Adaptive Systems

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Informatics

Evolutionary Robotics
3. Hot Topics

Some current research projects

- Brief overview of some research directions in Evolutionary Robotics in recent years.
- Plastic controllers
  - Evolving plastic rules
  - GasNets
  - Spiking neural networks
- Evolving body morphology
  - Golem project, passive dynamics, and extensions
- Social coordination

Evolving plastic rules

- Work by Floreano and Urzelai (EPFL, Lausanne).
- Instead of genetically specifying values for weights in neural networks, genotypes encode rules for plastic change. Weights are initialised at random and plasticity acts during the lifetime of the robot.

- Aiming at:
  - Proof of concept.
  - Controllers that are able to cope with more environmental uncertainty.
  - Comparison with more traditional approach of direct weight encoding.
  - Cross-platform transfer.

Encoding and rules

- 4 Rules. (You could think of other possibilities as well.)
- Rules can be encoded for each connection, or the same rule for all incoming synapses to each neuron
- Each 100 ms weights are updated according to:

$$w_{ij}^{t} = w_{ij}^{t-1} + \eta \Delta w_{ij} \quad w_{ij} \in [0,1]$$

- <u>Hebb</u>: Strengthen synapse in proportion to correlated activity.

$$\Delta w = (1-w)xy$$

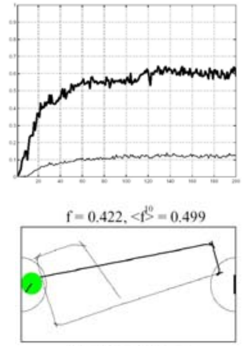
- <u>Postsynaptic:</u> As Hebb, but weakens synapses when postsynaptic node is active and presynaptic node is not. (<u>Presynaptic:</u> same but invert x-y).

$$\Delta w = (1-w)xy - w(1-x)y$$

- <u>Covariance:</u> stronger when neurons have synchronous activity and weaker otherwise.

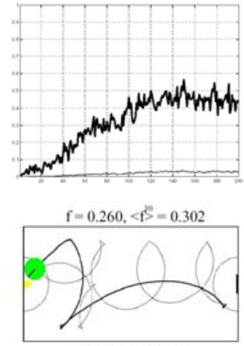
A sequential task

- A Khepera robot gains fitness by staying on grey area while light is on. But must switch on light first by stepping onto black area at the other end. IR, ambient light, and vision system. Discrete recurrent neural network as controller.



$f = 0.422, \langle f \rangle^{10} = 0.499$

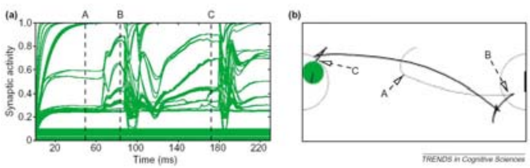
Adaptive synapses



$f = 0.260, \langle f \rangle^{10} = 0.302$

Fixed synapses

Some weights remain static, some change at a similar timescale as that of behaviour. Different "phases" can be identified

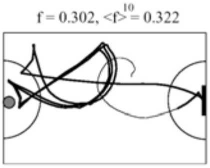


Cross-platform transfer

- Test Khepera controller in Koala robot (larger robot, six wheels, two motors, 16 IR sensors) without further evolution.

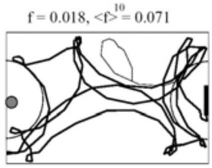
- Fairly good transfer for adaptive synapses. No transfer at all for fixed synapses

$f = 0.302, \langle f \rangle^{10} = 0.322$



Adaptive synapses

$f = 0.018, \langle f \rangle^{10} = 0.071$



Fixed synapses

GasNets

- A different kind of plastic neural controller. Inspiration from contemporary neuroscience. (Husbands, O'Shea, Smith, Phillipides at Sussex)
- Real nervous systems can be viewed as involving several interacting dynamical processes each with different characteristics: electrical, short range chemical, long range chemical, etc.

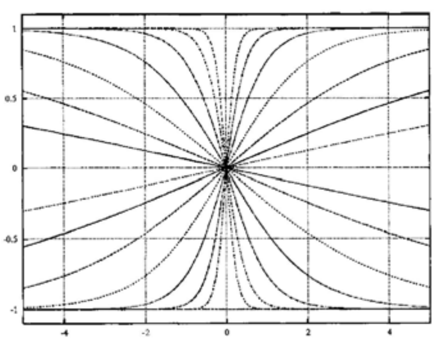
- Much interest has been generated recently regarding NO as a neurotransmitter. Unlike classical transmitters that act mainly at the synaptic site, NO can diffuse over large volumes of space and remain active for long periods, affecting many cells and synapses. It has been implicated in many modulatory roles
- Modulatory effects could be used to change synaptic or cell properties, as well as modifying adaptive processes such as Hebbian learning.
- Will controllers evolve faster with such mechanisms? Will they be more robust?

A GasNet controller

- Neurons are spread on a 2D plane. They can be connected by inhibitory or excitatory links.
- Some nodes, under certain circumstances, can emit 'gases' that change the transfer function (in a concentration-dependent way) of other nodes.

$$O_i = \tanh(k_i(\sum w_{ji}O_j + I_i) + b_i)$$

- All parameters genetically set. *k* is affected by the local gas concentration (in ways that are genetically set).



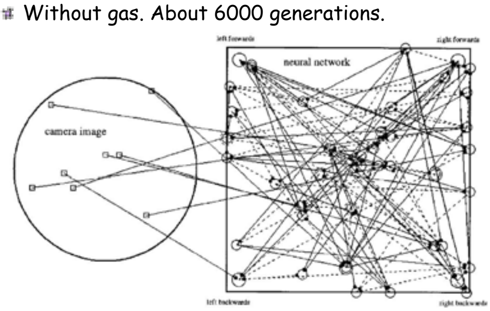
- Nodes can emit 2 'gases' under genetically set conditions:
  - node activation > *Te*
  - concentration of a gas in the vicinity > *Tc*
- Gas concentration:

$$C(d,t) = \begin{cases} C_0 e^{-2d/r} T(t) & d < r \\ 0 & else \end{cases}$$

- Radius of influence (*r*) genetically determined. *T(t)* linear build-up/decay function of time (slope genetically set). Gas 1 increases *k*, Gas 2 decreases *k*.

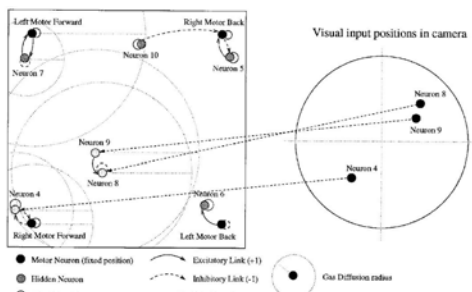
Results

- Without gas. About 6000 generations.



Results

- With gas. ~600 generations, 'simpler' structures.

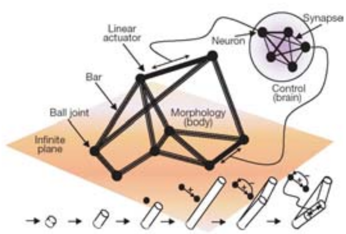


- More recently: looking a genetically set 'receptors': each neuron may or may not respond to gas concentrations. Evolvability increases roughly tenfold again.
- Many open questions: why? what happens to fitness landscape? what about other mechanisms? How stable are these controllers? How robust? WIP.

Evolving morphologies:

- **Golem project:** Lipson and Pollack, Brandeis University, 2000.
- Evolutionary design of body morphology, actuators and controller + automatic fabrication of designs.

- Building blocks: bars, joints, linear actuators, neurons. Evolve in simulation (maximize distance travelled), build using rapid prototyping (extrusion of thermoplastic layer by layer), test in reality (with fairly good results). Mutations introduce new body elements or neurons and modify them. No sensors.



Examples




Extensions

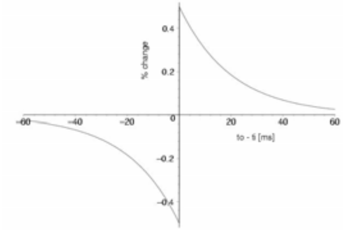
- Hornby & Pollack 2001. Looking for more complex structures; generative encoding using L-systems.
- Evolution of static and mobile 2-D and 3-D structures in simulation and tested in reality.

Spiking neurons

- Interesting from the point of view of novel neural mechanisms. More plausible with increasing computing power. Very difficult to design functional controllers by hand. Evolutionary methods ideal for this.
- Floreano and Matthiusi (2001) evolved visually guided Khepera to navigate in an enclosure avoiding striped walls. Also work in Alice robot and aiming at flying robots
- Di Paolo (2002/2003) Experiments evolving spike-timing synaptic plasticity (STDP)

STDP

- Synaptic plasticity depends on the precise relative timing between pre- and postsynaptic spikes.



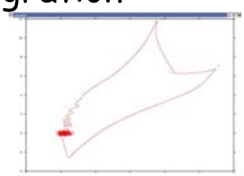
Evolving STDP

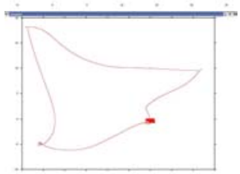
- It is possible to evolve only the parameters of the STDP rules and other forms of plasticity.
- Controllers are highly robust. With low neural noise they rely heavily on spike timing.
- With higher levels of noise, synchronous firing happens but is not essential. STDP works (paradoxically) in the absence of precise spike timing.
- Comparisons with plastic CTRNNs show STDP to be more efficient in achieving stable controllers

Evolving path integration

- Desert ants are able to forage and return to their nest travelling the equivalent of many miles.
- They use path integration and landmark navigation
- Evolution of 2-D path integration in robot.

R. Vickerstaff, E Di Paolo, (2005)





Active vision, arm movement

Evolved model-free, visually-guided arm control

Uses <u>body variables and proprioception</u> for locating, focusing on and reaching external objects.

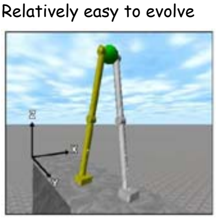
Robust to changes in arm length and weight, etc.

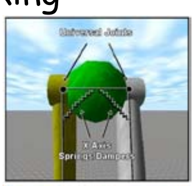
<u>Future tasks:</u> writing, painting

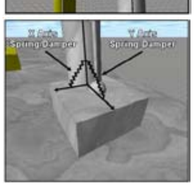
Thomas Buehrmann, 2003

Evolving natural walking

- 3-D walkers, hip movement, control.
- Very hard to design by hand
- Relatively easy to evolve



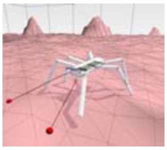


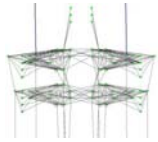


Current version

- full body 32 degrees of freedom including spine
- physical version currently being built

Mars rover



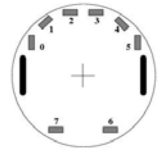


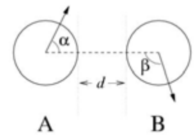
- Joint project with ESA and partners
- A six-legged neural-oscillator driven highly robust rover capable of planetary exploration on rough terrains.

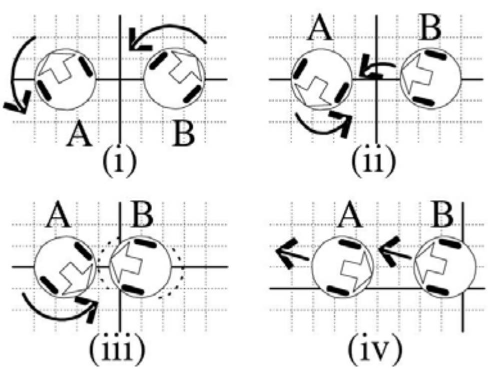
role allocation and signalling

- Two identical robots using only proximity sensors must coordinate their actions in a role-allocation task.
- Robots start with one of many possible relative orientations.
- They must move together in any direction maximizing the distance to the original position.

Matt Quinn (2001)



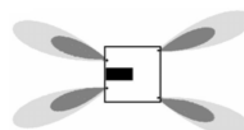




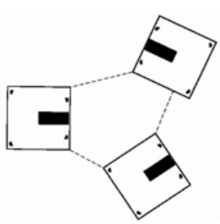
robot team coordination

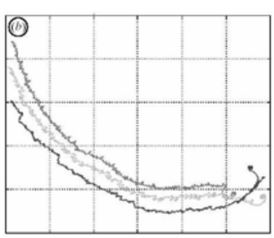
- Homogeneous teams of 3 robots interacting via infrared sensors.
- Evolve coordination and role allocation in simulation. Test in real-world.

Matt Quinn et al. 2002/2003



robot team coordination





Collective adaptation,
Emergent effects

Open avenues

- Spiking neurons, fast oscillators, stochastic resonance.
- Physiologies (hormones, chemical control).
- Evolution of learning (not the same as evolution of plastic controllers, but same ballpark area).
- Minimal cognition. Memory. Intentional robotics. Social behaviour (joint attention, pointing, etc).
- Developmental systems.