A new Programming Paradigm inspired by Algorithmic Chemistries

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Overview

- Conventional Computers
- The organic realm
- Artificial Chemistries
- Genetic Programming
- GP of an AC

Conventional Computers

- Information stored in bit sequences at memory locations
- Execution of program through instruction flow in specific sequence (translated into locations via the program counter)
- Paradigm follows the metaphor of a macroscopic machine: Parts are put together at specific locations in order to work properly
- Order of construction and locations essential to produce a working machine

Space and time are determined rigidly

The Organic Realm

- Molecules interact via reactions of different strength
- Single reactions are brought about by collisions of molecules, which in turn are generated by Brownian motion
- Both time and space of events are difficult to predict
- Sequences and locations of reactions cannot be easily specified
- Specificity is generated through patterns. 3D key-lock recognition is widely used as means of coordination

Space and time cannot be determined rigidly

The Organic Realm II

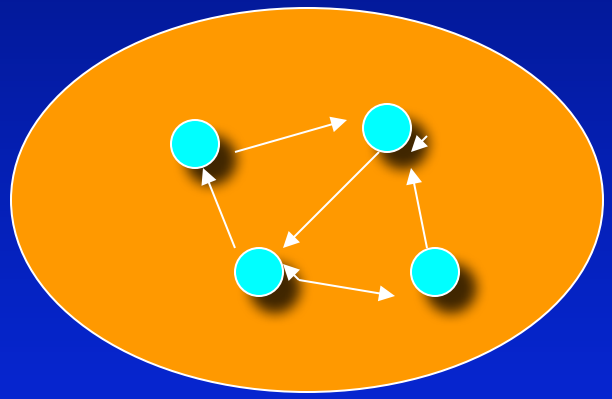
- Brownian motion as a source of energy and randomness
- Indeterminism in space and time
- Natural forces generate key-lock patterns and mechanisms
- Adaptivity is built-in at lowest level

How to achieve function?

- Quality measure for function: Fitness
- Artificial Evolution (breeding): Variation and selection

Artificial Chemistries as a Tool for Exploration

Objects and their interaction



- In an AC, an arbitray set of objects can be created to interact on terms the researcher defines.
- The system is then run on a computer and examined in its behavior.
- An Artificial Chemistry consists of
  - A set of objects (called molecules)
  - A set of interaction rules (called reaction or collision rules), and
  - A definition of the population dynamics
- Inspired by work on GAMMA and CHAM

Principles of Artificial Chemistries

- Objects / Molecules

  Characters, numbers, symbol strings, lambda-expressions, binary strings, proof statements, abstract data structures, magnets

- Reactions

  Tables of reactions (explicit), string matching rules, lambda-calculus operations, arithmetic operations, term rewriting rules, state transitions (e.g. finite automata), computations (e.g. Turing machine operations)

- Dynamics

  Differential equations, explicit simulation, „meta-dynamics“, mixed approaches

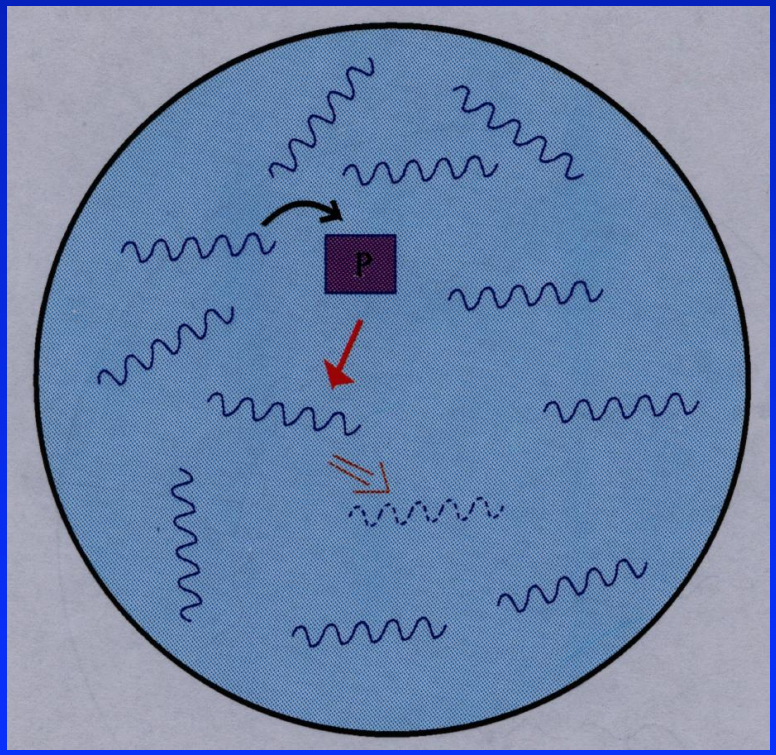
Principles of Artificial Chemistries (II)

An AC is tuple $\{S, R, A\}$ with

- S (multi)set of objects (molecules),
  S = (s1,s2,...sn)
- R set of rules (reactions)
  R = (r1,r2,...rk), each of one of the forms
  r1) $a \rightarrow b$ r2) $a + b \rightarrow b$
  r3) $a \rightarrow b + c$ r4) $a + b \rightarrow c + d$

  where a,b,c,d are from S
- A algorithm driving the system (dynamics)

Example: Matrix chemistry (1993)



Bit strings are interpreted as operators (binary matrices);

Operators generate, in interaction with bit strings new bitstrings (matrix multiplication):

Self replicating bit strings or those which produce other that in turn produce them will be dominant in the longer run.

Stable organizations appear spontaneously

Bit strings

Matrices

What is Genetic Programming?

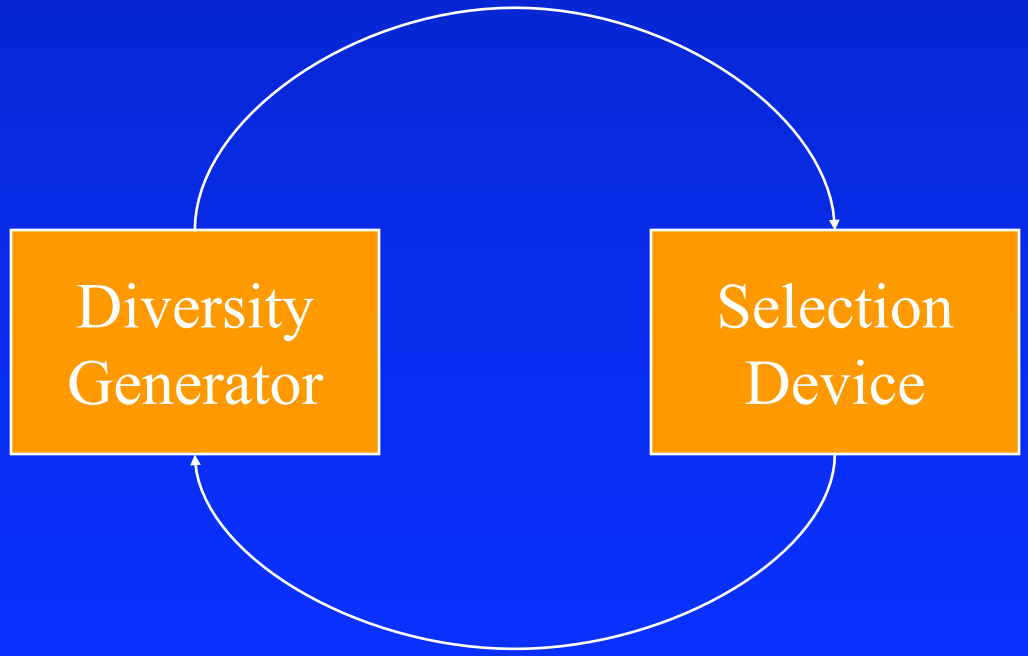
- Induction of computer code by evolutionary means
  - Darwinian approach
  - Application of stochastic operators
  - Population-based
- Low-level and high-level computer code
  - Parse trees (Koza)
  - C-code, JAVA-code
  - Machine code (AIM)
- GP useful for other types of algorithms
  - Neural Networks, circuits
  - Mathematical Formulae

What is Genetic Programming? (II)

A Darwinian approach to prgramming:

The variation – selection loop

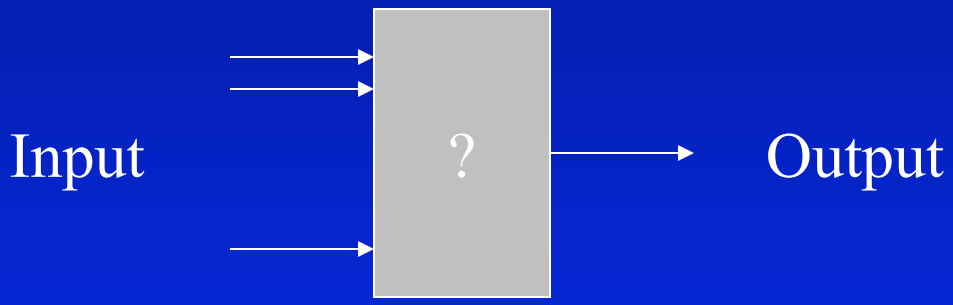
- Invalidates probability argument
- Appreciates relative performance advantages



What is Genetic Programming? (III)

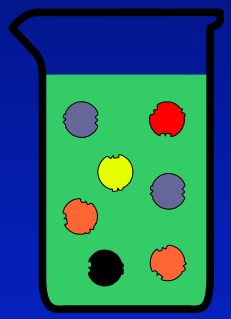
- A population of programs is subjected to the GP algorithm
- Programs consist of elements which can be combined
  - Terminals (variables and constants) and functions
  - Instructions (having operators and operands)
  - Nodes and edges of a graph
- The GP-algorithm uses
  - Operators for reproduction, mutation and recombination (for the production of program variants)
  - An evaluation measure
  - A selection operator

How does it work?



- Generation of different programs that solve the problem more or less accurately
- Test of programs on „fitness cases“
- Improvement of better solutions

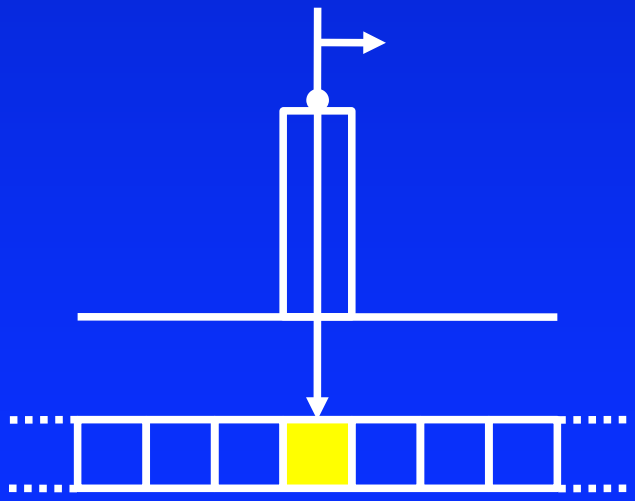
Genetic Programming of an AC

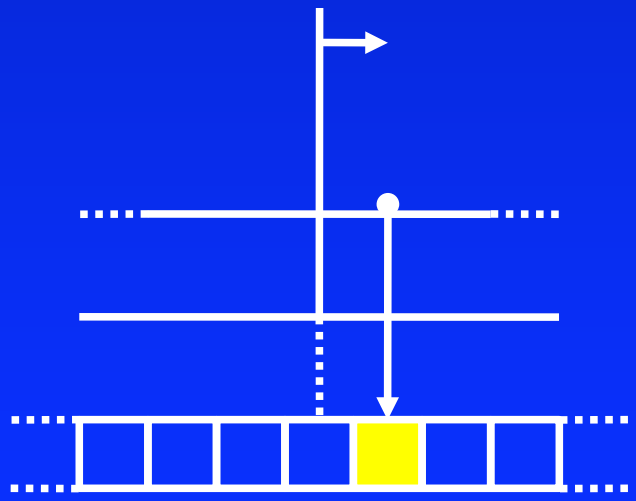


- Choose a particular representation
  - Multiset of instructions
  - Let them “react”: Execute an instruction
  - Data (values in registers) are transformed in multiple ways, depending on which instruction is executed when
  - If output of an instruction is picked up by another instruction, then a more complex computation is realized
  - Lock-Key principle: Output register of Instruction_1 is used as input register of Instruction_2
- Implementation
  - Contiguous block of *random access* memory for technical and practical reasons

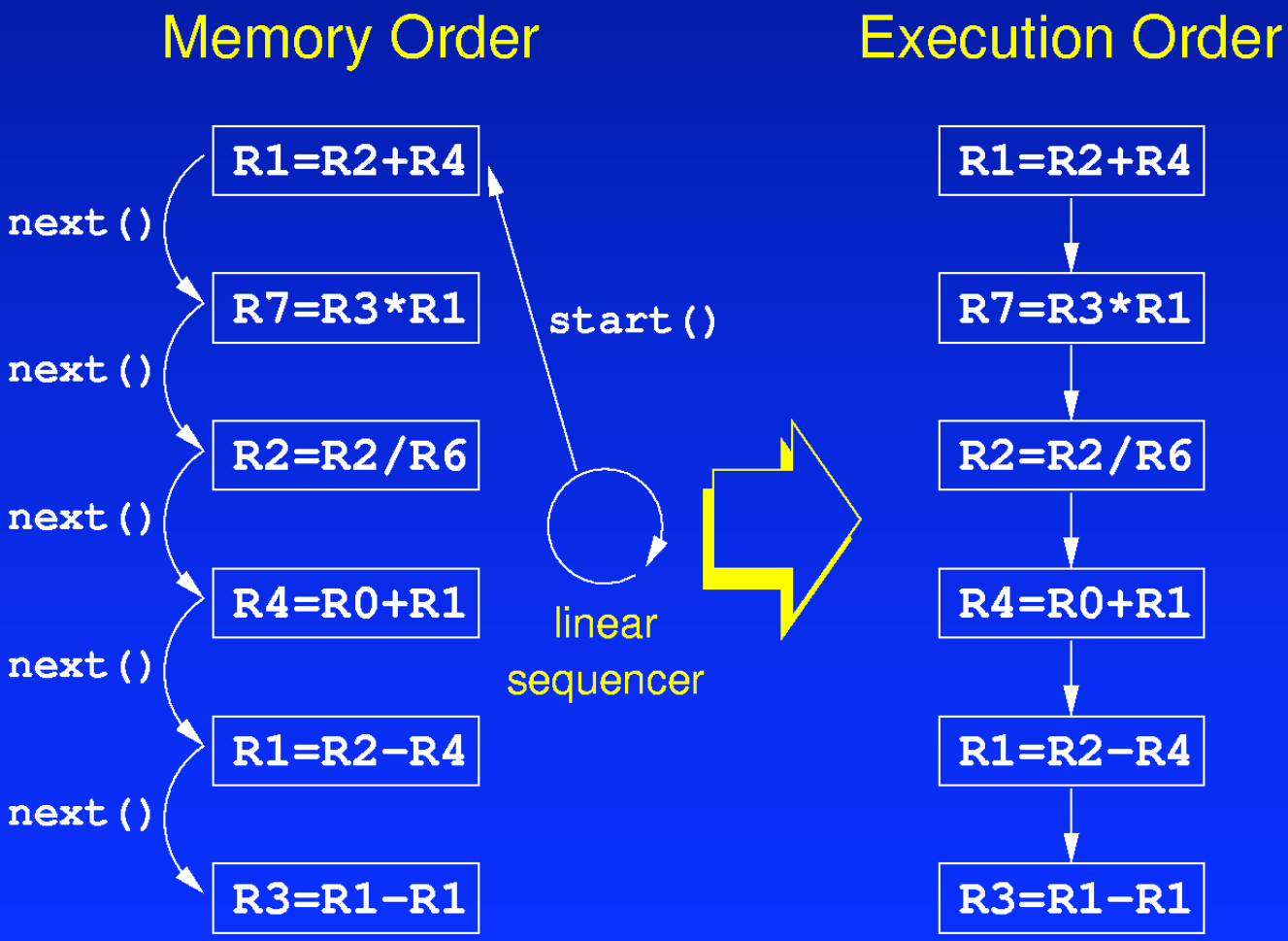
Evaluation

- Linear GP
  - Linear access
- ACs
  - Random access

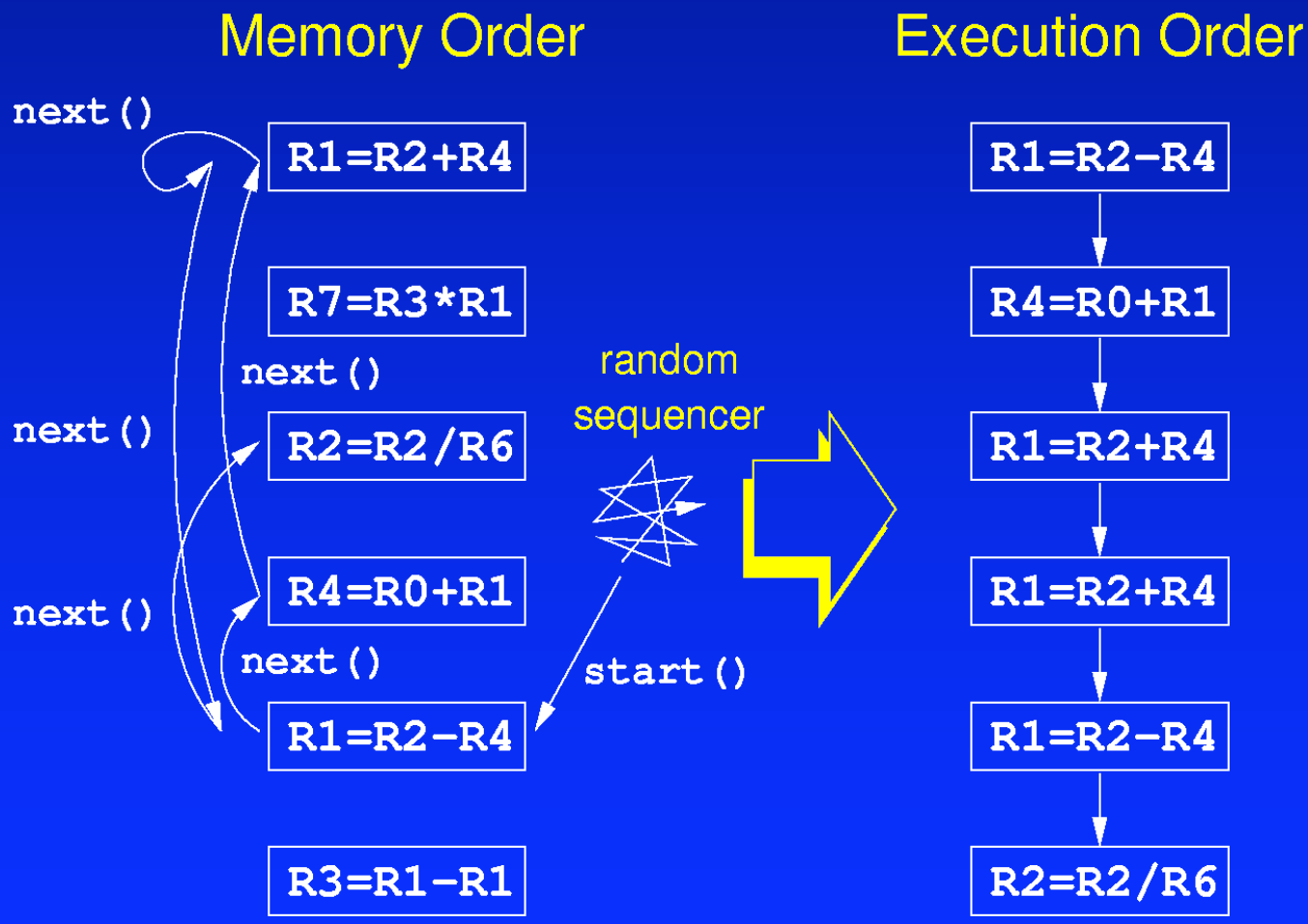




Evaluation – Linear GP

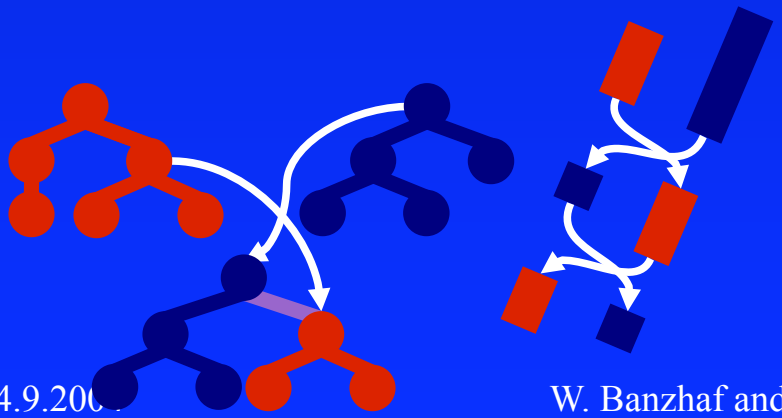


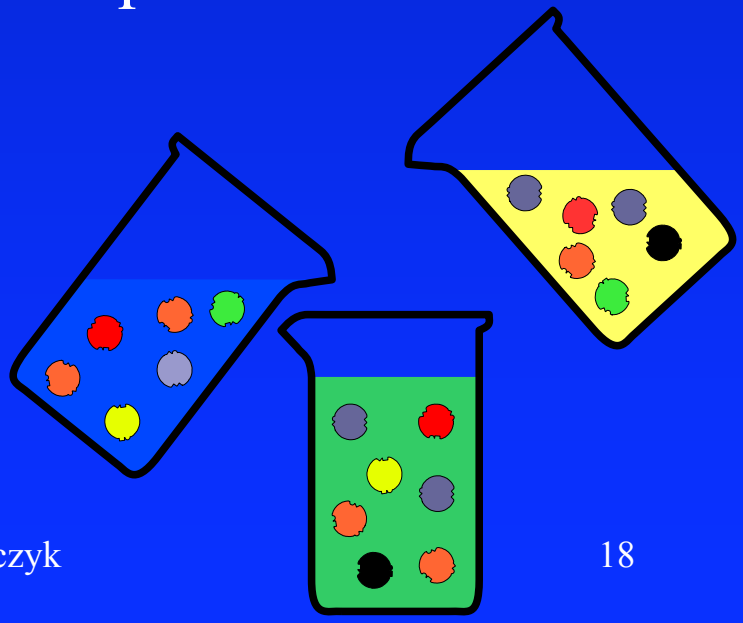
Evaluation – Algorithmic Chemistry



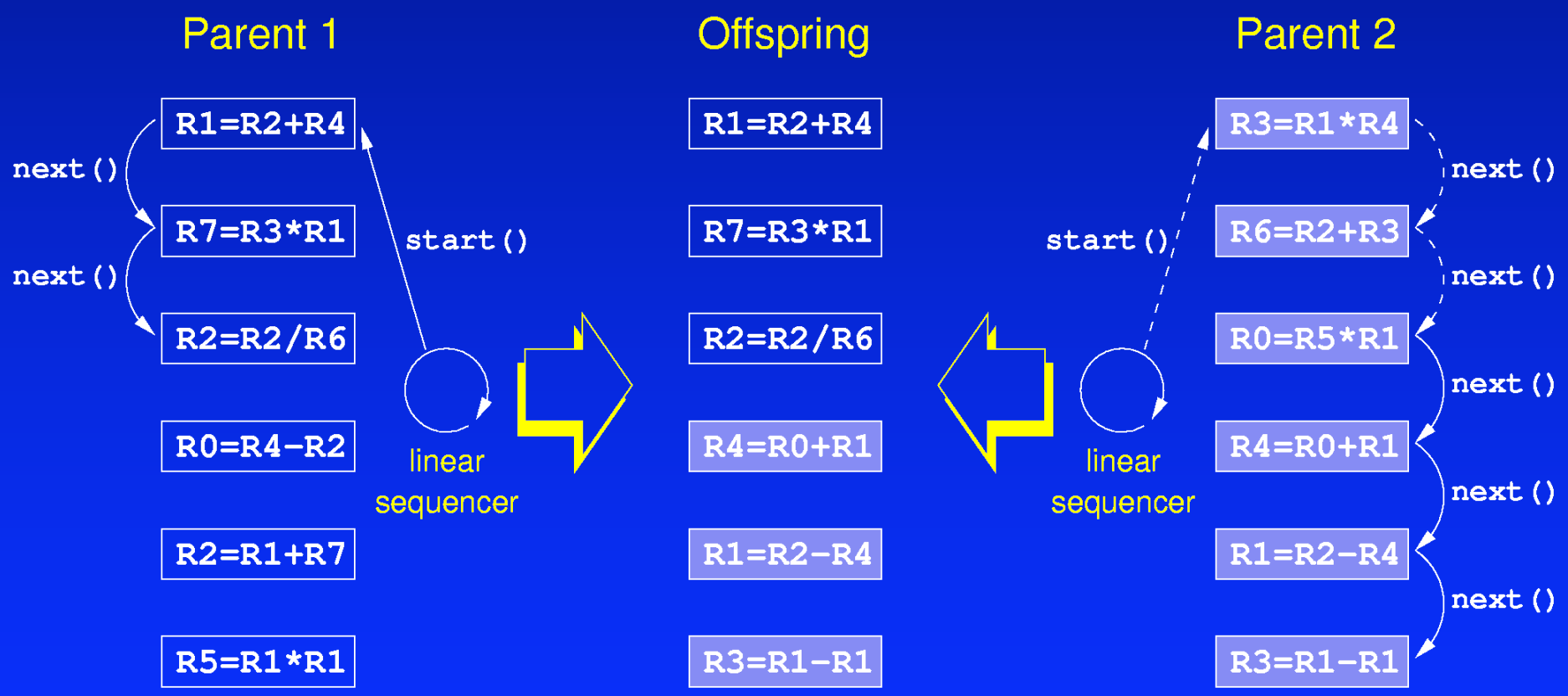
Crossover

- Genetic Programming
  - Sequence manipulated by crossover
  - Bloat
- Algorithmic Chemistries
  - Sequence emerged
  - Inheritance of frequencies

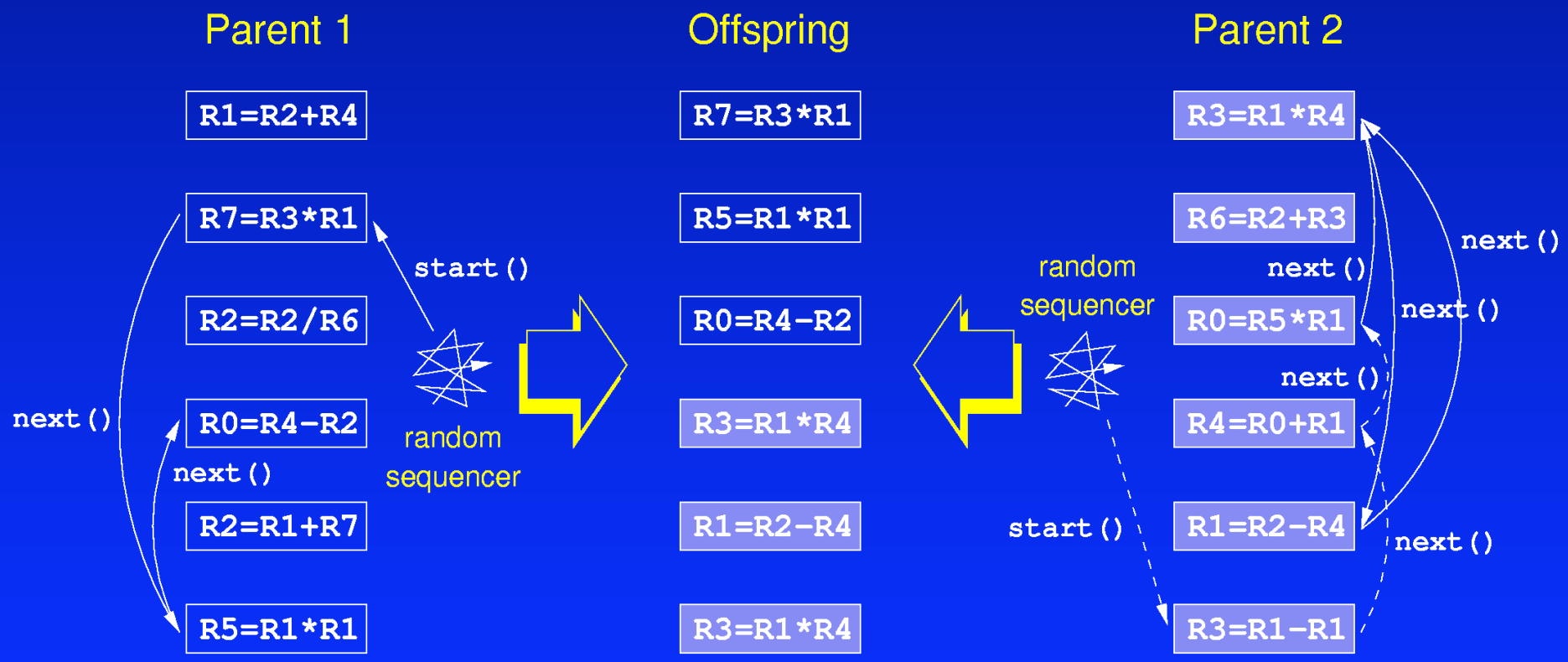




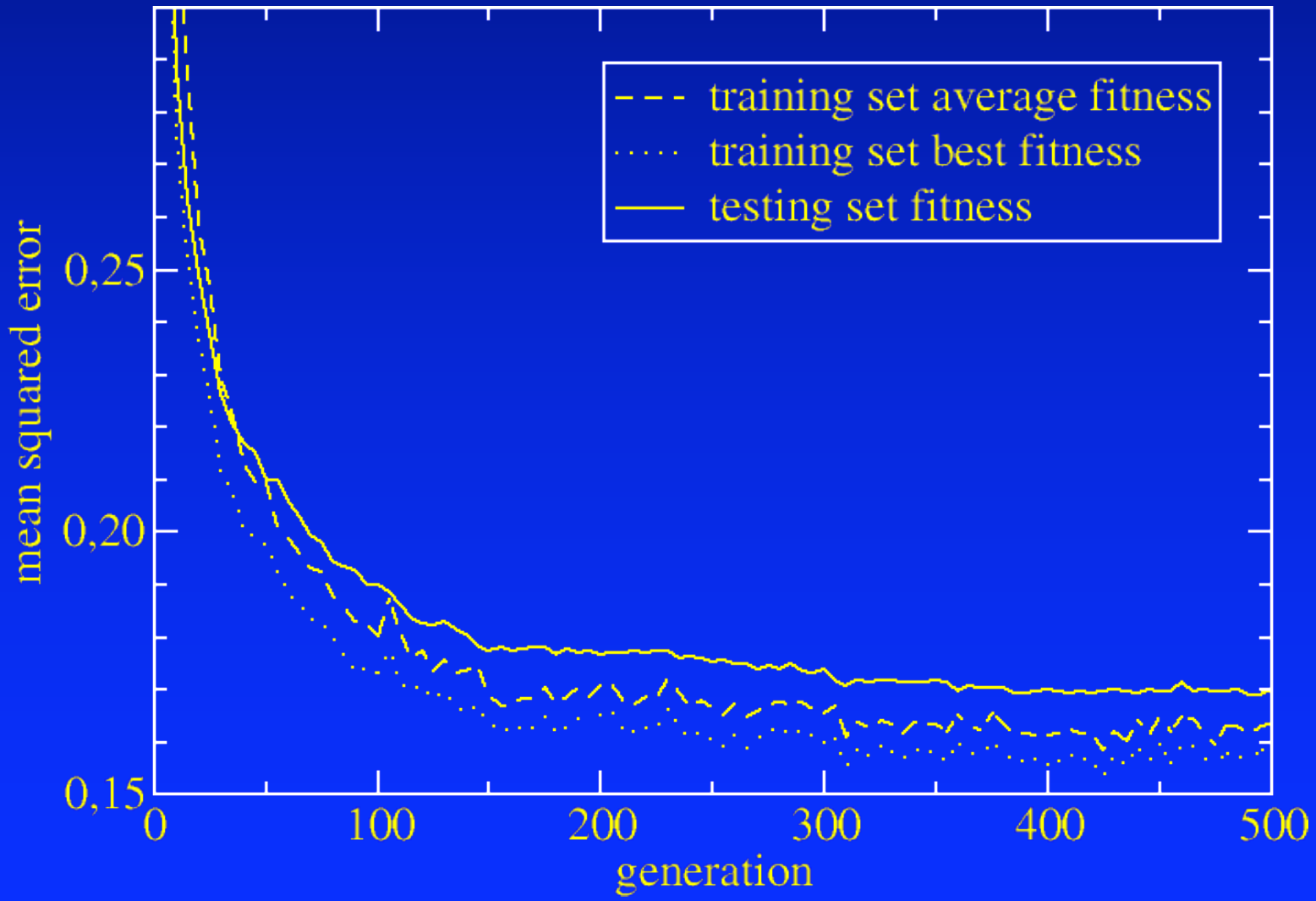
Crossover – Linear GP



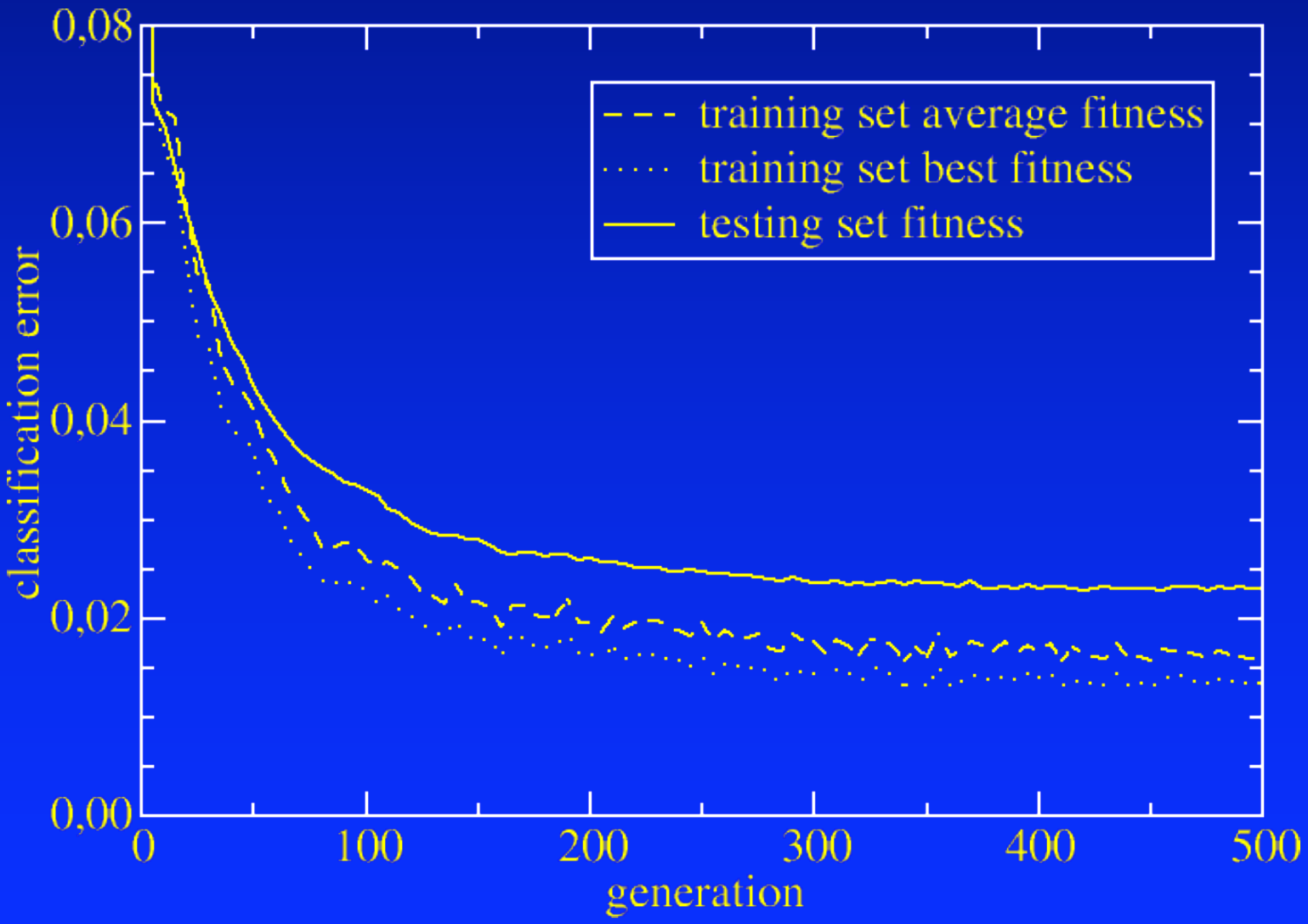
Crossover – Algorithmic Chemistrie



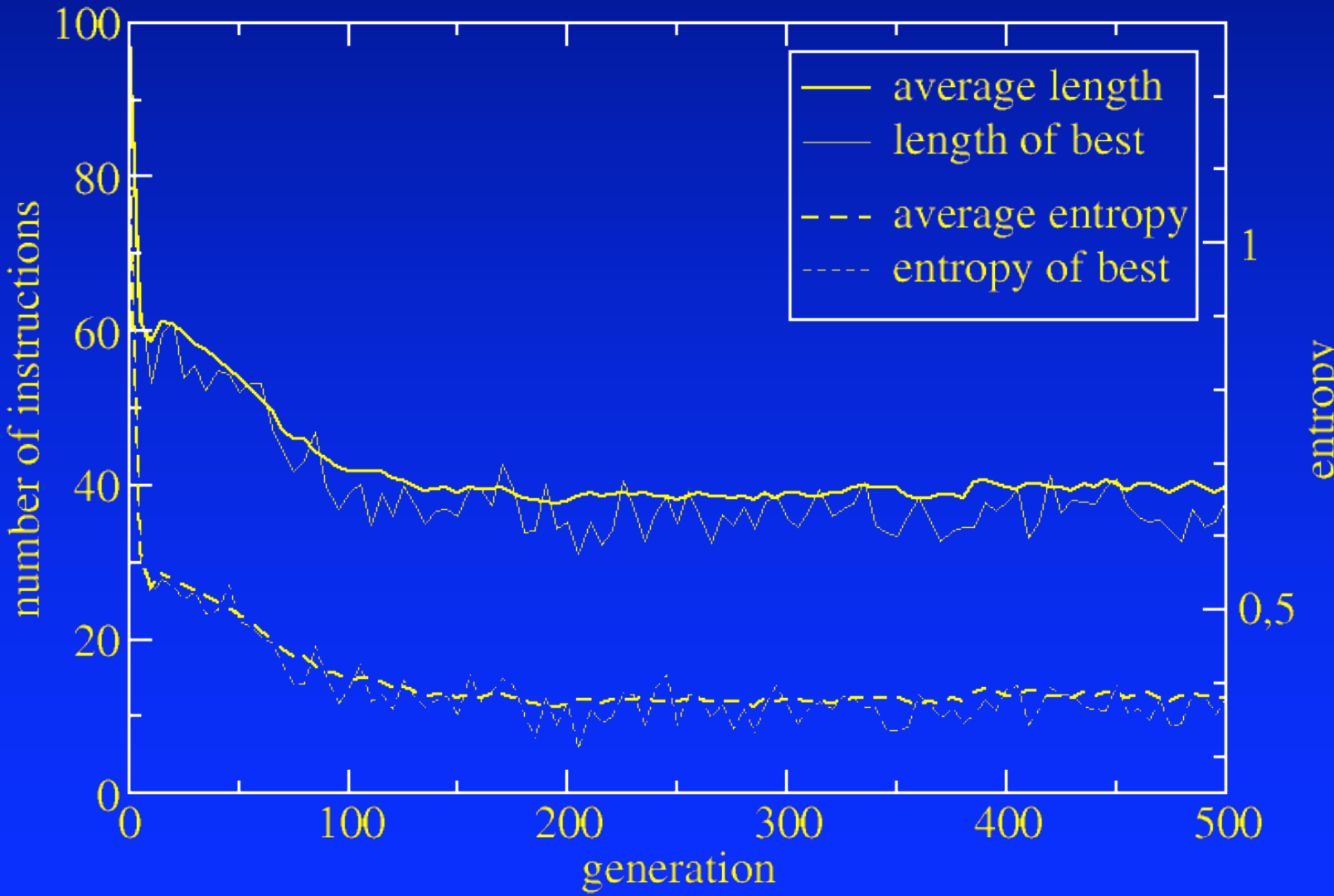
Result - Sine Function

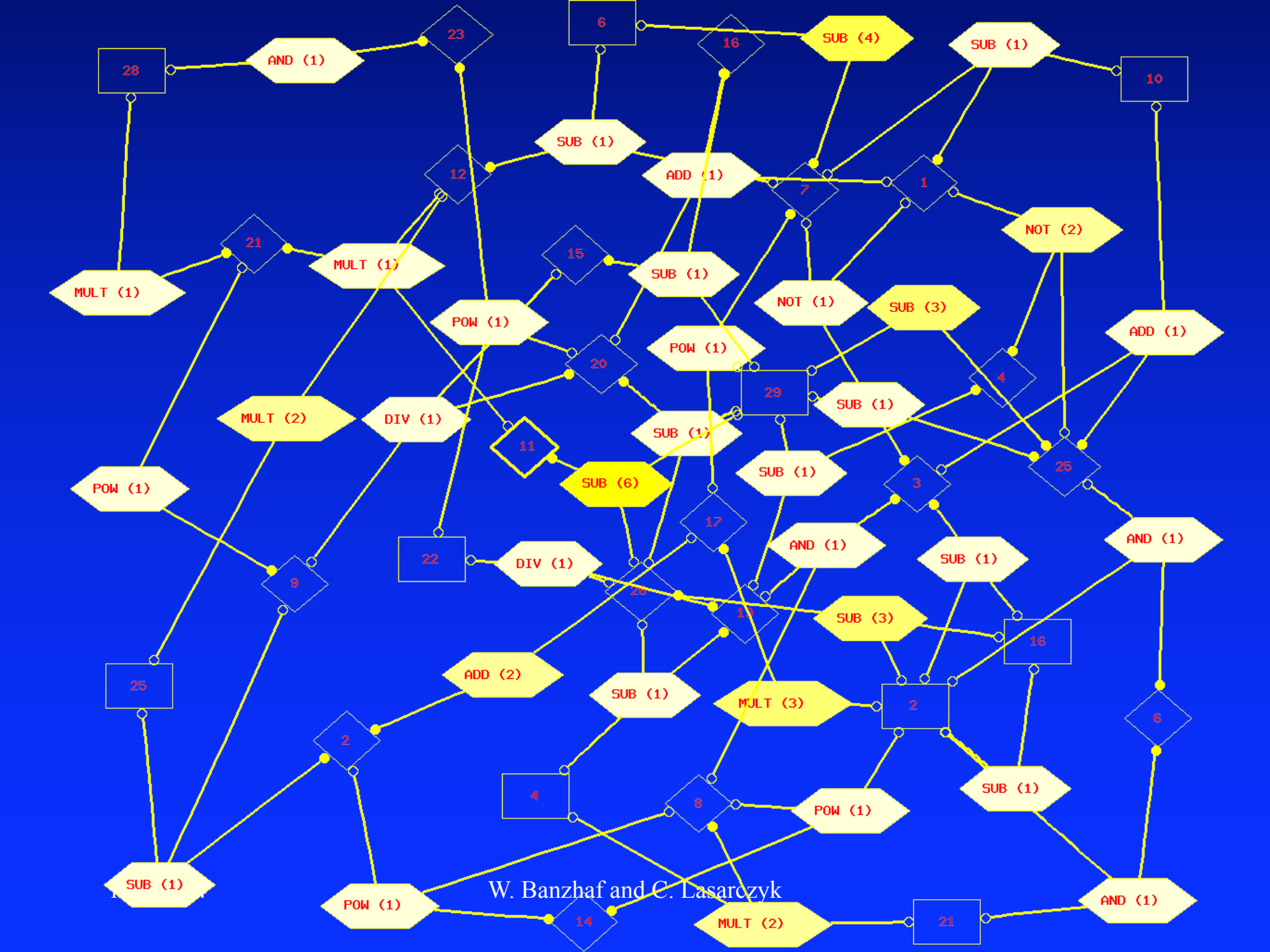


Result - Thyroid Problem



Length & Entropy – Sine Function





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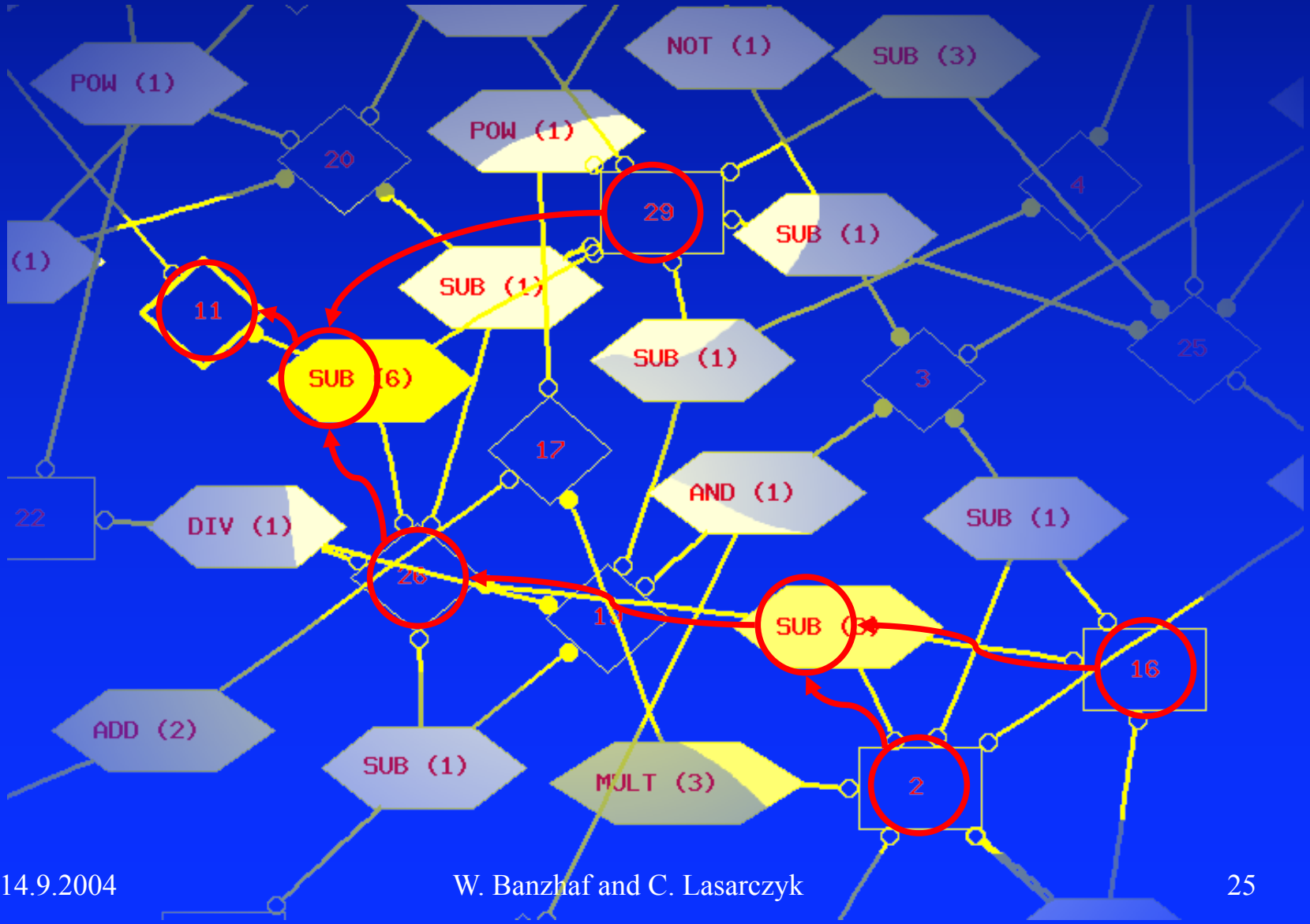
Dataflow

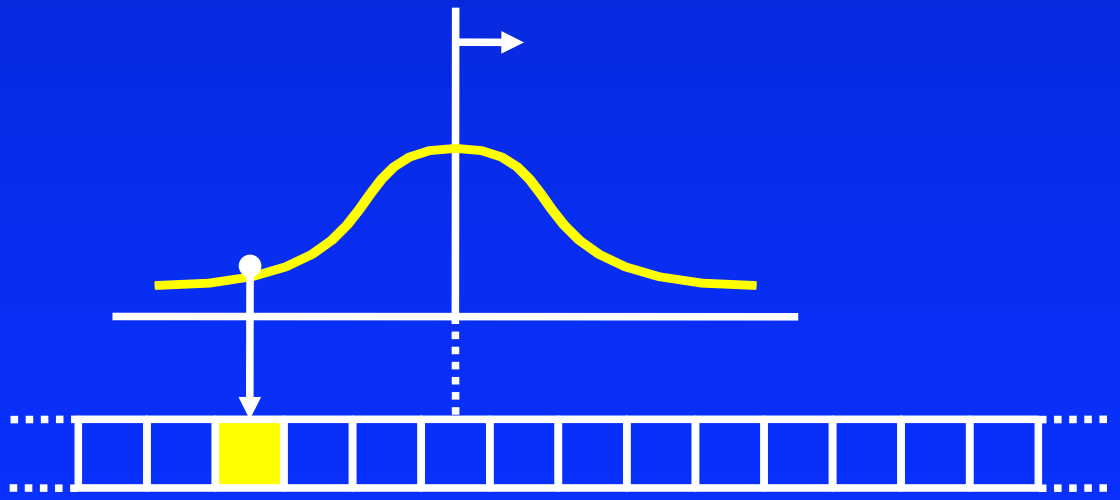

POW (1)
NOT (1)
SUB (3)
POW (1)
20
29
4
(1)
SUB (1)
11
SUB (1)
SUB (16)
SUB (1)
25
3
17
AND (1)
22
DIV (1)
SUB (1)
26
SUB (3)
16
ADD (2)
SUB (1)
MULT (3)
2

Outlook

- Fuzzy hierarchies
- Multiprocessor ACs
- More problems, e.g. Sorting Networks
- Statistical Evaluation of the Approach

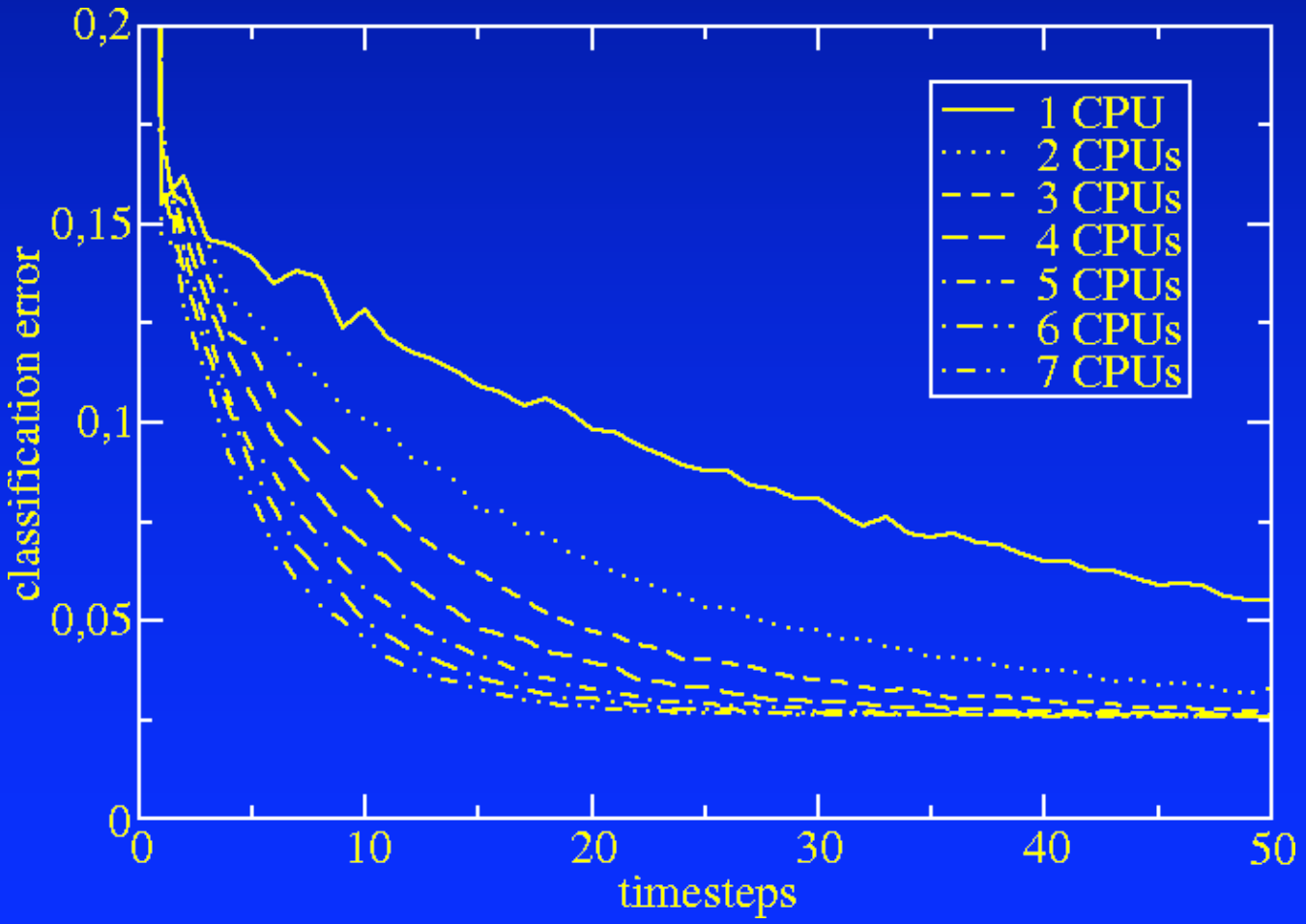
Fuzzy Hierarchies

- Gradual linearization
- From N(x,∞) to N(x,0)
- Via:



Multiprocessor AC

- Thyroid problem



References

- *Artificial Chemistries – A Review*, Artificial Life, 7, 2001, 225 – 275 (by P.Dittrich, J. Ziegler and W. B.)
- *Genetic Programming of an Artificial Chemistry*, Proc. of Genetic Programming in Theory and Practice Workshop, Ann Arbor, MI, 2004, Kluwer Academic, 2004
- http://www.cs.mun.ca/~banzhaf/

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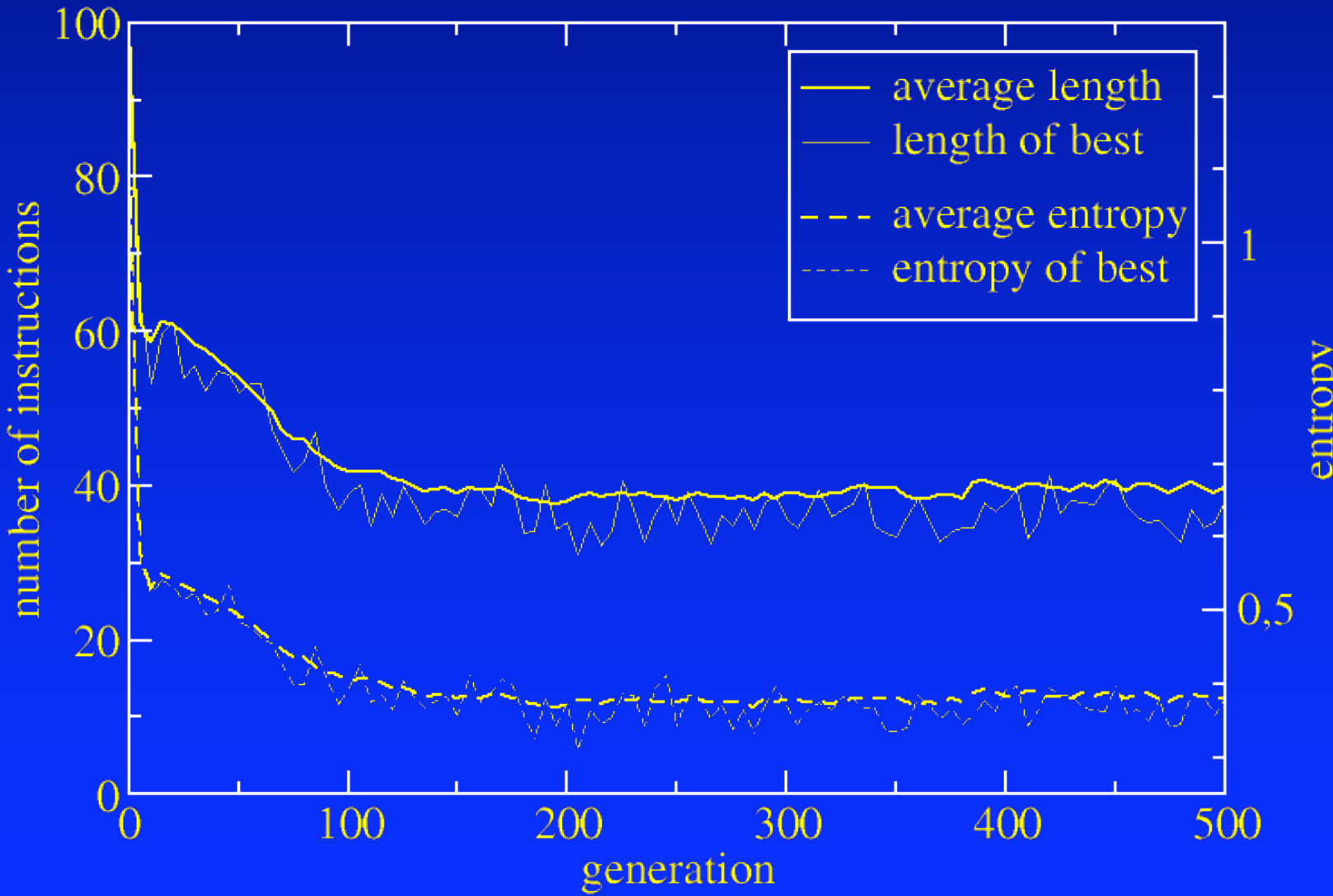
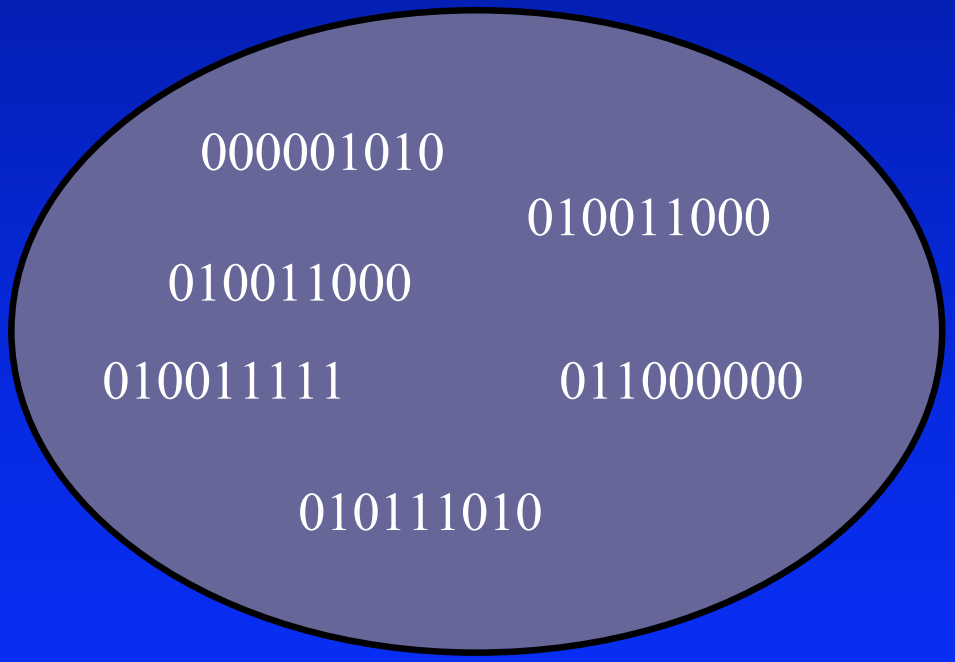


Matrix reactions – Step by step



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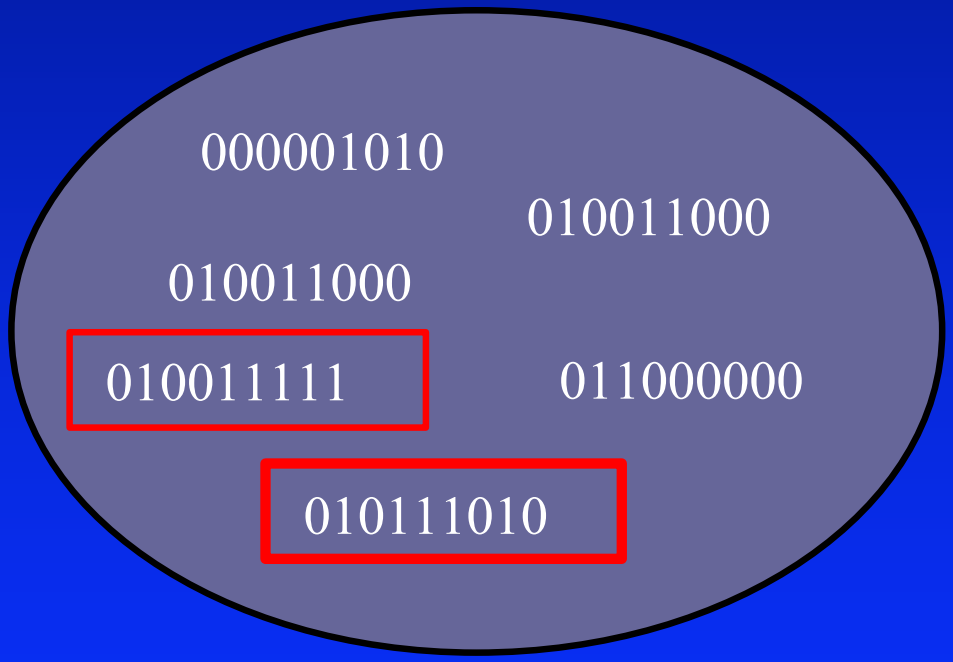

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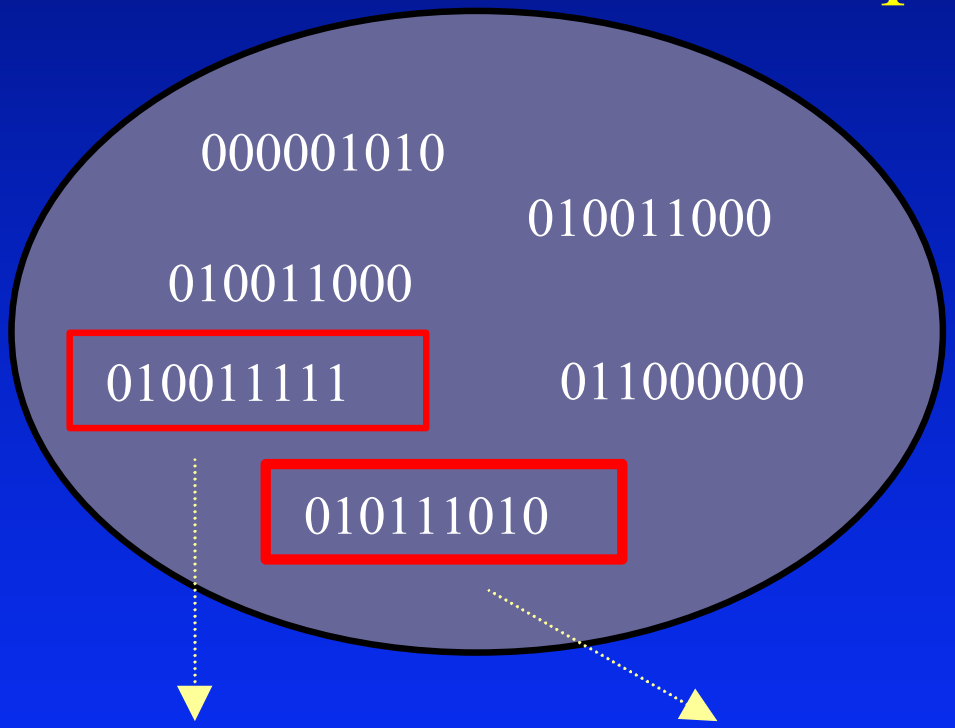
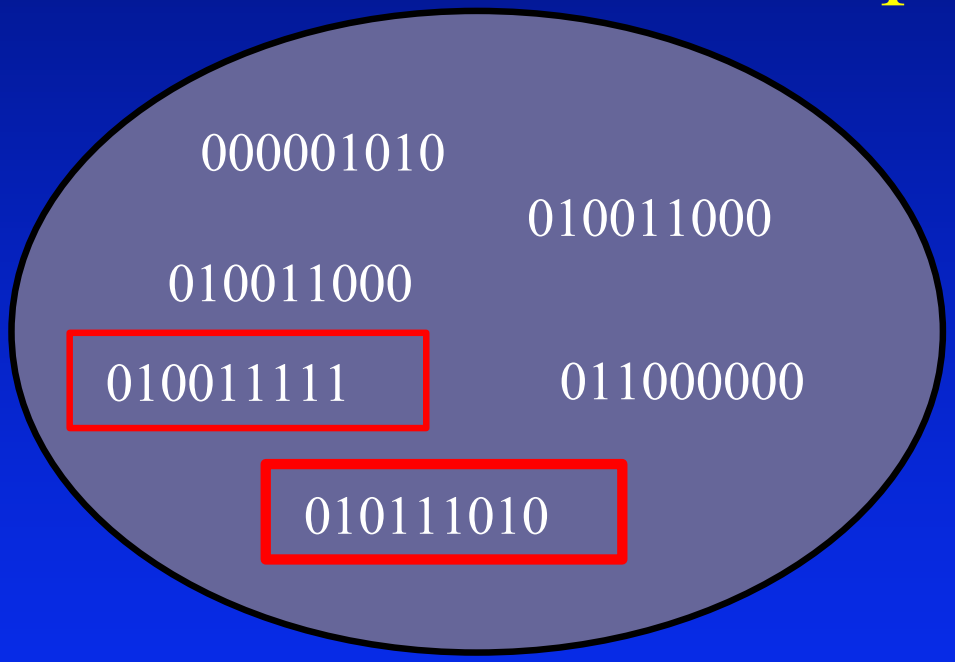


010011111 + 010111010 → ?

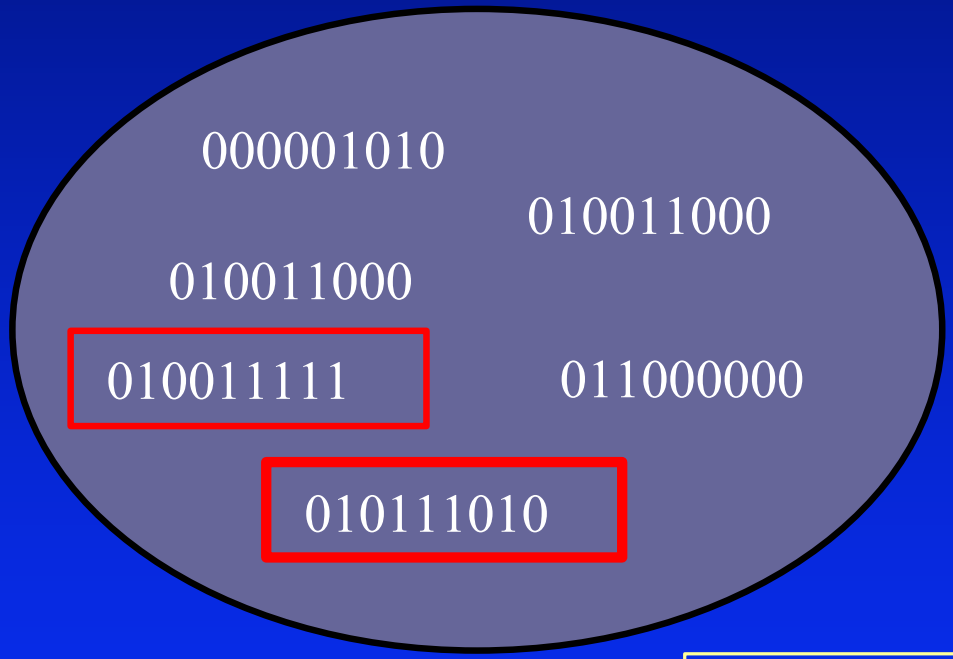
Matrix reactions – Step by step



010
011
111

010111010 → ?

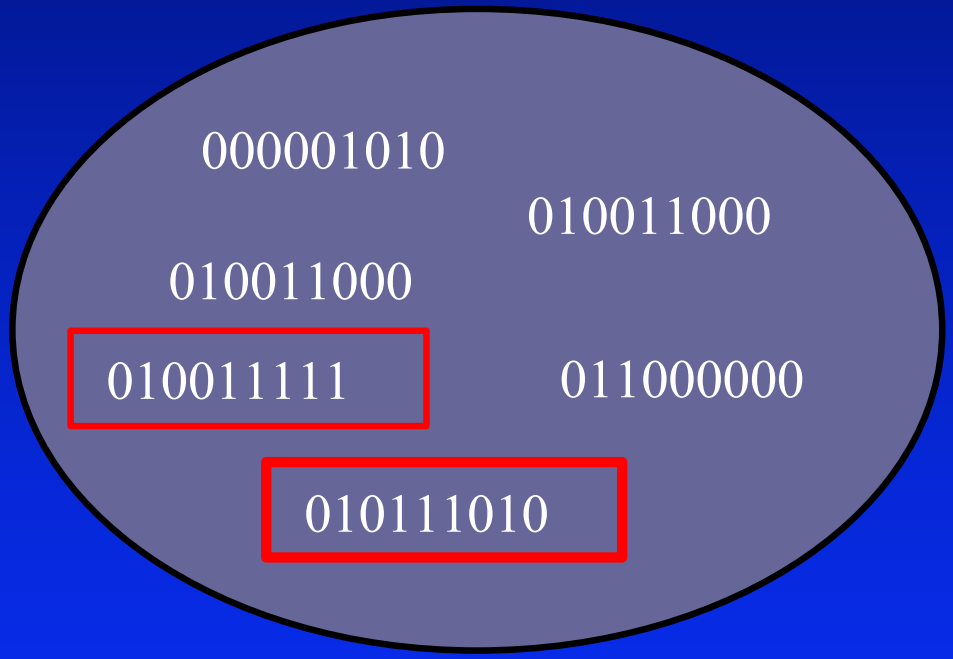
Matrix reactions – Step by step

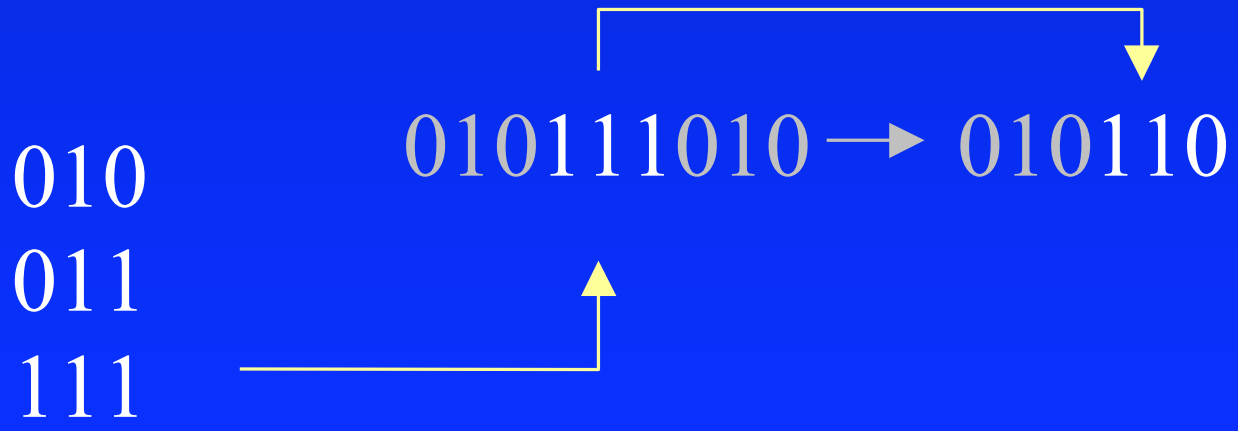


010111010 → 010

010
011
111

Matrix reactions – Step by step





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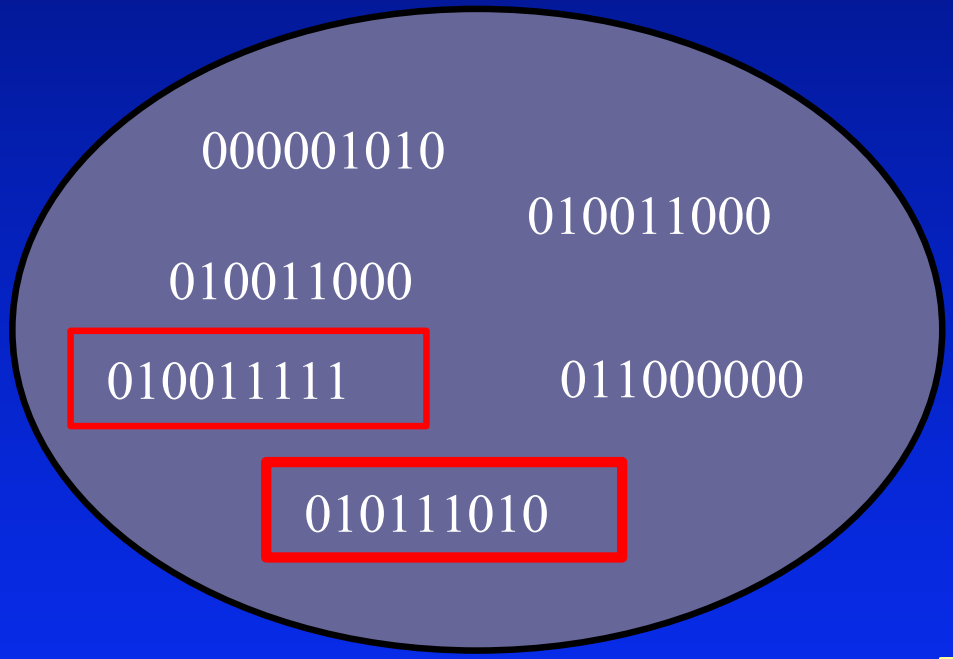
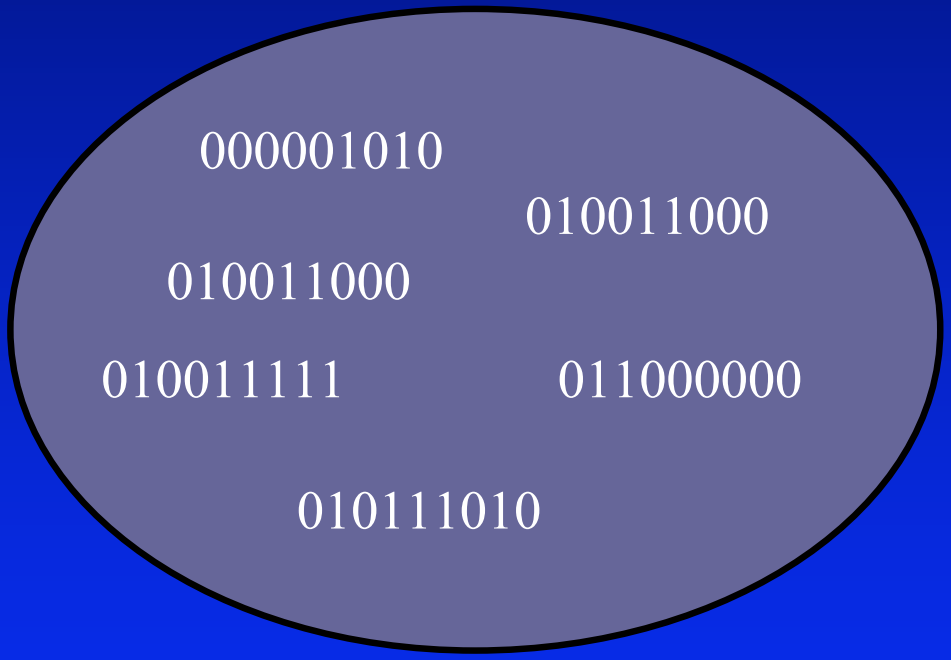


010111010 → 010110101

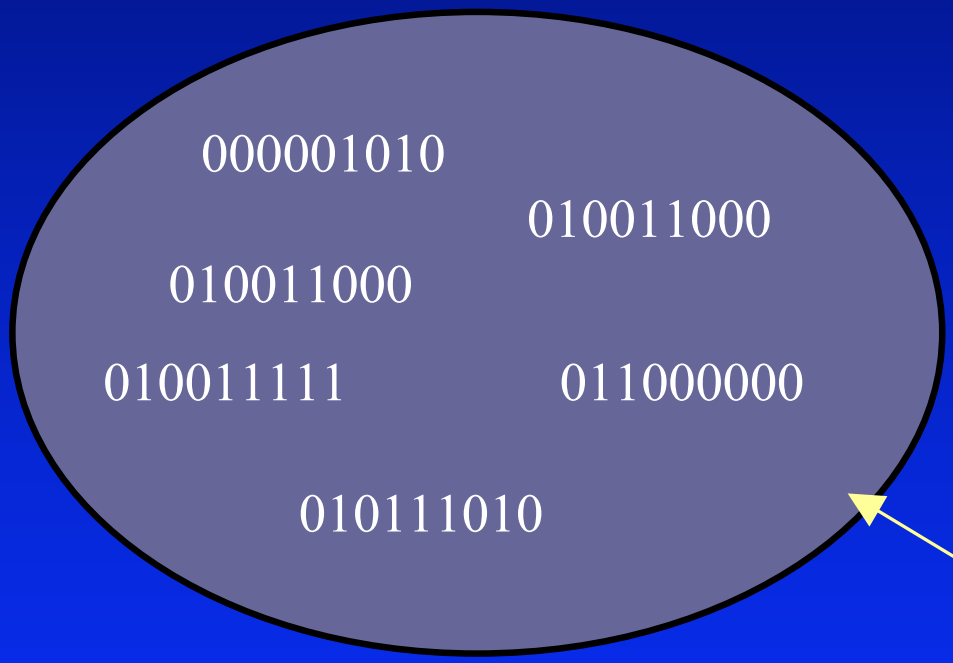
010
011
111

Matrix reactions – Step by step



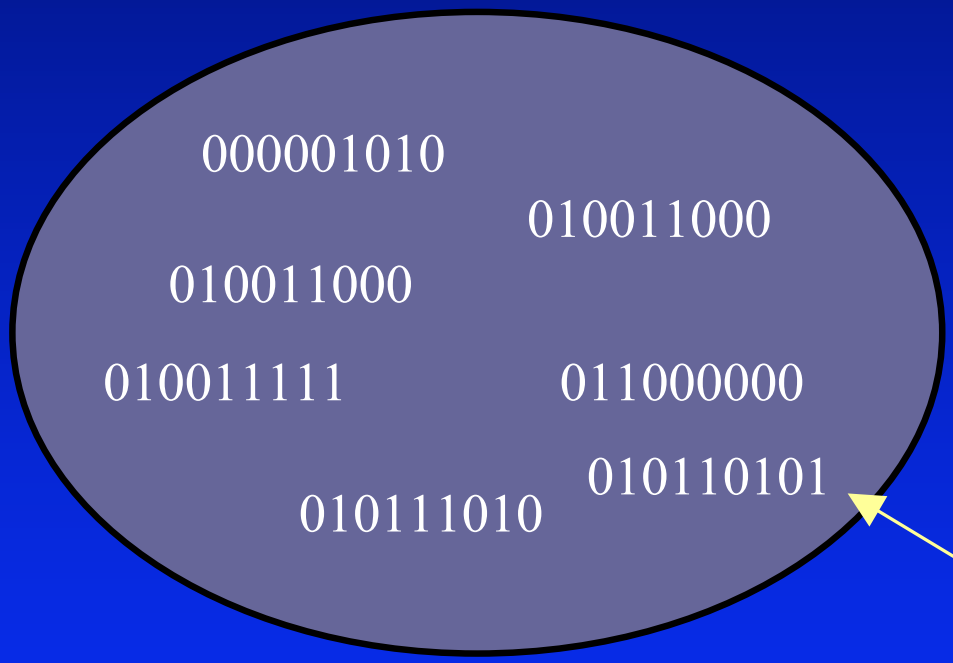
010110101

Matrix reactions – Step by step



010110101

Matrix reactions – Step by step



010110101

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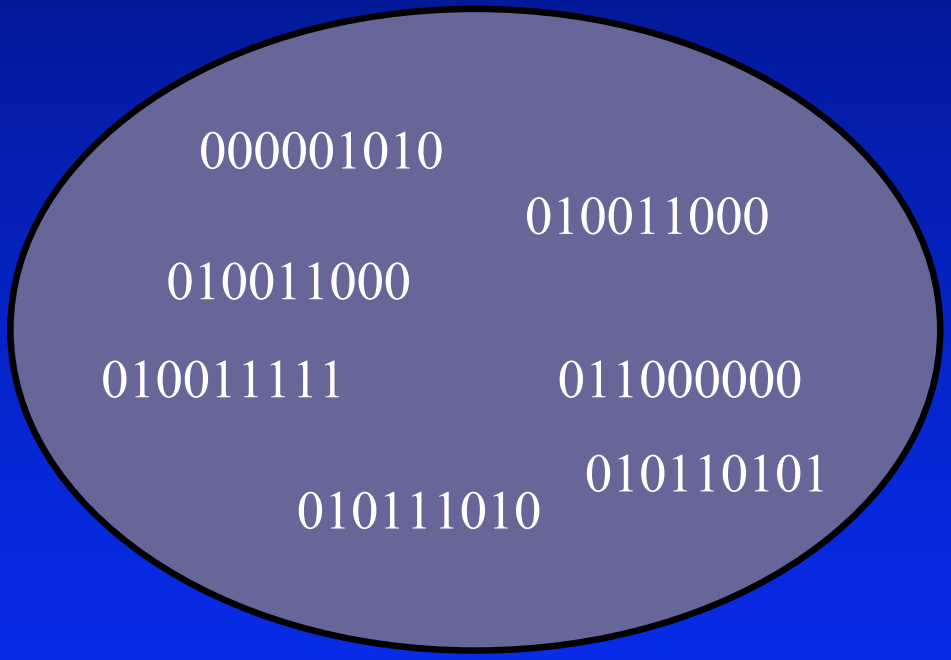

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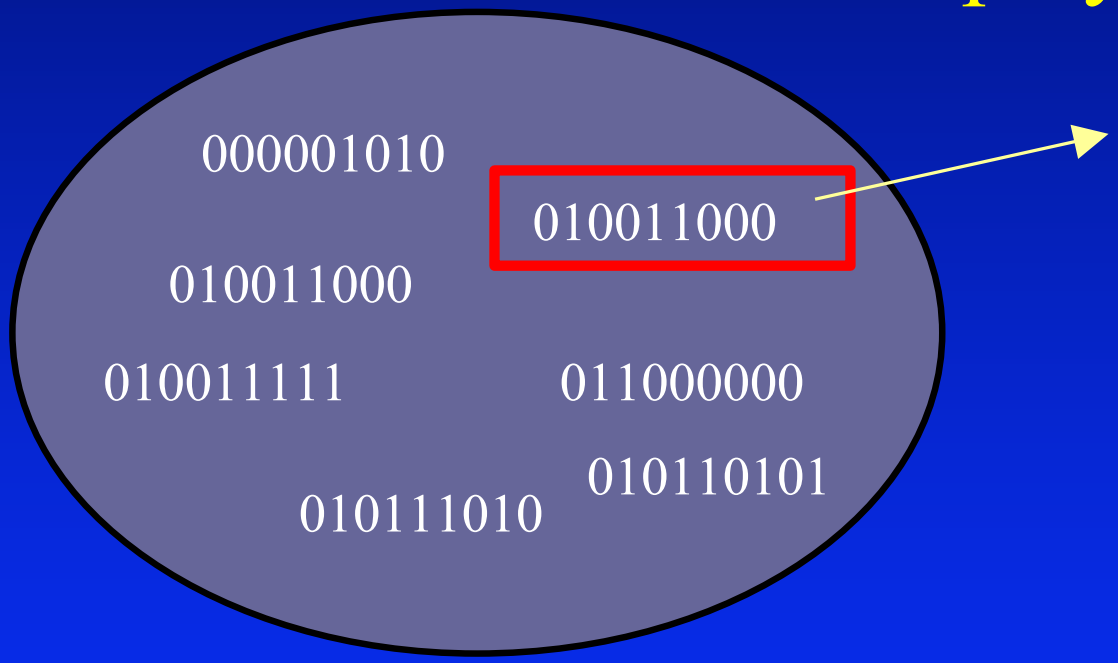

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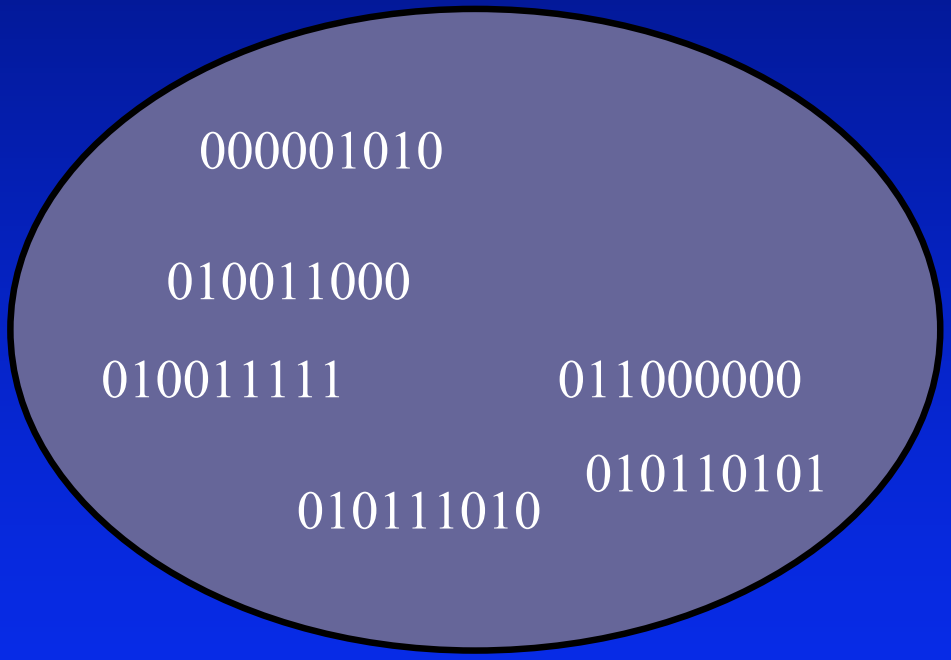

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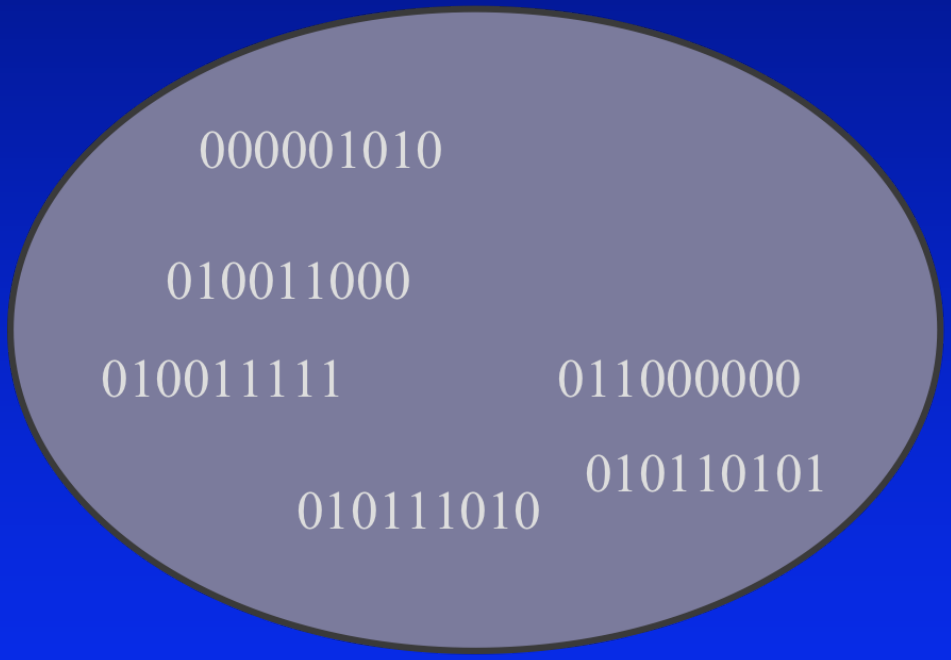

1 Generation = M Steps