How do animals gather useful information about their environment and act on it?

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What is involved in gathering information and acting on it?

- How do you perceive objects in ways that allow manipulation?
- What do you pay attention to (filtering and selective attention)?
- How do you detect affordances?
- How do you assign causality to actions, events or agents?
- How can competences be re-combined flexibly to generate appropriate behaviour in novel contexts, or creativity?
- How does this all develop?

If you were trying to build a robot to behave spontaneously like the chimp in the following clip, how would you do it?

Pal, 2.5 years old

video taken by Misato Hayashi, Primate Research Institute, Kyoto University, used with permission

Hayashi & Matsuzawa (2003) Animal Cognition

Questions raised

- Why did she specifically pay attention to the blocks (attention)?
- What mechanism could have allowed Pal to learn that she could stack the blocks (detect the affordances of blocks)?
- Did she understand causal relationships (e.g. that hitting the blocks would make them fall)?
- Would she be able to stack other shapes or different objects (re-combinable competences)?
- How did this behaviour develop?

What kinds of mechanisms make it possible for animals to find out about affordances, attribute causes to effects and generate appropriate (sometimes novel) behaviour?

What mechanisms do we know of?

- Developmentally-fixed behaviour - usually genetically determined
  - Fast and reliable, but inflexible
- Associative learning
  - Gradual process, but fairly flexible and surprisingly subtle
- Social learning
  - Can provide a short-cut to learning a novel behaviour
- Some extended learning mechanism—some ‘core knowledge’, new competences acquired, extended and re-combined through exploration and play?

Developmentally-fixed behaviour

- Complex behaviour triggered by simple cues
- Useful when:
  - Limited opportunity for learning
  - Behaviour needs to be perfect on the first attempt (e.g. flight in cliff or tree-nesting birds)
  - There are time constraints (e.g. short life span)
- Common in precocial species where young are relatively independent from birth

Associative learning

- Classical conditioning and operant conditioning
- Can lead to a complex chain of behaviour → novel responses to the environment
- Relatively slow and gradual process (though one-trial learning is possible)

Social learning

- Learn from the behaviour of others:
  - Directly, by observation
  - Or via products of another's behaviour
- Can spread novel behaviour rapidly through a population → cultural transmission → cultural evolution

Extended learning mechanism and exploration

- Animals can learn about the space of possible actions with an object, unusual properties etc.
- Time consuming, but possible for altricial species during development, when parent(s) care for offspring
- May also enable very rapid learning if 'chunks' of knowledge about the environment can be reused
- Exploration (not directly reinforced) may be very important

What do you pay attention to?

- Some genetically-determined biases which limit the stimuli that form associations (e.g. taste conditioning in rats)
- Exploration → classification of some things as 'interesting'?

“Appropriateness” of the stimulus or response matters (Domjan & Wilson, 1972)

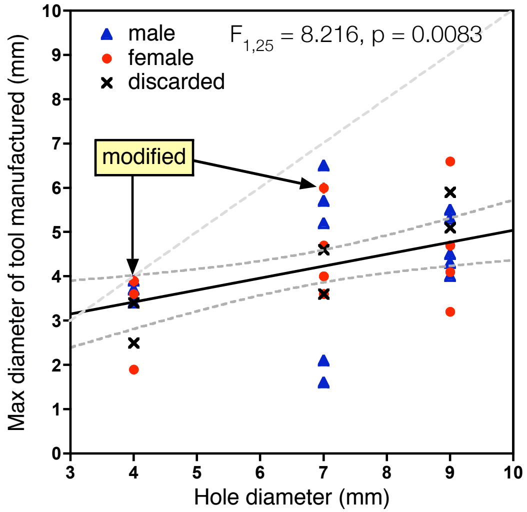
	Group taste	Group noise
Train	Sweet water → illness	Noisy water → illness
Test	Sweet water vs. Plain water	Noisy water vs. Silent water
RESULT	LEARNING	NO LEARNING
Train	Sweet water → shock	Noisy water → shock
Test	Sweet water vs. Plain water	Noisy water vs. Silent water
RESULT	NO LEARNING	LEARNING

So, natural selection constrains associations to those likely to be causally linked

How to detect affordances?

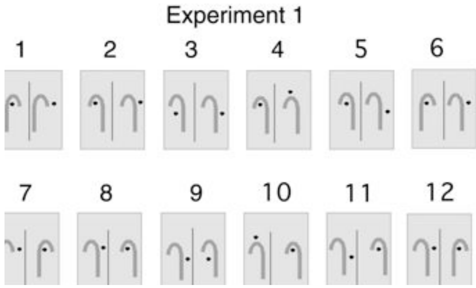
- Are affordances tied to specific stimuli, or can animals abstract more general properties?
- What is the role of experience?
- Is this an adaptation specific to the tool-using domain?

Making an appropriate tool for a novel task (New Caledonian crows)



(Chappell & Kacelnik 2004)

What do non-tool users understand about the function of tools?



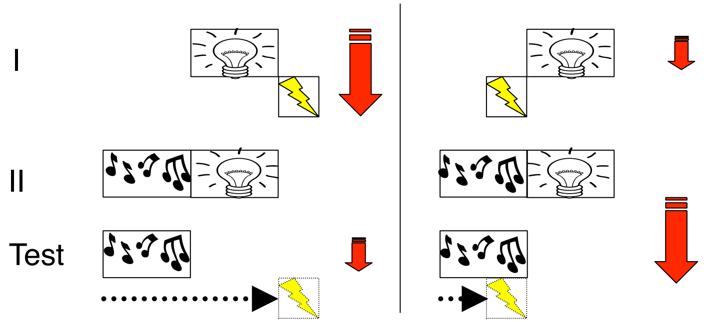
(Santos et al. 2005)

How to assign causality?

- Probabilistically, through contingency and contiguity (Rescorla & Wagner 1972)
- Test hypotheses by performing interventions (Gopnik & Schultz 2004)
- Core knowledge about the structure of the world (acquired or developmentally fixed) → expectations about causal structure (not all causes are equally possible) (Carey & Spelke 1996)

Animals can learn about the temporal relationship between events → causal attribution

(Barnet, Cole & Miller, 1997)



What causes objects to fall?

Possibly gaining dynamic feedback from environment, and adjusting behaviour appropriately

Re-combinable competences

- To what degree can animals re-combine existing competences to generate novel behaviour?
- How does this depend on previous experience?

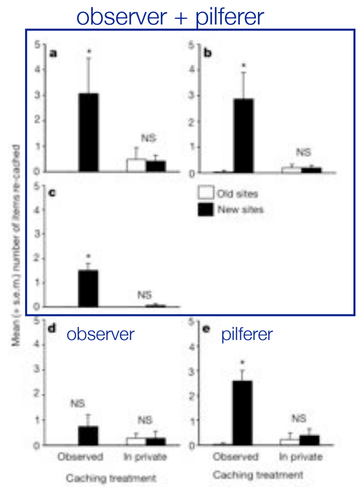
Pilfering in scrub jays: it helps to have been a thief to catch a thief

- Three groups:
  - Observer + Pilferer—had experience of both observing conspecifics caching, and of pilfering others caches
  - Observer—only experience with observing caching
  - Pilferer—listened to others caching, then allowed to pilfer caches

(Emery and Clayton 2001)

Experimental protocol

- Birds allowed to cache food in a tray:
  - With an observer bird watching from an adjoining cage ('observed' trial)
  - With no bird watching them ('in private' trial)
- Then allowed to retrieve cache and also given opportunity to re-cache in old tray or a new one



- Pilferers re-cached food when observed caching (in new sites)
- Specific to the tray which was observed, not a general increase in re-caching
- Observation of caching not sufficient to prompt re-caching

(Emery and Clayton 2001)

Novel manufacturing behaviour with a new material

- In an experiment on choice between a hooked wire and a straight one, Betty bent the hook spontaneously on the 5th trial
- In a subsequent experiment, she bent the hook and used it to remove the bucket on 9/10 trials

(Weir, Chappell & Kacelnik 2002)

[Weir, Chappell & Kacelnik 2002]

What might the mechanism allowing re-combination of competences be?

- Built-in drive to explore (with no immediate reinforcement consequences)
- Cognitive structures (genetically determined) which might guide or constrain exploration (‘bootstrapping’ of behaviour)
- Construction of reusable ‘chunks’ which can themselves be recombined into more complex structures (e.g. language learning)

How do these abilities develop?

- Exploration and play
  - Lack of neophobia—you can’t discover properties of objects you never go near
- Altricial species often have a large amount brain development going on after birth/ hatching
  - Is it important that the developing brain is exposed to the environment?
- To what degree are animals limited by their exploratory tendencies?

Are animals limited by species-specific representational capacities, or by the their exploratory tendencies?

- Representational view vs. Ecological view (Cummins-Sebree and Fragaszy, 2005)
- Capuchin monkeys spontaneously re-positioned canes to pull a food reward towards them, unlike tamarins
- Is this difference because of species differences in exploratory/manipulatory behaviour?

Summary

- We need to combine the richness of animals' behaviour with the depth of knowledge of the mechanisms involved in artificial systems to explore this
- There is almost certainly more than one solution to the problem (*in vivo* and *in silico*)—the optimal solution depends on the 'habitat' of the agent
- Animals (and robots) need to be tested in ethologically valid ways to reveal their competences fully
- It's a very difficult (but interesting) problem!