## Artificial Life Lecture 5

Towards the more concrete end of the Alife spectrum is robotics.

Alife -- because it is the attempt to synthesise -- at some level -- 'lifelike behaviour'.

AI is often associated with a particular style of robotics – here the emphasis may be different.

A **Dynamical Systems** approach, and one of the methodologies being **Evolutionary Robotics.**

## Evolutionary Robotics

ER can be done
- ✓for Engineering purposes - to build useful robots
- ✓for Scientific purposes - to test scientific theories

It can be done
- ✓for Real or
- ✓in Simulation

Here we shall start with the most difficult, robots with Dynamic Recurrent Neural Nets, tested for Real.

Then we shall look at simplifications and simulations.

## The Evolutionary Approach

Humans are highly complex, descended over 4 bn yrs from the 'origin of life'.

Let's start with the simple first - 'today the earwig'
(not that earwigs are that simple ...)

Brooks' subsumption architecture approach to robotics is 'design-by-hand', but still inspired by an incremental, evolutionary approach:

- ✓Get something simple working (debugged) first
- ✓Then try and add extra 'behaviours'

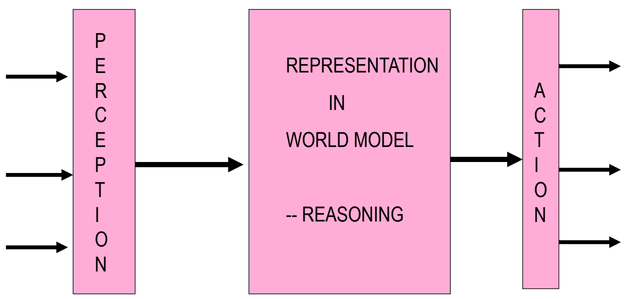
## What Class of 'Nervous System'

When evolving robot 'nervous systems' with some form of GA, then the genotype ('artificial DNA') will have to encode:

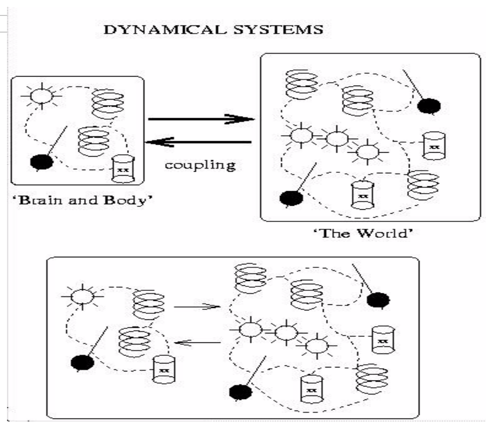
- ✓The architecture of the robot control system
- ✓Also maybe some aspects of its body/motors/sensors

But what kind of robot control system, what class of possible systems should evolution be 'searching through' ?

## … could be a classical approach ?




## … or a Dynamical Systems Approach



## ‘Reasoning all the way down’

The Classical AI approach, obsessed with reasoning and computing, assumed that ***even*** something as simple as walking across the room, maintaining one’s balance, required reasoning and computation … …

… … “Sense Model Plan Action” …

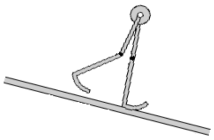
… … Brain controlling muscles

But look at this ---

## Passive Dynamic Walking

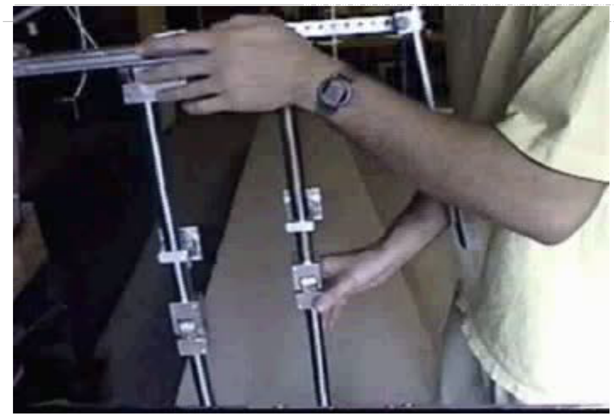
‘Natural walking behaviour', stable to small perturbations, can emerge from 'all body and no brain' !
It is the dynamics that count, whether the dynamics arise with or without a coupled nervous system.

Dan Jung’s walker movie -- see selection from http://ruina.tam.cornell.edu/research/topics/robots/index.html
"Passive Dynamic Walking", from Tad McGeer



## Walking without a nervous system

## For real …



## Compare with the Honda Humanoid

## Dynamic skills all the way up?

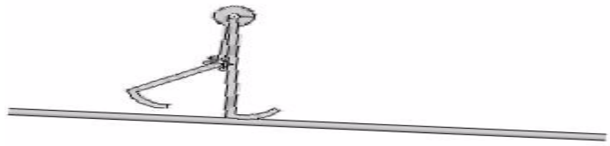
Perhaps rather than ‘Reasoning all the way down’ …

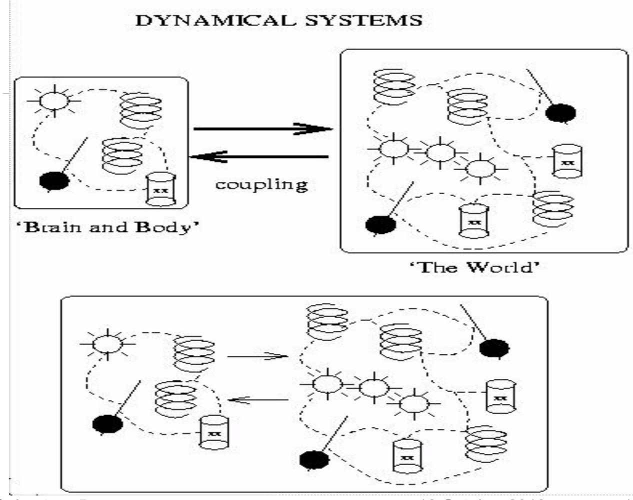
… we should think in terms of ‘Dynamic skills all the way up’

## Two initial lessons -- cognition is

●Situated: a robot or human is always already in some situation, rather than observing from outside.

●Embodied: a robot or human is a perceiving body, rather than a disembodied intelligence that happens to have sensors.






## DS approach to Cognition

cf R Beer 'A Dynamical Systems Perspective on Autonomous Agents' Tech Report CES-92-11. Case Western Reserve Univ. Link via http://vorlon.ces.cwru.edu/~beer/pubs.html also Beer, R.D. (2000). Dynamical approaches to cognitive science. *Trends in Cognitive Sciences* **4**(3):91-99.

In contrast to Classical AI, computational approach, the DS approach is one of 'getting the dynamics of the robot nervous system right', so that (coupled to the robot body and environment) the behaviour is adaptive.

Brook's subsumption architecture, with AFSMs (Augmented Finite State Machines) is one way of doing this.

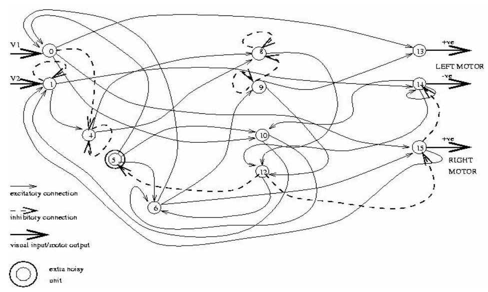
## Dynamic Recurrent Neural Networks

DRNNs (and one specific kind: CTRNNs = Continuous Time Recurrent Neural Networks) are another (really quite similar way).

You will learn about other flavours of Artificial Neural Networks (ANNs) in Adaptive Systems course.
-- eg ANNs that 'learn' and can be 'trained'.

These DRNNs/CTRNNs are basically different -- indeed basically just a convenient way of specifying a class of dynamical systems
-- so that different genotypes will specify different DSs, giving robots different behaviours.

## One possible DRNN, wired up

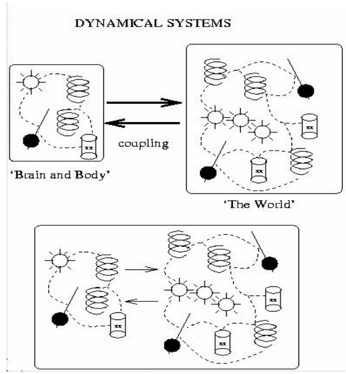



This is just ONE possible DRNN, which ONE specific genotype specified.

## Think of it as ...

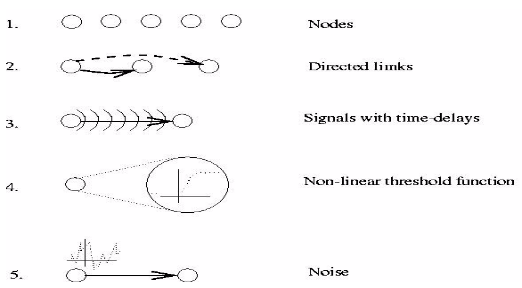
Think of this as a nervous system with its own Dynamics.

Even if it was not connected up to the environment (I.e. it was a 'brain-in-a-vat'), it would have its own dynamics, through internal noise and recurrent connections)



## DRNN Basics

The basic components of a DRNN are these
(1 to 4 definite, 5 optional)




## ER basics

The genotype of a robot specifies
*(through the encoding genotype->phenotype that WE decide on as appropriate)*
how to 'wire these components up' into a network connected to sensors and motors.

*(Just as there are many flavours of feedforward ANNs, there are many possible versions of DRNNs – in a moment you will see just one.)*

Then you hook all this up to a robot and evaluate it on a task.

## Evaluating a robot

When you evaluate each robot genotype, you
- ✓Decode it into the network architecture and parameters
- ✓Possibly decode part into
  body/sensor/motor parameters
- ✓Create the specified robot
- ✓Put it into the test environment
- ✓Run it for n seconds, scoring it on the task.

Any evolutionary approach needs a selection process, whereby the different members of the population have different chances of producing offspring according to their **fitness**

## Robot evaluation

**(Beware - set conditions carefully!)**

Eg: for a robot to move, avoiding obstacles -- have a number of obstacles in the environment, and evaluate it on how far it moves forwards.

Have a number of trials from random starting positions
- ✓ take the average score, **or**
- ✓ take the worst of 4 trials, **or**
- ✓ (alternatives with different implications)

Deciding on appropriate fitness functions can be difficult.

## DSs -> Behaviour

The genotype specifies a DS for the nervous system

Given the robot body, the environment, this constrains the behaviour

The robot is evaluated on the behaviour.

The phenotype is (perhaps):

- ✓the architecture of the nervous system(/body)
- ✓or ... the behaviour
- ✓or even ... the fitness

## Robustness and Noise

For robust behaviours, despite uncertain  circumstances, noisy trials are needed.

Internal noise (deliberately put into the network) affects the dynamics (eg self-initiating feedback loops) and (it can be argued) makes 'evolution easier'
-- 'smooths the fitness landscape'.

## Summarising DSs for Robot Brains

They have to have **temporal** dynamics.
Three (and there are more...) possibilities are:

(1) Brook's subsumption architecture

(2) DRNNs as covered in previous slides

(3) Another option to mention here: Beer's networks (= CTRNNs)

see Beer ref. cited earlier, or "Computational and Dynamical Languages for Autonomous Agents", in Mind as Motion, T van Gelder & R. Port (eds) MIT Press

## Beer's Equations

Beer uses **CTRNNs** (continuous-time recurrent NNs), where for each node (i = 1 to n) in the network the following equation holds:

$$\tau_i \frac{dy_i}{dt} = -y_i + \sum_{j=1}^{n} w_{ji}\sigma(y_j - \theta_j) + I_i(t)$$

$y_i$ = activation of node i
$\tau_i$ = time constant, $w_{ji}$ = weight on connection from node j to node i
$\sigma(x)$ = sigmoidal = $(1/1+e^{-x})$
$h_i$= bias,
$I_i$ = possible sensory input.

## Applying this for real

A number of different examples will be given in the reading for the Week 4 seminars (Floreano paper and Sussex paper)

One issue to be faced is:
- Evaluate on a real robot, or
- Use a Simulation ?

On a real robot it is expensive, time-consuming -- and for evolution you need many many evaluations.

## Problems of simulations

On a simulation it should be much faster
(though note -- may not be true for vision)
cheaper, can be left unattended.

BUT AI (and indeed Alife) has a history of toy, unvalidated simulations, that 'assume away' all the genuine problems that must be faced.

Eg: grid worlds "move one step North"

Magic sensors "perceive food"

## Principled Simulations ?

How do you know whether you have included all that is necessary in a simulation?

-- only ultimate test, **validation,** is whether what works in simulation ALSO works on a real robot.

How can one best insure this, for Evolutionary Robotics ?

## 'Envelope of Noise' ?

Hypothesis: -- "if the simulation attempts to model the real world fairly accurately, but where in doubt extra noise (through variations driven by random numbers) is put in, then evolution-in-a-noisy-simulation will be more arduous than evolution-in-the-real-world"

Ie put an envelope-of-noise, with sufficient margins, around crucial parameters whose real values you are unsure of.

"Evolve for **more robustness** than strictly necessary"

**Problem:** some systems evolved to rely on the existence of noise that wasnt actually present in real world!

## Jakobi's Minimal Simulations

See, by Nick Jakobi:

(1) Evolutionary Robotics and the Radical Envelope of Noise Hypothesis (csrp457) http://drop.io/alergic ➔ csrp457.pdf
(2) The Minimal Simulation Approach To Evolutionary Robotics
http://citeseer.nj.nec.com/116192.html
also see
Csrp497 http://drop.io/alergic ➔ csrp497.pdf

Minimal simulation approach developed explicitly for ER – the problem is often more in simulating the environment than the robot.

## Minimal Simulation principles

Work out the minimal set of environmental features needed for the job -- the **base set**.

Model these, with some principled envelope-of-noise, so that what uses these features in simulation will work in real world
-- '**base-set-robust**'

Model everything ELSE in the simulation with wild, unreliable noise -- so that robots cannot evolve in simulation to use anything other trhan the base set
-- '**base-set-exclusive**'

## Guidelines for robotic projects

Working with real robots is very hard - maintenance.

When using simulations be aware of the shortcomings of naive, unvalidated simulations

Worry about Grid worlds, Magic sensors ... ...

There are now simulations, here and elsewhere (eg Khepsim) that have been validated under some limited circumstances - through downloading/testing some control systems on real robot.

## Agent projects

Useful robotics projects can be done with such careful simulations.

Then there is still a role for more abstract simulations for tackling (eg) problems in theoretical biology
-- but then these are not robotics simulations

Many useful Alife projects are of this latter kind – but then it is almost certainly misleading to call these 'robotics'.

*'AGENTS'* is a more general term to use here.