Hierarchically Evolvable Components for Complex Systems

Biologically Inspired Algorithmic Design

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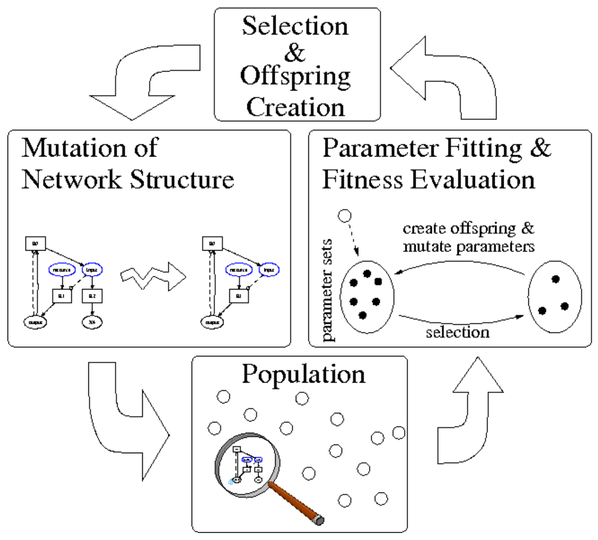
SPONSORED BY THE Federal Ministry of Education and Research; Deutsche Forschungsgemeinschaft DFG
Sixth Framework Programme

Summary

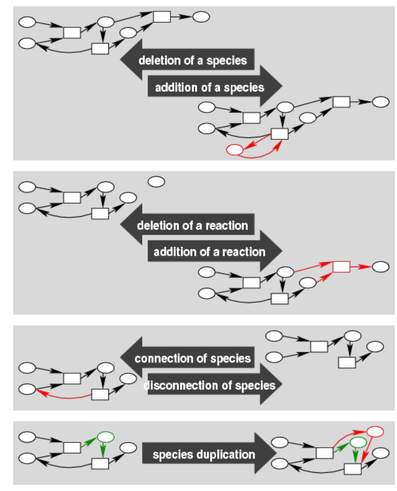
Artificial evolution is a powerful tool to automatically devise complex systems capable of computational tasks. We have designed and implemented an algorithm for evolving biological models encoded in SBML. Analysing the evolutionary process, the results show that explicit distinction between structural modification of reaction network and parameter adjustment significantly increases the success rate of the evolution.
The software has also been used to modify a model of the human spindle checkpoint mechanism to improve its performance.
Another design method for chemical reaction networks has been researched, and a comparison between manual design and evolutionary design is expected.

Evolution of SBML Models

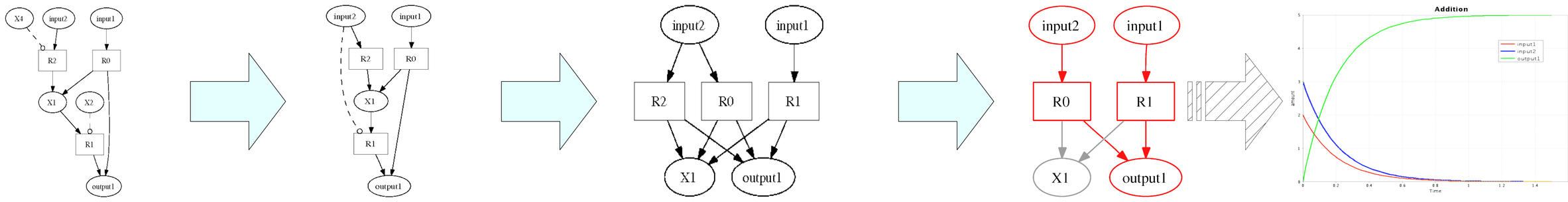


We have developed a software tool that can evolve - i.e. automatically design - SBML models fulfilling desired properties. Our algorithm involves two levels of evolution: a graph-based variant of Genetic Programming for structural modification of the reaction network and an Evolution Strategy for parameter fitting. The software is available upon request.

ESIGNET

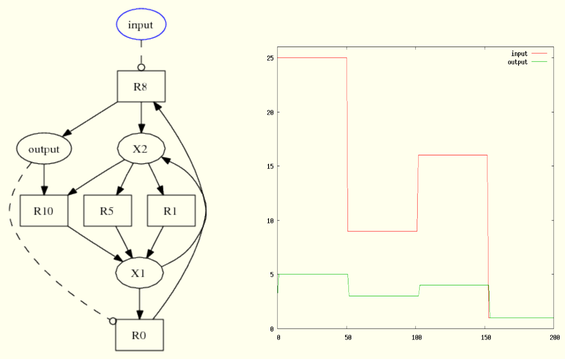


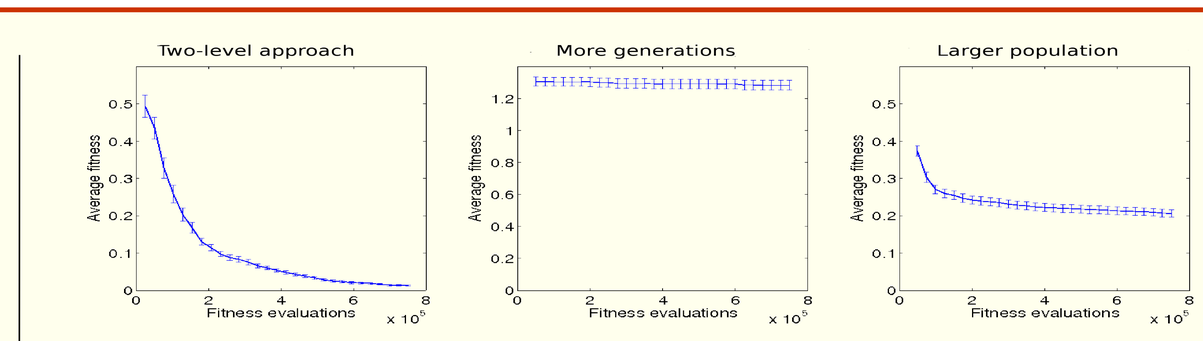
Snapshots of the evolution of a network capable of adding two numbers



Investigating Artificial Evolution

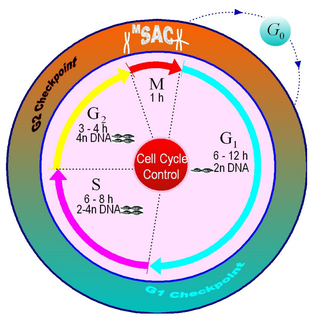
Utilizing the software, we successfully evolved a network that computes a square root. Shown here is the evolved network, together with its input-output behaviour.



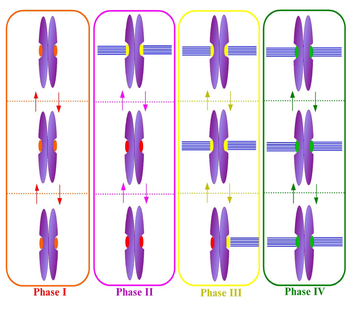


Benefits of the designed two-level approach are evaluated. We compared the effect of separating the evolutionary process into two levels with the effect of either a larger population or a longer run. The two-level approach significantly increases the evolutionary success.

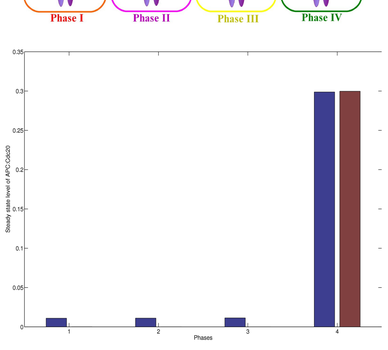
Case Study: Spindle Assembly Checkpoint

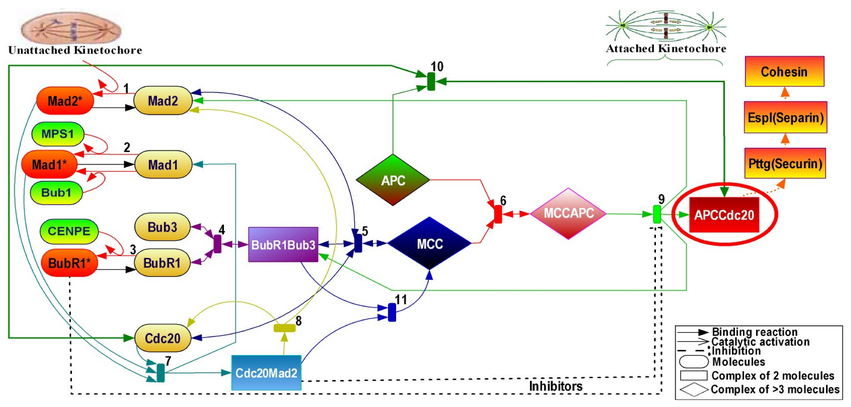


The spindle assembly check-point (SAC) prevents cell cycle progression until all chromo-somes are attached to the mitotic spindle. Defects lead to cell death, aneuploidy, ageing, and cancer.

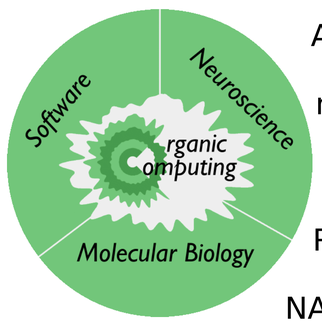


Given a network model of SAC (below), we used artificial evolution to find reactions improving checkpoint performance, hinting at further biological mechanisms to be explored in experiments. Shown on the right are the four modes of behaviour of the model: in phase IV the concentration of APCCdc20 is supposed to rise. The improved model(red) outperforms the given model(blue).

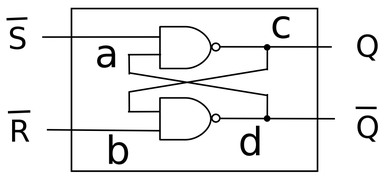




Hand-Crafted Reaction Network



A chemical reaction network is manually designed for a RS flip-flop with two NAND gates. Organization-oriented pro-gramming for a general chemical logic circuit is discussed in [3].



$\overline{S}$	$\overline{R}$	Q_{t+1}
0	0	-
0	1	1 set
1	0	0 reset
1	1	Q_t hold

Recipe of chemical RS flip-flop

1. Each NAND gate is converted to 4 reactions.

NAND 1	a	d	c
	0	0	1
	0	1	1
	1	0	1
	1	1	0

$s_a^0 + s_d^0 \to s_c^1$
$s_a^0 + s_d^1 \to s_c^1$
$s_a^1 + s_d^0 \to s_c^1$
$s_a^1 + s_d^1 \to s_c^0$

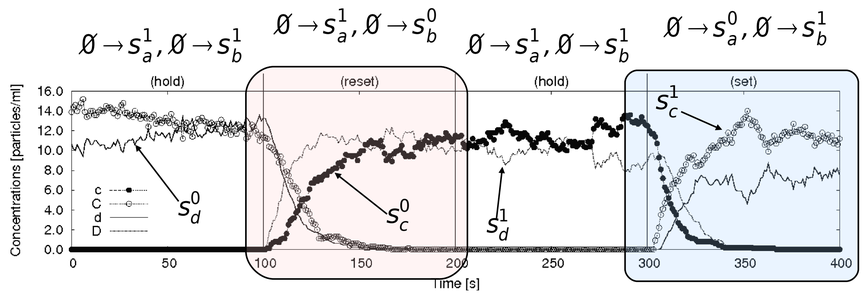
Species Name: s_i^{bin} — bin: Binary state Variable; i: name

2. Species representing contradictory situations are defined to decay.

$$i = a,b,c,d : (s_i^0 + s_i^1 \to \emptyset)$$ ($\emptyset$: empty set)

8 species and 12 reactions total

3. Operations are specified with inflows.



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The JCB is a member of the NBCC.