Evolutionary Computation

Lee Spector
Amherst College, Hampshire College, UMass Amherst

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Outline

- What is evolutionary computation?
- What can it do?
- Improving it
- Connections
- COSC-452

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- **What is evolutionary computation?**
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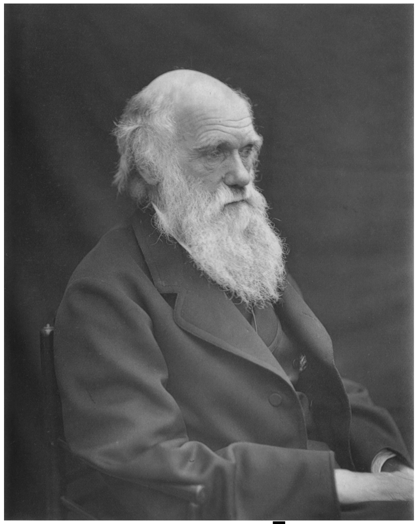
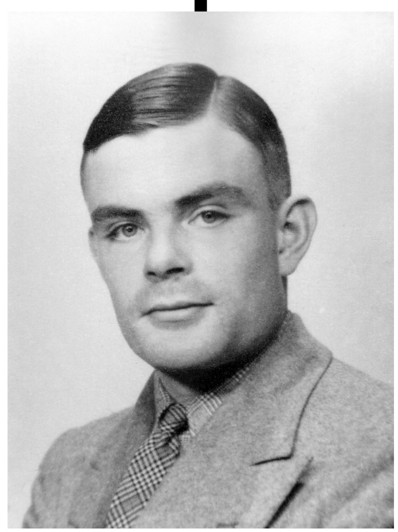
- COSC-452



Charles Darwin

Ada Lovelace



Alan Turing

https://en.wikipedia.org/wiki/Charles_Darwin

https://www.cnn.com/ampstories/tech/meet-ada-lovelace-the-first-computer-programmer

https://www.britannica.com/biography/Alan-Turing

EvoBio & CompSci

- Bioinformatics
- Modeling & simulation
- Artificial life
- Evolutionary algorithms

EvoBio & CompSci

- ✴ **Bioinformatics**
- Modeling & simulation
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- Evolutionary algorithms

https://www.scripps.edu/science-and-medicine/cores-and-services/bioinformatics-core/index.html

EvoBio & CompSci

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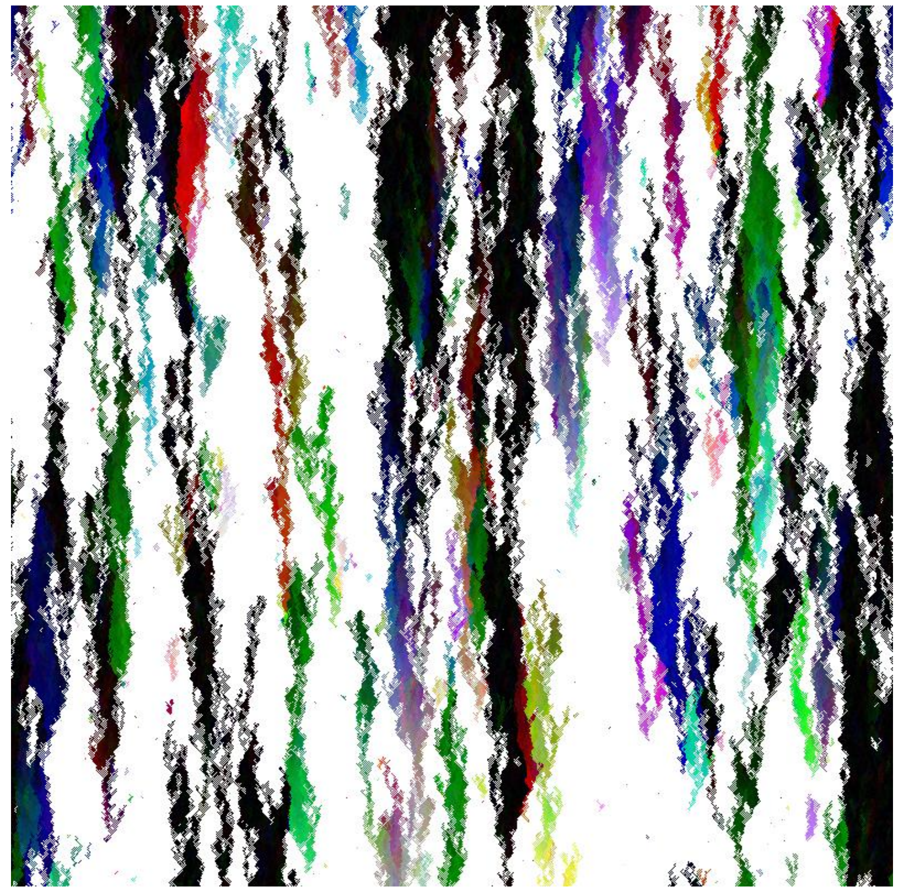

EvoBio & CompSci

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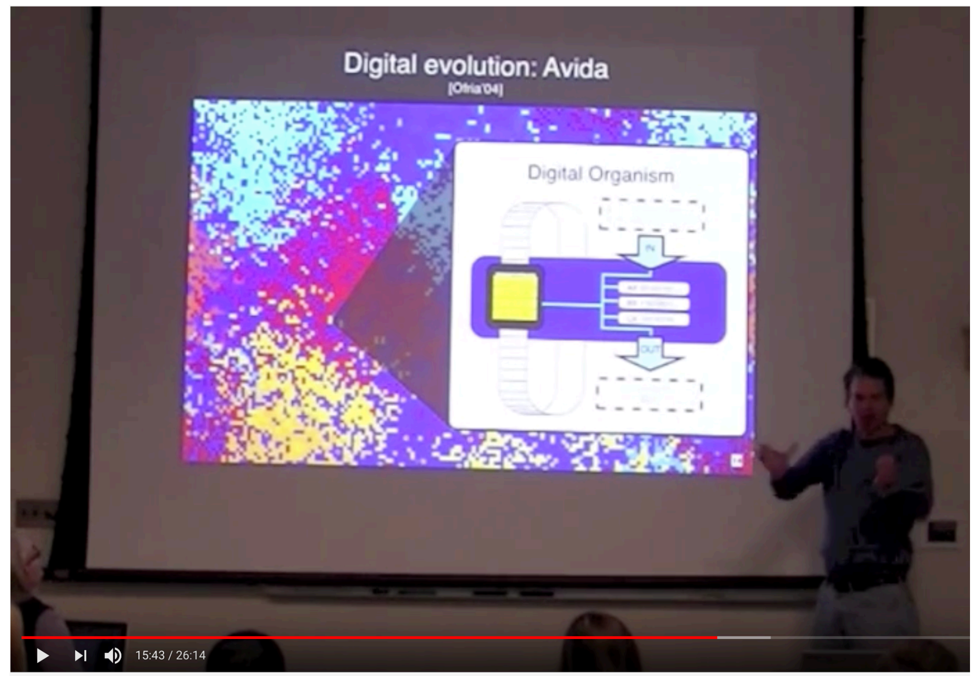

Christoph Adami - Introduction to the digital evolution platform Avida

https://www.youtube.com/watch?v=ouF8wKxXWFQ

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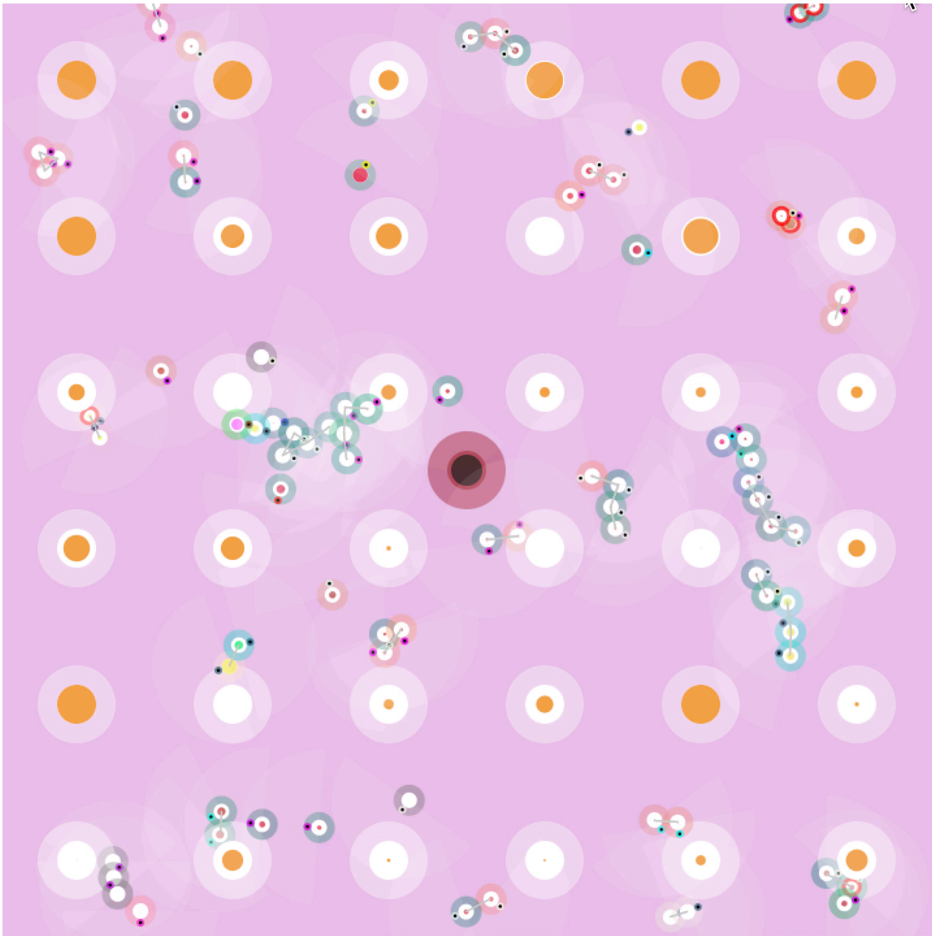

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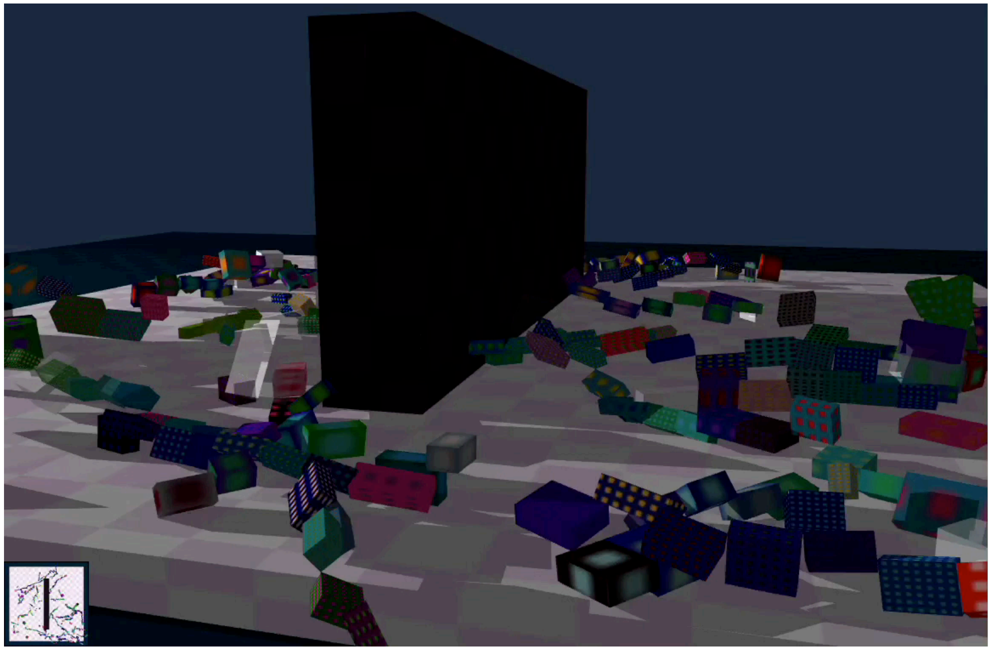

EvoBio & CompSci

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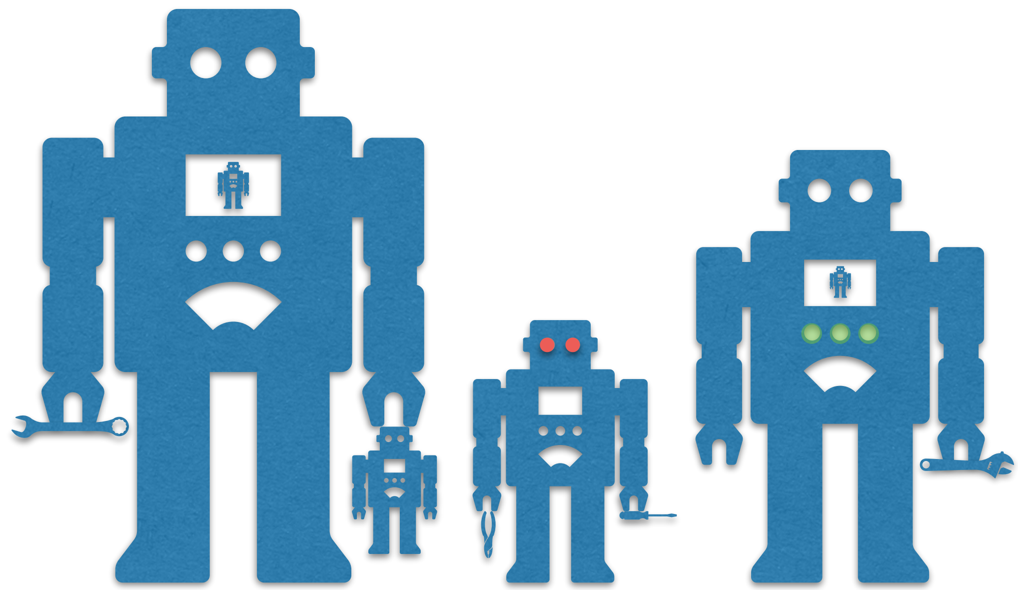
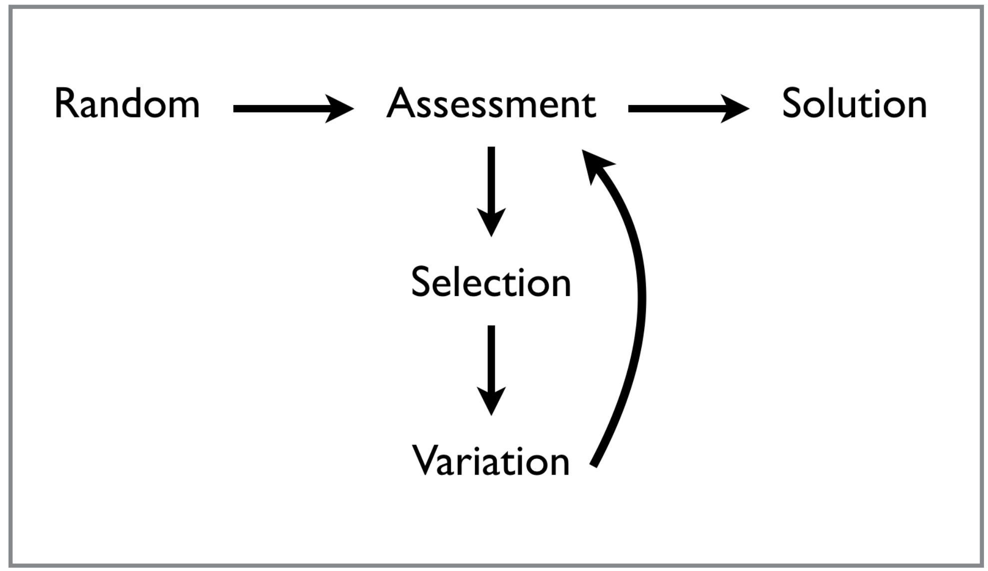


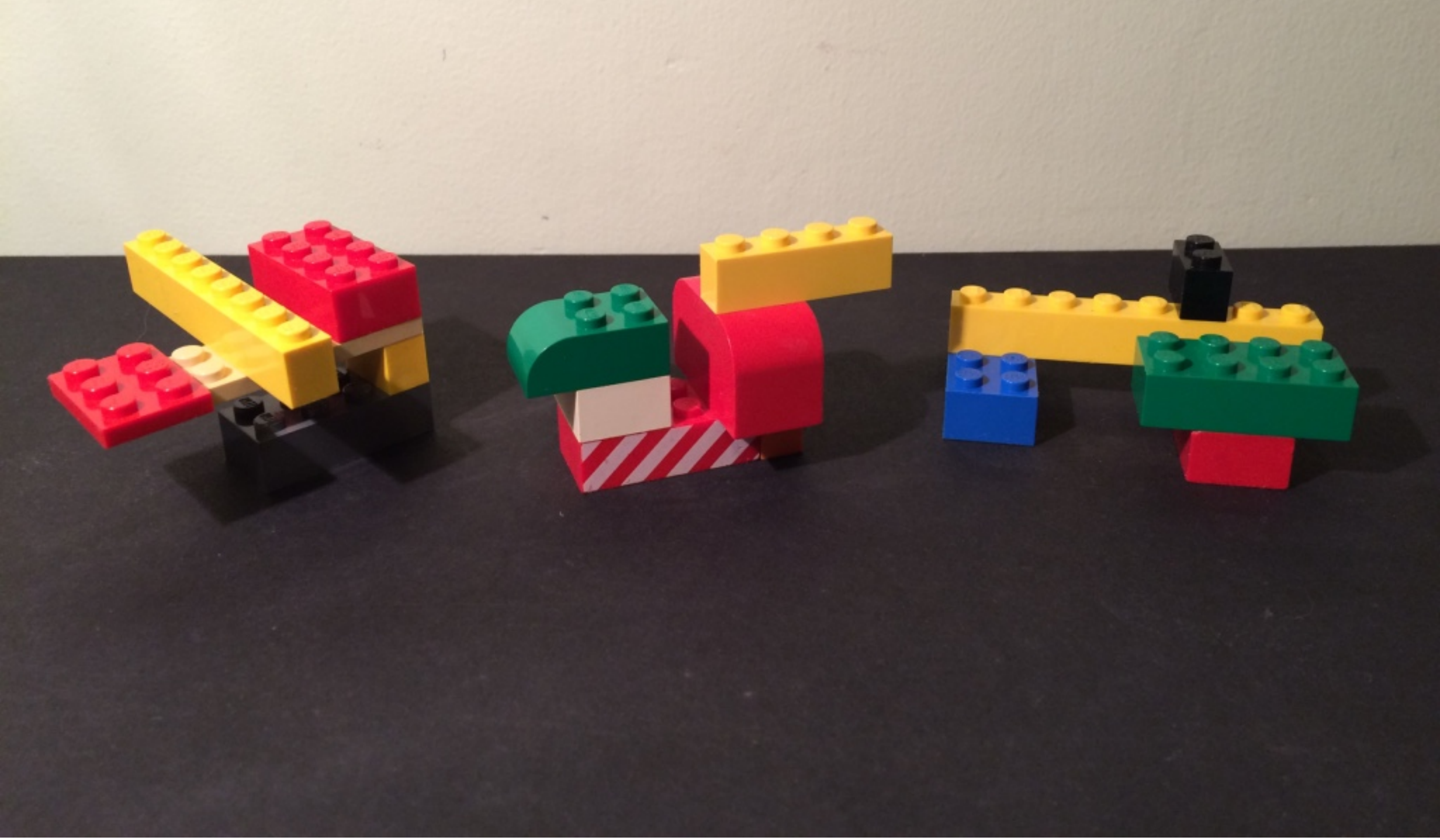
EvoBio & CompSci

- Bioinformatics
- Modeling & simulation
- Artificial life

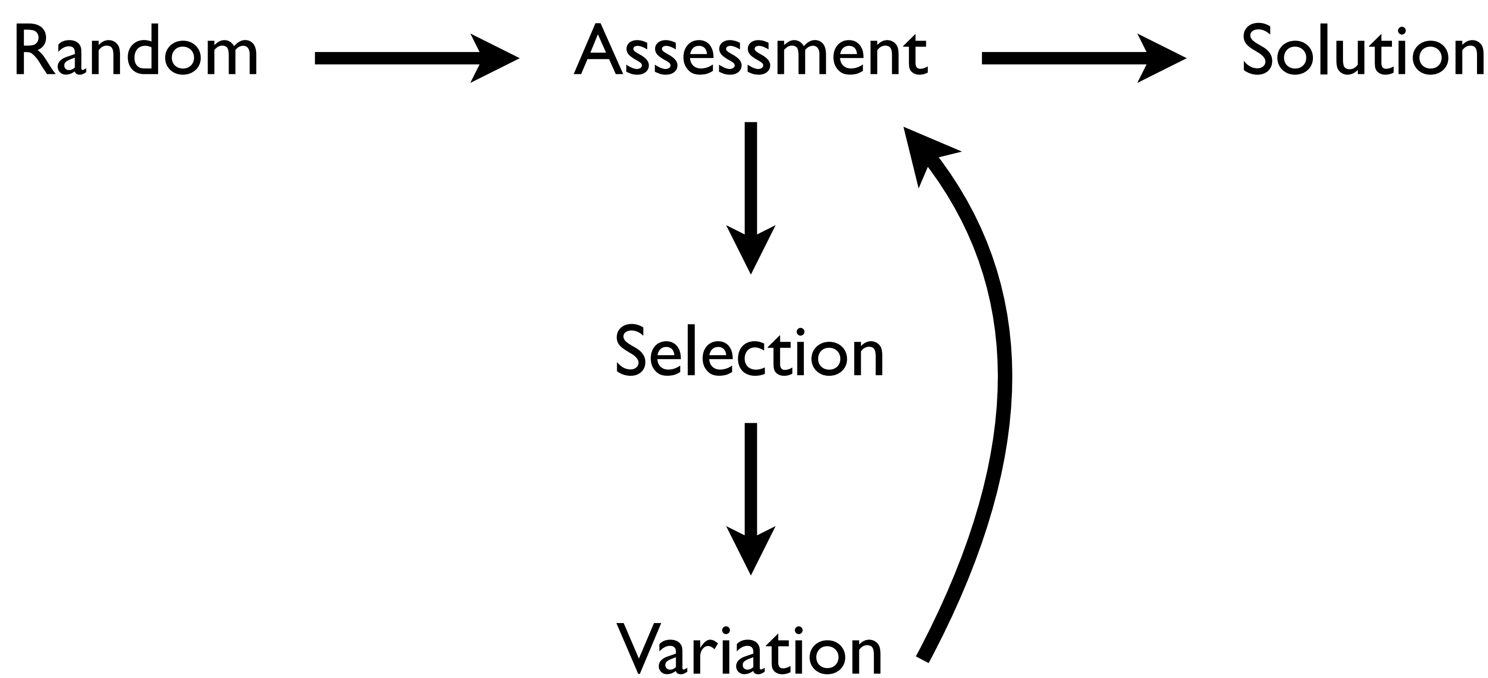
✳ **Evolutionary algorithms**



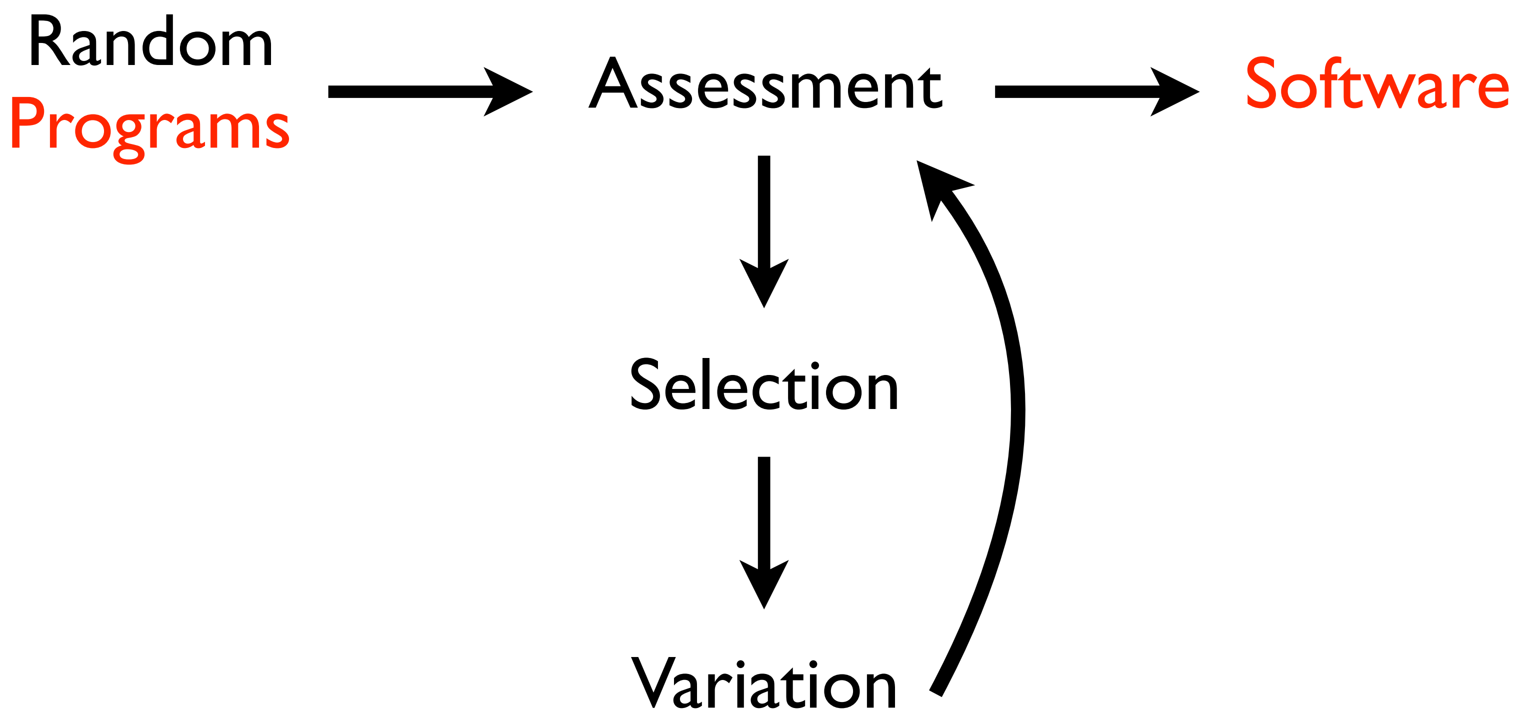
Evolving LEGO bridges



Evolutionary Algorithms



Genetic Programming



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Annual "Humies" Awards For Human-Competitive Results

Produced By Genetic And Evolutionary Computation

The result was **patented as an invention** in the past is an improvement over a patented invention or would qualify today as a patentable new invention.

The result is equal to or better than a result that was accepted as a **new scientific result** at the time when it was published in a peer-reviewed scientific journal.

The result is equal to or better than a result that was placed into a database or archive of results maintained by an **internationally recognized panel of scientific experts**.

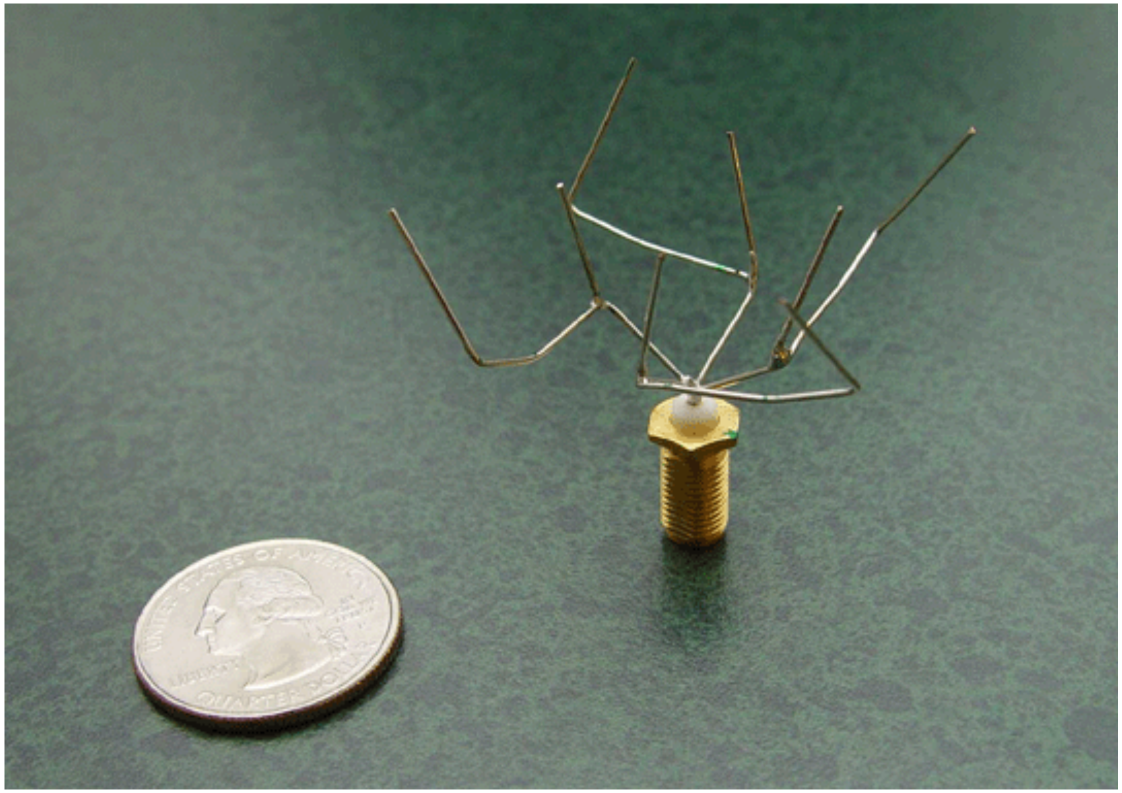
The result is **publishable in its own right** as a new scientific result independent of the fact that the result was mechanically created.

The result is **equal to or better than the most recent human-created solution** to a long-standing problem for which there has been a succession of increasingly better human-created solutions.

The result is equal to or better than a result that was considered an **achievement in its field** at the time it was first discovered.

The result **solves a problem of indisputable difficulty** in its field.

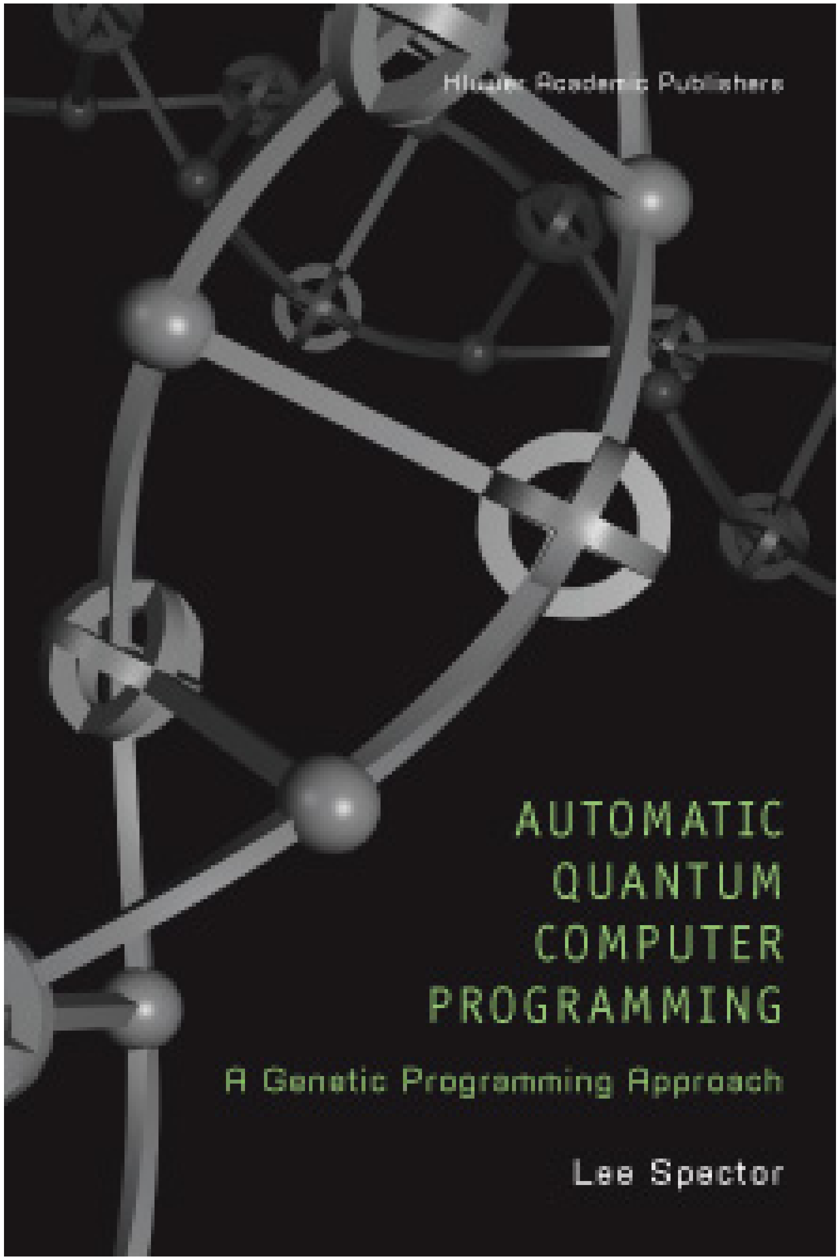
The result holds its own or **wins a regulated competition involving human contestants** (in the form of either live human players or human-written computer programs).



An Evolved Antenna for Deployment on NASA's Space Technology 5 Mission

Jason D. Lohn, Gregory S. Hornby, Derek S. Linden
NASA Ames Research Center

Humies Gold Medal, 2004



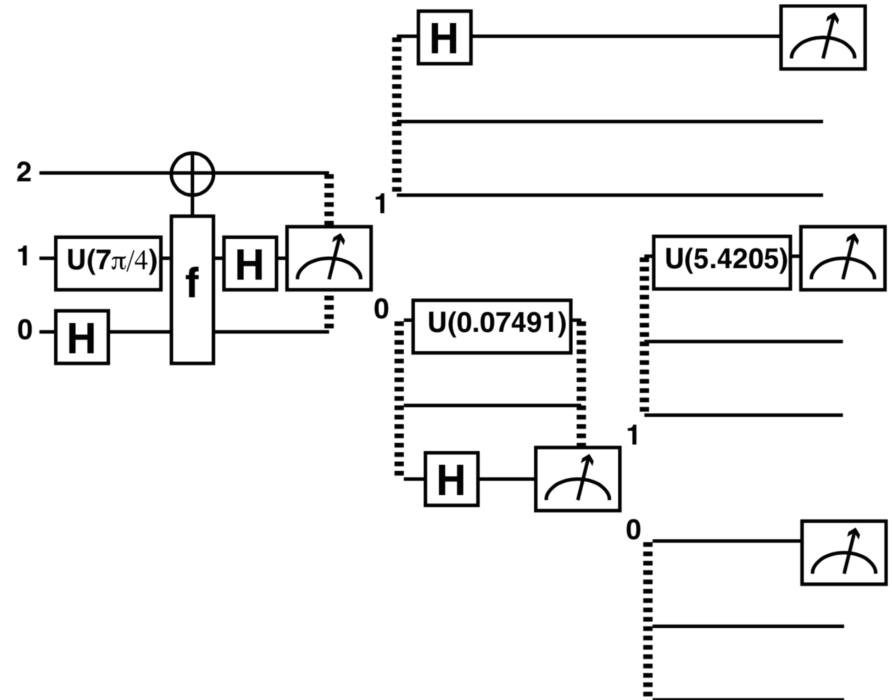


Figure 8.11. A gate array diagram for an evolved solution to the AND/OR oracle problem. The gate marked "f" is the oracle. The sub-diagrams on the right represent the possible execution paths following the intermediate measurements.

Lee Spector
Hampshire College

Humies Gold Medal, 2004

Genetic Programming for Finite Algebras

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$$((((((((x*(y*x))*x)*z)*(z*x))*((x*(z*(x*(z*y))))*z))*z)*z)*(z*((((x*(((z*z)*x)*(z*x)))*x)*y)*(((y*(z*(z*y)))*(((y*y)*x)*z))*(x*(((z*z)*x)*(z*(x*(z*y)))))))))$$

Humies Gold Medal, 2008

International Journal of Algebra and Computation | Vol. 28, No. 05, pp. 759-790 (2018)

Evolution of algebraic terms 3: Term continuity and beam algorithms

David M. Clark and Lee Spector

Fixing software bugs in 10 minutes or less using evolutionary computation

University of New Mexico
Stephanie Forrest
ThanhVu Nguyen
University of Virginia
Claire Le Goues
Westley Weimer

THE UNIVERSITY of NEW MEXICO

Humies Gold Medal, 2009

Yavalath

Yavalath is an abstract board game for two or three players, invented by a computer program called LUDI. It has an easy rule set that any player can pick up immediately, but which produces surprisingly tricky emergent play.

Yavalath is available from nestorgames, making it the first — and still only — computer-generated game to be commercially published, together with its sister game Pentalath.

In October 2011, Yavalath was ranked in the top #100 abstract board games ever invented on the BoardGameGeek database. This helped it win the GECCO "Humies" gold medal for human-competitive results in evolutionary computation for 2012.

Here is a Yavalath article in the November 2013 issue of Bitcoin magazine.

Rules

The board starts empty.

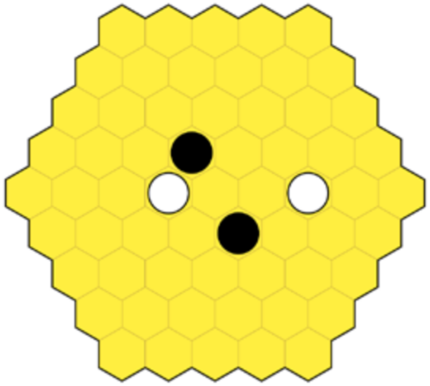
Two players take turns adding a piece of their colour to an empty cell.

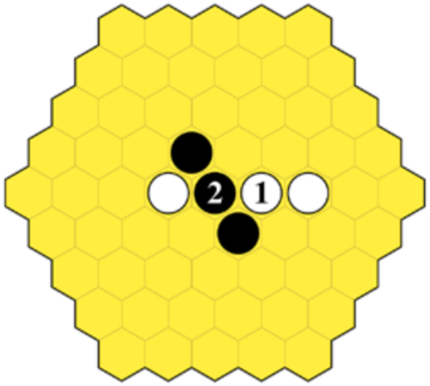
Win by making a line-of-4 (or more) pieces of your colour.
Lose by making a line-of-3 pieces of your colour beforehand.
Draw if the board otherwise fills up.

No, players are not allowed to pass.

Tactics and Strategy

The key tactical play in Yavalath is the *forcing move*, as shown below. White move **1** forces Black to lose with the blocking move **2**.



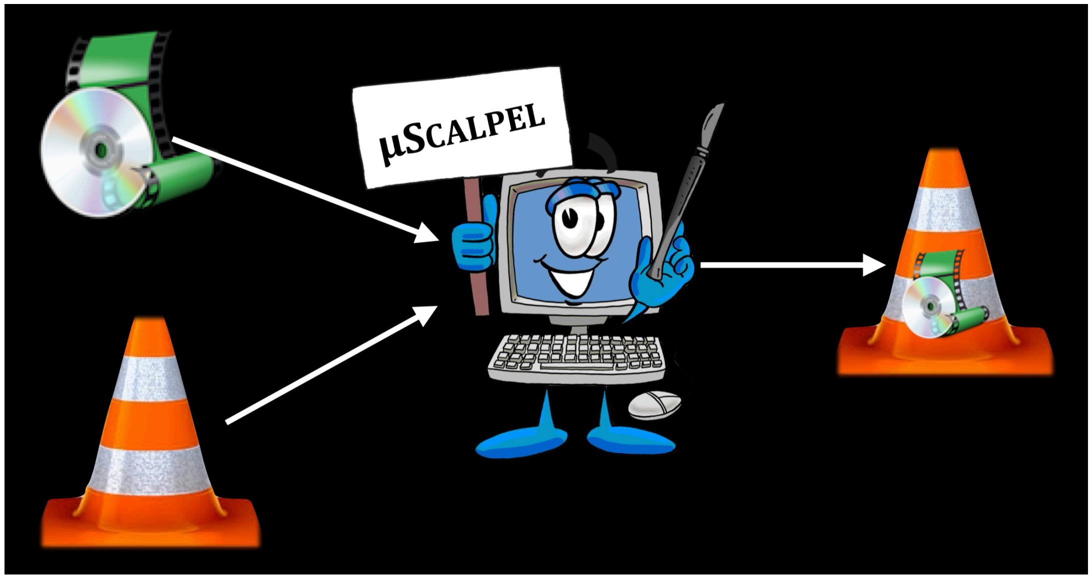


Cameron Browne
Imperial College London

Humies Gold Medal, 2012

https://www.human-competitive.org/awards

Automated Software Transplantation



Earl T. Barr, Mark Harman, Yue Jia, Alexandru Marginean, Justyna Petke
University College London

Humies Gold Medal, 2016

https://www.human-competitive.org/awards

Darwinian Data Structure Selection

Michail Basios
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Lingbo Li
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Fan Wu
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Leslie Kanthan
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Earl T. Barr
University College London, UK
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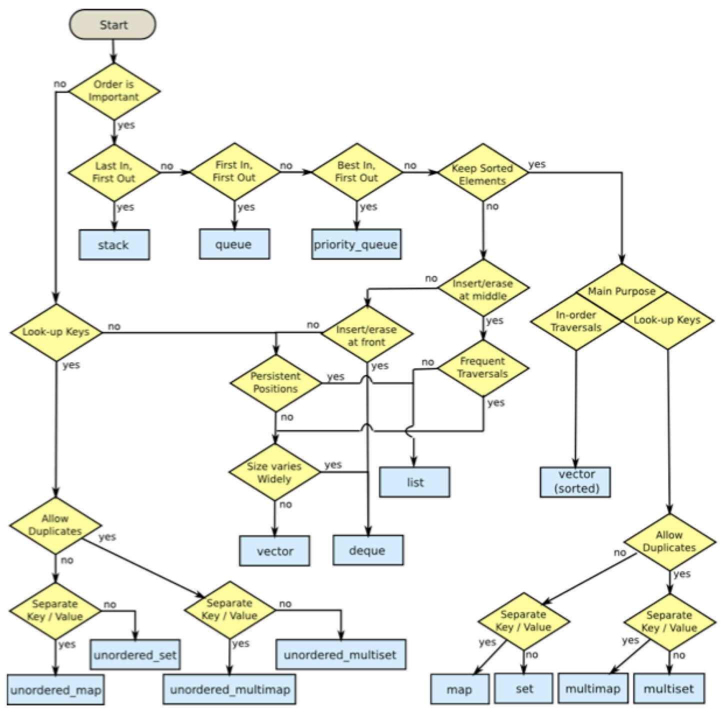
Data Structure Selection/Optimisation Process



Hmmm, maybe just use defaults that work in most cases.

https://www.human-competitive.org/sites/default/files/basiosslides.pptx

Humies Bronze Medal, 2019

https://www.human-competitive.org/awards

ELSEVIER

Brachytherapy 18 (2019) 396–403

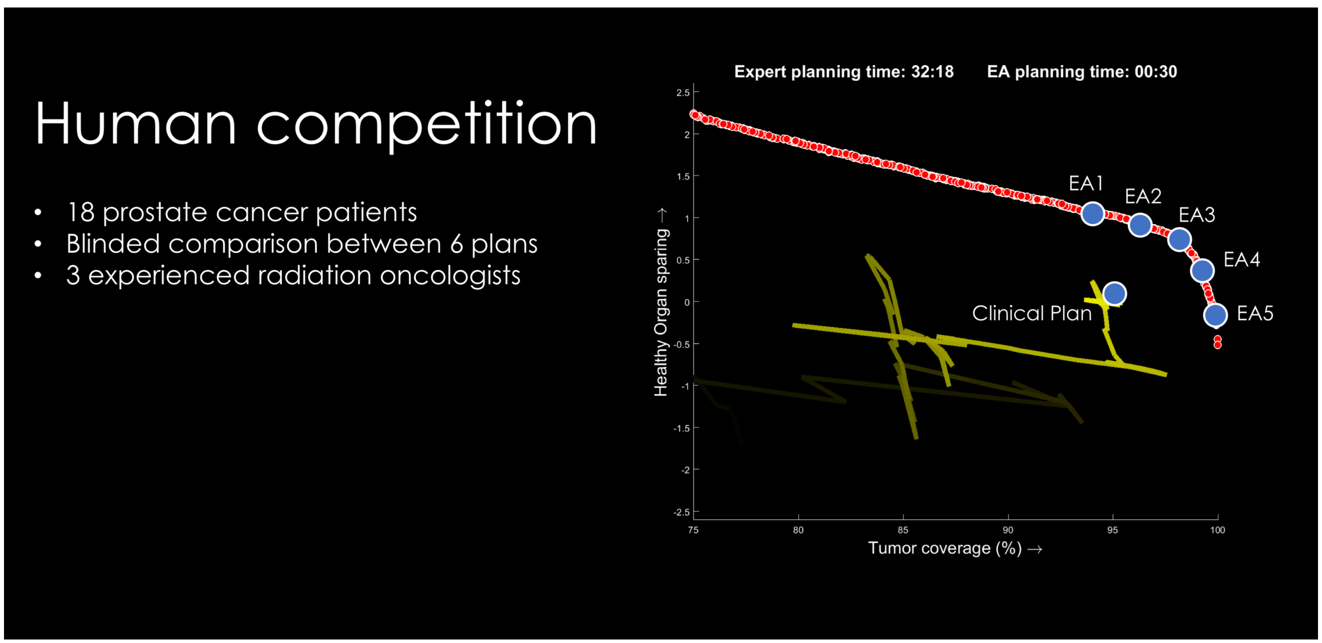
BRACHYTHERAPY

Physics

Evaluation of bi-objective treatment planning for high-dose-rate prostate brachytherapy—A retrospective observer study

Stefanus C. Maree[1,*], Ngoc Hoang Luong[2], Ernst S. Kooreman[1], Niek van Wieringen[1], Arjan Bel[1], Karel A. Hinnen[1], Henrike Westerveld[1], Bradley R. Pieters[1], Peter A.N. Bosman[2,3], Tanja Alderliesten[1]

[1]*Department of Radiation Oncology, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands*
[2]*Life Sciences and Health Research Group, Centrum Wiskunde & Informatica, Amsterdam, The Netherlands*
[3]*Algorithmics group, Department of Software Technology, Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, Delft, The Netherlands*

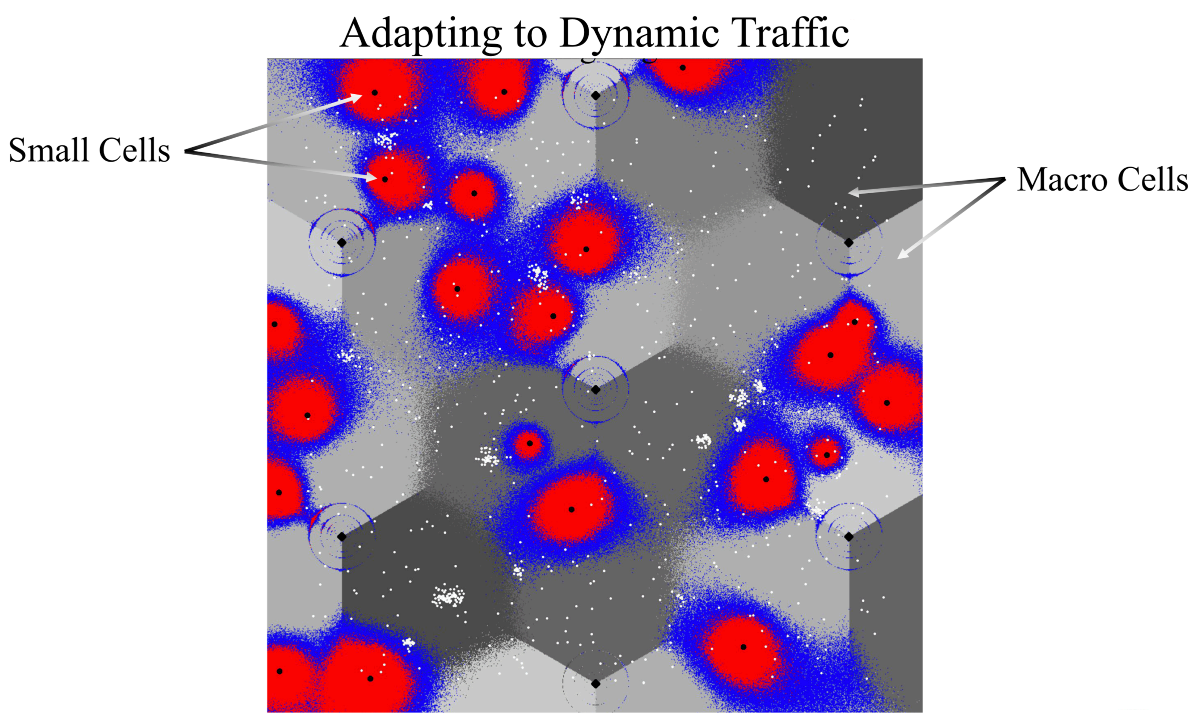


Humies Silver Medal, 2019

https://www.human-competitive.org/awards

Automated Self-Optimization in Heterogeneous Wireless Communications Networks

David Lynch, Michael Fenton, David Fagan, Stepan Kucera, *Senior Member, IEEE*, Holger Claussen, *Senior Member, IEEE*, and Michael O’Neill



Humies Gold Medal, 2019

https://www.human-competitive.org/awards

ELSEVIER

Renewable Energy
Volume 87, Part 2, March 2016, Pages 892-902

Automatic identification of wind turbine models using evolutionary multiobjective optimization

William La Cava [a], Kourosh Danai [a], Lee Spector [b], Paul Fleming [c], Alan Wright [c], Matthew Lackner [a]

Show more

https://doi.org/10.1016/j.renene.2015.09.068

Highlights

- Accurate, succinct models of wind turbine dynamics are identified from normal operating data.
- A novel evolutionary multi-objective optimization system is described.
- The proposed method produces physically meaningful models without prior knowledge of the system.
- The method is bench-marked against other modeling techniques.

ELSEVIER

Swarm and Evolutionary Computation
Volume 44, February 2019, Pages 260-272

Multidimensional genetic programming for multiclass classification

William La Cava [a], Sara Silva [b, c, d], Kourosh Danai [e], Lee Spector [f], Leonardo Vanneschi [c], Jason H. Moore [a]

Show more

https://doi.org/10.1016/j.swevo.2018.03.015

Abstract

We describe a new multiclass classification method that learns multidimensional feature transformations using genetic programming. This method optimizes models by first performing a transformation of the feature space into a new space of potentially different dimensionality, and then performing classification using a distance function in the transformed space. We analyze a novel program representation for using genetic programming to represent multidimensional features and compare it to other approaches. Similarly, we analyze the use of a distance metric for classification in comparison to simpler techniques more commonly used when applying genetic programming to multiclass classification. Finally, we compare this method to several state-of-the-art classification techniques across a broad set of problems and show that this technique achieves competitive test accuracies while also producing concise models. We also quantify the scalability of the method on problems of varying dimensionality, sample size, and difficulty. The results suggest the proposed method scales well to large feature spaces.

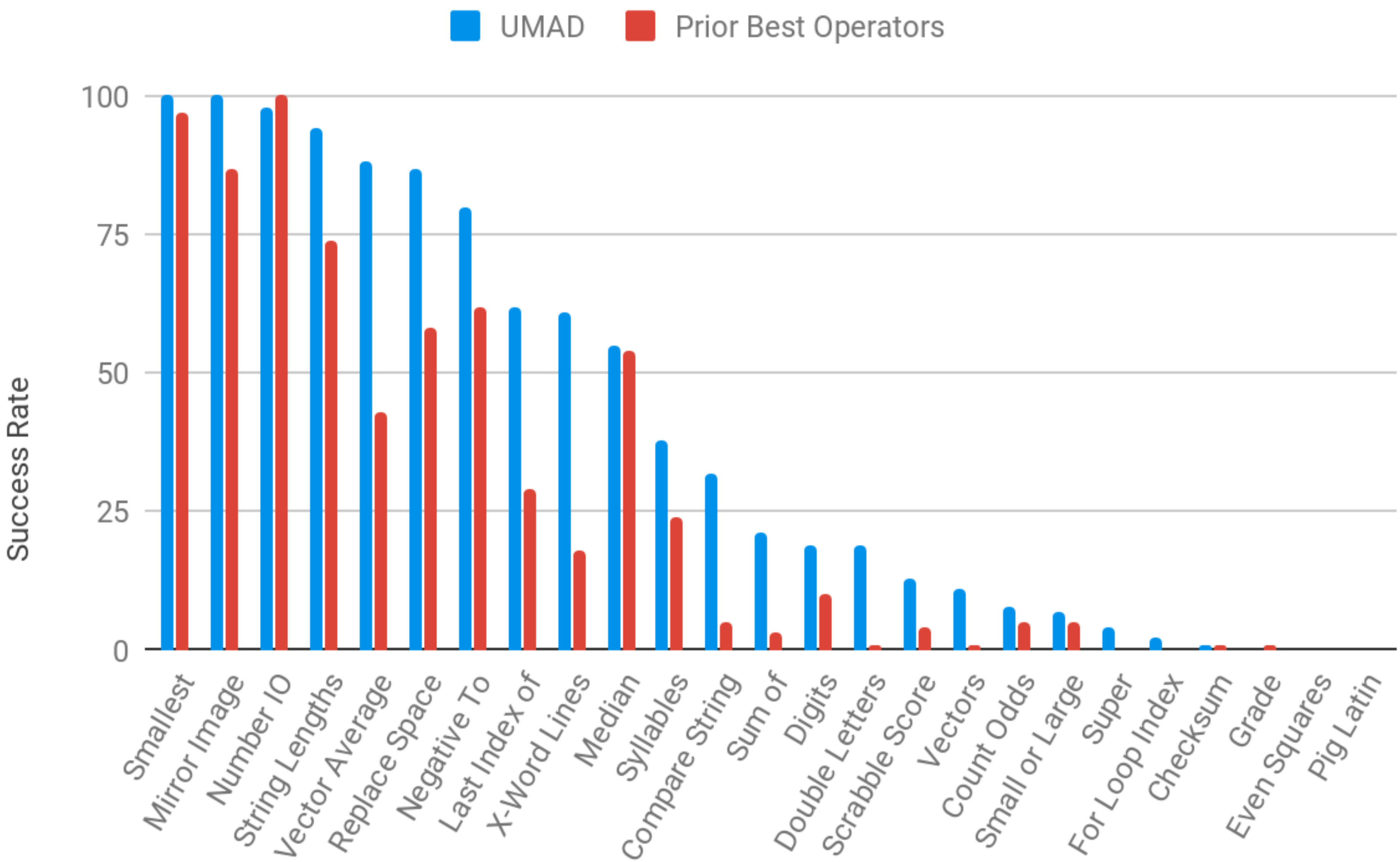
Software Synthesis

- 29 benchmark problems taken from intro CS textbooks
- Require multiple data types and control structures
- Driven by software tests, input/output pairs
- Used for studies of program synthesis, by us and by others

7. **Replace Space with Newline (P 4.3)** Given a string input, print the string, replacing spaces with newlines. Also, return the integer count of the non-whitespace characters. The input string will not have tabs or newlines.

8. **String Differences (P 4.4)** Given 2 strings (without whitespace) as input, find the indices at which the strings have different characters, stopping at the end of the shorter one. For each such index, print a line containing the index as well as the character in each string. For example, if the strings are "dealer" and "dollars", the program should print:

```
1 e o
2 a l
4 e a
```


UMAD
Prior Best Operators
Success Rate
100
75
50
25
0
Smallest
Mirror Image
Number IO
String Lengths
Vector Average
Replace Space
Negative To
Last Index of
X-Word Lines
Median
Syllables
Compare String
Sum of
Digits
Double Letters
Scrabble Score
Vectors
Count Odds
Small or Large
Super
For Loop Index
Checksum
Grade
Even Squares
Pig Latin

Application	Count	Application Category
Antennas	1	Engineering (19)
Biology	2	Science (7)
Chemistry	1	Science (7)
Computer vision	2	Computer science (7)
Electrical engineering	1	Engineering (19)
Electronics	5	Engineering (19)
Games	6	Games (6)
Image processing	3	Computer science (7)
Mathematics	2	Mathematics (3)
Mechanical engineering	4	Engineering (19)
Medicine	2	Medicine (2)
Operations research	1	Engineering (19)
Optics	2	Engineering (19)
Optimization	1	Mathematics (3)
Photonics	1	Engineering (19)
Physics	1	Science (7)
Planning	1	Computer science (7)
Polymers	1	Engineering (19)
Quantum	3	Science (7)
Security	1	Computer science (7)
Software engineering	3	Engineering (19)

Problem Type	Count
Classification	5
Clustering	1
Design	20
Optimization	8
Planning	1
Programming	4
Regression	3

Kannappan, K., L. Spector, M. Sipper, T. Helmuth, W. La Cava, J. Wisdom, and O. Bernstein. 2015. Analyzing a decade of Human-competitive ("HUMIE") winners -- what can we learn? In *Genetic Programming Theory and Practice XII*. New York: Springer.

Evolution, the Designer

WHAT WOULD DARWIN SAY? | LEE SPECTOR

The Boston Globe

And now, digital evolution

By Lee Spector | August 29, 2005

RECENT developments in computer science provide new perspective on "intelligent design," the view that life's complexity could only have arisen through the hand of an intelligent designer. These developments show that complex and useful designs can indeed emerge from random Darwinian processes.

"Darwinian evolution is itself a designer worthy of significant respect, if not religious devotion."

What it is **Not** Good For

- Quite a lot
- It is solving "problems beyond the reach of other forms of AI"
- But also **not** solving problems **within** the reach of other forms of AI

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- ✳ **Improving it**
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Areas for Improvement

- Representation
- Variation
- Selection

Areas for Improvement

- Representation
- Variation
- ✴ **Selection**

Parent Selection

- Traditionally based on overall scores
- Roulette wheels or tournaments
- Unbalanced, qualitatively diverse test sets


STAPLES
SPL-110
12345678
%
OFF
ON/C
MRC
M-
M+
CE
7
8
9
÷
4
5
6
×
1
2
3
−
0
•
=
+

Biological Selection

- Survive challenges that you happen to face
- Until you can reproduce
- Each challenge may be competitive

Lexicase Selection

- Don't use overall scores

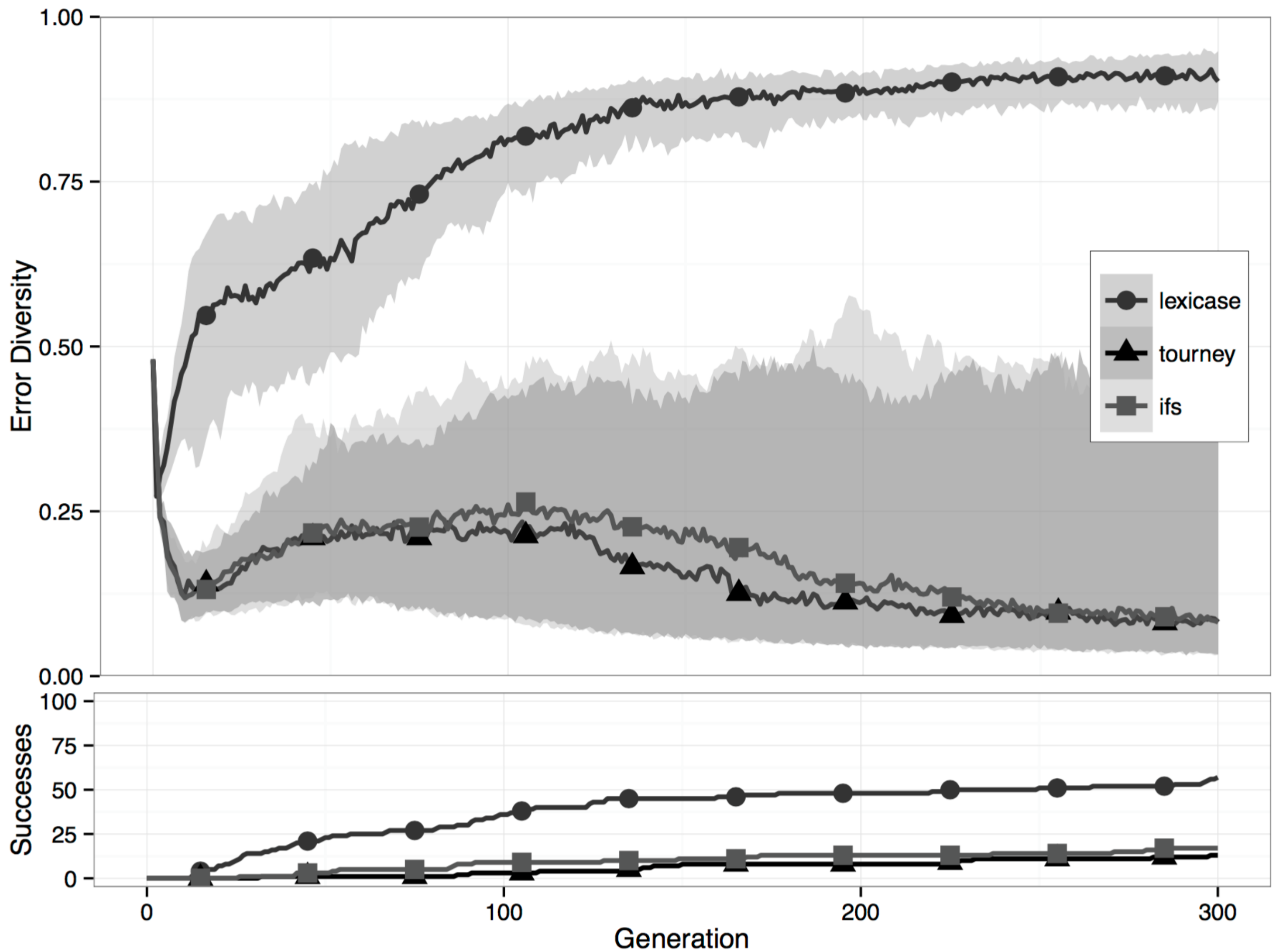
- To select single parent:
    1. Shuffle test cases
    2. First test case – keep best* individuals
    3. Repeat with next test case, etc.

  Until one individual remains

- Selected parent may be specialist, not great on average, but lead to generalists later

Problem name	Lexicase	Tournament
Replace Space With Newline	57	13
Syllables	24	1
String Lengths Backwards	75	18
Negative To Zero	72	15
Double Letters	5	0
Scrabble Score	0	0
Checksum	0	0
Count Odds	4	0

Diversity



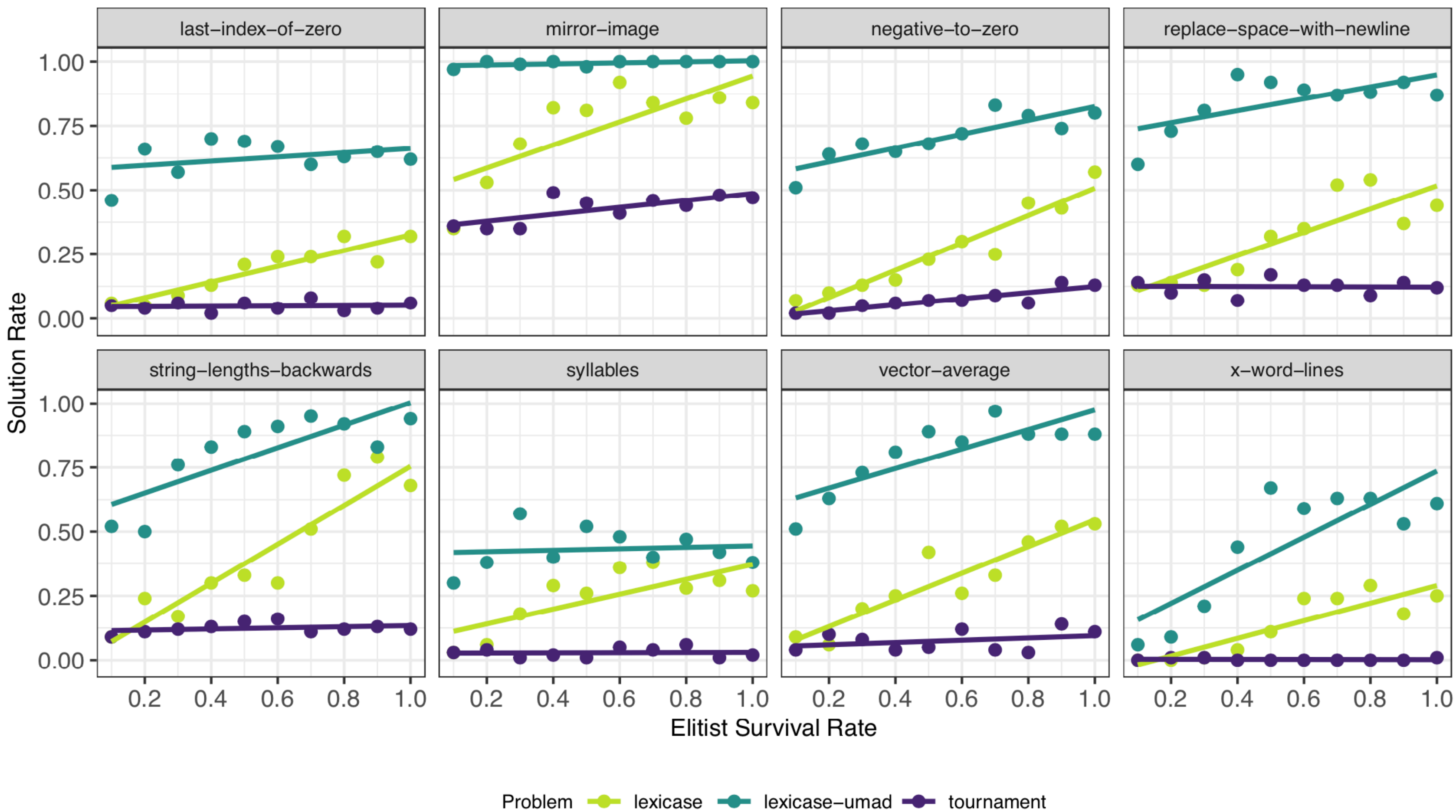
GPTP-2015

Fig. 1 Replace Space With Newline – error diversity

Why Does it Work?

- Prior results: Diversity alone is not the answer
- Hypothesis: Selecting specialists is important
- Test by only allowing programs with good overall scores (good non-specialists) to be selected
- Degraded performance would suggest that specialists are important

Specialists Help



General Lessons?

In what ways might specialists be important in:

- Other forms of machine learning?
- Biological evolution?
- Engineering teams?
- Educational communities?

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Connections

- Machine learning
- Software engineering
- Programming languages
- Theory
- Evolutionary biology
- Applications

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✳ **COSC-452**

Note: this is preliminary information about this course. Final course information will be published shortly before the start of the semester.

Sem: Evolutionary Comp

SPRING 2020

Seminar in Computer Science: Evolutionary Computation

Listed in: Computer Science, as COSC-452

Formerly listed as: COSC-40

Faculty

Lee Spector (Section 01)

Description

Evolutionary computation techniques harness the mechanisms of biological evolution, including mutation, recombination, and selection, to build software systems that solve difficult problems or shed light on the nature of evolutionary processes. In this course students will explore several evolutionary computation techniques and apply them to problems of their choosing. The technique of genetic programming, in which populations of executable programs evolve through natural selection, will be emphasized.

Requisite: COSC 112. Limited to 20 students. Preference given to Computer Science majors. Spring semester. Professor Spector.

COSC-452

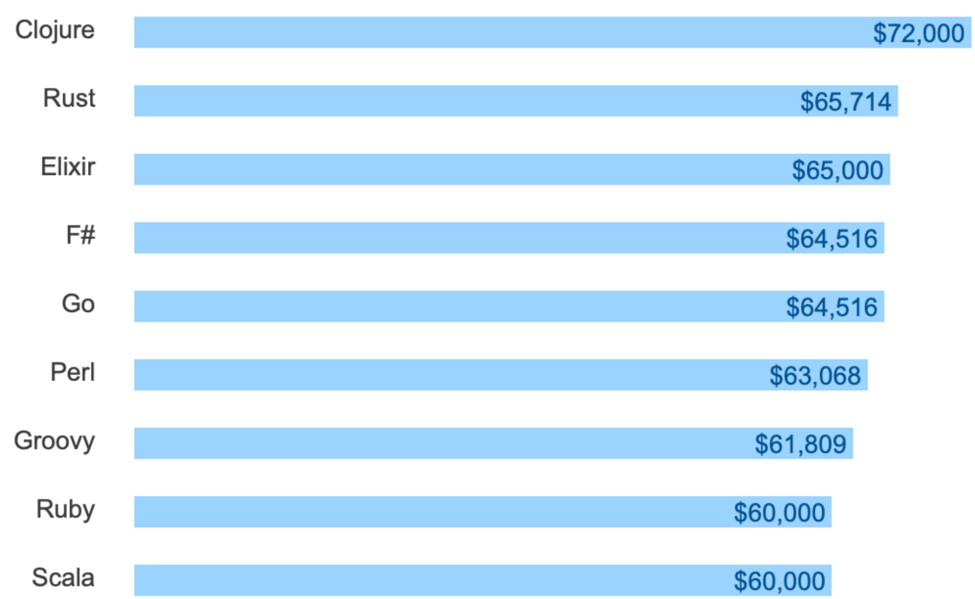
- Projects applying and/or improving EC
- First half of course: preparing to do this
- First **weeks** of course: learning **Clojure**, a language in which progress will be faster:
    - Child of Java and Lisp
    - Functional, high level, concise
    - Full GP system in a few hundred lines

https://insights.stackoverflow.com/survey/2017

Top Paying Technologies

Top Paying Technologies by Region

Worldwide | US | UK | Germany | India | France



Takeaways

- Many EvoBio/CompSci intersections
- Evolutionary algorithms use variation and selection to solve hard, interesting, and important problems
- Ample opportunities for improvement and application
- Specialists appear to be important
- CS-452 will be fun