Some thoughts on curiosity in infants and neural network models

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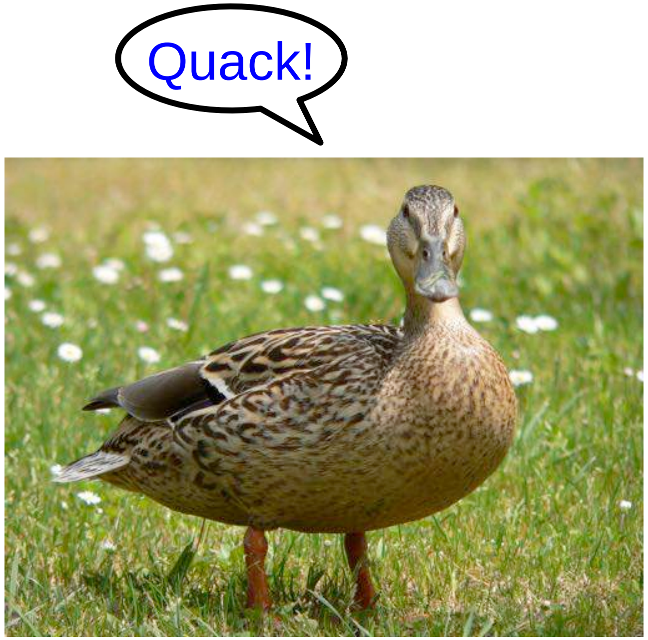
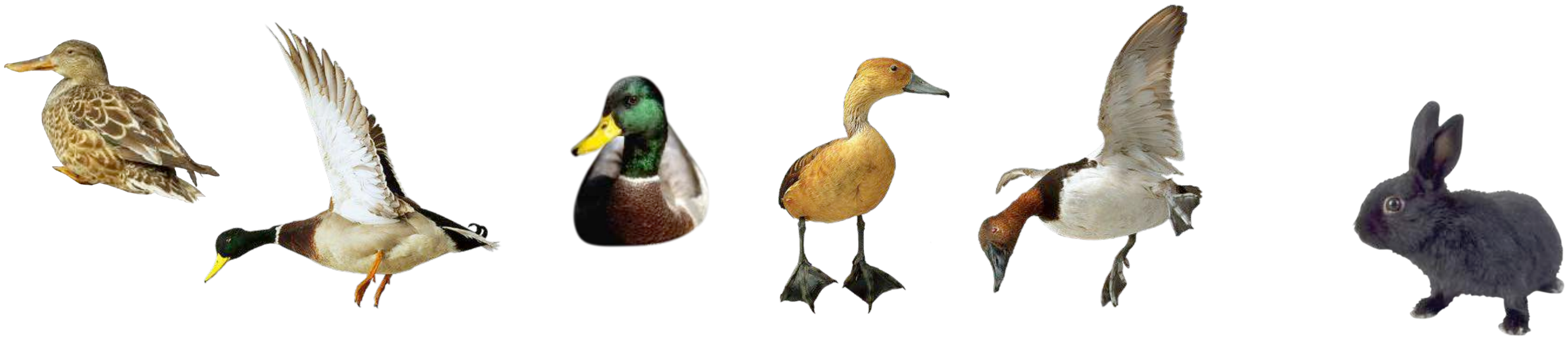
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

My work

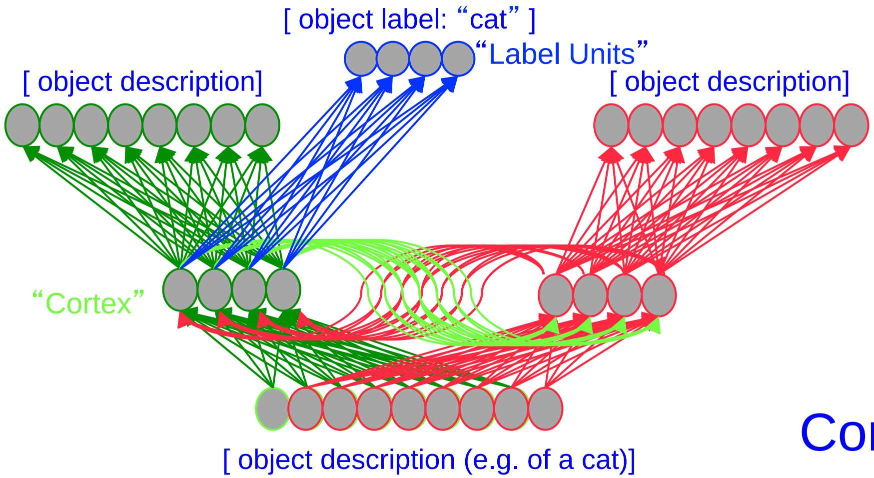
Object learning, categorization, word learning





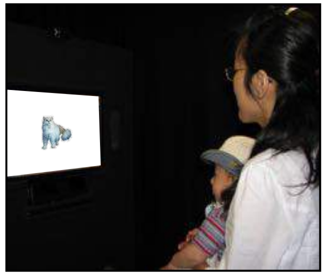
Methods

Behavioural measures
(eye tracking: looking times and pupil dilation)



Computational modelling

Behavioural measures



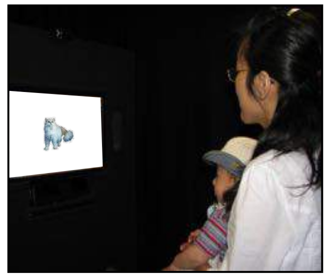
Familiarization/novelty preference method for categorization

1. Show the infants a number of objects from one category, one after the other, until they get familiarised and look less.

2. Then, show two test stimuli, one from the trained category, one from another.
   - Preference for the ‘other’ stimulus: categorisation

Behavioural measures

Familiarization/novelty preference method

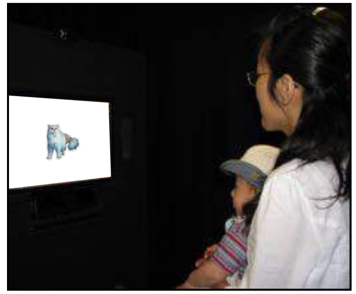


Randomized presentation of individual stimuli.

Where is curiosity in this?

Curiosity and looking times

Curiosity is not seeking out novelty per se,
but learning from novelty.



Intrinsic reward is not merely for encountering surprise, but for *eliminating* surprise by learning about it and making it unsurprising.

Therefore we need to understand (changes in) the learning mechanism to understand which information is selected in curiosity-driven learning.

Looking time studies help reveal the learning mechanism

- ✓ Looking time at individual stimuli
- ✓ Looking preference at test

Looking time as an index of the information selection mechanism

We can ask: What affects looking time?

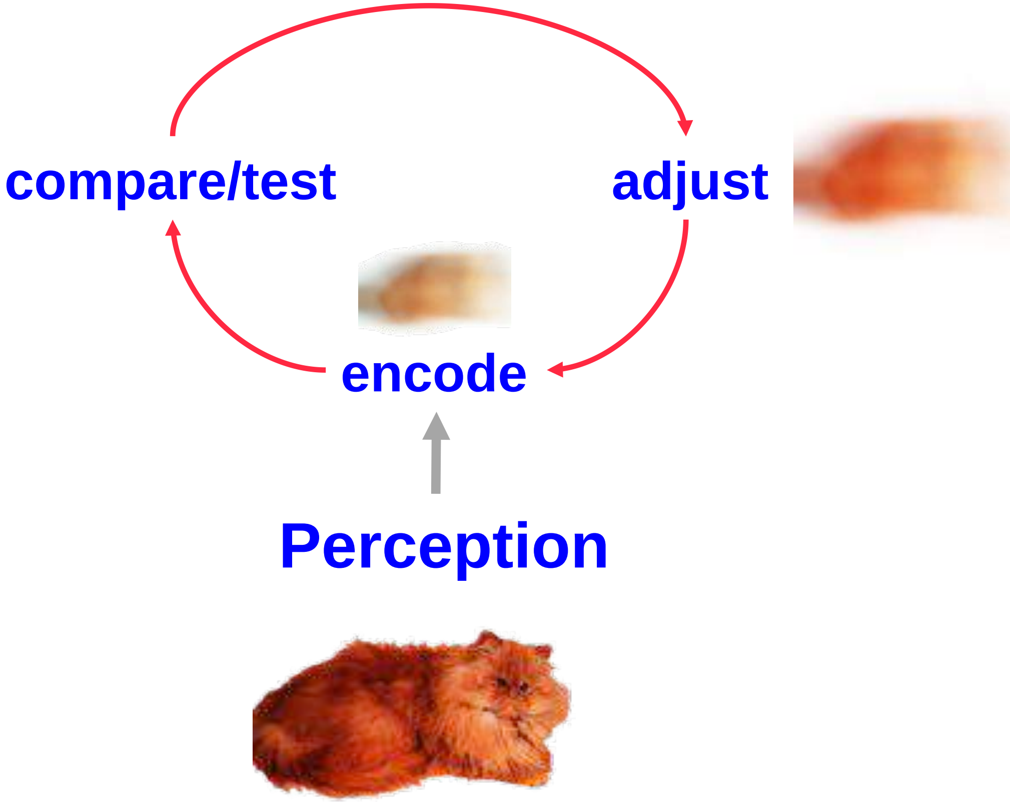
- ✓ Age
- ✓ Nature (variability) of stimuli
- ✓ Order of stimuli

Rest of this talk

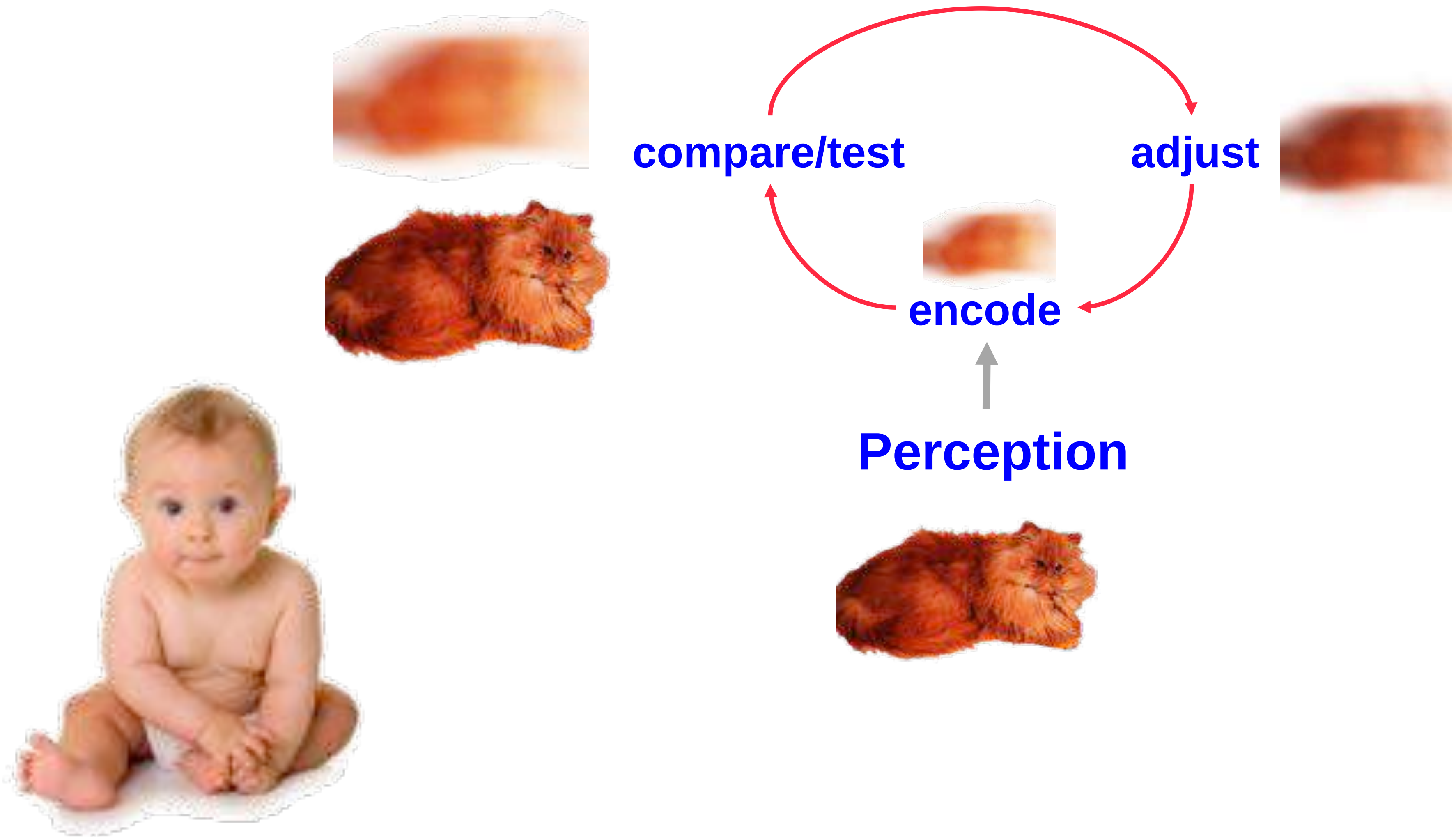
- ✓ What affects how much time infants spend looking at objects?
- ✓ A computational model of some experimental results
- ✓ Curiosity-driven learning in this model.

Infant looking time – what does it mean?

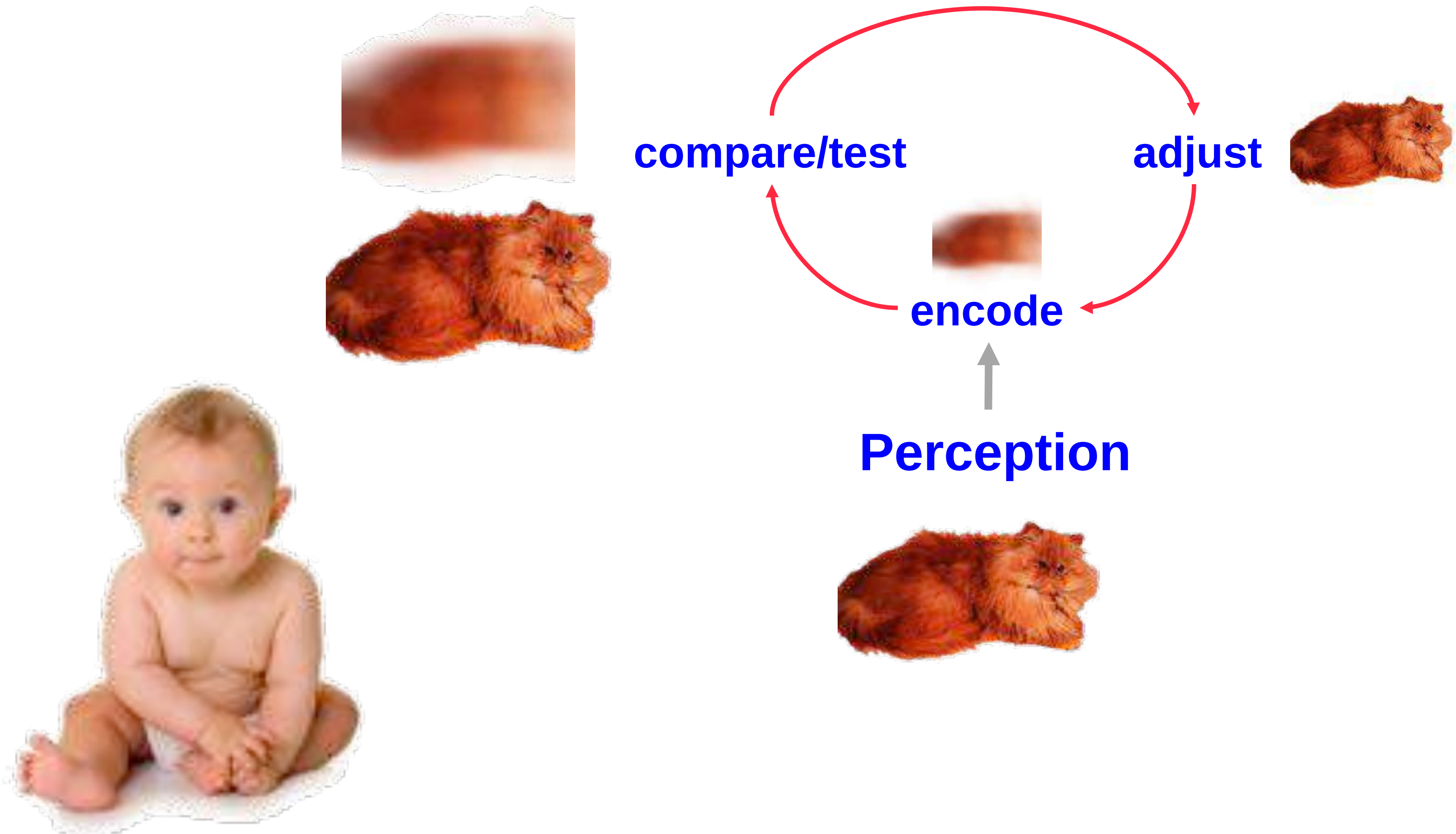
Sokolov (1963)



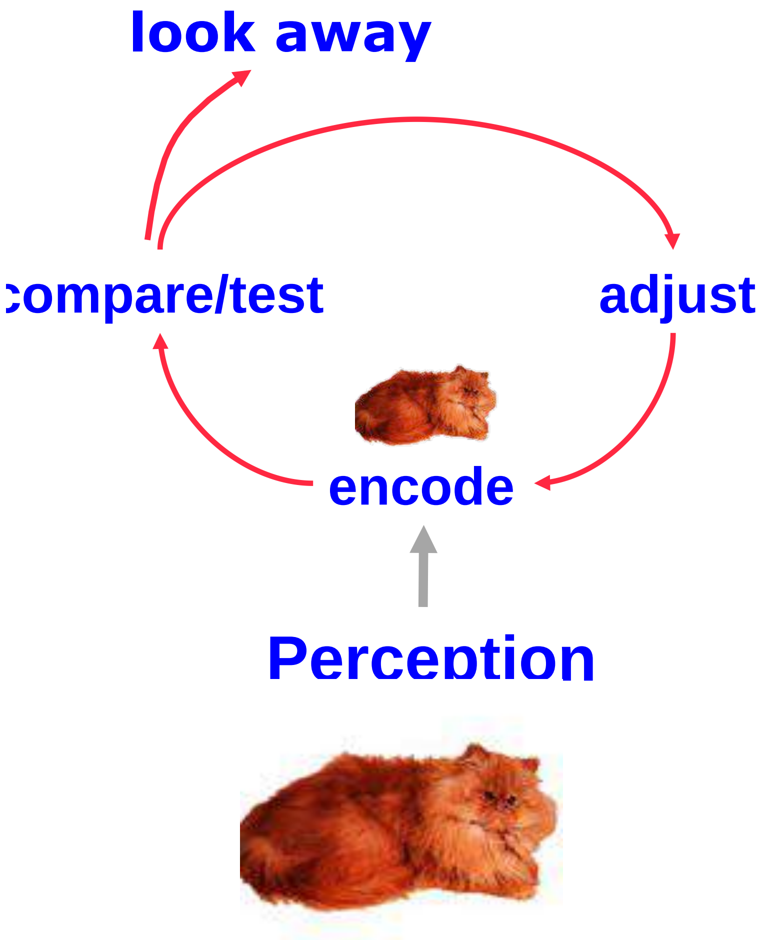
Infant looking time – what does it mean?



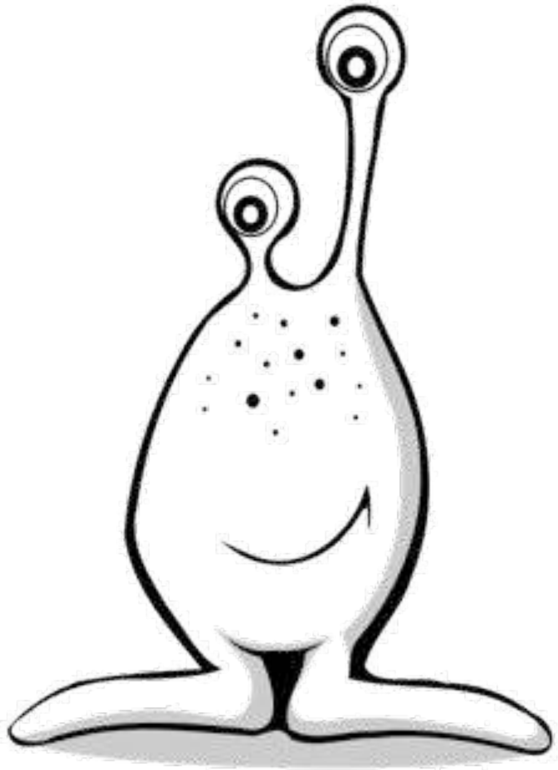
Infant looking time – what does it mean?



Infant looking time – what does it mean?



Infant looking time – what does it mean?



Therefore, the more unusual something is,
The longer the infant looks at it.

Age effects on looking time

- Familiarization speeds up with age.

  Processing speed hypothesis: Infants process visual information faster with age.

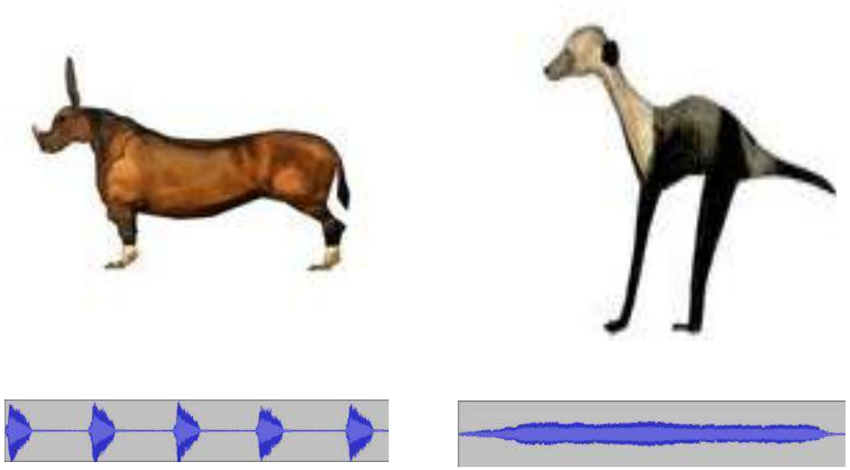
- Individual differences: Familiarization speed predicts IQ at a later age (Bornstein & Sigman, 1986)

Age effects on object processing

Audiovisual integration: Learning to link objects with the sound they make.

Training Phase

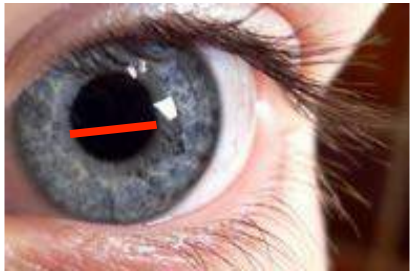
16 trials



V1-A1 **V2-A2**

(Chen & Westermann, in prep)

Measure: Pupil dilation

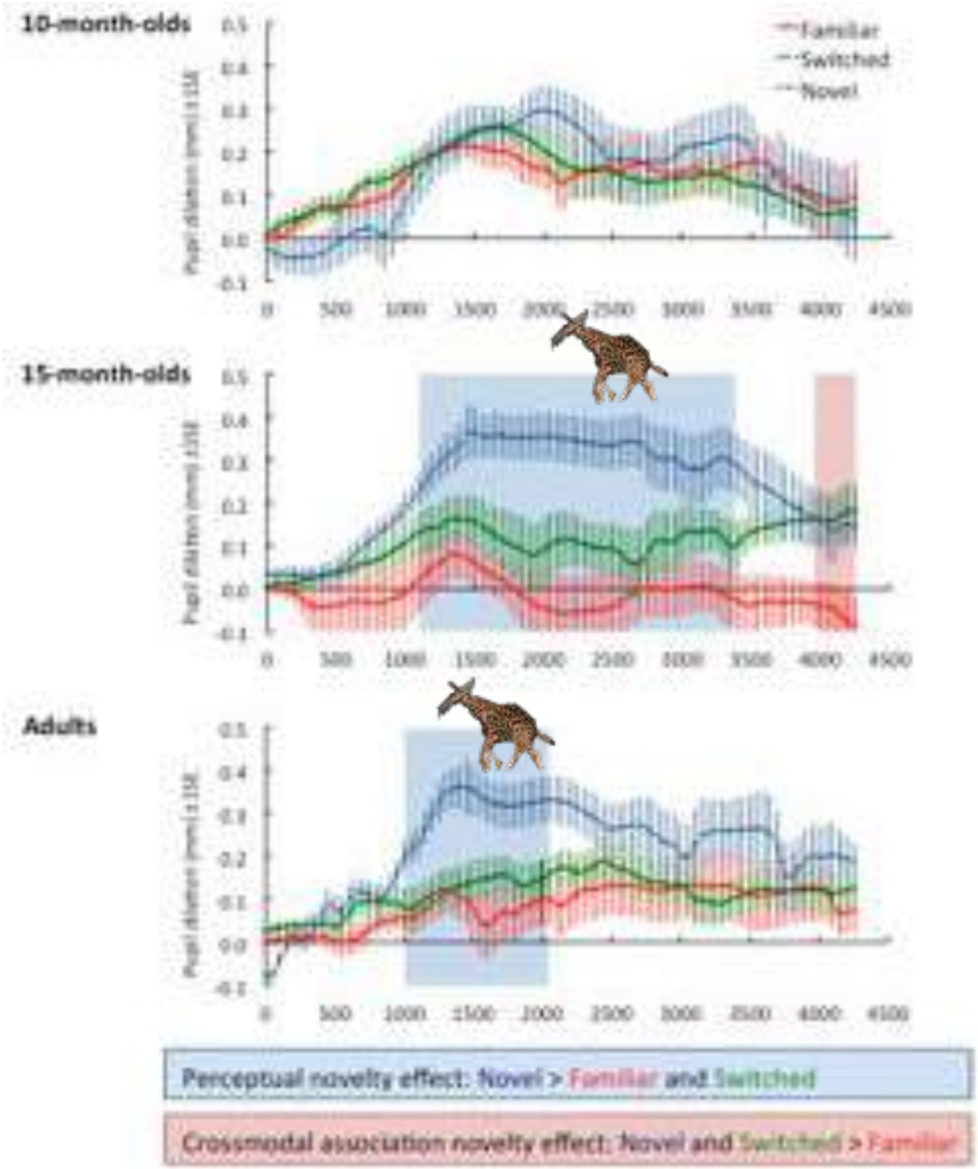


Measure of attention/memory load/surprise, also in infants.

10-month olds (N=18), 15-month-olds (N=16), adults (N=19)

Results

0 = onset of sound



10-month-olds: no effect

15-month-olds:

Reaction to perceptual novelty

Reaction to crossmodal violation

Adults:

Reaction only to perceptual novelty

Perceptual narrowing, entrenchment

(Chen & Westermann, in prep)

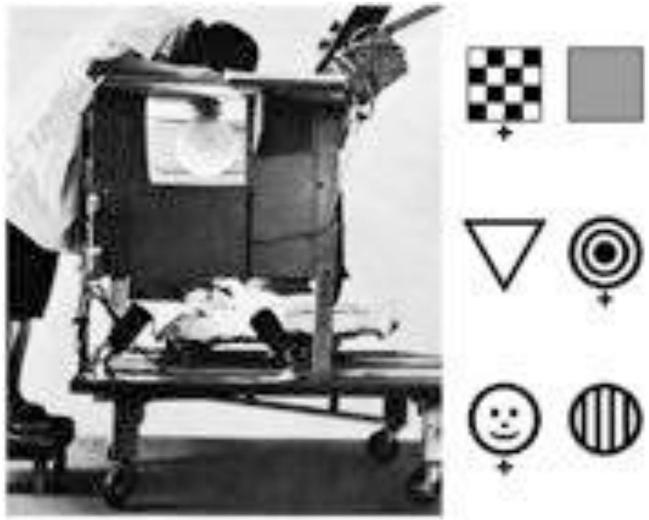
Summary: with age:

Faster processing, but also tuning of processing to ignore certain stimulus differences.

Individual differences.

Stimulus property effects on looking time

Young infants prefer to look at **complex** stimuli



(Fantz, 1964)

Infants prefer **dynamic** over static stimuli

Stimulus property effects on categorization

Object **variability** affects category formation

- Infants habituated to broader set of stimuli formed broader categories (Oakes et al, 1997)

Familiarity preference

Sometimes infants prefer to look at the *familiar* stimulus, not the novel stimulus.

Switch from familiarity to novelty preference

Depends on

- duration of exposure
- age
- stimulus complexity

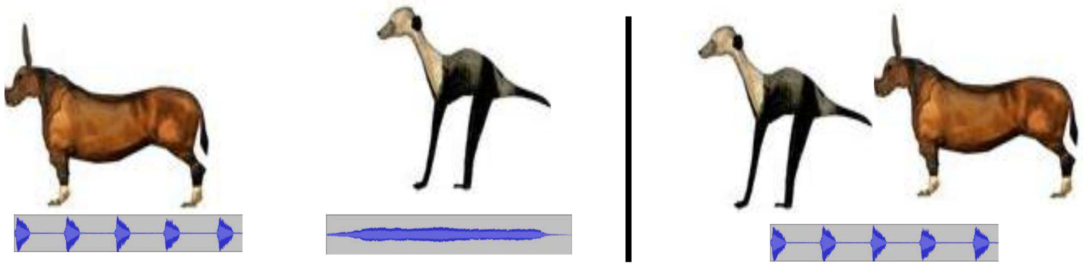
Roder, B. J., Bushneil, E. W., & Sasseville, A. M. (2000).

Familiarity preference

In some paradigms, we look for a familiarity preference!

Learning words for objects

Learning the sounds that objects make

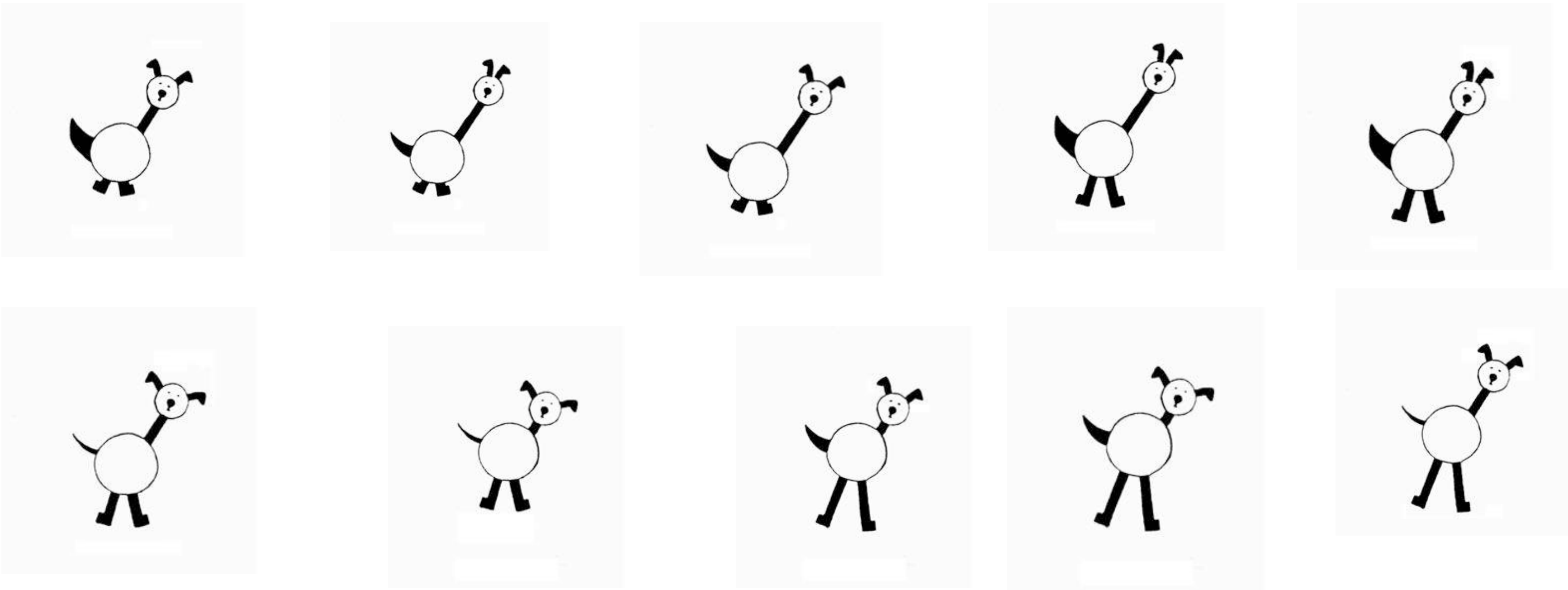


Learning regularities in sequences

Younger (1985)

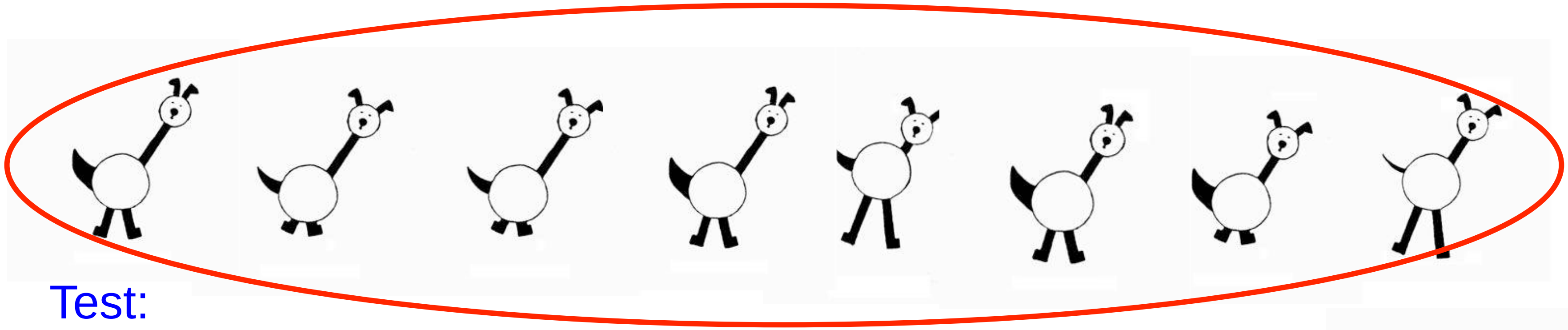
Categorization of animals drawings

4 features: leg length; neck length; ear distance; tail width

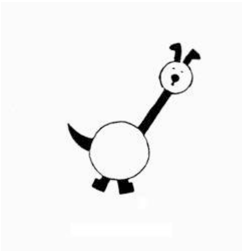


Younger (1985)

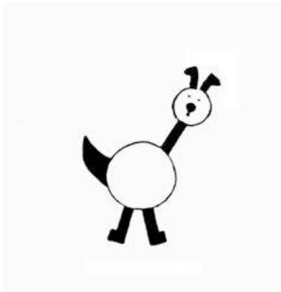
Familiarize:



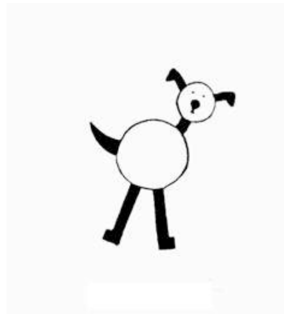
Test:



peripheral



Average
(prototype)



peripheral

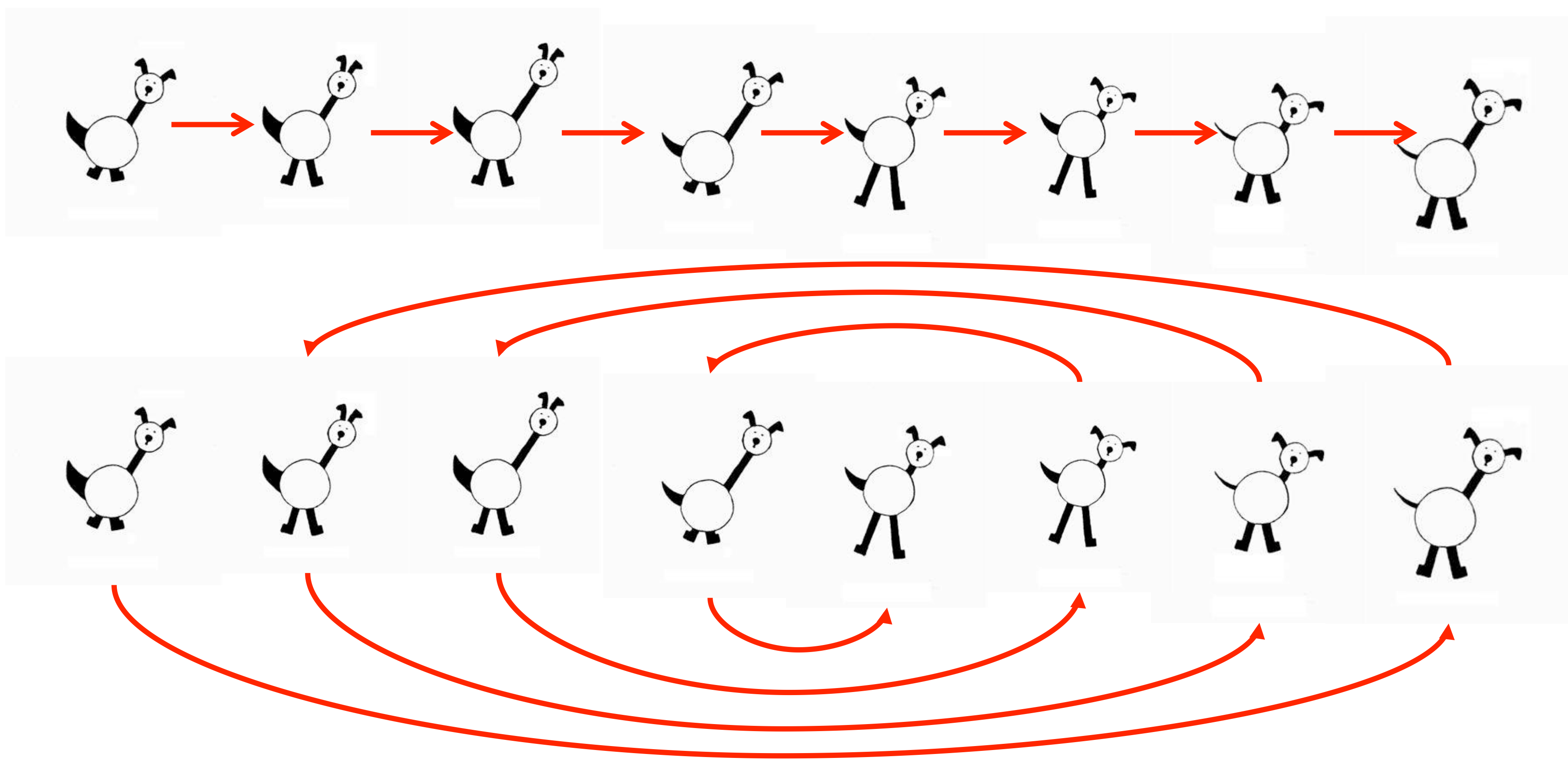
Result:

10-month-olds look longer at peripheral than at prototypical stimulus: evidence for category formation.

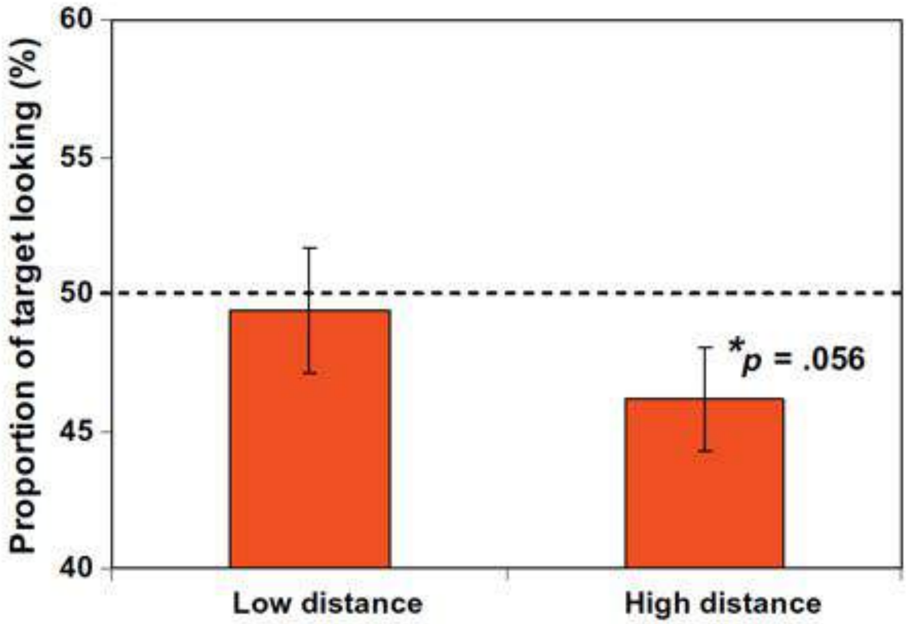
Familiarization sequence matters

Using these stimuli: Mather & Plunkett (2011)

- Familiarization: ordered stimuli to minimize/maximize perceptual similarity between successive stimuli



Familiarization sequence matters: Results



(target = prototype)

Category was formed only in the high-distance condition.

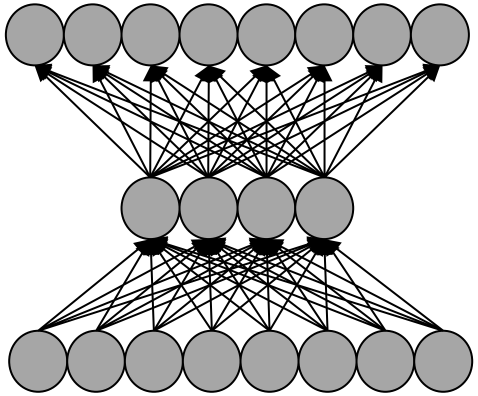
Mather & Plunkett (2011)

Summary: Stimulus property effects on looking time

- Preference for complex and dynamic stimuli.
- Familiarity-novelty preference shift, depending on age, stimulus complexity, exposure duration
- Variability of stimuli and specific sequence of stimuli affect category formation

Computational modelling of category learning

Here: with artificial neural networks



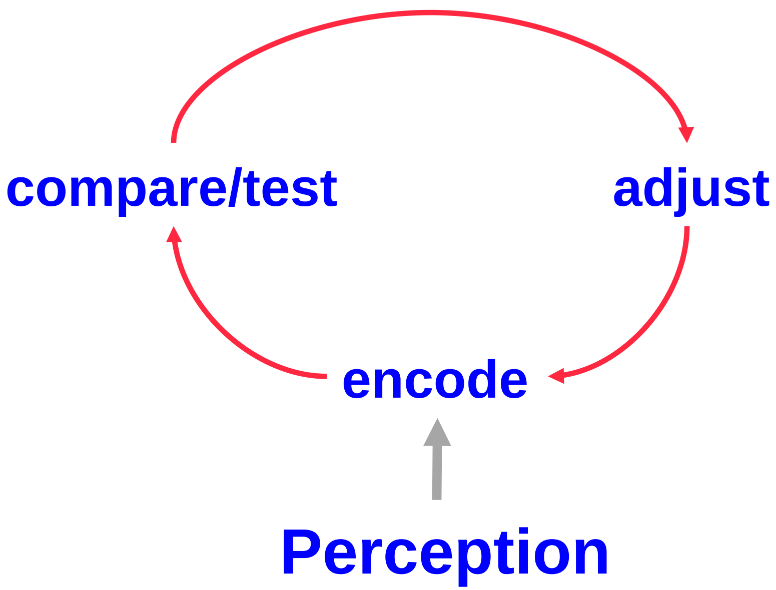
(with Katie Twomey)

Computational Modelling of Infant Looking Time

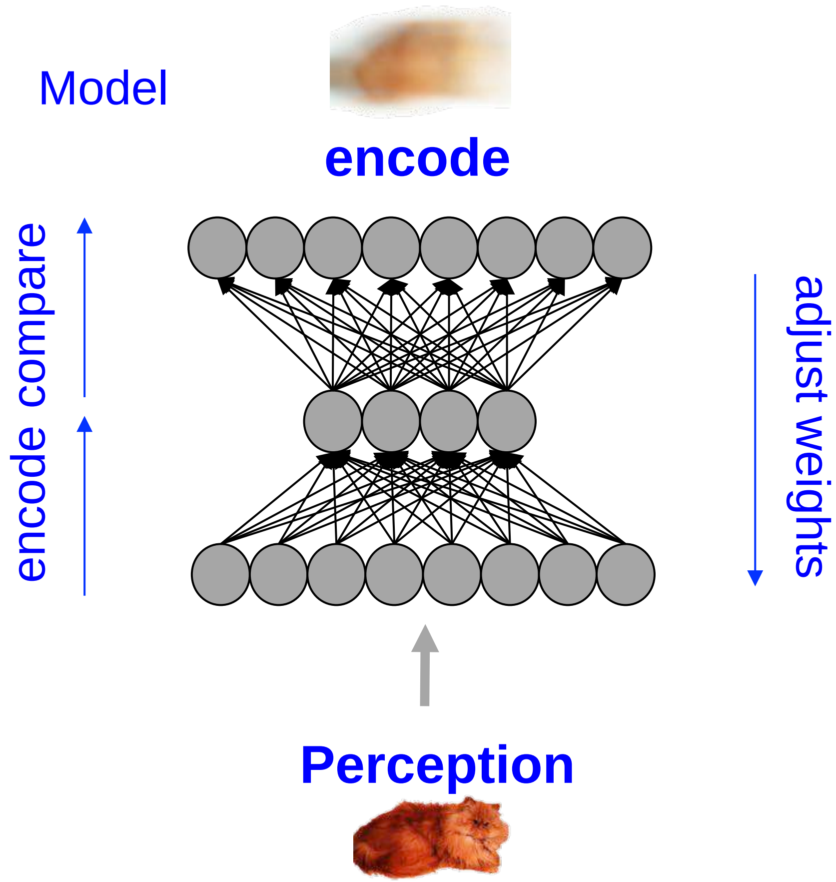
Auto-encoder neural network

input = target

Infants



Model



Mareschal & French (2000)

Computational Modelling of Infant Looking Time

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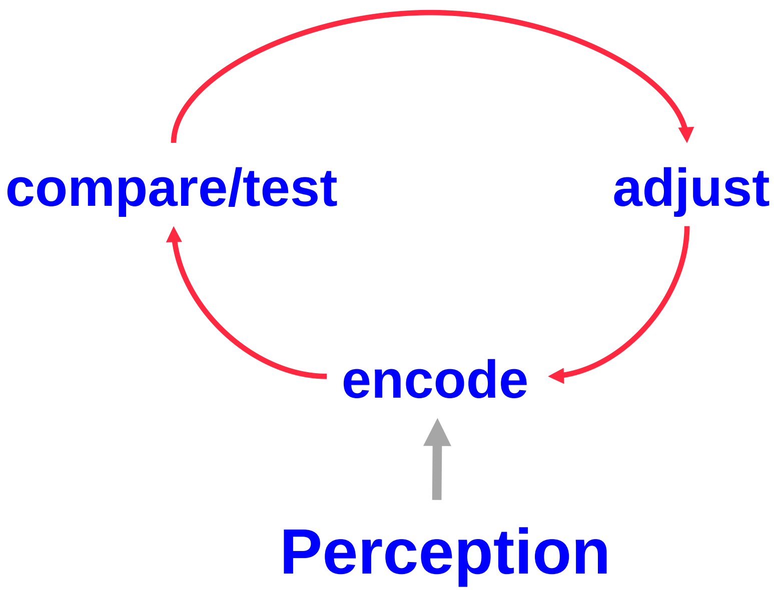

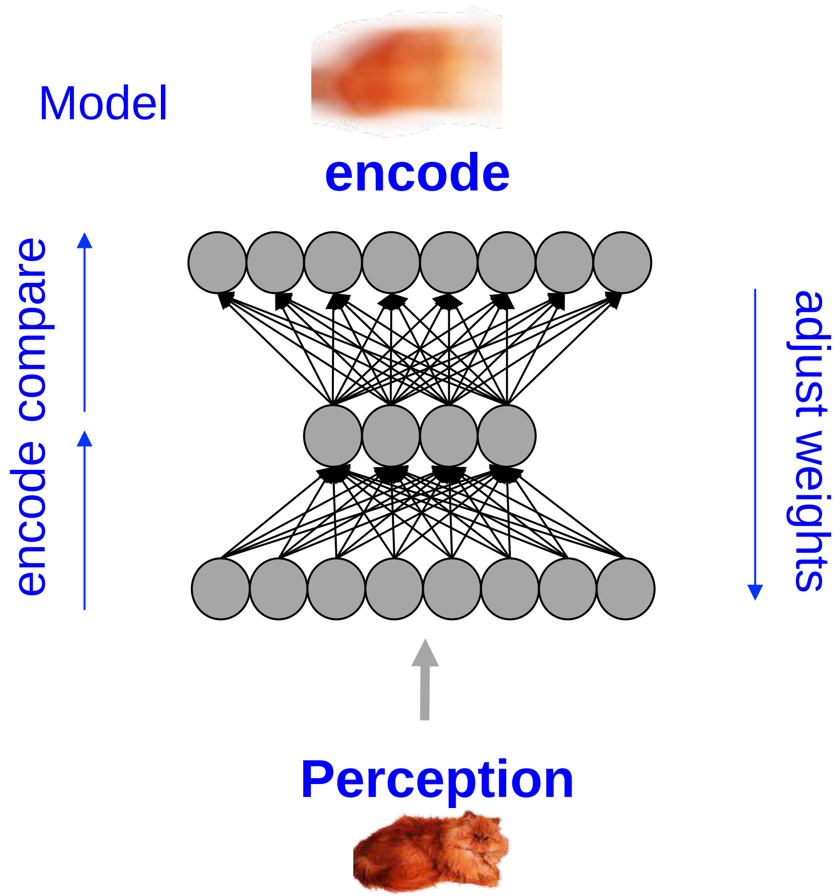

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Computational Modelling of Infant Looking Time

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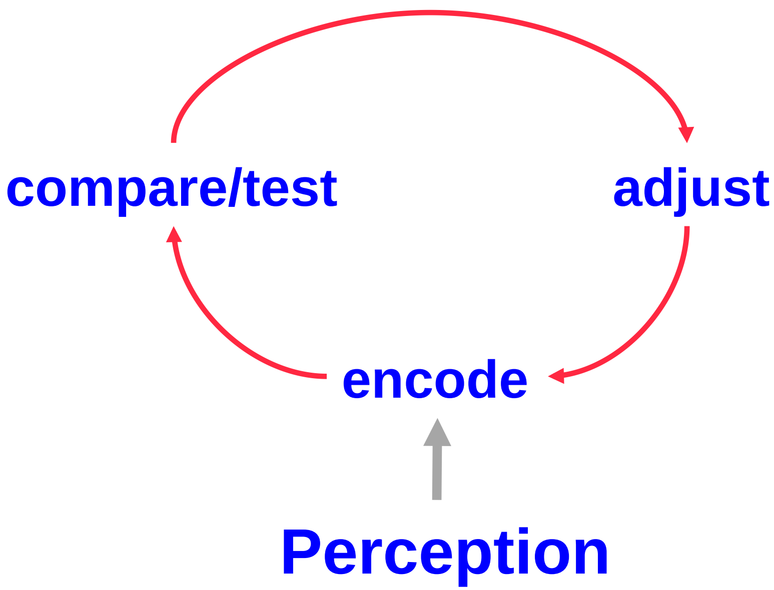
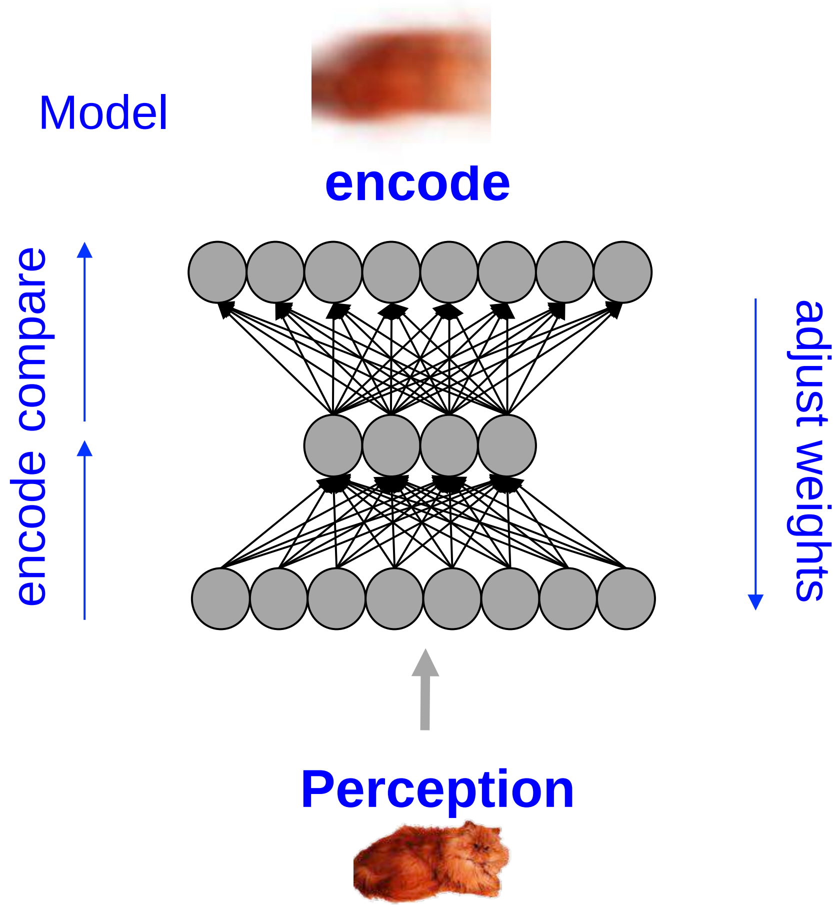


Model



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Computational Modelling of Infant Looking Time

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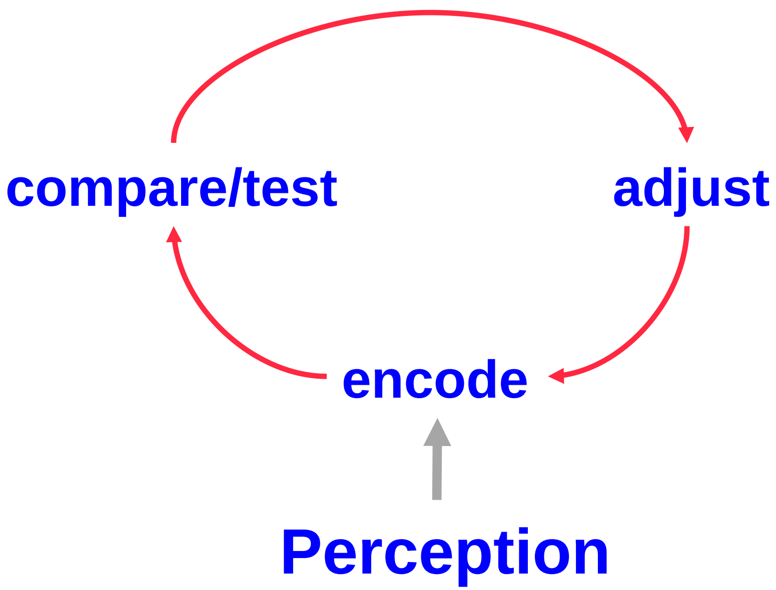
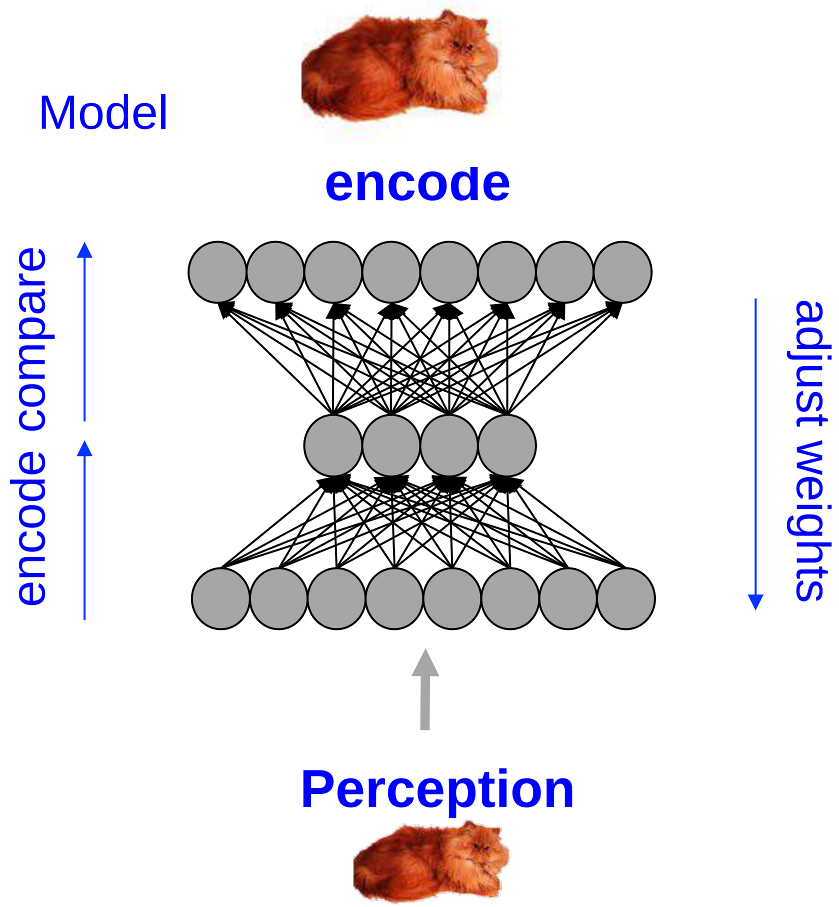
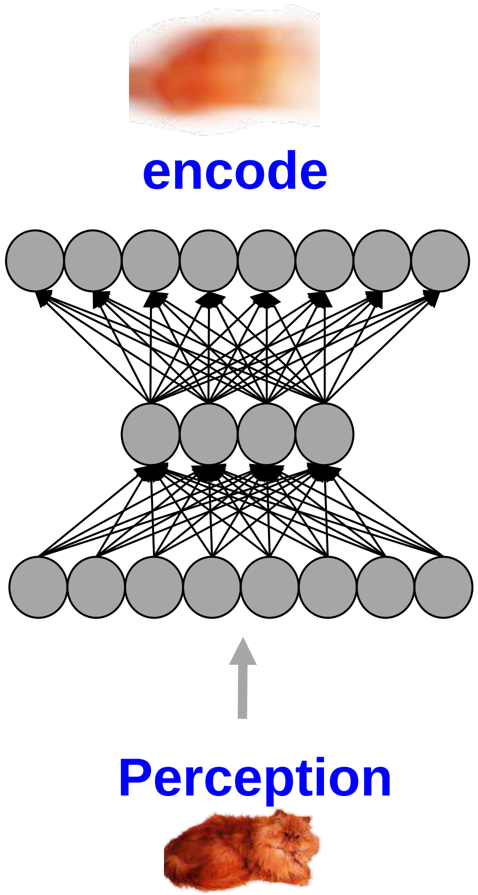


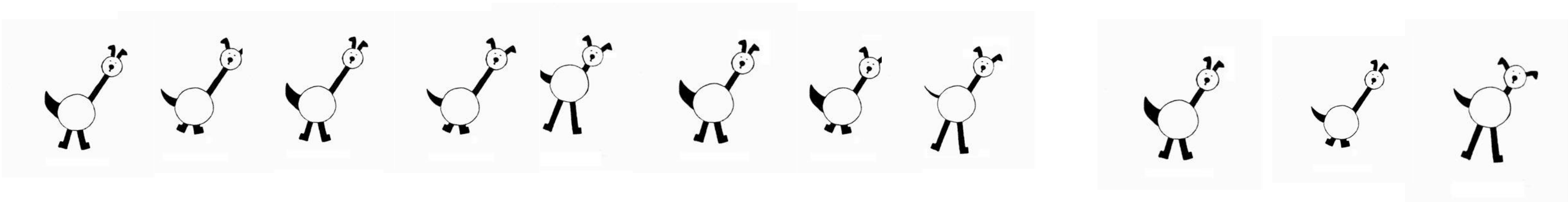


Mareschal & French (2000)



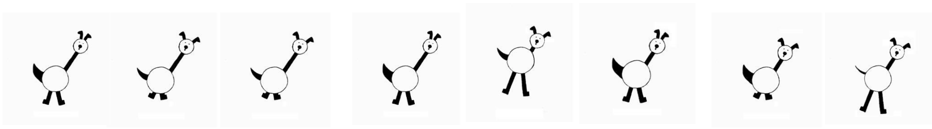
The model (brain?) as a regularity extractor to form semantic representations.

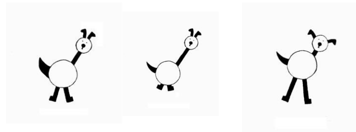
Modelling the effect of stimulus order



- ✓ Animal drawings encoded by their feature values
- ✓ Each familiarization stimulus shown for 20 weight updates
- ✓ After familiarization phase, testing on prototypical and peripheral stimuli
- ✓ 24 models per condition trained

Modelling the effect of stimulus order



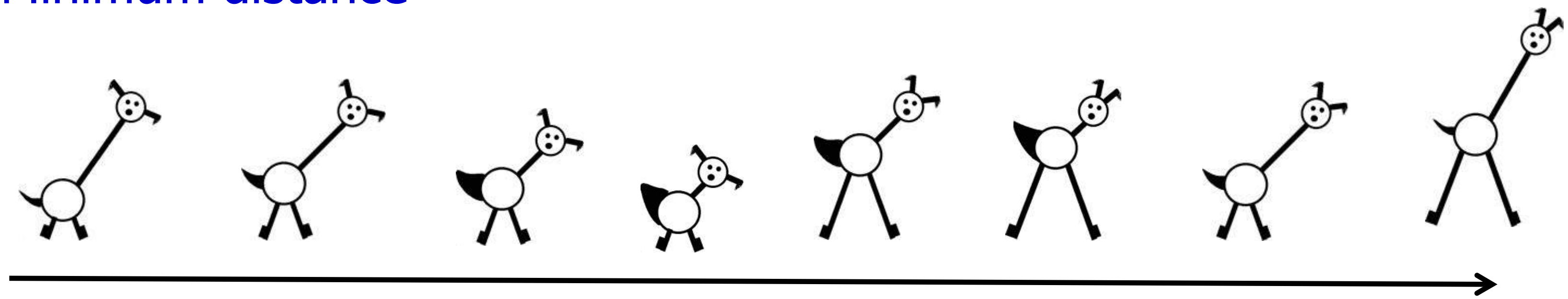


Does the **order** of familiarization stimuli make a difference?

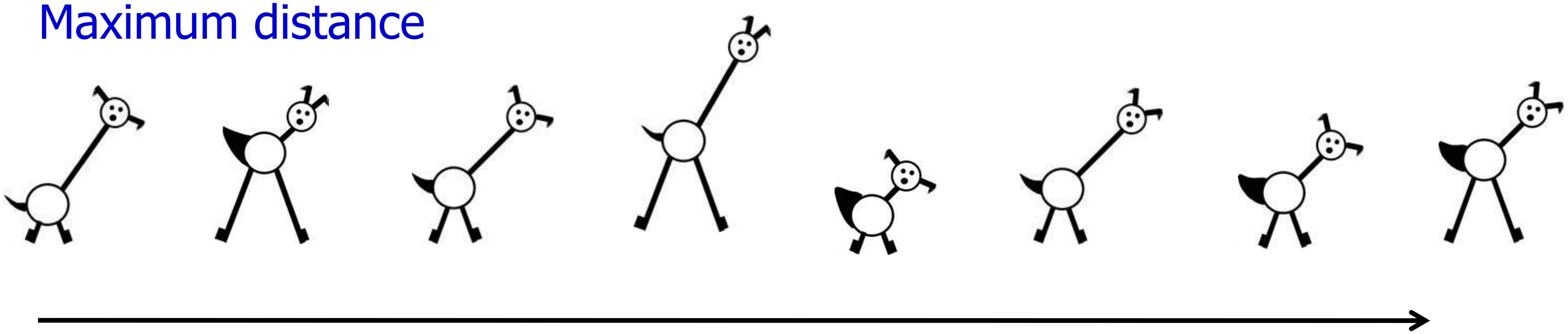
Order them in different conditions according to the perceptual distance between adjacent familiarization stimuli (like Mather & Plunkett, 2011)

- ✓ Minimum distance
- ✓ Maximum distance
- ✓ Medium distance

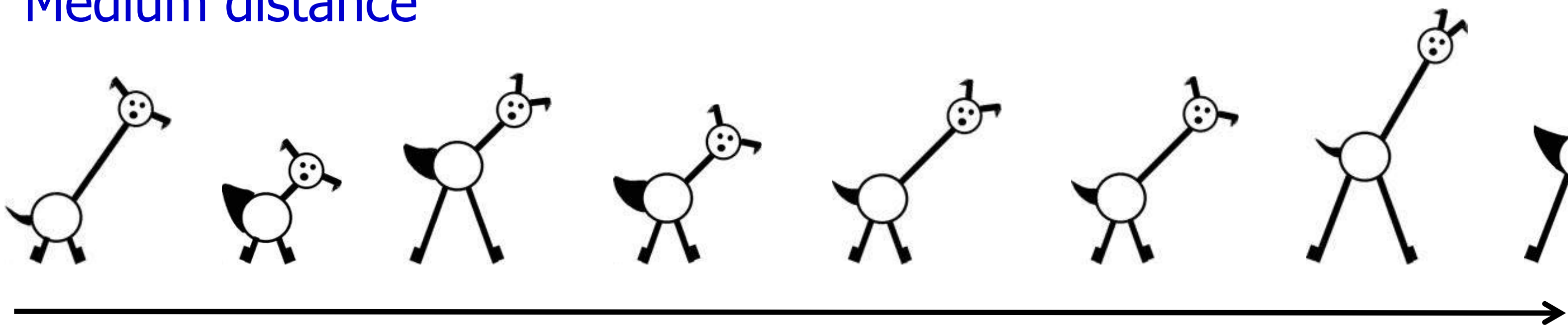
Minimum distance



Maximum distance

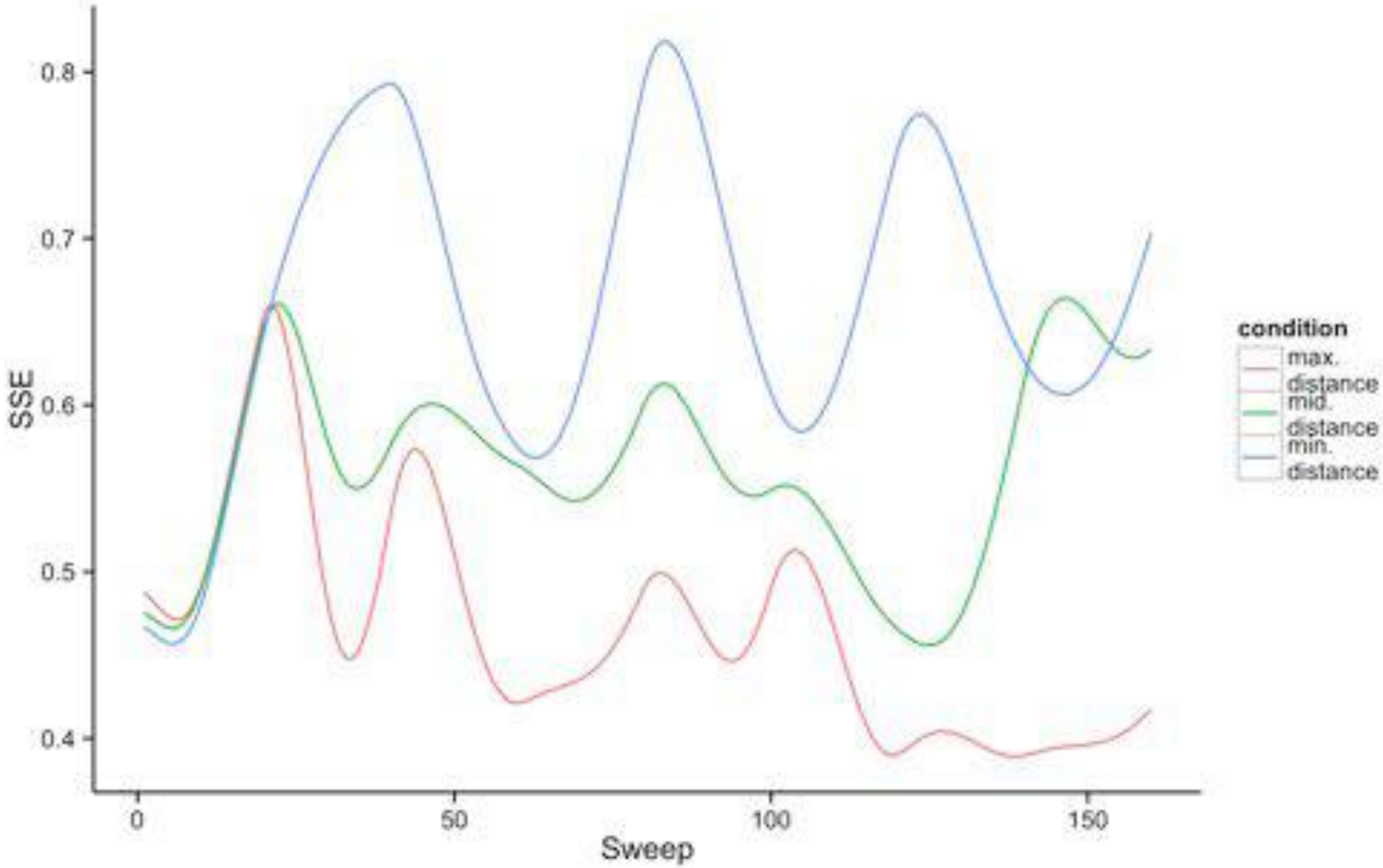


Medium distance



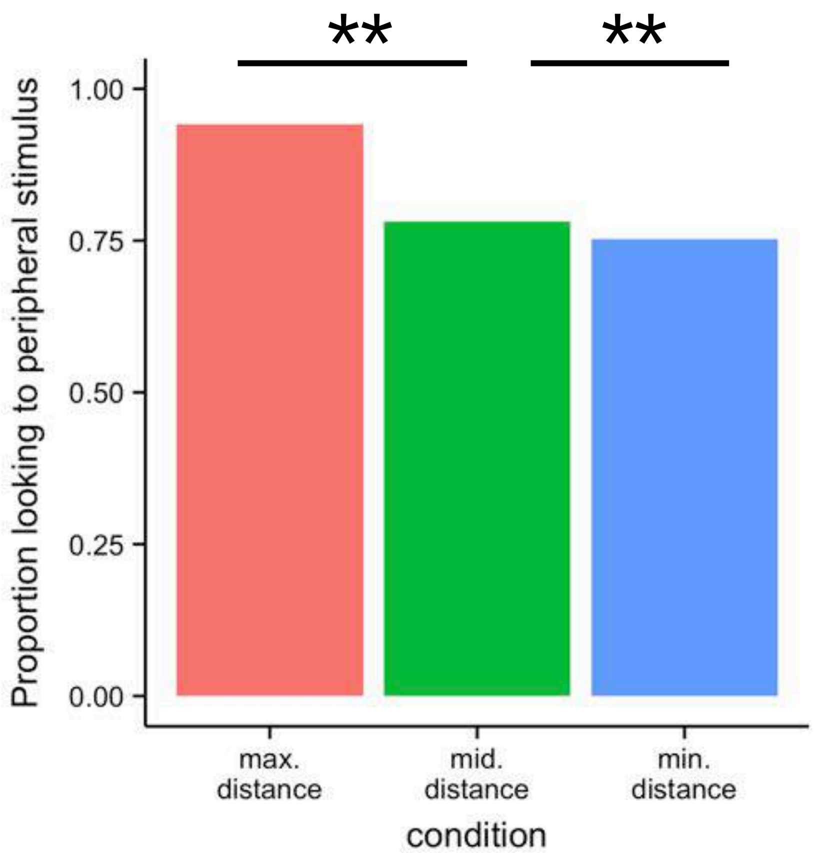
Results

Testing the model on the whole stimulus set during familiarization: how well does it learn?



Results

Error ratio (~looking time preference) at test



longer bar = better category learning

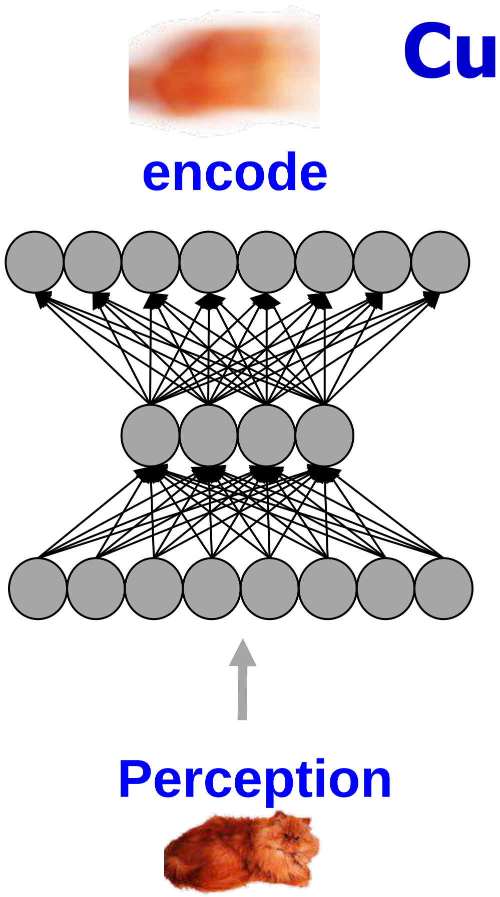
Maximal distance between successive stimuli optimizes learning.

Thus: Structuring the environment for the learner affects learning success.

- **But:** a 'curious' learner structures the environment for herself!

- Curiosity: drive to maximize learning progress.

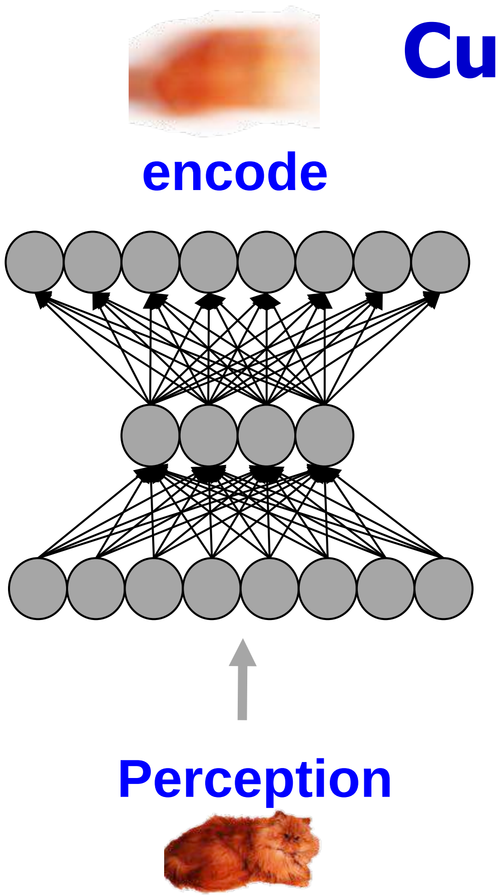
Curiosity in an auto-encoder network



- Network aims to minimize internal error: discrepancy between what it sees and how it reproduces what it sees.

- A 'curious' model should engage with those stimuli that enable it to minimize this error most effectively.

Curiosity in an auto-encoder network



- Learning in a neural network: weight adaptation through gradient descent.

- Gradient for a network with sigmoid units:

$$(t-o)*o*(1-o)$$

t = target (i.e., here: input)

o = output

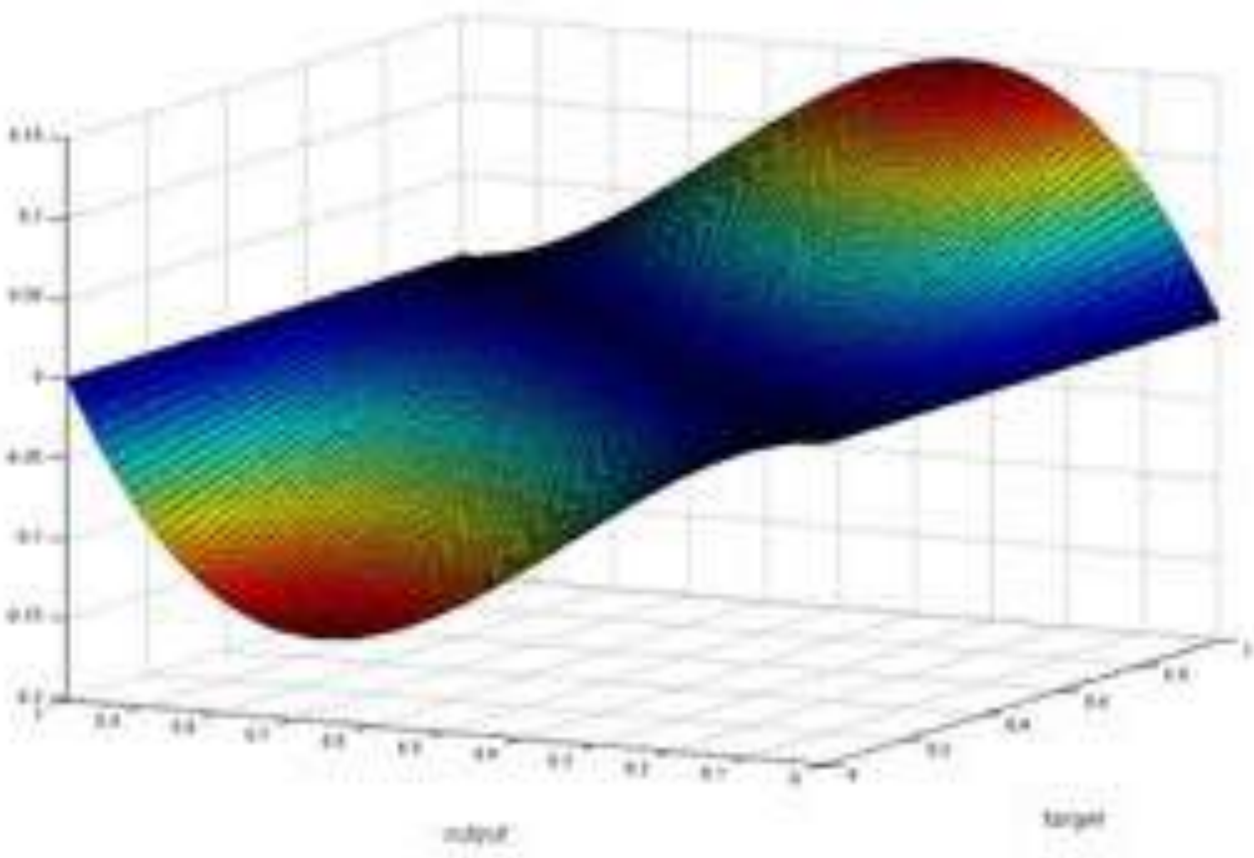
- Curiosity-driven learning: Always choose the next familiarization stimulus that maximizes this term.

$$(t-o)*o*(1-o)$$

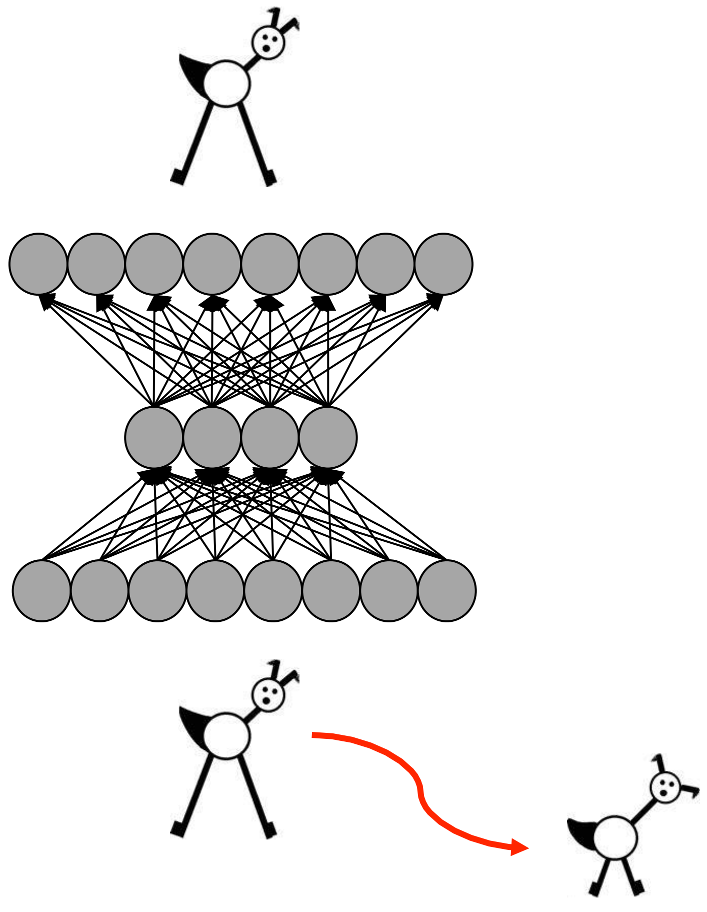
Relation between the learner and the environment

Internal state of the model: plasticity

(t-o)*o*(1-o)



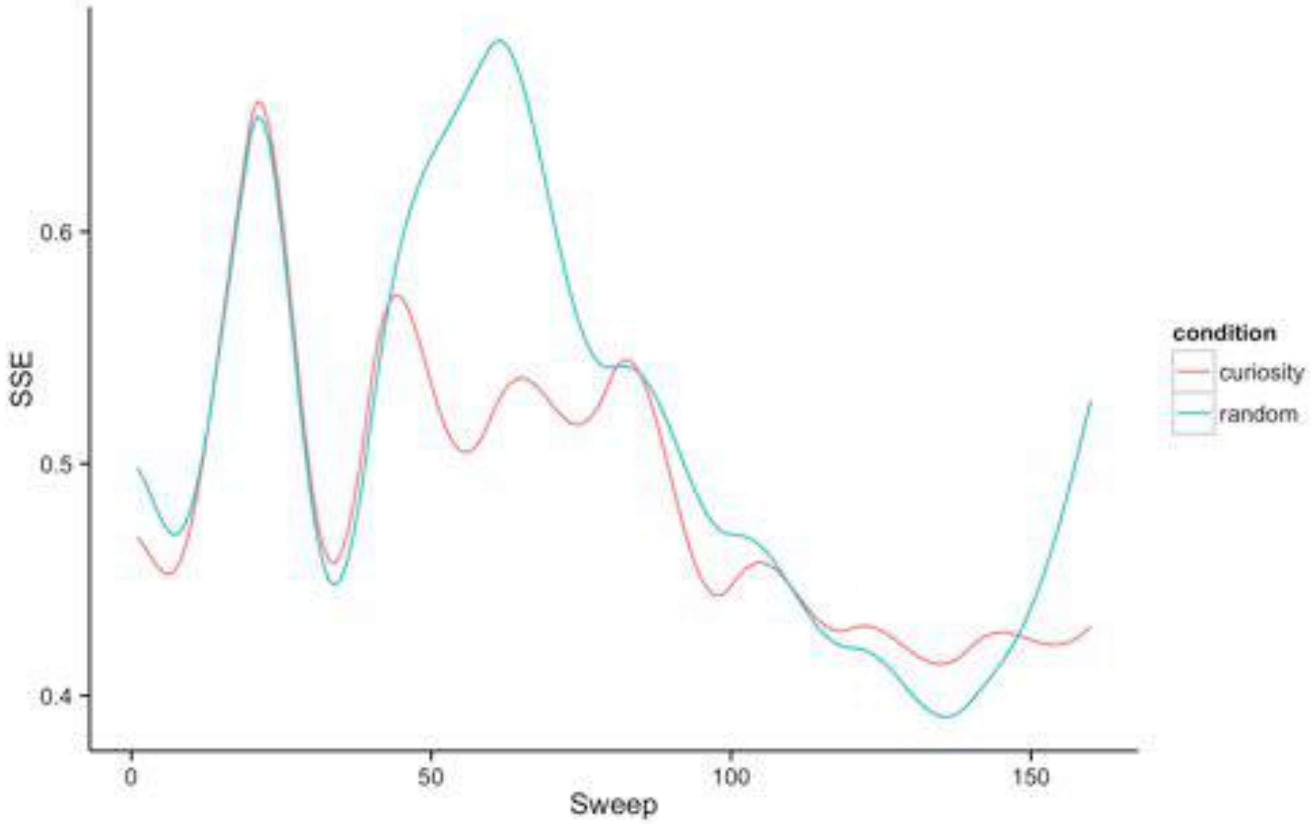
So, during familiarization training, choose the next stimulus that maximizes (t-o)*o*(1-o) to learn from it.



Results

Compare curiosity-driven learning with (usual) random presentation of familiarization stimuli.

Testing on the whole set during familiarization



Results

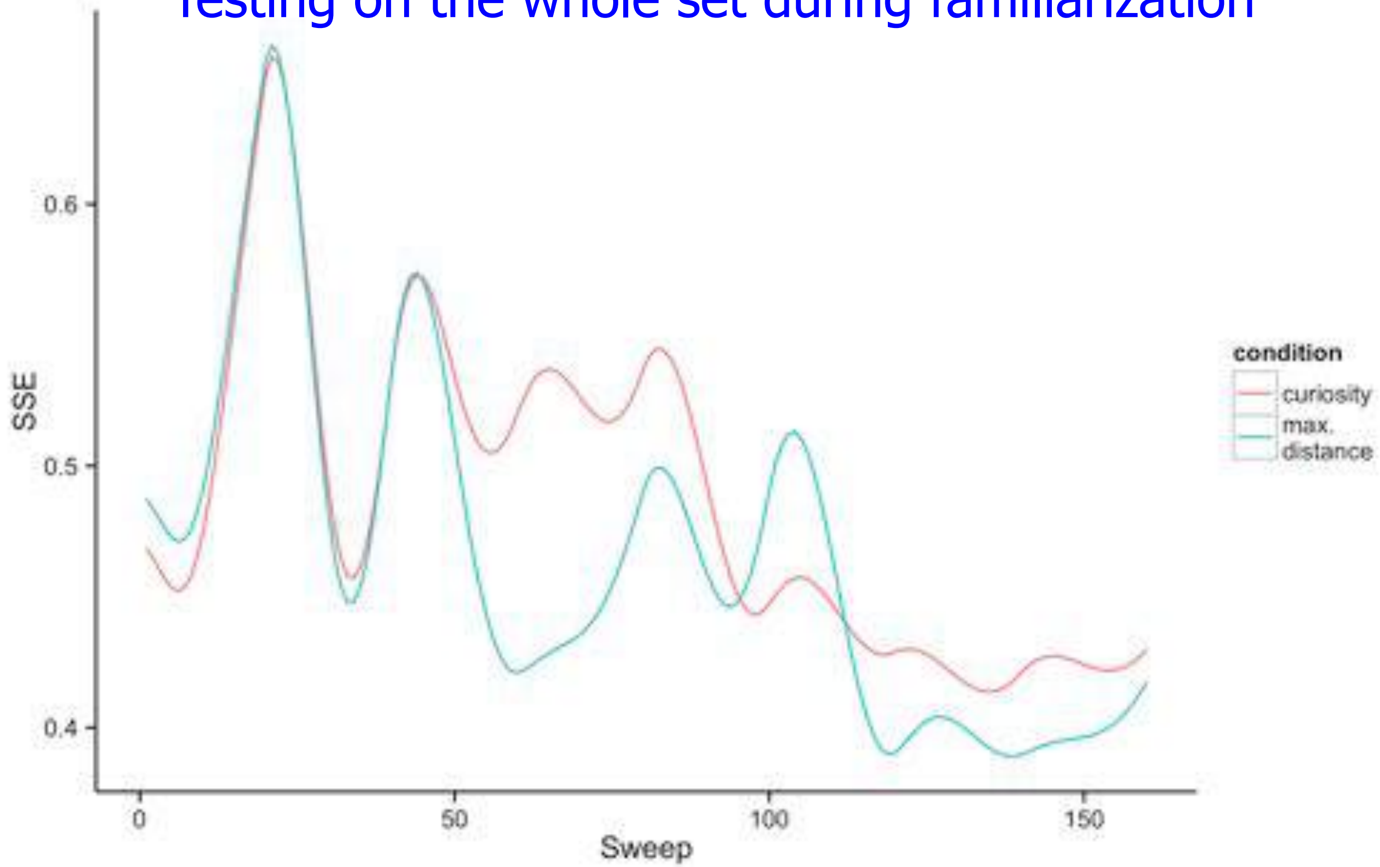
'Looking preference' at test

Curiosity-driven learning leads to better category formation than random learning.

Results

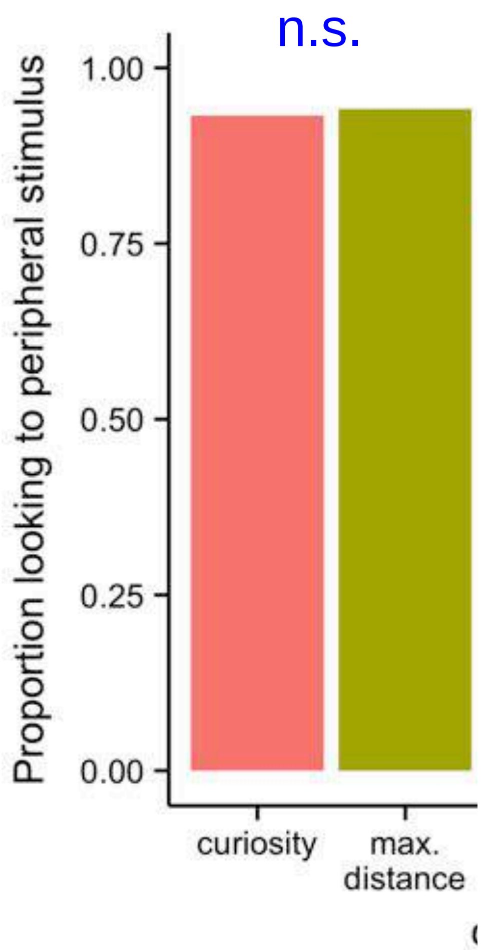
Compare curiosity-driven learning with maximal-distance ordering of the familiarization stimuli

Testing on the whole set during familiarization



Results

'Looking preference' at test



Results

- Intrinsic, curiosity-driven information selection does as well as the optimal structuring of the external environment.

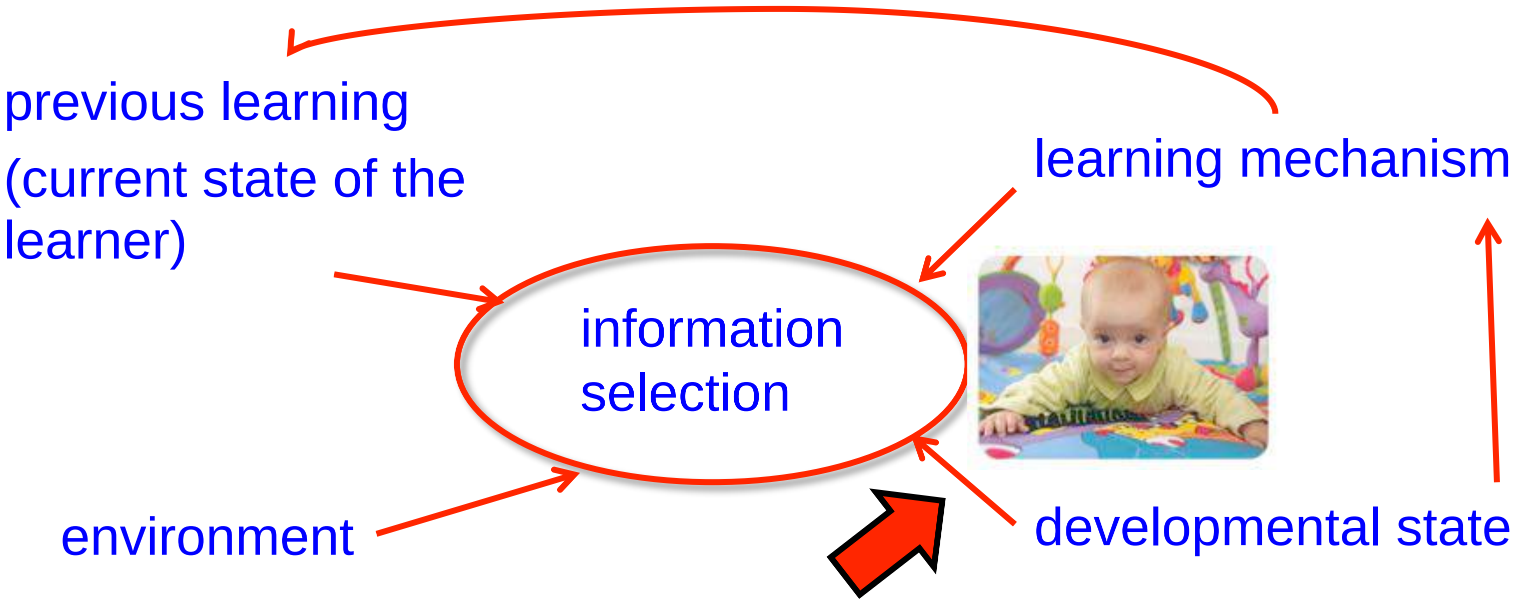
- **But:** curiosity-driven learning does not always choose the maximally distant stimulus.

Example sequence for curiosity-driven learning

Stimulus	distance to previous stimulus	nth most distant out of x remaining
f2	n/a	n/a
f8	1.2215	2/7
f1	1.1897	4/6
f7	1.2215	2/5
f4	1.2278	3/4
f3	0.2767	3/3
F6	1.2694	1/2
f5	0.2767	1/1

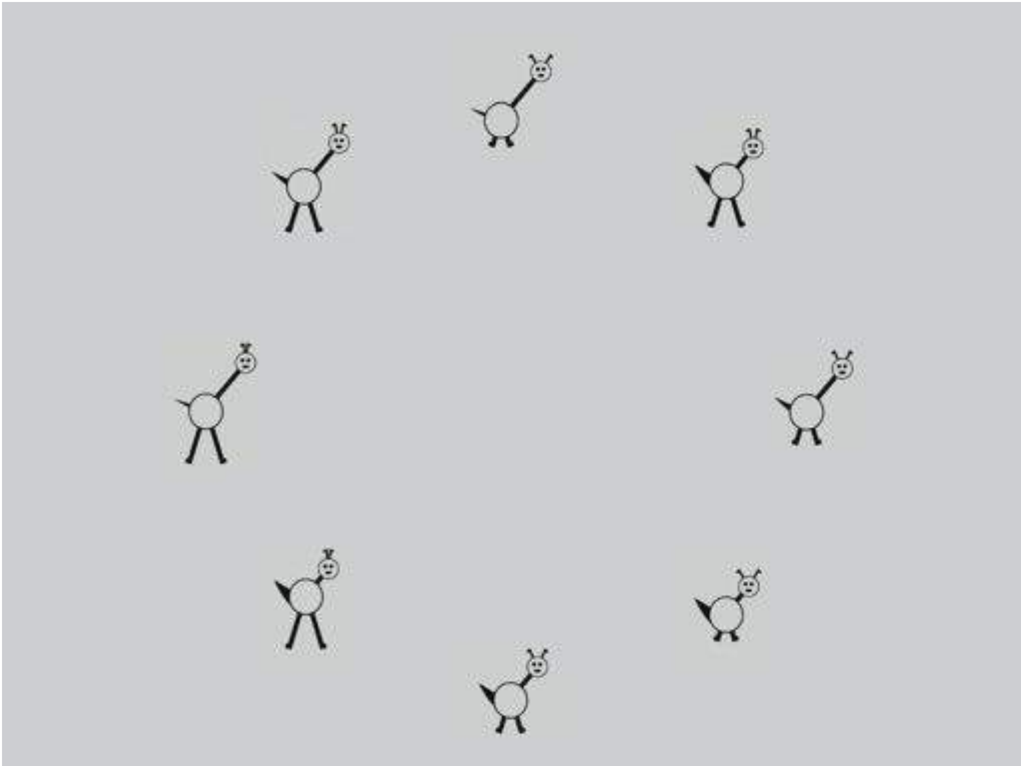
In sum

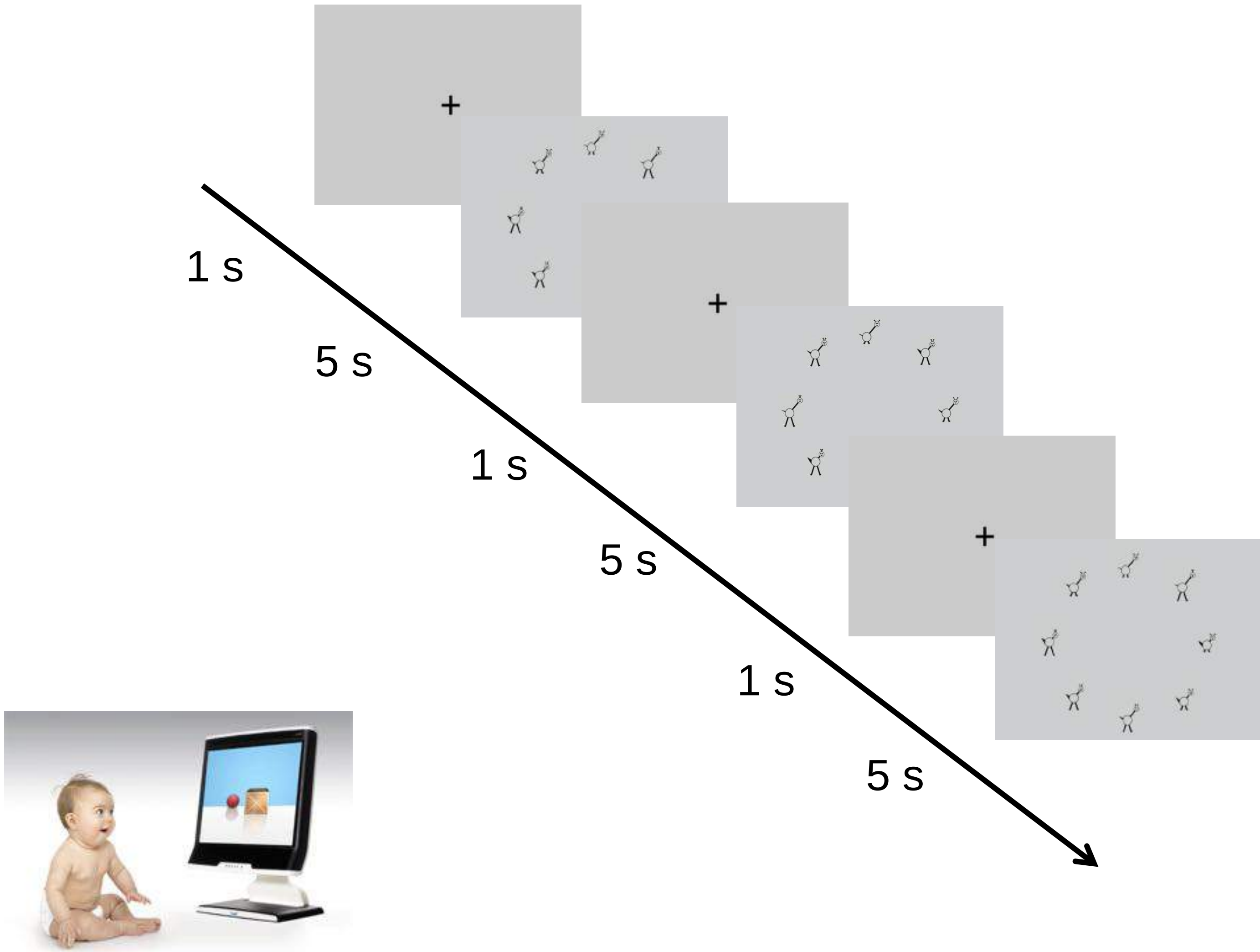
Choice of stimulus in curiosity-driven learning depends on:



Changes moment-by-moment.

Pilot study with 10-month-old infants




1 s
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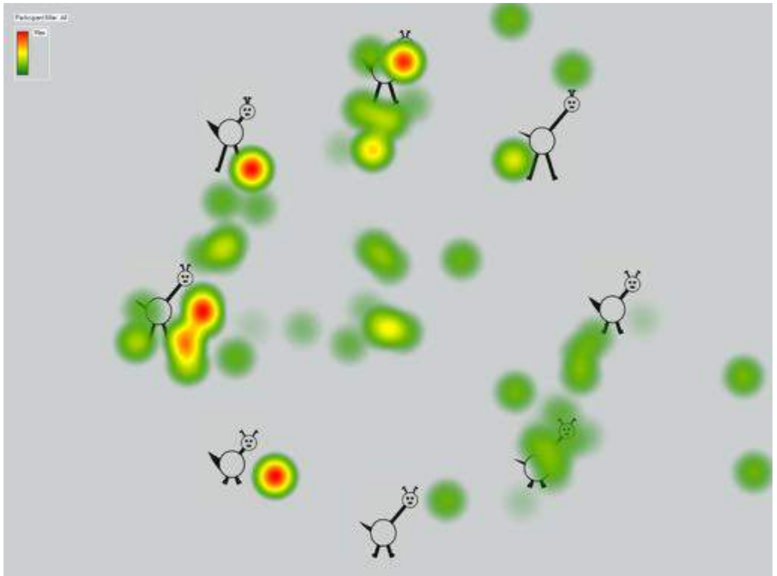

Conclusions

We can learn even from lab based experiments about curiosity:

- What is the learning mechanism for which curiosity provides the (optimal) inputs?
- How does this mechanism change over developmental time, thus,
- How will information selection change over developmental time?
- Curiosity as 'eliminating surprise' in a learning mechanism that works in the real world and in the lab.

Thank you.

Katie Twomey (Lancaster University)

Yi-Chuan Chen (now at Oxford University)

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