# Intelligence in Animals and Machines

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# Tool use

**Krutzen 2005; Breuer 2005; Finn 2009**

# ‘Man the tool-user’

- **In studies of animal intelligence tool use is still given prominence because of:**
  1. **Its rarity**
  2. **Suggested relation to human lineage**

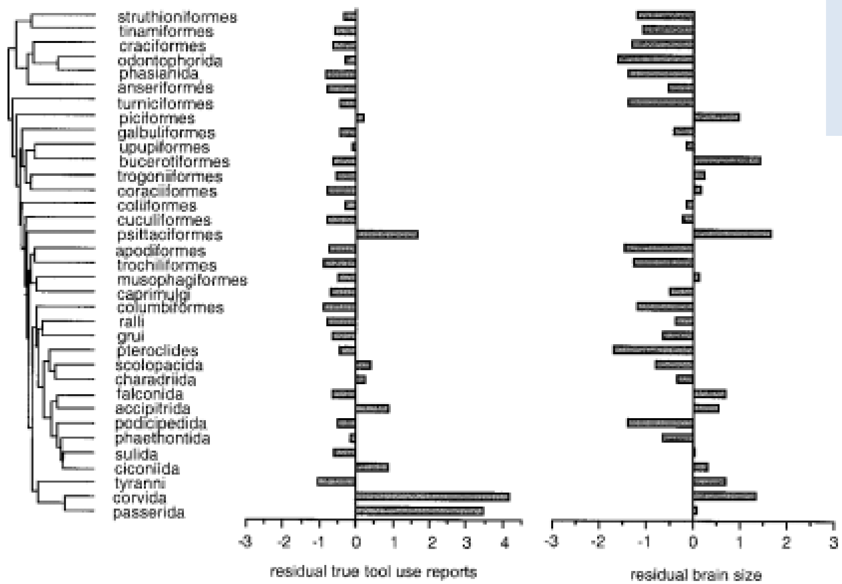
**Why rare?**

High cognitive requirements?

Seldom useful?

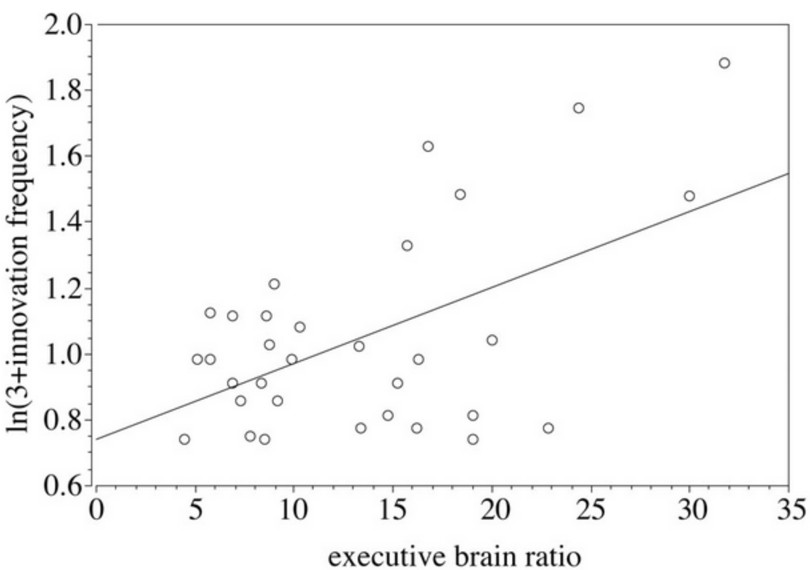
Definition

# Does tool-use need a big brain?




**Tool-use and brain size in birds**
***Lefebvre***

- There is a loose correlation between measure of observation of tool use in birds and the size of their brain




**Innovation rate and brain size in primates**
***Reader and Laland***

- Likewise how much primates perform innovative behaviour correlates with brain size

High cognitive requirements?

# Is tool-use actually useful?

- Why do we see tool use in chimps and orangutans but seldom in gorillas?
- Why is tool-use rare even in tool-using chimps?
  - Gorillas are herbivores, food is plentiful and does not need tool use
- Why do only female dolphins forage with sponges?
  - female dolphins are outcompeted by males so need to forage in difficult places
- Tool-use in capuchins is only seen in arid open areas.
  - Food scarcity and stability of rocks (anvils)
- Why are the most prodigious bird tool users island species?
  - Avoidance of competition from Woodpeckers

Seldom useful?

# Standard Definition – Beck(1980)

**‘tool use is the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper and effective orientation of the tool’**

Definition

# We’ve been here before

Opinion

# Towards a bottom-up perspective on animal and human cognition

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**Over the last few decades, comparative cognitive research has focused on the pinnacles of mental evolution, asking all-or-nothing questions such as which animals (if any) possess a theory of mind, culture, linguistic abilities, future planning, and so on. Research programs adopting this top-down perspective have often pitted one taxon against another, resulting in sharp dividing lines. Insight into the underlying mechanisms has lagged behind. A dramatic change in focus**

degree to which these mechanisms are either widespread or special adaptations.

## From a top-down to a bottom-up approach

Even if continuity among all life forms is widely accepted in relation to anatomy, genetics, development and neuroscience, this view remains controversial when it comes to cognition. Proposals of discontinuity are innate in the top-down perspective that has steered comparative cogni-

Starting with a definition is inherently top down and trying to find differences with all the problems that brings in

# Problems with the definition

- Scenario 1a. A string, anchored to the rim, hangs down a tube, with an otherwise inaccessible reward attached. A bird (e.g. a raven; Emery 2006) pulls the string to retrieve the reward.
- Scenario 1b. At the bottom of a tube sits a reward in a bucket with a handle. A bird (e.g. a Caledonian crow; Weir et al. 2002) finds a hook, catches the handle and pulls up the bucket.
- Scenario 1c. In a variation on 1a, the anchored string has a hook at its end. A bucket is in the tube. A bird swings the hook to catch the handle, and pulls up the bucket.

**St Amant and Horton 2008**

# Problems with the definition

- Example 2a: Orb web spiders are excluded because their webs are not held by the spider but are attached to the substrate;
- Example 2b: bolas spiders *Mastophora*, which swing a large sticky blob at the end of a single thread to capture moth prey, are  borderline.
- Example 2c: ogre-faced spider *Dinopis longipes* makes a small web that it holds in its legs before bringing it down on passing prey  = tool user and tool maker

**St Amant and Horton  2008**

# Calling something tool-use gets a high profile paper

**"A well-camouflaged mugger crocodile"**

**Dinets et al. (2014)**

- By the definition this is tool use
- But the crocodile could do this just by floating around near nesting material

**Predation by a lure-using alligator**

# Tool use in bears


**"Advanced spatial cognition and motor skills for object manipulation provide a possible explanation for why bears have the largest brains relative to body size of all carnivores.", Deecke (2012) Anim Cog**

Simply because it fits definition of tool use, authors propose it is the driving reason for brain size

# Considering tool-use as part of a wider skill-set

**Hansell and Ruxton (2008)**

**Barnes (2005) Tool-use in beavers.**

- The beaver has moved the highlighted stick and stands on it
- This is said to be tool use and so very impressive and a sign of intelligence because they can manipulate and use sticks

- But we **know** that beavers can construct big dams which shows that they are very good at manipulating and using sticks!

# Considering tool-use as part of a wider skill-set

## What about tool-use and its relationship to construction?

- In the same way, the researchers were impressed that the gorilla used a stick to test water
- But gorillas use sticks to build a nest every day from sticks

**Hansell and Ruxton, 2008**

**Breuer (2005) First observation of tool-use in *Gorillas. PLoS Biology.***

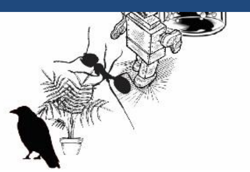
# So why study “tool-use”?

**“Those who feel tools are ‘special’ might be correct – but they might be more special to researchers than to the animals that use them”**

**Hansell and Ruxton**

This is because studies of these behaviours help us understand:

- What animals know about physical causality and cause and effect
- Do they have knowledge of folk/naïve physics: the basic understanding that children have of things like gravity eg objects fall down, things fall through holes and can’t move through walls, moving one object into another will make the second move
- This is important because it shows they have insight into the operation of the tools that they use



# Example:
# Cause and effect understanding in cotton tops

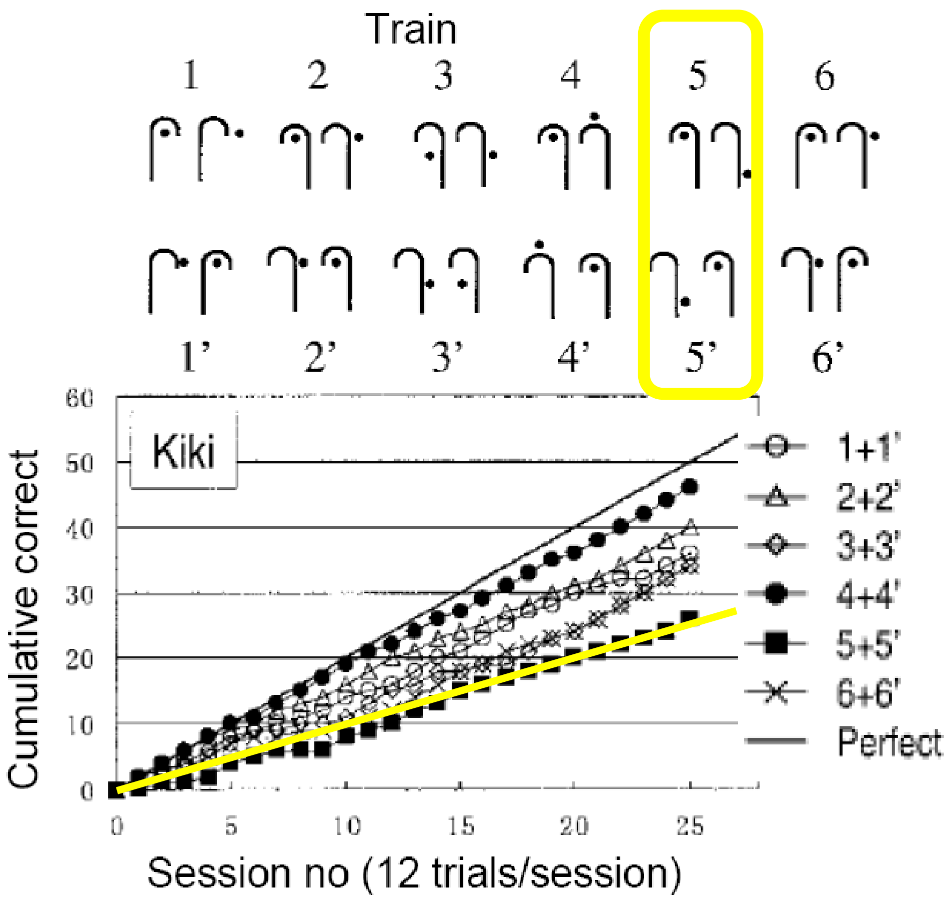
# Understanding cause and effect

Hauser and Santos

- Cottontops must pull cane round the food. If wrong, wait 5 minutes
- They neeed to understand about the cane to get the right one

# Dissecting the cane task

## Tendency to pull cane associated with nearer food.

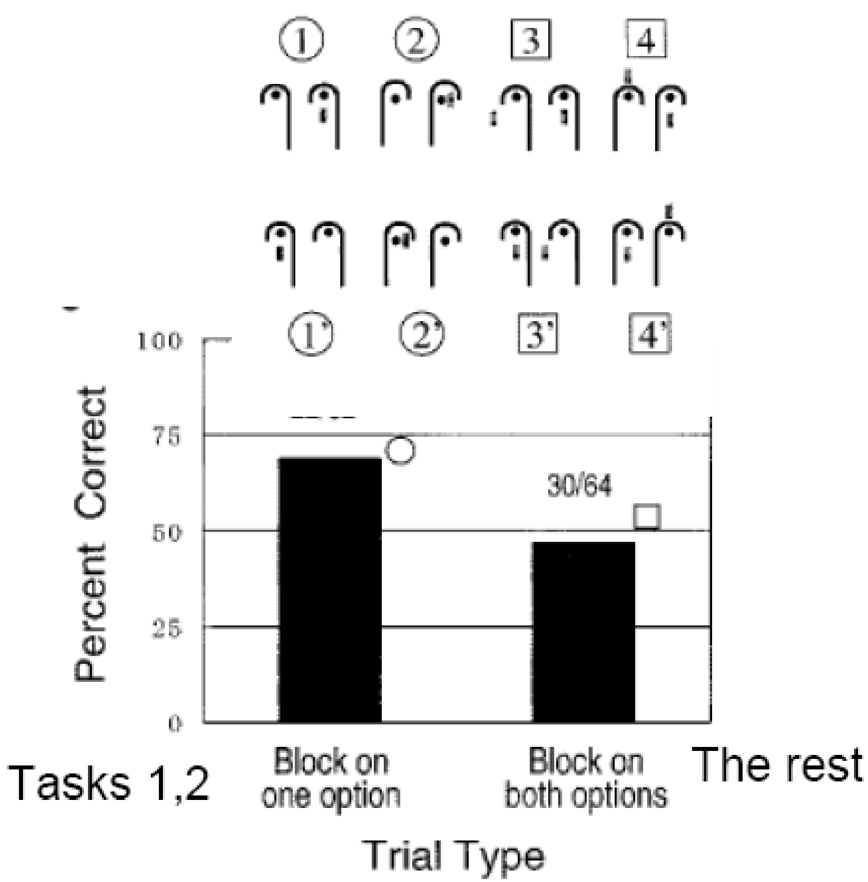


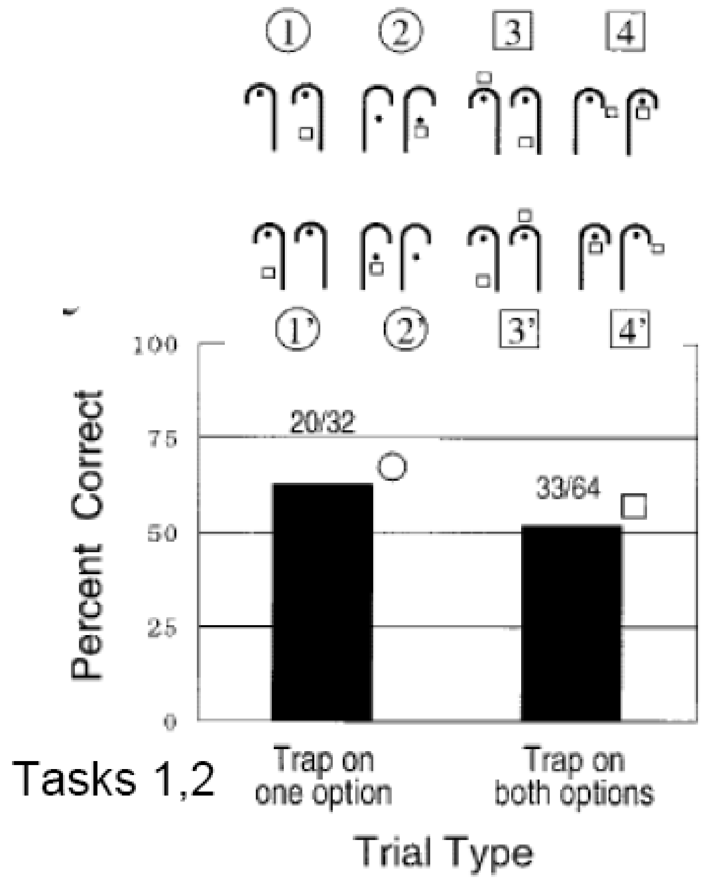

- Solid line is perfect results, yellow chance
- Kiki is above chance on all but set up 5 where the wring choice is the nearest food
- Kiki is biased towards something that's nearby, and is not able to overcome that by realizing that the connectivity of the object with the cane is more important than the proximity

**Fujita et al 2003 J Exp Psychol**

# Limitations on understanding

- Cotton-tops focus more on relation between food and tool than on the path over which the tool and food passes.
- They understand a block is bad but not really how they work
- Again shows that the understanding is limited



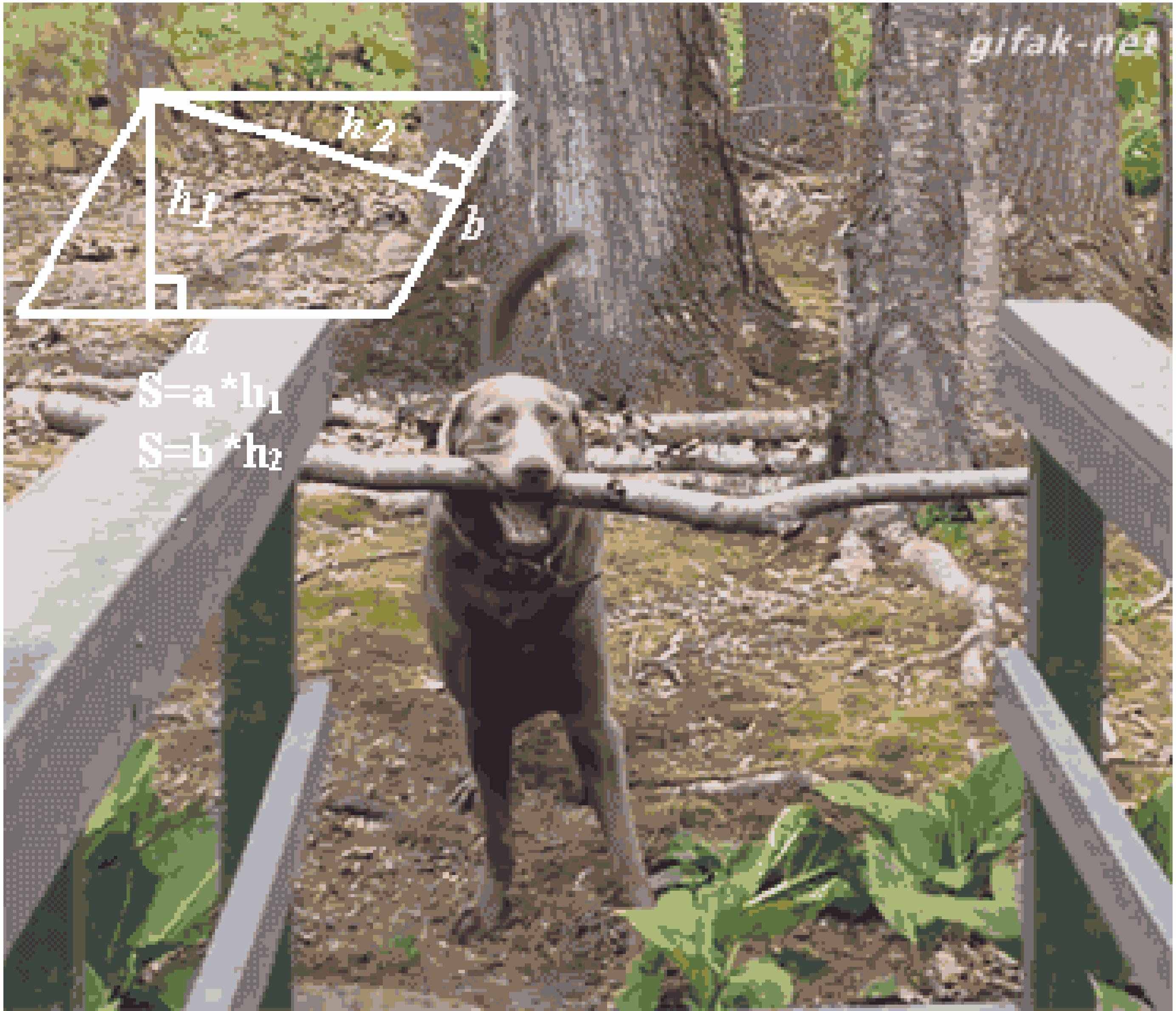

# Simple lab tasks: Summary

- Simple experiments can pick apart an animal's understanding of physical relationships

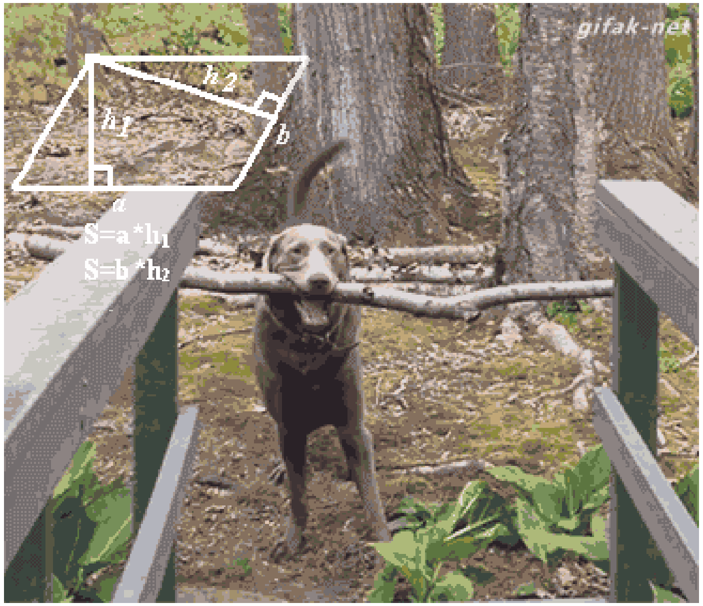
- Tasks demonstrate a range of limitations in an animal's folk physics:
  - Prediction failures
  - Proximity bias
  - Connectedness bias

- Perhaps what looks like tool use is not a real understanding of what's going on: killjoy explanation!

# Mini-break and discussion



# Discussion




**Are you cat or dog people?**

**What knowledge do you think makes up "Folk Physics" in cats or dogs. Give examples:**

# What helps to establish tool use
# Tool-use in birds

# Adaptations for tool use.

**New Caledonian Crows make tools to extract grubs**

**Lab reared juvenile NCCs use tools to extract food without any prior observation of tool use**

# The famous case of Betty making a hook

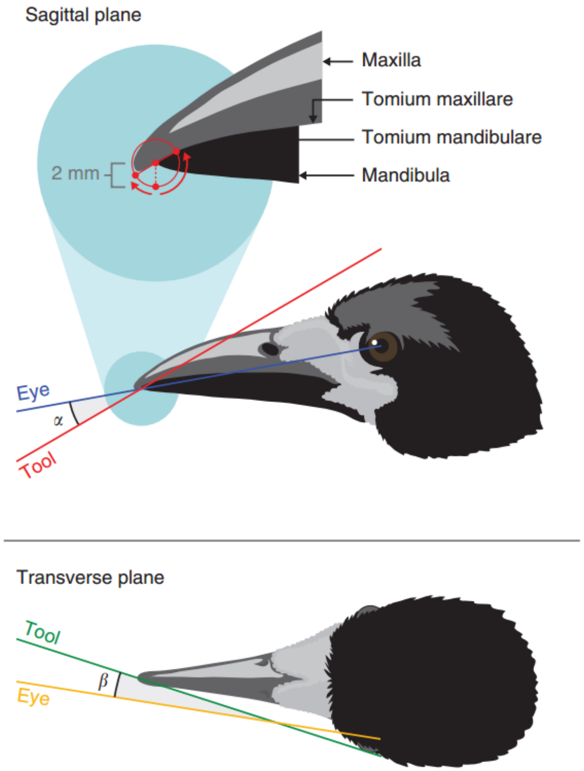
**Betty and Abel learned to select hooked tools for a bucket task.**

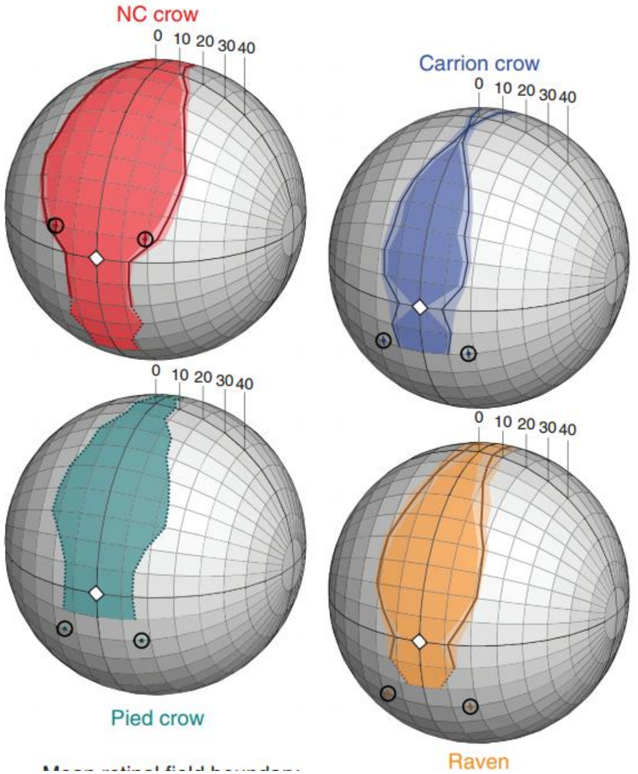
**Abel flew off with the only hooked tool …**


Betty made tools that resembled the tools that they had been given initially

# Sensory and morphological adaptations in NCCs

**Troscianko et al. 2012 Nat Comm**




**NCCs have straighter beaks and larger binocular visual fields**

# Tool-use in the lab

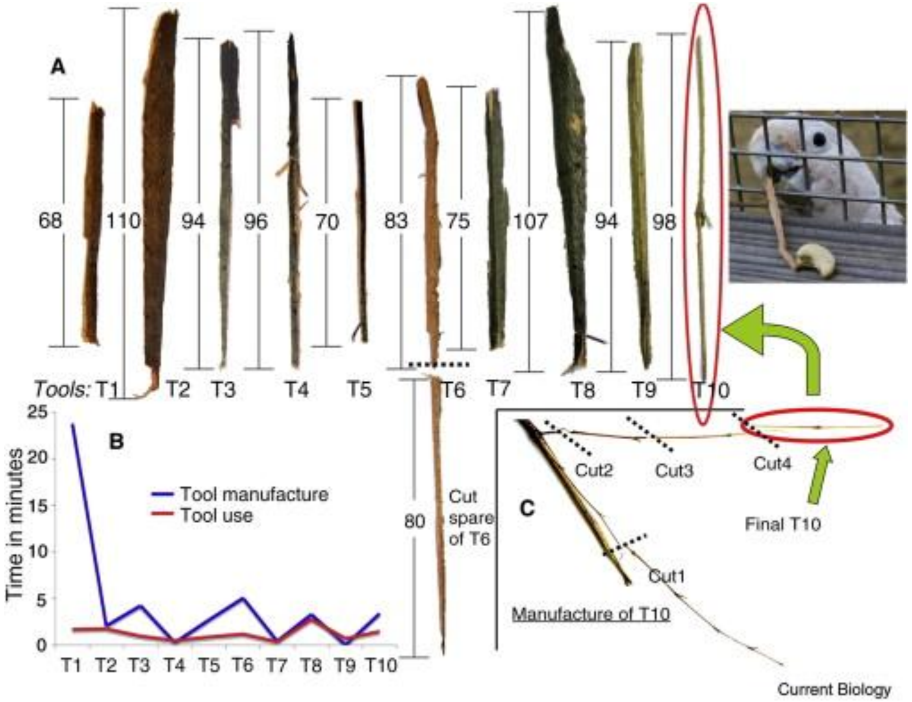
Rooks don’t normally use tools, but can learn this in the lab.

Bird and Emery PNAS, 2009

**Perspex tubes** **vs** **Natural environments**

- With a clear tube the rooks aren’t hampered by beak shape/eye position
- Rooks are smart enough they just haven’t got the right body
- Tool using adaptations seem to be sensory and morphological not cognitive

# Extraction and tool making in parrots

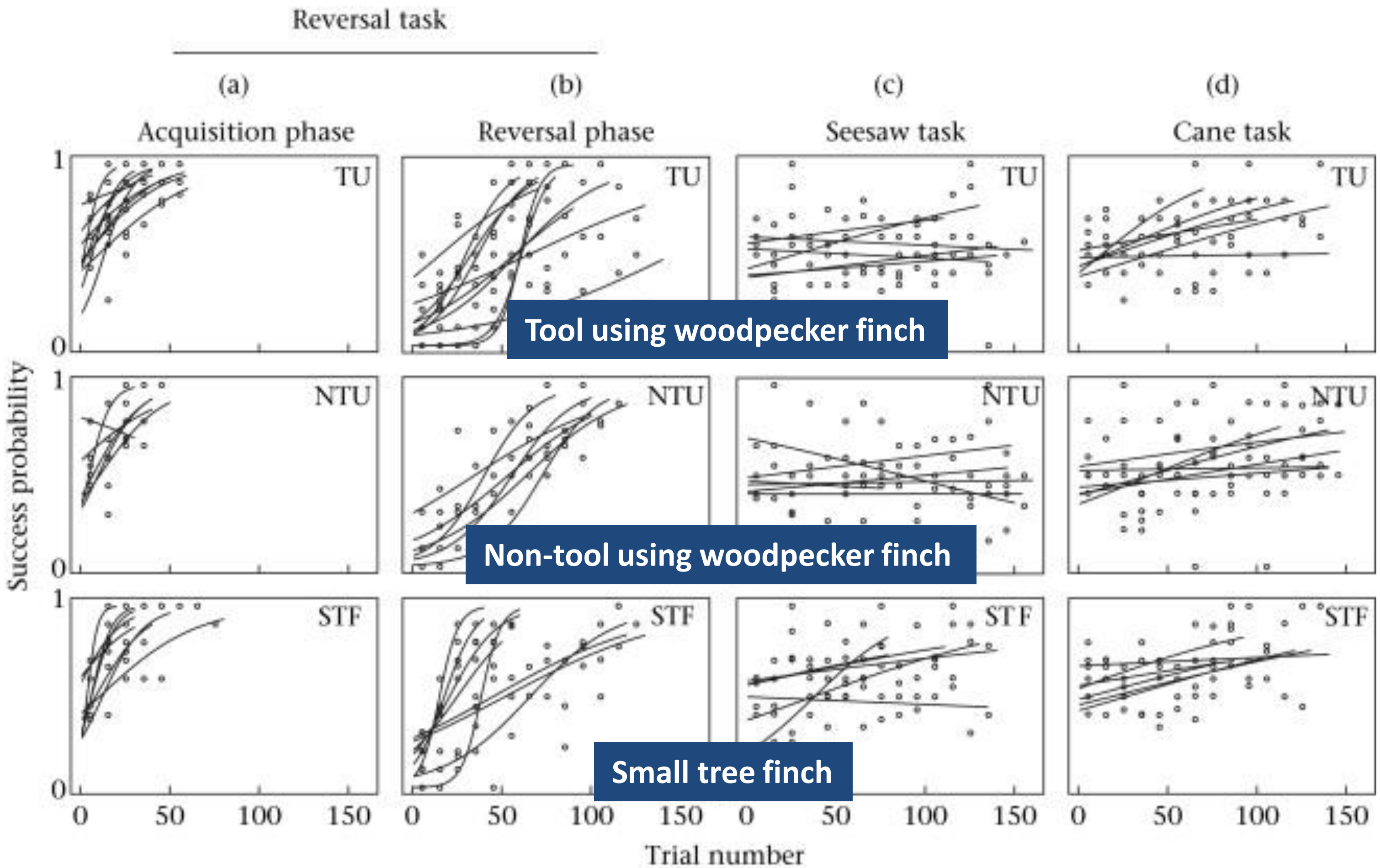



# Precision not needed when the visibility is good

- Despite their beak being very badly adapted for using tools, if they can see the object they have no problem

**Auersperg et al 2014**

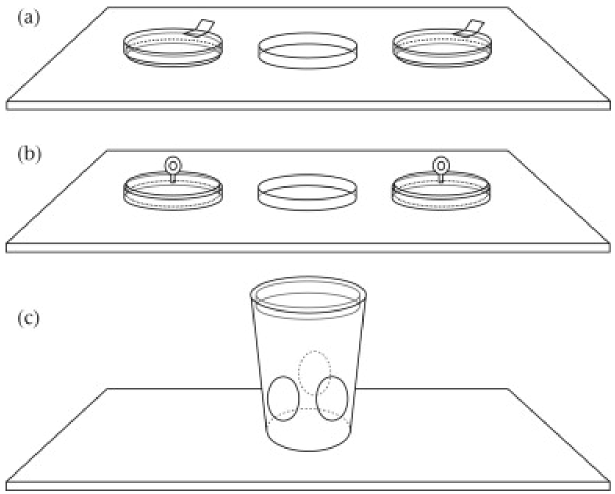
# Cognitive adaptations in tool-using birds?



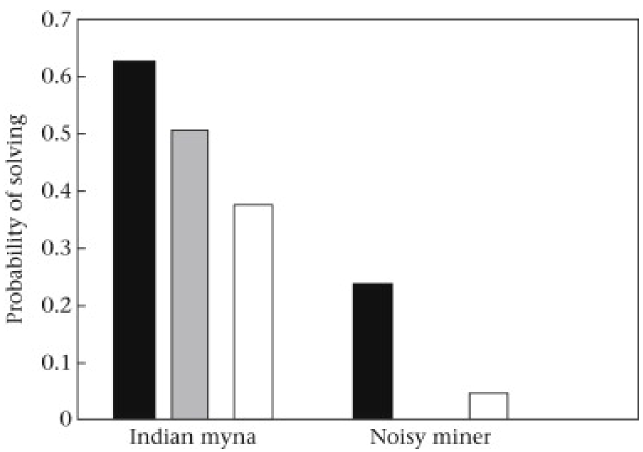

- Tool using species are not any better at learning or adapting to tasks that show elements of tool use

**Teschke et al. 2011**

# Adaptations for innovation.


Extraction task




Increased success comes from increased motor variability and persistence

Griffin and Diquelou, 2014

- However tool using species try more new things and try things for longer


# General intelligence in Kea


# Factors in Kea intelligence

A rich behavioural repertoire:

– Peeling, hooking, scratching, pushing, digging, turning, probing, prying, flinging, levering.

Long life and slow development

Sociality

Social learning and local enhancement

- Faster approach
- More persistence
- More exploration
- Emulation not imitation

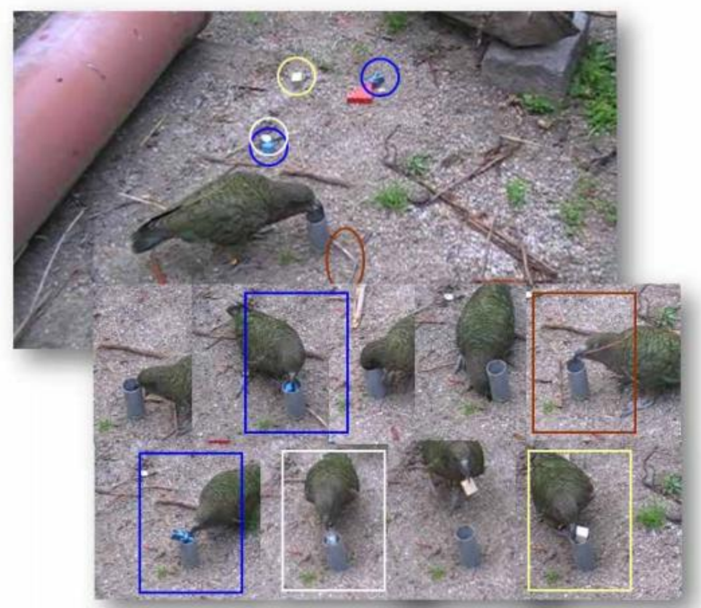

Huber and Gajdon 2006 Anim Cog

# Factors in Kea intelligence: Play

**Toddler-typical object play**

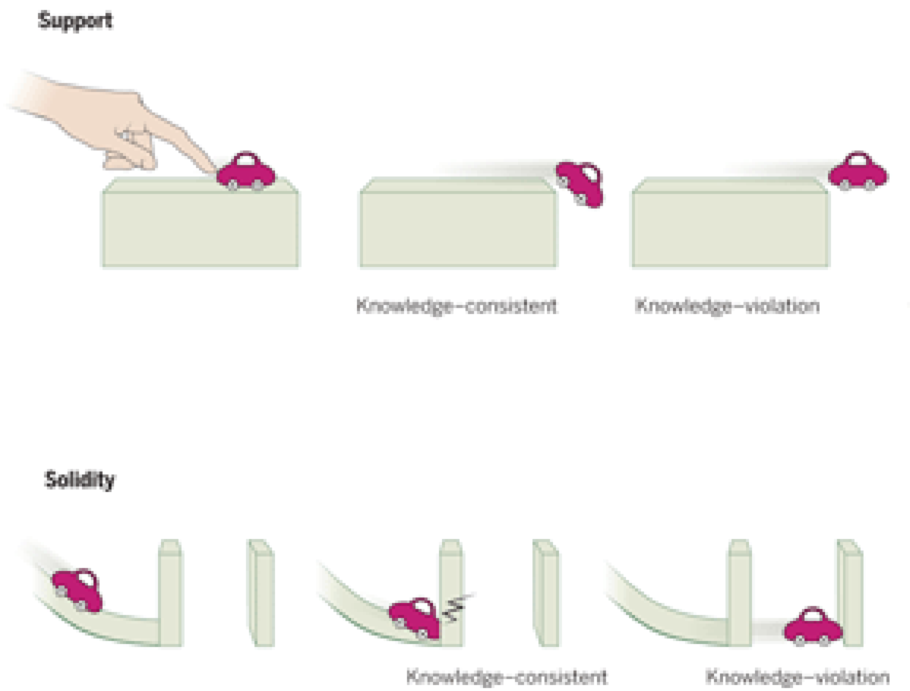
- Children will play with toys for longer the more things you can do to it
- Kea show the same pattern as toddlers in play

✓Stacking objects
✓Inserting objects into other objects
✓Throwing objects
✓Putting objects into water
✓Smashing objects on different surfaces

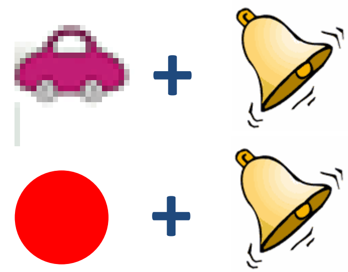


# Learning about the properties of objects

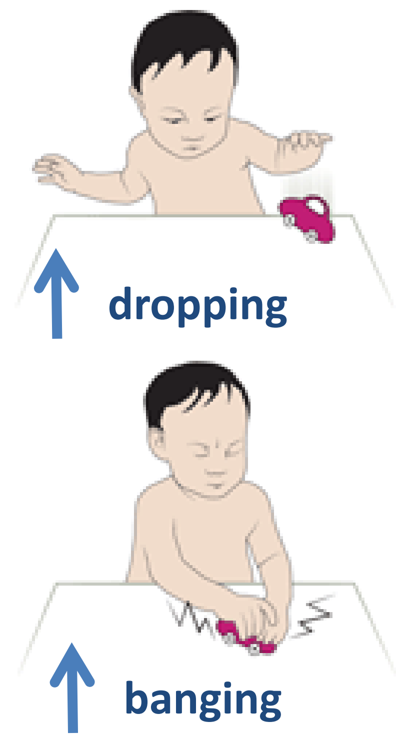
**Observation**




**Learning**




**Play**




- Babies play with the toy in the way that it broke the rules of physics

**Stahl and Feigenson 2015 Science**

# Summary

- Tool use is treated as a special case of animal behaviour by some scientists.
- It is part of a class of behaviours that show animals can understand folk physics and cause and effect.
- A top-down approach grounded in definitions is not helpful when trying to study underlying cognition.
- Successful tool-use can also depend on non-cognitive factors as well as ‘animal intelligence’.

# Robotic Tool Use

# Robotic ~~Tool Use~~ Grasping

# Robotic ~~Tool Use Grasping~~ Object Manipulation

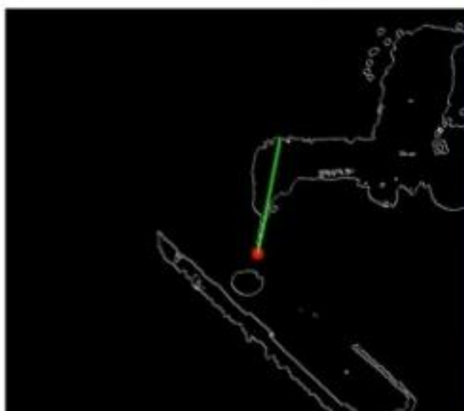
# Using tools requires accurate perception + feedback

1. Fix tool to gripper to make problem easier

Hoffmann et al, 2014, Adaptive robotic tool use under variable grasps. Robotics and Autonomous Systems

Depth disparity map

2. Identify target and calculate depth map



Localization of drill bit tip (red dot)

Drill bit pose (the blue line shows the computed drill bit axis)

3. Calculate position *AND* angle (pose) of drill bit relative to target

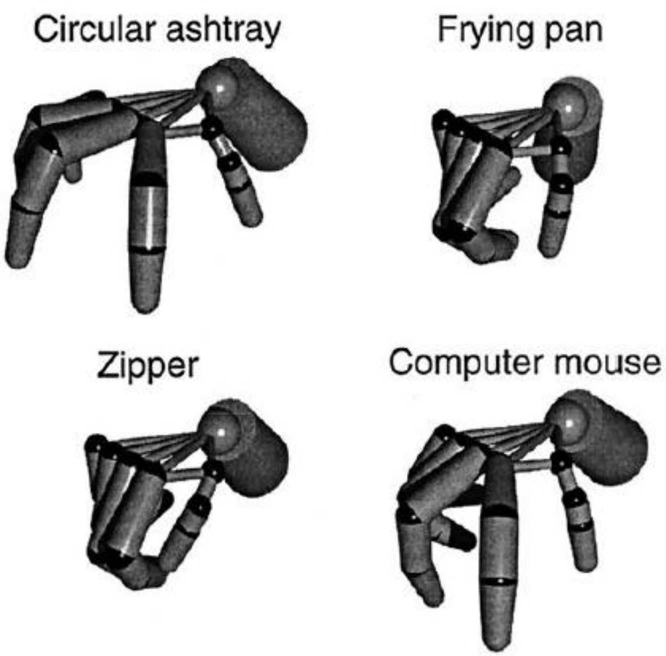
4. Feedback to maintain correct angle

# Grasping also requires accurate depth estimation

- Interacting with the world is very complex as shown by Winners of IROS2018 mobile manipulation challenge: [https://youtu.be/_3wZ3J6NWCc](https://youtu.be/_3wZ3J6NWCc)
- Pick and Place: get specific items out of a basket and replace on a shelf
- Assuming accurate limb control (!!), before grasp, robot must identify which object to grasp (one on top)
- 3D structure from vision: Tricky, esp. transparent and partially obscured (note long pauses and fail at start of vid2)
- And then has to manipulate


# Robot Grasping: an open problem

- Hands have many degrees of freedom
- Controlling high-dimensional prosthetic hands is difficult
- synergies can help  but most anthropomorphic prostheses do not have nearly as many controllable degrees of freedom
- And even controlling simple robotic hands is difficult
- We do not have materials to make flexible tactile hands
  - Rigid fingers may move rather than grasp object if pose is not perfectly estimated
  - Tactile feedback is an open problem




Santello, et al (1998). Postural hand synergies for tool use. *J Neurosci*

# Two approaches: imitation + machine learning

## Trends and challenges in robot manipulation

**Aude Billard[1*] and Danica Kragic[2]** *Science*, 2019, *364*(6446), eaat8414.

- Progress made from advances in visual and haptic perception and in bodies via soft grippers
- However, most progress from advances in machine learning. Two classes:
  - Imitation learning (Teach and repeat etc) Learn skills from "observing" humans performing complex manipulation (typically human teleoperates or moves robot arm
  - ML approach. Learn the problem from scratch: "To avoid computing an optimal grasp [...] build a database of grasps and employ methodologies for sampling and ranking candidate grasps in real time"
- However with more autonomy need more work to keeping humans safe from robots

# Learning from demonstration for object manipulation


Example of a bi-arm robot straightening shoe laces and tying them into a bow.

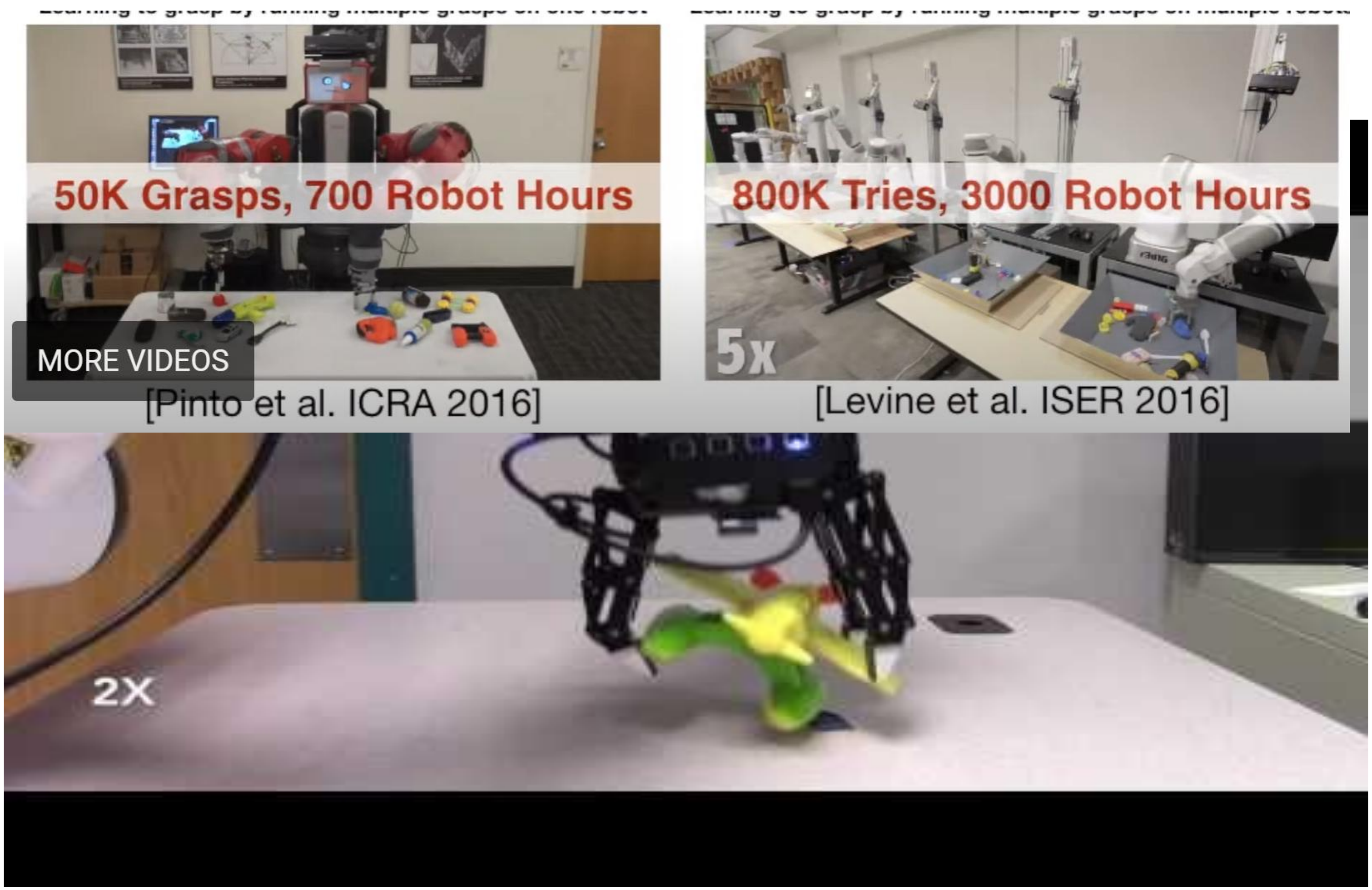
- Zhao, et al. (2025, January). ALOHA Unleashed: A Simple Recipe for Robot Dexterity. In *Conference on Robot Learning* (pp. 1910-1924). PMLR.
- More videos at: https://aloha-unleashed.github.io/
- https://aloha-2.github.io/ shows how you control the robot initially

# Grasping: machine learning approach


- Learn from trial and error = (undirected) play.
- Grasping as classification

Pinto and Gupta (2016) Supersizing Self-supervision: Learning to Grasp from 50K Tries and 700 Robot Hours, ICRA https://youtu.be/oSqHc0nLkm8

# Improved by directed learning (algorithms and data)

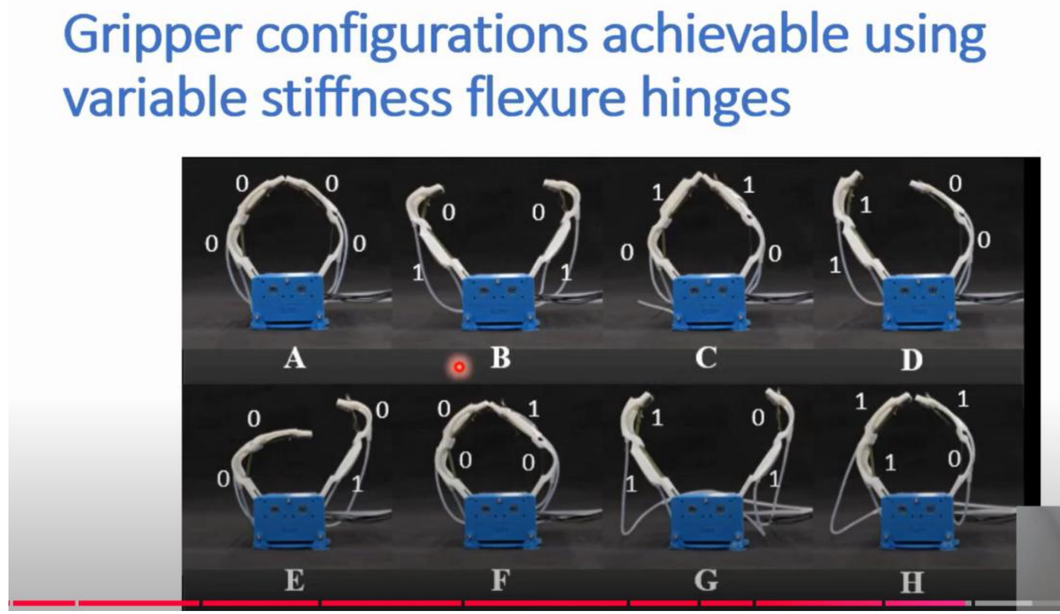



- "curriculum" approach (iterative learning of objects)
- Use "right way to collect a dataset" for learning manipulation:

Murali et al, CASSL: Curriculum Accelerated Self-Supervised Learning, 2018, ICRA, https://youtu.be/iCQsM7EE4HI,

# Embodiment: Soft robots and synergies

- Soft bodies conform to shapes
- Mechanical constraints (embodiment) allow synergies

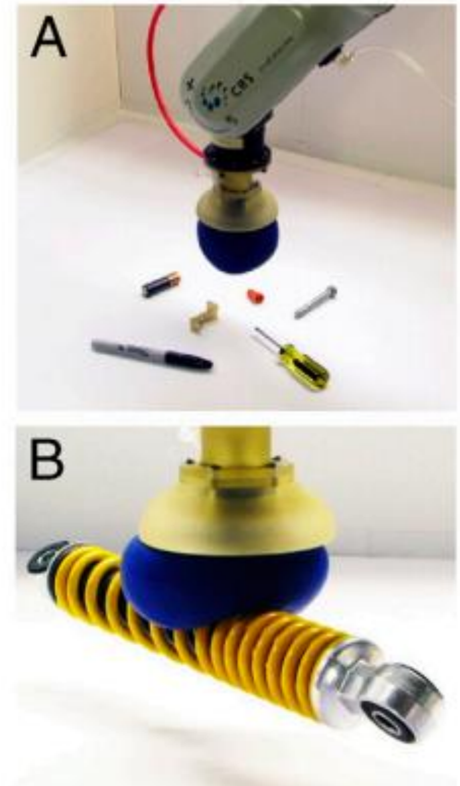




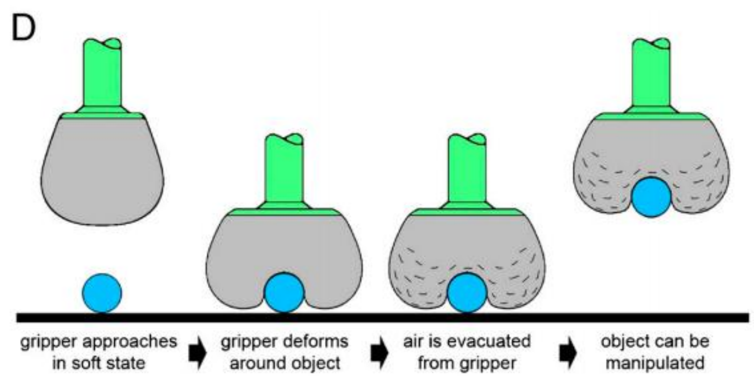
Godaba, 2020. Two-Fingered Robot Gripper with Variable Stiffness https://www.youtube.com/watch?v=PezvPWayKsg

Sardinha, et al. (2022). Embedding Soft Synergies into Soft Materials https://www.youtube.com/watch?v=lvUsnVZltDw

# Grasping: the embodied approach

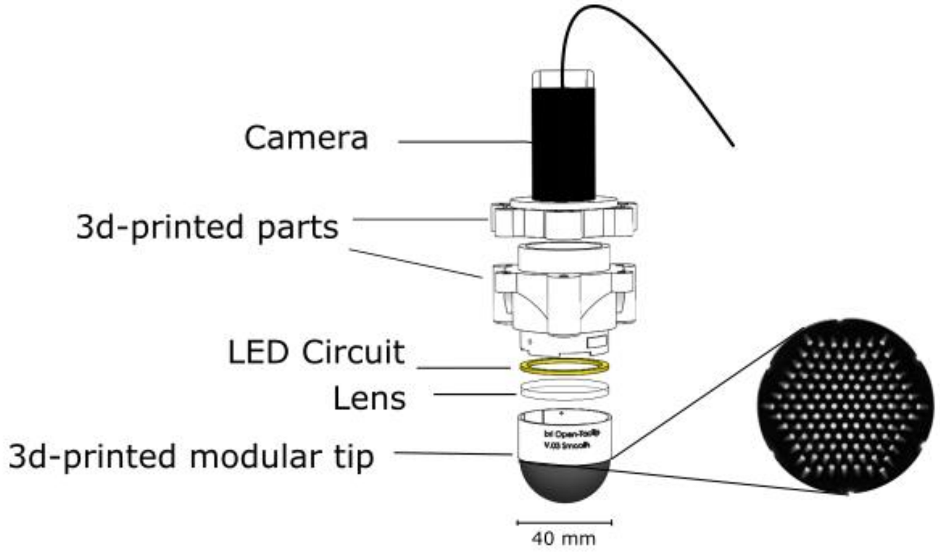

“Industrial grippers often use pneumatic vacuum pumps to pick up objects by sucking. unbeatable when it comes to grasping an object but is much less useful for object manipulation” : Billard and Kragic, Science (2024)

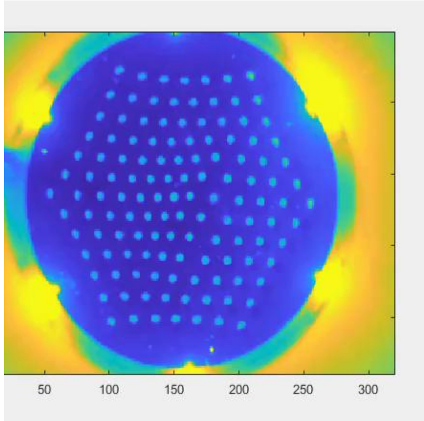


# Tactile feedback: soft sensors + cameras for sensory bandwidth

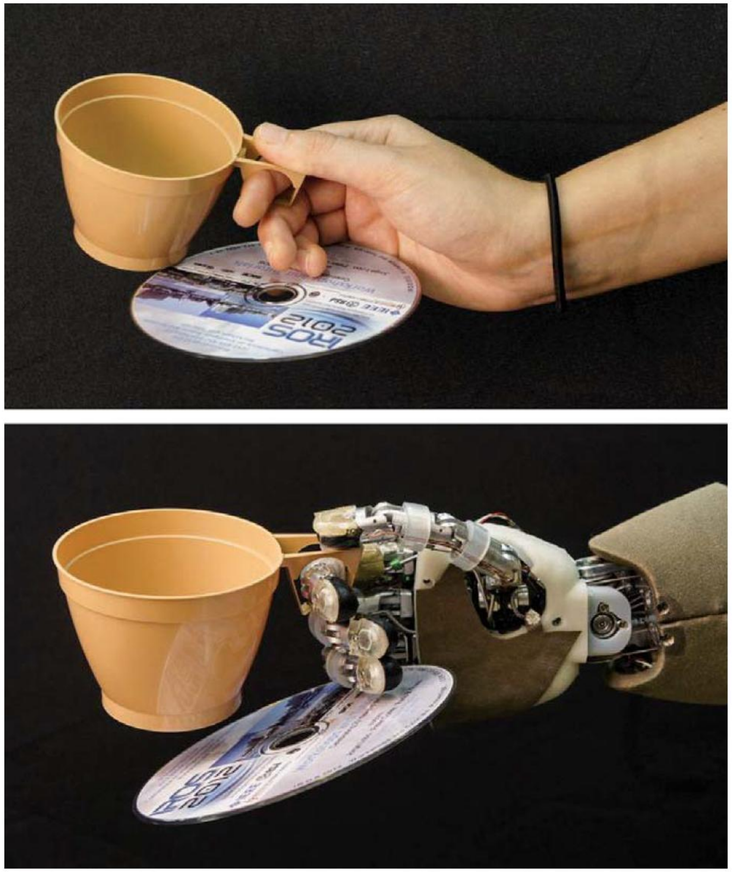
Eg Tactip family: Biomimetic sensor loosely based on human touch

Ward-Cherrier et al. (2018). Soft robotics https://www.youtube.com/watch?v=7VKQwpwZ0I4



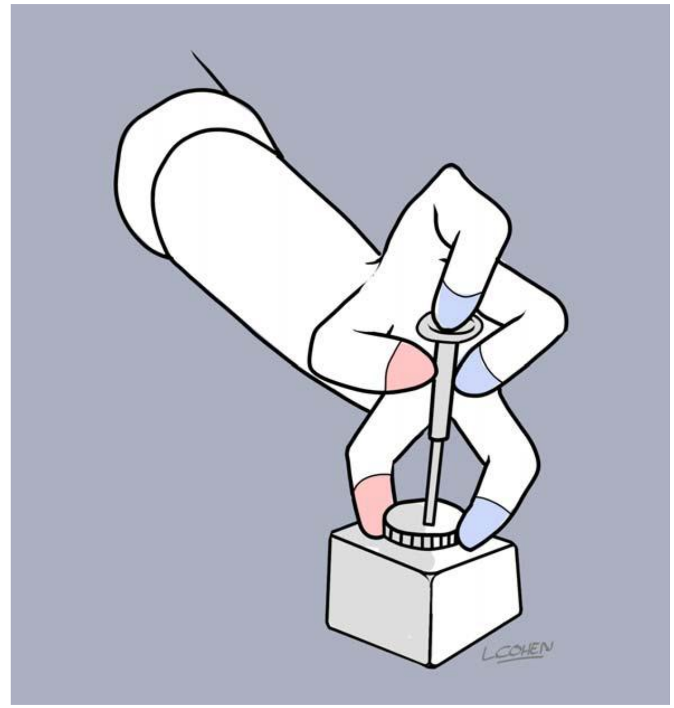




# Hands are still key to dexterity



**Holding two objects in one hand requires dexterity.** Whereas a human can grab multiple objects at the same time (top), a robot (bottom) cannot yet achieve such dexterity. In this example, a human has placed the objects in the robot's hand.

Billard, A., & Kragic, D. (2019). Trends and challenges in robot manipulation *Science*, *364*(6446), eaat8414.



- We need better grippers: Billard (2024). In good hands: A case for improving robotic dexterity. *Science*, *386*(6727), eadu2950.
- Why be constrained by biology…??

# Summary

- Tool use is a very hard problem for robots but maybe not for the same reasons as it's rare for animals
- Tool use requires a lot of skills that current robots don't have
- Great strides have been made in object manipulation largely driven by advances in ML algorithms (especially for imitation learning)
- But also by availability of data
- Generalisation and repeatability are still issues: LBMs and diffusion models hold promise but need data
- Better embodiment (better hands for compliant grasping and feedback) would make things much simpler