Artificial Life lecture 16

Game Theory: Evolution of Communication

Artificial Life methods are used to model and synthesise and understand all sorts of life-like behaviour on a spectrum from

Basic classes of low-level mechanisms that moderate simple intentional behaviour (eg CTRNNs for Braitenberg-type agents)

to

'Higher-level' strategic behaviour – including social or inter-agent behaviour ← This lecture !!

Game Theory

20th C development: maths originally developed by von Neumann.

Initial applications primarily towards economics, but then turned out to be really significant for biology.

John Maynard Smith (Sussex)

"Evolution and the Theory of Games" 1982

Evolutionar*ily* Stable Strategies

Basics of Game Theory

Suppose 2, or more, agents interact such that each has strategic choices (…fight or flee … chase or ignore… buy or don't buy….sell or don't sell … cooperate or defect…)

… and the outcome (…or outcomes, both short-term and longer-term) for each agent depends on what others do as well as its own choice

…then you can model this as a ***GAME***, in which agents can have better or worse strategies, which maybe they want to optimise

Eg Prisoners' Dilemma (One-time version)

2-person symmetric game: payoff is 'years in jail'

Non-zero sum (total outcome to both could be -2 or -10)

PAYOFF to each	B co-ops	B defects
A co-ops	A: -1 B: -1	A: -10 B: 0
A defects	A: 0 B: -10	A: -5 B: -5

Incentive for each player to 'defect' – yet that is worse for both than if they both co-operate!

Classic Dilemma: why altruism when cheating seems to pay?

Hawk Dove game: or 'Chicken'

Each bird can choose between Hawk-strategy (fight) or Dove-strategy (give in)

V is Value of victory

C is cost of conflict

C > V > 0

PAYOFFS	B acts as Hawk	B acts as Dove
A acts as Hawk	A: (V-C)/2 B: (V-C)/2	A: V B: 0
A acts as Dove	A: 0 B: V	A: V/2 B: V/2

J Maynard Smith, G.R. Price (1973) "The Logic of Animal Conflict" ***Nature*** 246: 15-18

Evolutionarily Stable Strategy

Surprisingly complex, for different choices of C and V.

One can analyse mathematically – or one can use an Alife-style computer strategy modelling large numbers of agents with genetically-specified strategies (or mixed strategies), where payoffs feed through to fitness and thus offspring.

An ***evolutionarily stable strategy*** would be one that could not be invaded.

For many games, such as versions of Hawk-Dove, one can prove there is no stable pure strategy – only mixed ones.

El Farol Bar

Santa Fe bar, busy every Thursday night. 100 potential customers decide independently each week whether to go

Symmetric, 100-player, non-zero sum

PAYOFF	If <=60 people go	If 61+ people go
For each person	+1	0

No deterministic strategy will work, clearly must be probabilistic or 'mixed strategy'.

BUT no mixed strategy exists that all players may use, in equilibrium !! Cf also 'The Minority Game'

Iterated Prisoners' Dilemma: Co-operate vs Defect

2 ways of having a varying strategy:

1. Probabilistically, eg throw dice: 60% C and 40% D
2. ***OR***, when same game is iterated many times, base your choice ***this*** time on what happened ***last*** time

Eg ***Tit-for-Tat*** strategy: first time **C**o-operate, thereafter copy what your opponent did last time.

IPD Iterated Prisoners' Dilemma: references

Robert Axelrod (1984): The Evolution of Cooperation. New York, Basic Books. ***[report of open tournaments]***

Axelrod, Robert and Hamilton, William D. (1981). "The Evolution of Cooperation." *Science*, 211(4489):1390-6

K. Lindgren, "Evolutionary phenomena in simple dynamics", pp. 295-312 in *Artificial Life II*, C. Langton et al (eds.), (Addison-Wesley, Redwood City, 1992).

K. Lindgren and J. Johansson, "Coevolution of strategies in n-person Prisoner´s Dilemma", in J. Crutchfield and P. Schuster, *Evolutionary Dynamics - Exploring the Interplay of Selection, Neutrality, Accident, and Function* (Addison-Wesley, 2001).

IPD: Alife relevance

Fertile field for ABMs (Agent Based Models) or IBMs (Individual Based Models) -- going beyond purely mathematical analysis that typically assumes uniformity within a population (eg Mean Field Theory)

Typical ALife-style simulation: large numbers of (relatively) simple agents interacting – sometimes with some basic geographical modelling – and analysing global behaviour. Potential to interact also with evolution

IPD, and other Game Theory models, immensely influential in Economics, Animal Behaviour, Social Sciences … etc…

Related: Evolution of Communication

Bruce **MacLennan** (1991): *Synthetic Ethology: An Approach to the Study of Communication* (pp 631-658)
Proc of Artificial Life II ed. CG Langton C Taylor JD Farmer and S Rasmussen, Addison Wesley

There are many more recent papers on all aspects of communication, in fact this is one of the more popular Alife subject areas. Not all the work is good!

Other work

Couple of other mentions of recent stuff:

Luc Steels 'Talking Heads'

Ezequiel di Paolo, on 'Social Coordination', DPhil thesis plus papers via web page http://www.informatics.susx.ac.uk/users/ezequiel/

General Lessons for Alife projects

As an Alife study of communication, the model discussed today attempted to ***simplify*** as much as possible whilst retaining only what MacLennan thought was the bare minimum he wanted to study.

He worked out objective criteria for success, and demonstrated that these were attained.

He did comparative studies.

Your own Alife project may be very different, but you will probably have to be concerned about similar issues.

What is communication ?

What is communication, what is meaning? Cannot divorce these questions from philosophical issues. Here is a very partial survey:

Naive and discredited **denotational** theory of meaning 'the meaning of a word is the thing that it denotes'

bit like a luggage-label.

Runs into problems, what does 'of' and 'the' denote?

What is it -- ctd

Then along came sensible people like Wittgenstein -- the idea of a 'language game'.

"Howzaaat?" makes sense in the context of a game of cricket.

The meaning of language is grounded in its use in a social context. The same words mean different things in different contexts.

Social context

cf Heidegger -- our use of language is part of our culturally constituted and situated world of needs,concerns and skilful behaviour.

SO... you cannot study language separately from some social world in which it makes sense.

Synthetic Ethology

So, (says MacLennan) we must set up some simulated world, some ethology in which to study language.

Ethology = looking at behaviour of organisms *within* their environment (not a Skinner box)

Burghardt's definition

GM Burghardt (see refs in MacLennan)
Definition of communication (see any problems with it?):

"Communication is the phenomenon of one organism producing a signal that, when responded to by another organism, confers some advantage (or the statistical probability of it) to the signaler or its group"

Grounding in evolutionary advantage

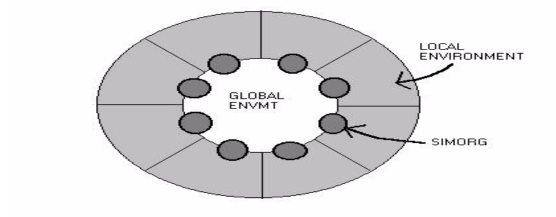
Criticisms

Ezequiel Di Paolo's methodological criticism of Burghardt:

"This mixes up a characterisation of the phenomenon of communication with an (admittedly plausible) explanation of how it arose"

Another dodgy area: treatment of *'communication'* as '*transmission of information*' without being rigorous about definition of **information** -- see Lecture 17 to come**.**

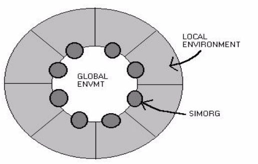
Simorgs



Simulated organisms: why should there be any *need* to communicate (MacLennan asks..) ??

Simorg world

OK, set it up so that each simorg has a *private* world, a **local environment** which only they can 'see', With one of 8 possible symbols *a b c d e f g h*



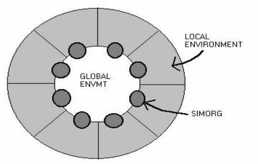
Plus there is a *shared* public world, a **global environment** in which any simorg can make or sense a symbol.
-- one of 8 possible symbols *p q r s t u v w*

Why communicate ?

Simorgs have to:

(a) 'try to communicate their private symbol'
and

(b) 'try to guess the previous guy's'



Each simorg can **write** a symbol *p-to-w* in global env ('emit') and **raise a flag** with symbol *a-to-h* ('act')

Writing a new symbol over-writes the old.

Simorg actions

When it is its turn, a simorg both writes a symbol and raises a flag, eg [*q, d*] -- depending on what its genotype 'tells it to do' (see later for explanation).

What counts as success is when it raises a flag *matching* the **private symbol** of the simorg who had the previous turn (normally turns go round clockwise)

Ie if simorg 5 does [*q, d*], when simorg 4's private symbol happened to be *d*', then this counts as 'successful communication' (via the global symbols) and **both** simorg4 and simorg5 get a point !

Evaluating their success

How do you test them all, give them scores? --

(A) minor cycle -- all private symbols are set arbitrarily by 'God', turns travel 10 times round the ring, tot up scores

(B) major cycle -- do 5 minor cycles, re-randomising all the private symbols before each major cycle.

Total score from (B) for each simorg is their 'fitness'

Simorg genotype

Each simorg faces 64 possible different situations --
8 symbols *a-to-h* privately, plus
8 symbols *p-to-w* in the public global space.

For each of these 64 possibilities, it has a genetically specified pair of outputs such as [*q, d*] which means '**write** *q* in public space, **raise flag** *d*'

So a genotype is 64 such pairs, eg

[*q d*] [*w f*] [*v c*]... ... 64 pairs long .. .. [*r a*]

The Evolutionary Algorithm

A Genetic Algorithm selects parents according to fitness (actually he used a particular form of steady-state GA) and offspring generated by crossover and mutation, treating pairs [*q d*] as a single gene.

NOTE: the importance of using steady-state GA, where only one simorg dies and is replaced at a time -- it allows for '*cultural transmission*', since the new simorg is born into '*an existing community*'

Adding learning

To complicate matters, in some experiments there was an additional factor he calls 'learning'.

Think of the genotype as DNA, which is inherited as characters.

When a simorg is born, it translates its DNA into a lookup table, or transition table, which is used to determine its actions.

How 'learning' works

WHEN learning is enabled, then after each action it is checked to see if it 'raised the wrong flag'.

If so, the entry in the lookup table is changed so that another time it would 'raise the correct flag' (ie matching previous simorg's private symbol)

BUT this change is *only* made to the phenotype, affecting scores and fitness, **NO CHANGE** is made to the genotype (which is what will be passed on to offspring) -- ie it is *not* Lamarckian.

How to interpret results?

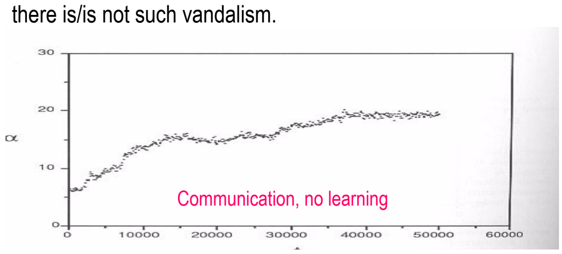
Suppose you run an experiment, with 100 simorgs in a ring, 8 private (*a-h*) and 8 public (*p-w*) symbols, for 5000 new births.

You *may* find communication taking place, after selection for increased fitness, with some (initially arbitrary) code being used such as
'if my private symbol is *a*, write a *p* into public space -- if you see a *p*, raise a flag with *a*' -- etc etc.

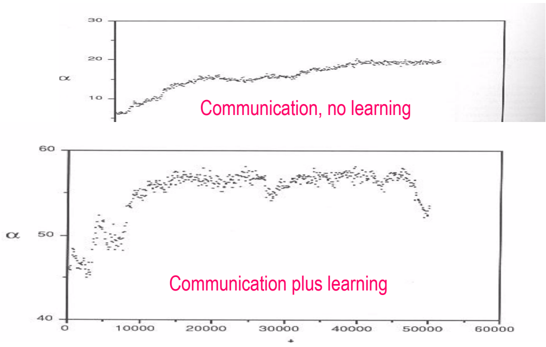
But how can you objectively check whether there really is some communication?

Tests for 'communication'

(1) Compare results doing as above with results when the global envt symbol is vandalised at every opportunity -- ie replaced with a random symbol. Fitnesses should differ when there is/is not such vandalism.



Comparison with learning



Dialects test

(2) Second way to test for communication: keep a record of every symbol/situation pair, such as

'see a global p, raise flag a' -- how often seen?
'see a global p, raise flag b' -- ditto
... ...
see a global w, raise flag h' -- ditto

If no communication, one should not expect any particular pattern to emerge, whereas with communication you should expect such statistics to have some discernible structure.

Evidence of dialects

TABLE 3 Denotation Matrix, Communication Permitted and Learning Disabled

	situation							
symbol	0	1	2	3	4	5	6	7
0	695	5749	0	1157	0	2054	101	0
1	4242	11	1702	0	0	0	1	0
2	855	0	0	0	0	603	862	20
3	0	0	0	0	1003	430	0	1091
4	0	0	0	0	0	0	2756	464
5	0	0	40	0	548	0	817	0
6	1089	90	1	281	346	268	0	62
7	0	201	0	288	0	0	2	0

$V = 2.272352$
$H = 3.915812$
$\eta = 0.3052707$

Comments

- Rarely a one-to-one denotation in the matrix
- Not always symmetric
- Probabilistic -- symbol 4 'means' situation 6 84% of time, means situation 7 16% of time.

Interesting comment: this method of GA saw communication arising, ---- **but** the original experiments were deterministic in the sense that: “least fit always died, the two fittest simorgs always bred to produce the replacement offspring” -- in these original experiments communication never arose !

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Some different views on Communication

See Ezequiel di Paolo
"An investigation into the evolution of communication“
Adaptive Behavior, vol 6 no 2, pp 285-324 (1998)
via his web page
http://www.informatics.susx.ac.uk/users/ezequiel/

Suggests the idea of information as a commodity has contaminated many peoples' views, including MacLennan.

MacLennan explicitly sets up the scenario such that some information is not available to everyone.