The Altricial-Precocial Spectrum for Robots

Aaron Sloman and Jackie Chappell

University of Birmingham, UK

Outline

What are precocial and altricial species?

- Precocial species are:

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens
- Altricial species are:

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens
- Altricial species are:
  - Fairly helpless at birth

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens
- Altricial species are:
  - Fairly helpless at birth
  - Have sense organs which are not fully developed at birth

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens
- Altricial species are:
  - Fairly helpless at birth
  - Have sense organs which are not fully developed at birth
  - Dependent on parents for longer

What are precocial and altricial species?

- Precocial species are:
  - Well-developed at birth/hatching – sense organs developed, have fur/feathers
  - Independently mobile
  - Some can feed themselves
  - Dependent on parents for a shorter time
  - e.g. horses, gazelles, ducks, turtles, chickens
- Altricial species are:
  - Fairly helpless at birth
  - Have sense organs which are not fully developed at birth
  - Dependent on parents for longer
  - e.g. song birds, primates, cats, elephants

The precocial end of the spectrum

Great bustard chick

Great bustard chick (*Otis tarda*) hatching

Some examples of skills – altricial species

New Caledonian crow

New Caledonian crow (*Corvus moneduloides*) making a hook

What are the underlying strategies?

Precocial and altricial species differ broadly in the strategies they use to generate appropriate behaviour. We might call these approaches ‘pre-configured’ and ’constructed’, and they are characterised by broad differences in their origin (genetically determined or learned), their flexibility and their potential for variability. However, altricial and precocial species may have a mixture of pre-configured and constructed skills.

Why is this relevant to robots?

- Animals with pre-configured skills come pre-equipped with competences for a particular environment: fast, accurate but inflexible and unable to cope with much variation

Why is this relevant to robots?

- Animals with pre-configured skills come pre-equipped with competences for a particular environment: fast, accurate but inflexible and unable to cope with much variation
- Animals with constructed skills take longer to become competent (and risk failing to do so): slower, more investment needed in training/learning, but very flexible and adaptable

Choosing an appropriate behavioural strategy

- Pre-configured skills are not inherently better or worse than constructed ones: it depends on the context in which they are needed

Choosing an appropriate behavioural strategy

- Pre-configured skills are not inherently better or worse than constructed ones: it depends on the context in which they are needed
- Understanding the advantages and disadvantages of each approach in animals might help in choosing an appropriate model for a robot

Factors promoting pre-configured skills

- *Opportunity*: the animal has to first show the skill without having any opportunity to practice it, or the skill is unobservable (e.g. migration)

Factors promoting pre-configured skills

- *Opportunity*: the animal has to first show the skill without having any opportunity to practice it, or the skill is unobservable (e.g. migration)
- *Risk*: there is a large cost of performing the behaviour incorrectly (e.g. first flight of tree or cliff nesting bird)

Factors promoting pre-configured skills

- *Opportunity*: the animal has to first show the skill without having any opportunity to practice it, or the skill is unobservable (e.g. migration)
- *Risk*: there is a large cost of performing the behaviour incorrectly (e.g. first flight of tree or cliff nesting bird)
- *Time constraints*: saves the time that would be needed for learning (e.g. mason wasp egg-chamber construction)

Blackcap navigation (Helbig 1991)

- Some migratory species fly on a genetically-encoded vector on their first migratory flight

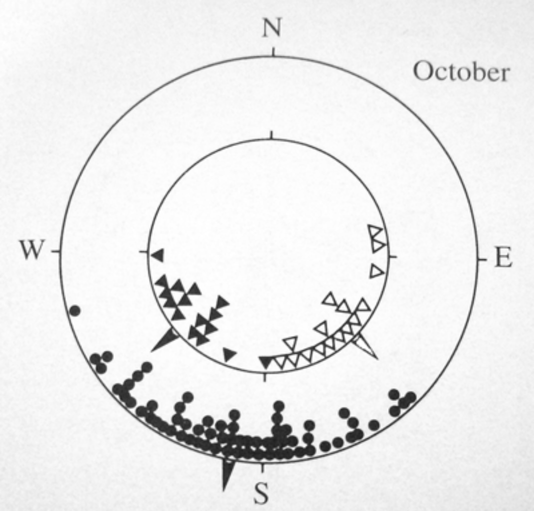
Blackcap navigation (Helbig 1991)

- Some migratory species fly on a genetically-encoded vector on their first migratory flight
- e.g. blackcaps (*Silvia atricapilla*)

Blackcap navigation (Helbig 1991)

- Some migratory species fly on a genetically-encoded vector on their first migratory flight
- e.g. blackcaps (*Silvia atricapilla*)
- If you cross blackcaps which migrate SE with those that migrate SW, the hybrid offspring migrate approx. S

Helbig 1991



Factors promoting constructed skills

- Opposite conditions to those above

Factors promoting constructed skills

- Opposite conditions to those above
- *Unpredictability*: if the environment is very variable, natural selection will not be able to provide an appropriate solution

Factors promoting constructed skills

- Opposite conditions to those above
- *Unpredictability*: if the environment is very variable, natural selection will not be able to provide an appropriate solution
- *New niches*: if the species has to cope with new niches, again, natural selection will not be able to cope with the change

Factors promoting constructed skills

- Opposite conditions to those above
- *Unpredictability*: if the environment is very variable, natural selection will not be able to provide an appropriate solution
- *New niches*: if the species has to cope with new niches, again, natural selection will not be able to cope with the change
- *But,* constructed skills are expensive in terms of time, parental care required while the animal is learning and growth and maintenance of neural tissue

Examples

- Foxes, bears and ravens moving into urban areas and using new sources of food

Examples

- Foxes, bears and ravens moving into urban areas and using new sources of food
- Foraging activity directed at new ‘prey’ which require different techniques (dustbins with lids), or same techniques directed at new targets (rubbish bags)

Are there different classes of constructed skills?

Some kinds of behaviour are too flexible to have be genetically determined, but appear to have been learned too rapidly to be explicable by standard learning mechanisms.

How might this work?

- Animals generate exploratory behaviour/play

How might this work?

- Animals generate exploratory behaviour/play
- Seek patterns or ‘interesting’ effects in the input or output of this behaviour

How might this work?

- Animals generate exploratory behaviour/play
- Seek patterns or ‘interesting’ effects in the input or output of this behaviour
- Combine these with genetically determined knowledge or skills => ‘chunks’ which can be reused

How might this work?

- Animals generate exploratory behaviour/play
- Seek patterns or ‘interesting’ effects in the input or output of this behaviour
- Combine these with genetically determined knowledge or skills => ‘chunks’ which can be reused
- ‘Chunks’ can themselves be combined to form new unit = new skill

So what advantages does this give us?

- Ability to exploit new features of the environment, even when these change rapidly, BUT...

So what advantages does this give us?

- Ability to exploit new features of the environment, even when these change rapidly, BUT…
- Genetically determined knowledge usefully limits exploration to those features most likely to be ‘interesting’, and provides a structure for learning

KEY IDEAS

In addition to physical growth –

biological organisms also grow their own

information-processing architectures

which are virtual machines, not physical machines

There are many ways this can happen in nature or in machines

Recapitulation: The ‘altricial’ variants

There is an important sub-class of animals in which competences are not all pre-configured, whose development makes use of:

- **Genetically determined actions, perceptual capabilities and representations,**
- **Genetically determined play/exploration mechanisms driving learning which extends those actions, etc., using abilities to chunk, recombine and store**
  - **new more complex action fragments**
  - **new more complex perceptual structures,**
  - **new more complex goals,**
- **Creating new ontologies, theories, competences (cognitive and behavioural),**
  - **i.e. new more complex thinking resources,**
- **Thereby extending abilities to search in a space built on larger chunks: solving ever more complex problems quickly.**
  - **(unlike most statistical forms of learning)**

For AI systems

this will require new architectures and learning mechanisms.

Two ‘altricial’ species and a pointer to a third

- You have seen Betty, the hook-making New Caledonian crow.

- Show Josh, yogurt manipulator.

- The key ideas are quite old – e.g. Piaget.
  Compare Oliver Selfridge’s program that learns to ‘count’.

  (Demonstrated in a Pop-11 program written over 20 years ago on the basis of an idea described to me by Oliver Selfridge.)

  Partly like Case-based or Explanation-based learning.

Oliver Selfridge's Finger/Count Program

```
Initial state
Counter: 20
             v
    [] [] [] [] [] [] []
  0 1  2  3  4  5  6  7
```

There is a 'finger' adjacent to a row of blocks. It has two actions

- goright
- goleft

and a 'counter' that has two actions

- increment
- decrement

Actions can be composed in various ways

- in sequences
- loops

Loops terminate when either the finger or the counter hits a 'boundary'.

Example snapshots of the program working

```
Initial state
Counter: 20

           v
   [] [] [] [] [] [] []
 0 1  2  3  4  5  6  7
```

The program asks for a goal state and I type in ‘1 1’

```
Target finger position and target counter value? 1 1
.............................................................
.............................................................
I give up on this one
```

Each dot represents a tested combination of actions.
It gives up after trying 120 different systematically varied actions.

After carefully selected training examples

Because successful chunks are stored as new action units, the set of available 'basic actions' increases:

```
(1) [goright increment]
(2) [[repeat goleft] [repeat decrement]]
(3) goleft
(4) goright
(5) increment
(6) decrement
```

After a few example tasks it gets to this collection:

```
(1) [[repeat goleft] [repeat decrement] [repeat [goright increment]]]
(2) [goright increment]
(3) [[repeat goleft] [repeat decrement]]
(4) goleft
(5) goright
(6) increment
(7) decrement
```

Now it can always solve the ‘counting’ problem

No matter what the starting configuration, if given the ‘count blocks’ goal
(same target number for finger and counter),

it always solves the problem using only one stored action.

E.g. I give it the goal 17 17 in this configuration

```
Counter: 20
                                         v
    [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] []
  0 1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17

Target finger position and target counter value? 17 17
.
Plan was: [[repeat goleft] [repeat decrement] [repeat [goright increment]]]
```

A single complex action reliably solves the problem
which previously was found too difficult.

Conjecture

We conjecture that rapid learning in altricial species depends on similar mechanisms, where the learner spontaneously attempts things without requiring a teacher.

This may require discretisation (chunking) of continuous domains.

Limitations of the program

The program is obviously very limited

- **very simple actions**
- **very simple kinds of perception**
- **no conditionals**
- **no parameters**
- **only very simple loop terminations**
- **very restricted kinds of goals**
- **it is essentially passive: goals must come from outside**
- **very simple 'environment' – e.g. no 3-D rotateable structures**
- **very restricted ways of composing actions**
- **no parallelism**
- **very few actions: and no neeed for action-selection mechanisms**

Some requirements for artificial intelligence

Expanding this sort of mechanism to account for 'altricial' (flexible, creative, constructive, non-preconfigured path-makers) will not be easy.

- **It requires a host of specialised (probably genetically determined) mechanisms including mechanisms generating playful exploratory behaviour**

- **It needs recursive (?) syntactic competence and meta-semantic competence.**

  Meta-semantic competence is needed in mechanisms that can represent systems which themselves have representational capabilities – in the same agent or in others

- **Some of the required elements seem to exist in AI developments of the last 40 years (some of them nowadays forgotten).**

  E.g. Sussman's HACKER program (MIT, circa 1973?), and various kinds of symbolic learning mechanisms, including concept learning, rule learning, mechanisms (e.g. Explanation-based learning), as well as the more statistical mechanisms that now get most attention.

- **The bootstrapping process needs**

  precocial (pre-configured) meta-level capabilities

A spectrum of competences

- Every organism is a mixture of both kinds of capabilities:

  pre-configured — constructed

- Not all of the first kind are manifested at birth/hatching – many are ‘time-bombs’.
- Architectures for altricial species can do many things that are not directly biologically useful:

  including (possibly dangerous) exploration of a space of possibilities.

- Architectures can change over time.
- **Altricial architectures are virtual machines that grow themselves.**

  But we have over-simple ideas about how: e.g. the notion of a knowledge-free, general-purpose learning system is current favourite, but inadequate mechanism.

See our IJCAI paper
http://www.cs.bham.ac.uk/research/cogaff/altricial-precocial.pdf

and the H-CogAff architecture described on the Cognition and Affect web site:
http://www.cs.bham.ac.uk/research/cogaff/

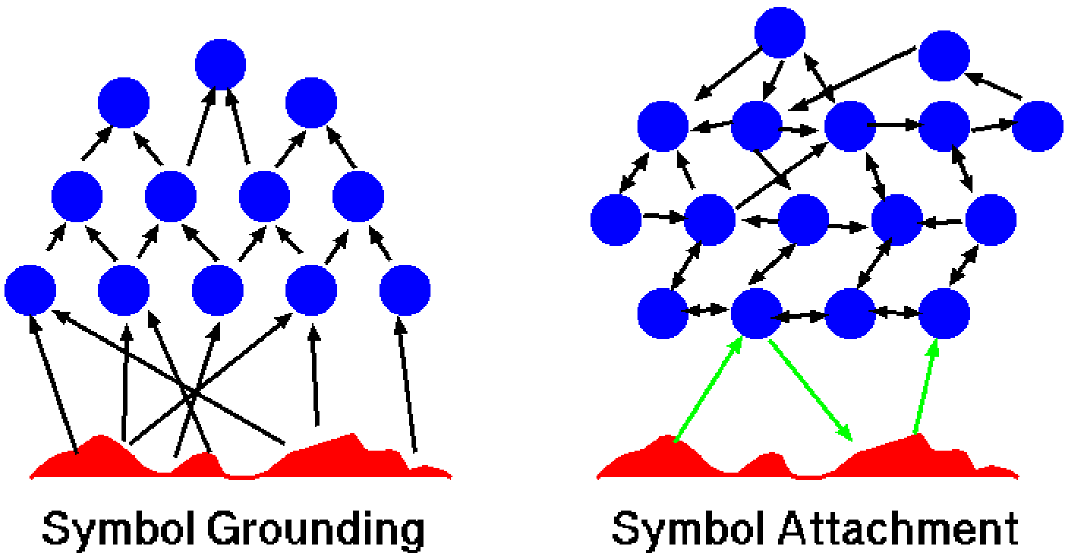
Final comment

The existence of precocial species refutes 'symbol-grounding' theory

(The theory that all meaning has to be derived by processes of abstraction from sensory experiences).

In the paper we distinguish two sources of meaning

- **the structure of a theory in which 'undefined terms' occur**
- **links to sensing and acting**



The paper talks about 'symbol attachment' as an alternative to 'symbol grounding'.

Jackie has suggested a better term: 'symbol tethering'.

Thanks for your attention

See also

http://www.cs.bham.ac.uk/research/cogaff/altricial-precocial.pdf
(paper for IJCAI05)

and

http://www.cs.bham.ac.uk/research/cogaff/talks/