

# Inductive reasoning

Informatics 1 CG: Lecture 15

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# Knowledge

How do we acquire knowledge?

*“How comes it that human beings, whose contacts with the world are brief and personal and limited, are nevertheless able to know as much as they do know?”*

(Bertrand Russell)

[The poverty of of stimulus]

# Knowledge

Where does knowledge come from?

- (1) Non-experiential sources (innate)
- (2) Perception and memory
- (3) Deduction
- (4) Induction

# Knowledge

Inductive reasoning:

- Reasoning about cases or principles that go beyond current data.
- Could be wrong; entail uncertainty or ambiguity.
  - Having seen only black ravens, we might expect a new, hidden raven to be black.
  - A new raven could be white!
- E.g., Hume: “instances of which we have had no experience must resemble those of which we have had experience.”

# Perception



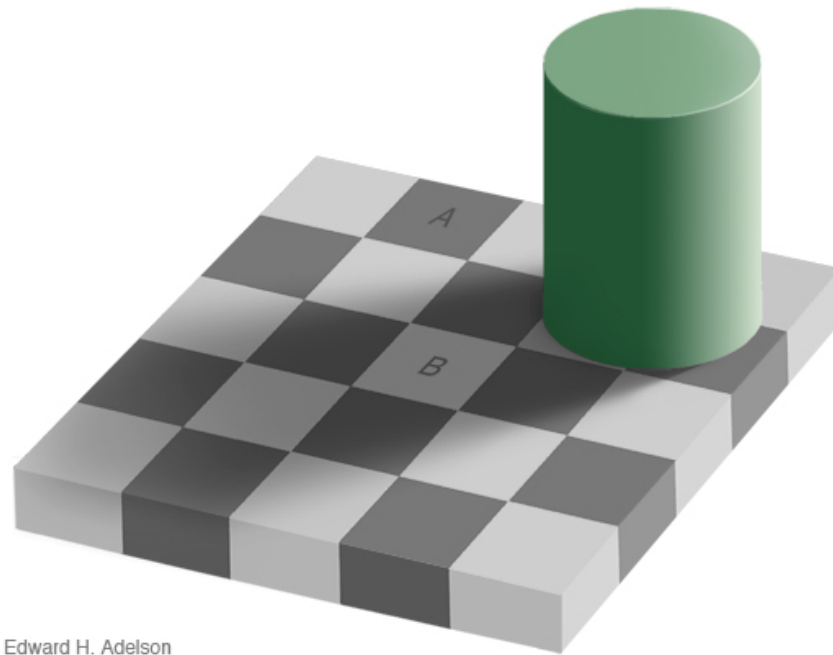
Jubal called out, "That new house on the far hilltop - can you see what color they've painted it?"

Anne looked in the direction in which Jubal was pointing and answered, "It's white on this side." She did not inquire why Jubal had asked, nor make any comment.

Jubal went on to Jill in normal tones. "You see? [...] it doesn't even occur to her to infer that the other side is probably white too ... [even if she saw it] she wouldn't assume that it stayed [that color] . . . because they might repaint it as soon as she turned her back.

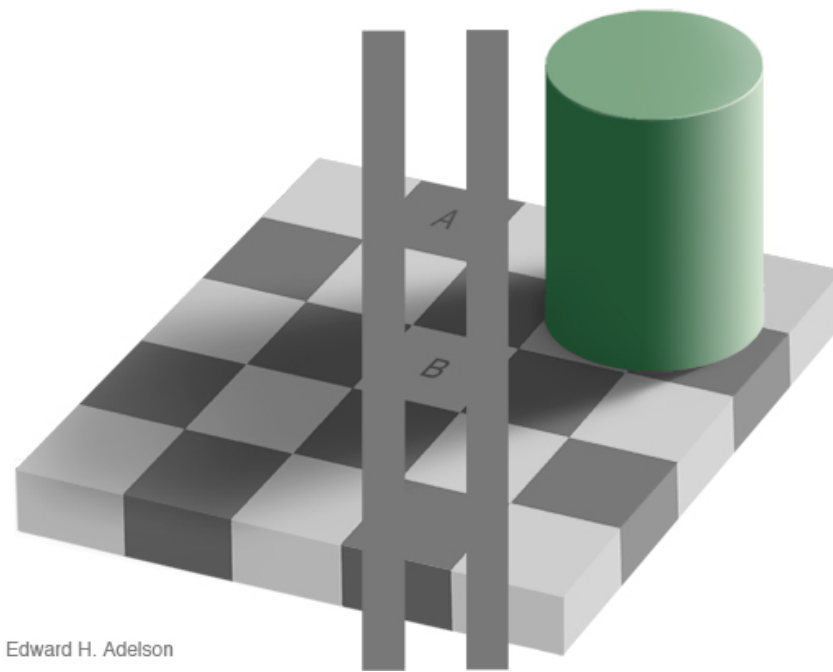
*(Heinlein, 1961)*

# Perception



Edward H. Adelson

# Perception



Edward H. Adelson

# Memory

Serial reproduction experiments:



“Person 1: Draw this!”

(Bartlett, 1932 via Xu & Griffiths, 2010)



# Memory

Serial reproduction experiments:



Person 1 drew this.  
“Person 2: Draw this!”

(Bartlett, 1932 via Xu & Griffiths, 2010)

# Memory

Serial reproduction experiments:



Person 2 drew this.  
“Person 3: Draw this!”

(Bartlett, 1932 via Xu & Griffiths, 2010)

# Memory

Serial reproduction experiments:



Person 3 drew this.  
“Person 4: Draw this!”

(Bartlett, 1932 via Xu & Griffiths, 2010)

# Memory

Serial reproduction experiments:

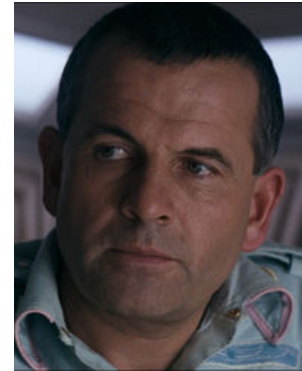


(Bartlett, 1932 via Xu & Griffiths, 2010)

# Deduction

A syllogism:

1. All humans are mortal.
2. Ash is human.
3. Therefore, Ash is mortal.



# Deduction

A syllogism:

1. All humans are mortal.
2. Ash is ~~human~~ a killer android
3. Therefore, ... ?

Perfect certainty is rare in the real world.



# Induction

- We categorise objects we've never seen before
- We can make sense of new and ambiguous sentences:  
    "I once saw a deer riding my bicycle."
- We can learn how to use new tools and technology
- We make new scientific discoveries



([https://en.wikipedia.org/wiki/List\\_of\\_linguistic\\_example\\_sentences](https://en.wikipedia.org/wiki/List_of_linguistic_example_sentences))

# Induction

How is all this possible?



# Induction

The **rationalist** answer:

- The mind has lots of innate structure.
- Knowledge comes from this structure and its interactions with experience.

# Induction

The **rationalist** answer:

- The mind has lots of innate structure.
- Knowledge comes from this structure and its interactions with experience.

The **empiricist** answer:

- The stimulus is not as impoverished as one might think.
- We can learn and generalise with minimal innate structure.

# Inductive biases

## **Consensus:**

- People learn *something* from experience.
- We need to have *some* starting knowledge (or assumptions) to generalise at all.

We can call this “knowledge” our *inductive biases*.

# Inductive biases

We can think of many questions in cognitive science in term of:

(1) What inductive biases shape human behaviour?

(2) Where do our inductive biases come from?

# Inductive biases

Inductive biases can be understood in different ways:

They can be made explicit, e.g.,

- Tacit knowledge of a “universal grammar”
- Assumption that categories are defined in terms of a prototype
- Assumption that categories have hierarchical structure

# Inductive biases

Inductive biases can be understood in different ways:

They can arise from a learner's structure or its environment:

- The architecture of a neural network
- The kinds of experiences an infant has

# Inductive biases

These aren't mutually exclusive.

A person's inductive biases might

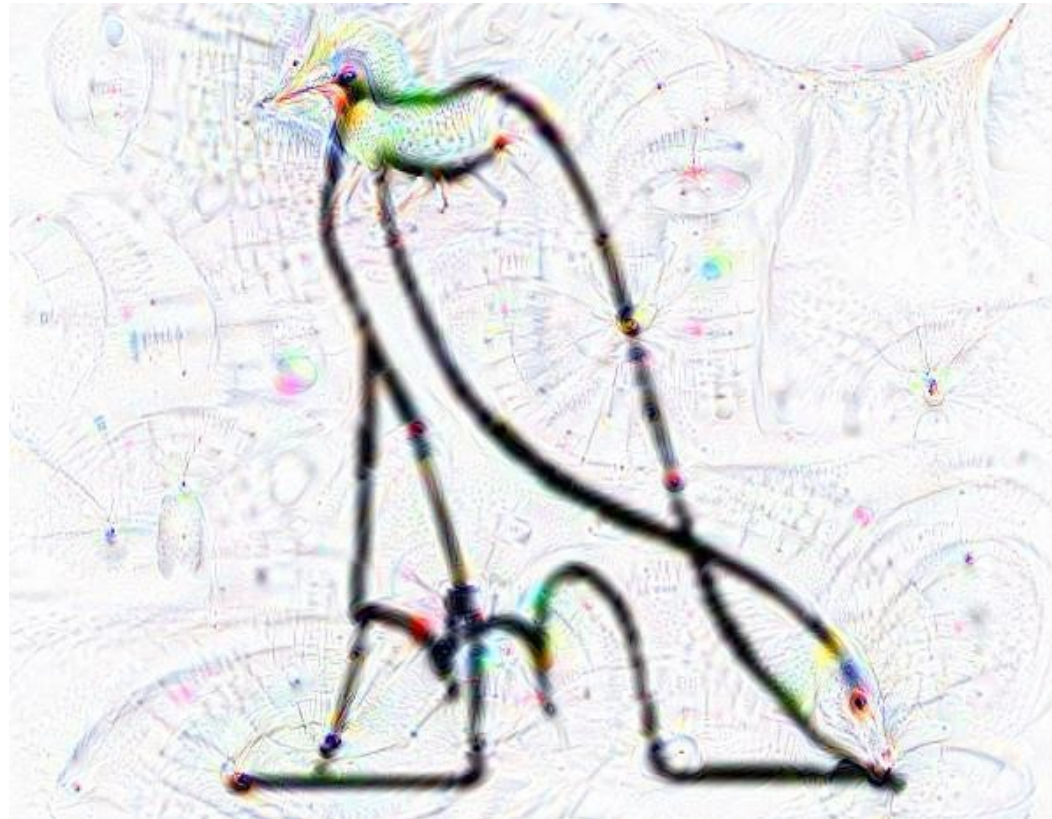
- be accurately captured by rules or probability distributions **and**
- emerge from complex biological phenomena.

Example: Inductive biases of a neural net



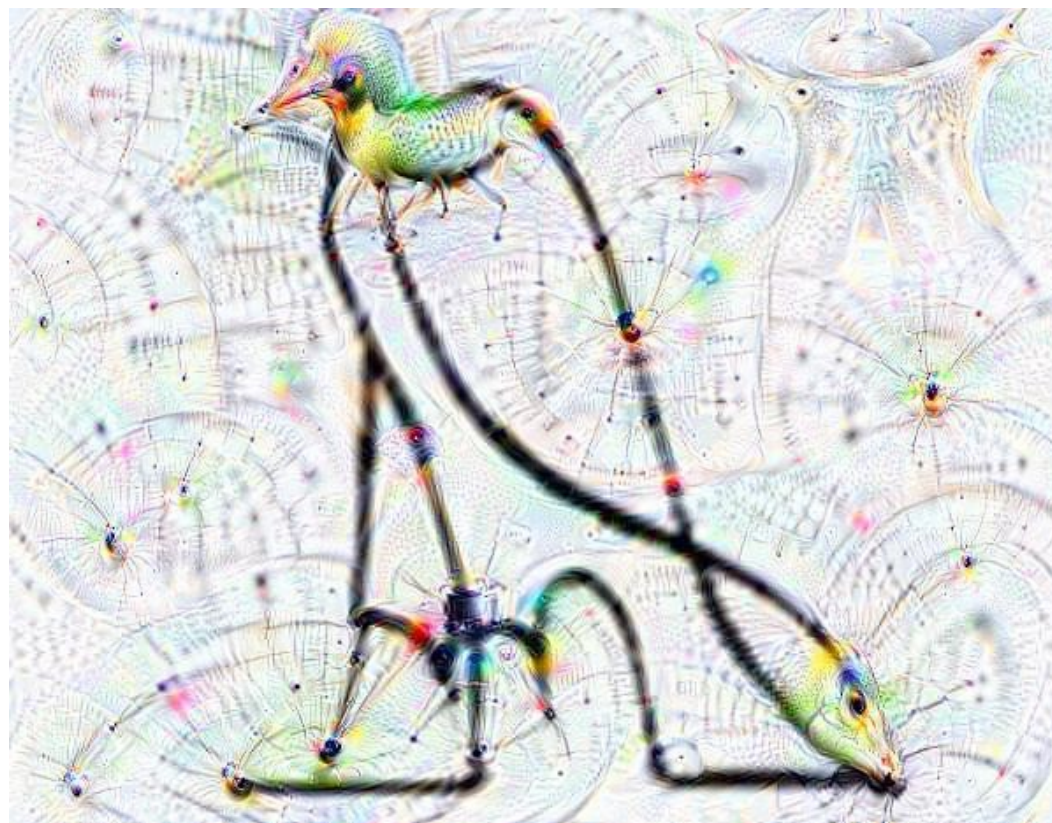


# Example: Inductive biases of a neural net



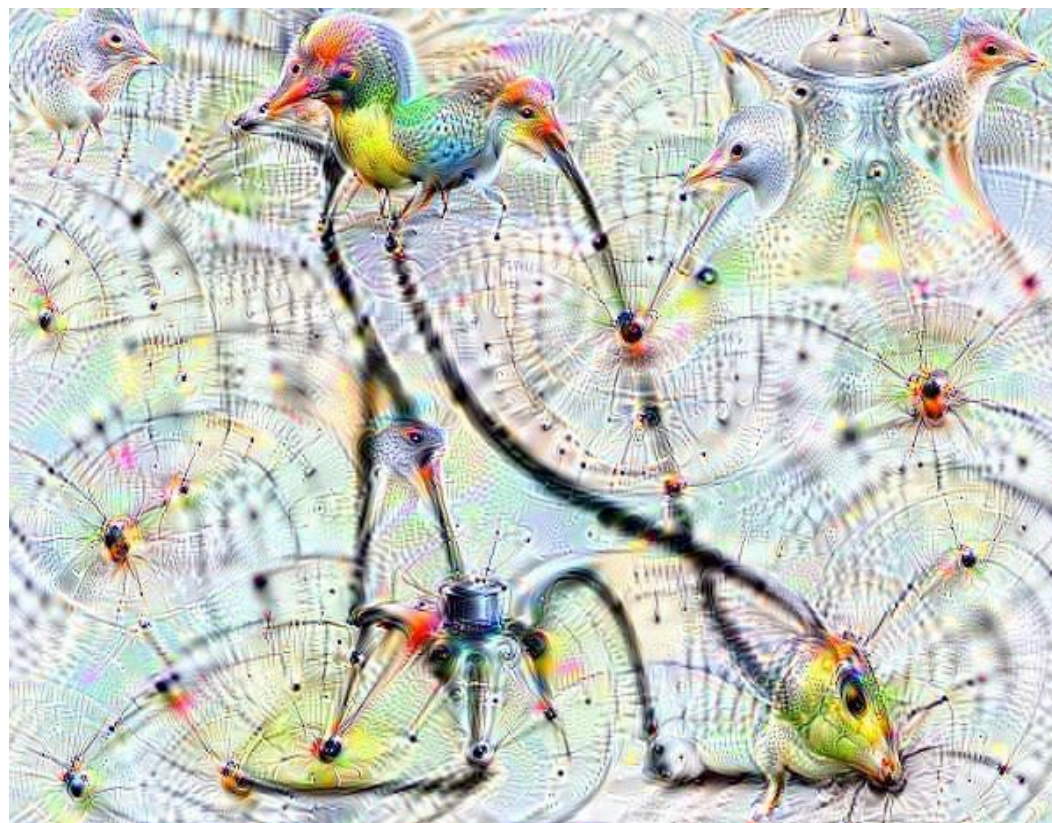
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# Example: Inductive biases of a neural net



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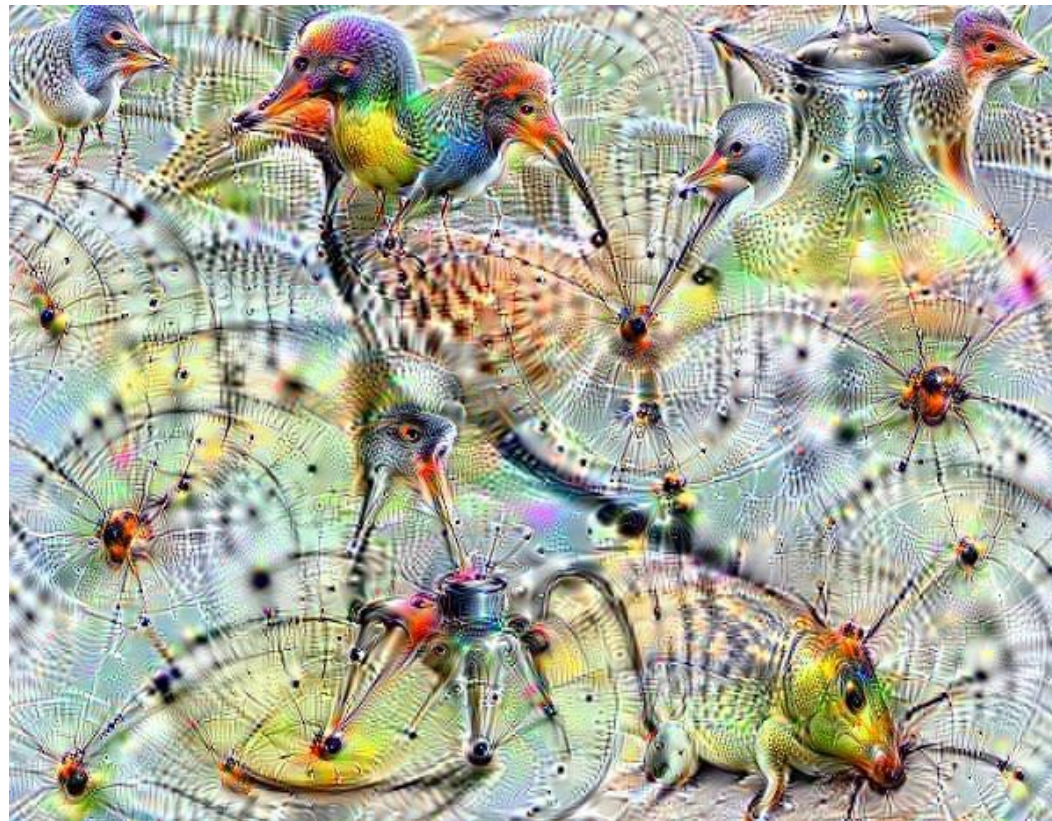
# Example: Inductive biases of a neural net



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# How can we study inductive biases?

Some options:

1. Look at what people find surprising.
2. Look at what patterns people find easy/hard to learn.
3. Predict specific human judgments and generalizations.
4. Look at statistical regularities in human judgments.
5. Understand what constraints biology imposes.

# How can we study inductive biases?

1. Look at what people find surprising.

“If <X> is innate, infants should be surprised by <Y>.”

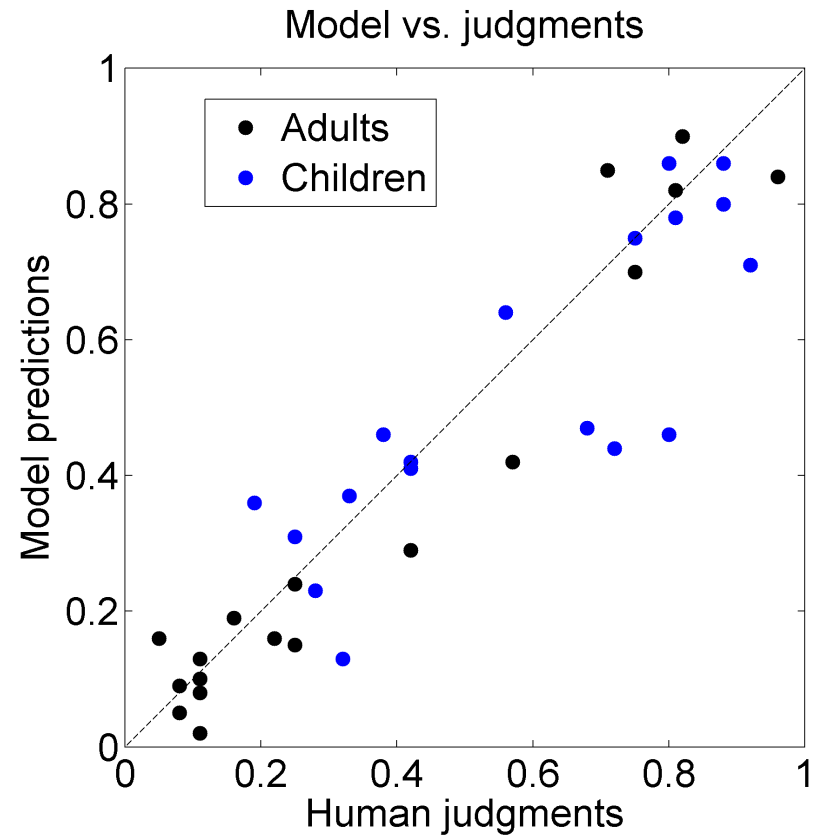
# How can we study inductive biases?

2. Look at what patterns people find easy/hard to learn.

“If people rely on representation  $\langle X \rangle$ ,  
they should commit the following kinds of errors...”

# How can we study inductive biases?

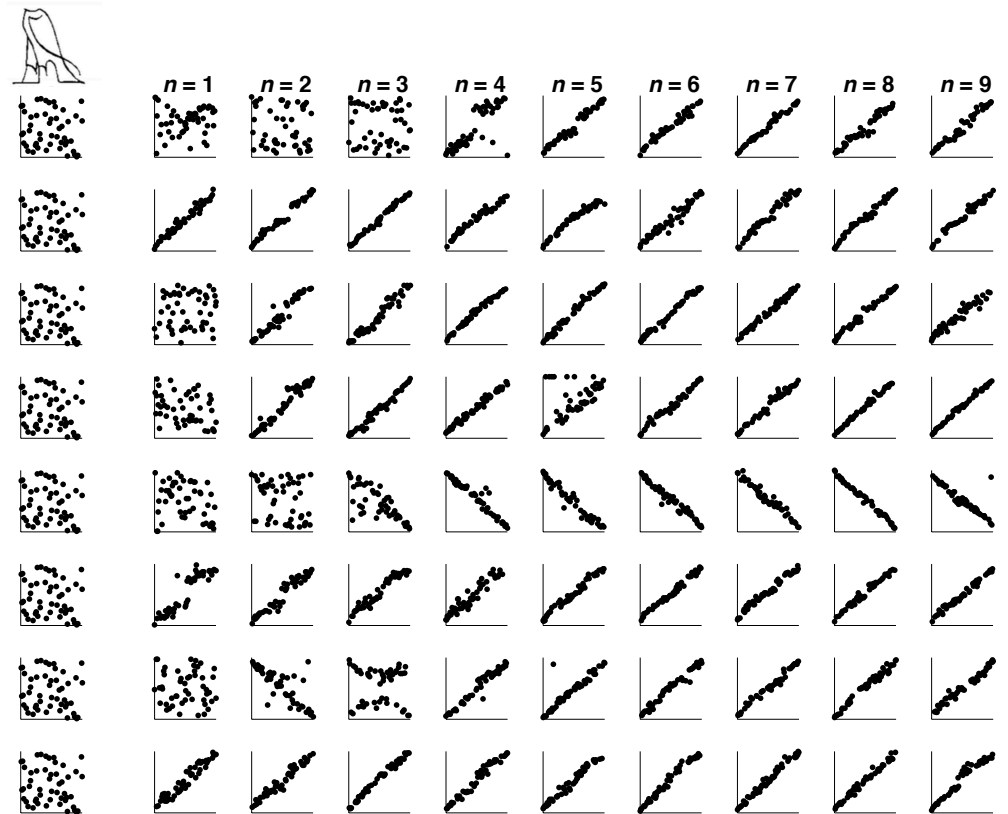
3. Predict specific human judgments and generalizations.





# How can we study inductive biases?

4. Look at statistical regularities in human judgments.

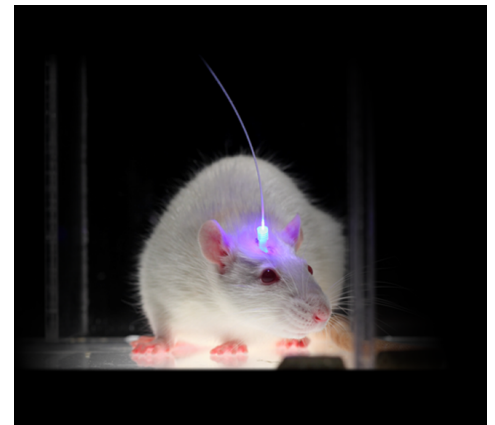


# How can we study inductive biases?

## 5. Understand what constraints biology imposes

### Neuroscience! Examples:

- Multi-unit recording
- Models of cells and cell populations
- Genetic manipulation (e.g., knockouts and optogenetics)



<http://web.stanford.edu/group/dlab/optogenetics/>

(For readings on this, see <http://homepages.inf.ed.ac.uk/pseries/ccn16.htm>)

# Summary

- Inductive reasoning is everywhere:
  - To perceive, understand, and act on the world around us, we must generalise, using information that is noisy, incomplete, and ambiguous.
- Generalisation is impossible without inductive biases.
- Inductive biases include acquired knowledge and biological constraints.
- Many big questions in cognitive science can be framed in terms of:
  - What are our inductive biases?
  - Where do they come from?