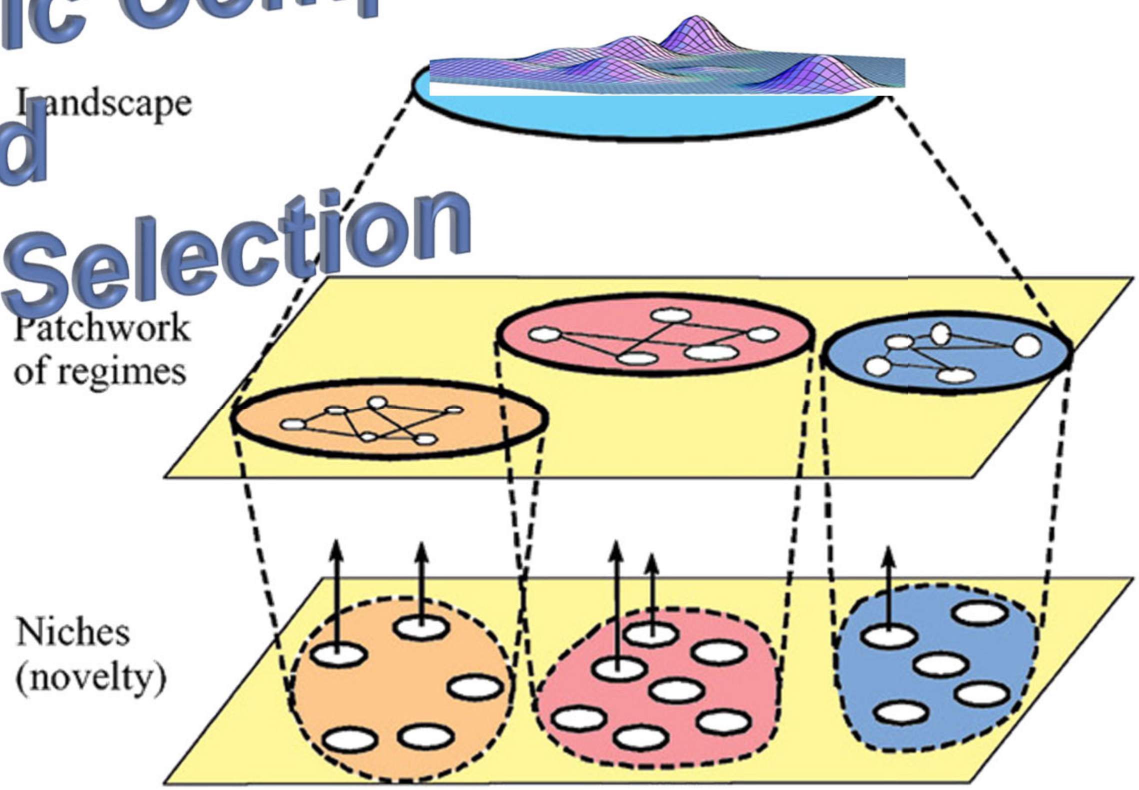
Adding Genomic Complexity And Multi-level Selection



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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

bit.ly/atBIC

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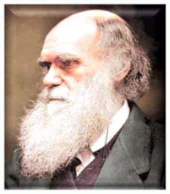
until now

- 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.



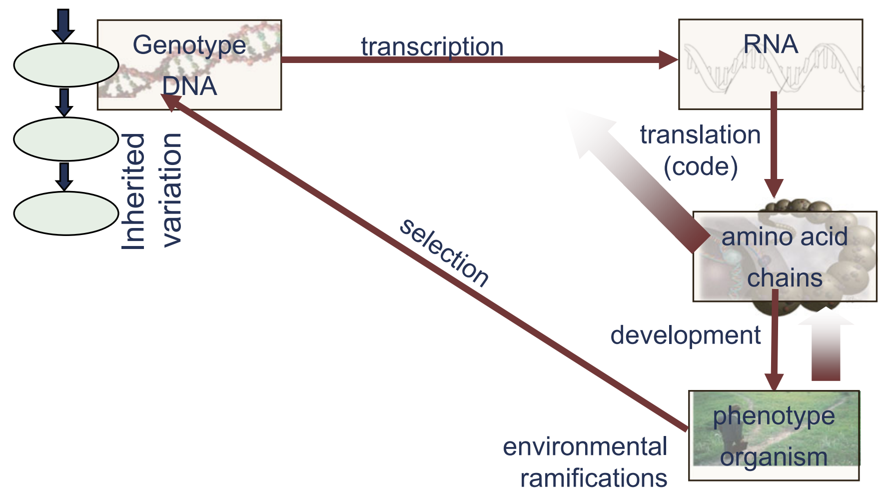
- Projects
  - Due by **May 8th** in Brightspace, "Final Project Paper" assignment
    - ALIFE 2023
      - Not to submit to actual conference due date (April 3rd , 2024)
      - https://2024.alife.org/
      - 8 pages, author guidelines:
      - https://2024.alife.org/call_paper.html
      - MS Word 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

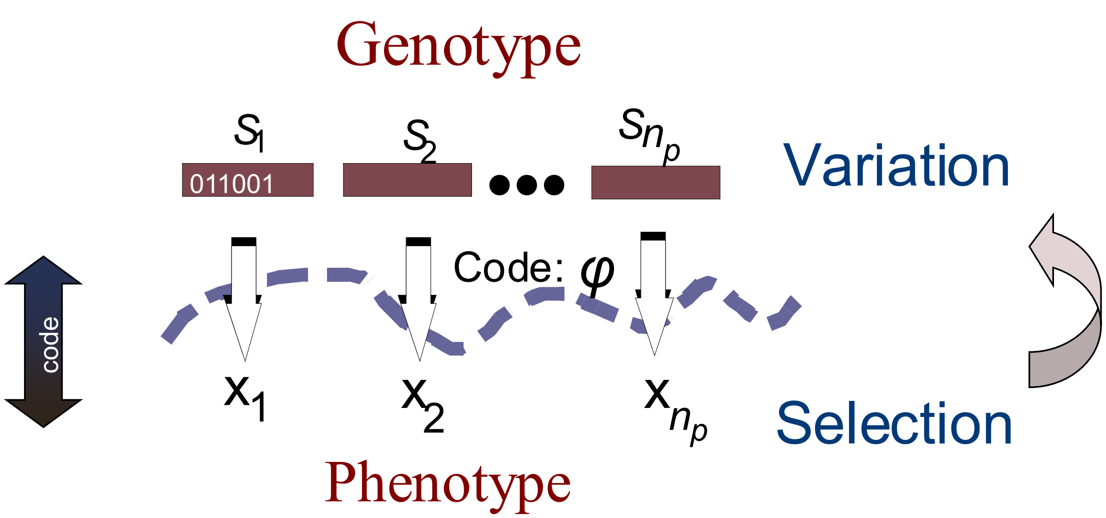
Tackle a real problem using bio-inspired algorithms, such as those used in the labs.

artificial genotype/phenotype mapping

- Search algorithms based on the mechanics of Natural Selection
  - Based on distinction between a machine and a description of a machine
  - Solution alternatives for optimization problems



Traditional Genetic Algorithm



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Search algorithms based on the mechanics of Natural Selection
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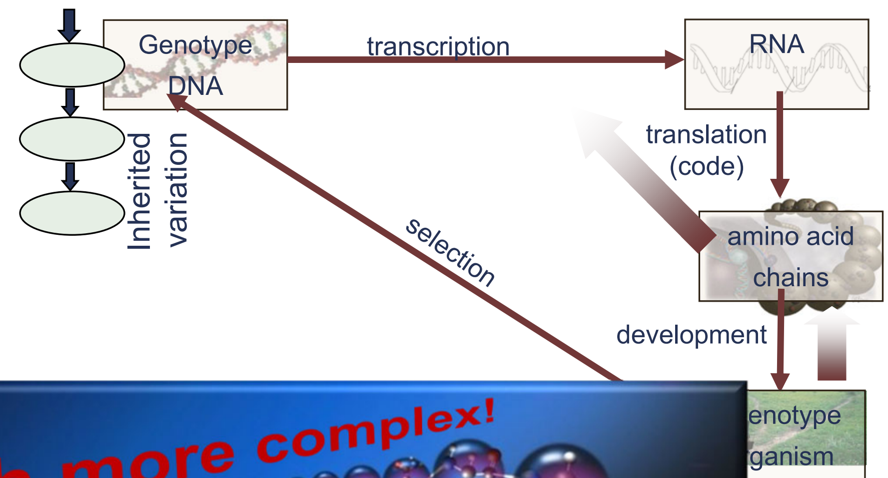
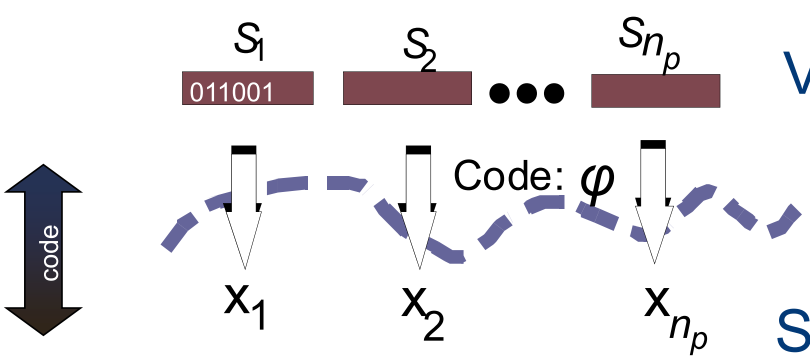


Traditional Genetic Algorithm

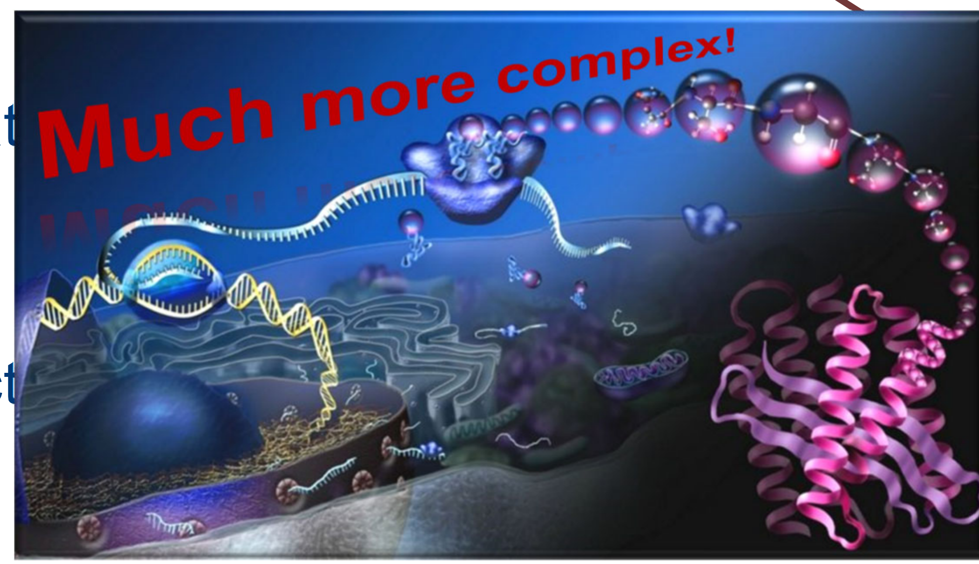
Genotype



Phenotype

Variat

Select



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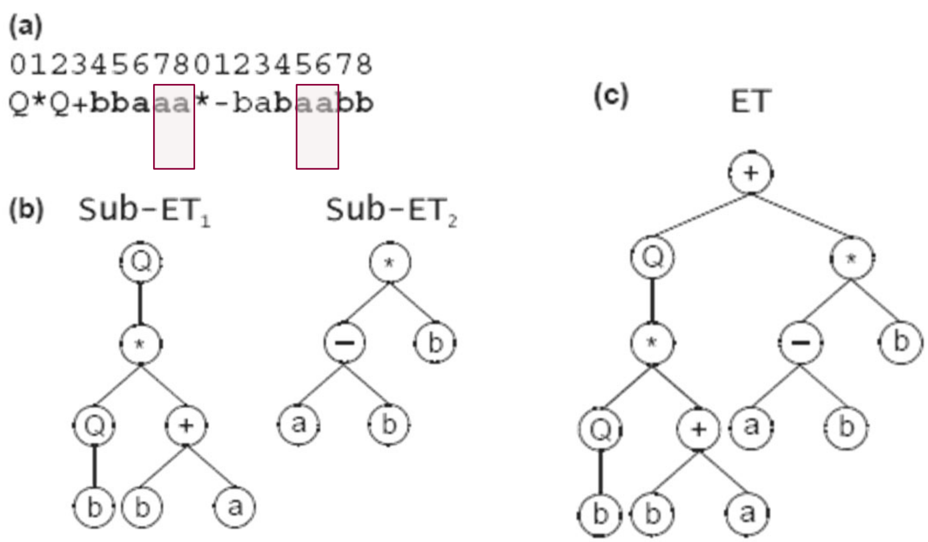
Including a genotype/phenotype map in GP

- Proposed by Candida Ferreira
- Program trees are encoded in fixed-length linear genotypes
- Genotypes
  - Open-reading frame architecture
    - Stop signal not necessarily at end of genotype
  - Non-coding genes are possible
    - Can include genetic operators
  - Genes contain two types of symbols
    - Functions (only at the head) and terminals
  - Multigenic solutions
    - Assembled from non-coding operations between various open-reading frames

012345678012345678012345678
-b*b**abbab***Qb+**abbba**-*Qa**bbaba**

C. FERREIRA [2001]. Gene Expression Programming: A New Adaptive Algorithm for Solving Problems. *Complex Systems*, **13** (2): 87-129.



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Including transcription regulation and translation

Ser Gly Glu Lys

AuGuuuCGuuGuAGAuuuuuAuuAuuuuuuuuAuuA

Mer Phe Arg Cys Arg Phe Leu Leu Phe Phe Leu Leu

Gln Glu Gly Arg Gly Lys •••

CAGGAGGGCCGUGGAuAAG

Gln Glu Gly Arg Gly STOP

Bass, B.L. (Ed.) (2001). *RNA Editing*.
Benne, R. (Ed.) (1993). *RNA Editing*

- RNA Editing: post-transcriptional alteration of genetic information
  - can be performed by ncRNA structures and proteins (i.e enzyme cascades).
- U-Insertion/deletion RNA Editing (mitochondria of kinetoplastid protozoa)
  - Involve small guide RNAs (gRNA) complementary to the target mRNA, and editosome (multi-protein complex)
    - gRNA is a template for editing
  - insertion/deletion of Uracil (U) residues, usually in coding regions of mRNA transcripts
    - e.g. creation of open reading frames

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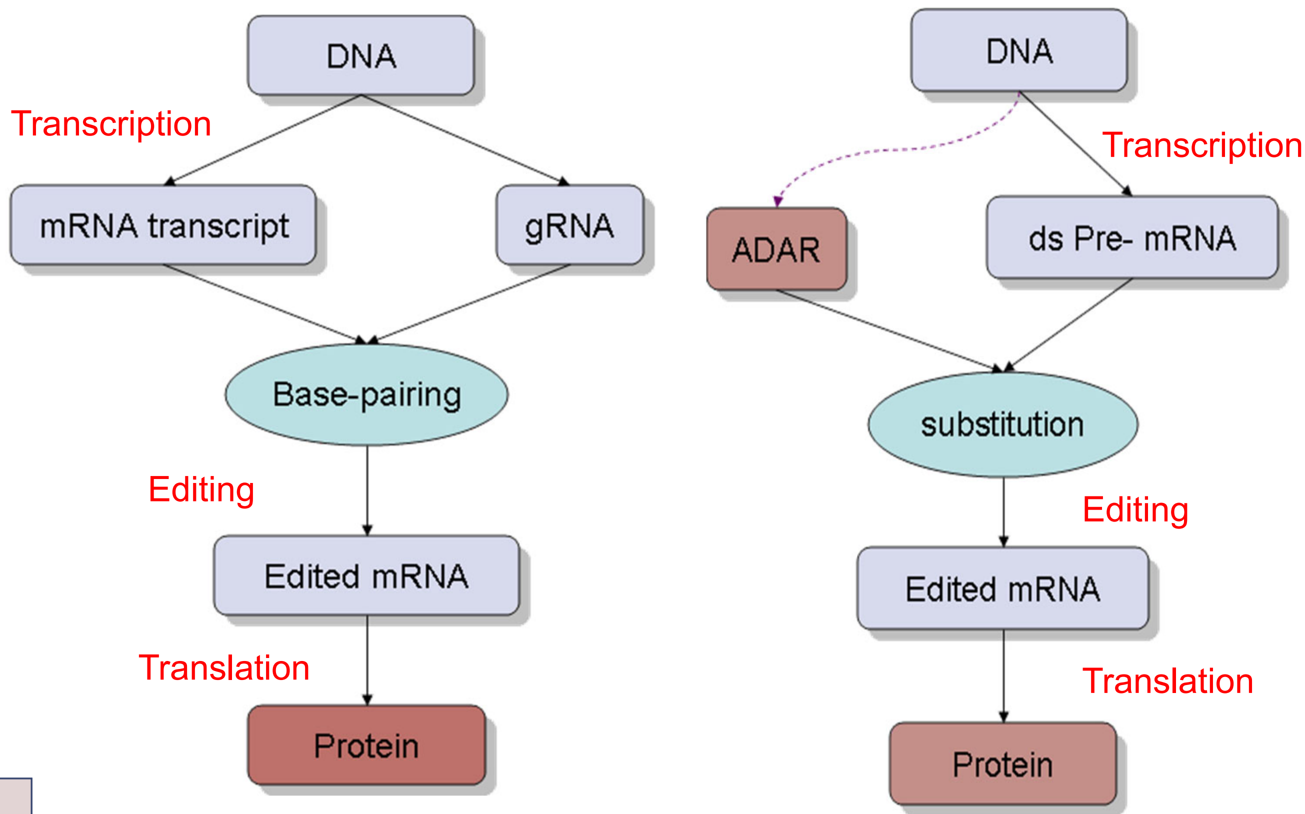
U-insertion and A-to-I subtitution



is there a **general principle** at play?

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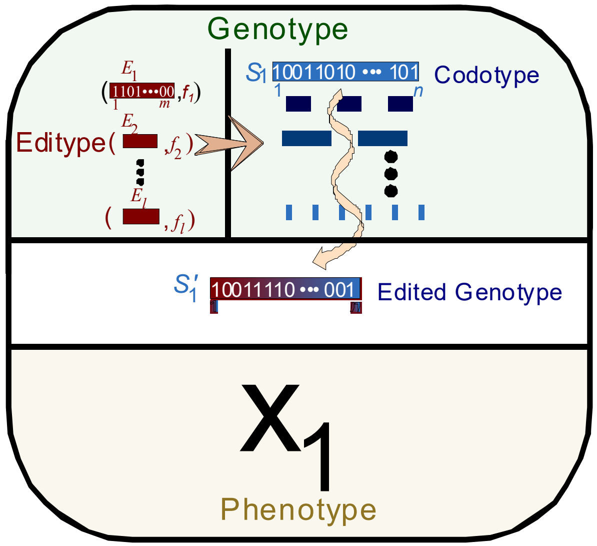
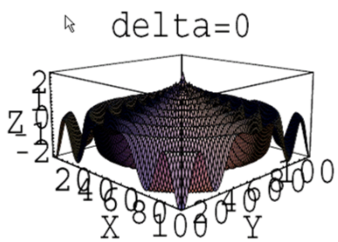
RNA Editing





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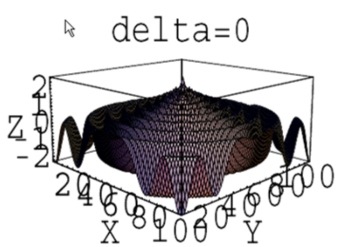
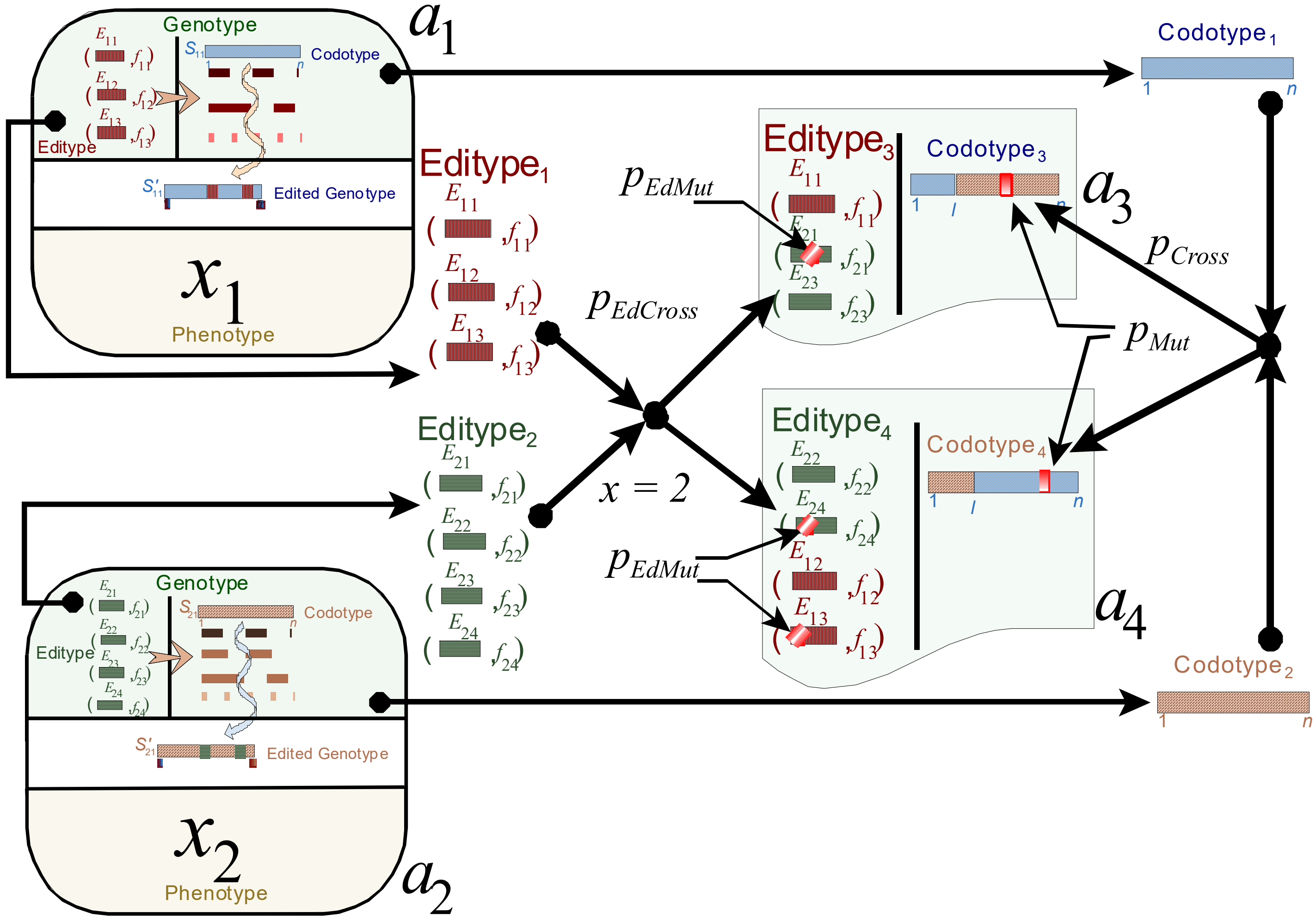
RNA Editing





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Simple fitness function

$$
\begin{aligned}
s_1 &= 11111{*};\ c_1 = 10\\
s_2 &= {*}{*}{*}{*}{*}11111{*};\ c_2 = 10\\
s_3 &= {*}{*}{*}{*}{*}{*}{*}{*}{*}{*}11111{*};\ c_3 = 10\\
s_4 &= {*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}11111{*};\ c_4 = 10\\
s_5 &= {*}11111{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*};\ c_5 = 10\\
s_6 &= {*}11111{*}{*}{*}{*}{*}{*}{*}{*}{*}{*};\ c_6 = 10\\
s_7 &= {*}11111{*}{*}{*}{*}{*};\ c_7 = 10\\
s_8 &= {*}11111;\ c_8 = 10
\end{aligned}
$$

Royal road

$$F(x) = \sum_{s_i \in S} c_i \sigma_{s_i}(x)$$

- Miniature of "Royal Road" function (Forrest and Mitchell, 1993)
  - Schemata $S = (s_1, \ldots, s_8)$
  - c_i is a value assigned to each schema s_i
  - $\sigma_{si}(x)$ = 1 if x is an instance of s_i and 0 otherwise
  - Fitness of the global optimum string (40 1's) is 10*8 = 80

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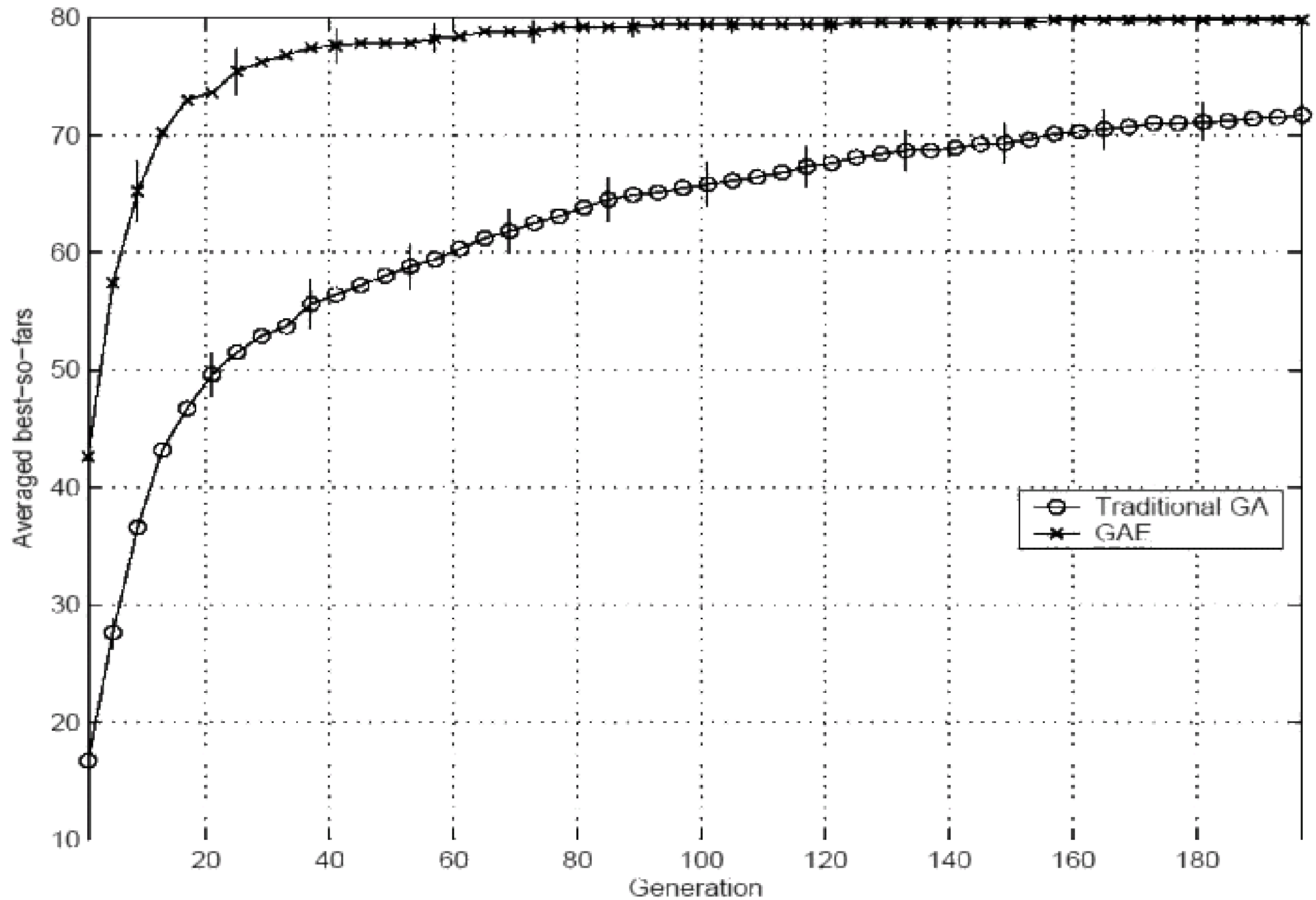
Simple example

50 runs for small royal road testbed



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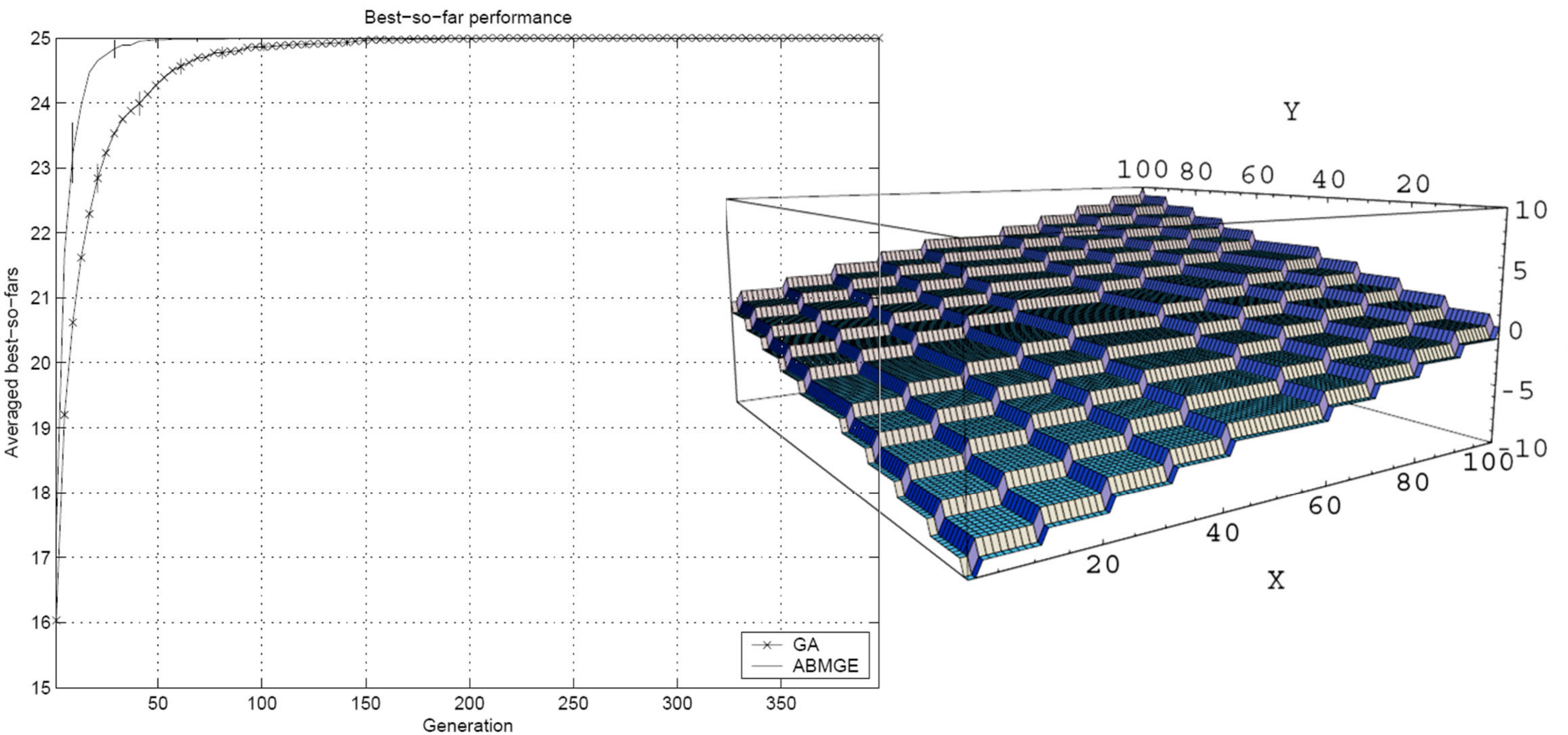
De Jong F3 function



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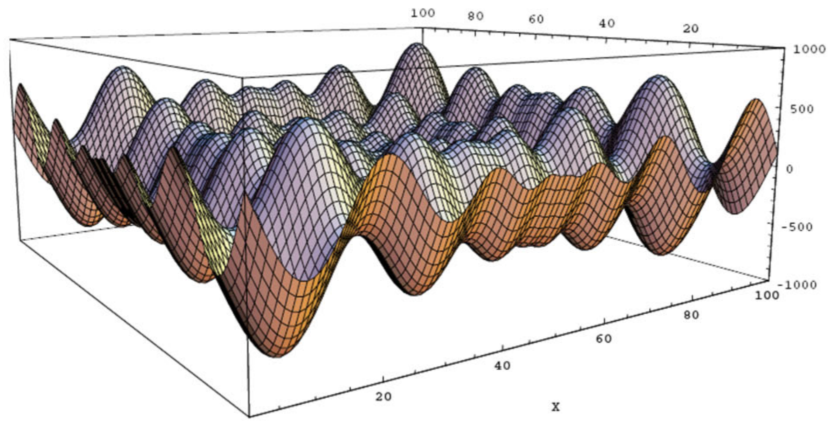
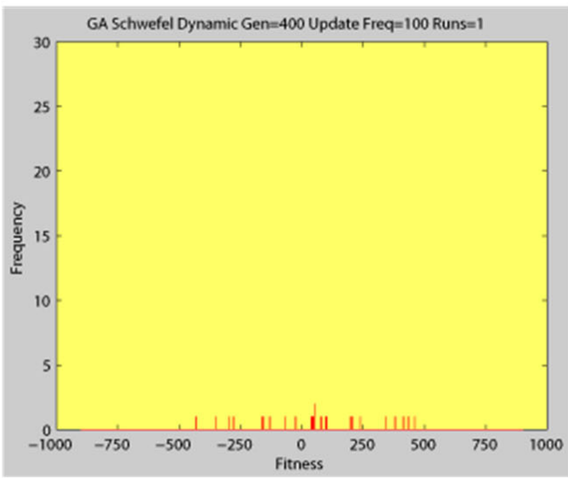
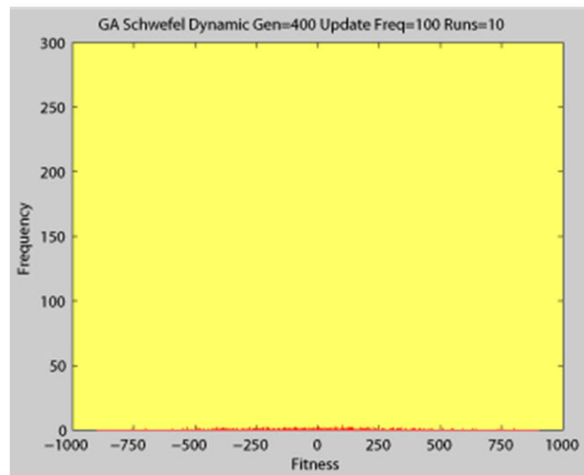
example run: Schwefel function







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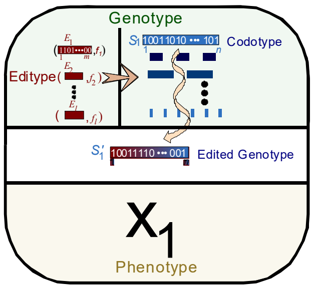
ABMGE on oscillatory fitness landscapes (Royal Road)



$$s_1 = 11111{*};\ c_1 = 10$$
$$s_2 = {*}{*}{*}{*}{*}11111{*};\ c_2 = 10$$
$$s_3 = {*}{*}{*}{*}{*}{*}{*}{*}{*}{*}11111{*};\ c_3 = 10$$
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$$s_5 = {*}11111{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*}{*};\ c_5 = 10$$
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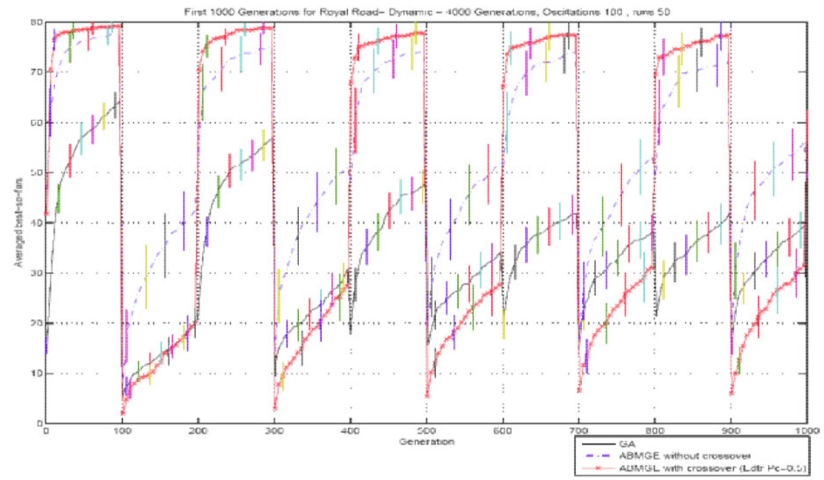
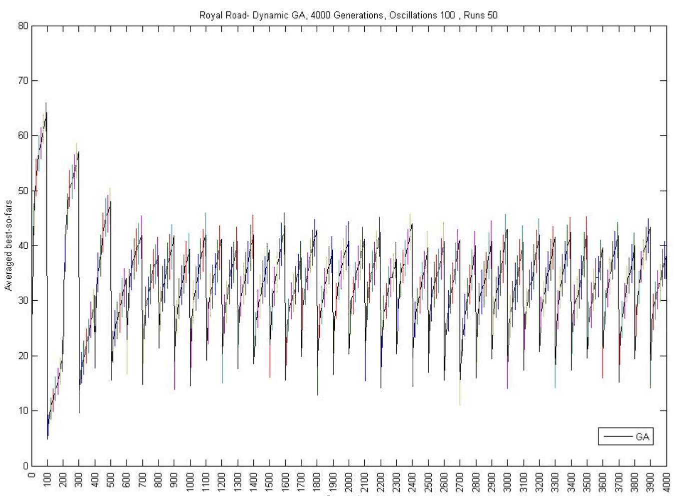
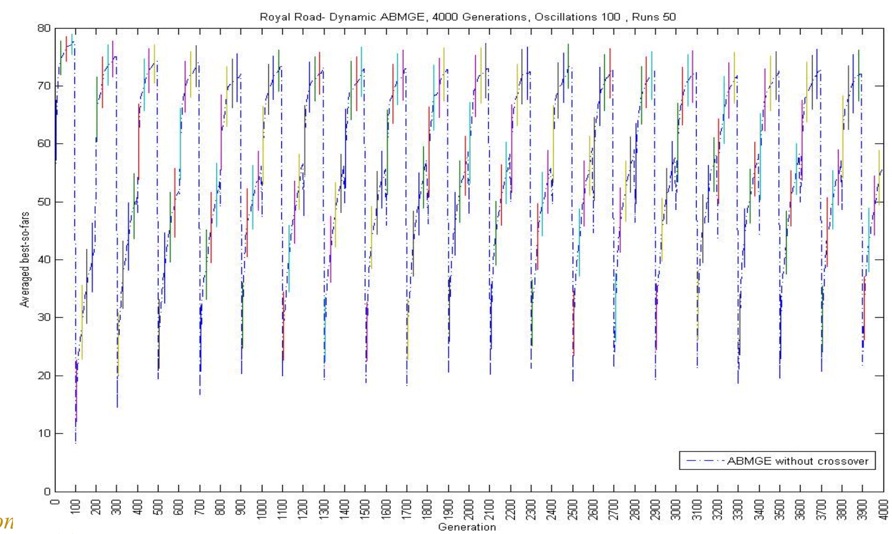
$$s_8 = {*}11111;\ c_8 = 10$$



GA



ABMGE



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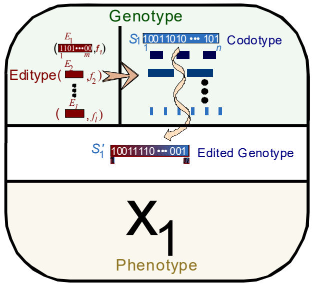
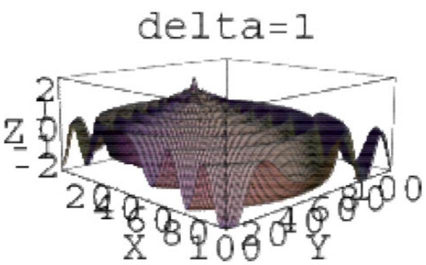
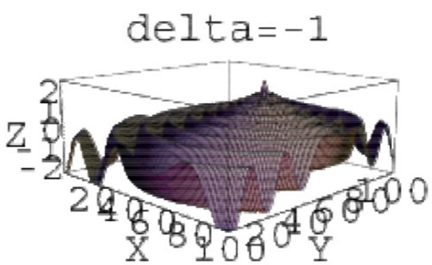
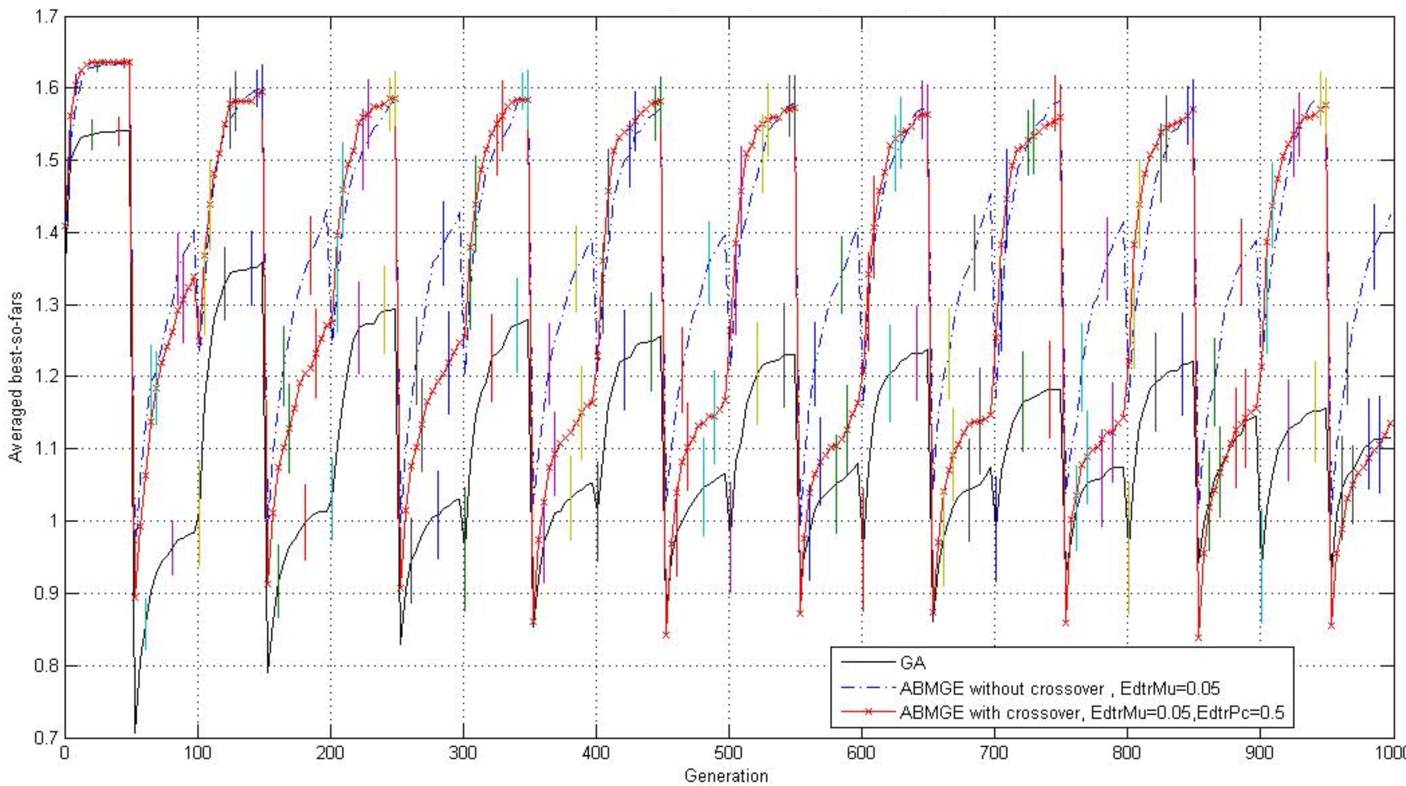
ABMGE on dynamical environments









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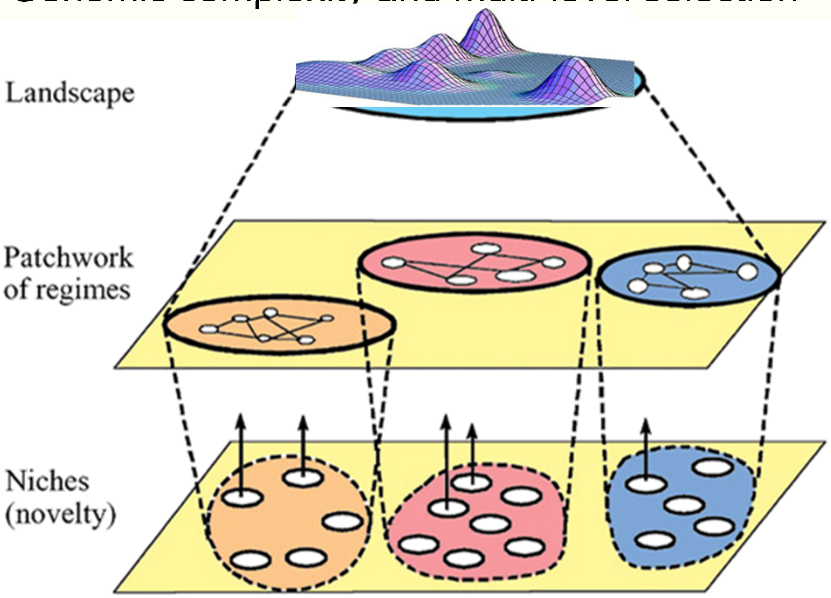
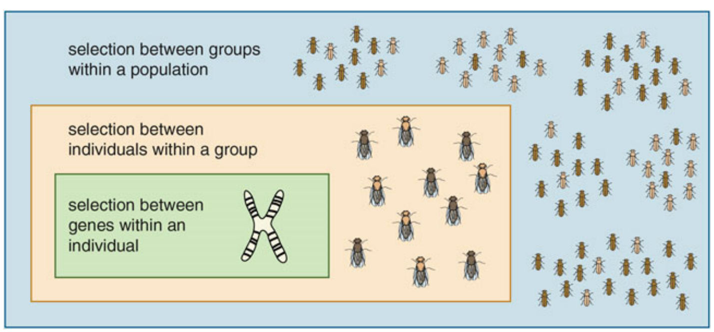
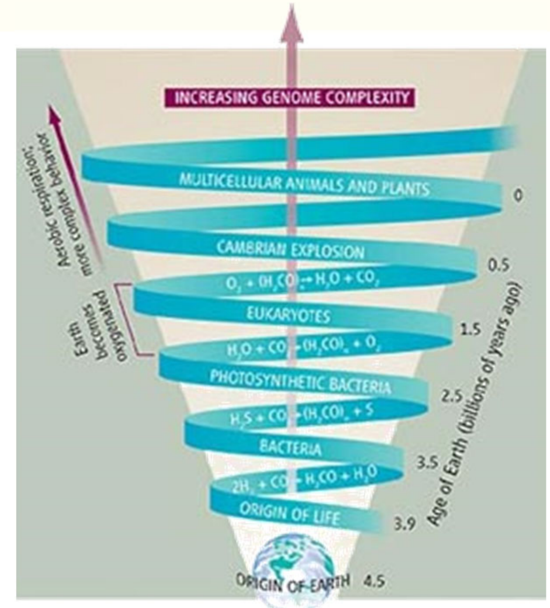
Genomic complexity and multi-level selection







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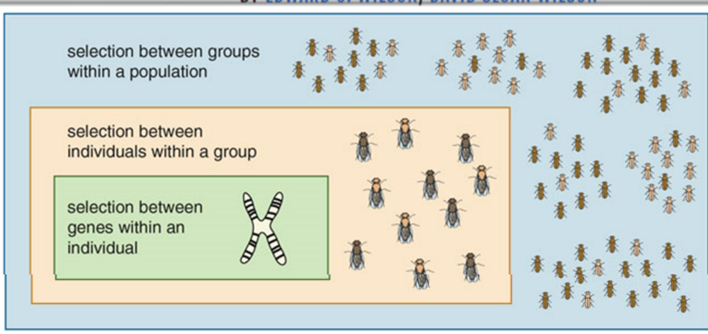
Wilson, David Sloan, and Edward O. Wilson. "Evolution 'for the Good of the Group' "
American Scientist **96**.5 (2008): 380-389.

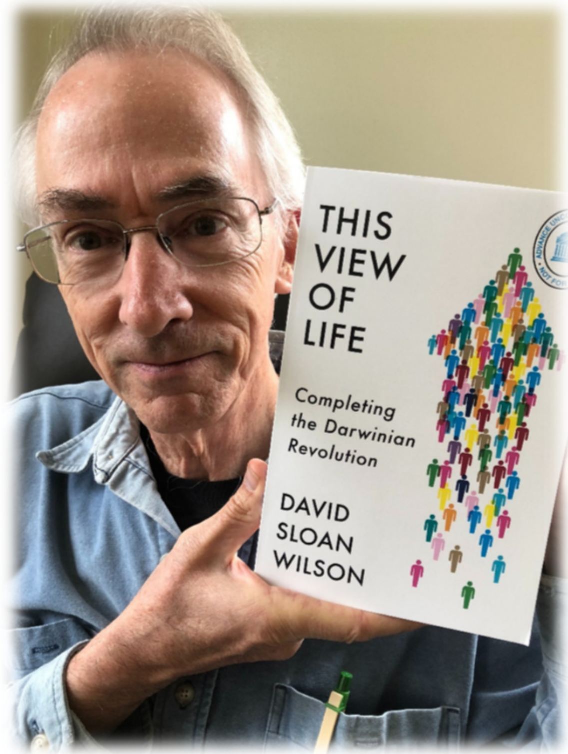
Genomic complexity and multi-level selection

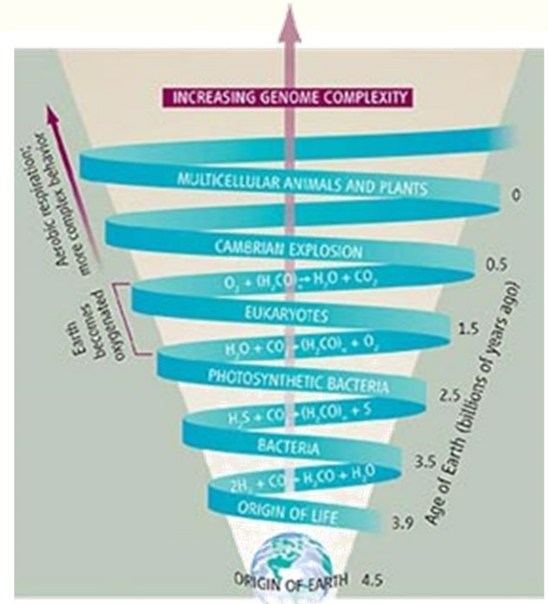

AMERICAN Scientist

Evolution "for the Good of the Group"

BY EDWARD O. WILSON, DAVID SLOAN WILSON







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units of selection

moral men might not do any better than immoral men but tribes of moral men would certainly "have an immense advantage" over fractious bands of pirates. (Charles Darwin)

- Multilevel selection theory
  - Selection occurs in multiple levels simultaneously
  - No general-case scenario, each organism on a case-by-case basis
    - David Wilson and E.O. Wilson
- Experiments with *Pseudonas fluorescens*
  - Oxygen-exhausting bacteria in liquid
  - Groups with enough altruists survive
- Kin-selection as special case of group selection
  - Leading to various, diverse (selectable) groups with high genetic similarity
- Sociobiology
  - Selfishness beats altruism within groups. Altruistic groups beat selfish groups.

"Morality is herd instinct in the individual".
(Friedrich Nietzsche)

Sci. American, Jan 2009 (Steve Mirsky)

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altruism and selection

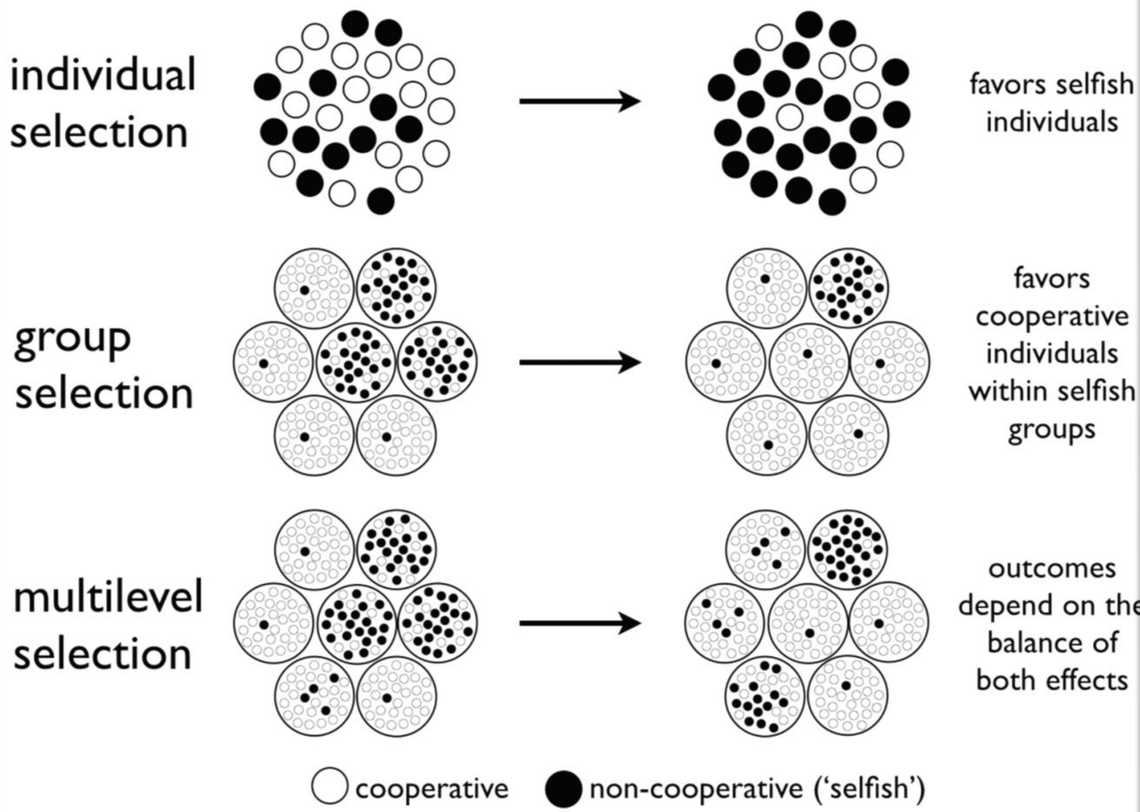
units of select

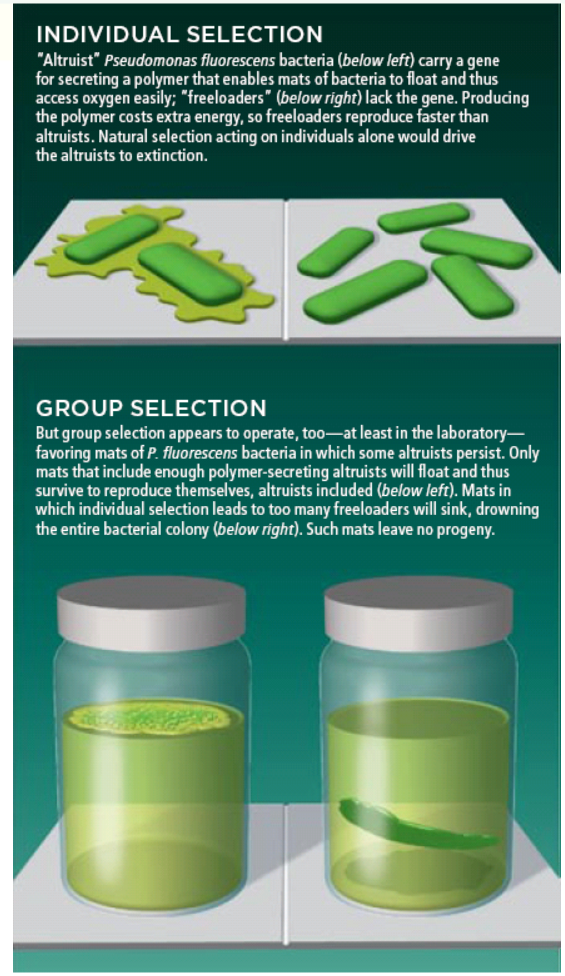
moral men might
certainly "have a

- Multile
  - Sele
  - No g
    case
    - [
- Experi
  - Oxy
  - Gro
- Kin-sel
  - Lea
    gen
- Sociob
  - Self
    bea

"Morality
(Friedrich Nietzsche)

Waring, Timothy M., Michelle Kline Ann, Jeremy S. Brooks, Sandra H. Goff, John Gowdy, Marco A. Janssen, Paul E. Smaldino, and Jennifer Jacquet. "A multilevel evolutionary framework for sustainability analysis." *Ecology and Society* 20, no. 2 (2015).





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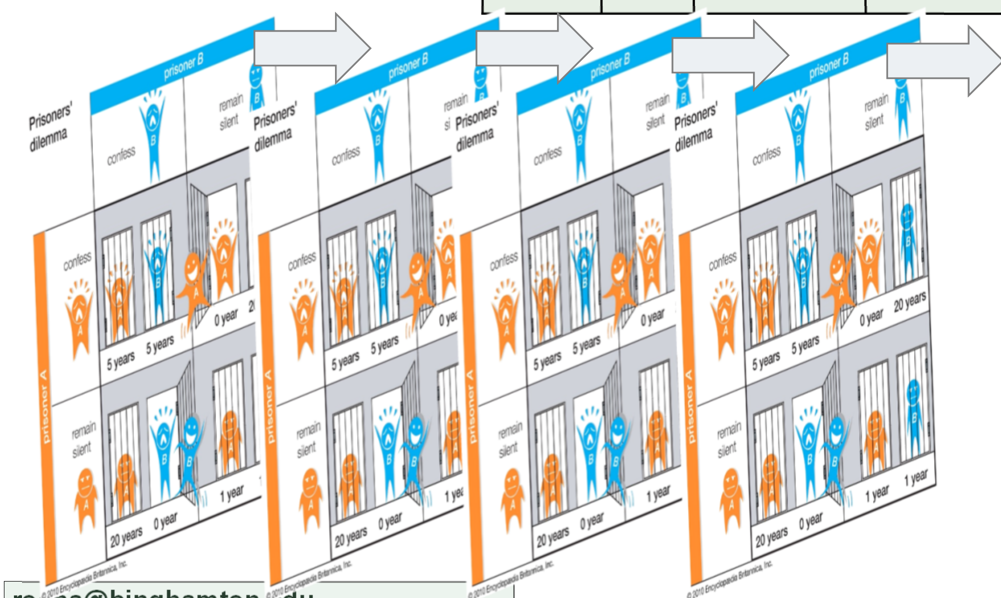
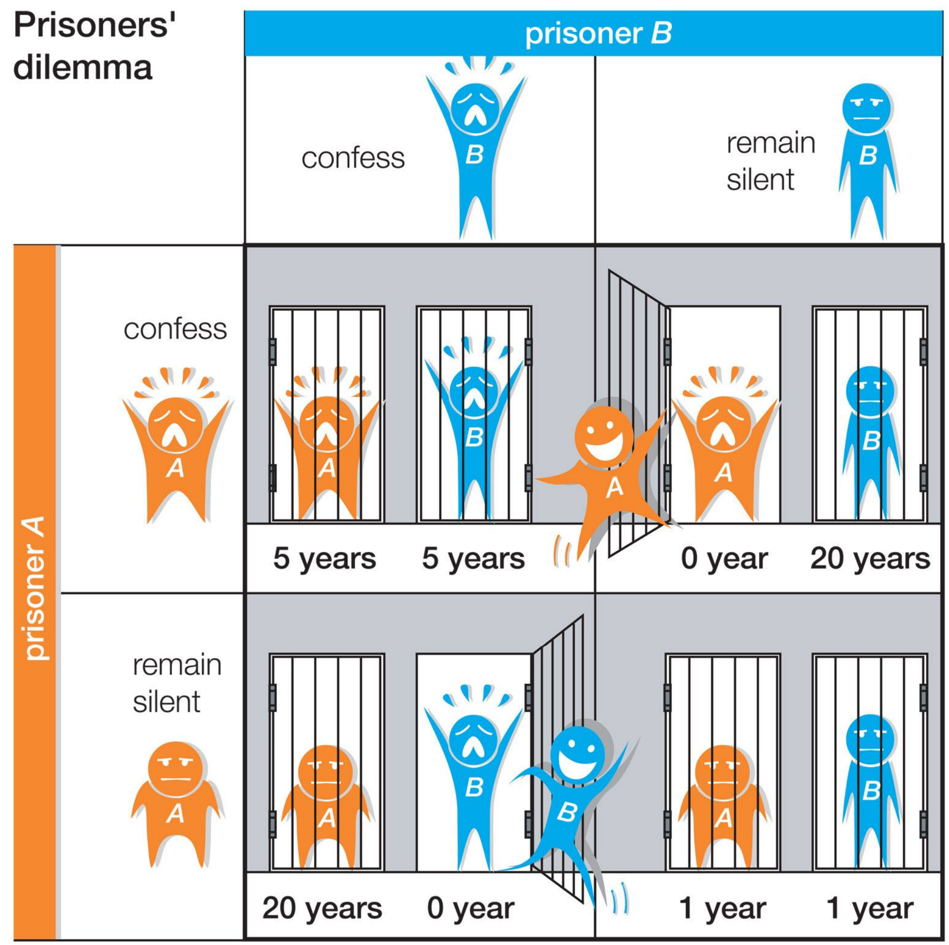
encoding

		P2	
		C	D
P1	C	(3,3)	(0,5)
	D	(5,0)	(1,1)





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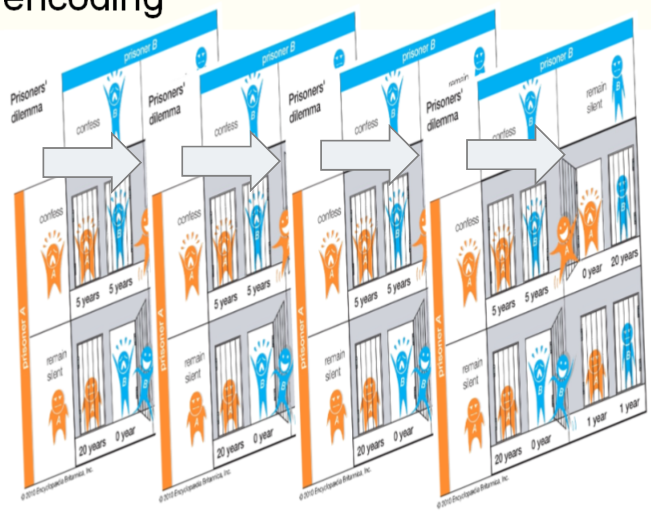
iterated prisoner's dilemma

encoding



		P2	
		C	D
P1	C	(3,3)	(0,5)
	D	(5,0)	(1,1)

$$h_m = (a_{m-1}, \ldots, a_1, a_0)$$

agent (a_1), opponent (a_0)

Lindgren's iterated game for agents with memory

$$h_0 = (a_0)$$

D	0
C	1

→

	TFT		
0	0	1	1
0	1	0	1

4 possible strategies (genotype=2 bits)

$$h_1 = (a_1, a_0)$$

			TFT	
0	0	→ …	0	1 …
0	1		1	1
1	0		0	0
1	1		1	1

Used in the evolutionary search by GA (tournament selection)

16 possible strategies (genotype=4 bits)

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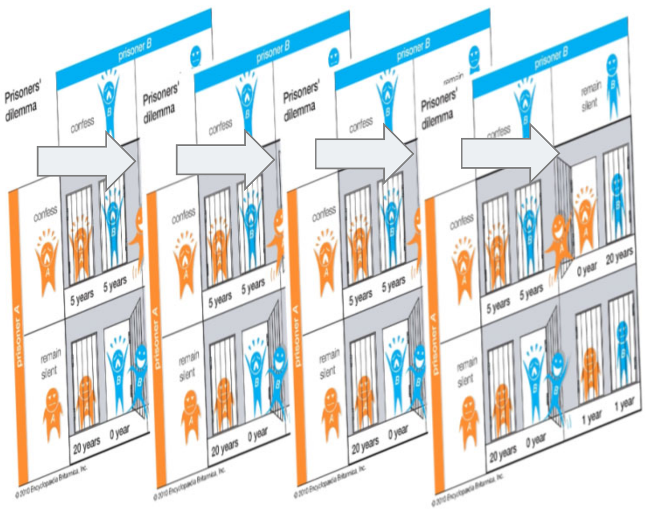
Lindgren, Kristian. "Evolutionary phenomena in simple dynamics." *Artificial life II* (1991): 295-312.

memory 0 strategies



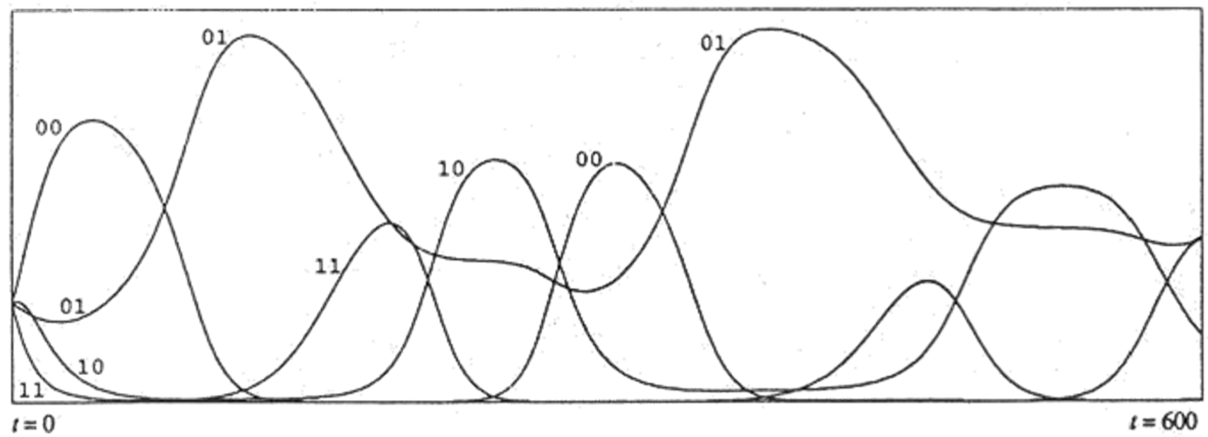


FIGURE 1 The evolution of a population of strategies starting with equal fractions of the memory one strategies [00], [01], [10], and [11] is shown for the first 600 generations. The fractions of different strategies are shown as functions of time (generation).

$$h_0 = (a_0)$$

D	0
C	1

→

TFT

0	0	1	1
0	1	0	1

4 possible strategies

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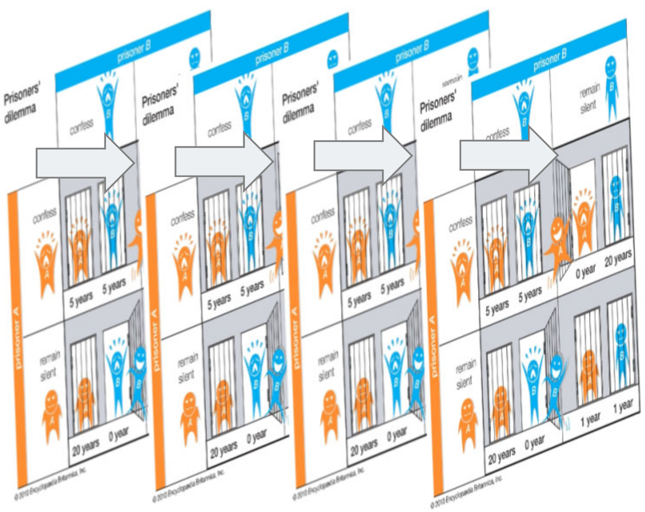
higher memory rules

16 possible strategies (genotype=4 bits)

$$h_1 = (a_1, a_0)$$

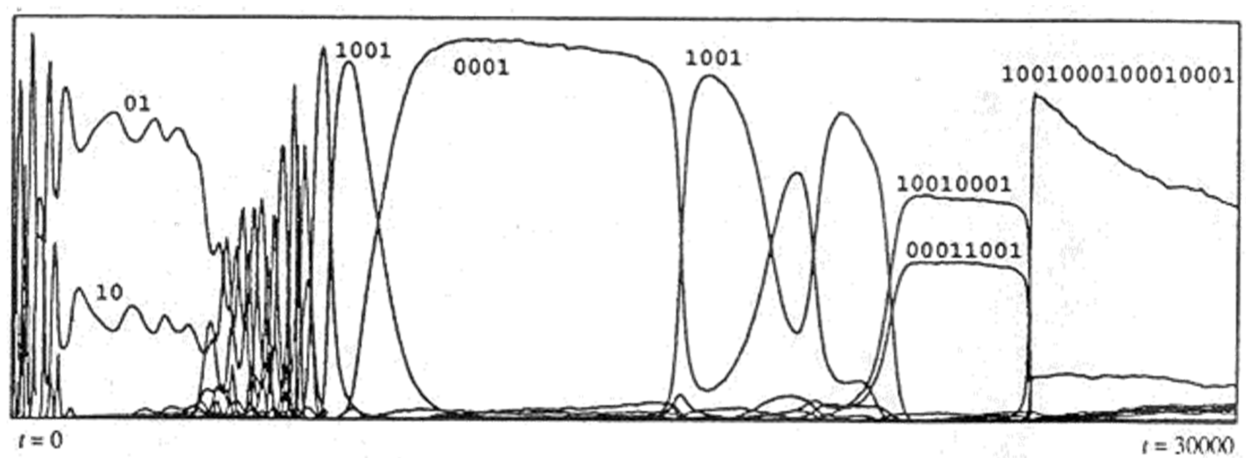
0	0
0	1
1	0
1	1

→ … TFT: 0 1 0 1 | 1 1 0 1 …



Used in the evolutionary search by GA (tournament selection)

GA uses variable length genotype



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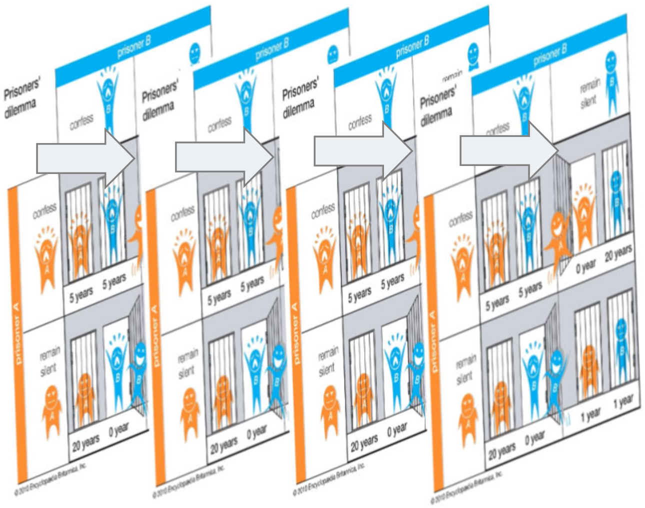
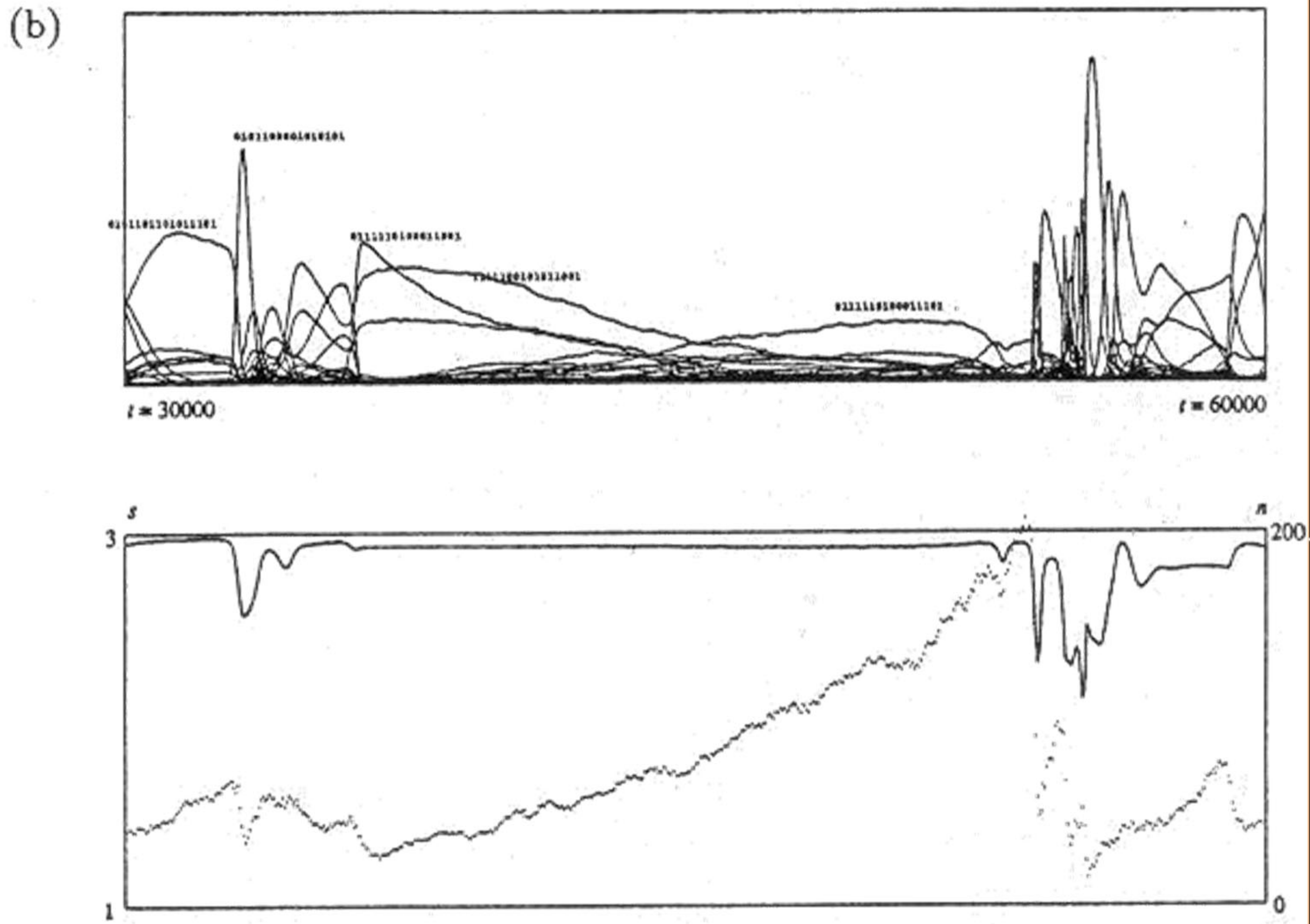
Lindgren, Kristian. "Evolutionary phenomena in simple dynamics." *Artificial life II* (1991): 295-312.





Punctuated equilibria and complex evolutionary dynamics

Lindgren, Kristian. "Evolutionary phenomena in simple dynamics." *Artificial life II* (1991): 295-312.

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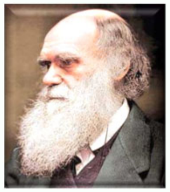
readings

- 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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