In this lecture consider Hard A Life
Includes some ‘real robots’ and simulated ones
We mention some of the early work done here
Seven dwarves – simple robots that can learn and interact
Also a variety of work done elsewhere
Robots that swarm, self replicate and flock
We also outline methods for learning, including
Finite State Automata, Markovian Domains, Machine Learning
Reinforcement Learning; Cognitive Learning; Mental Acting
Temporal Difference Learning; Q Learning
Evolutionary Robotics ... Learning Classifier Systems
Robotics in Cybernetics

Perceive environment (ultrasonics) and act (motors drive wheels)

Program series of rules for obstacle avoidance /following

Then KW wanted to demonstrate real time learning in public lecture

Learn by trial and error - fuzzy automata

Interesting to observe ‘emergent’ behaviour (from rules)

Demonstrate benefit of sharing experiences - locally/USA

Also flocking behaviour, finding ‘food’
Other Reading Robots

Six legged 'Elma'
Controller each leg
Off line, GAs evolve 'gait'

Tracked robots -rugged

Engaging Robots: Innovative Outreach for Attracting Cybernetics Students
Flocking Robots

“The Swarmbots have already shown their ability to co-operatively explore and navigate, for example searching an area in the most efficient way without central co-ordination.”
www.defensetech.org/

http://www.youtube.com/watch?v=Kk4OZnuzNNw
NB: Better fish
http://uk.youtube.com/watch?v=eO9oseiCTdk&NR=1
Swarm Bots

Much work on implementing swarm intelligence on Robotics
Commercial / Govt funded projects

http://news.bbc.co.uk/1/hi/technology/7548190.stm

SYMBRION - Symbiotic Evolutionary Robot Organisms
I-SWARM SWARM-BOTS

http://uk.youtube.com/watch?v=e44hA6IBtkA&NR=1

iRobot and Frontline Robotics : teaching how to work together.
See http://www.irobot.com/
Issues in Swarms

Collective intelligence
  Self-organisation
  Goal switching
Morphology - structures of A-Life
  Heterogeneous or homogenous robots
  Global or local control
Hardware
  Scaling i.e., miniaturisation
  Communication
  Power e.g., storage and recharging
Infrastructure
  Operating system
  Visualisation & tracking
Issues in Swarms: Scaling

Large-scale
Mine disposal, search & rescue, cleaning

http://dilab.eecs.utk.edu/index.html

Miniaturised-scale
Medical applications, repair, surveillance

http://groups.csail.mit.edu
Self Replicating / Repairing

Cornell University's self-replicating robot modules: cubes about 4" inches on a side.
Able to swivel along a diagonal.

http://www.youtube.com/watch?v=gZwTcLeelAY

ckBot: Self-Assembly after Explosion + Dynamic Rolling
Decentralized, fault-tolerant system with structural isomorphism.

http://uk.youtube.com/watch?v=uIn-sMq8-Ls
Slug Bot

http://news.bbc.co.uk/1/hi/sci/tech/503149.stm

Once robot collected a load of slugs it must return to the static fermentation station before battery fully flat.

Next we give an overview of methods used for learning..
Finite State Automata

A model of a system which has states; current set by past Conditions exist for Transitions - often set by inputs Actions can occur also - eg output set

Eg to see if odd/even number of 0/1s

Deterministic FA:
Exactly one transition for each combination of ins

Non Deterministic FA:
Can be 0, 1 or more transitions for each combination of ins

Can convert N DFA to DFA

Often used in Machine Learning
**Markovian Domains**

Markov chain: process for moving through set of states

A Markov process: model for random evolution of a memoryless system: future state depends only on its present state.

Maze - unique s-a (state-action) pairs - know where you are.
Mazes often used in machine learning

**Non-Markovian Domain**

needs memory to optimise
Various Machine Learning methods exist
These are briefly outlined ...

**Reinforcement Learning (RL)**

Reinforcement Learning: an Introduction
Richard S. Sutton and Andrew G. Barto MIT Press, 98

(Book is on-line)
Fuzzy Automata – used in Cyb

Have series of actions: each wheel Forward / Off / Backward
Probability associated with 9 possible combinations
Choose one action probabilistically; test if success

In open - how well moved; - or if moved away from object
If so, increased prob of that action, else decrease

BUT, need set of such automata for different conditions
Chose 5 automata -
Open; Near on R; on L; Close on R; on L

BB BO BF OB OO OF FB FO FF
Automatic Selection of Automata

Have more automata; Detect when similar, so merge them. To speed up, when adjust probabilities in chosen automaton, adjust adjacent ones also.

Ashdown and Mitchell (2005) IASTED CI Conf
Cognitive Learning

Mental Acting

Mental acting uses an evolved generalised environmental model to propagate reinforcement internally.

In cognitive terms:

- Mental acting is comparable to a thought process.
- Occurs independently of the current (outside) environment, e.g.
  - Planning
  - Mental problem solving
  - Imagination of certain events
  - Dreaming

Used in anticipatory control / learning classifier systems.
Temporal Difference (TD) Learning

Combines Monte Carlo & Dynamic Programming Ideas:

- Learn directly from raw experience
- No model of an environment’s dynamics
- Update estimates due to other learnt estimates
  - without waiting for outcome (bootstrap)

Used for solving Reinforcement Learning problem


Q-Learning


Paul Werbos, 1977-1987

A R-L technique: learn expected utility of taking a given action in a
given state then following a fixed policy

Simple way for agents to learn optimally in controlled Markovian
environment

Convergence of trial-and-error learning & dynamic prog

Q : function of quality of action A in state S

Simplifies TD analysis and has convergence proofs

But Q-learning can require excessive memory and often contains non-
optimum paths
For interest : Algorithm

Initialise $Q(s,a)$ and $Model(s,a)$ for all $s \in S$ and $a \in A(s)$

Do forever:

1. $s \leftarrow$ current (non terminal) state
2. $a \leftarrow \varepsilon$-greedy($s,Q$)
3. Execute action $a$; observe resultant state $s'$ and reward $r$
4. $Q(s,a) \leftarrow Q(s,a) + \alpha \left[ r + \gamma \max_{a'} Q(s',a') - Q(s,a) \right]$
5. $Model(s,a) \leftarrow s',r$ (assuming deterministic environment)
6. Repeat $N$ times
   - $s \leftarrow$ random previously
   - $a \leftarrow$ random action previously taken in $s$
   - $s',r \leftarrow Model(s,a)$
   - $Q(s,a) \leftarrow Q(s,a) + \alpha \left[ r + \gamma \max_{a'} Q(s',a') - Q(s,a) \right]$

Can utilise models in Q-learning
Evolutionary Design and E. Robotics

The Golem project  http://www.demo.cs.brandeis.edu/golem/
Genetically Organized Lifelike Electro Mechanics
Simple electro-mechanical machines evolve from scratch

Robots that are "self-aware"

'real robot'

Software version


in own time watch this

Concluded progress not limited by computational power - rather need better approach
Machine Consciousness

http://cswww.essex.ac.uk/staff/owen/machine/mchome.html

CRONOS Project

Hardware robot CRONOS, a virtual copy SIMNOS,
visual system closely based on the human brain,
the SpikeStream neural simulator,
systematic methods for identifying and describing the conscious states of the system.

David Gamez investigates: might a machine be conscious

Owen Holland: intelligent agent needs own world model: SIMNOS provides basis CRONOS’ model
'Anthropomimetic' robot

http://cswww.essex.ac.uk/staff/owen/machine/videos.html

Videos from the development of CRONOS and SIMNOS
http://www.youtube.com/watch?v=3_0ig6g46Jw
Holland's view

http://cswww.essex.ac.uk/staff/owen/adventure.ppt

Want robot that is conscious like humans -
   really conscious and feelings - not mimicking them

Consider agent with mission in hostile changing world
   Cant be programmed with all eventualities
   Cant learn consequences of all actions in all situations
   Could succeed if learned enough so can predict consequences for
   mission of tried and untried actions, and by selecting suitable
   actions

Proposes IAM ...
IAM Internal Agent Model

We're trying to build a robot that has an internal model of itself and an internal model of the world, and that uses them to predict the outcomes of novel or untried actions. And maybe the IAM will be conscious...

Is this The Future of Embodied Artificial Intelligence? See Owen Holland: www.machineconsciousness.org
Other Web Sites

http://www.idsia.ch/~juergen/rl.html

http://ccsl.mae.cornell.edu/
http://www.mae.cornell.edu/Lipson/
http://ccsl.mae.cornell.edu/papers/Science06_Bongard.pdf
   Resilient Machines Through Continuous Self-Modeling
   << a robot that can recover from change through self modelling >>

Next lecture - looking at Wet Life and Biological Aspects
Wet alife is artificial life created in chemical substrates based on water or another solvent. It is created in vitro (in glass) as opposed to the normal in silico. Generally involves expts with chemical substrate in water/solvent hence "wet" in "wet alife".

The holy grail of wet artificial life is to create an artificial cell in the laboratory out of materials found in a chemical supply room.

If we let “soft” artificial life refer to computer simulations or other purely digital constructions that exhibit life-like behavior, we should also recognize “hard” artificial life which produces hardware implementations of life-like systems, and “wet” artificial life which involves the creation of life-like systems from biochemical substances in the laboratory. Mark Bedau
**Belousov-Zhabotinsky reaction**

The BZ reaction is an auto-catalytic reduction-oxidation (redox) process. Each step of multi-step reaction sequence generates a catalyst that speeds up the counter reaction:


**Standard:**

http://uk.youtube.com/watch?v=SZncQG8dPVI&NR=1

**Spirals:**

http://uk.youtube.com/watch?v=GEF_NtTNeMc

http://online.redwoods.cc.ca.us/instruct/darnold/DEProj/Sp98/Gabe/bzreact.htm where can see chemistry/maths...
Animats

Artificial animals, a contraction of anima-materials. The term includes physical robots and virtual simulations. Animat research became popular since Rodney Brooks' seminal paper "Intelligence without representation". The word coined by S.W. Wilson in 1991, in first proceedings of the Simulation of Adaptive Behaviour, or "From Animals to Animats".

An example using the Animat model as proposed by Wilson is discussed in chapter 9 of Stan Franklin's book, Artificial Minds.

Here, the animat learns independently about its environment by application and evolution of pattern-matching rules called "taxons".

In 2001 Thomas DeMarse performed studies on 'Neurally controlled Animat'.

Society of Adaptive Behaviour meets every two years - journal
Anti-Animats: Alan H Goldstein

Based on the Animat Test (reference "I, Nanobot.") any nonbiological material or entity that exhibits the minimum set of behaviors that define a life form is, de facto, an Animat.

Goldstein's basic premise: in age of nanobiotechnology must follow the chemistry and molecular engineering rather than watching for emergence of some pre-conceived minimum level of 'intelligence'.

He cautions: serious disconnect between nanobiotechnology and A-life based on profound differences in scientific training, experimental systems, and the different sets of terminology (jargon).

Nanobiotechnologists (really molecular engineers who work with both biological and nonbiological molecules) are generally not concerned with complex systems per se.

A-Life researchers mainly take a systems-level approach.

Nanotechnology could produce animats that don't fit A-Life paradigms.
In Vitro Neuronal Networks

A hybrot (short for "hybrid robot"): cybernetic organism : robot controlled by a computer with both electronic and biological elements (rat neurons connected to a computer chip).

First accomplished by Dr. Steve Potter, Prof of biomedical engineering at the Georgia Institute of Technology:

Droplet of solution with 1000s rat neurons onto Si chip with 60 electrodes. Signals from firing cells picked up by electrodes, amplified into computer, which wirelessly relays to robot.

Robot manifests neuronal activity with physical motion.

Robot sends info back to cells. Knows environment via light sensors.

Not a cyborg as is not a human augmented by computer...
In Vitro Neuronal Networks

Another interesting feature of the hybrot is its longevity. Neurons separated from a living brain usually die after a short period of time; however, due to a specially designed incubator utilizing a new sealed-dish culture system, a hybrot may live as long as two years.

http://www.neuro.gatech.edu/groups/potter/
http://neuro.gatech.edu/groups/potter/articles/TechReviewArticle.htm
Thomas DeMarse: Neuronal Networks

http://neural.bme.ufl.edu/
In Vitro Neuronal Networks


In this paper we describe the use of a learning classifier system to control the electrical stimulation of cultured neuronal networks. The aim is to manipulate the environment of the cells such that they display elementary learning, i.e., so that they respond to a given input signal in a pre-specified way. Results indicate that this is possible and that the learned stimulation protocols identify seemingly fundamental properties of *in vitro* neuronal networks. Use of another learning scheme and simpler stimulation confirms these properties.
Cultured NNs and Mobile Robots

Ben Whalley, Kevin Warwick, Slawek Nasuto, Mark Hammond, Julia Downes, Dimitris Xydas: U of Reading

Used on ‘Gordon’, robot in Science Museum
Project Connectivity Layout

Offline Analysis (incl. online capabilities / "Mex" files)

MATLAB

Online Experimentation

Communication over University's LAN. Server deals with robot movement commands and sensory data acquisition, off-loading some processing load of the system. Stimulator and spike detection client communicate with robot client, providing a closed-loop link between culture/robot.
Live Run

http://www.youtube.com/watch?v=1-0eZytv6Qk

Wall -> Stimulation -> Response
Wall -> Stimulation 100%
Stimulation -> Response 100%
Total closed loop time: 75 ms

Run time: 4 min
Total Turns: 41
Meaningful turns: 41
Spontaneous turns: 0
Wall Hits: 0

http://www.reading.ac.uk/sse/about/news/sse-newsarticle-2008-08-18b.asp
Cleaning and spike sorting data

Raw data needs processing.

Saved spikes contain other spikes, overlaps etc which need to be removed before clustering on spike shape.

Most units successfully separated and clustered, usually between 2 and 6 per channel.
The Grand Plan

Spike shape + Firing pattern (ISI), amplitude changes etc + Morphology = Possibility of identifying unit type

Cross correlations between unit firing times. + Other temporal and spatial info (e.g. distance between electrodes) = Identification of a set of feasible networks of specific units underlying robot behaviour.

p39 RJM 30/01/13 SE4SI12 Artificial Life - Part B © Dr Richard Mitchell 2013
Wet-Alife Issues

1. Ethics

“Our goal is not to hook up primate brains to a robot,” said Higgins. “There’s the possibility, when you start to tap into brains, for all sorts of evil applications. There are certainly all these ethical issues when you start talking about human and primate brains.”

Creation of artificial viruses and lifeforms may have unknown effects on the ecosystem

Sullins J; Ethics and artificial life : From modeling to moral agents
Ethics and information technology 2005, vol. 7, no 3 pp. 139-148

2. Results too simple

Utilising known patterns within biology is not the same as the biology learning useful patterns.

Inserting material into the host cell and utilising the living machinery ... is not the same as creating a self-replicating life.
Biological A Life

Evolutionary Biology
Epigenetics
Baldwin Effect
Unconventional computing
Wetware computing
Miscellaneous topics
  Synchronisation
  Small Word Theory
Evolutionary biology

Charles Taylor (of UCLA) recommends the following books

   Evolutionary Biology, by Douglas J. Futuyma.
   Evolutionary Genetics, by John Maynard Smith.

From the perspective of mathematical modelling:

   Theory of population genetics and evolutionary ecology: an introduction, by Jonathan Roughgarden.
   ('bit old, but good')

   Principles of population genetics, by Daniel L. Hartl and Andrew G. Clark. ('a class of its own; contains ref list')

   http://www.faqs.org/faqs/ai-faq/alife/
Epigenetics

http://www.stanford.edu/class/cs273a/papers.spr07/10/epigenetics.pdf

Recently evolved diverse phenomena to defined field

Term coined by Waddington, 1942 - ‘branch of biology which studies causal interactions between genes and their products, which bring the phenotype into being’

‘Epi’ may be thought of as “outside of” or “in addition to”.

Now, E is 'bridge' between genotype & phenotype

Phenomenon that changes final outcome of chromosome without changing underlying DNA sequence

Multiple cells : same genotype, but different ‘profiles’

Cellular differentiation governed by changes in Waddington’s ‘epigenetic landscape’ not by genetic inheritance
Epigenetic Landscapes

Cell (ball), rolls down an landscape
End represents different ‘fates’ of cell,
External factors, set if reach A, B, C or D

Current view of epigenetic machinery
Known phenomena shown directing pinballs (cells)
Epigenetic Landscape

Four "dimensions" in evolution—

Four inheritance systems that play a role in evolution:

• genetic,
• epigenetic (non-DNA cellular transmission of traits),
• behavioral,
• symbolic (transmission through language and other forms of symbolic communication).

These systems, they argue, can all provide variations on which natural selection can act.
The role of genetic inheritance dominates current evolutionary theory.

Learned behaviors could also affect the direction and rate of evolutionary change.

This notion was called the Baldwin effect, (after psychologist James Mark Baldwin)

In recent years, various philosophers and theorists have begun to employ the Baldwin effect in their accounts of the evolutionary emergence of mind and of how mind, through behavior, might affect evolution.

Evolution and Learning The Baldwin Effect Reconsidered

Edited by Bruce H. Weber and David J. Depew
Baldwin Effect

Assume a trait is absent from a population
(e.g. using sticks as tools)
A number of the population members learn this trait
The Baldwin effect allows for the trait to become innate throughout
the population.
This may be considered as local learning
(as opposed to global learning through genetics)
This is different to Lamarckian learning, where the traits alter the
genesis.
It may help to explain innate skills where several traits are needed
at once, e.g. hook making
Betty the Crow

http://www.youtube.com/watch?v=TtmLVP0HvDg
http://www.sciencemag.org/feature/data/crow/

Uses tool to get food
Unconventional Computing

Computing by a wide range of new or unusual methods (also known as alternative computing) including

- optical computing,
- chemical computing,
- biologically-inspired computing,
- DNA computing,
- amorphous computing,
- reversible computing,
- analogue computing.

- quantum computing,
- natural computing,
- wetware computing,
- molecular computing,
- nanocomputing,
- ternary computing,
Unconventional Computing

'Avoids' limitations of the von-Neumann computer architecture and the Turing machine concept, e.g. serial processing, computability ...

Slime moulds solve maze ...

Wetware computing

Prof Higgins, See http://neuromorph.ece.arizona.edu/

Project areas Higgins Lab - Arizona

Computational neuroscience : insect visual motion proc

Biologically-inspired engineering systems : inc robots

Hybrid bio-robotics : robots with insects as sensors

Visual electrophysiology : in flies, moths and dragonflies

Behavioral experiments : in honeybees and bumblebees.

Robotic electrophysiology instrument : velocity set by bioelectrical signals from hawk moth
Small World Networks (of real life?)

Networks of coupled dynamic systems often studied
Connection topology usually either regular or random
Many biological/social networks in-between
Can 'rewire' dynamic systems to this middle ground
to be highly clustered with small characteristic path lengths
These are called small world networks
Eg Neural Network of a worm, Power Grid; film actors
“Small-world phenomenon” - we are linked by few acquaintances -
Pioneering academic work of Stanley Milgram in the 1960's.
'Bacon' Number

Studies of movie stars: find number of steps necessary to link just about anybody who has ever been in a movie to, say, Kevin Bacon

http://oracleofbacon.org/center.php

<table>
<thead>
<tr>
<th>Steps</th>
<th># of people</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1806</td>
</tr>
<tr>
<td>2</td>
<td>145024</td>
</tr>
<tr>
<td>3</td>
<td>395126</td>
</tr>
<tr>
<td>4</td>
<td>95497</td>
</tr>
<tr>
<td>5</td>
<td>7451</td>
</tr>
<tr>
<td>6</td>
<td>933</td>
</tr>
<tr>
<td>7</td>
<td>106</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

$$A_v = \frac{\sum \text{Step} \times \text{NumPeople}}{\sum \text{NumPeople}}$$

Bacon : 2.95
Connery 2:828 better
**Small World Phenomenon**

Connected graph or network with a high graph diameter.
Add a few edges randomly, the diameter tends to drop drastically.

A random generation model that produces graphs with small-world properties, including short average path lengths and high clustering.

---

ordered  small-world  random

---

randomness 0 1
Application – Spread of Infection

Watts and Strogatz use simple model of infection in pop.
Pop. Modelled by family of graphs.
  At \( t = 0 \), one 'bod' infected.
  Infected bods die after a time.
  But infect healthy neighbours with probability \( r \)
Disease spreads along edges of graphs
  Whole pop infected, or disease dies – having infected only some
Critical infectiousness decreases rapidly for small \( p \)

www.tam.cornell.edu/tam/cms/manage/upload/SS_nature_smallworld.pdf
Synchronisation – and Biology

Synchronization of chaos is a phenomenon that may occur when two, or more, chaotic oscillators are coupled, or when a chaotic oscillator drives another chaotic oscillator.

When a male cricket wants to attract the ladies, he serenades: one wing on one, opens and closes wings: finely tuned tone...

Henry Bennet-Clark: in theory, wings vibrate in opposite directions, disrupting the sound's constant and even tone.

Crickets must have found a way ... so both wings vibrate in sync.

http://jeb.biologists.org/cgi/content/full/212/2/i-a

1967 Winfree proposed a model for spontaneous synchronization in large pops of biological oscillators such as flashing fireflies or cardiac pacemaker cells.
Synchronisation

In 1967, Winfree proposed a model for spontaneous synchronization in large pops of biological oscillators such as flashing fireflies or cardiac pacemaker cells.

In system of weakly coupled, nearly identical oscillators, more coupling strength $\rightarrow$ temporal analogue of a phase transition and, beyond a threshold value, the oscillators synchronize, with finally locked amplitudes and phases.

Ariaratnam and Strogatz take special case of Winfree model and identify (using phase plane) conditions for locking, etc. See http://www.nature.com/physics/highlights/6834-3.html
Synchronisation

Example: pacemaker and heart autosynchronise..

Ariaratnam and Strogatz take special case of Winfree model and identify (using phase plane) conditions for locking, etc. See http://www.nature.com/physics/highlights/6834-3.html
**Synchronisation**

Amount of Sync

Fraction of Pop at same speed

Perfect Sync

Phase transition

Amount of homogeneity in Pop.

- Incoherent
- Very diverse
- Moderately d.
- Clones

Sync: The Emerging Science of Spontaneous Order, Steven Strogatz
More Websites

http://www.kcl.ac.uk/ip/davidpapineau/Staff/Papineau/OnlinePapers/SocLearnBald.htm

http://www.cems.uwe.ac.uk/~lbull/

http://users.ox.ac.uk/~kgroup/tools/introduction.shtml

http://www.youtube.com/watch?v=8HN86pEfNc8

http://www.youtube.com/watch?v=tLO2n3YMcXw

(4 – 6.30mins)

http://tinkerlog.com/2007/05/11/synchronizing-fireflies/

http://en.wikipedia.org/wiki/Brainwave_synchronization

Here endeth Lectures