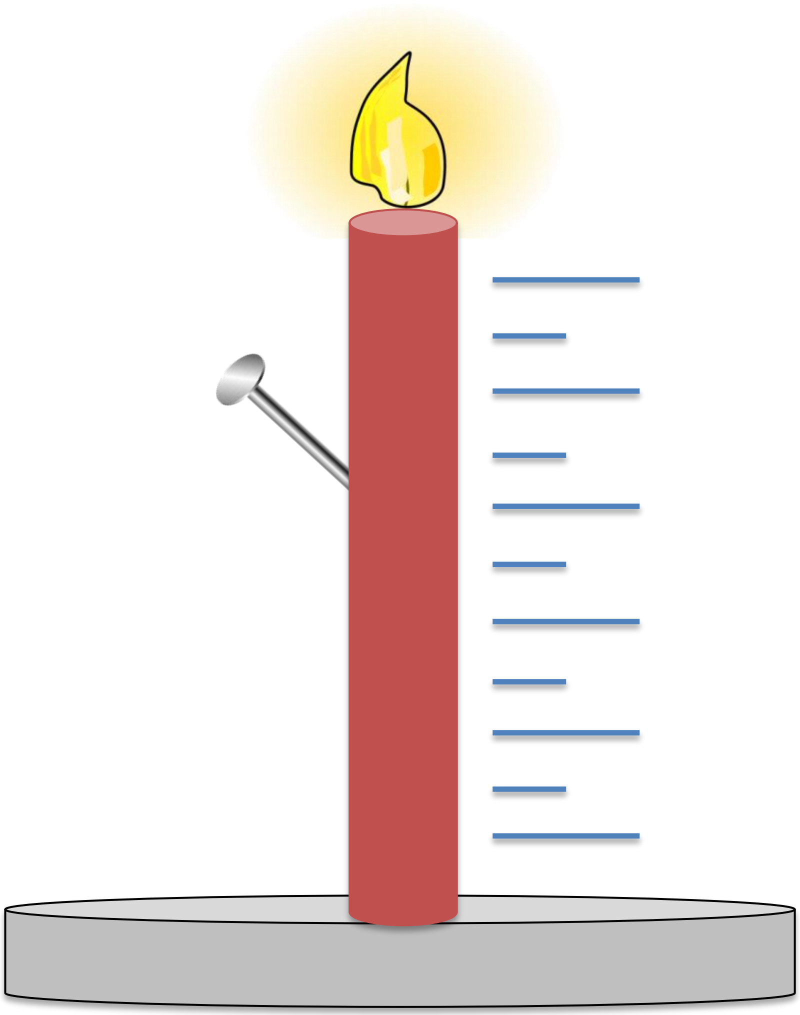
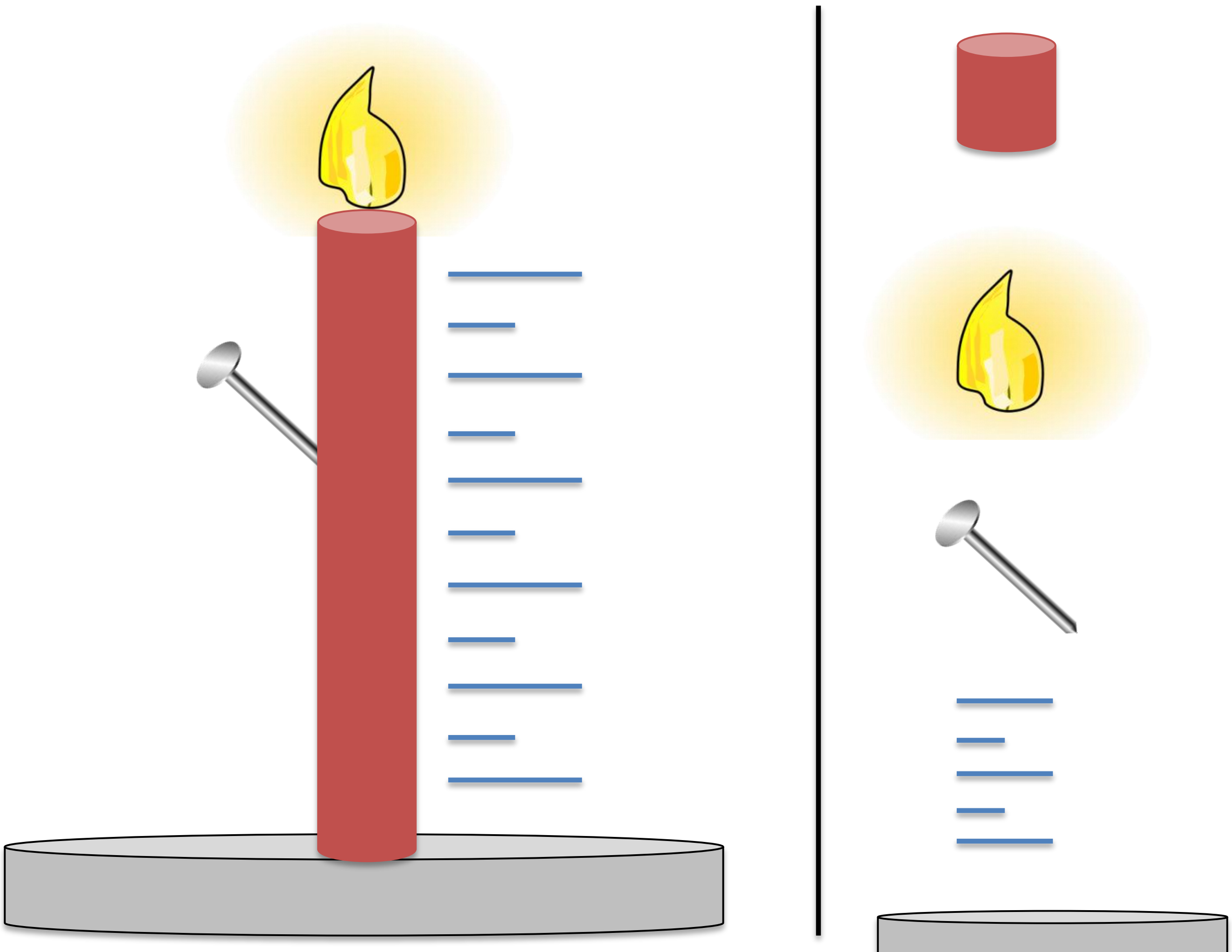
Computational modeling of cognitive development

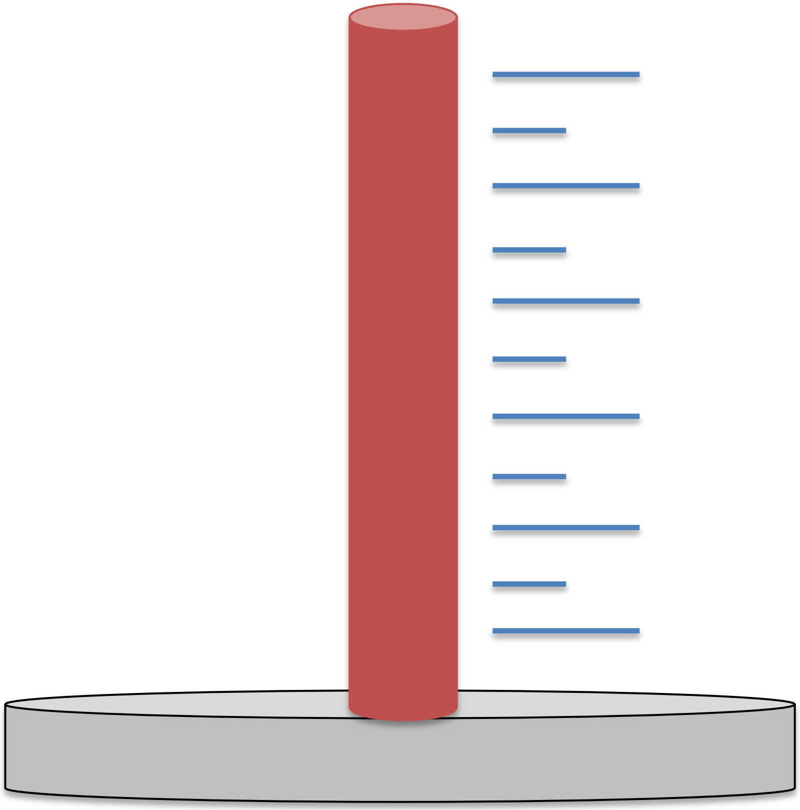
Guest Lecture
Julian Jara-Ettinger
Infant & Childhood Cognition
Fall, 2012



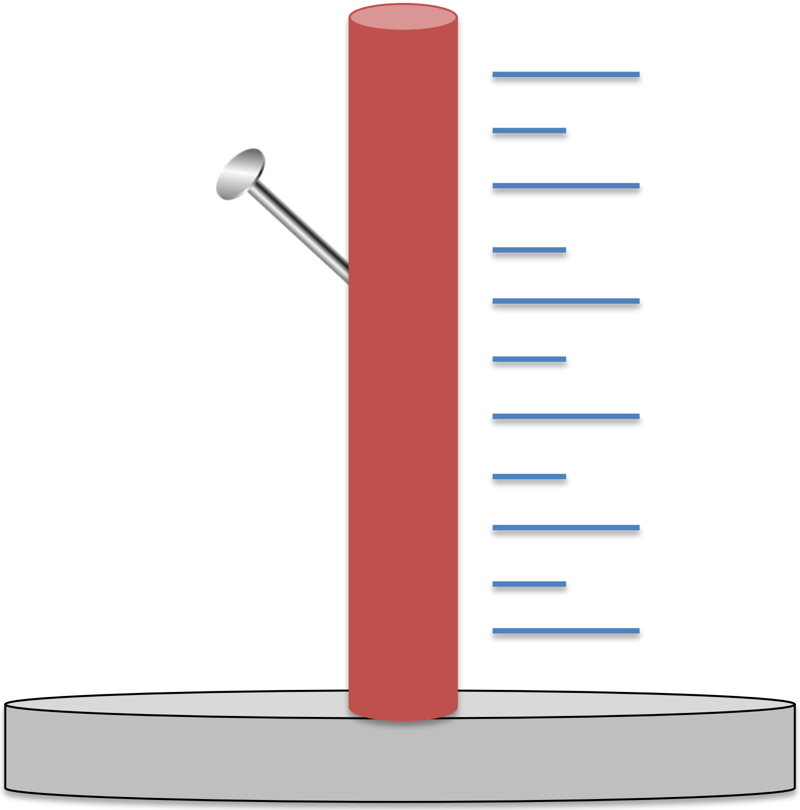
Bottom-Up



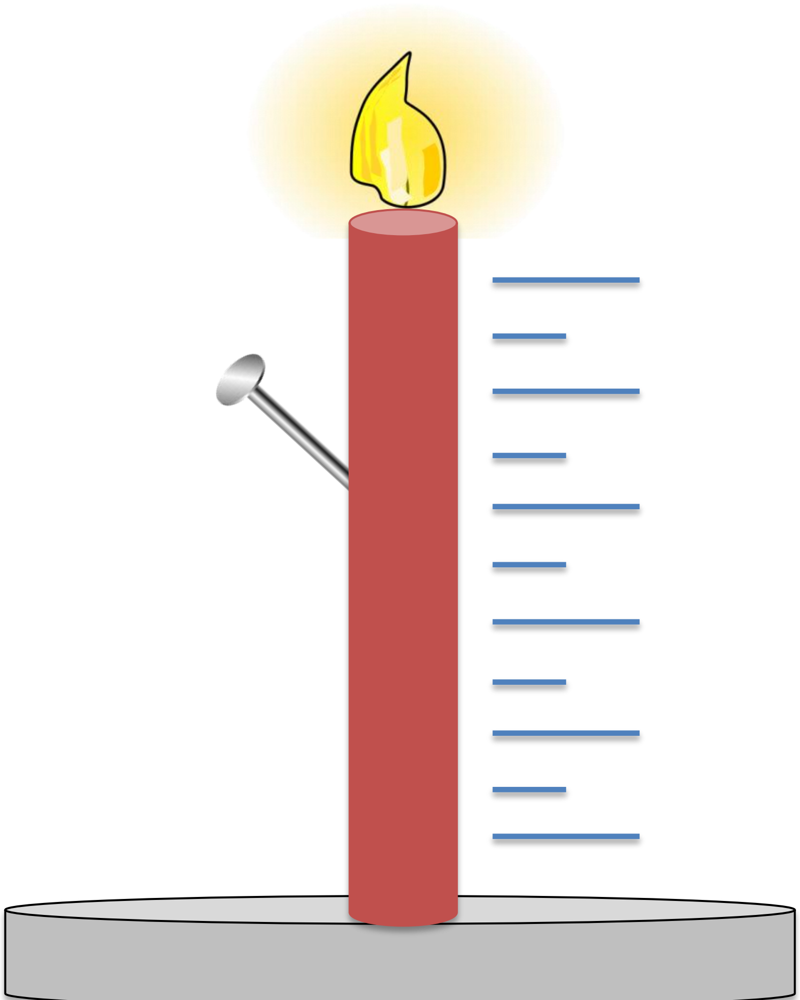
Top-Down: The Design Stance



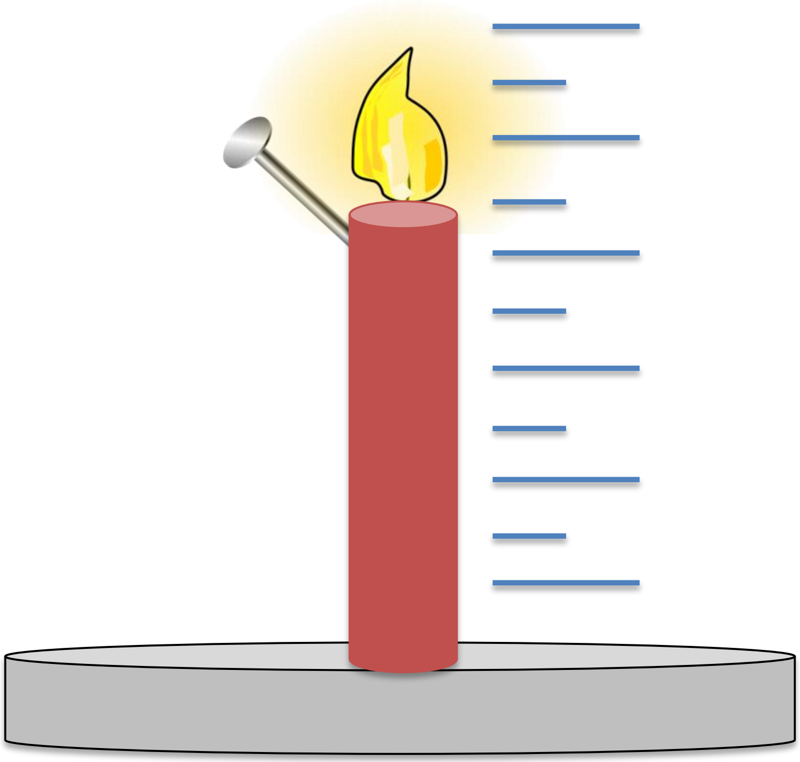
Top-Down: The Design Stance



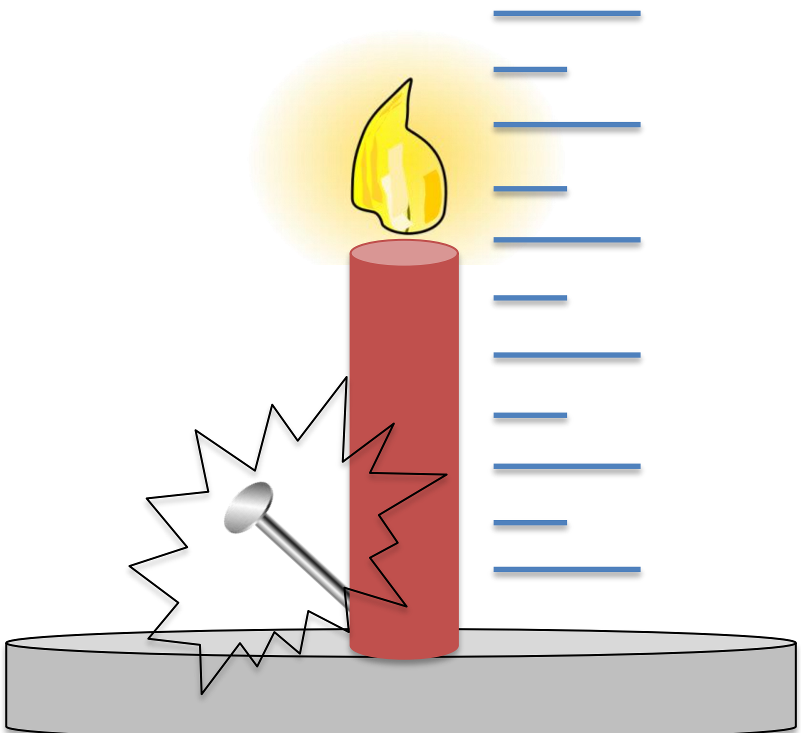
Top-Down: The Design Stance



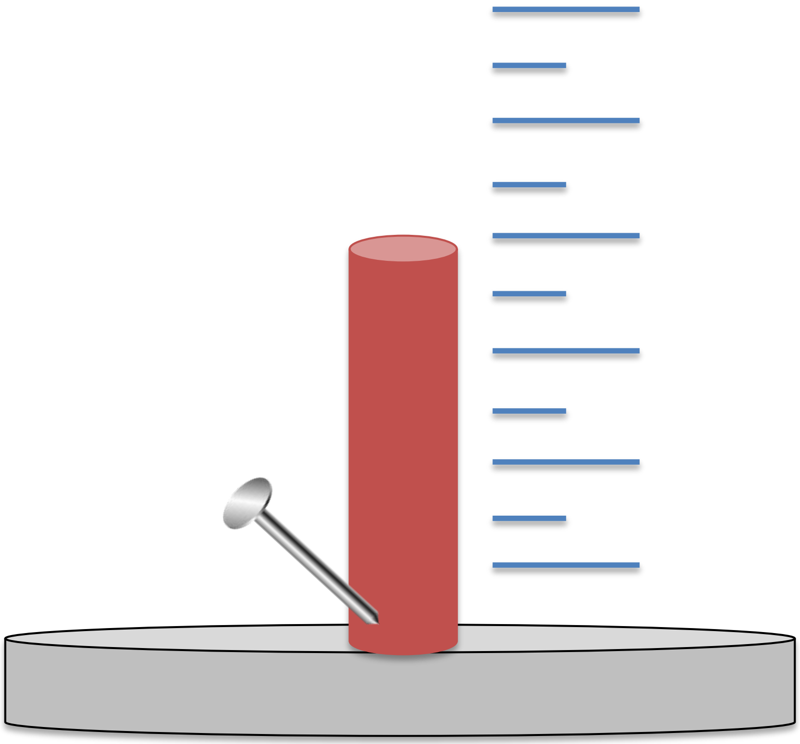
Top-Down: The Design Stance



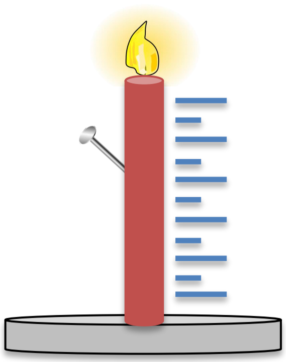
Top-Down: The Design Stance



Top-Down: The Design Stance



Top-Down



Alarm Clock

Wax, Nails, etc.

Burning wax

Alarm Clock

Springs, Gears, etc.

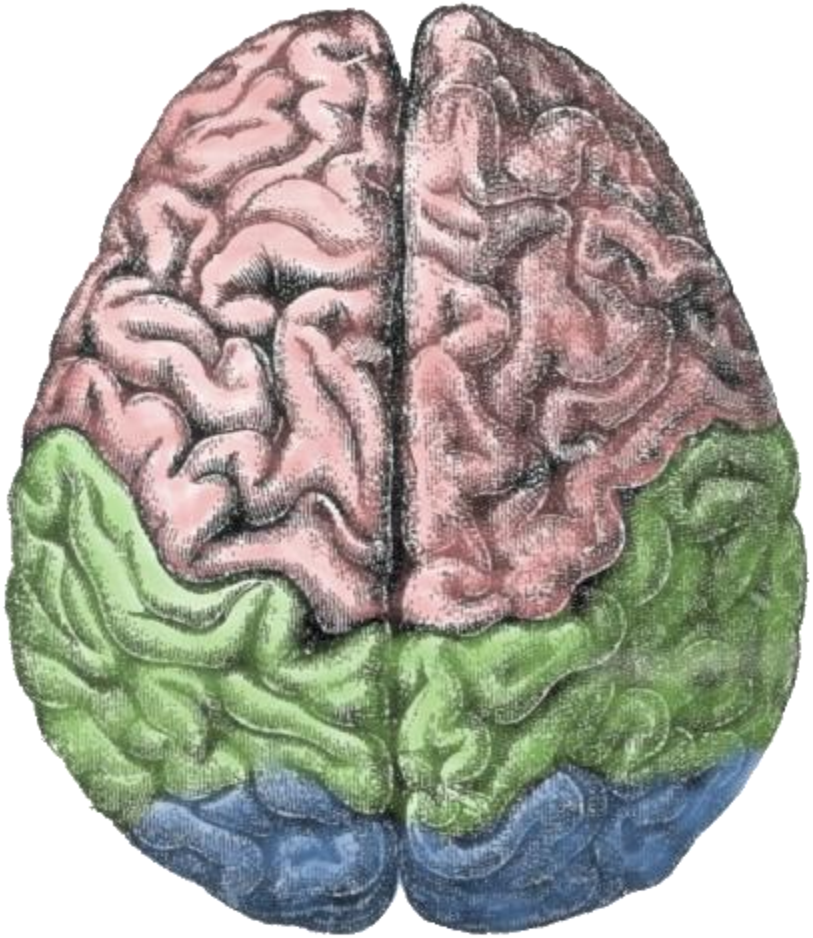
Spring oscillations

Alarm Clock

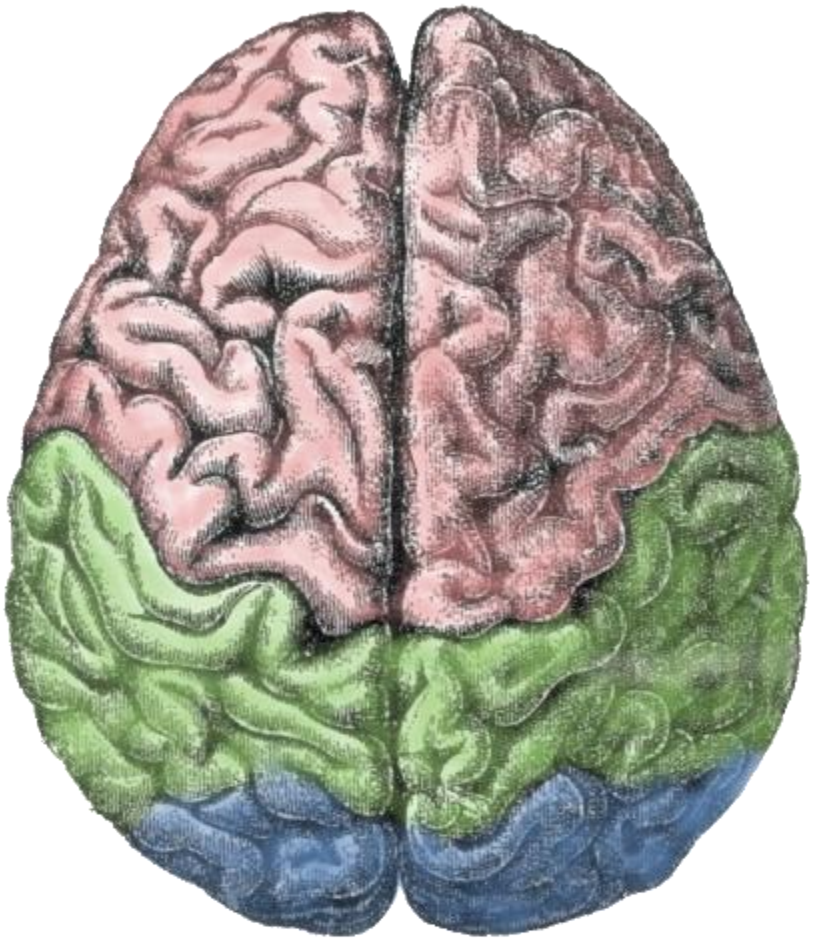
Capacitors, Transistors, etc.

Charging capacitors

But no one designed the brain!



~~But no one designed the brain!~~



The brain evolved to do certain computations

The Computational Level of Analysis

Understand the logic of the computations, not the specific algorithm or implementation.

Bayesian Models of Cognition

The Assumptions

Beliefs can be represented as a real number between 0 and 1.

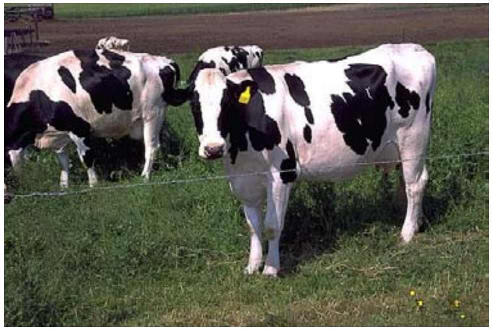


Image: USDA. Public Domain.

Image: Arlo MagicMan. Flickr. CC BY-NC

Figure removed due to copyright restrictions. Téglás, Ernő, Edward Vul, et al. "Pure Reasoning in 12-Month-Old Infants as Probabilistic Inference." *Science* 332, no. 6033 (2011): 1054-9.

Bayes rule

$$P(H \mid D) \propto P(D \mid H) P(H)$$

Bayes rule

$$P(H \mid D) \propto P(D \mid H)P(H)$$

Your belief that a hypothesis is true given the data

Bayes rule

$$P(H \mid D) \propto P(D \mid H)P(H)$$

Your belief that a hypothesis is true given the data is proportional

Bayes rule

$$P(H \mid D) \propto P(D \mid H)P(H)$$

Your belief that a hypothesis is true given the data is proportional to your prior belief in the hypothesis

Bayes rule

$$P(H \mid D) \propto P(D \mid H)\,P(H)$$

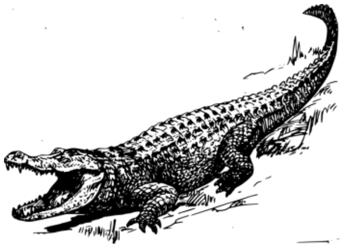
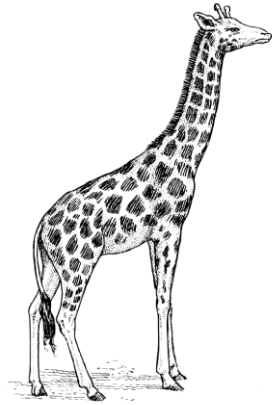
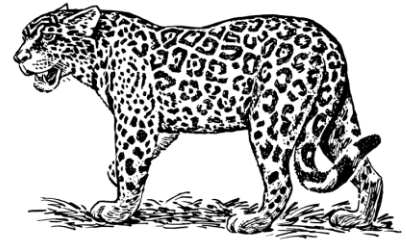
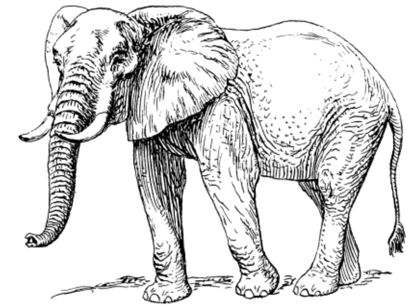
Your belief that a hypothesis is true given the data is proportional to your prior belief in the hypothesis times the likelihood of the hypothesis producing the data.

Dier?

Animal
Mammal
Giraffe

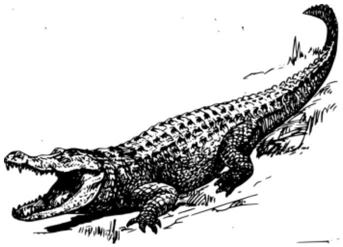
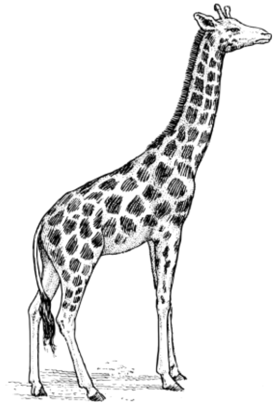
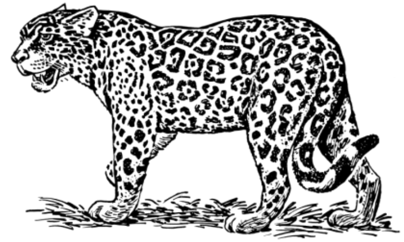
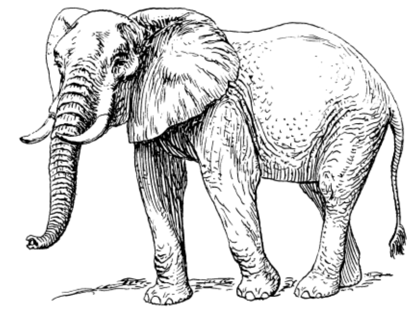
Dier?

Animal	**1/3**
Mammal	**1/3**
Giraffe	**1/3**
	P(H)

Animal	**1/3**
Mammal	**1/3**
Giraffe	**1/3**
	P(H)

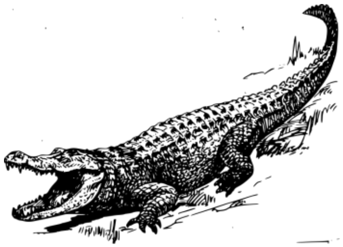
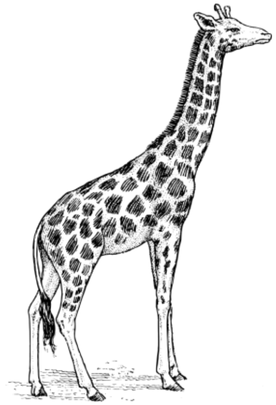
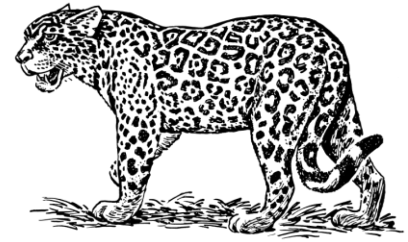
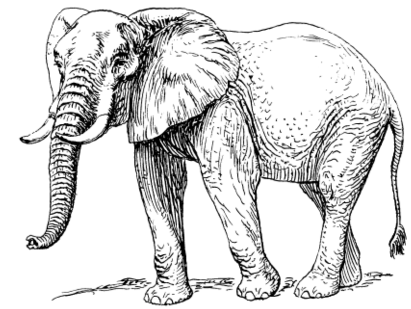
Images: Wikipedia. Public Domain.

Dier!

Animal	**1/3**
Mammal	**1/3**
Giraffe	**1/3**
	P(H)

Images: Wikipedia. Public Domain.

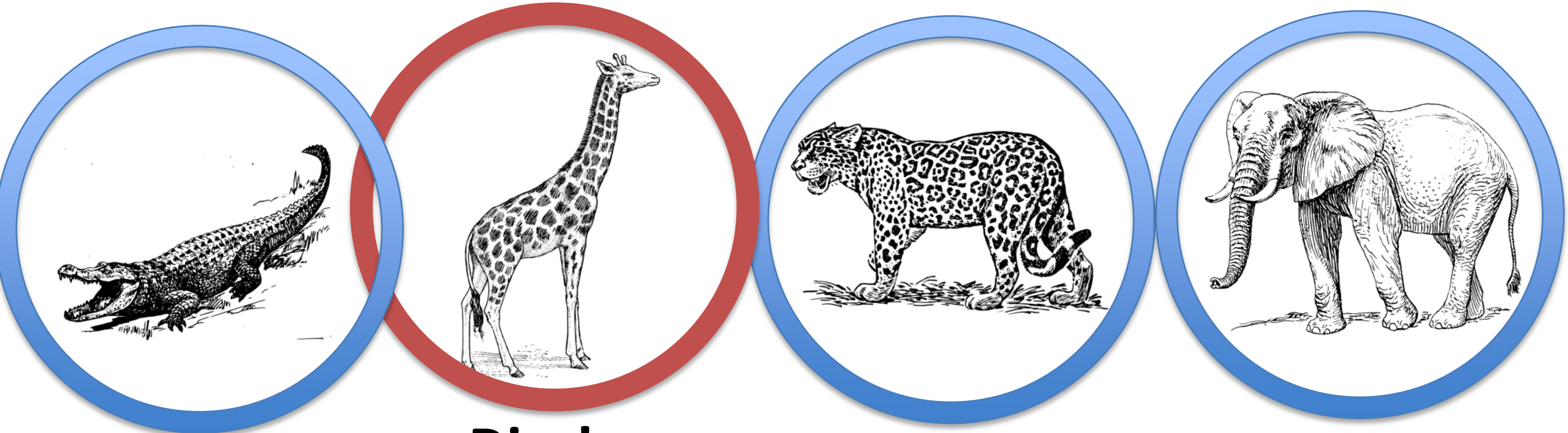





Dier!

Animal	**1/3**
Mammal	**1/3**
Giraffe	**1/3**
	P(H)

P(D|H)

Images: Wikipedia. Public Domain.



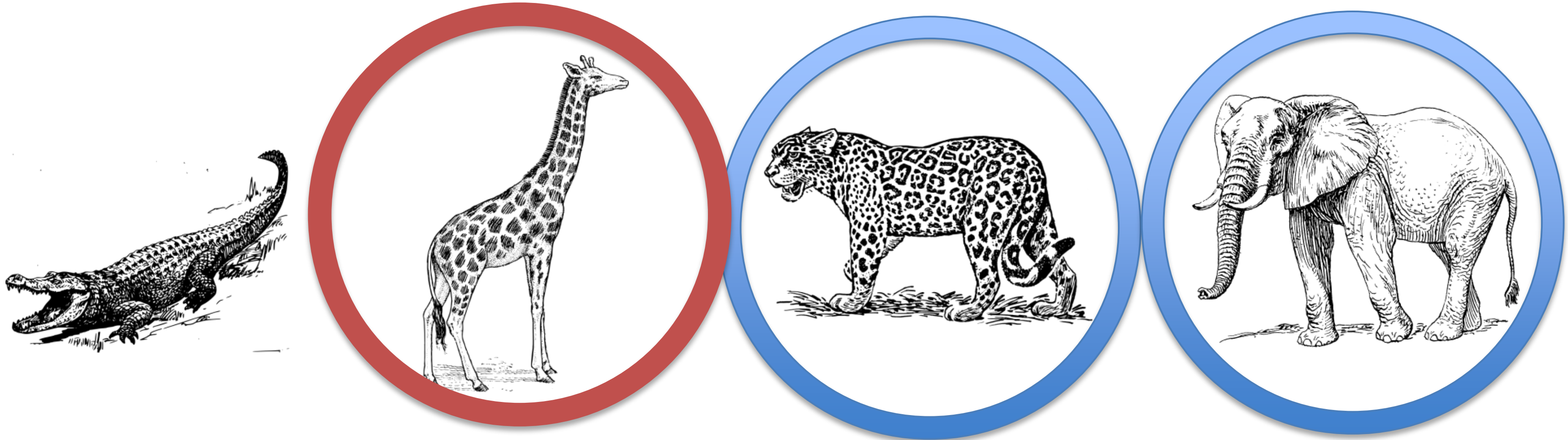
Dier!

Animal (1/3)*(1/4)

Mammal 1/3

Giraffe 1/3

P(H) P(D|H)



Dier!

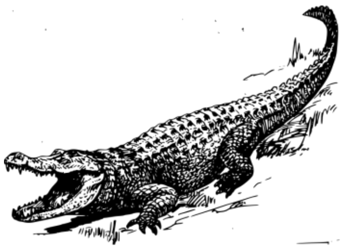
Animal $(1/3)*(1/4)$

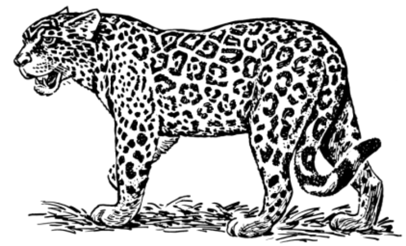
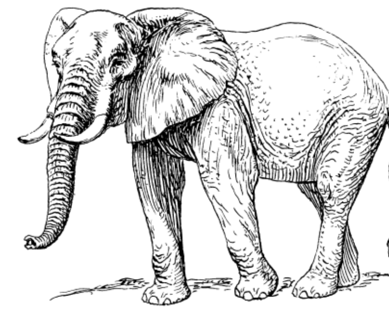
Mammal $(1/3)*(1/3)$

Giraffe $1/3$

$P(H)$ $P(D|H)$

Images: Wikipedia. Public Domain.



Dier!

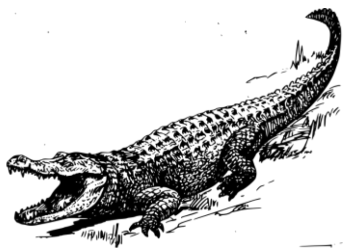
Animal $(1/3)*(1/4)$

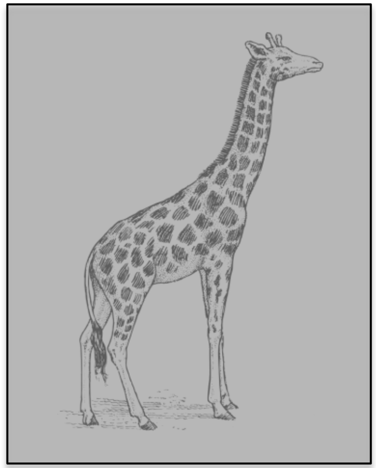
Mammal $(1/3)*(1/3)$

Giraffe $(1/3)*(1/1)$

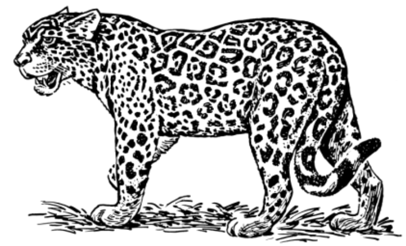
$P(H)$ $P(D|H)$

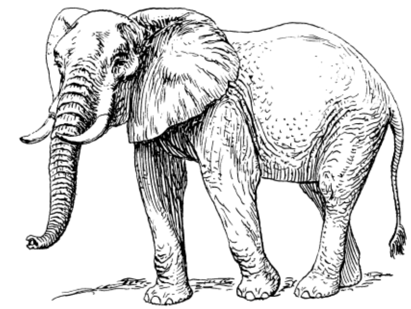
Images: Wikipedia. Public Domain.





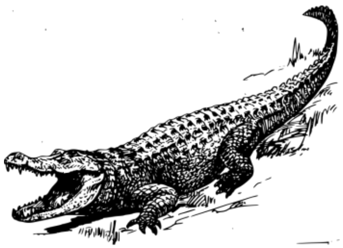
Dier!

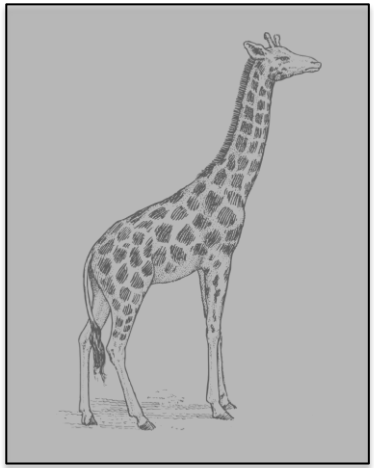




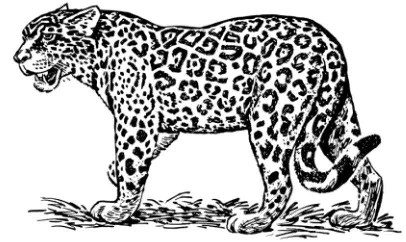
Animal (3/19)
Mammal (4/19)
Giraffe (12/19)

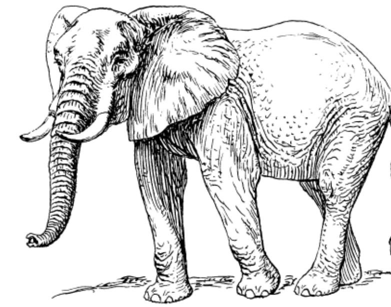
$P(H|D)$





Dier!





Dier!

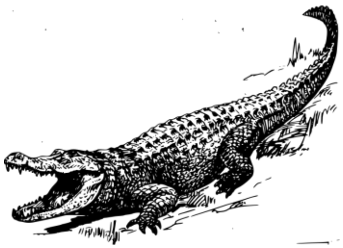
Animal (3/19)

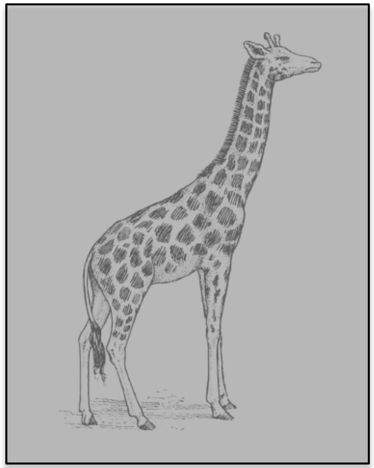
Mammal (4/19)

Giraffe (12/19)

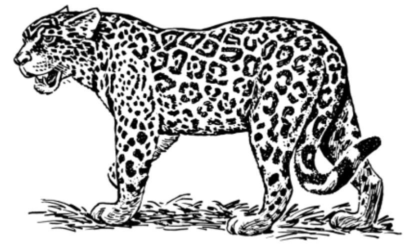
P(H)

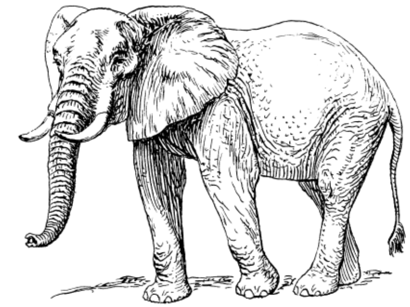
Images: Wikipedia. Public Domain.





Dier!



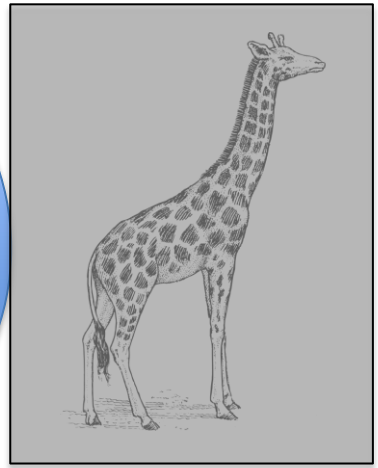


Dier!

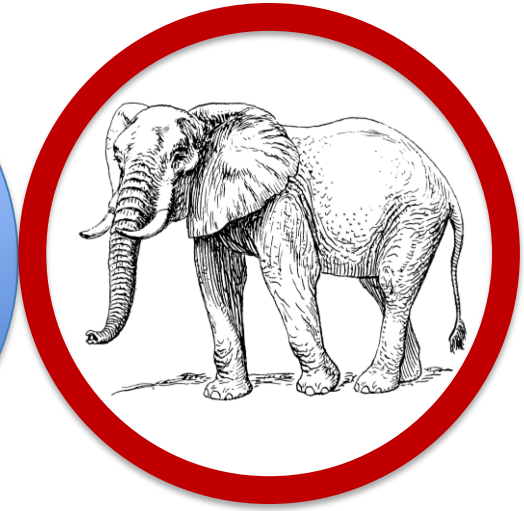
Animal (3/19)
Mammal (4/19)
Giraffe (12/19)

P(H) P(D|H)

Images: Wikipedia. Public Domain.



Dier!



Dier!

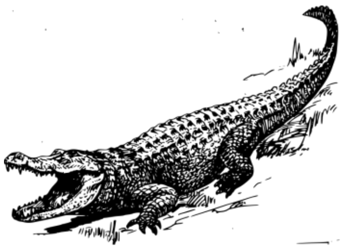
Animal (3/19) * (1/3)

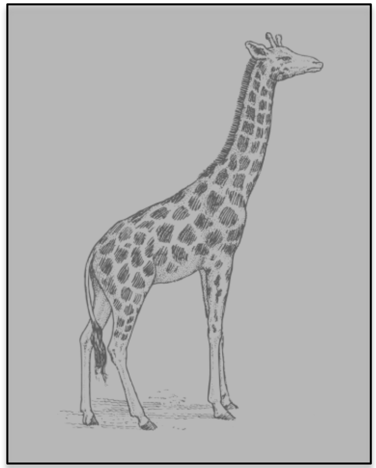
Mammal (4/19)

Giraffe (12/19)

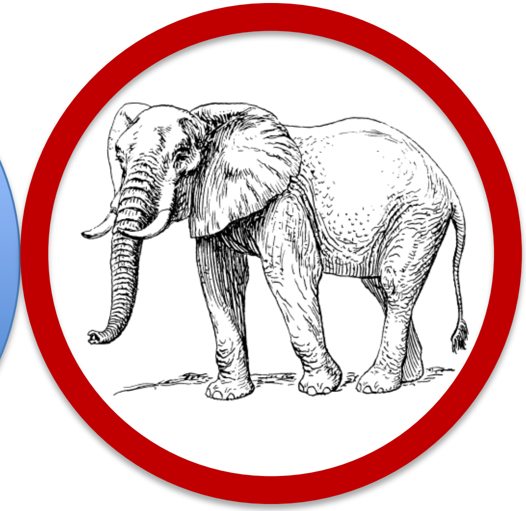
P(H) P(D|H)

Images: Wikipedia. Public Domain.





Dier!



Dier!

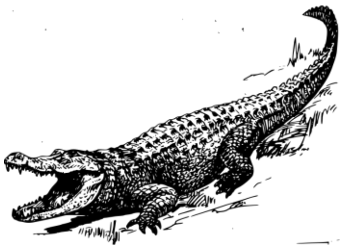
Animal (3/19) * (1/3)

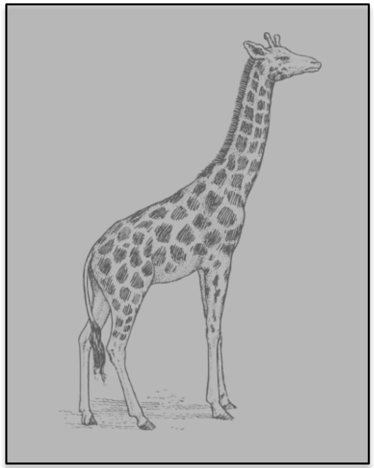
Mammal (4/19) * (1/2)

Giraffe (12/19)

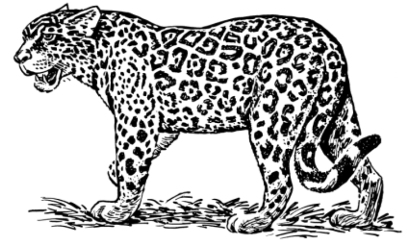
P(H) P(D|H)

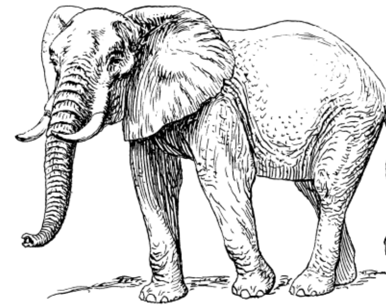
Images: Wikipedia. Public Domain.





Dier!





Dier!

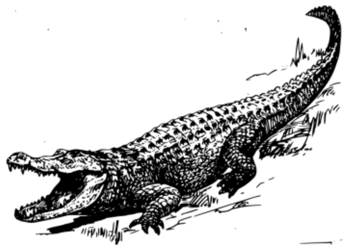
Animal (3/19) * (1/3)

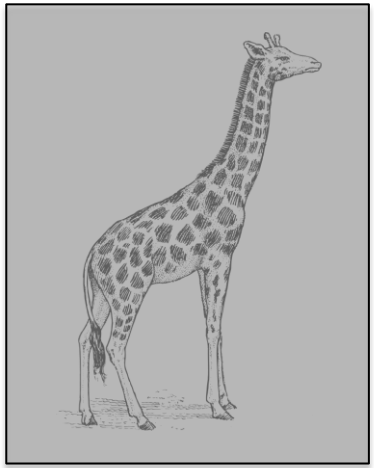
Mammal (4/19) * (1/2)

Giraffe (12/19) * (0)

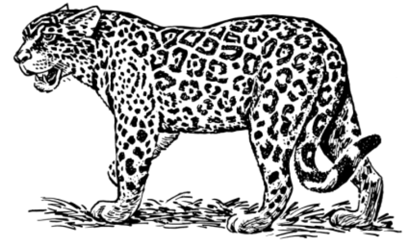
P(H) P(D|H)

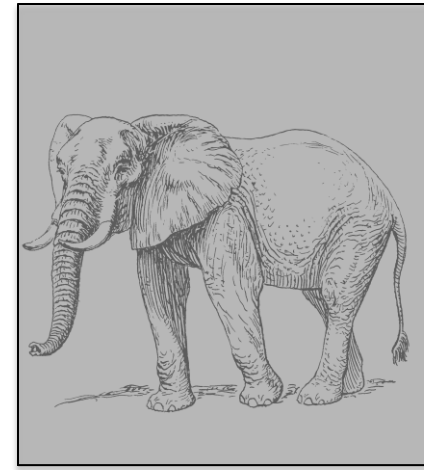
Images: Wikipedia. Public Domain.





Dier!

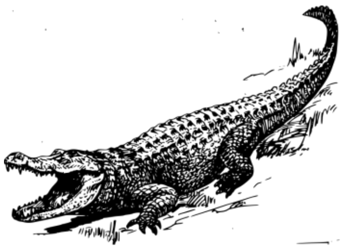




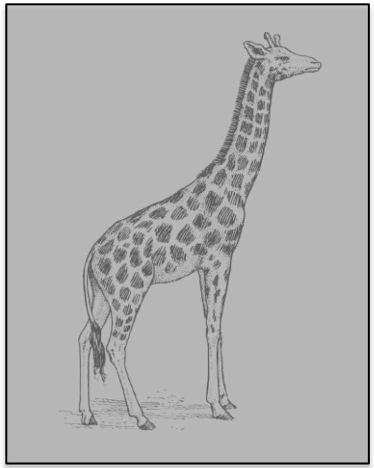
Dier!

Animal (1/3)
Mammal (2/3)
Giraffe (0)

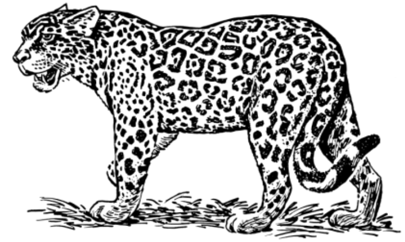
P(H|D)

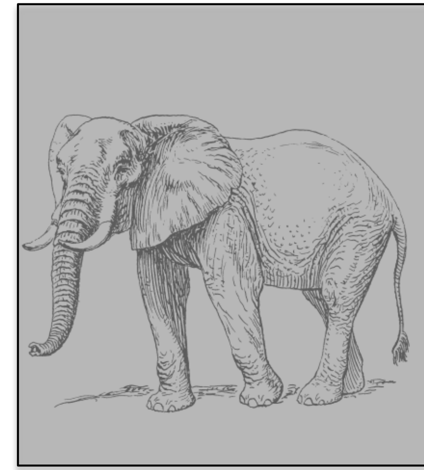


Dier!



Dier!



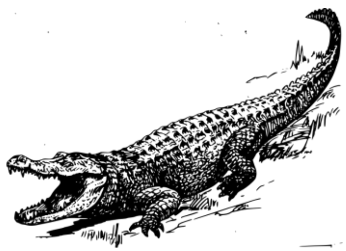
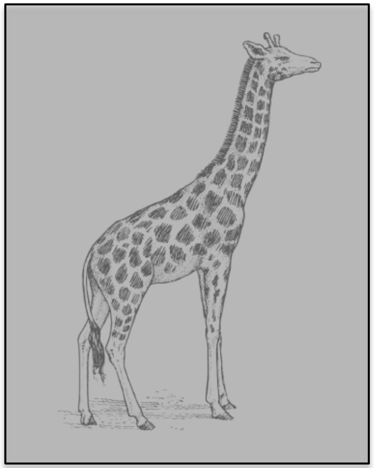
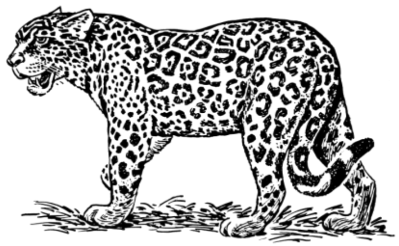
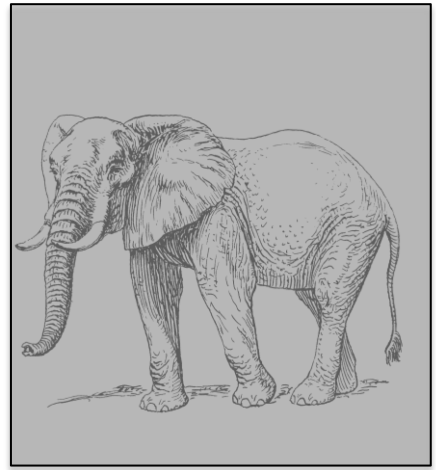


Dier!

Animal (1/3)
Mammal (2/3)
Giraffe (0)

P(H)

Images: Wikipedia. Public Domain.

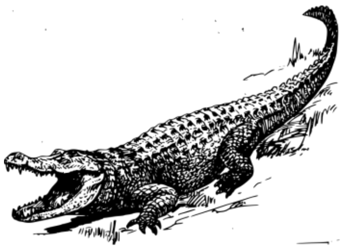
   

Dier! Dier! Dier!

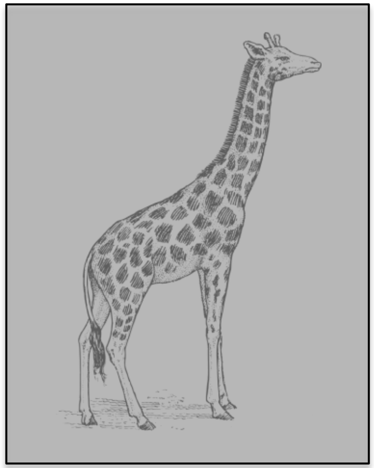
Animal (1/3)
Mammal (2/3)
Giraffe (0)

P(H) P(D|H)

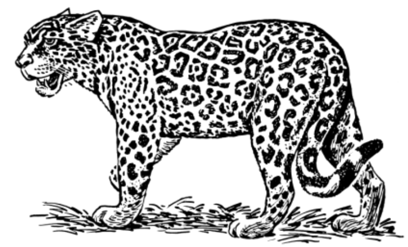
Images: Wikipedia. Public Domain.

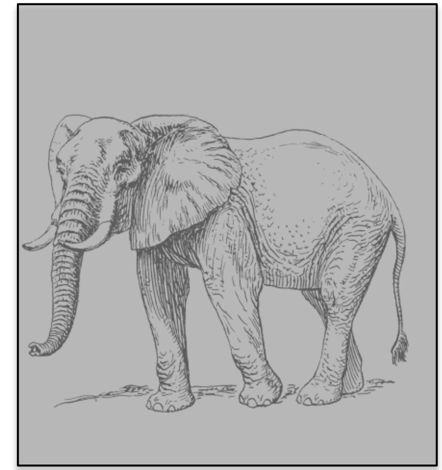


Dier!



Dier!





Dier!

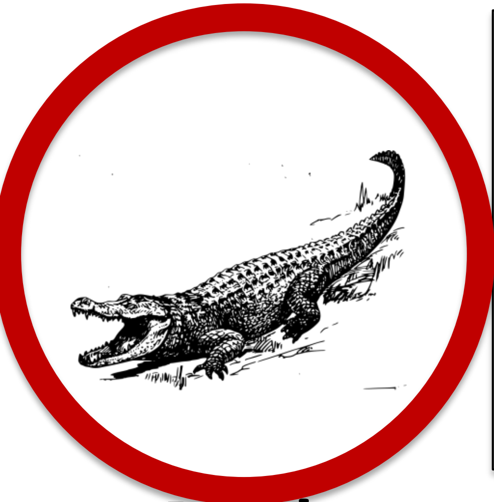
Animal (1/3) * (1/2)

Mammal (2/3)

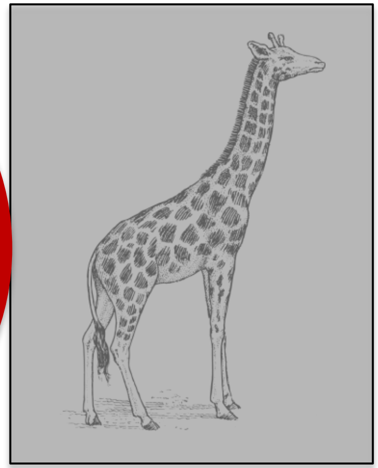
Giraffe (0)

P(H) **P(D|H)**

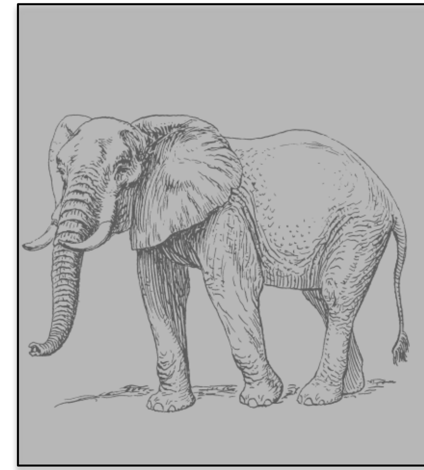
Images: Wikipedia. Public Domain.



Dier!



Dier!



Dier!

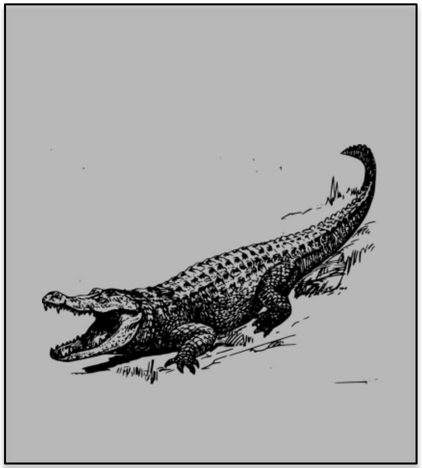
Animal (1/3) * (1/2)

Mammal (2/3) * (0)

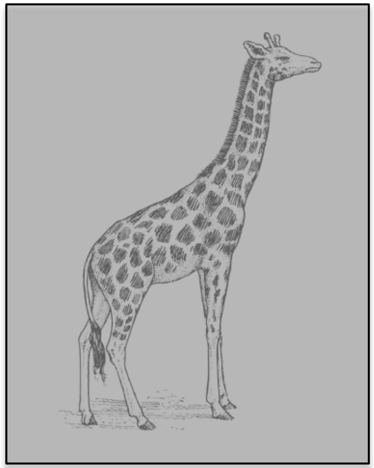
Giraffe (0)

P(H) P(D|H)

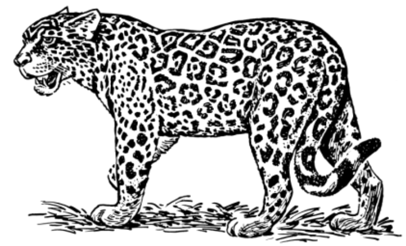
Images: Wikipedia. Public Domain.

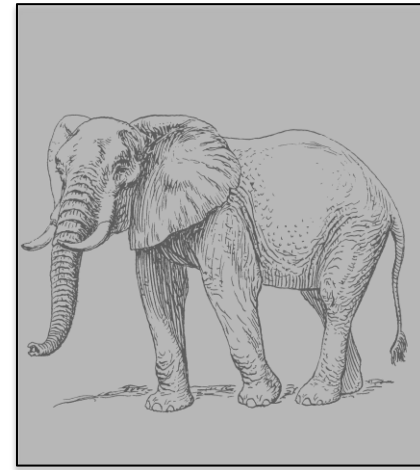


Dier!



Dier!





Dier!

Animal (1)

Mammal (0)

Giraffe (0)

P(H|D)

Images: Wikipedia. Public Domain.

Does this actually look like what our minds do?

- **Theory of Mind** *(Baker et al. 2007, 2009, 2011)*
- **Intuitive Physics** *(Battaglia et al. 2011, 2012)*
- **Object Recognition** *(Yullie et al. 2006)*
- **Pragmatic Inference** *(Bergen et al. 2012)*
- **Everyday Cognition** *(Griffiths et al. 2006)*

The most difficult problems

- Objects
- Space
- Time
- Causality
- Number
- Minds
- Morality

The most difficult problems

CAN'T

Image: John Ryan. Flickr. CC BY-NC-SA.

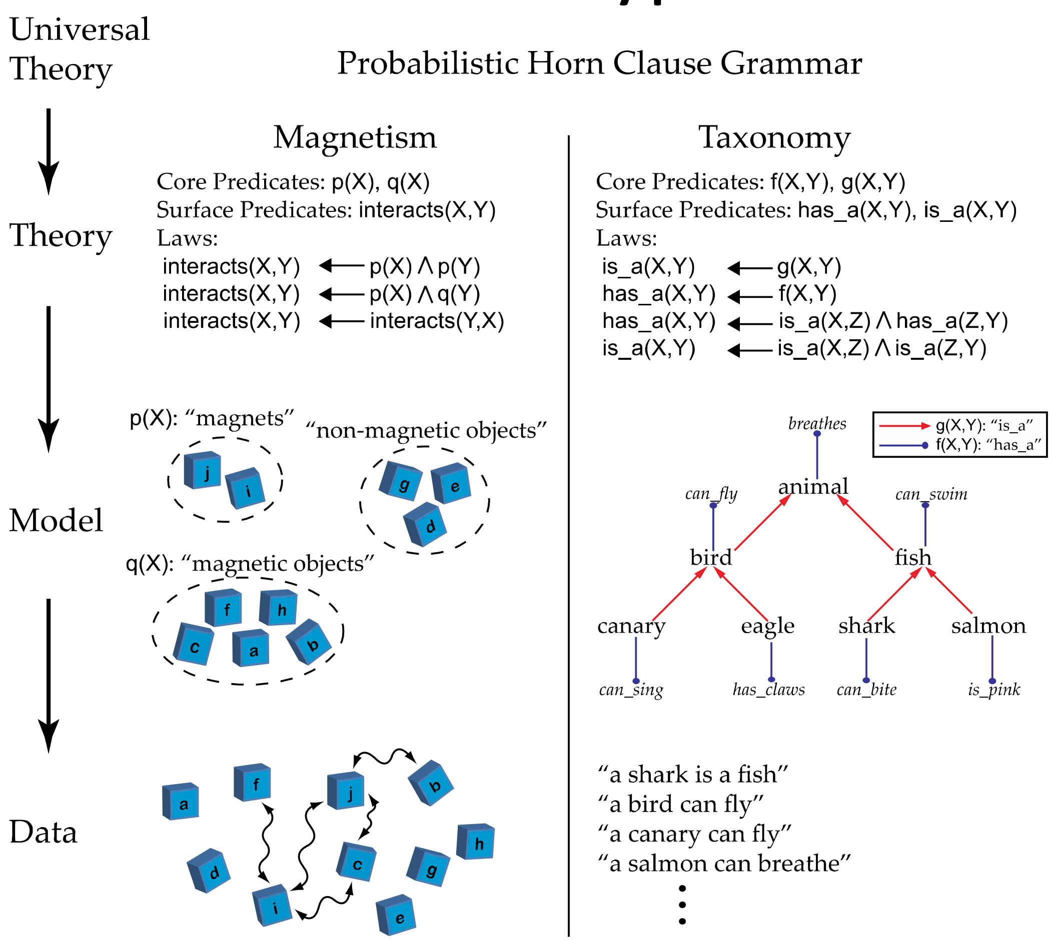
CAN

Image: Zsolt Botykai. Flickr.
CC BY-NC-SA.


MOST
POWERFUL
INFERENCE
MACHINE

Computational Modeling and the Theory Theory

- Generative theories as hypothesis



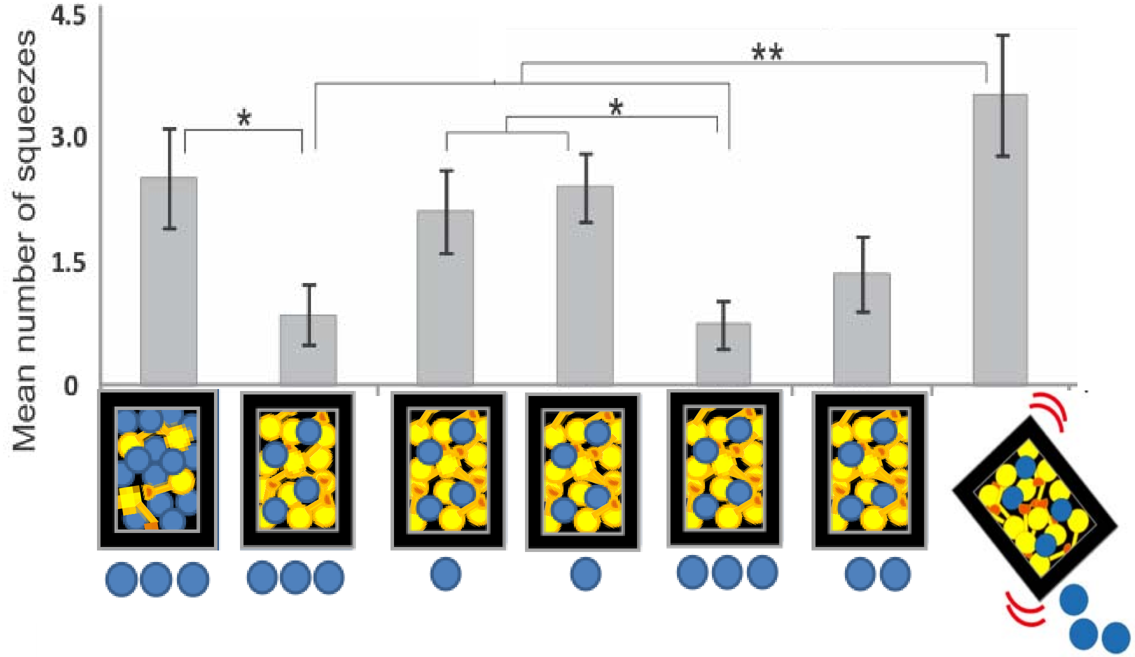
Ullman et al. (2010)

Computational Modeling and the Theory Theory

1. Search the space of all possible theories and use bayesian inference to find the theories that best explain the data.
2. Give the model the same data that a baby/infant/toddler observes.
3. Use the best theory to generate new predictions, going beyond the observed data (the problem of induction).

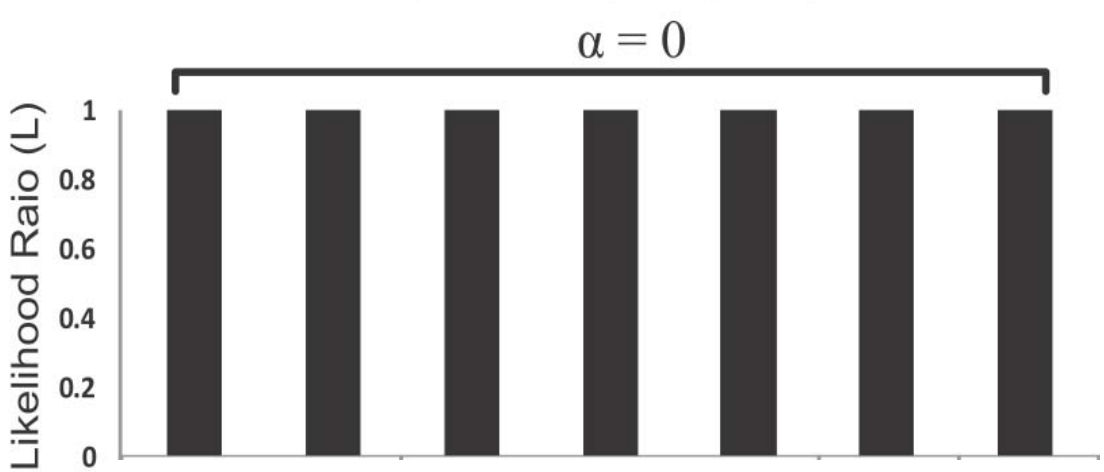
Does it work?

- We'd like to have computational models of cognitive development and show that infants and children's learning matched the prediction of the models.
- You have already read through a couple of them…
  - Pure reasoning in 12-month-old infants as probabilistic inference (*Teglas et al. 2011*).
  - Infants consider both the sample and the sampling process in inductive generalization (*Gweon et al. 2010*).



$\alpha = P(s_{\text{strong}}) = 0$

Assuming agents choose items at random from the whole box



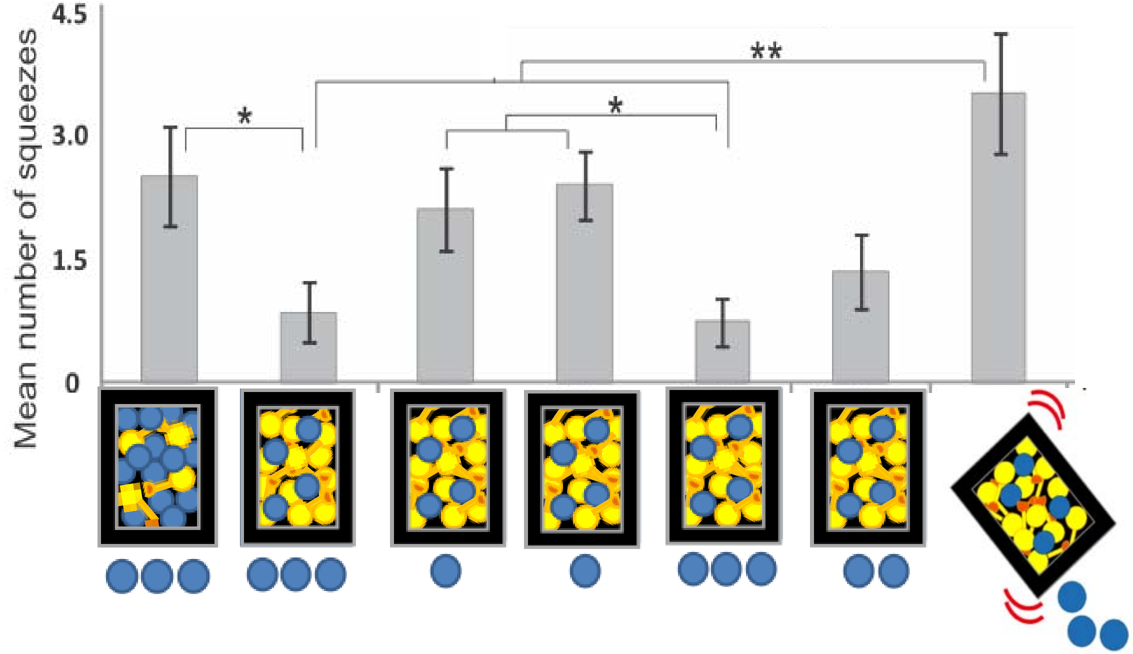
Gweon, Tenenbaum, & Schulz (2010) *PNAS*

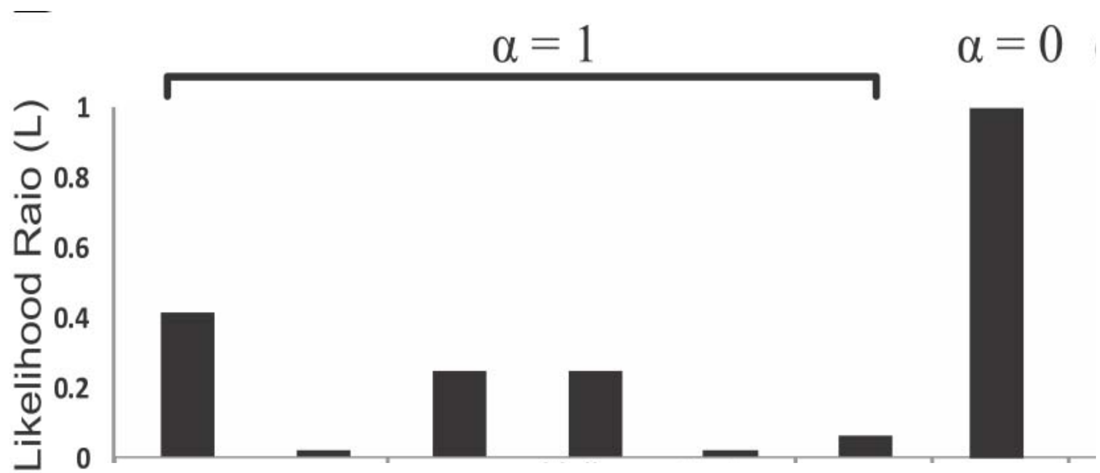
Model & Predictions& (weak&sampling)

Source: Gweon, H., Tenenbaum, J. B., et al. "Infants Consider Both the Sample and the Sampling Process in Inductive Generalization." *Proceedings of the National Academy of Sciences* 107, no. 20 (2010): 9066-9071.

$\alpha = P(s_{strong}) = 1$

Assuming agents choose items selectively based on their properties



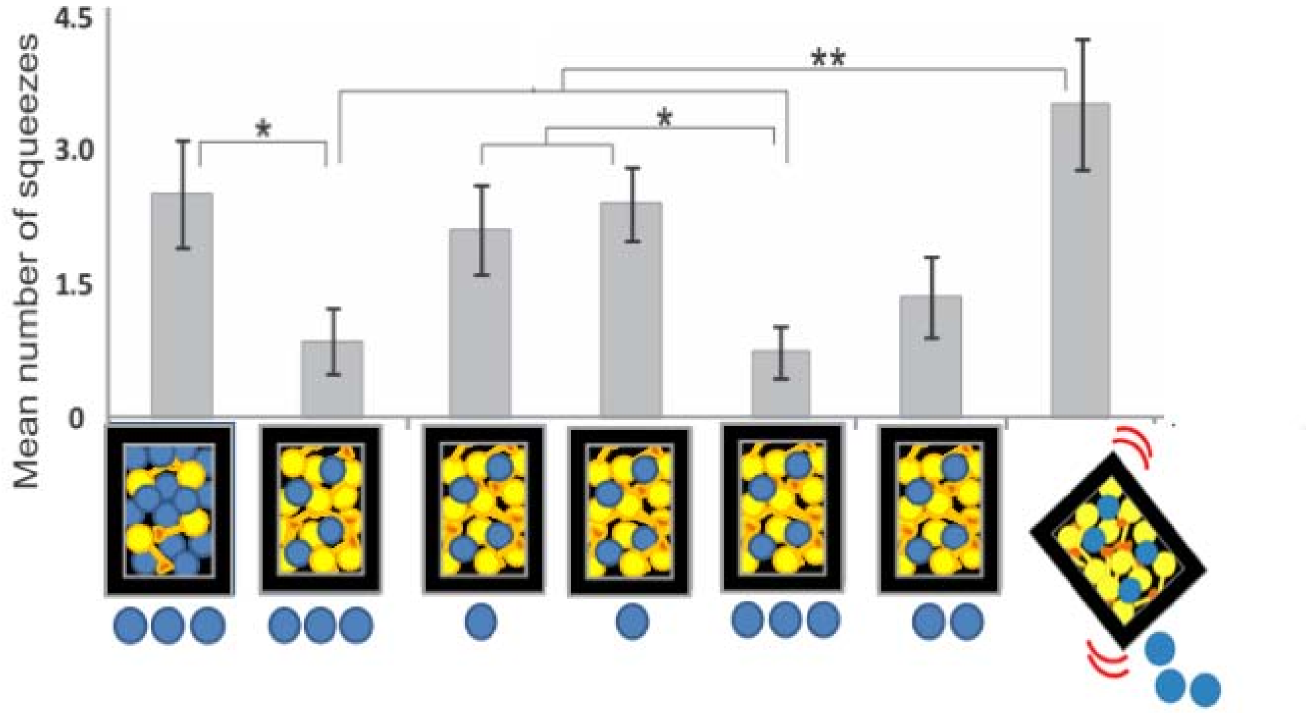


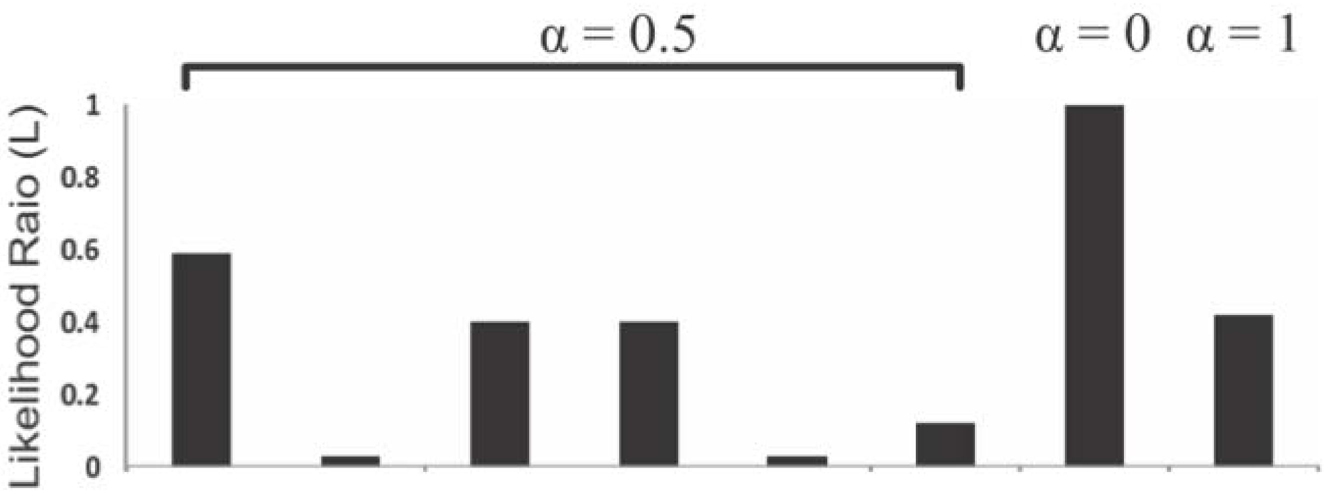
Model & Predictions&

(strong&sampling)

Gweon, Tenenbaum, & Schulz (2010) *PNAS*

Source: Gweon, H., Tenenbaum, J. B., et al. "Infants Consider Both the Sample and the Sampling Process in Inductive Generalization." *Proceedings of the National Academy of Sciences* 107, no. 20 (2010): 9066-9071.





Source: Gweon, H., Tenenbaum, J. B., et al. "Infants Consider Both the Sample and the Sampling Process in Inductive Generalization." *Proceedings of the National Academy of Sciences* 107, no. 20 (2010): 9066-9071.

Conclusion

- At a computational level of analysis, we can ask what problems the mind is solving and what an optimal solution might look like.
- We can make specific models of how particular theories might interact with particular patterns of data to affect the kind of learning that occurs.
- We can then investigate the prior beliefs that infants and children have and see if, given those theories, they respond to the data as predicted by the model.
- This can help constrain our search for the algorithms and mechanisms that could implement these computations.

9.85 Infant and Early Childhood Cognition
Fall 2012