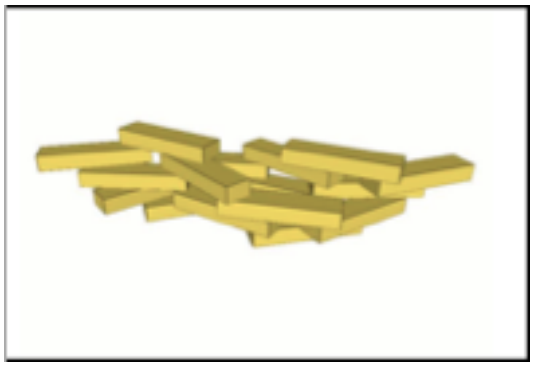
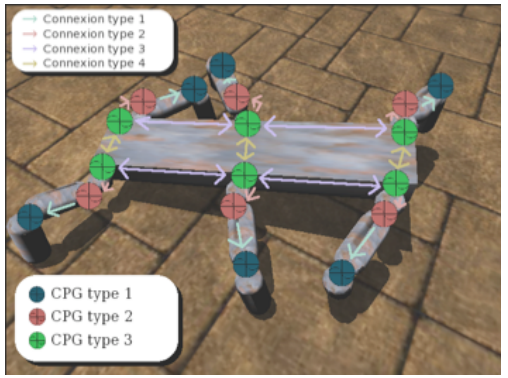
Current work in Evolutionary Developmental Systems at TAO





TAO / LRI

Univ. Paris-Sud ; CNRS ; INRIA Futurs

Orsay, France

Presenter : Nicolas Bredèche

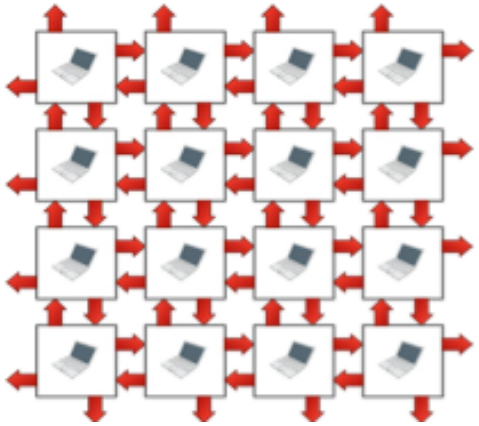
Participants:

Alexandre Devert (Doctorant), Marc Schoenauer (DR/INRIA), Nicolas Bredèche (MdC, Univ. Paris-Sud)

Journée Amorphous Computing - Orsay, France - July, 18th 2007

Developmental systems

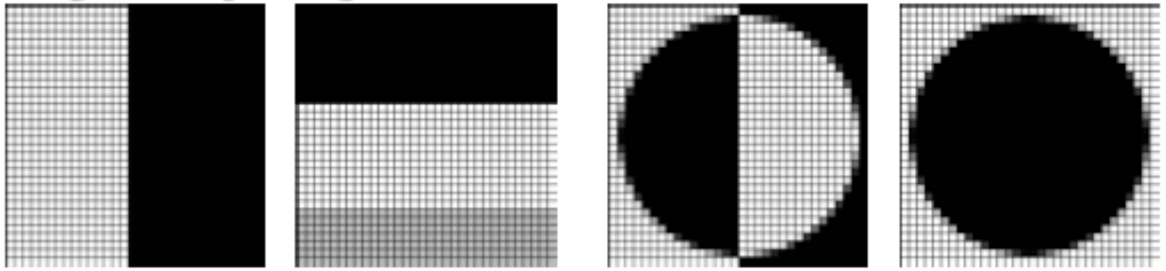
A new paradigm for evolutionary design



- multi-cellular approaches
  - an environment full of cells, cells exchange "chemicals"
  - each cell has a controller
  - controller is the same for all cells
- Expected properties
  - scalability : genotype independent from phenotype!
  - robustness

Applications

goal: optimize genotype (i.e. controler) towards a given objective

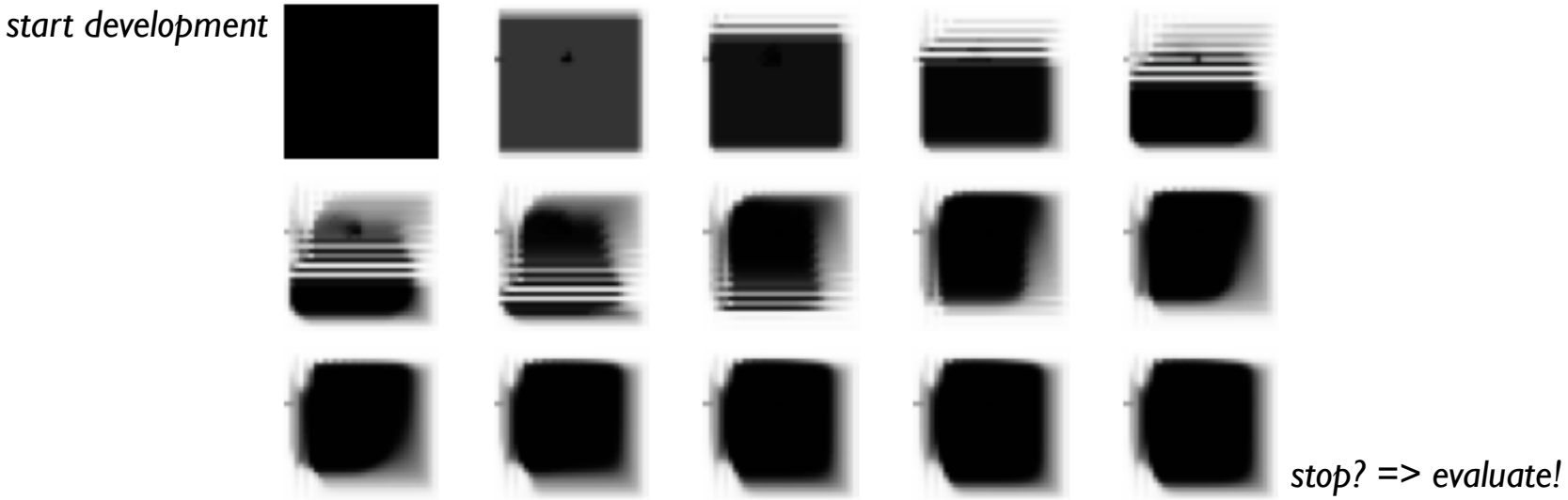


$$s(A,B) = \frac{1}{wh}\sum_{i=0}^{h-1}\sum_{j=0}^{w-1}(A(i,j) - B(i,j))^2$$

- classic benchmarks : image
- other benchmarks:
  - topology optimization (NN, trusses, ...)
  - 3D structures/robots

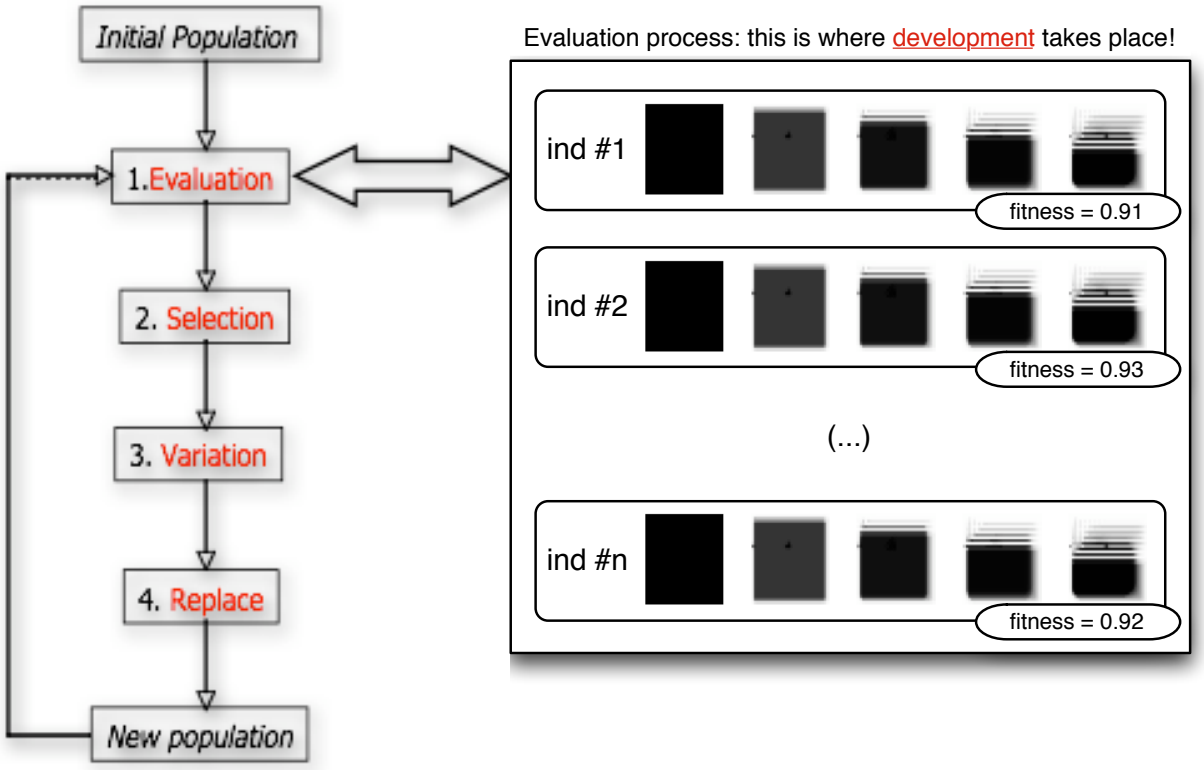
Developmental process

Example from the flag benchmark



- genotype-phenotype mapping
  - start with initial configuration
  - develop until stopping criterion (stability, ressources, ...)
  - evaluate phenotype once

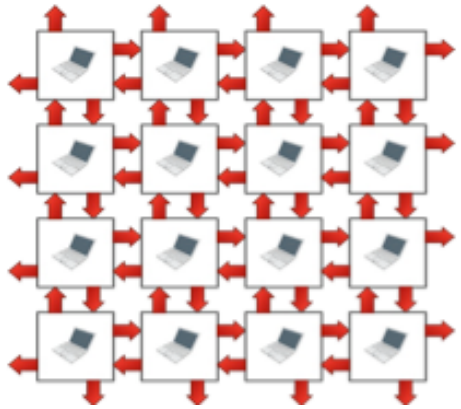
Optimization process



- Evolutionary Algorithm
  - flexibility when defining the objective
  - representation (real values, graph, etc.)

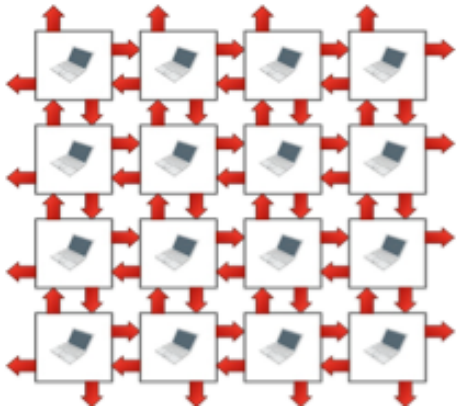
Elements of an approach

- multi-cellular environment
  - cell-cell or substrata communication
  - model expressivity
- controller
  - expressivity
  - evolvability
- development process
  - stopping criteria?



Previous works [miller2004, federici2004, gordon2006]

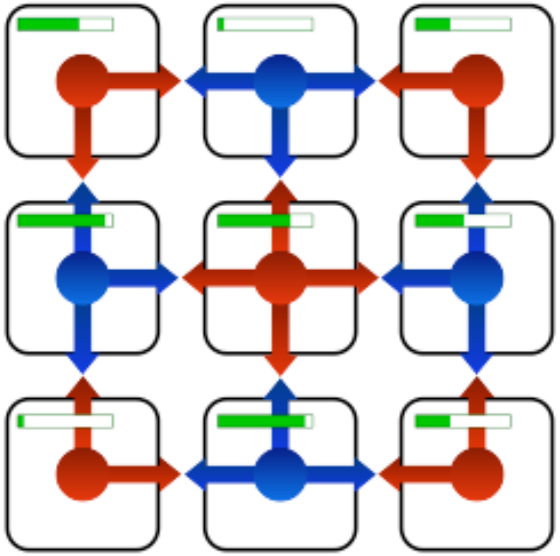
- environment ("flag-problem")
  - grid (4 or 8 neighbors, totalistic automata or not)
    - a growing cell
    - fully filled grid
  - 1+ chemicals for communication
    - cell-cell
    - diffusion in the environment
- controller (discrete outputs)
  - representation: neural nets, logic circuit, rule-based
  - optimizers : ES, Cartesian GP, GA
- arbitrary stopping criteria (stop after fixed nb of iterations)



also related: amorphous computing, cellular NN, ...

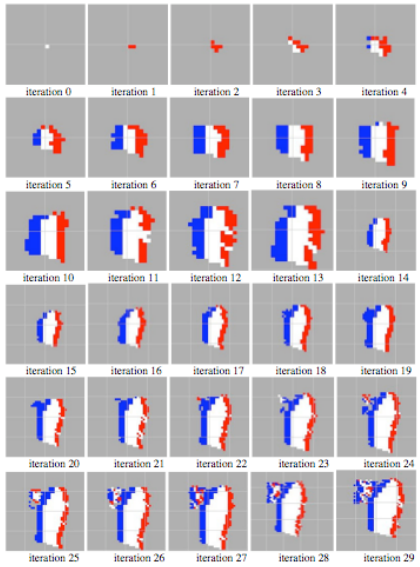
Outline of our Model

Devert et al., GECCO 2007



- Model properties
  - cell-cell communication, von neumann neighbourhood
  - discrete time, continuous outputs, synchroneous update
  - initialize cells at 0, border cells bootstrap the process

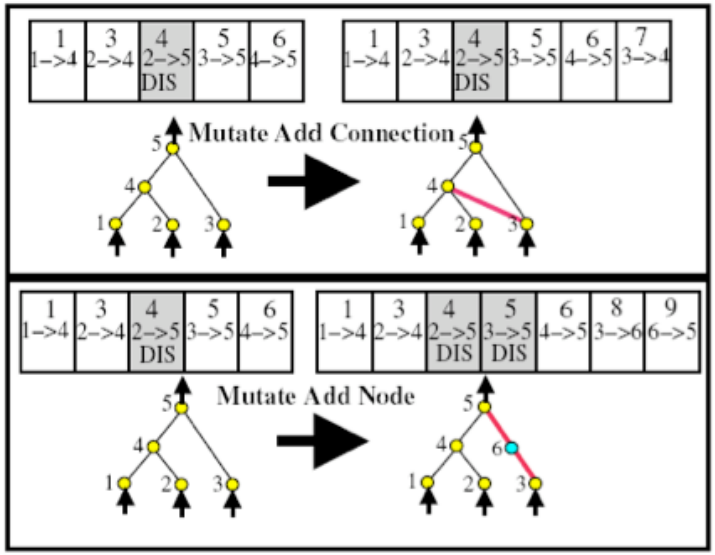
Halting problem?

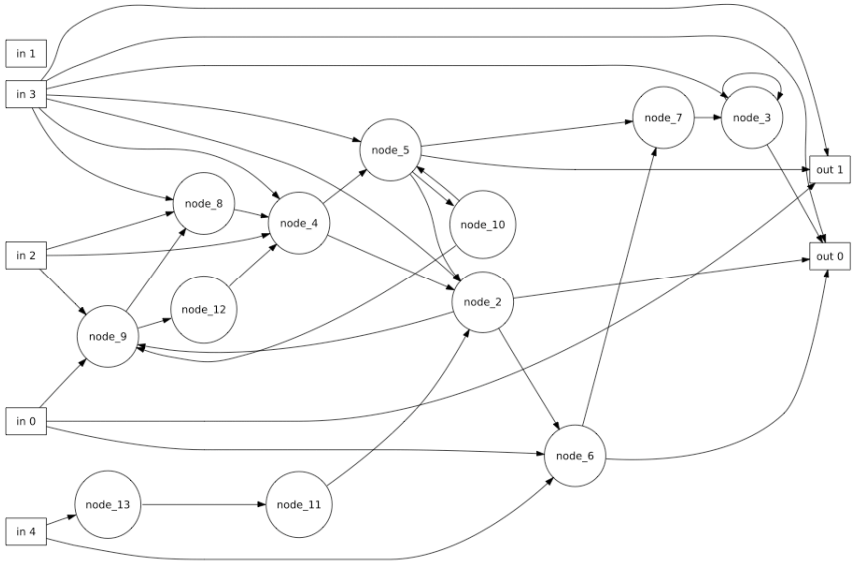


from Miller2003

- When to stop?
  - how many iterations?
  - current approach: arbitrary stop at a given nb of iterations
  - problem: lack of robustness (degenerate through time)
- Proposed Solution
  - Consider only stable phenotype
  - Stopping criterion forces stabilization:
    - if no stabilization (i.e. time-out) then penalize (i.e. worst fitness)
    - i.e. force convergence towards a fixed point

Controller (1) : NEAT





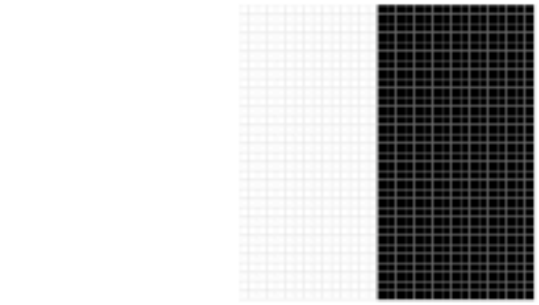
- Neuro-Evolution of Augmenting Topologies [Stanley 2002]
  - state-of-the-art NN topology and weight optimizer
  - with/without recurrent connections
  - properties
    - non-destructive variations
    - genetic diversity
    - innovation protection

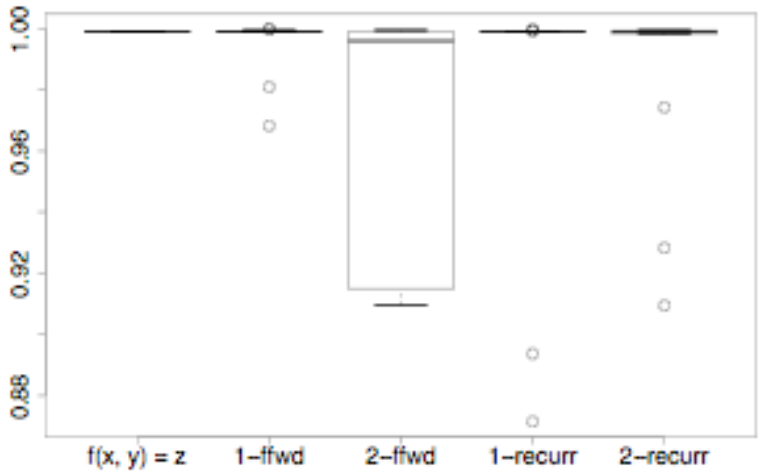
Experiments (with NEAT) [Stanley02]

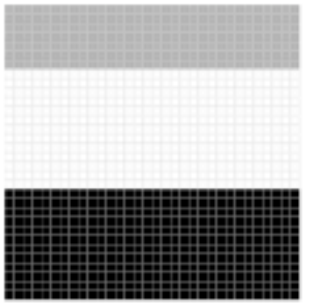
	feedforward topology	reccurent topology
one chemical	1-ffwd	1-reccur
two chemicals	2-ffwd	2-recurr

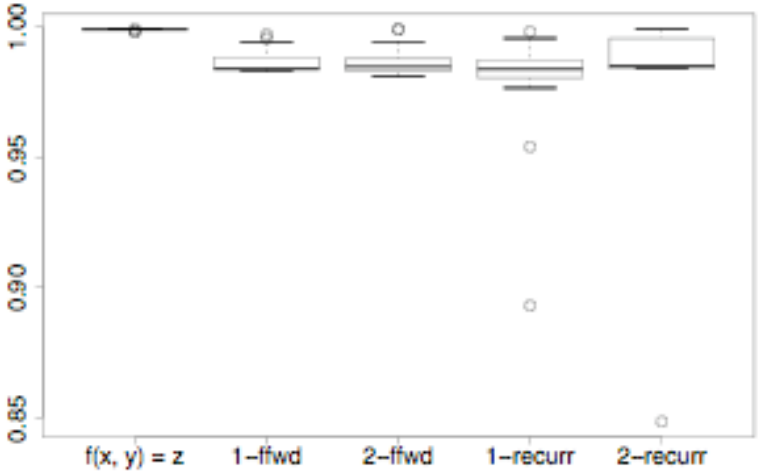
- 250000 evaluations, 16 runs
- baseline: regression approach (i.e. *f(x,y)=>color*)
- recurrent and non recurrent NN
- max number of steps is 1024

Results (1/2)

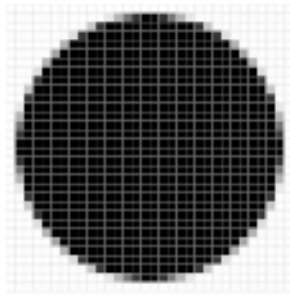


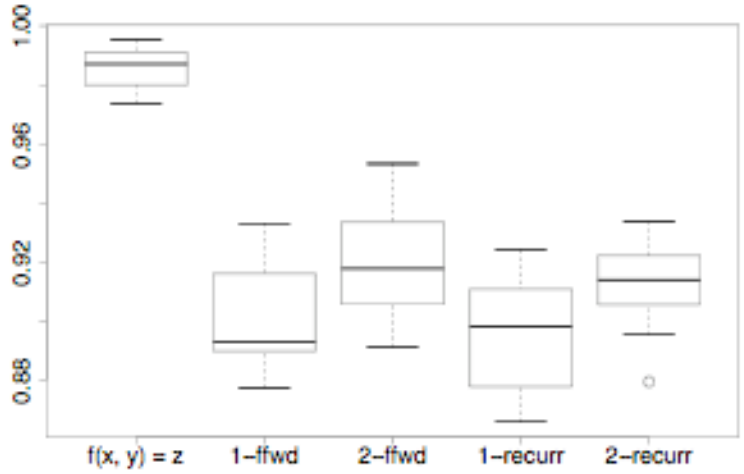

1.00
0.96
0.92
0.88
f(x, y) = z
1−ffwd
2−ffwd
1−recurr
2−recurr

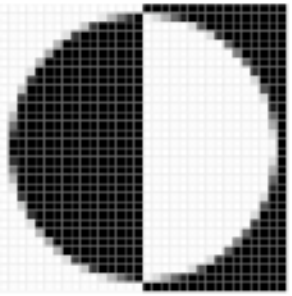


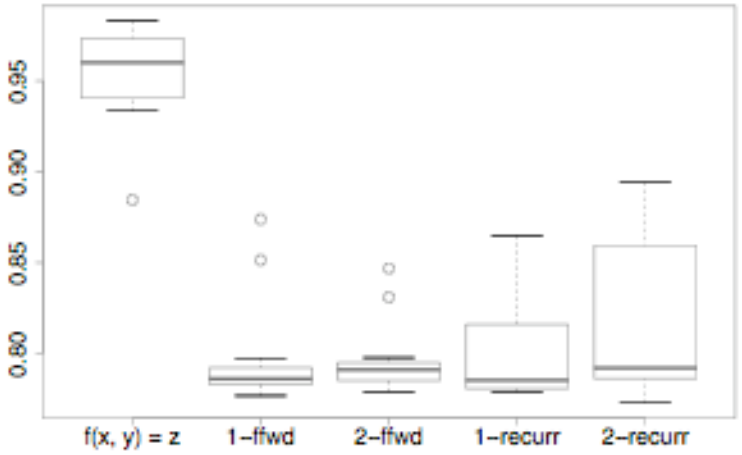

1.00
0.95
0.90
0.85
f(x, y) = z
1−ffwd
2−ffwd
1−recurr
2−recurr

Results (2/2)

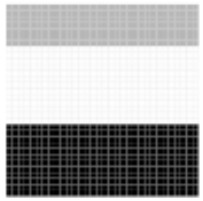



1.00
0.96
0.92
0.88
f(x, y) = z
1−ffwd
2−ffwd
1−recurr
2−recurr

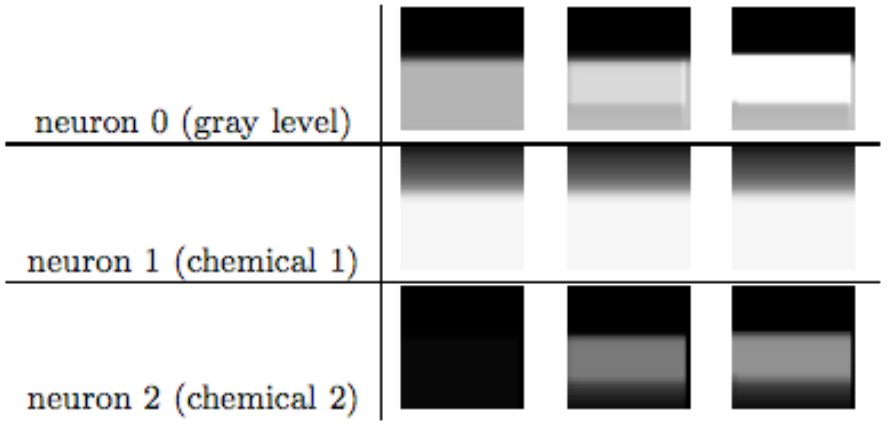



0.95
0.90
0.85
0.80
f(x, y) = z
1−ffwd
2−ffwd
1−recurr
2−recurr

Chemicals and Development



3-bands

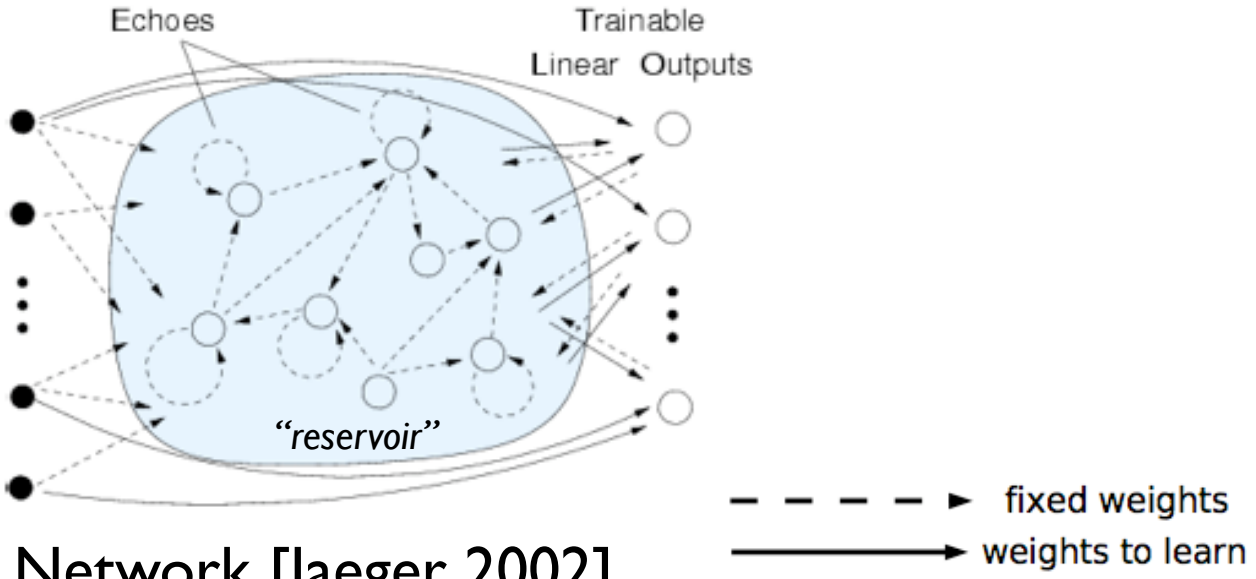


development of the best individuals for the 2-chemicals setup

Self-healing property

- Robustness
  - how? add noise, compute fitness after stabilization
  - self-healing : from 75% (Recurrent) up to 100% (feed-fwd)
    - We've got a global attractor!
    - non-predicted (and welcome) property!
    - note: previous work never achieved such results

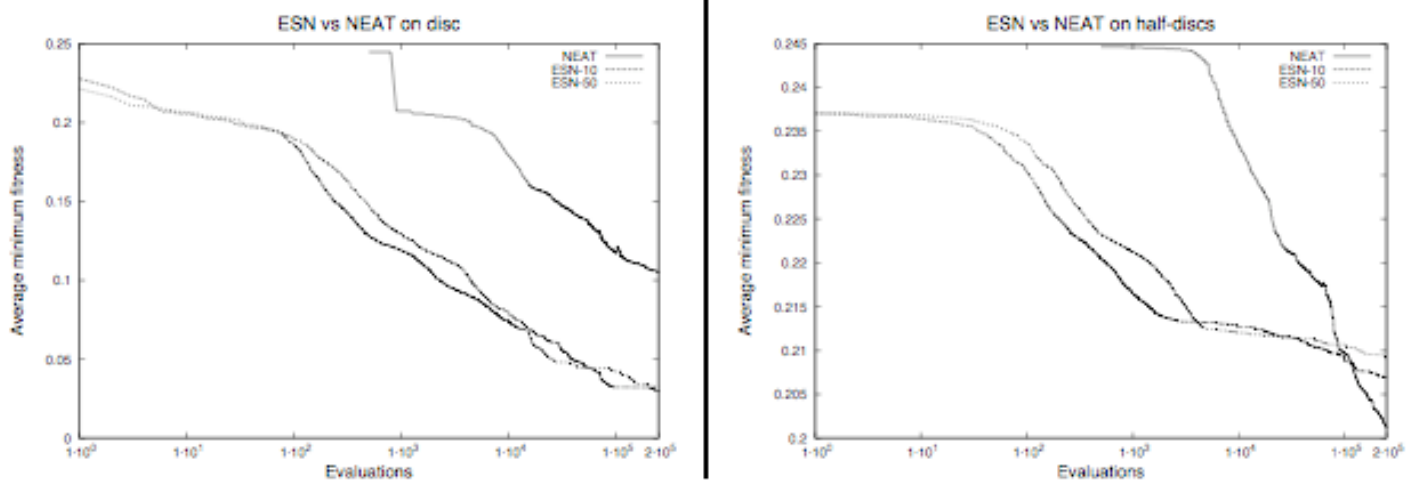
Controller (2) : ESN



- Echo State Network [Jaeger 2002]
  - random connection, sparse matrix
  - many embedded dynamics
  - Only few weights to learn/optimize
  - reservoir parameters:
    - connectivity of 8%, size of 20 nodes, damping btw 0.8 and 0.9
  - optimizer: (1+1)-SAES

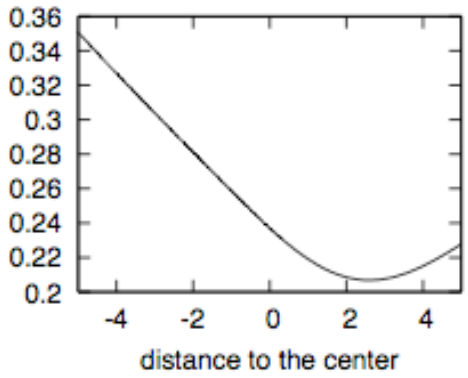
Experiments (with ESN)

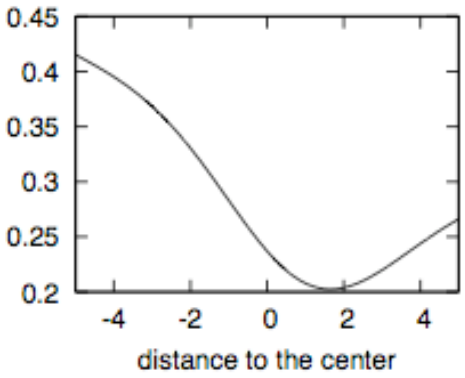
Devert et al., under review

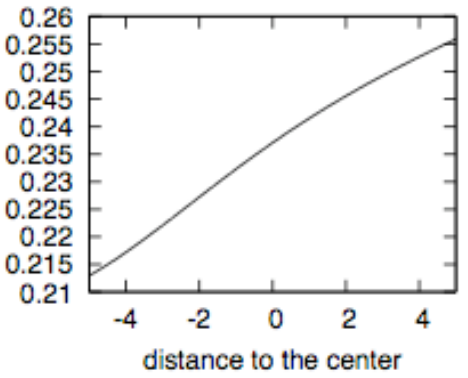


- preliminary results
  - faster, better on simple problem
  - comparable on more difficult problems (still faster)
  - very nice fitness landscape (not shown here)
  - ongoing work with state-of-the-art CMA-ES optimizer

(nice) fitness landscape







- best individual with ESN-10 on the disc problem
- a random direction from the optimal
- smooth fitness landscape

concluding remarks

- Summary
  - multi-cellular developmental system
  - scalability
    - independent from phenotype size
    - may be coupled with environment
- Contributions
  - energy-based stopping criterion
  - perfect (in some case) self-healing property
- Current work
  - large 3D metallic trusses topology optimization
  - dynamic modular robots evolution (see next slide)


Current FPS: 5.36193
Average FPS: 5.35286
Worst FPS: 5.15907 233 ms
Best FPS: 9.68054 99 ms
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Batch Count: 111
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Short bibliography about multi-cellular developmental systems

- Artificial Evolution and Multi-Cellular Artificial Embryogeny
  - J. Miller. Evolving a self-repairing, self-regulating, french flag organism. GECCO 2004.
  - D. Federici. Using embryogenic stages to increase the evolvability of development. GECCO 2004, Worlds workshop.
  - Gordon and P. Bentley. Bias and scalability in evolutionary development. GECCO 2005.
  - J. Bongard, R. Pfeiffer. Evolving complete agents using artificial ontogeny. In Morpho-functional Machines: The New Species. 2003.
  - GECCO 2007 track on developmental systems

- informations diverses
  - Ma page web: http://www.lri.fr/~bredeche
  - Projet TAO / INRIA Futurs : http://tao.lri.fr