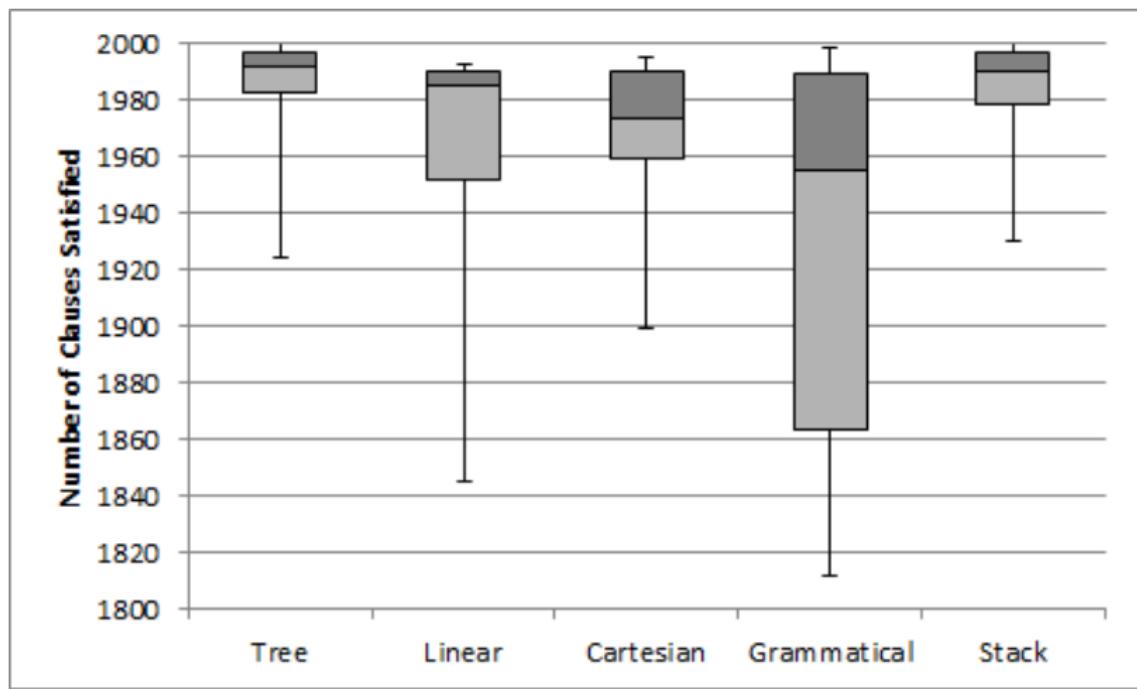
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GP variants tested:

- Cartesian GP
- Linear GP
- Stack-based GP
- Tree-based GP
- Grammatical Evolution

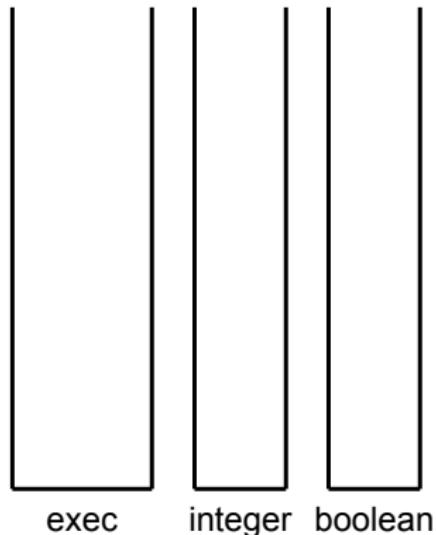
Why should we care?



Graph taken from Harris et al. [1]

Stack-based genetic programming

Data-stacks are used for managing input and output of operations.

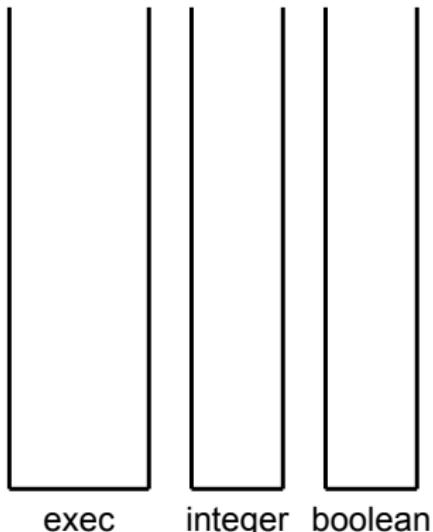


Stack-based genetic programming

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Programs are represented as linear sequences of literals and instructions.
Below is an example of a simple Push program:

(1 integer_add 2 integer_equal)

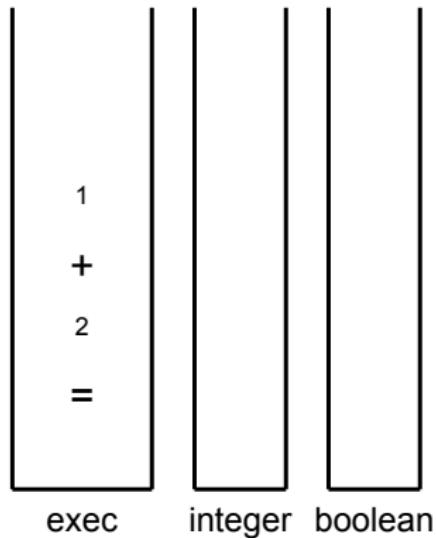


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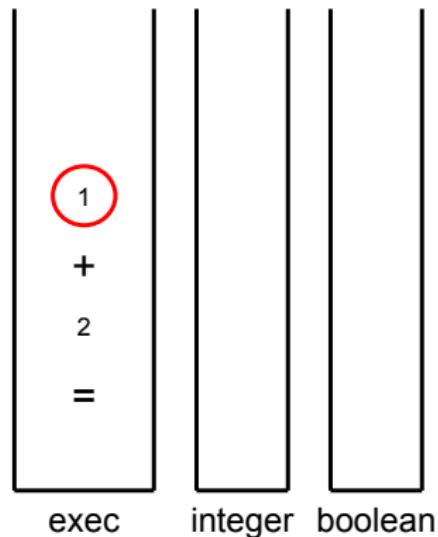


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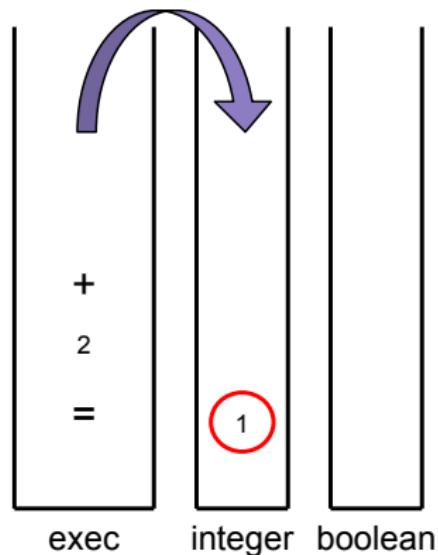


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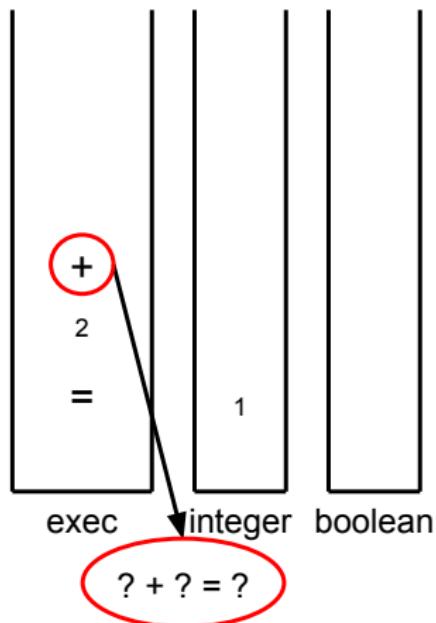


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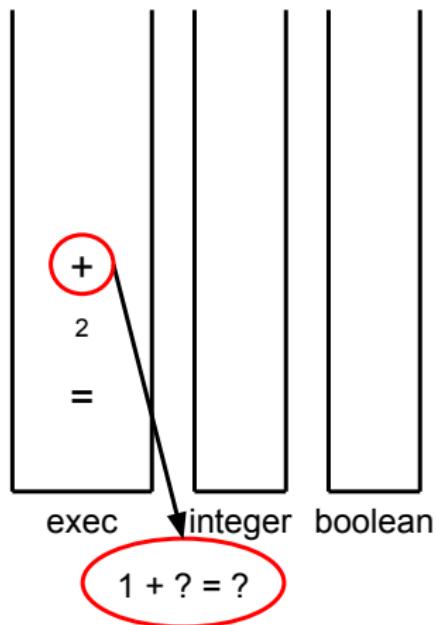


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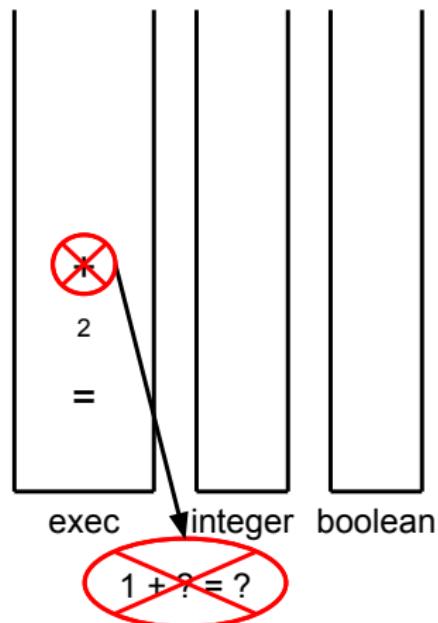


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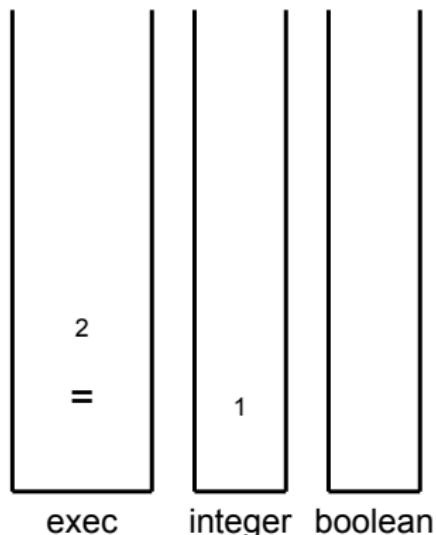


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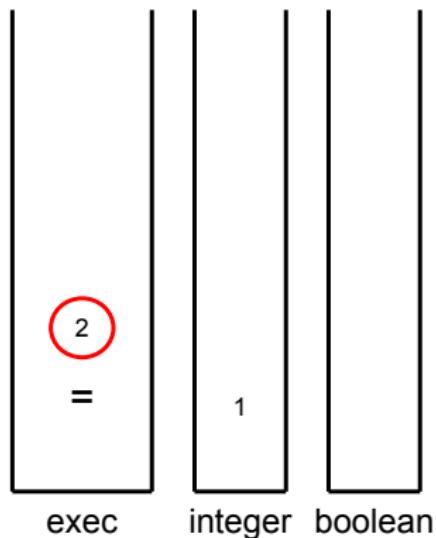


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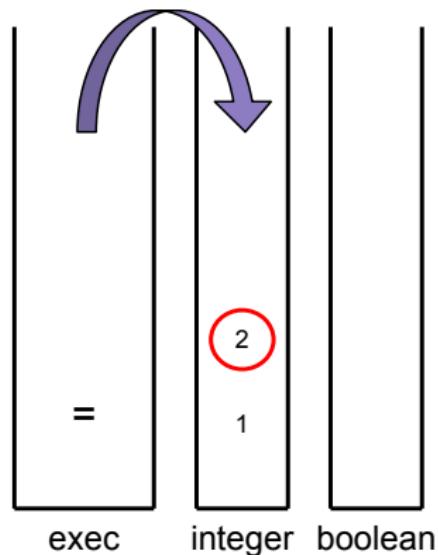


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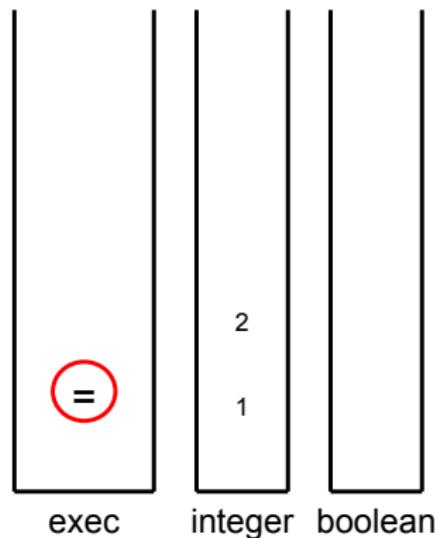


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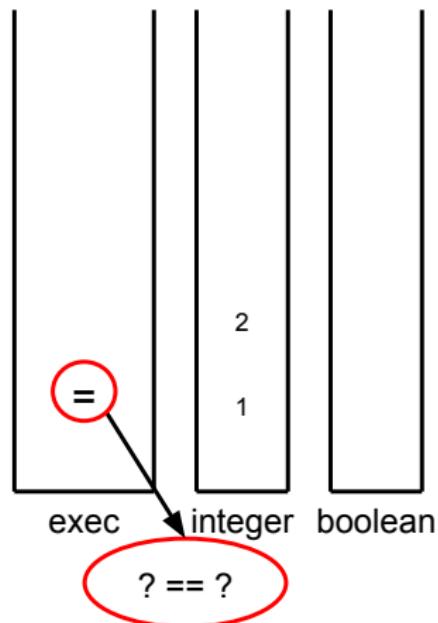


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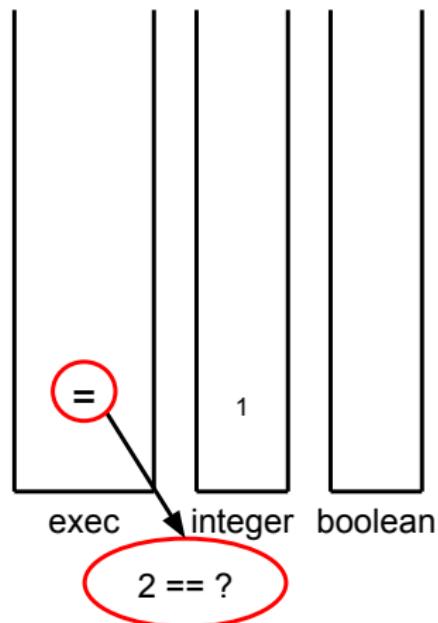


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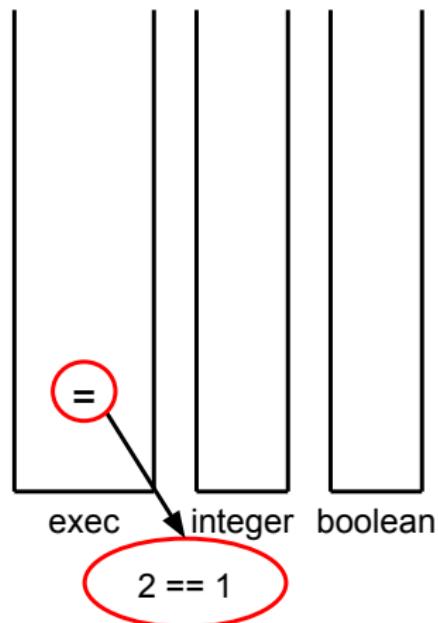


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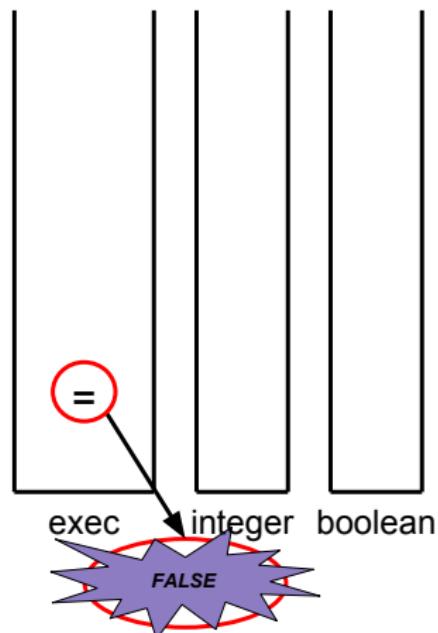


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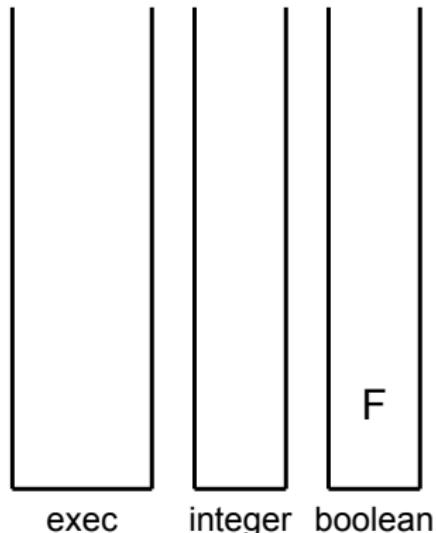


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4 Autoconstruction

- What is it?
- AutoDoG
- Results of AutoDoG

5 Summary

What is Autoconstruction?

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- Autoconstruction is a type of genetic programming hyper-heuristic (GPHH)
- In most GPHH, the individual programs are evolving, but everything else is specified by the engineer; in autoconstruction, evolution is evolving as well.
- Programs are responsible for evolving solutions *and* responsible for constructing their offspring.

AutoDoG

- A system designed by Spector et al. [2] that uses autoconstruction to evolve programs.

AutoDoG

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- Uses the Push programming language

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- Uses the Push programming language
- Uses Plush, a linear genome format for Push

AutoDoG – reproduction

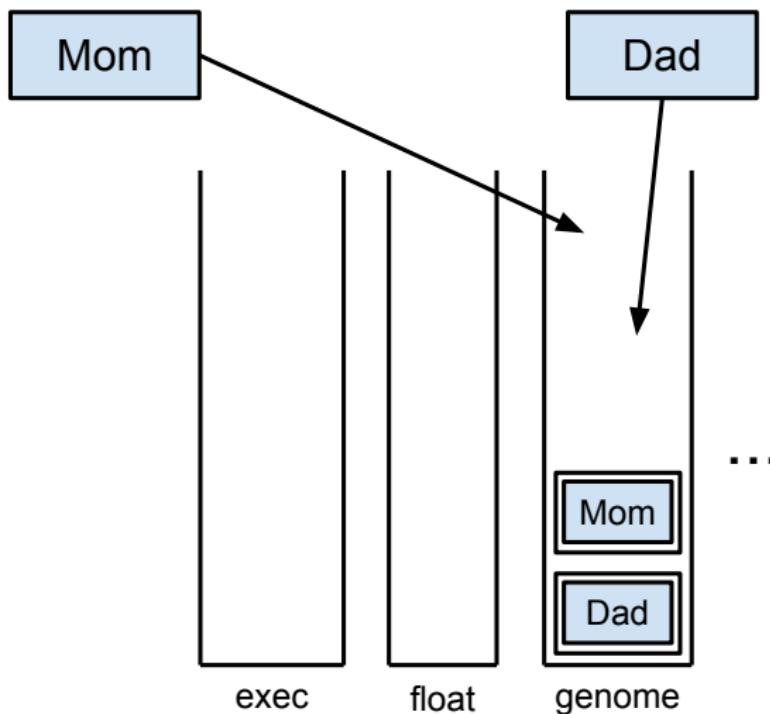
Mom

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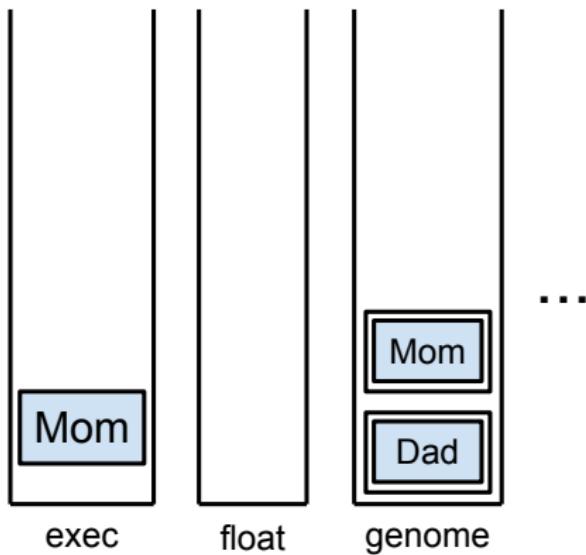
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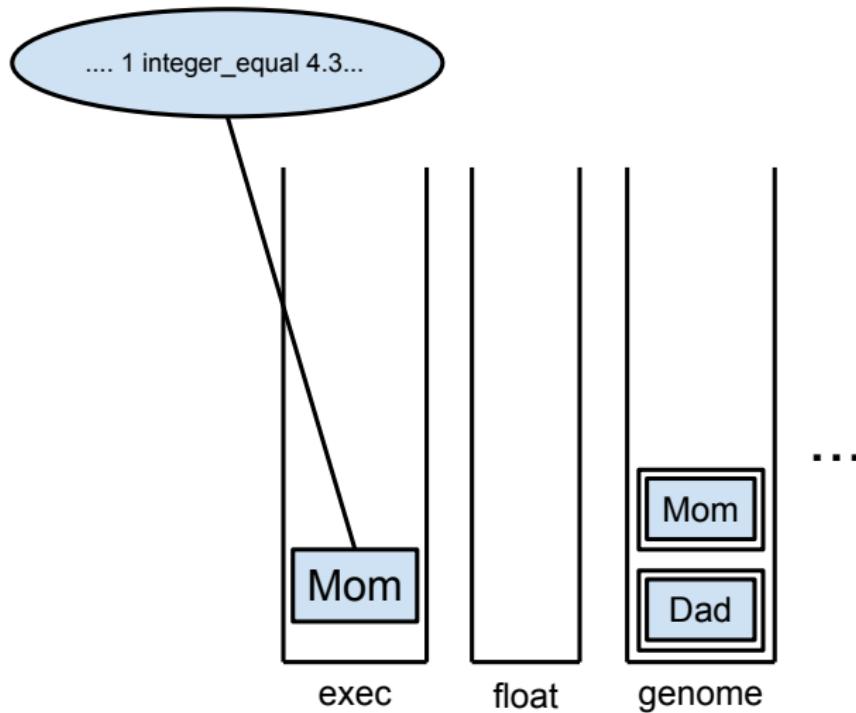
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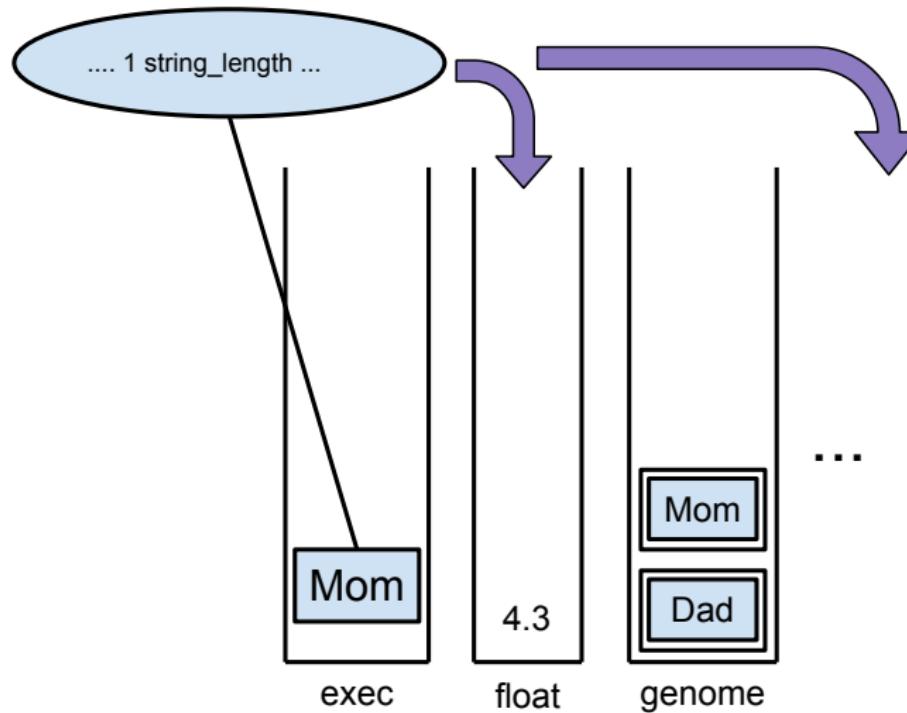
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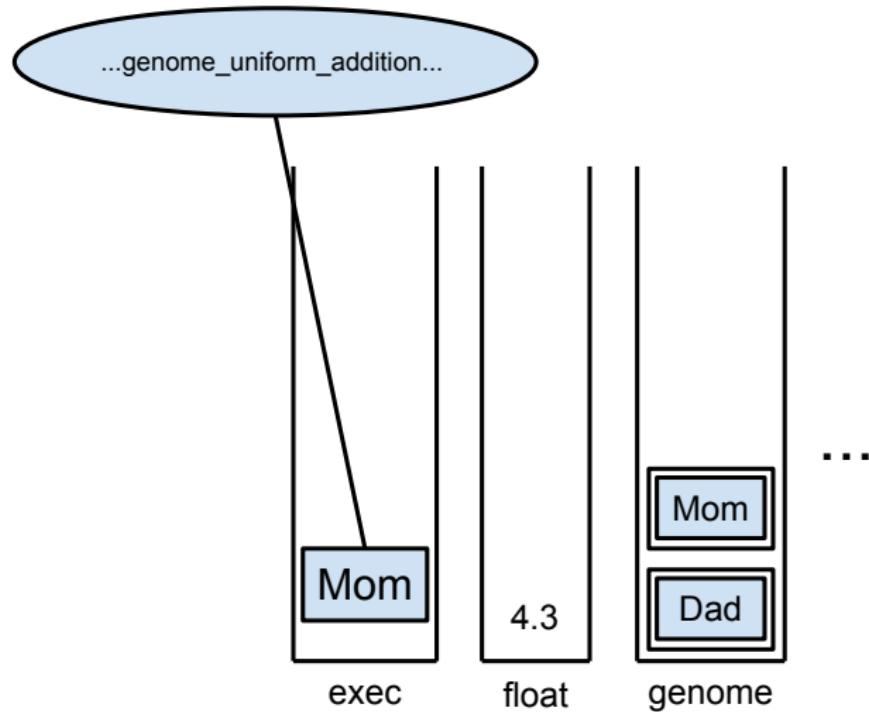
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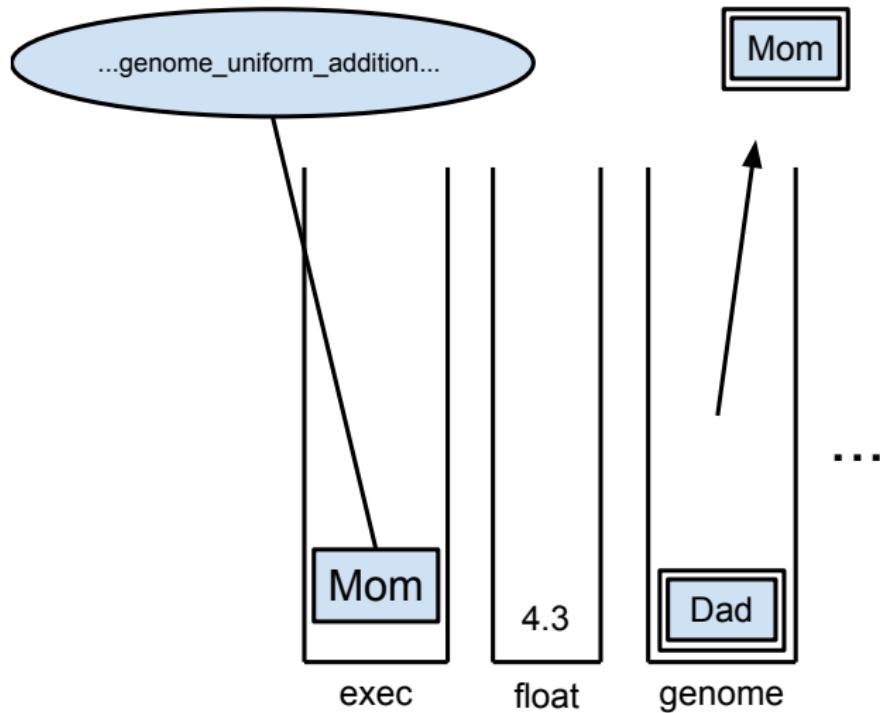
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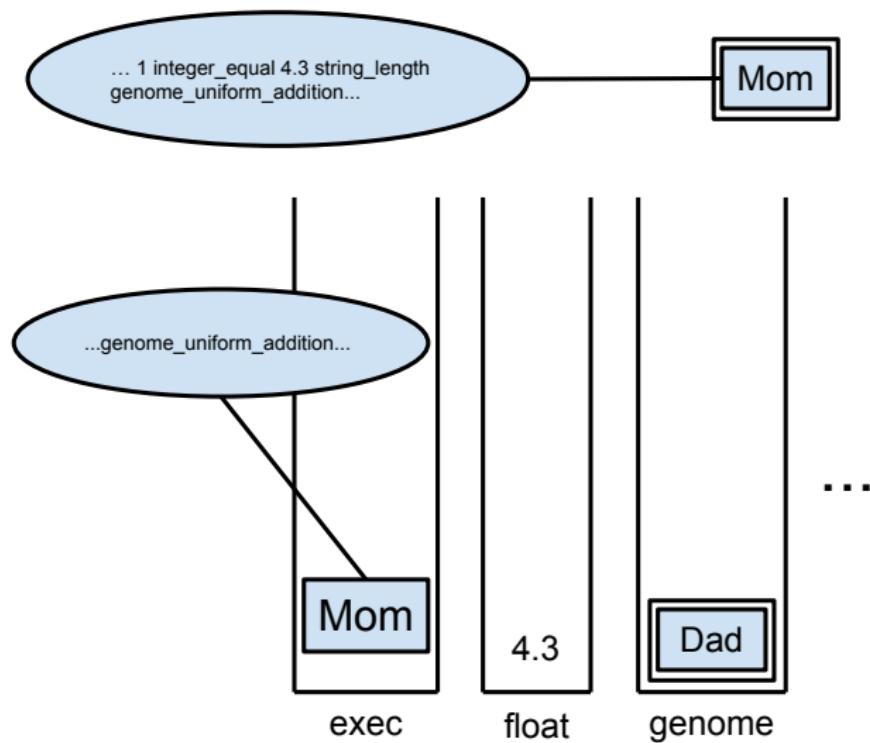
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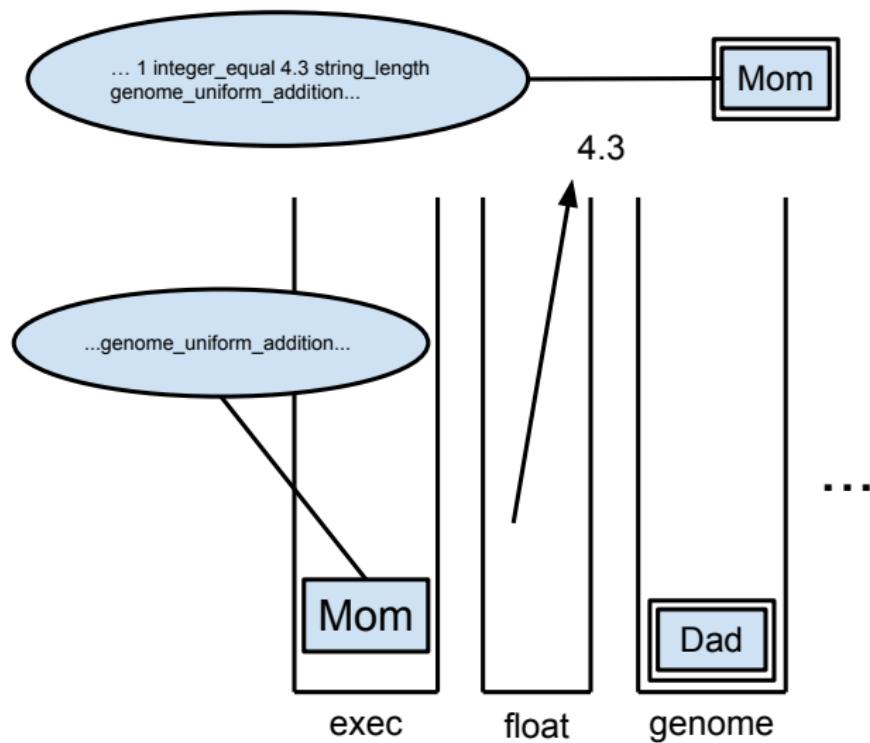
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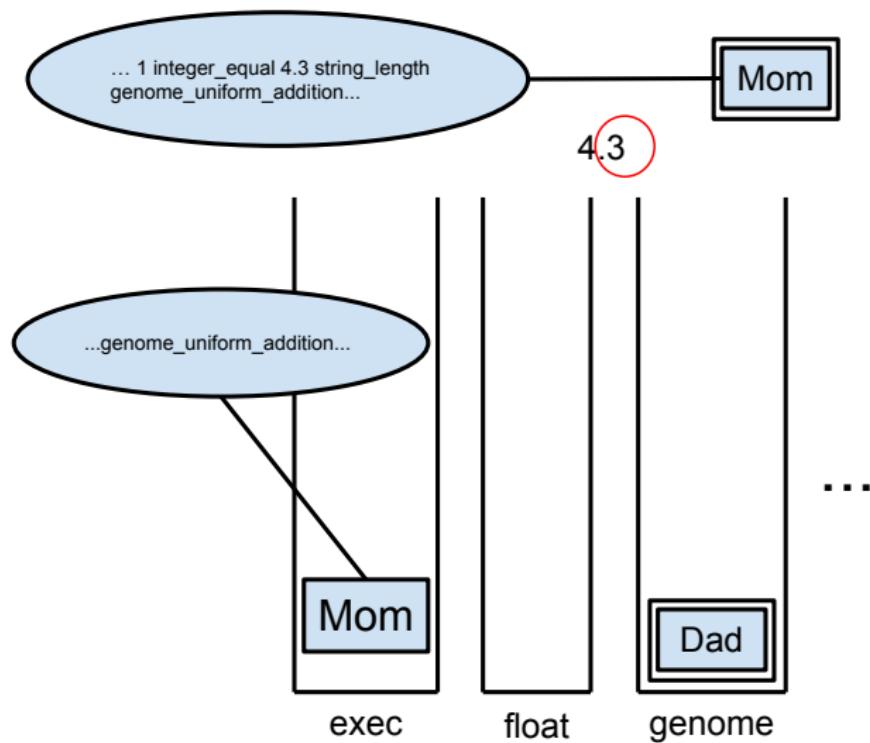
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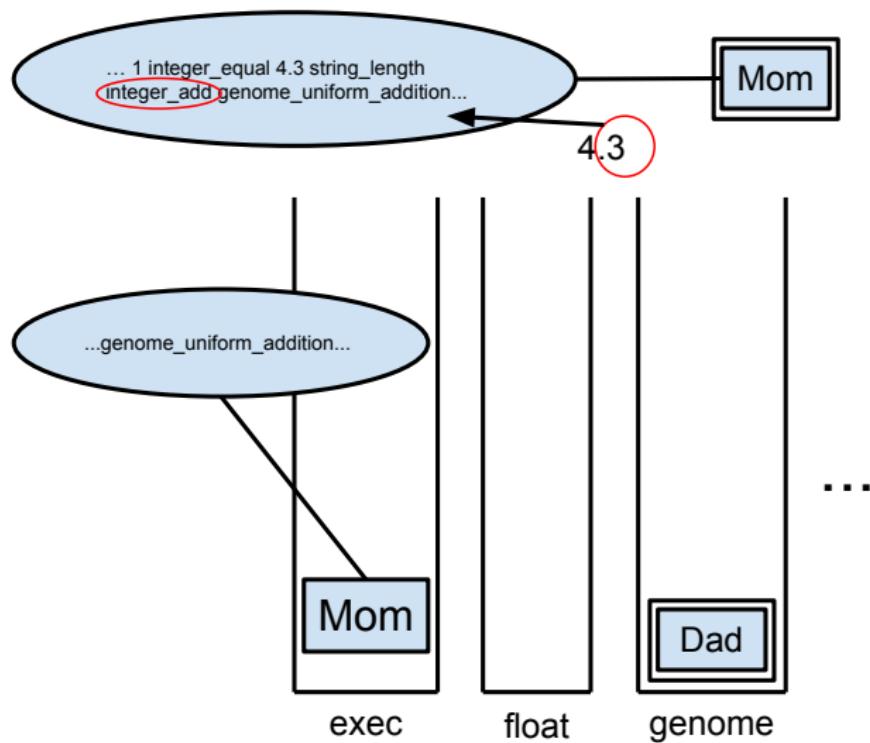
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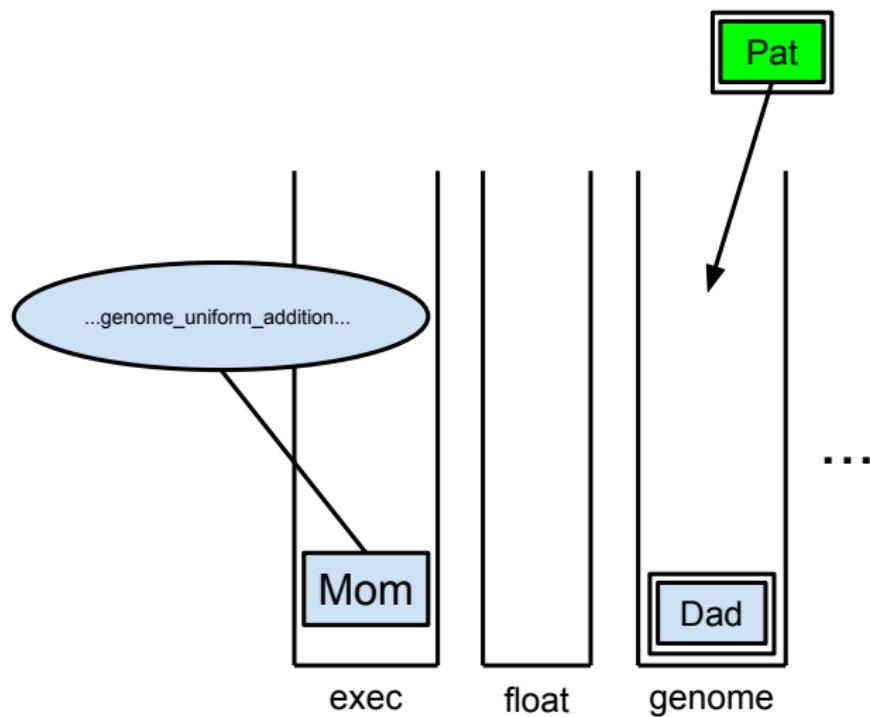
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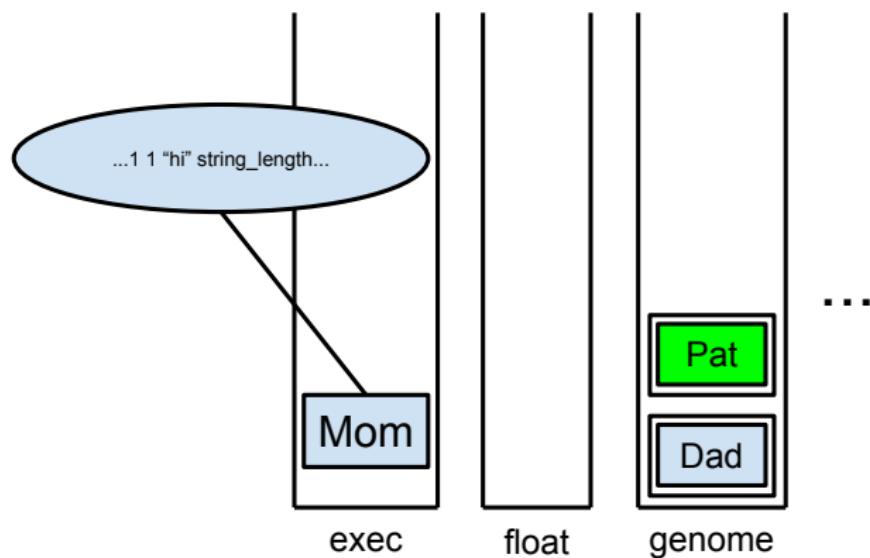
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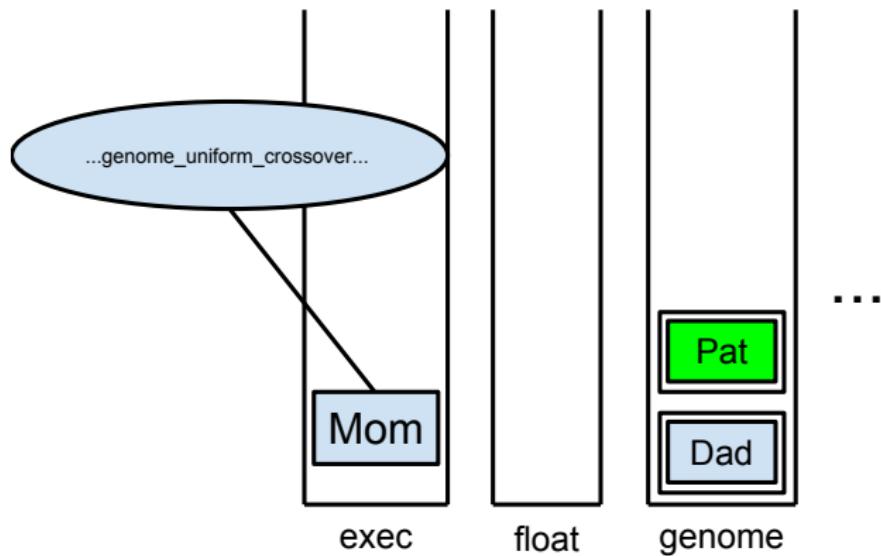
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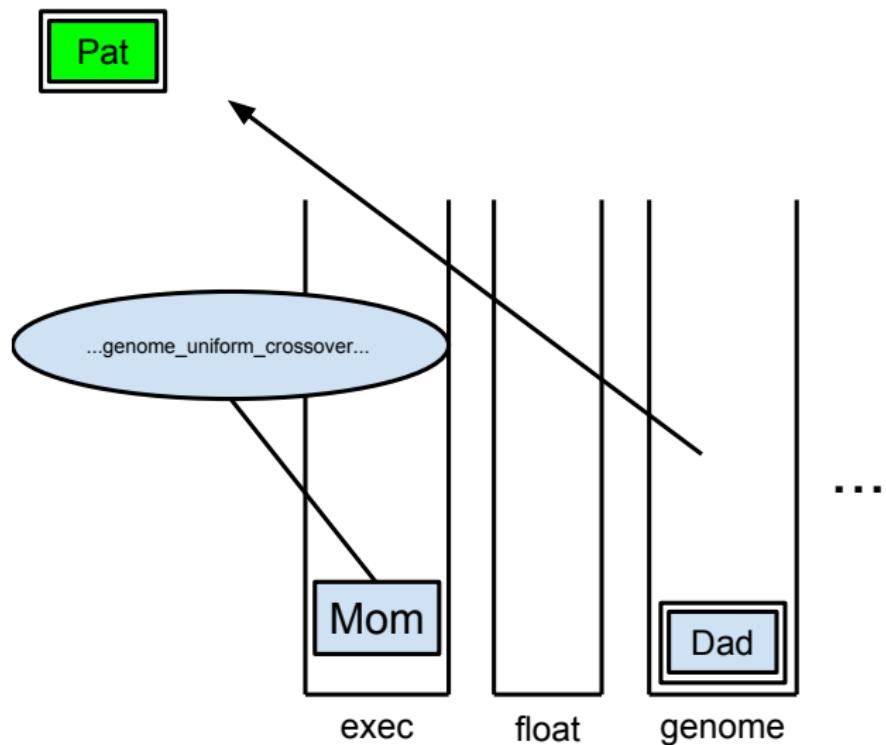
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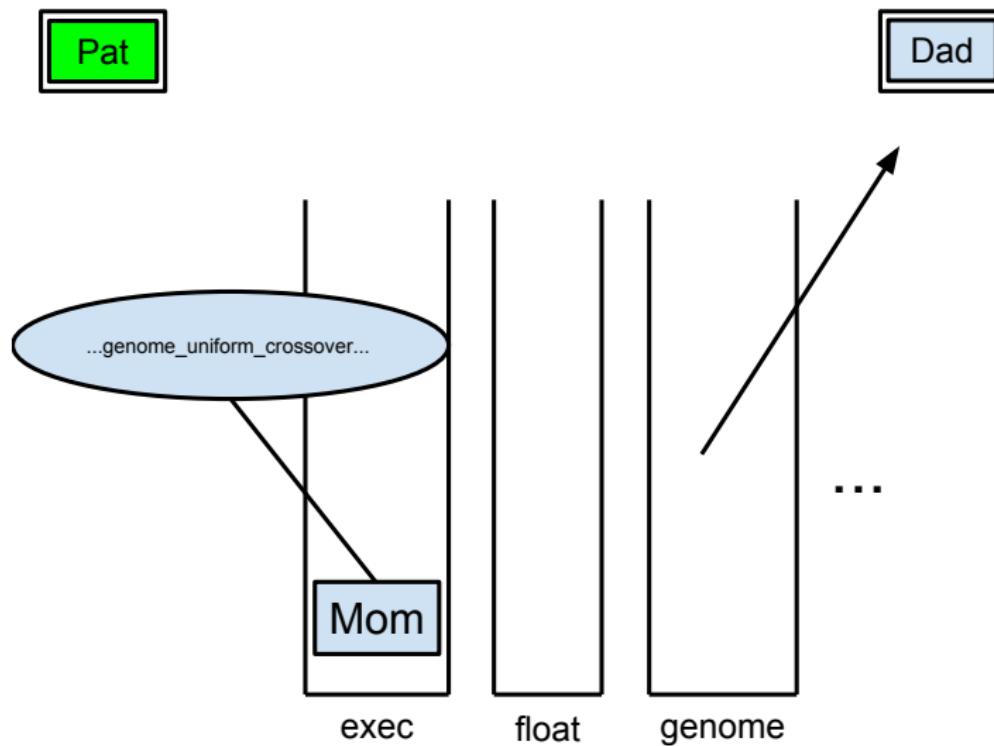
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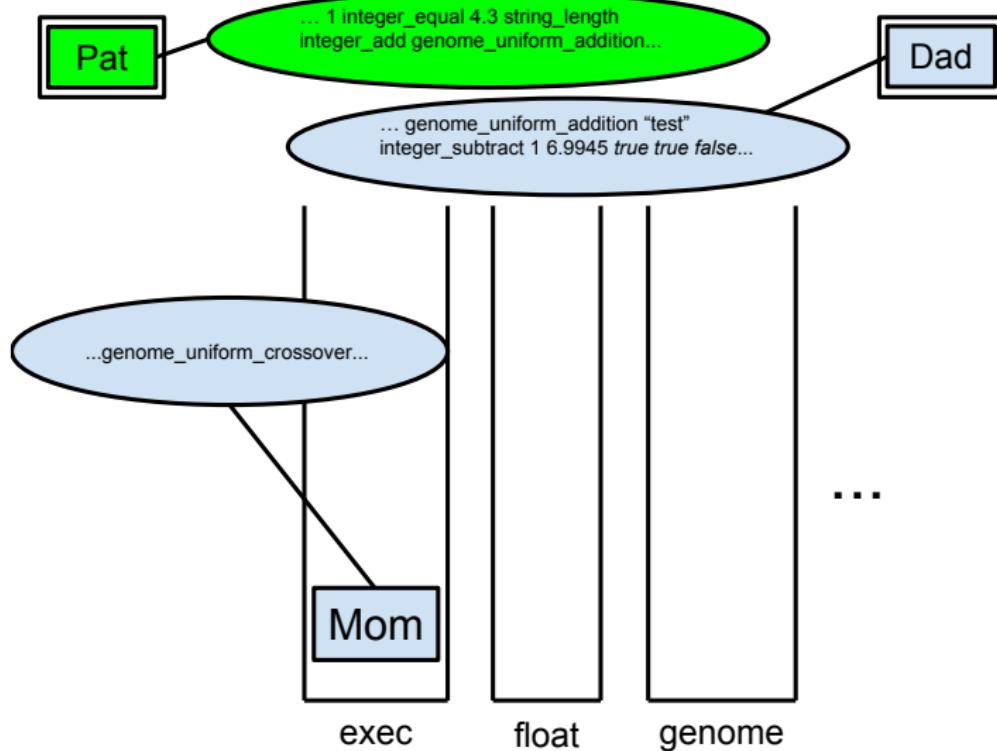
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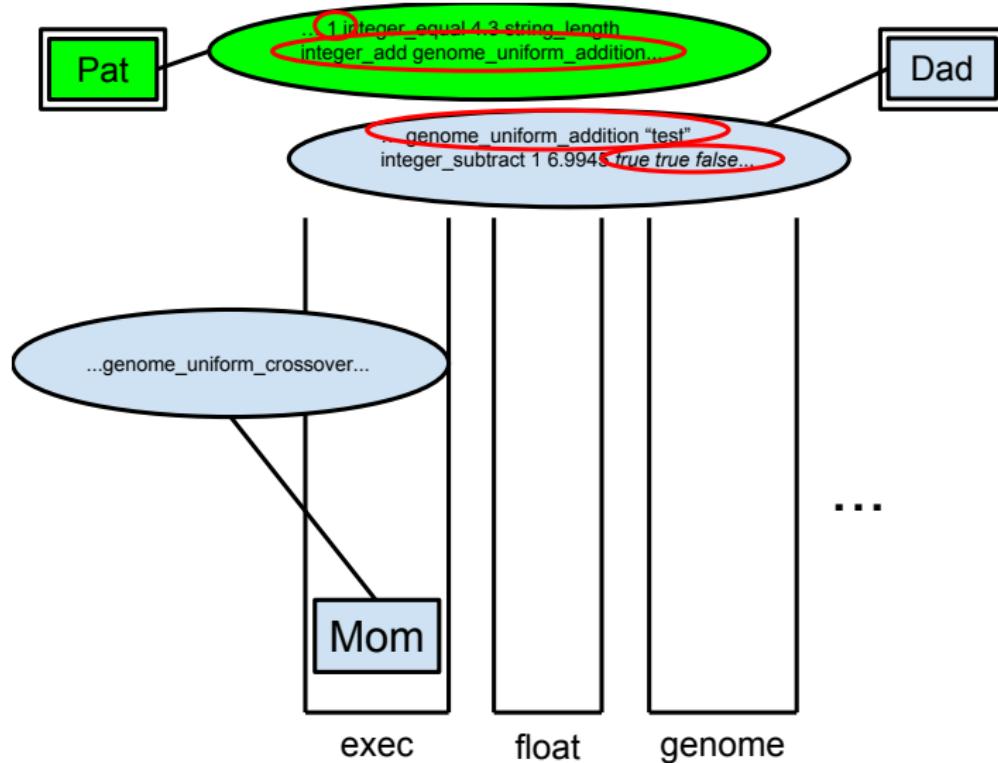
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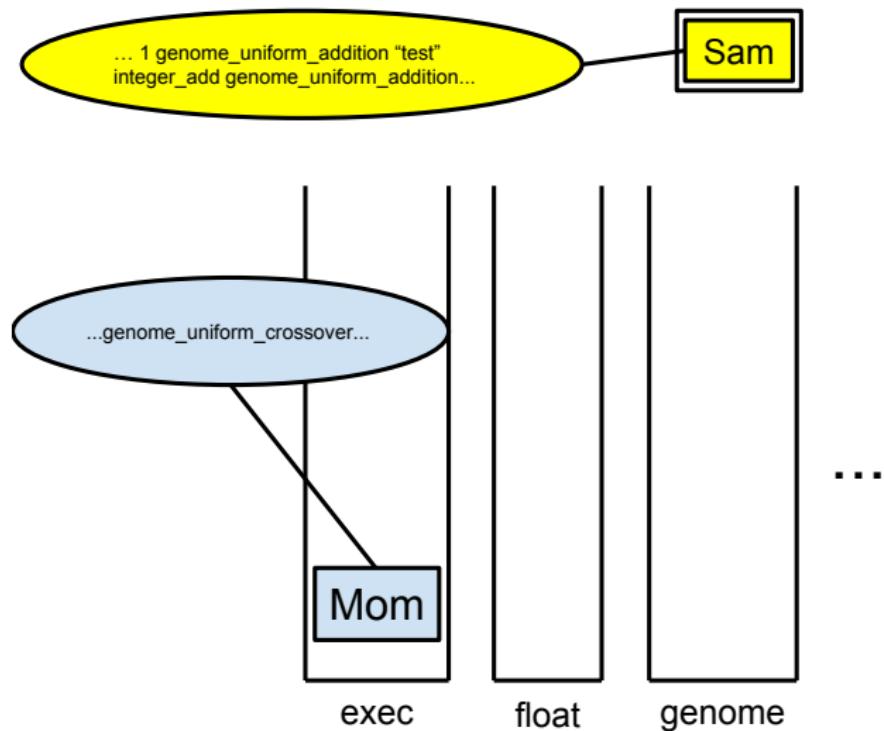
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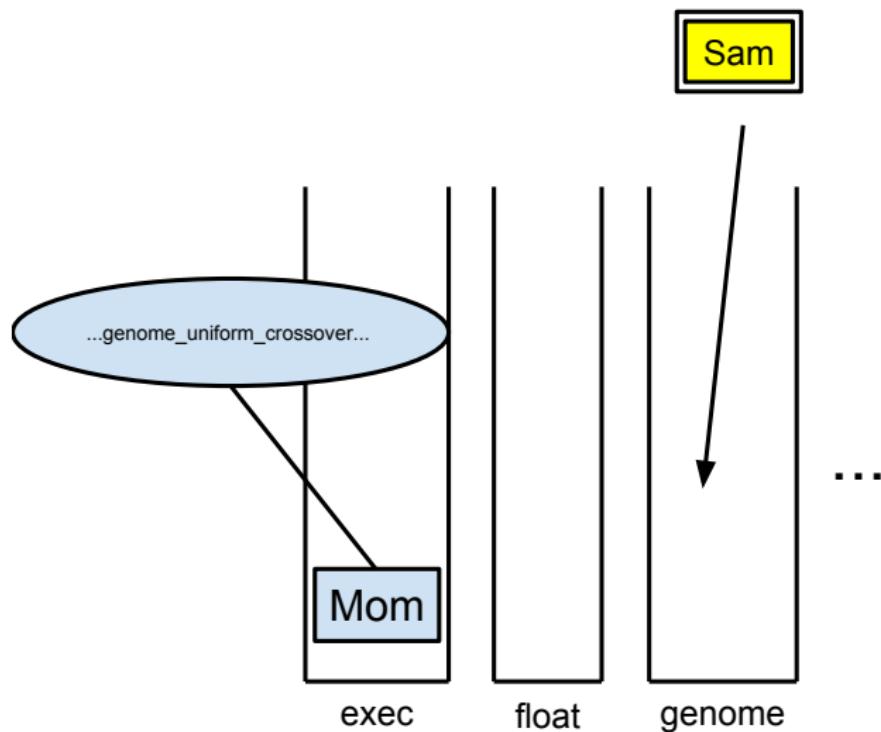
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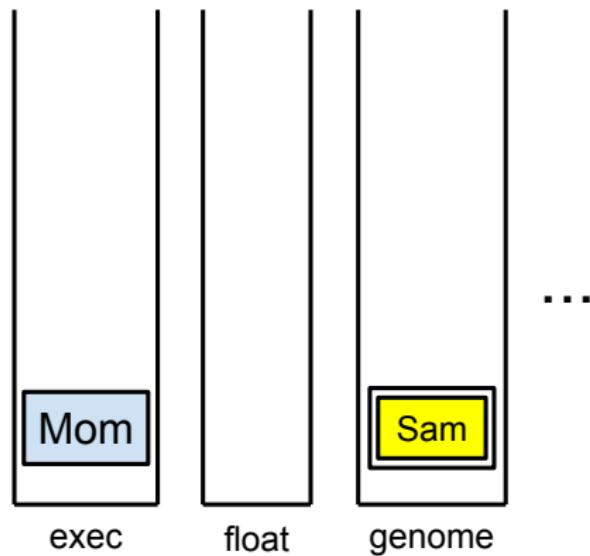
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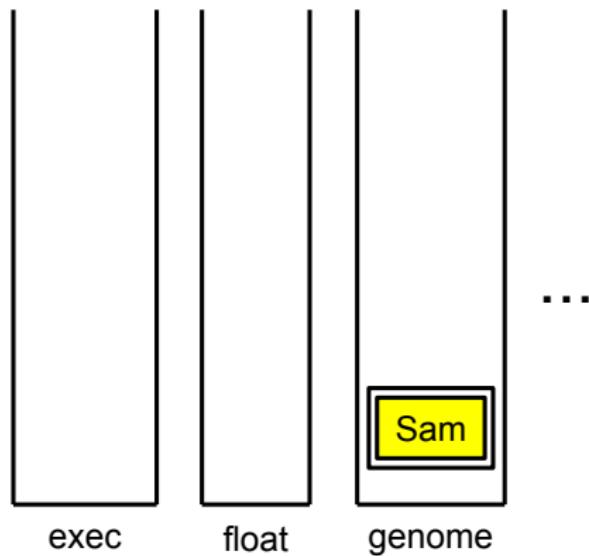
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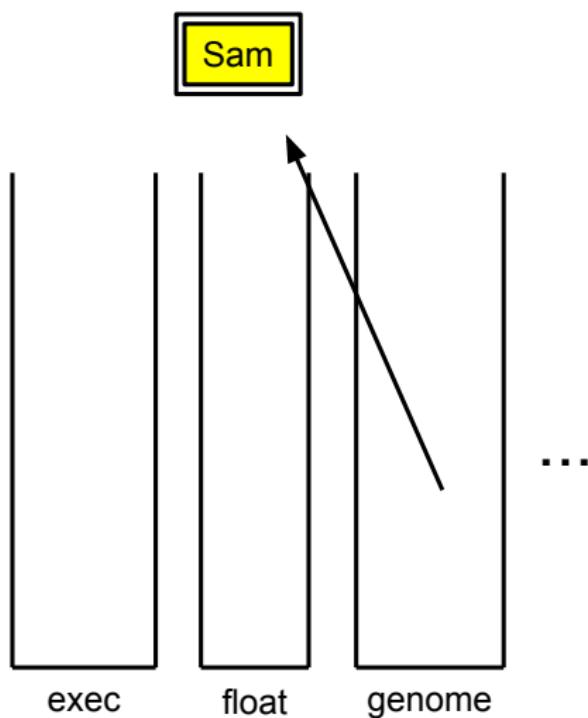
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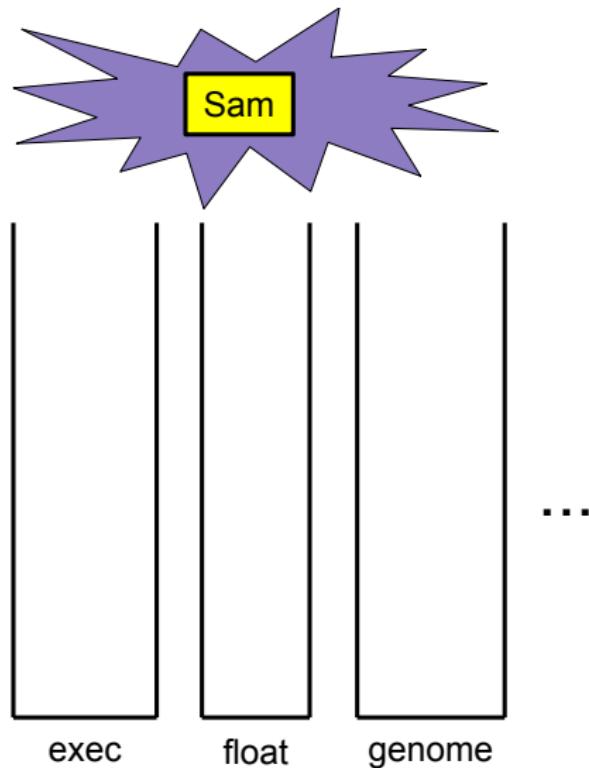
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AutoDoG – reproduction



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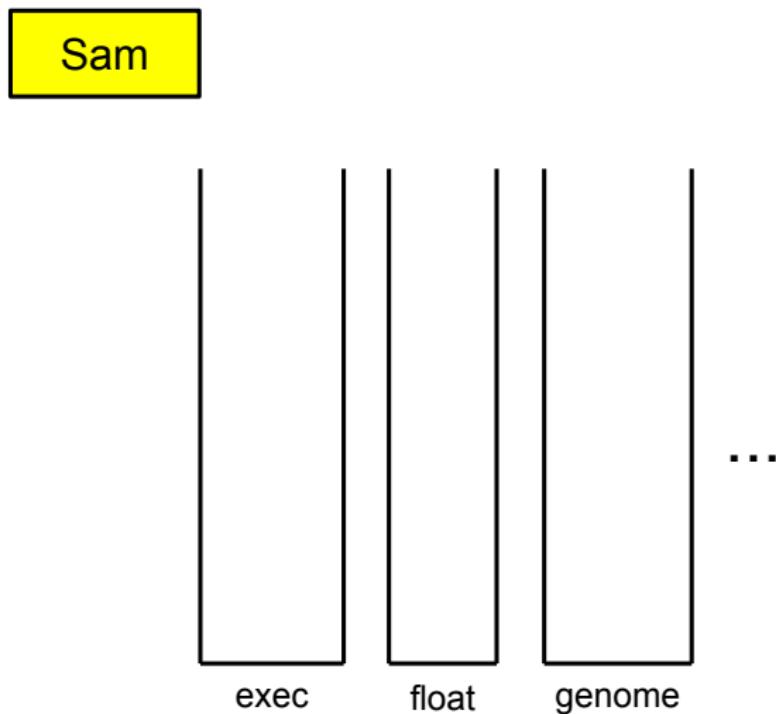
Now Child moves on to the next generation, right?

AutoDoG – reproduction

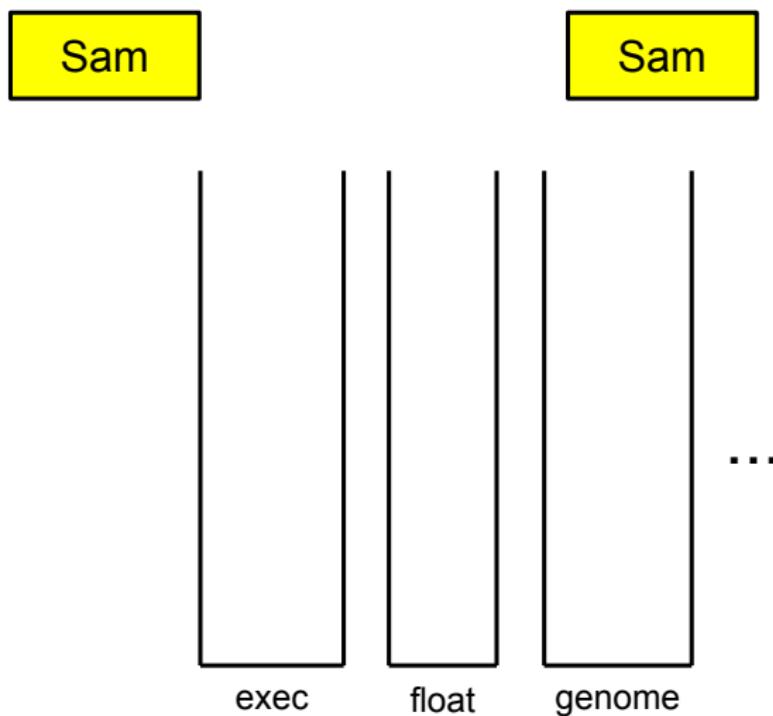
Now Child moves on to the next generation, right?

WRONG!

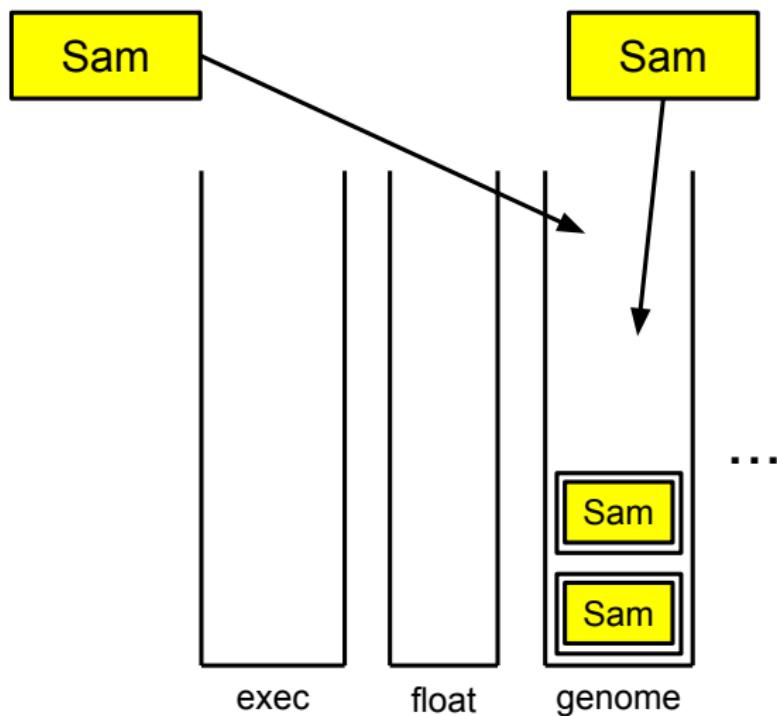
AutoDoG – diversification test



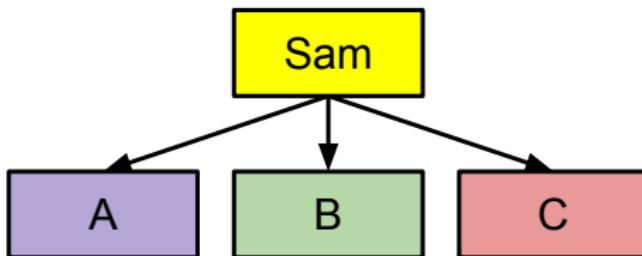
AutoDoG – diversification test



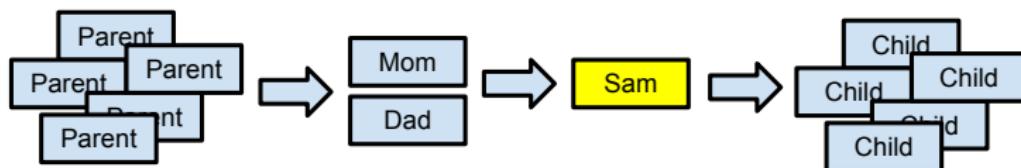
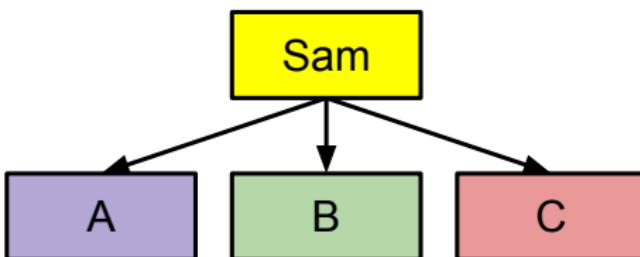
AutoDoG – diversification test



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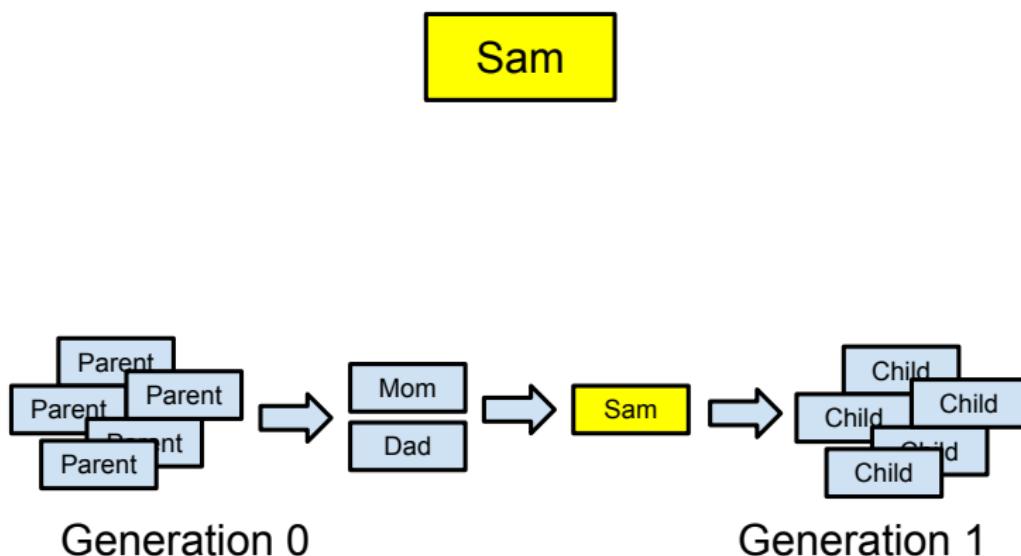
AutoDoG – diversification test



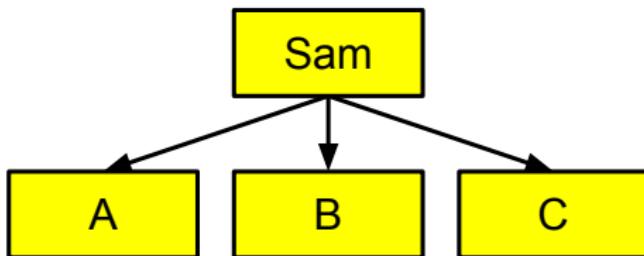
Generation 0

Generation 1

AutoDoG – diversification test



AutoDoG – diversification test



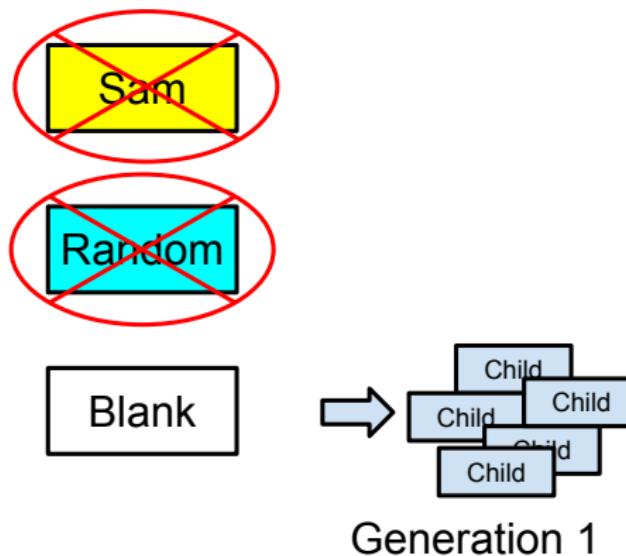
AutoDoG – diversification test



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AutoDoG – diversification test



Results of AutoDoG

AutoDoG has solved Replace Space with New Line (RSWN).

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AutoDoG has solved Replace Space with New Line (RSWN).

RSWN: given a string S, print S with all spaces replaced with new lines and return the integer count of all non-whitespace characters.

Results of AutoDoG

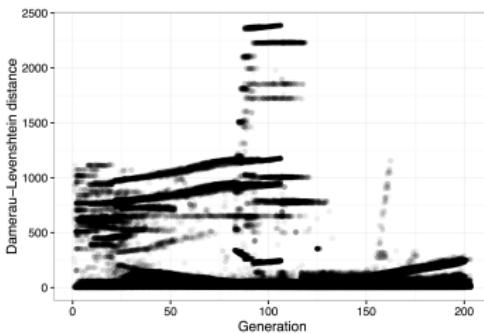
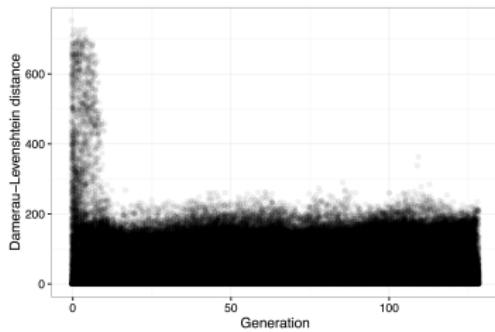
AutoDoG solves RSWN 5–10% of the time, where PushGP solves this problem 50% of the time.

Results of AutoDoG

AutoDoG solves RSWN 5–10% of the time, where PushGP solves this problem 50% of the time.

This is actually really impressive!

Results of AutoDoG



Graphs taken from Spector et al. [2]

Outline

- 1 Background
- 2 Hyper-heuristics
- 3 Genetic Programming Variants
- 4 Autoconstruction
- 5 Summary

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Summary

- Genetic programming hyper-heuristics (GPHH) for heuristic/program evolution
- There are many types of GP variants, and the variant chosen may affect the success of the hyper-heuristic
- Autoconstruction is a type of GPHH
- AutoDoG is a newer autoconstructive system that uses stack-based GP and has had recent success in the field of automating algorithm design
- AutoDoG/autoconstruction is special because evolution is evolving

Summary

This may drastically change the way we program in the future!

Acknowledgments

Special thanks to Nic McPhee and Elena Machkasova for their feedback and constructive comments.

Thanks for coming!

Questions?

If your question was not answered during the presentation today, feel free to contact me: <brow3924@morris.umn.edu>

References

-  [S. Harris, T. Bueter, and D. R. Tauritz.
A Comparison of Genetic Programming Variants for
Hyper-Heuristics.
In Sara Silva, editors, *GECCO '15*, pages 1043–1050,
Madrid, Spain 2015.](#)
-  [L. Spector, N. F. McPhee, T. Helmuth, M. M. Casale, and
J. Oks.
Evolution Evolves with Autoconstruction.
In T. Friedrich, *et al*, editors, *GECCO '16*, pages
1349–1356, Denver, Colorado, USA 2016.](#)
-  [D. R. Tauritz, and J. Woodward.
Hyper-heuristics.
In T. Friedrich, *et al*, editors, *GECCO '16*, pages 273–304,
Denver, Colorado, USA 2016.](#)

See my paper for additional references.