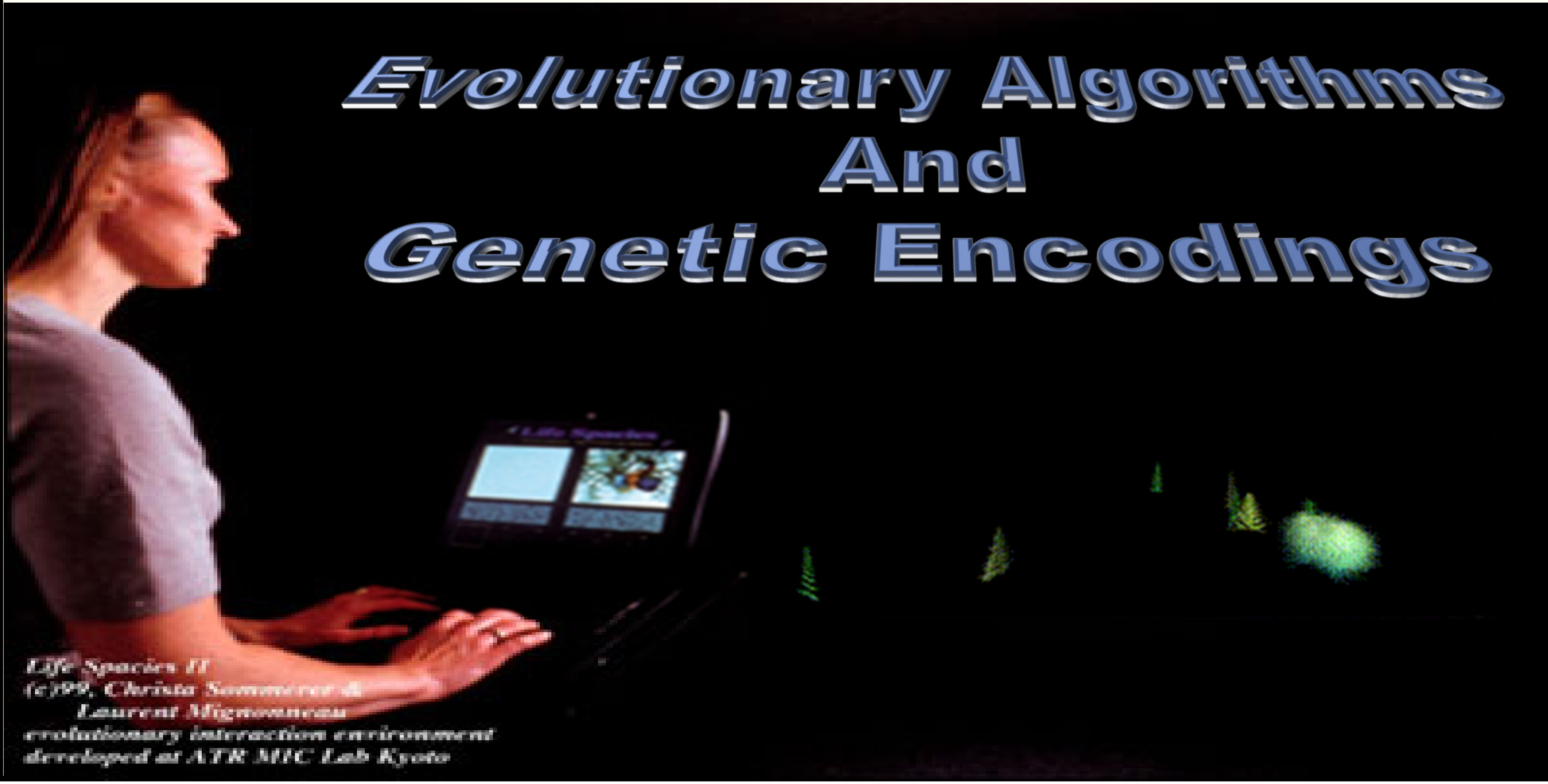
Evolutionary Algorithms And Genetic Encodings



key events coming up

- Labs: 35% (ISE-483)
  - Complete 5 (best 4 graded) assignments based on algorithms presented in class
    - Lab 4 : April 8th
      - Evolutionary Algorithms, (Assignment 4)
        - Delivered by SSIE583 Group 2
        - Due April 22nd
    - Lab 5: April 29th
      - Ant Clustering Algorithm, (Assignment 5)
        - Delivered by Group 1
        - Due May 6th
- SSIE – 583 -Presentation and Discussion: 25%
  - Present and lead the discussion of an article related to the class materials
    - Enginet students post/send video or join by Zoom
  - April 25th or April 29th
    - Conrad, M. [1990]. "The geometry of evolution.“ *Biosystems* **24**: 61-81.
      - Mario Franco
    - Stanley, Kenneth O., Jeff Clune, Joel Lehman, and Risto Miikkulainen. “Designing Neural Networks through Neuroevolution.” *Nature Machine Intelligence* **1**, no. 1 (January 2019): 24–35.
      - Jessica Lasebikan
    - Lindgren, K. [1991]."Evolutionary Phenomena in Simple Dynamics." In: *Artificial Life II*. Langton et al (Eds). Addison-wesley, pp. 295-312.
      - Akshay Gangadhar
    - Salahshour, Mohammad. “Interaction between Games Give Rise to the Evolution of Moral Norms of Cooperation.” *PLOS Computational Biology* **18**, no. 9 (September 29, 2022): e1010429
      - Srikanth Iyer
    - Discussion by all

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rocha@binghamton.edu
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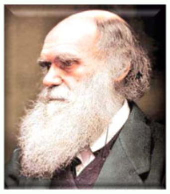
until now

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press. Preface**, Chapters 1 and 4.**
- Lecture notes
  - Chapter 1: What is Life?
  - Chapter 2: The logical Mechanisms of Life
  - Chapter 3: Formalizing and Modeling the World
  - Chapter 4: Self-Organization and Emergent Complex Behavior
  - Chapter 5: Reality is Stranger than Fiction
  - Chapter 6: Von Neumann and Natural Selection
    - posted online @ http://informatics.indiana.edu/rocha/i-bic



- Papers and other materials
  - Optional
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall.
      - Chapter 2, 7, 8
      - **Chapter 3, sections 3.1 to 3.5**

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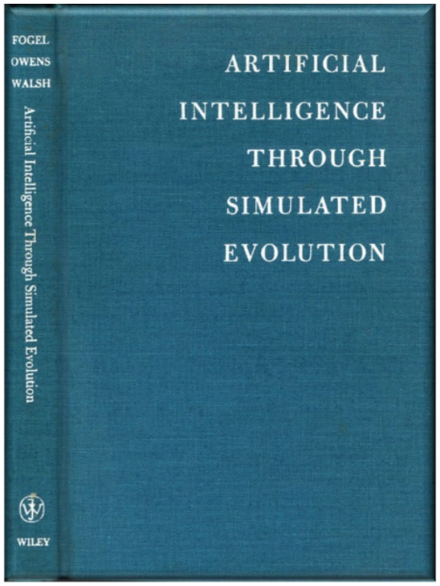
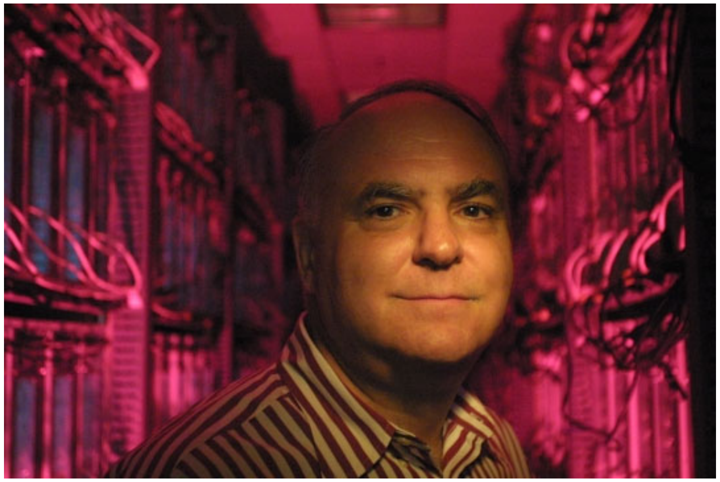
- Projects
  - Due by **May 8th** in Brightspace, “Final Project Paper” assignment
    - ALIFE 2023
      - Not to submit to actual conference due date (April 3rd , 2024)
      - https://2024.alife.org/
      - 8 pages, author guidelines:
      - https://2024.alife.org/call_paper.html
      - MS Word and Latex/Overleaf templates
    - Preliminary ideas **by March 15**
      - Submit to “Project Idea” assignment in Brightspace.
  - Individual or group
    - With very definite tasks assigned per member of group

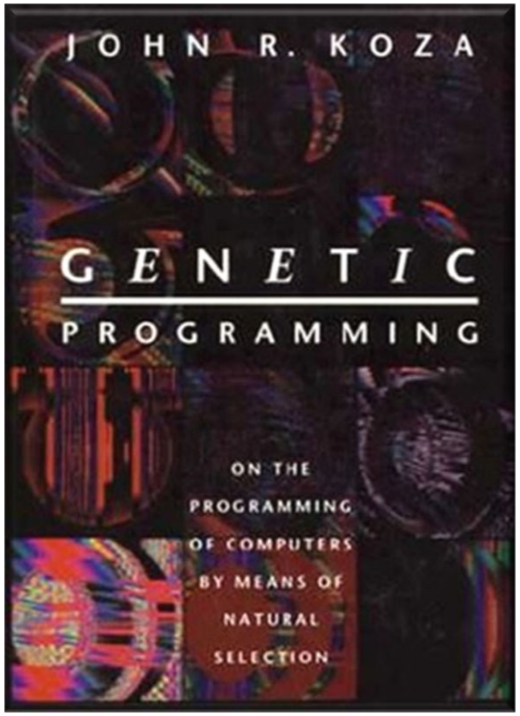
ALIFE 2024

Tackle a real problem using bio-inspired algorithms, such as those used in the labs.

- Fogel, Owens and Walsh (1966)
  - *Artificial Intelligence through simulated evolution*. Wiley.
    - Evolution of finite-state machines
- John Koza (1992) at Stanford University
  - *Genetic Programming: On the programming of computers by means of Natural Selection*. MIT Press.

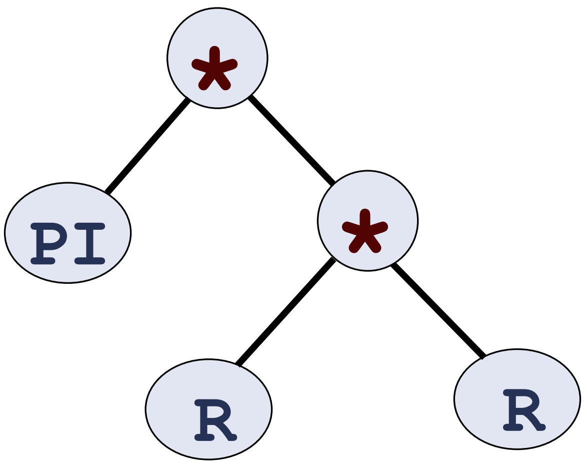






tree encodings

- Evolving computer programs to perform a task
  - No strict genotype-phenotype mapping
  - LISP programs
    - Can be expressed in the form of parse trees




```
(DEFUN AREA-OF-CIRCLE ()
  (SETF R 45)
  (SETF PI 3.1415)
  (* PI (* R R)))
```

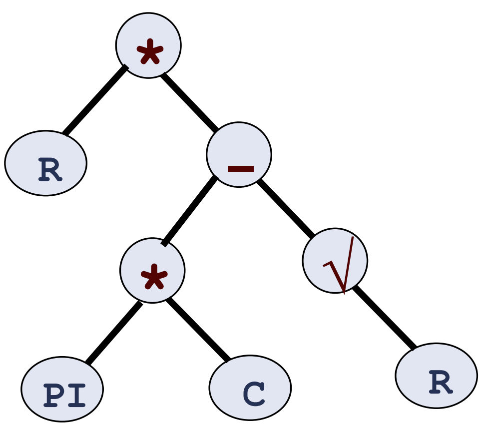
functions terminals

the workings

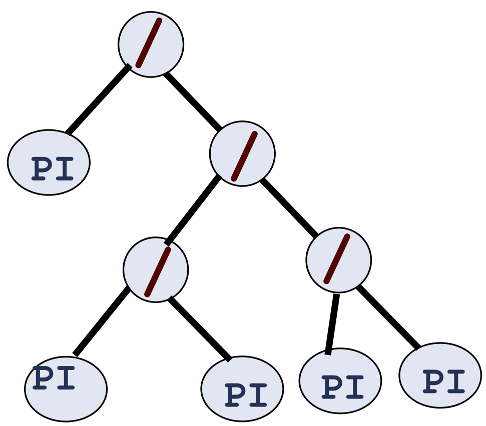
1) Choose a pool of possible functions and terminals
   - Setting up a language of description
2) Generate Random population of trees (programs)
   - Must be syntactically correct (parsing)
   - Size is usually restricted
3) Evaluate Fitness Function for each tree
   - Desired I/O
   - Simplicity, speed
4) Reproduce next generation with variation
   - Trees with higher fitness value reproduce with higher probability
5) Go back to 3)

`- / + == √ ABS …`

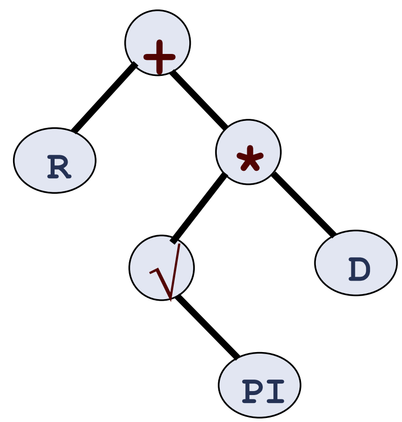
`PI C R B …`



R*[(PI*C)-√R]



PI/{[(PI/PI)/(PI/PI)]}



R+(√PI*D)

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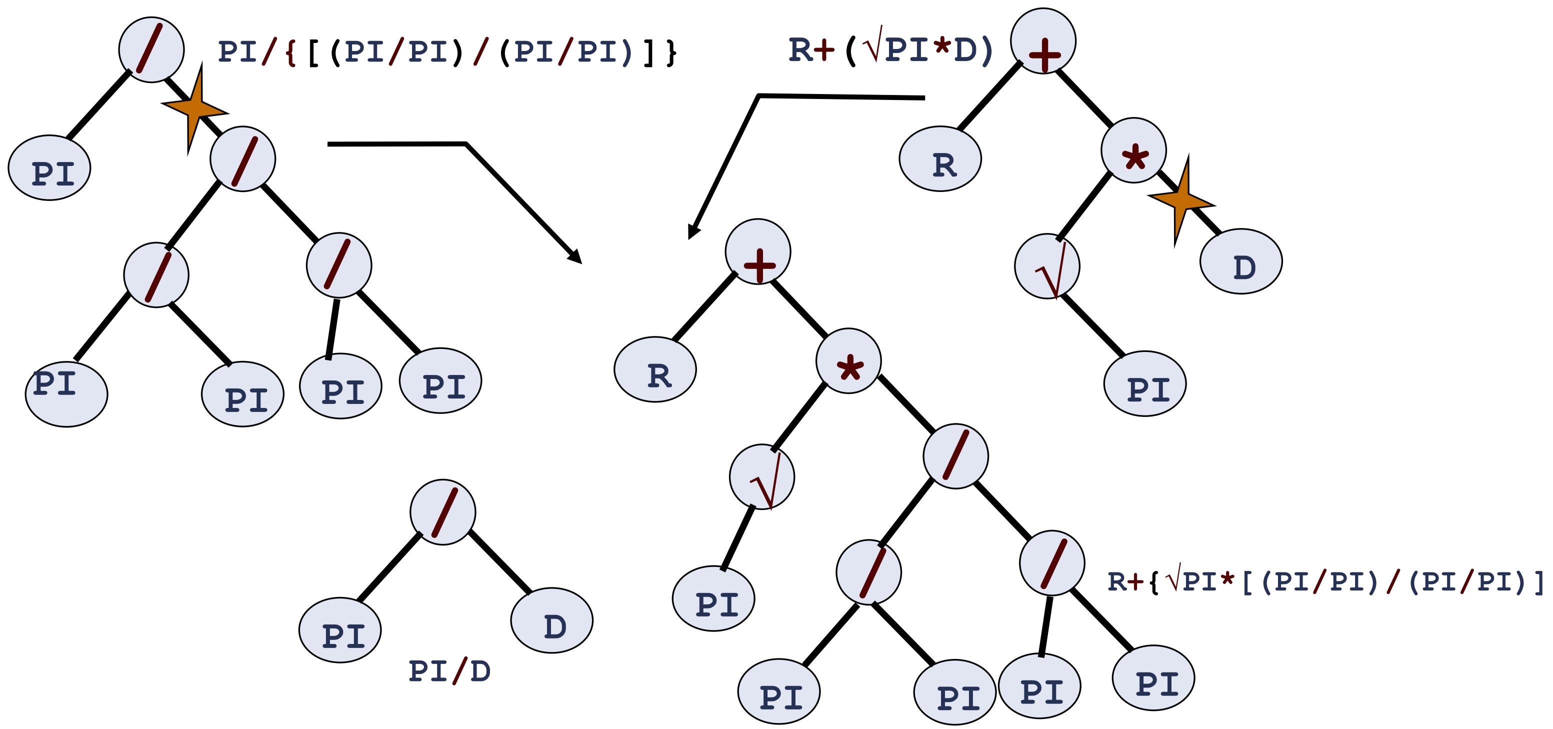
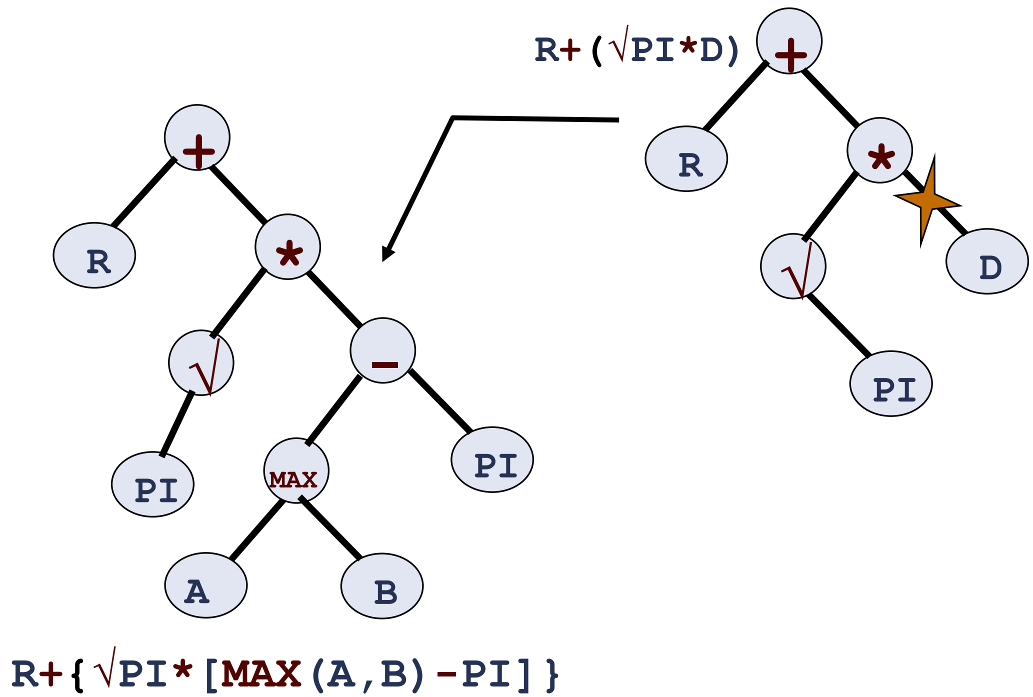
crossover

- Choose random point in each parent's tree
- Exchange subtrees beneath to produce offspring
  - Allows size of program to increase or decrease



mutation

- Choose random point in a tree
- Replace subtree beneath with random tree



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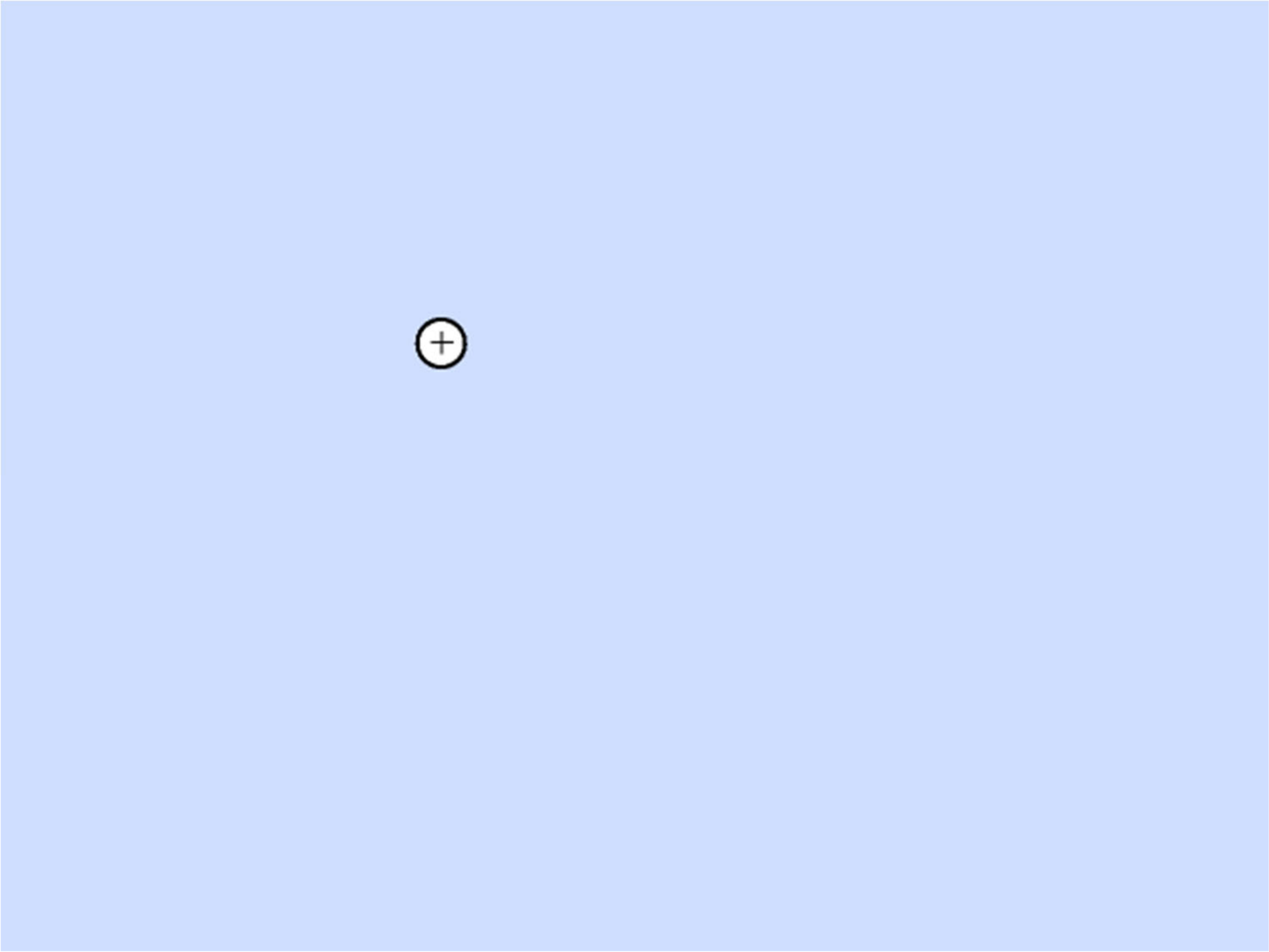
Creation demo



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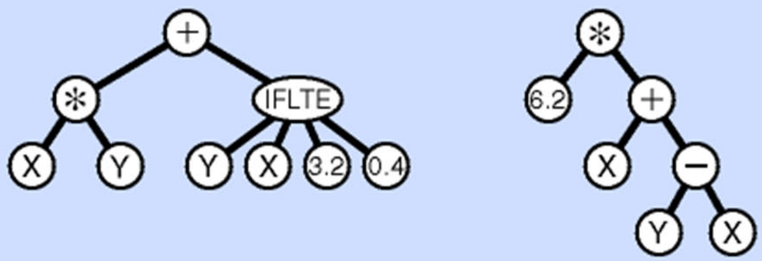

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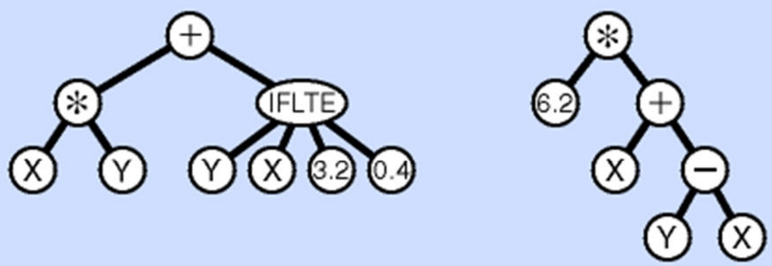
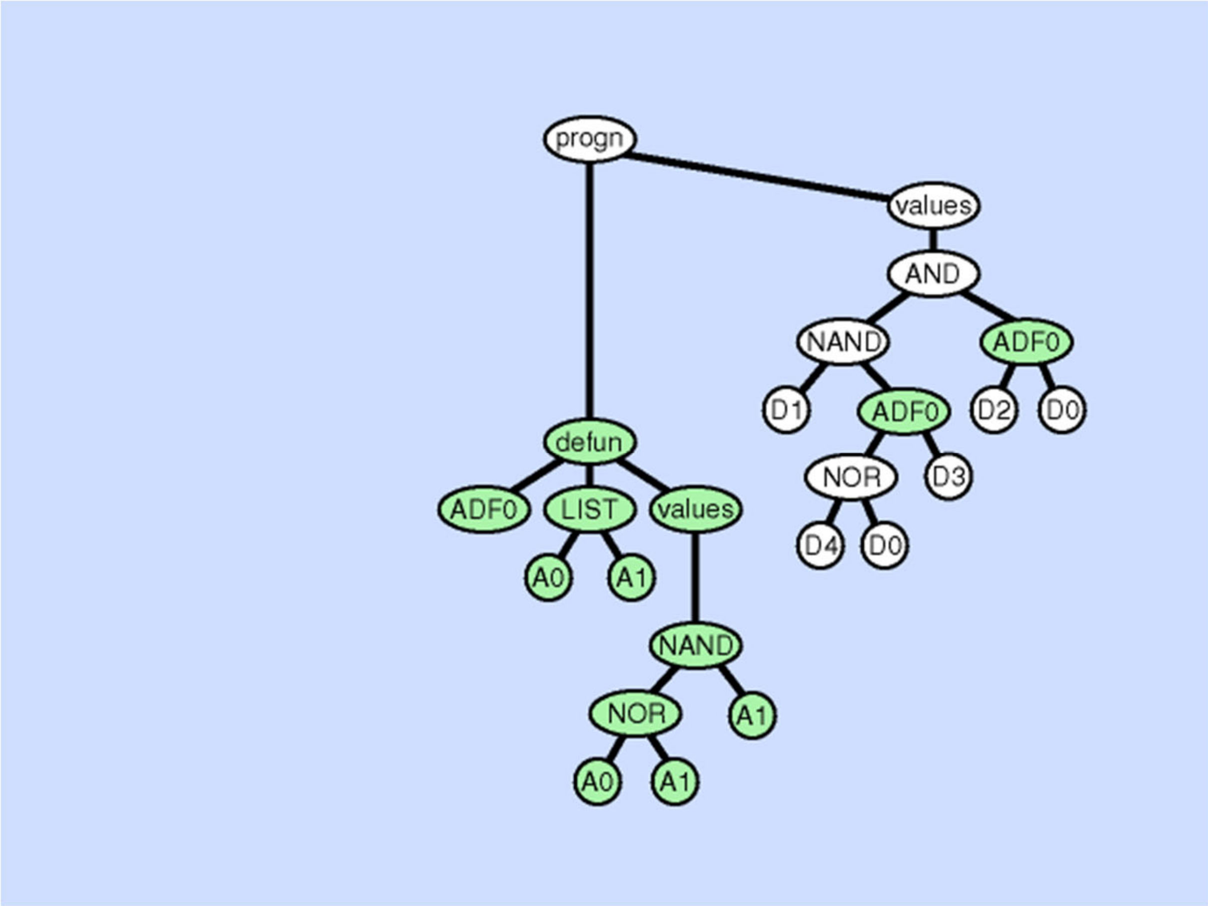
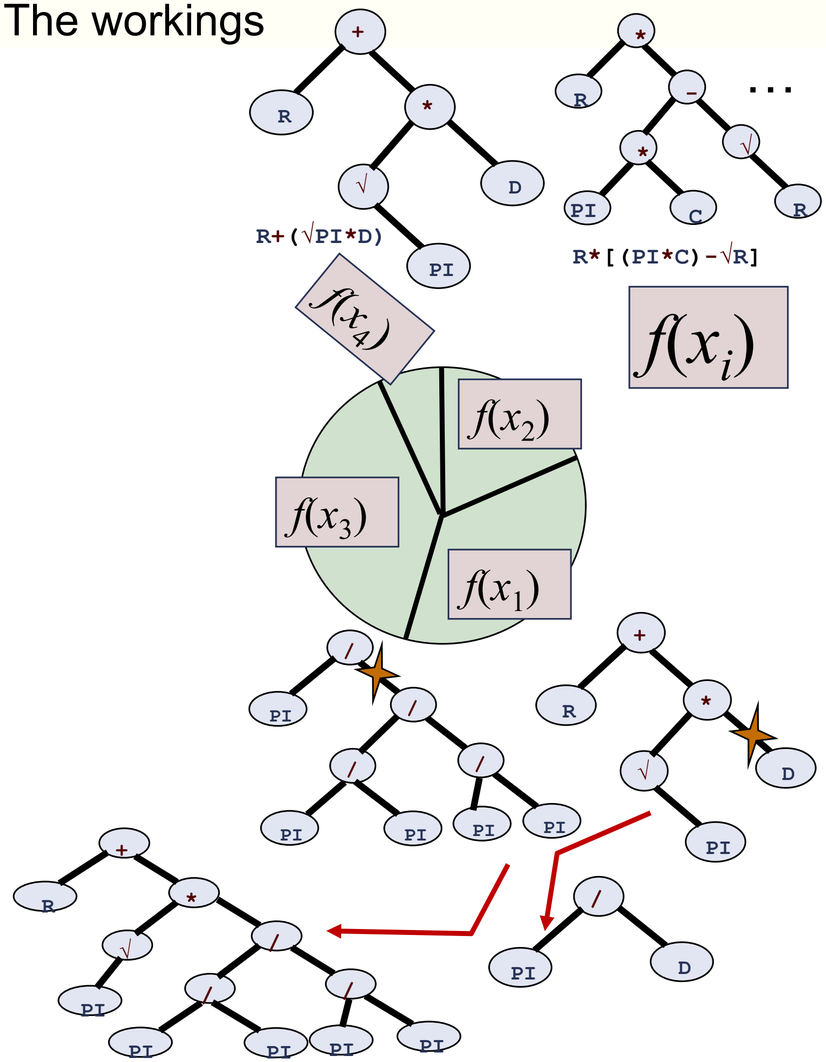

+
*
IFLTE
X
Y
Y
X
3.2
0.4
*
6.2
+
X
−
Y
X

Architecture-altering operations



The workings



1) Generate Random population of trees/programs
2) Evaluate Fitness Function for each program
   - Desired I/O, simplicity, speed
3) Reproduce next generation
   - Selection by fitness
   - Variation
     - crossover and mutation
   - Fill new population
4) Go back to 2) until stop criteria is met
   - Desired fitness
   - Specified number of generations
   - Convergence

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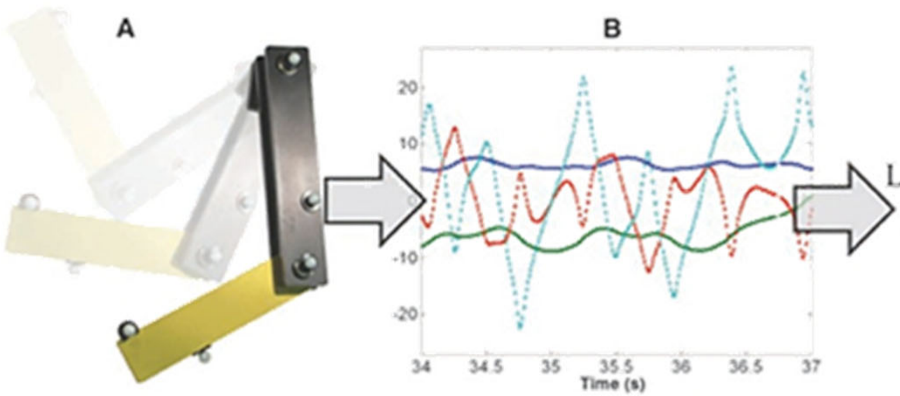
applications

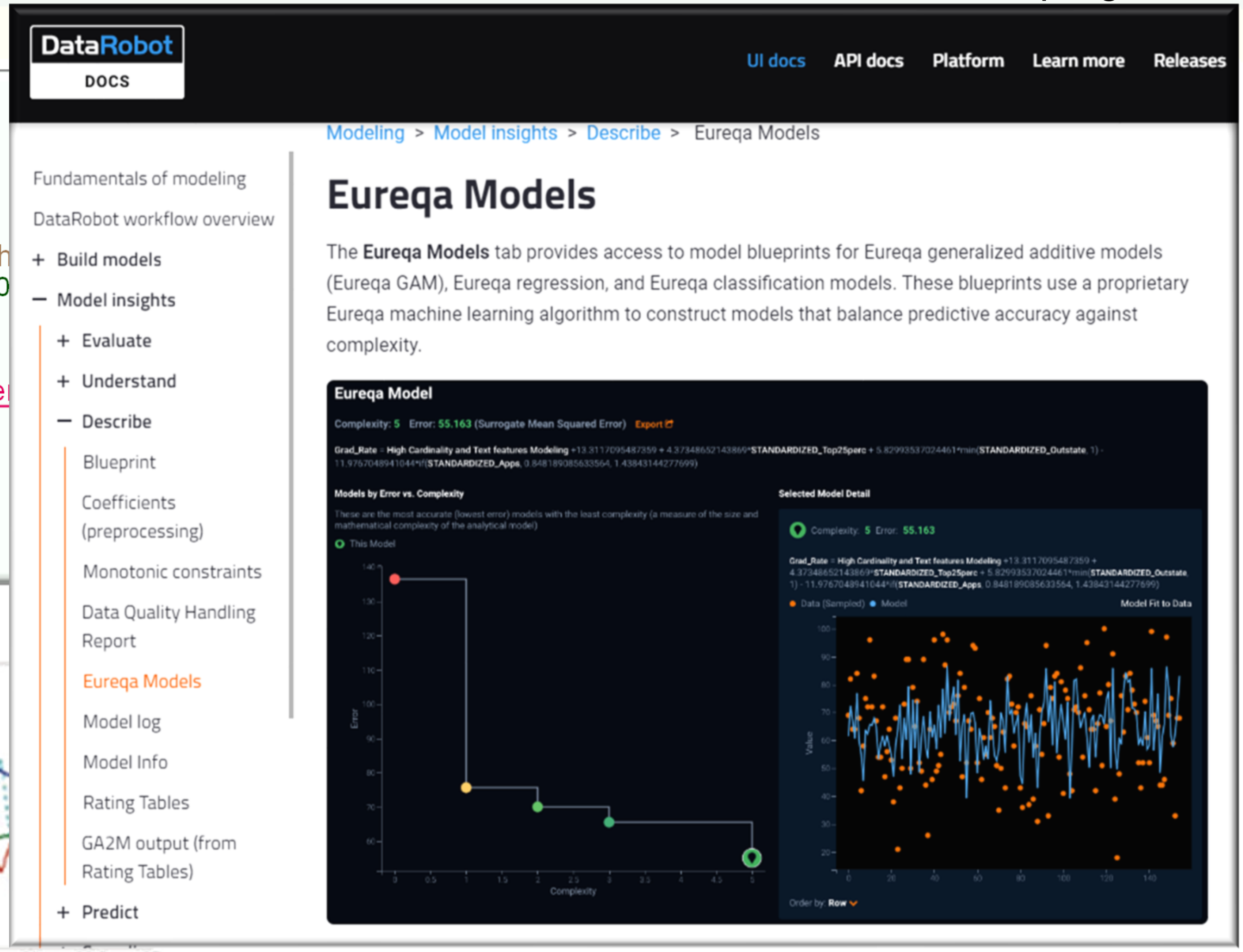
- Optimal control
- Planning
- Symbolic regression
  - Fit real data
    - Example: Uncover laws of physics
      - Schmidt M., Lipson H. (2009) "Distilling Free-Form Natural Laws from Experimental Data," *Science*, **324** (5923): 81 - 85.
    - Binary Classification
  - Software Tool
    - Eureqa: https://www.creativemachineslab.com/eureqa.html
- Robot strategies
  - Robocup
- Evolvable hardware



$$L_1^2(m_1+m_2)\omega_1^2 + m_2L_2^2\omega_2^2 + m_2L_1L_2\omega_1\omega_2\cos(\theta_1-\theta_2) - 19.6L_1(m_1+m_2)\cos\theta_1 - 19.6m_2L_2\cos\theta_2$$

applications

- Optimal control
- Planning
- Symbolic regression
  - Fit real data
    - Example: Uncover laws of ph
      - Schmidt M., Lipson H. (200
    - Binary Classification
  - Software Tool
    - Eureqa: https://www.creative



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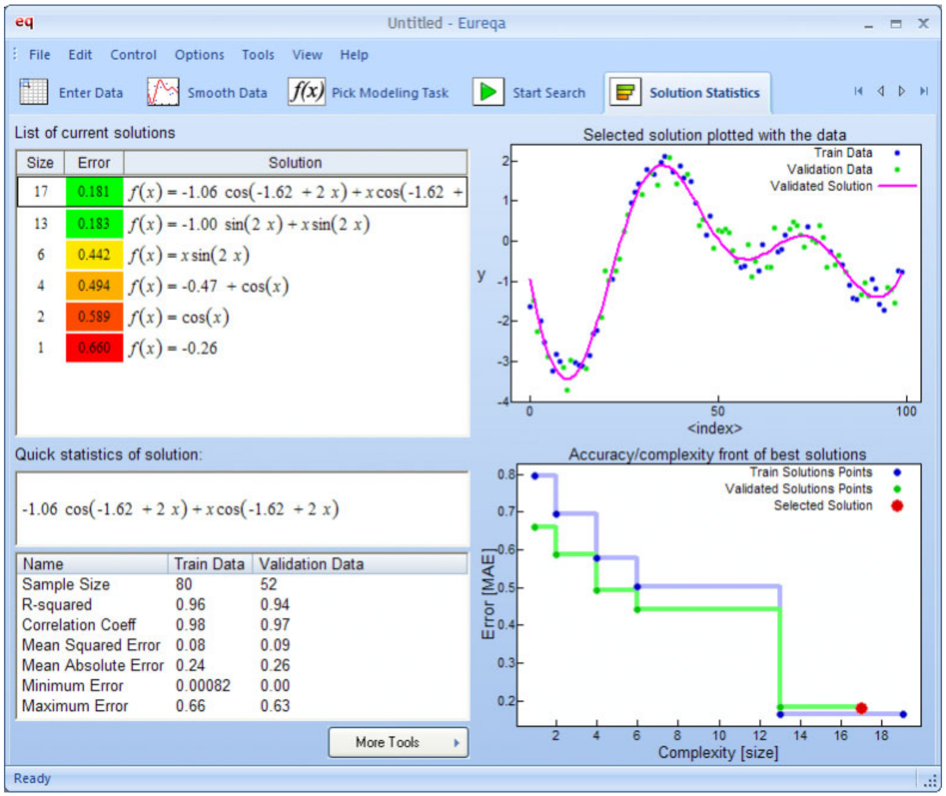
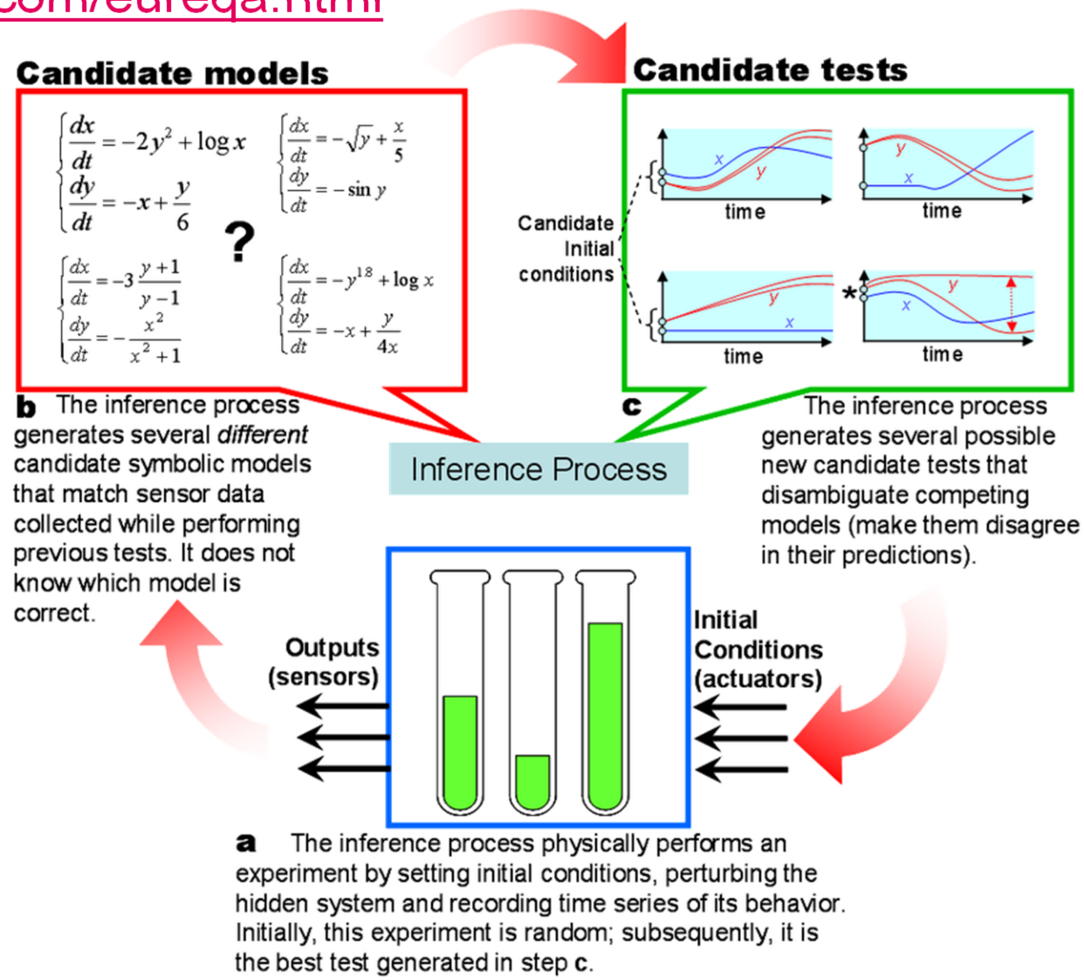
A symbolic regression tool

Eureqa: https://www.creativemachineslab.com/eureqa.html





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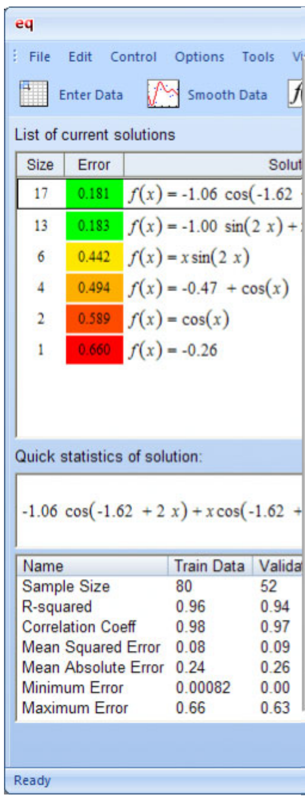

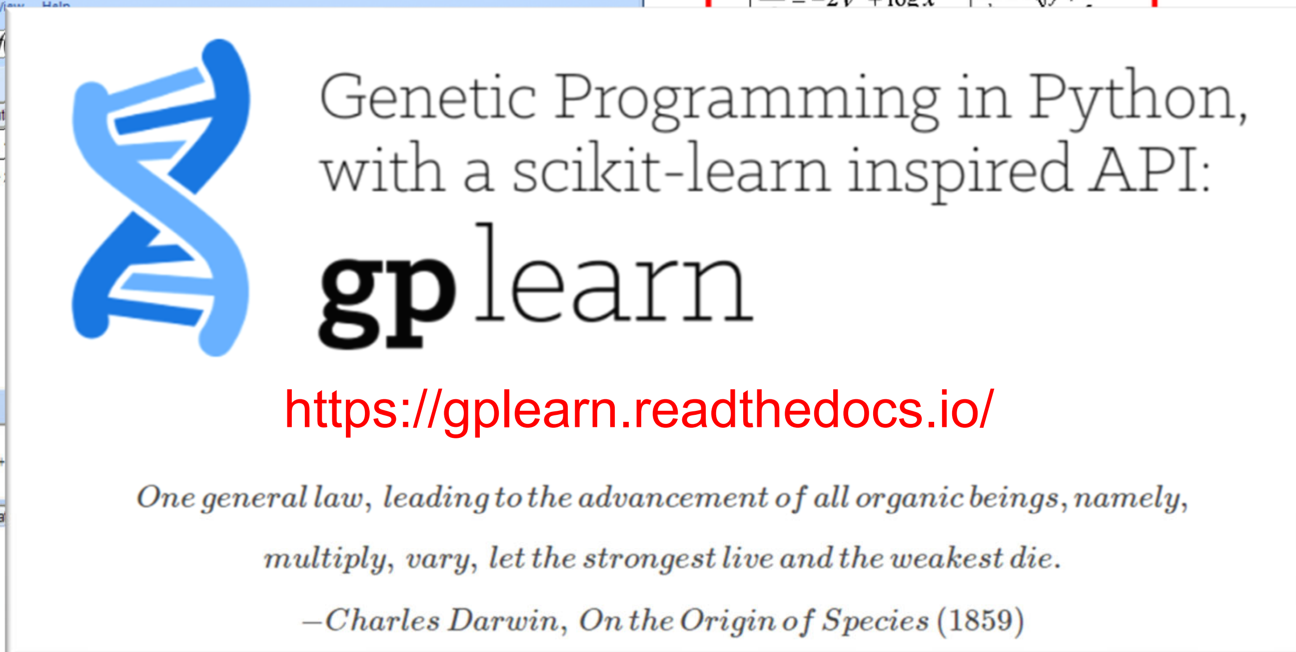

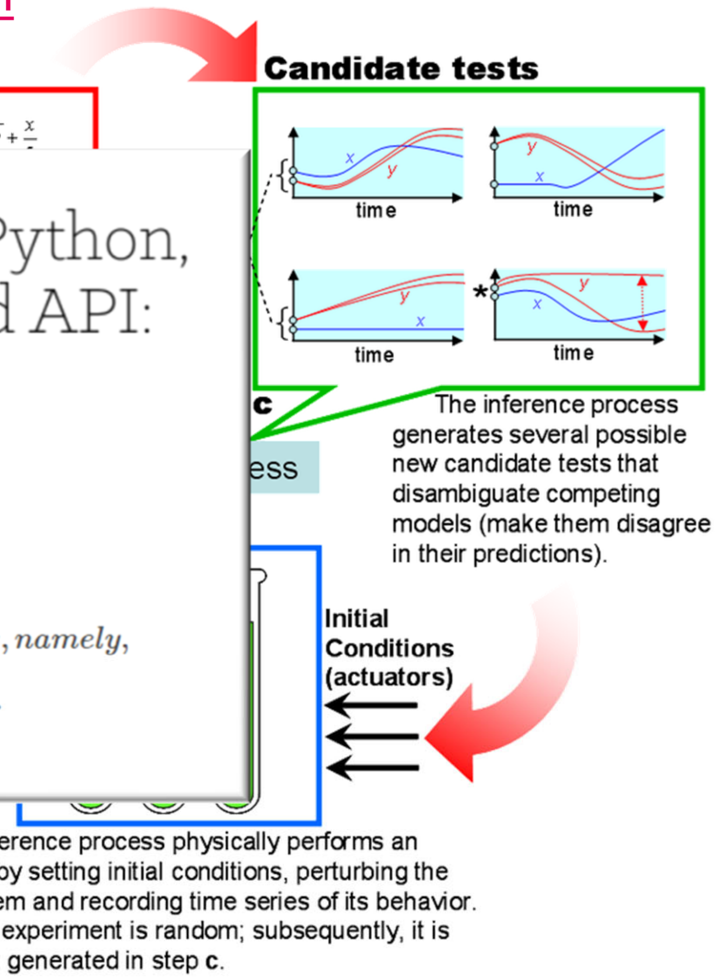

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- Binary encodings
  - Typically fixed-length
- Many-letter encoding
  - Larger alphabet (e.g. graph-generation grammars)
- Real-valued encodings
  - Genes take real values
- Tree Encodings
  - Genetic programming
- Indirect Encodings
  - Modeling Phenotype **development** or **post-transcription** processes
    - L-Systems, Dynamical systems, evolutionary robotics

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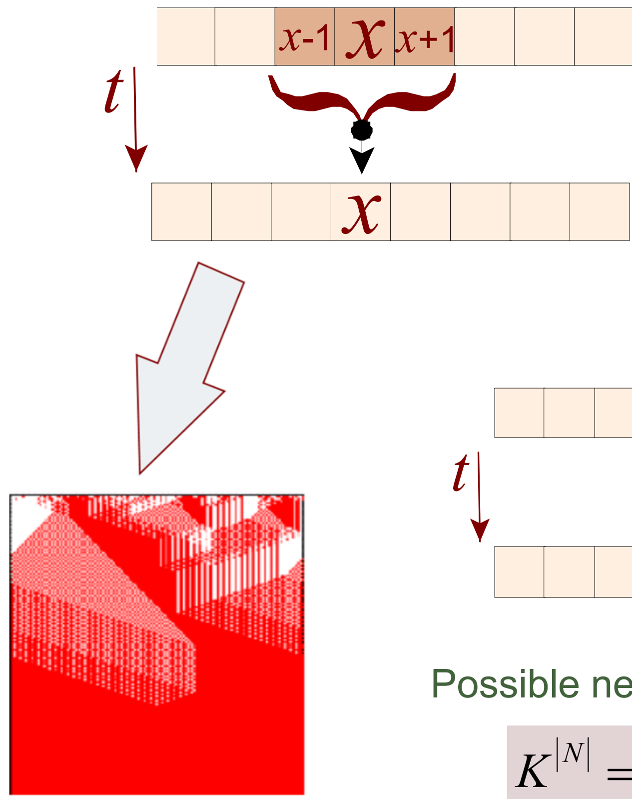
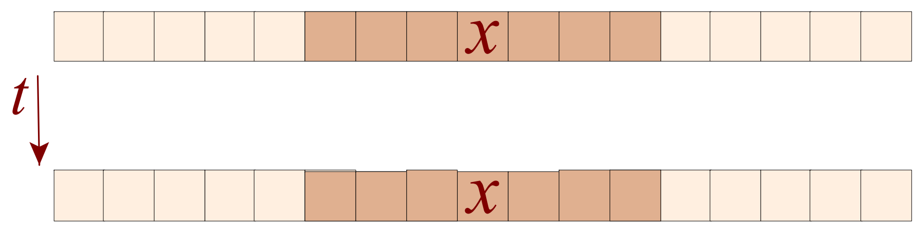
homogenous lattice of state-determined systems

Cellular Automata



Density Task
(a.k.a majority classification problem)

- Lattices of 149 Binary Cells (599, 999)
- Rules of Radius 3 (7 Cells in Neighborhood)
- Task: Organize to
  - All 1's if Initial Configuration (IC) has more 1 Cells
  - All 0's if IC has more 0 Cells



Possible neighborhood states

$$K^{|N|} = 2^7 = 128$$

Possible CA transition functions

$$K^{K^{|N|}} = 2^{128} \approx 3.4 \times 10^{38}$$

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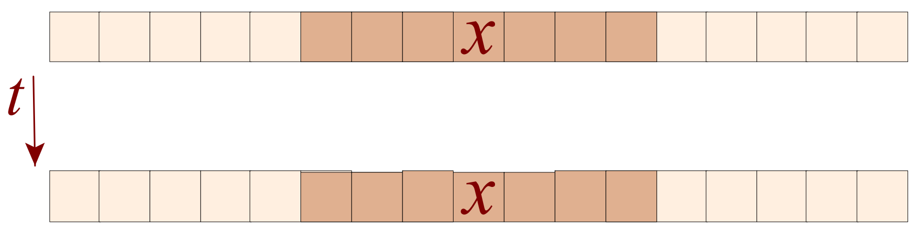
encoding in GA with binary encoding



Possible neighborhood states $K^{|N|} = 2^7 = 128$

Pop of rules

010010101100100

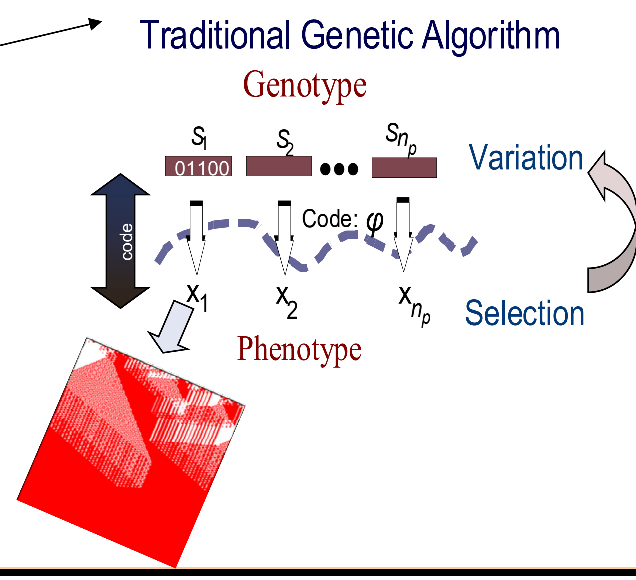
010010101100100

010010101100100

010010101100100

010010101100100

Used in the evolutionary search by GA (elite selection)



0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0
0	0	0	0	0	1	0	1
0	0	0	0	0	1	1	0
0	0	0	0	1	0	0	1
0	0	0	0	1	0	1	0
0	0	0	0	1	1	0	0
0	0	0	0	1	1	1	0
0	0	0	1	0	0	0	1
0	0	0	1	0	0	1	0
0	0	0	1	0	1	0	1
0	0	0	1	0	1	1	1
0	0	0	1	1	0	0	0
0	0	0	1	1	0	1	0

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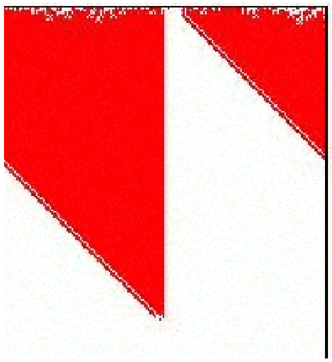
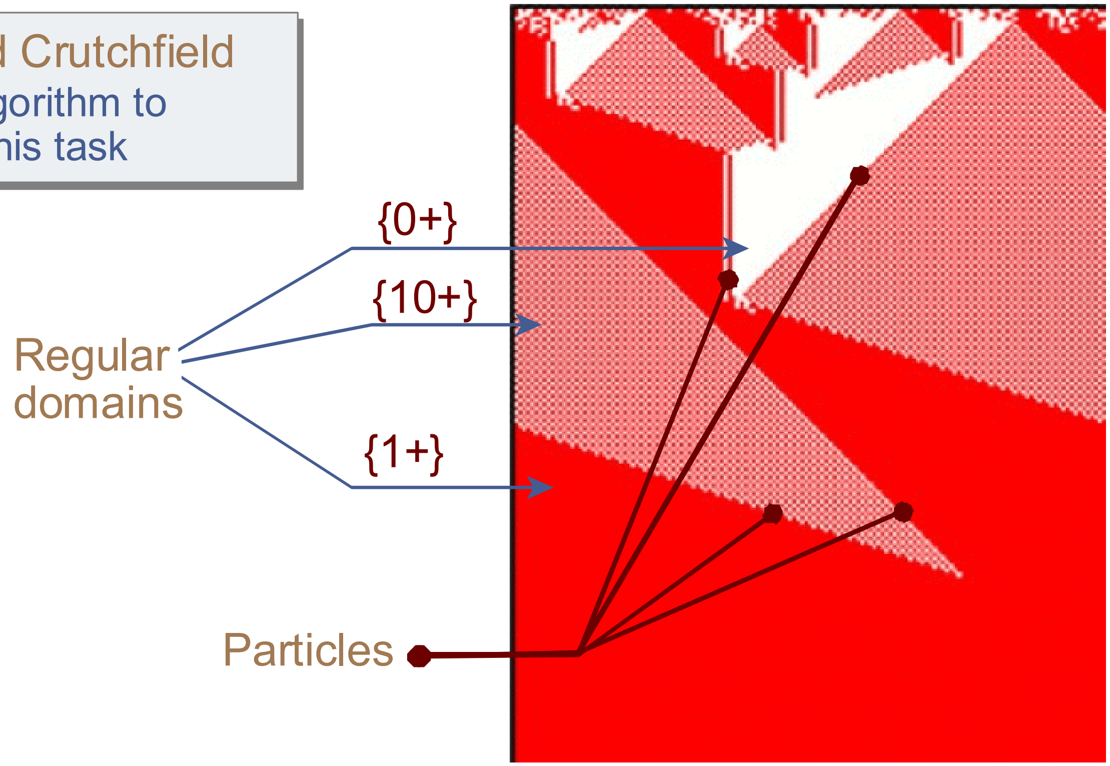
With genetic algorithms

- Das, Mitchell and Crutchfield
  - Used Genetic Algorithm to evolve rules for this task

Typical Result:
Block Expansion

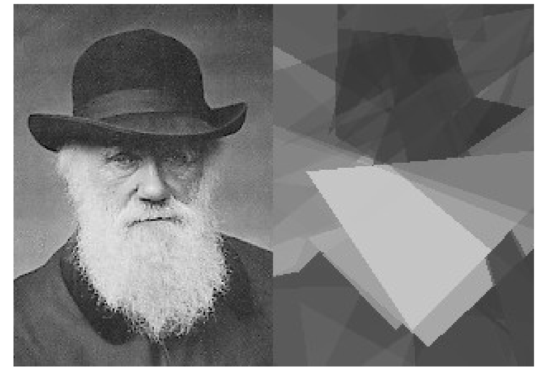


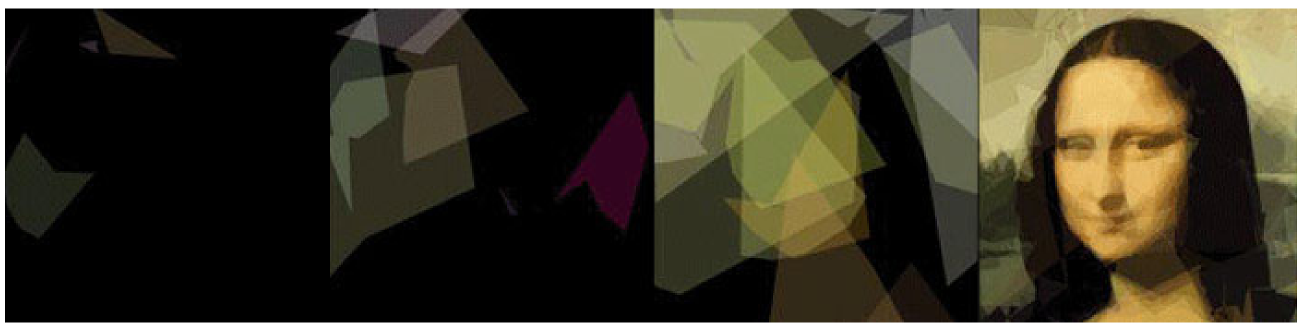


Das,R., Mitchell,M., Crutchfield,J.P., [1994]. "A genetic algorithm discovers particle-based computation in cellular automata". In: *Parallel Problem Solving from Nature - PPSN III*. Davidor,Y., Schwefel,H.-P., Manner,R. (Eds.), Springer-Verlag, pp. 344-353.

to evolve photos with numerical encodings

Original 128 circles 256 circles





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In genetic algorithms

1) Genotypes contain real or integer values
    1) Crossover is performed in the same way
    2) Mutation assigns a random number in a given interval
2) More computationally demanding for Reals
3) Attention to crossover points
    1) Conversion to binary avoids crossover issues, but longer genotypes

0.3	1.7	3.8	1.7	6	1.2	3.2	6.4	2.8	0

↓

0.3	1.7	3.8	1.7	2.9	1.2	3.2	6.4	2.8	0

n circles

x	y	r	R	G	B													
54	108	25	201	11	192	254	18	100	1	141	12	…	254	18	100	1	141	12

$\underbrace{\qquad}_{}$ n Genes

Agent Chromosome/Genotype (Population of p agents)

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Evolutionary algorithms to optimize neural networks

- Capabilities (not in gradient-based ANN)
  - Generation of ANN building blocks
    - Activation functions
  - Hyperparameter optimization
  - Architecture and learning algorithm search and optimization
- Massive Paralellism
  - Population of solutions

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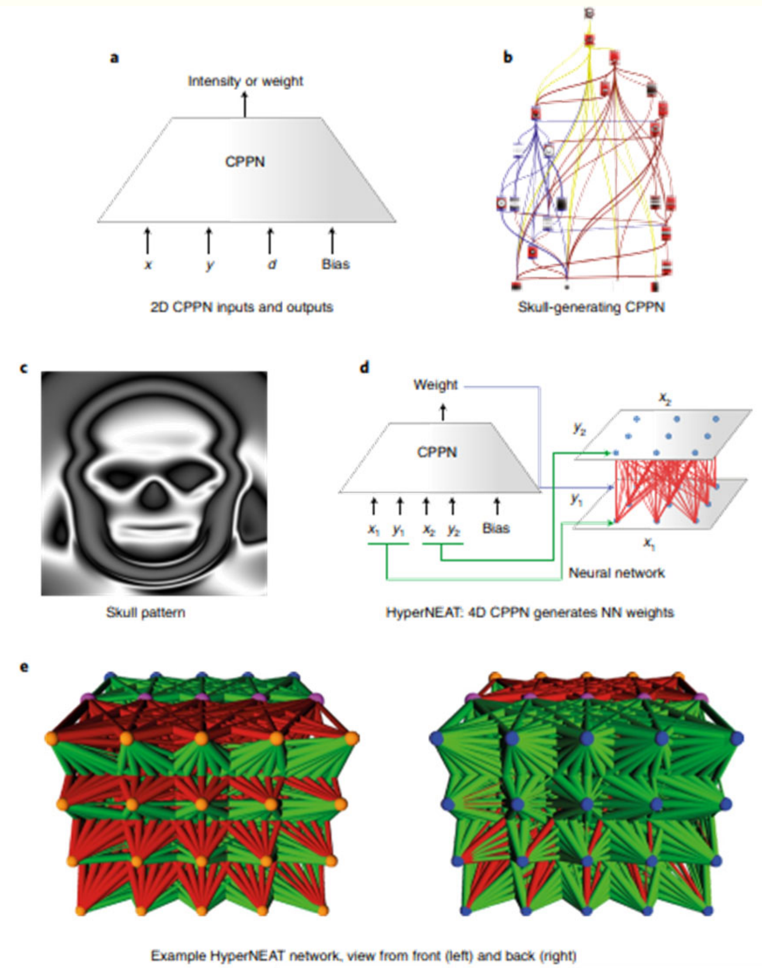
Review Article | Published: 07 January 2019

Designing neural networks through neuroevolution

Kenneth O. Stanley, Jeff Clune, Joel Lehman & Risto Miikkulainen

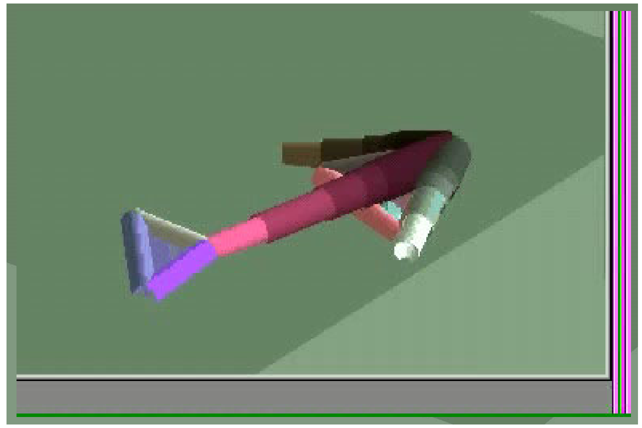
Nature Machine Intelligence **1**, 24–35 (2019) | Cite this article

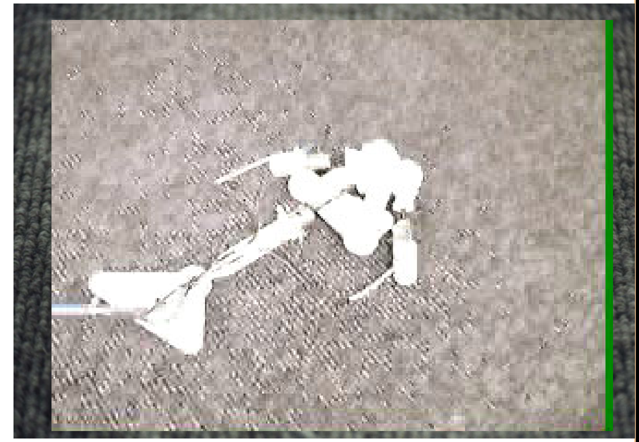


Stanley, K.O., Clune, J., Lehman, J. et al (2019). Designing neural networks through neuroevolution. *Nat Mach Intell*, 24–35.

Karl Sim´s simulations, Genobots, and the Golem project

Sims, Karl. "Evolving virtual creatures."
In *Seminal Graphics Papers: Pushing the Boundaries, Volume 2*, pp. 699-706. 2023.





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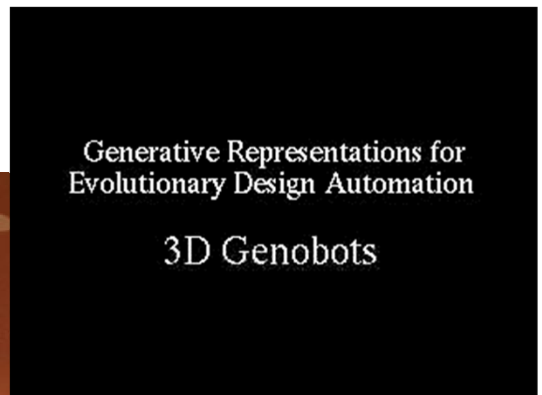

https://www.karlsims.com/evolved-virtual-creatures.html

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http://www.demo.cs.brandeis.edu/pr/evo_design/evo_design.html objective function may be subjective

"Once a Darwinian process gets going in a world, it has an open-ended power to generate surprising consequences: us, for example" Richard Dawkins

Biomorphs

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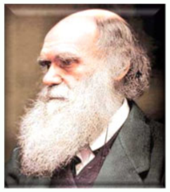
readings

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press.
    - **Chapter 7**
- Lecture notes
  - Chapter 1: What is Life?
  - Chapter 2: The logical Mechanisms of Life
  - Chapter 3: Formalizing and Modeling the World
  - Chapter 4: Self-Organization and Emergent Complex Behavior
  - Chapter 5: Reality is Stranger than Fiction
  - Chapter 6: Von Neumann and Natural Selection
    - posted online @ casci.binghamton.edu/academics/i-bic



- Papers and other materials
  - Optional
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall.
      - Chapter 5, 7.7, 8.3.1, 8.3.6,

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