Self-consistent inference in perception and cognition

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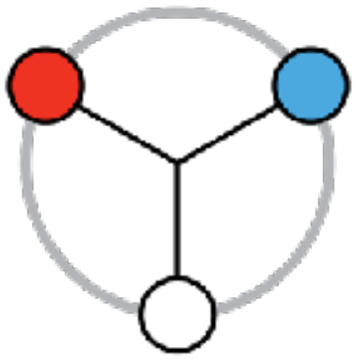
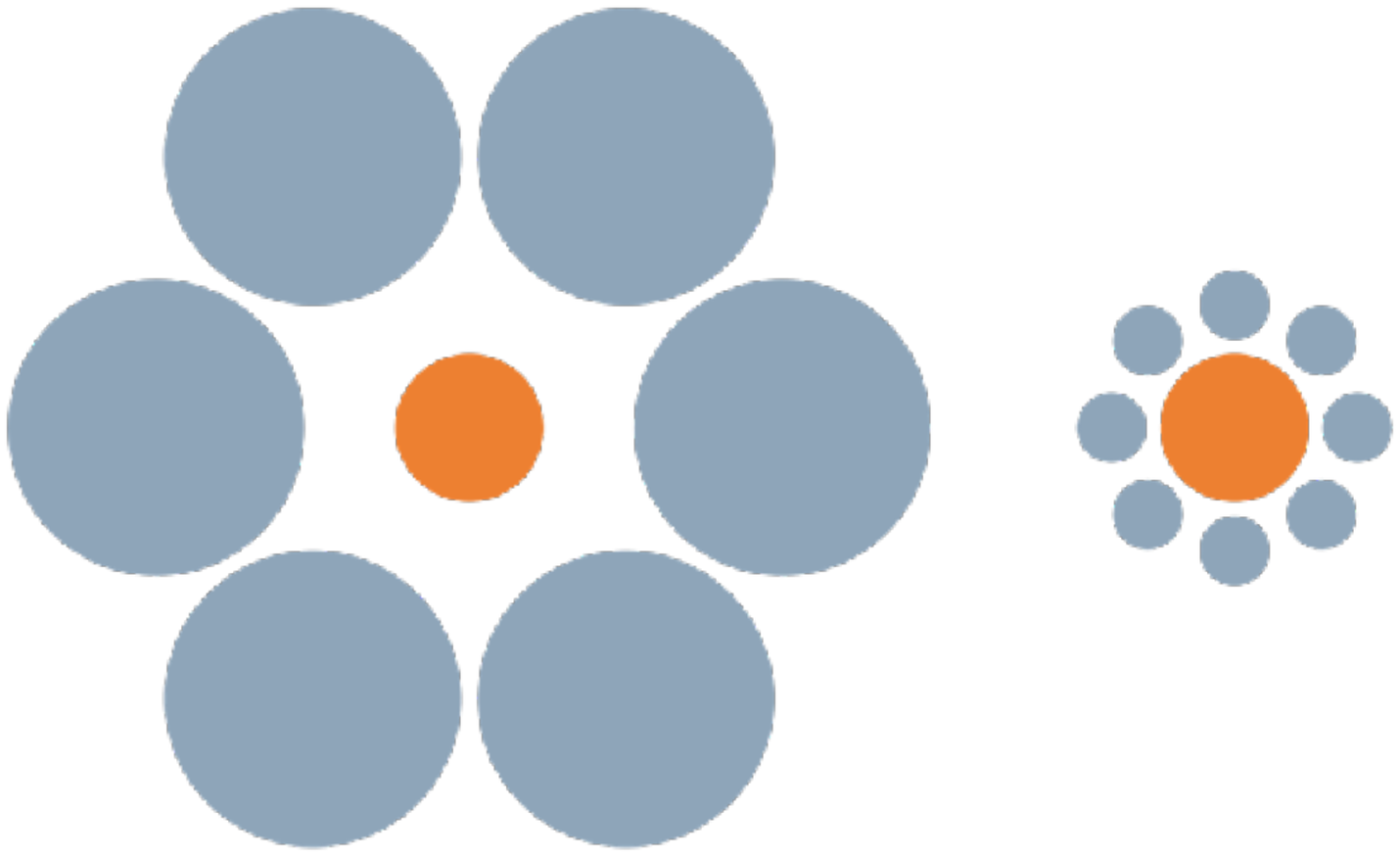
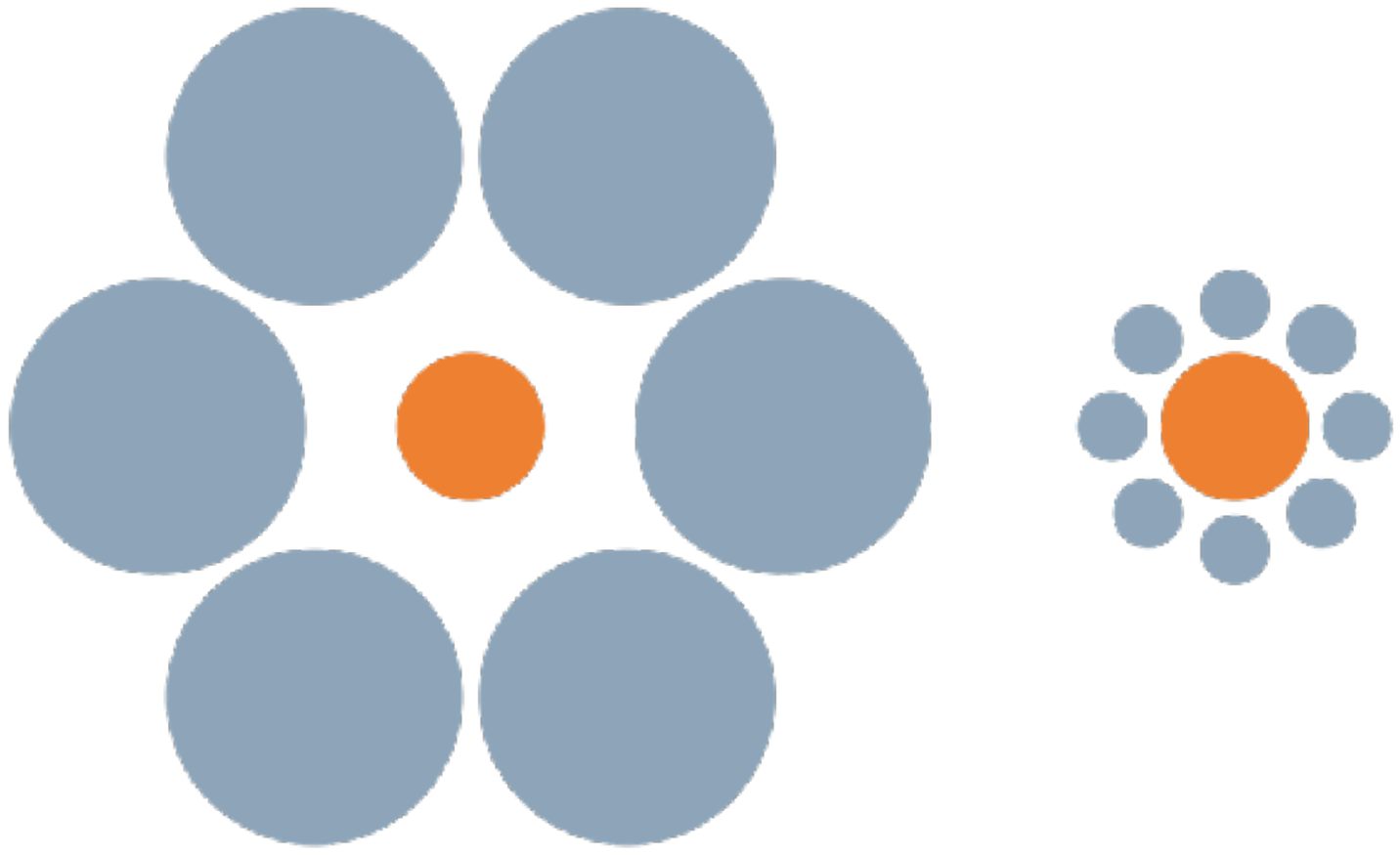


computational perception
and cognition lab

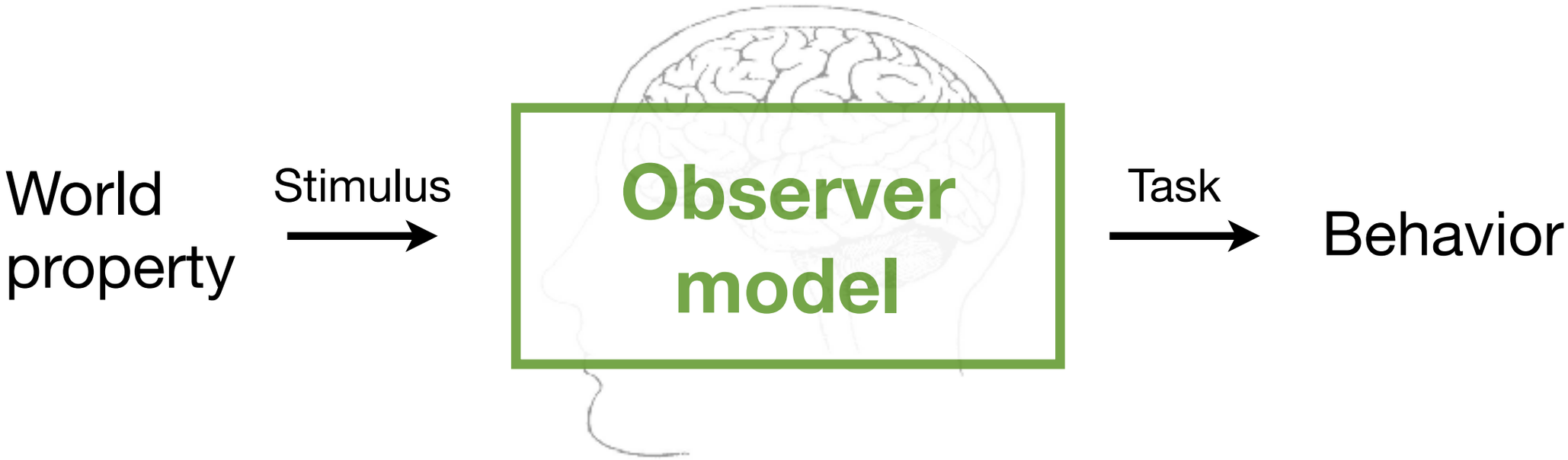




Perception can be biased …

… and <u>almost always</u> is!

Approach



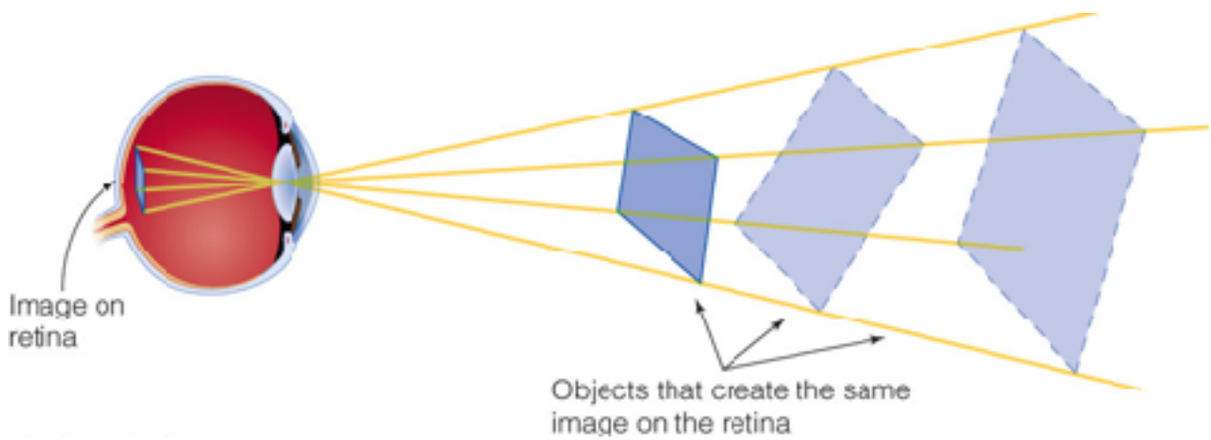
- quantitative predictions
- validation with experiments

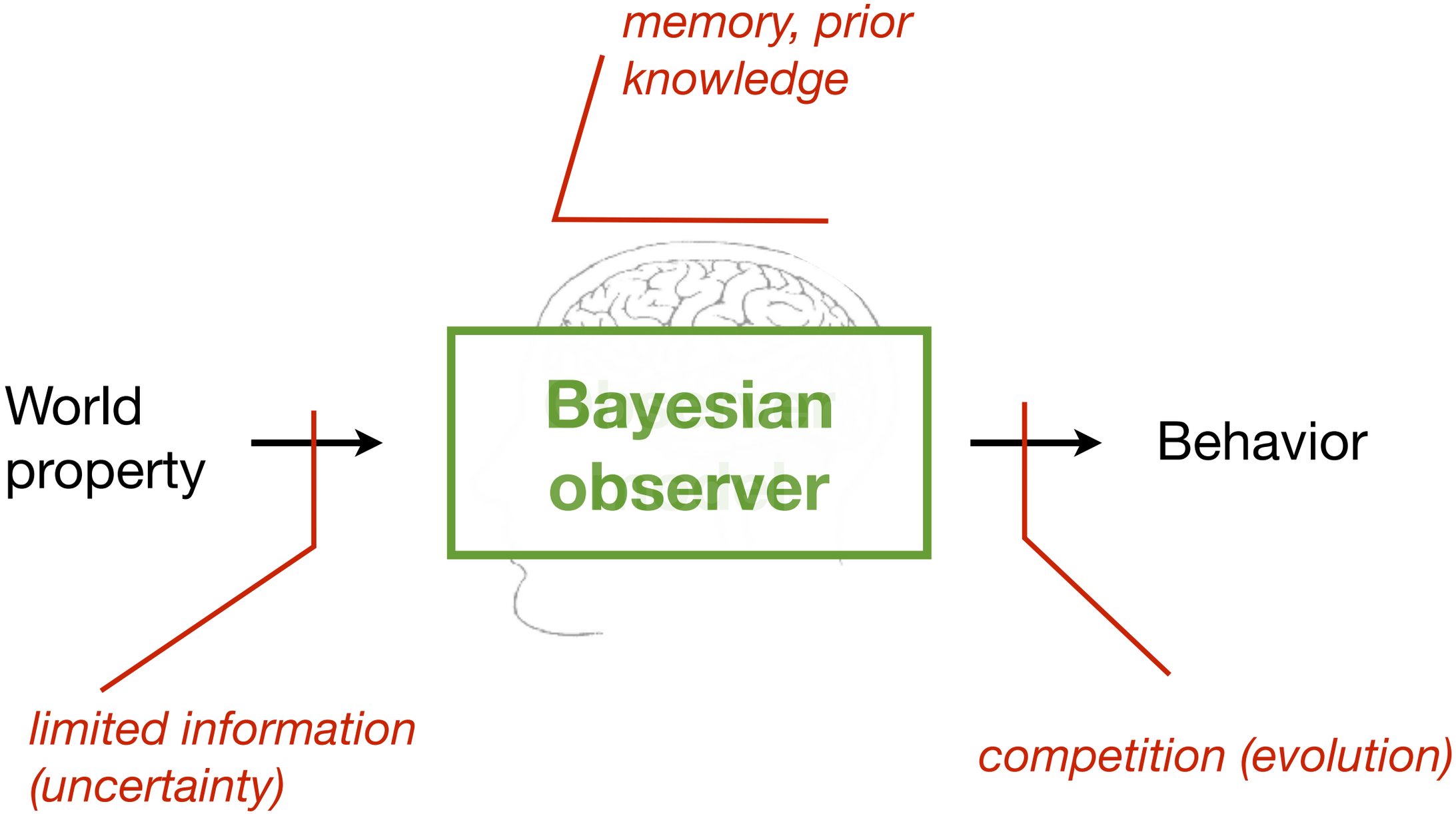
World property

Observer model

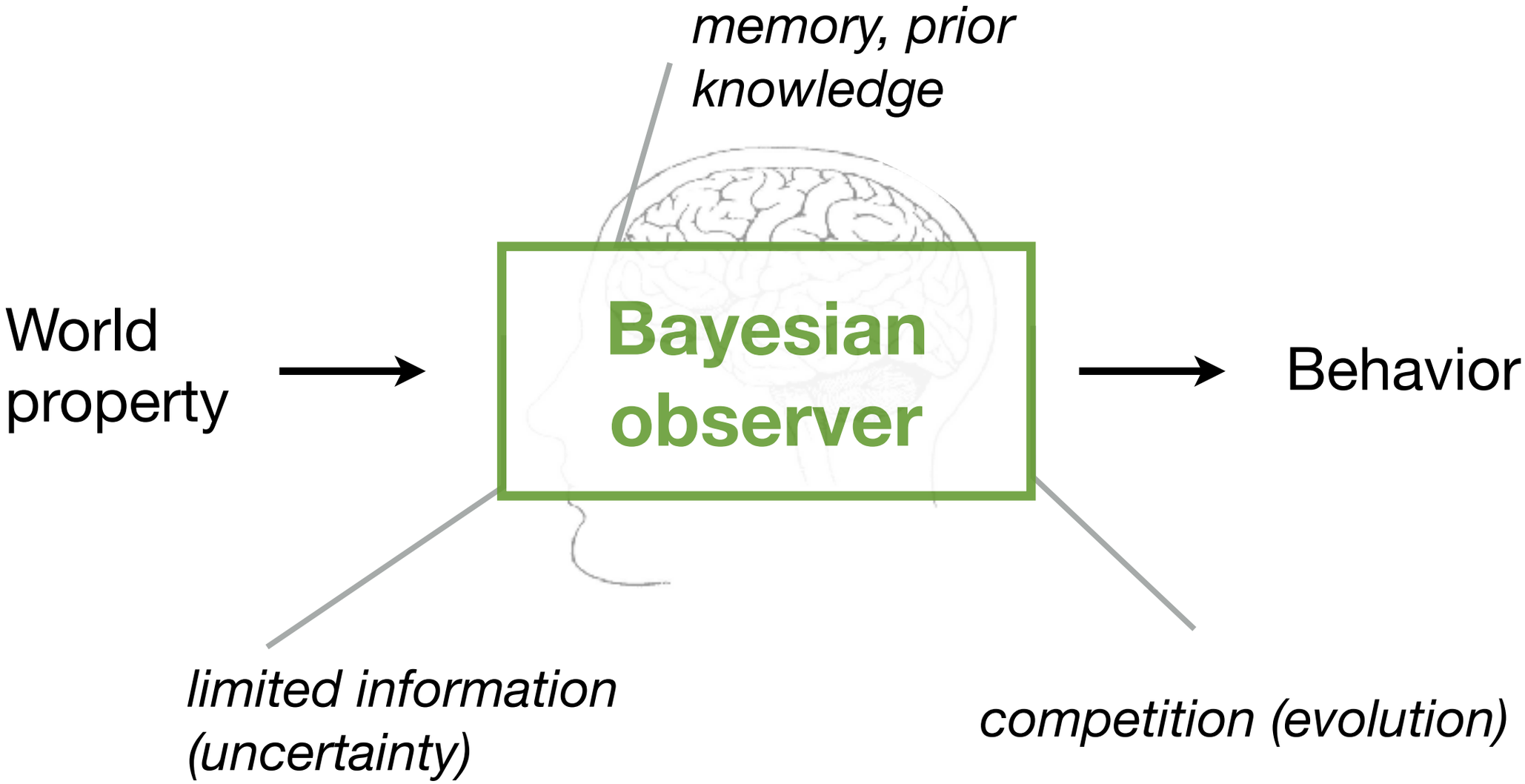
Behavior

limited information (uncertainty)



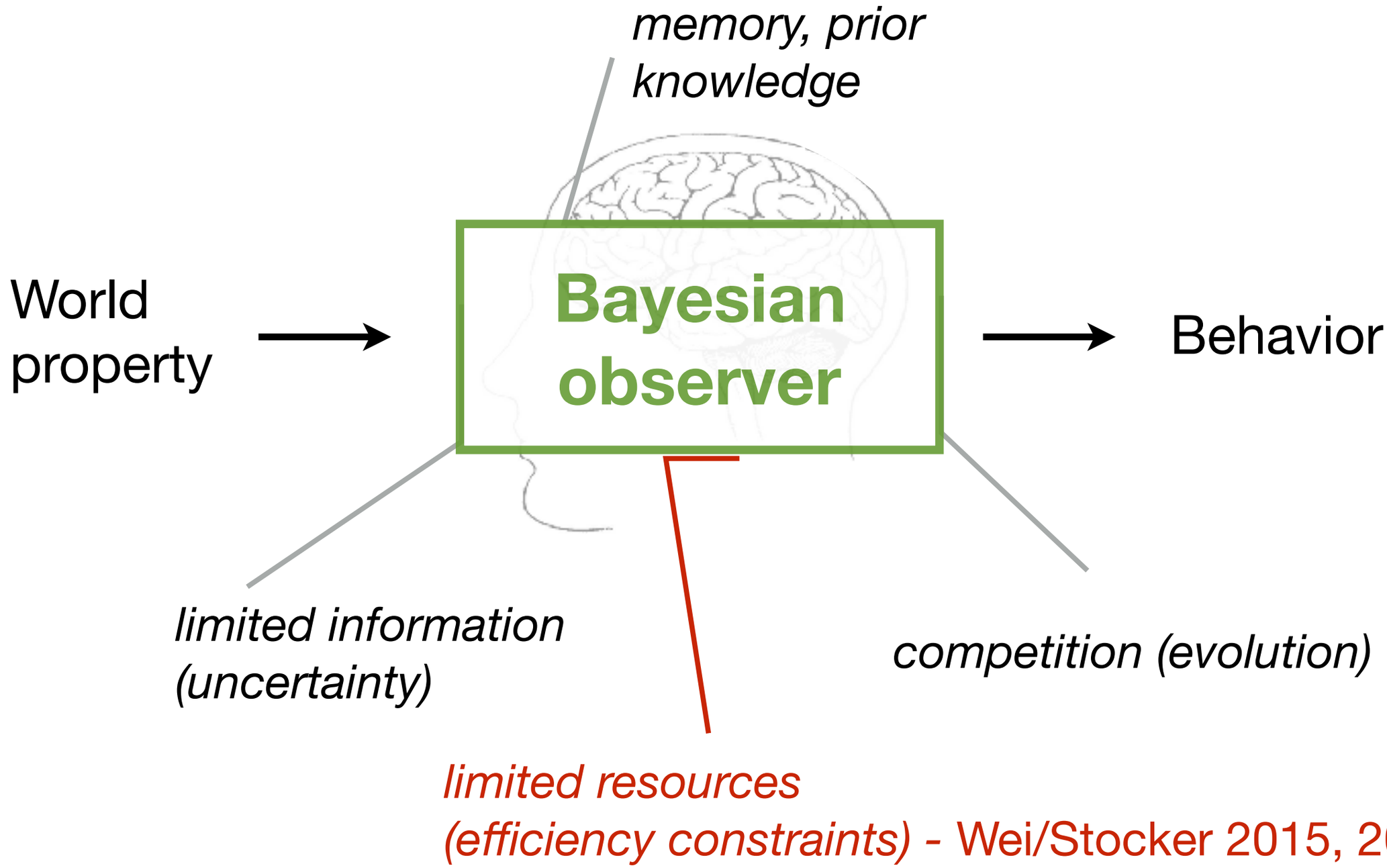

memory, prior knowledge
World property
Bayesian observer
Behavior
limited information (uncertainty)
competition (evolution)

Bayesian observer hypothesis



Knill/Richards 1996
… and thousand others by now.

Bayesian observer hypothesis



Being biased is the computational consequence of being rational under uncertainty - optimal combination of prior and stimulus information.

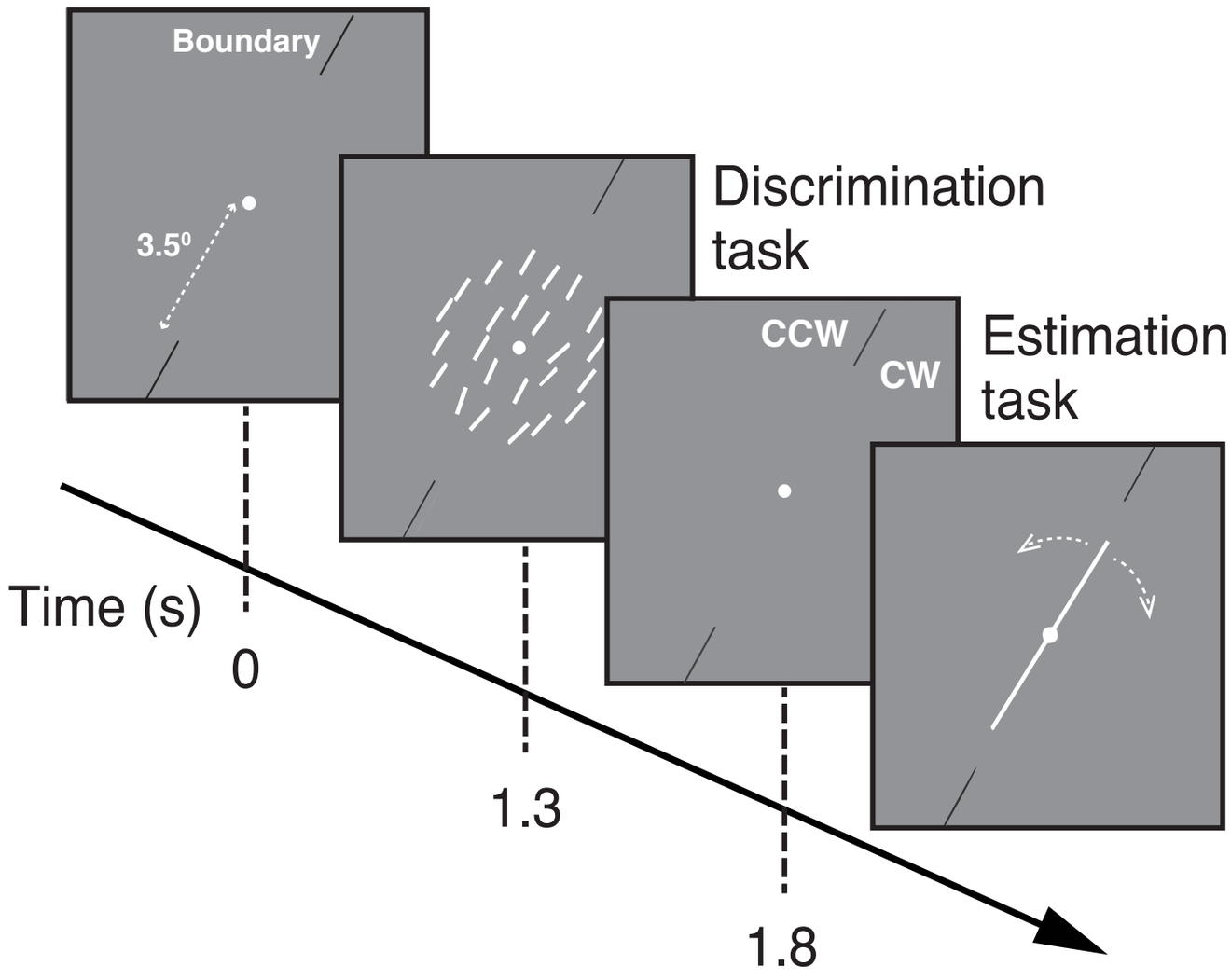
Contextual (fast established) biases?

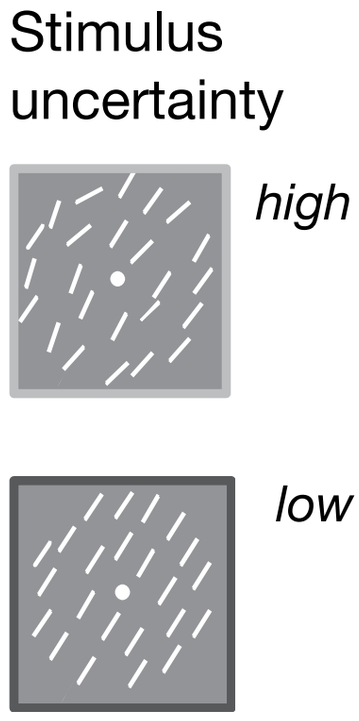
Context by subjective category commitment

1) Apple or orange? ?

2) Perceived color?

Sequential inference

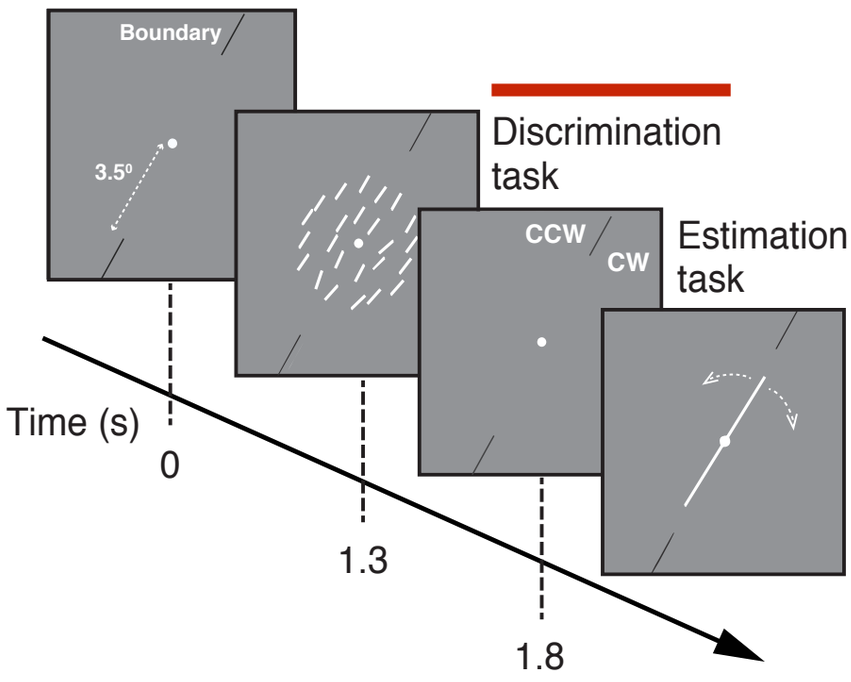




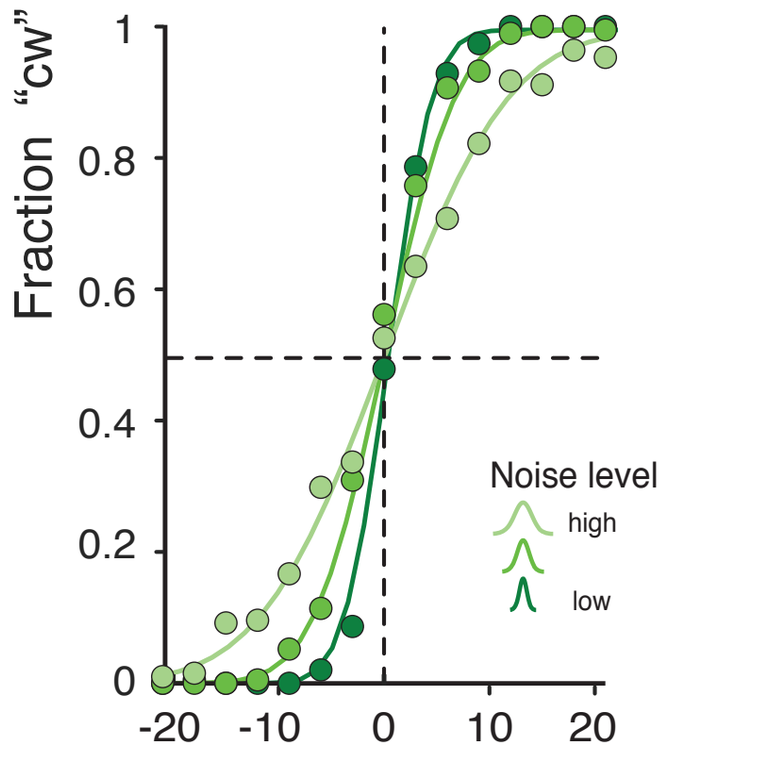
Jazayeri/Movshon 2007
Zamboni et al 2016

Luu/Stocker 2016

Task 1: categorical judgment



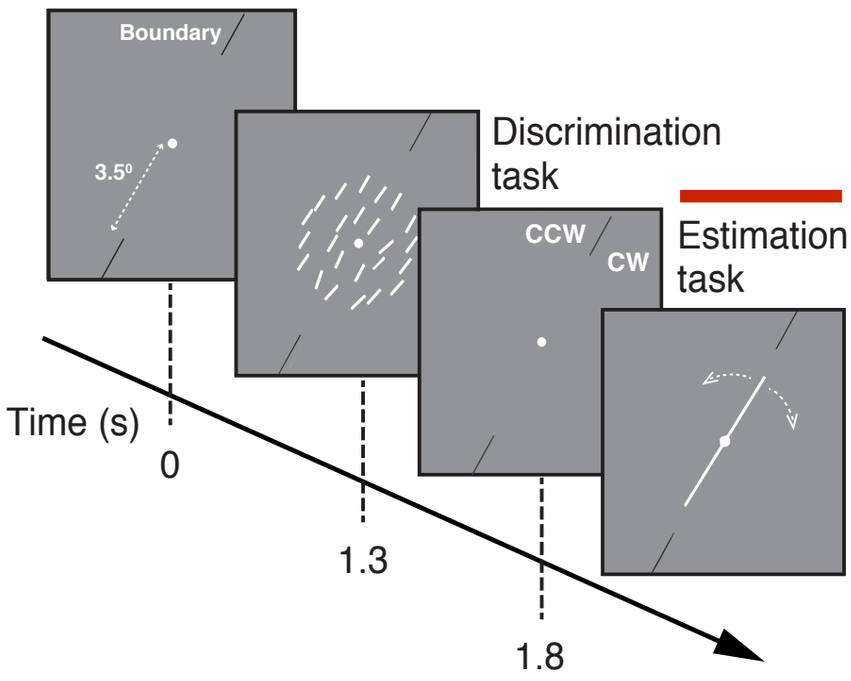
combined subject (N=5)

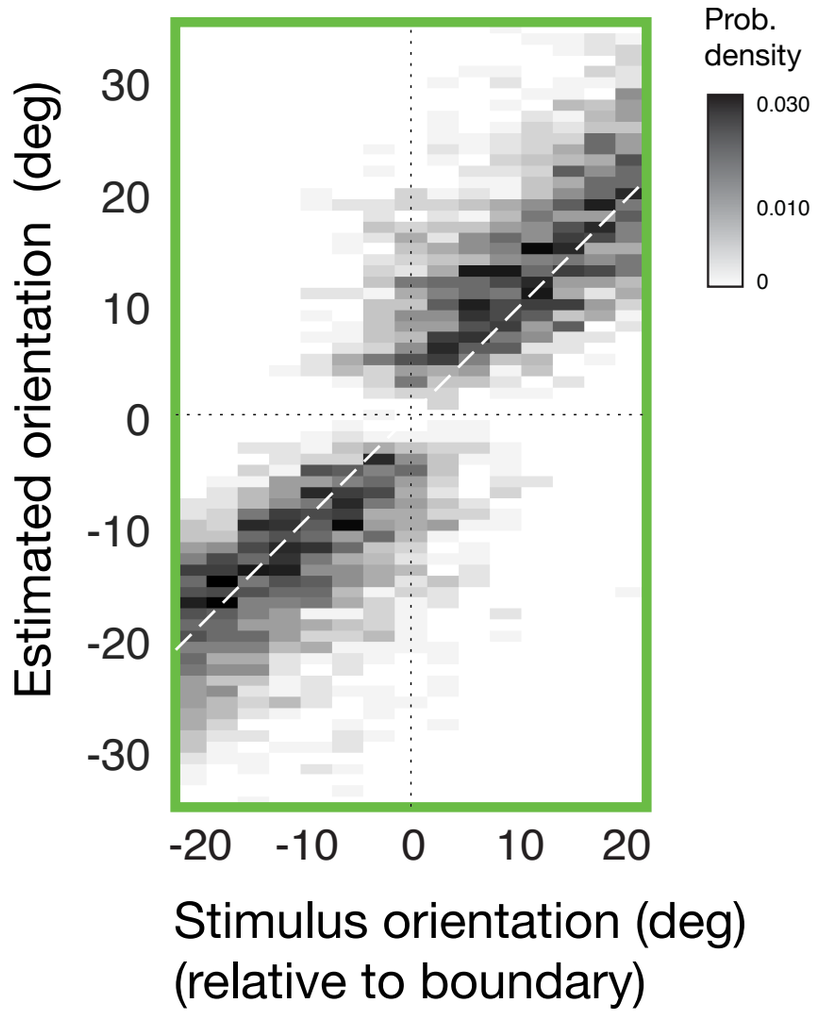


Stimulus orientation [deg]
(relative to boundary)

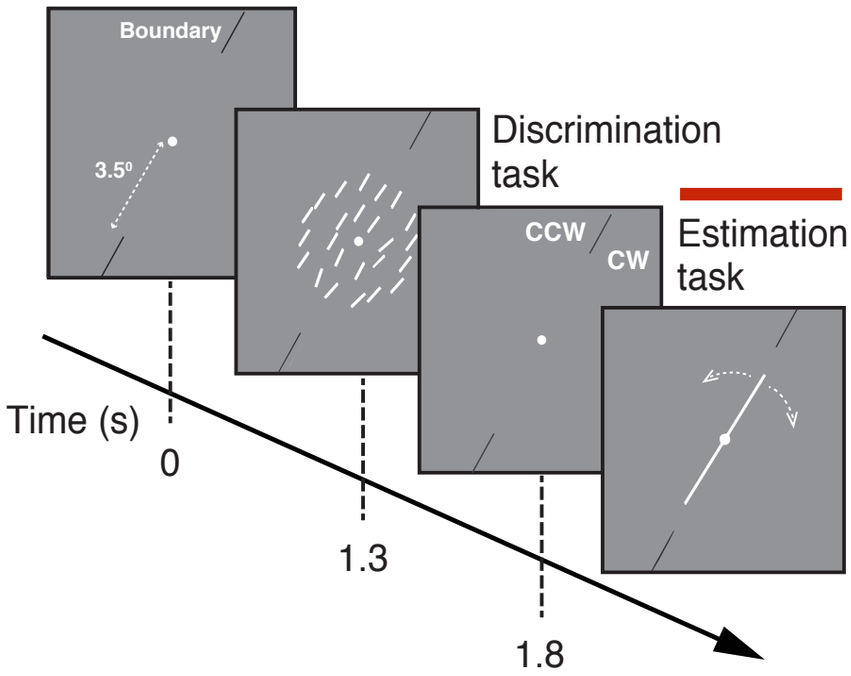
Task 2: orientation estimate

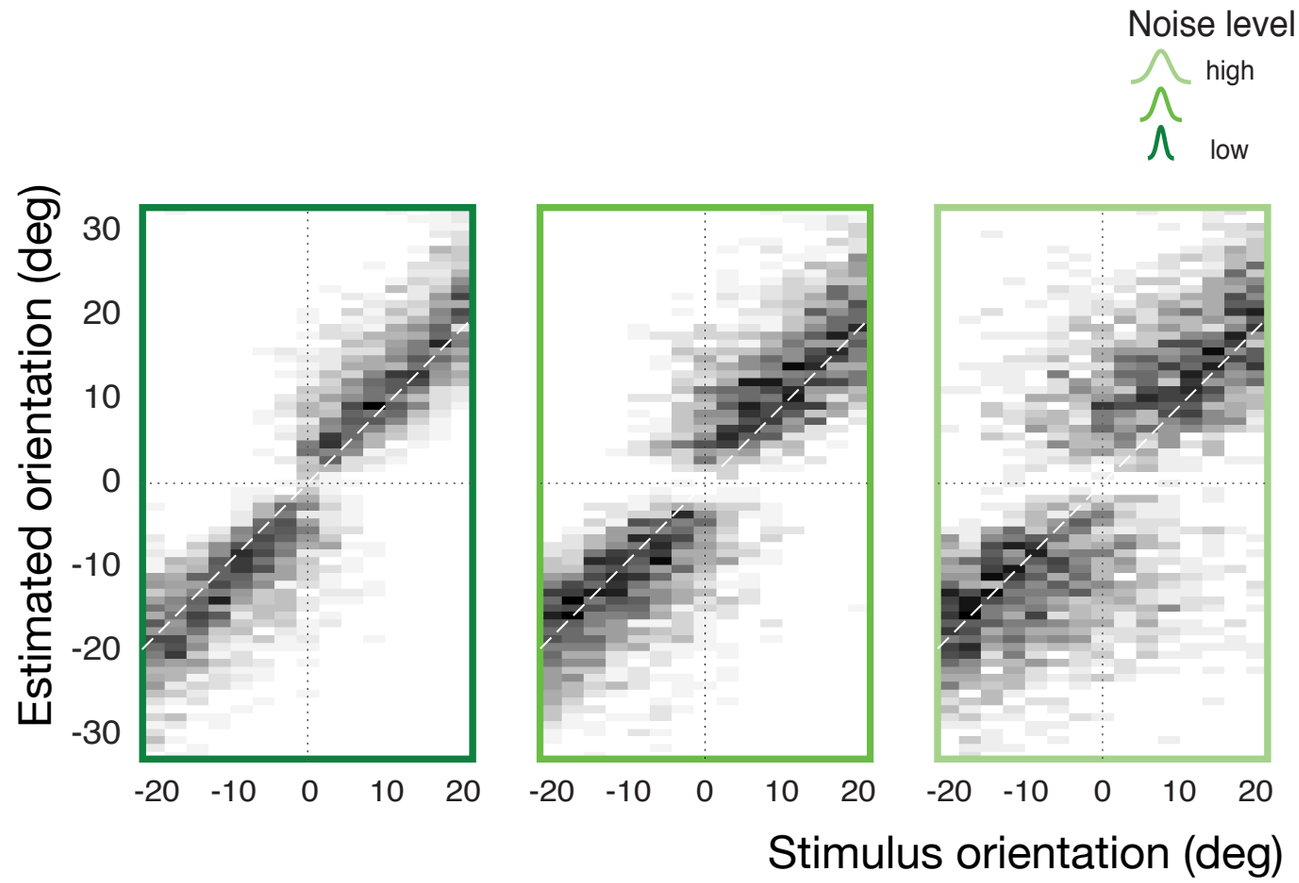
combined subject (N=5)

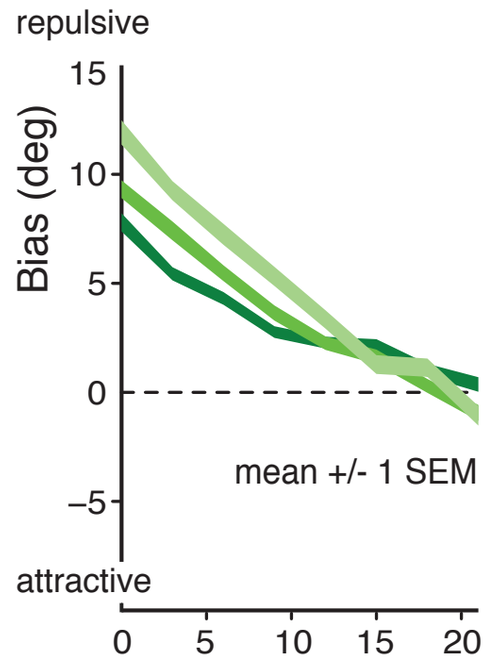




Choice-induced biases in perceived orientation

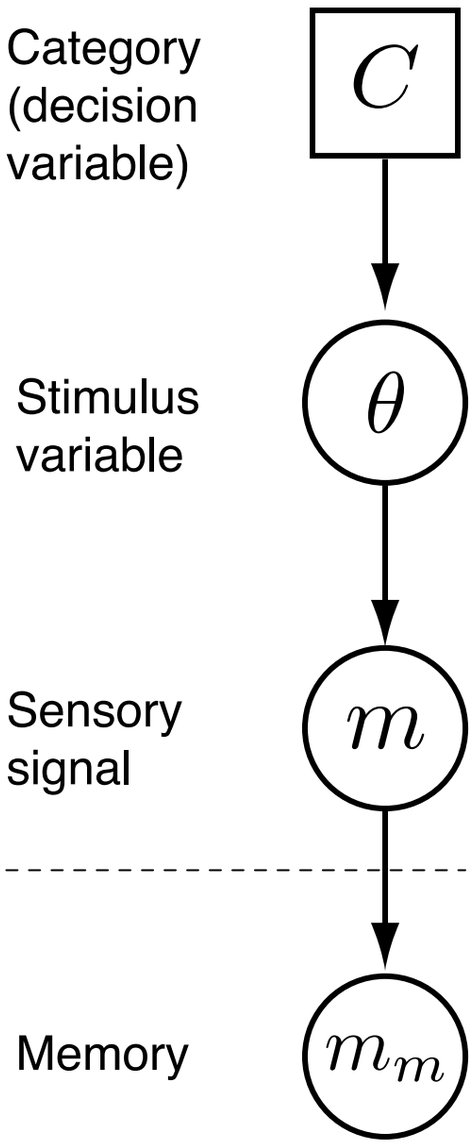






Jazayeri/Movshon 2007
Zamboni et al 2016

Hierarchical generative model



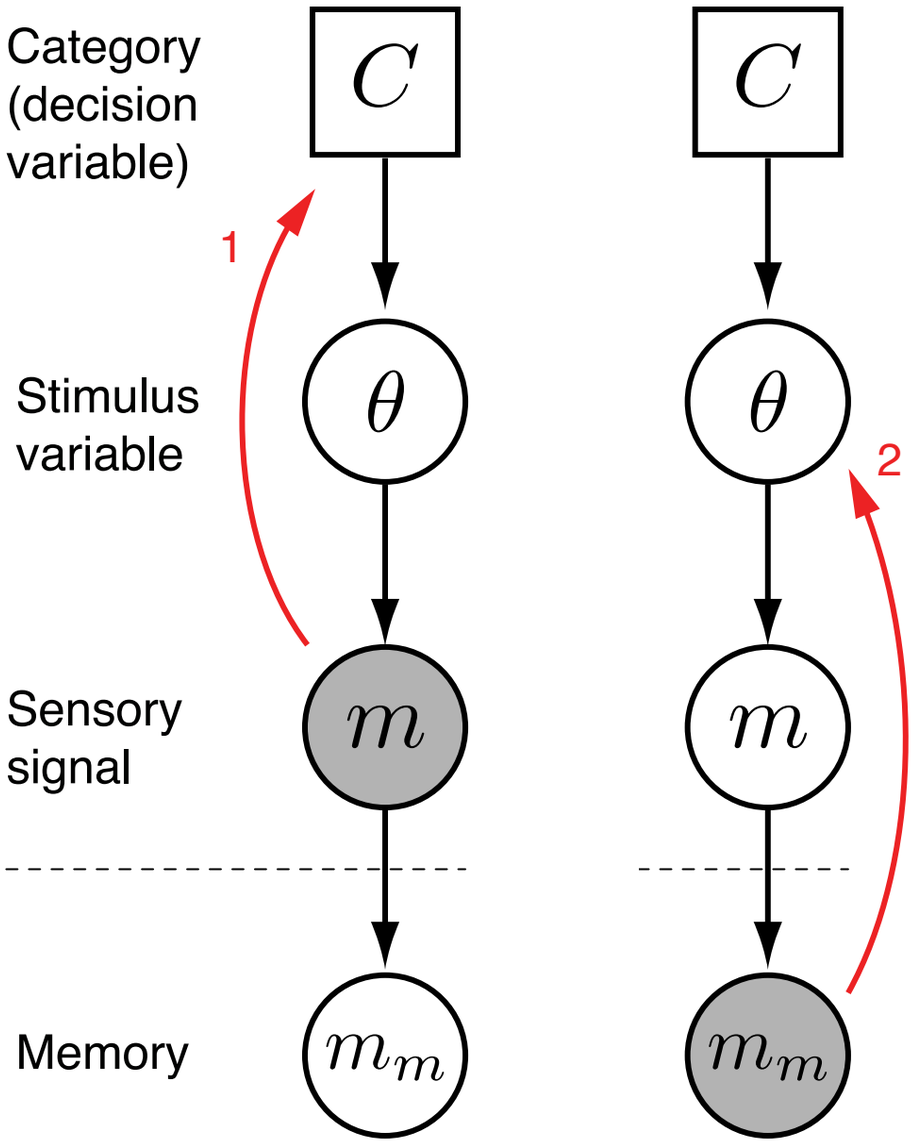
$P(C)$ Category prior

$p(\theta|C)$ Stimulus prior

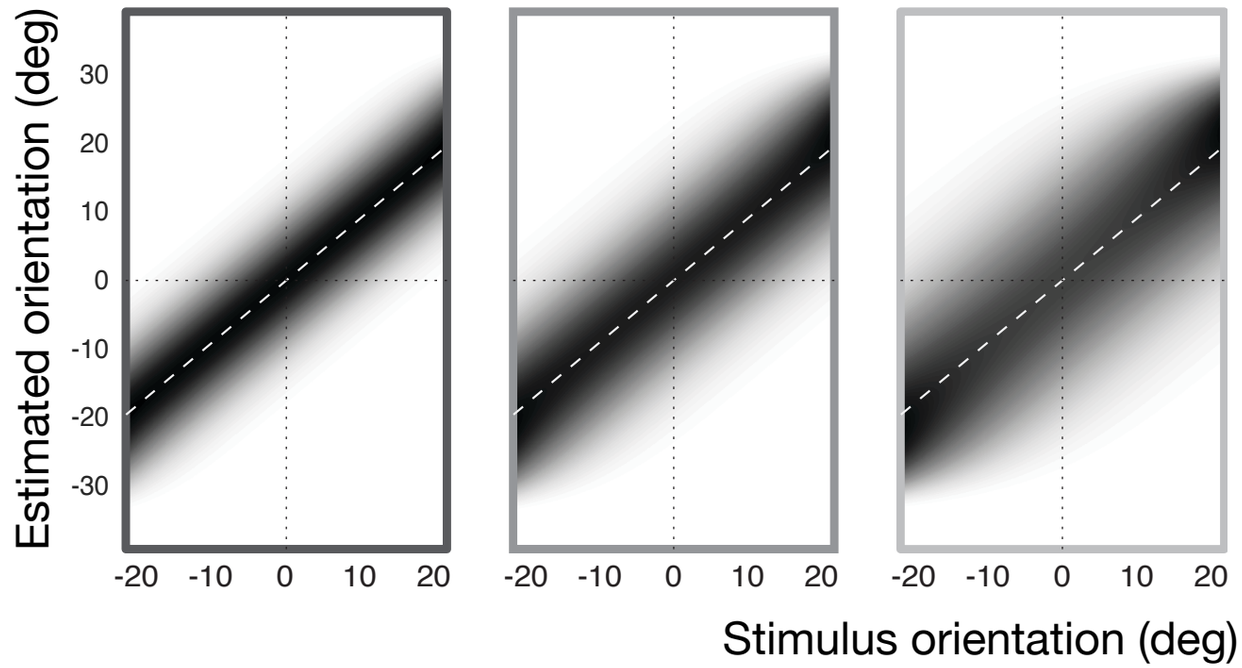
$p(m|\theta)$ Sensory uncertainty

$p(m_m|m)$ Memory/recall uncertainty

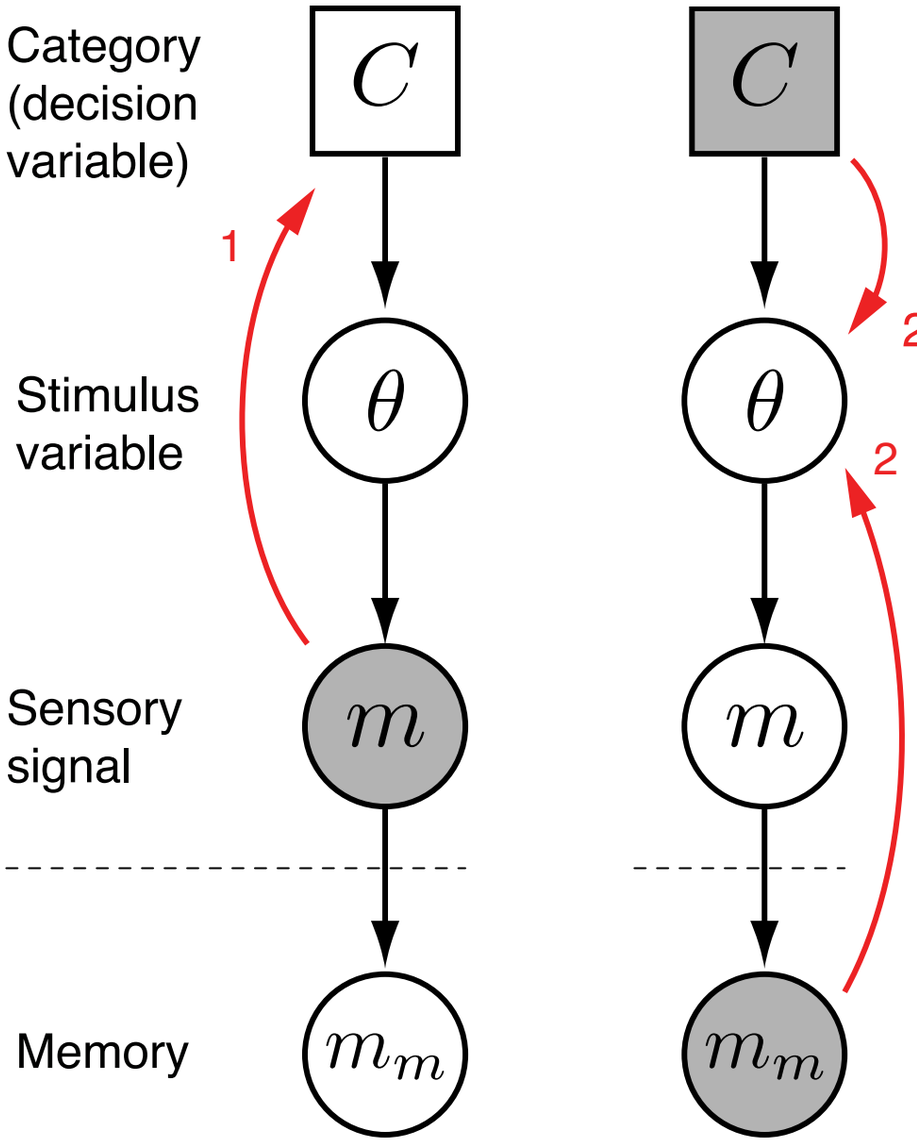
Independent inference



$$p(\theta|m_m) = \frac{p(m_m|\theta)}{p(m_m)} \sum p(\theta|C_i)P(C_i)$$



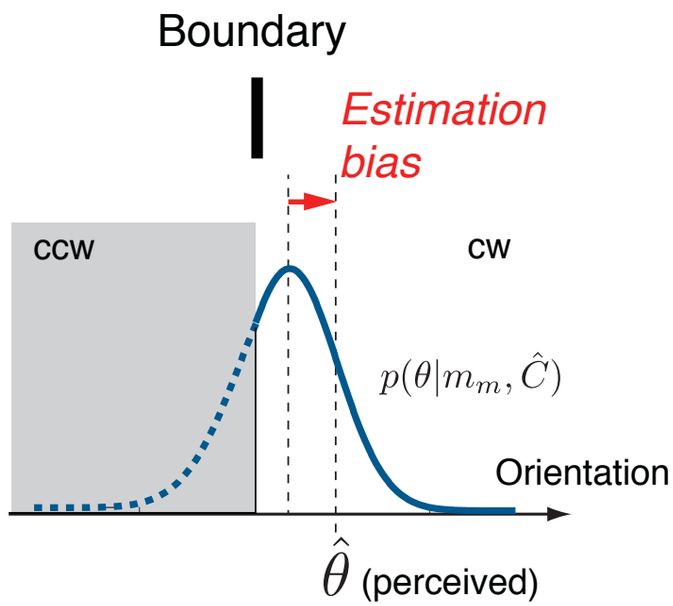
“Self-consistent” inference



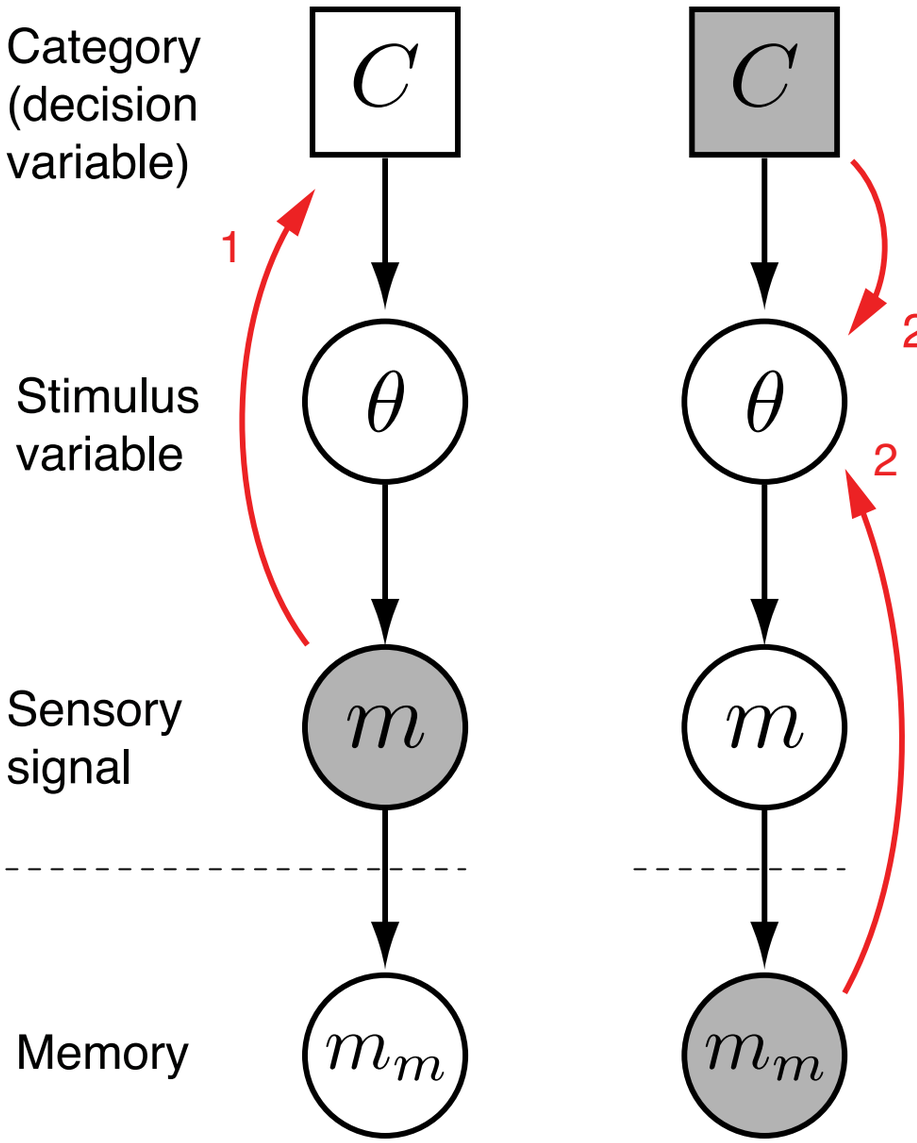
Stocker/Simoncelli 2007

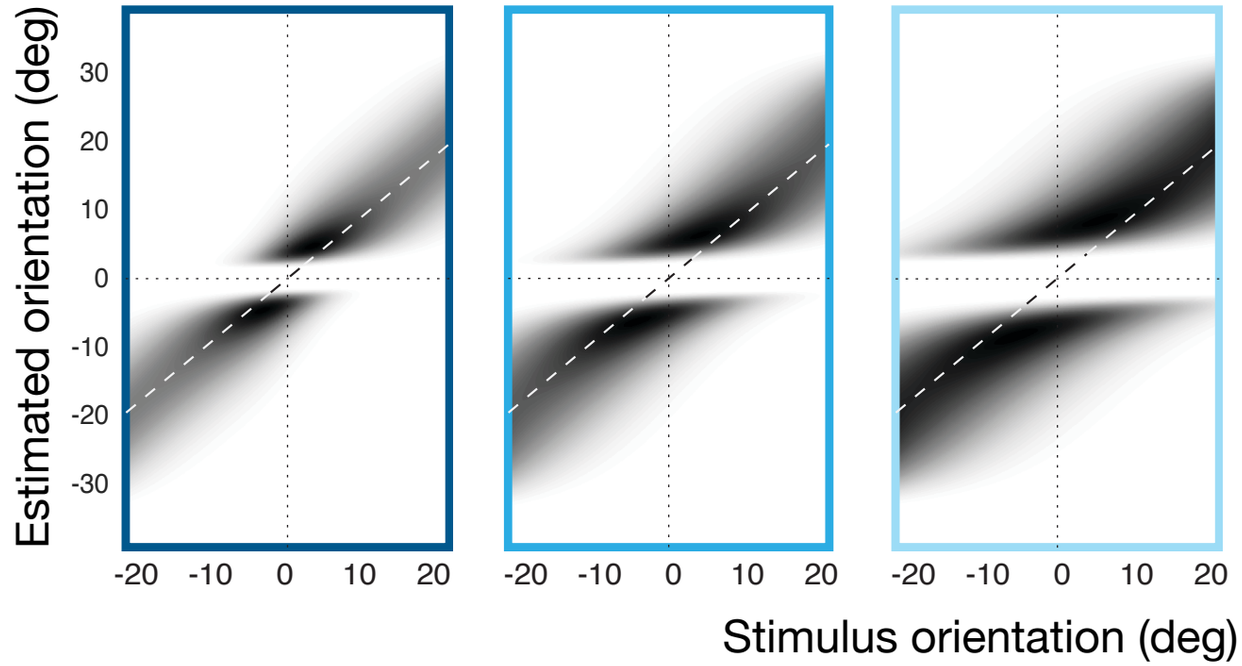
conditioned prior

$$p(\theta|m_m, \hat{C}) = \frac{p(m_m|\theta)}{p(m_m)} p(\theta|\hat{C})$$

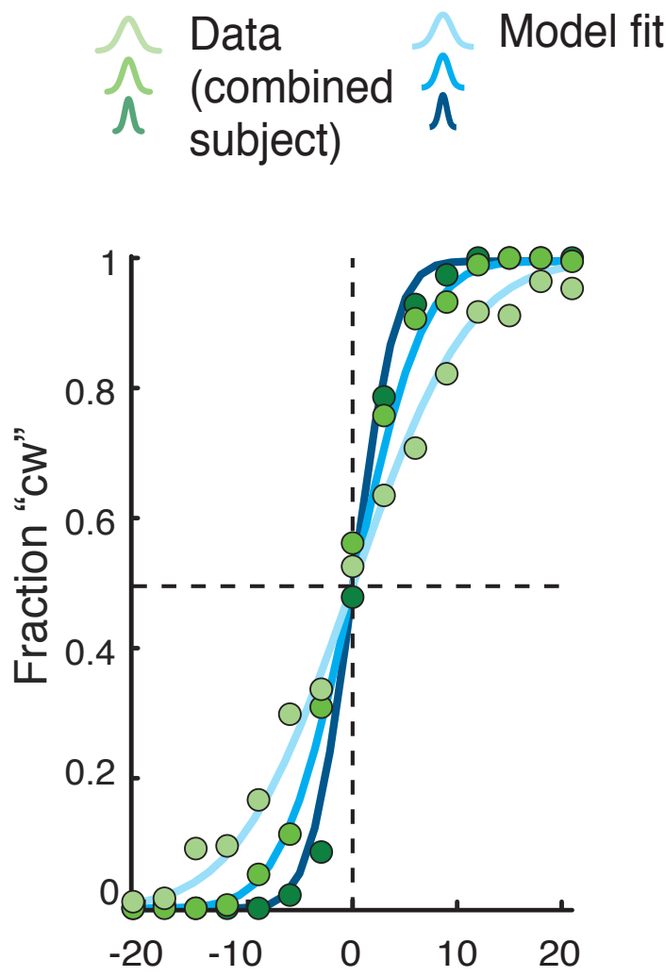


Self-consistent observer



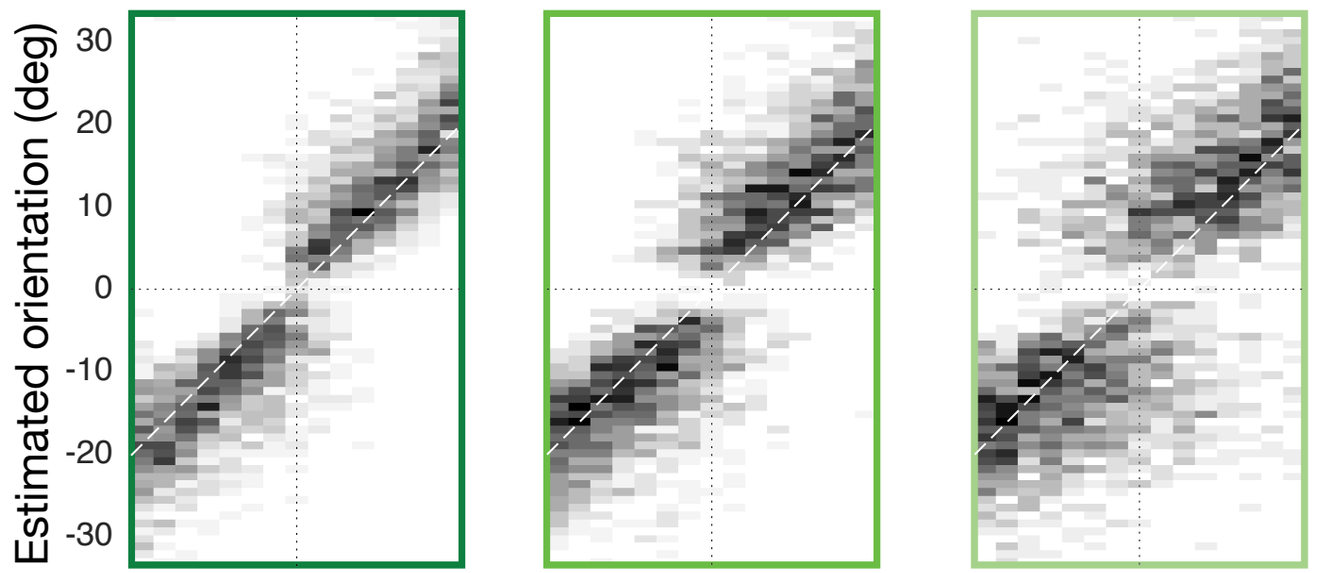


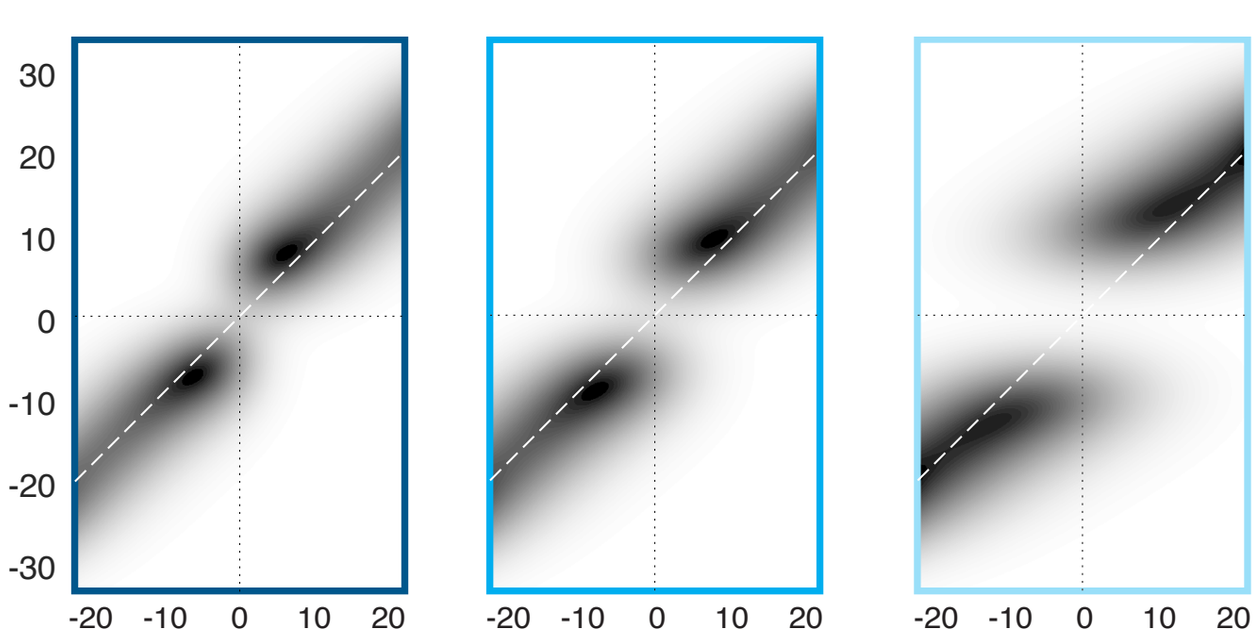
Fits



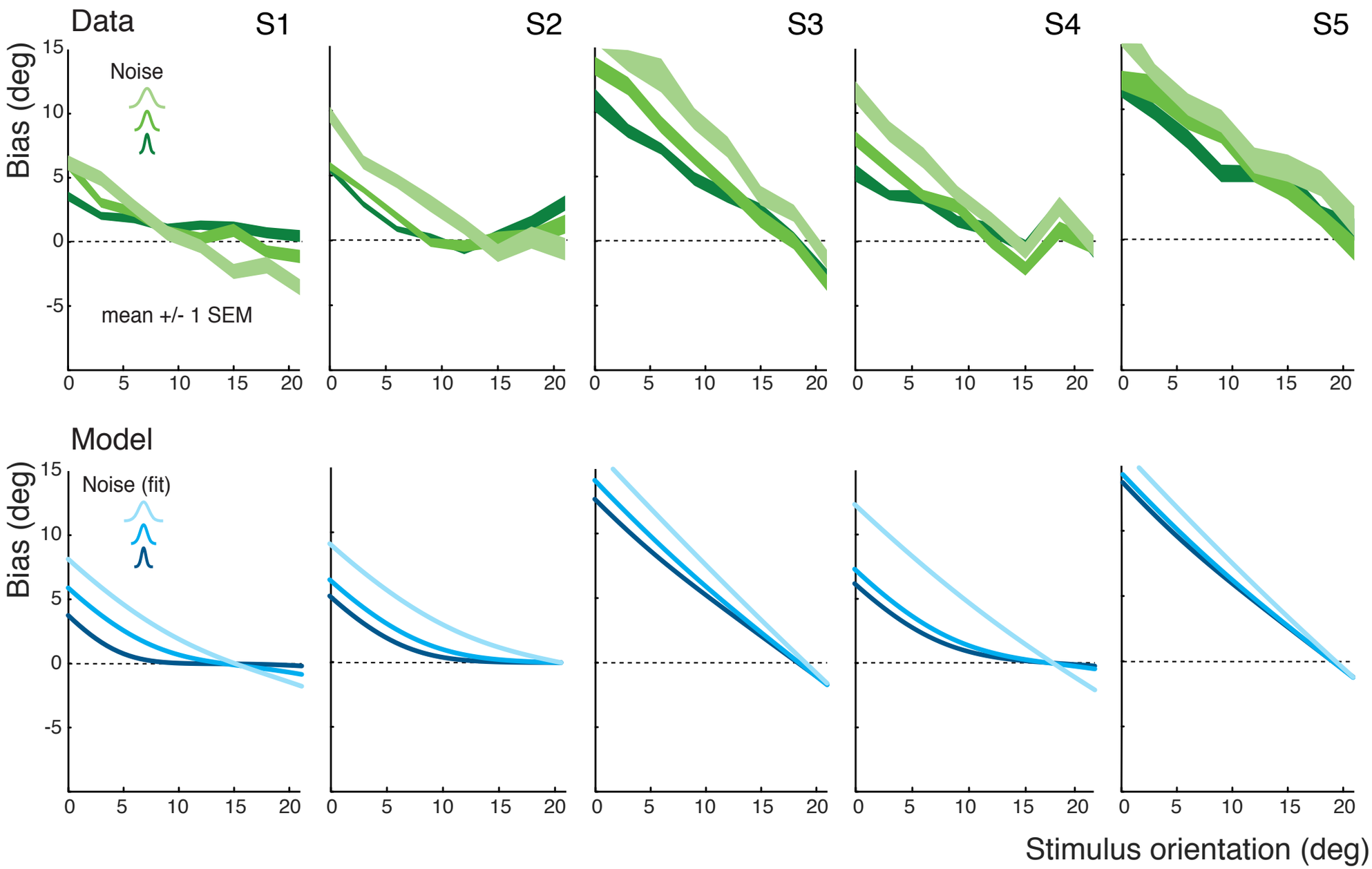
Joint ML fit

combined subject

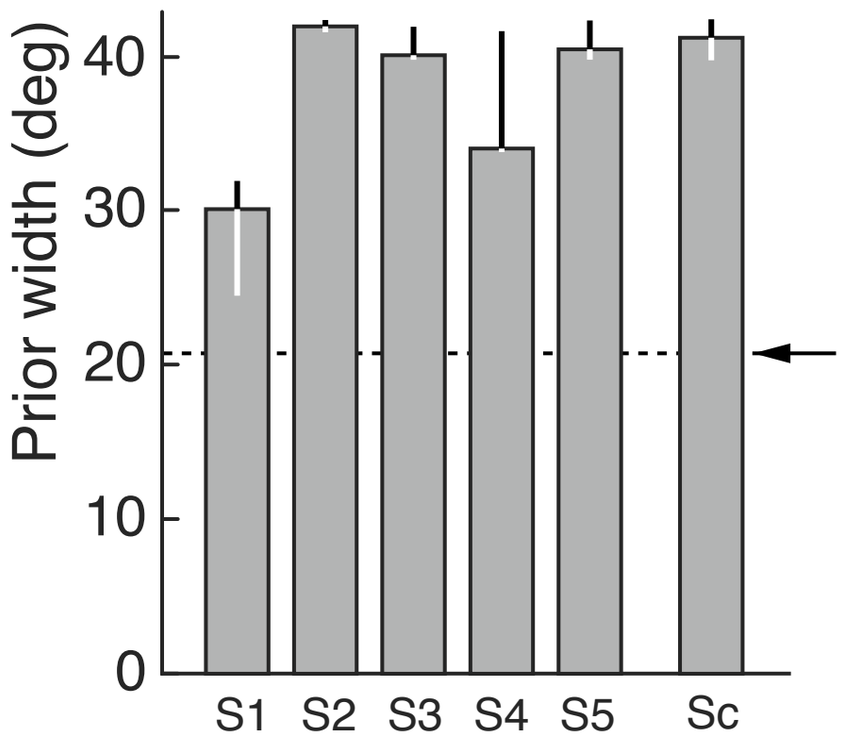


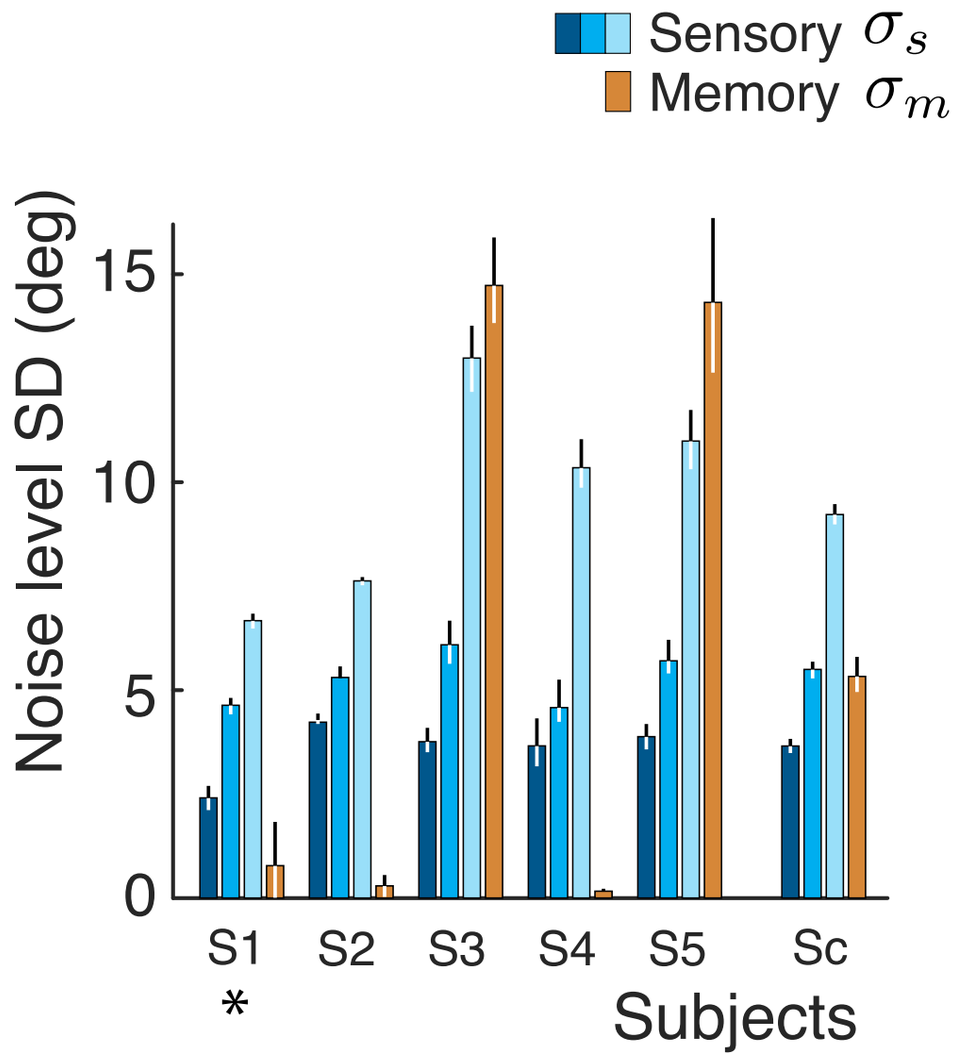


Individual subjects

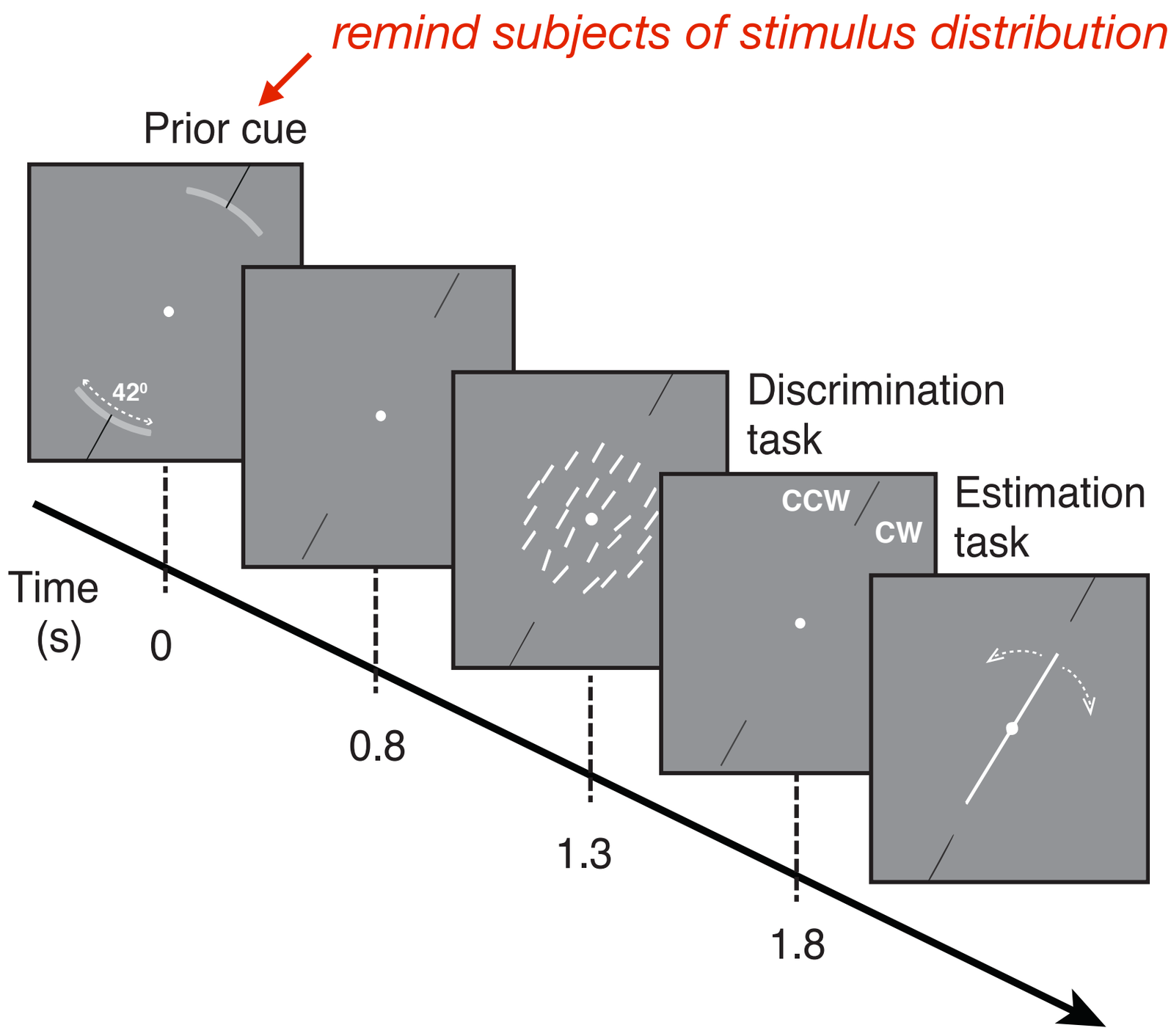


Fit parameter values



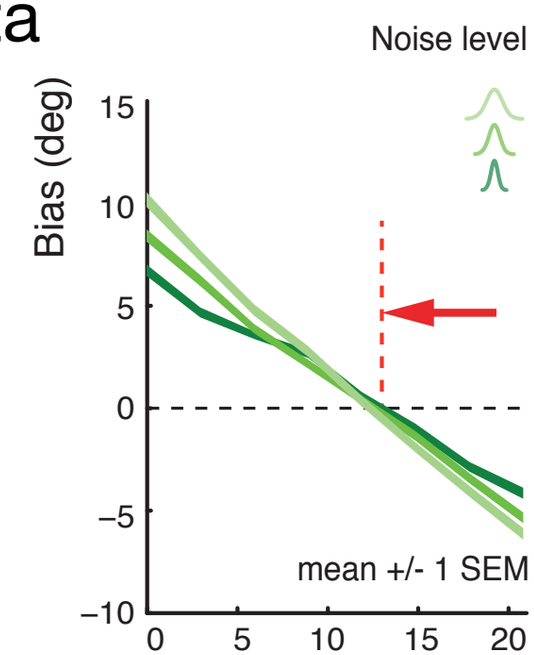


Experiment 2: influence of the stimulus prior

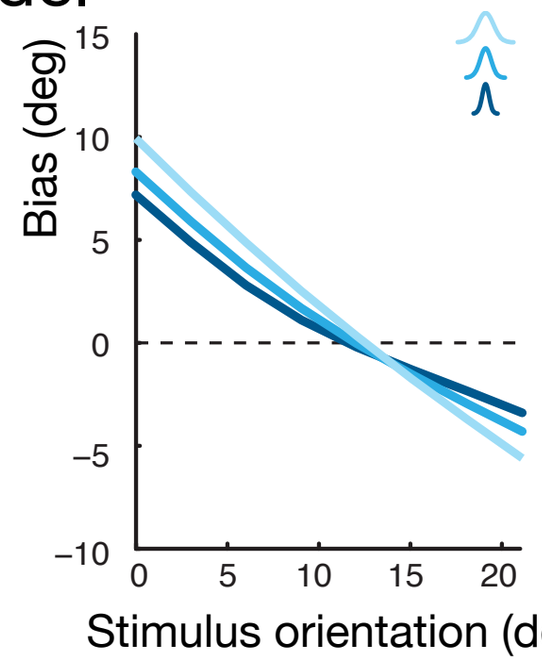


Results

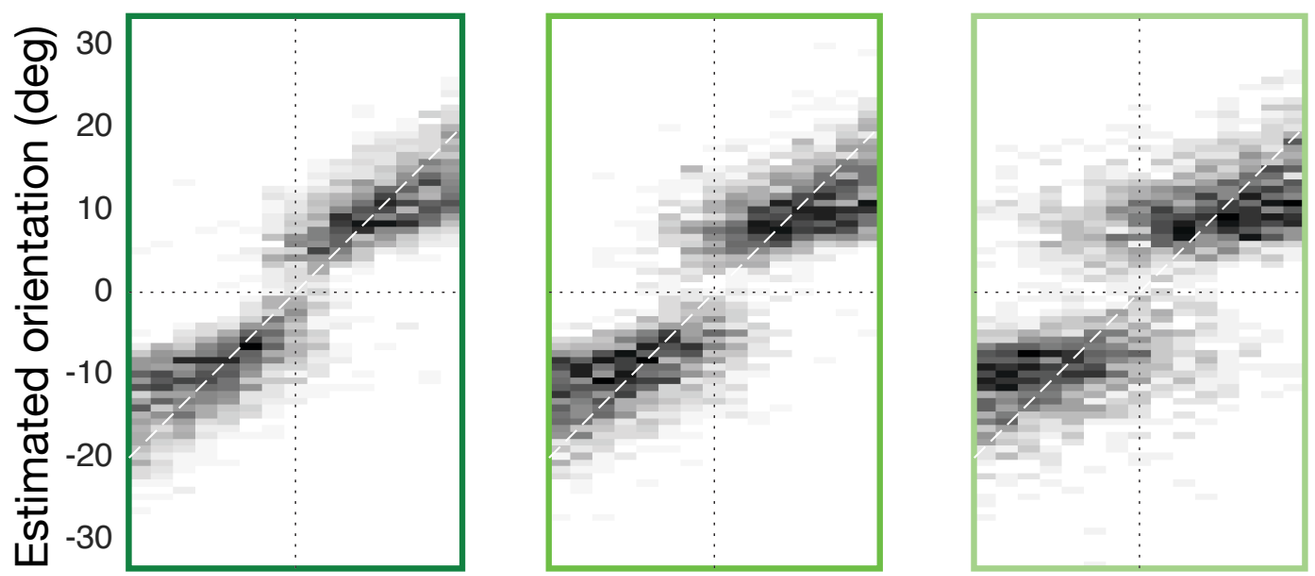
Data

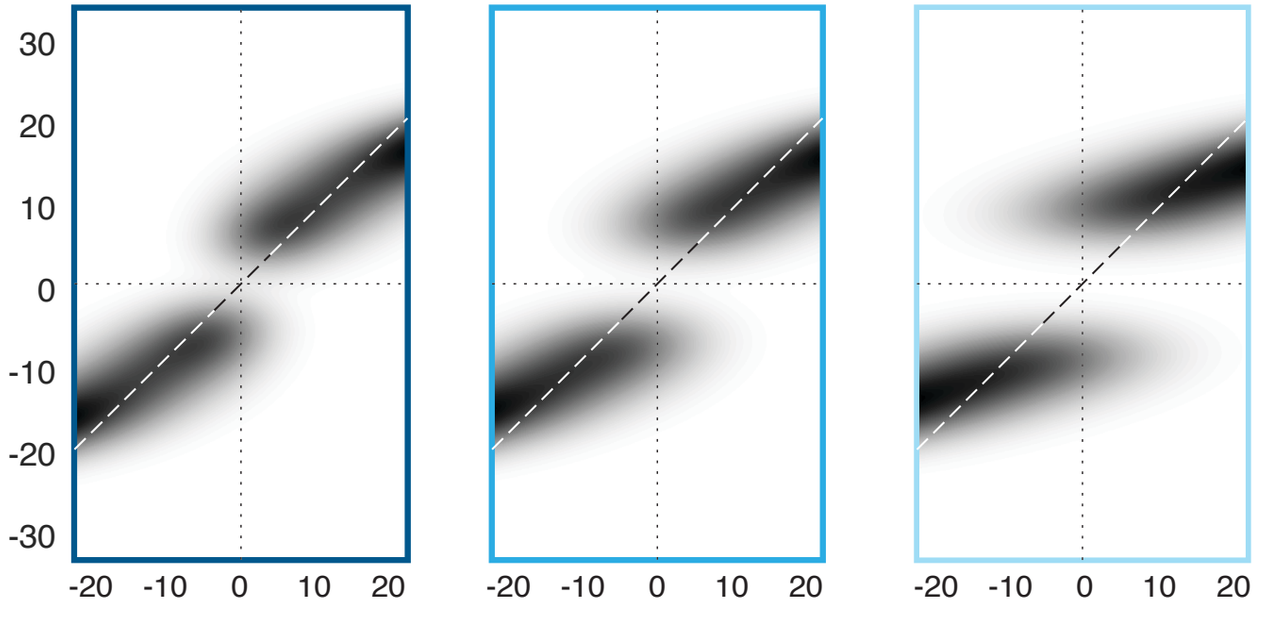


Model

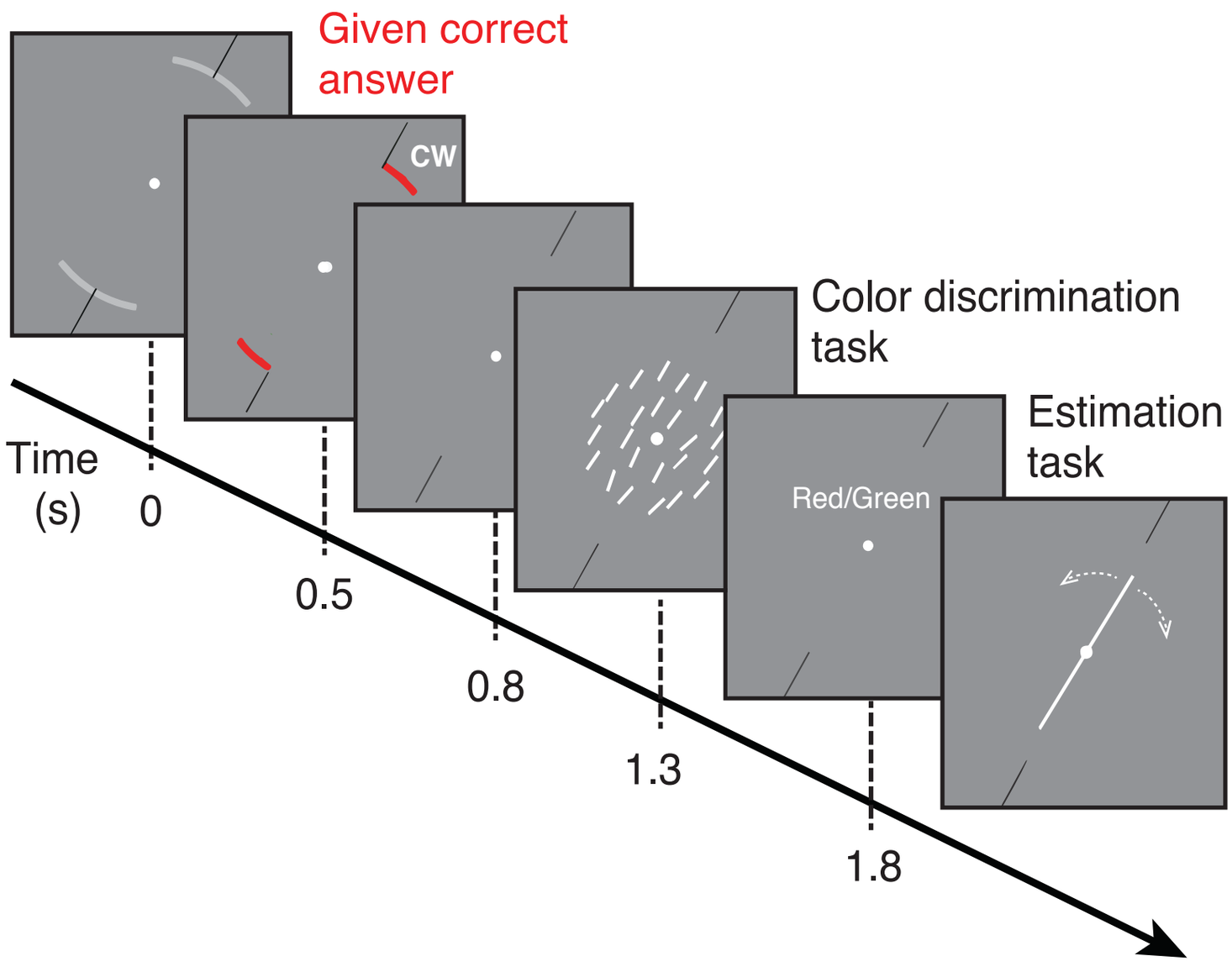


combined subject (N=5)



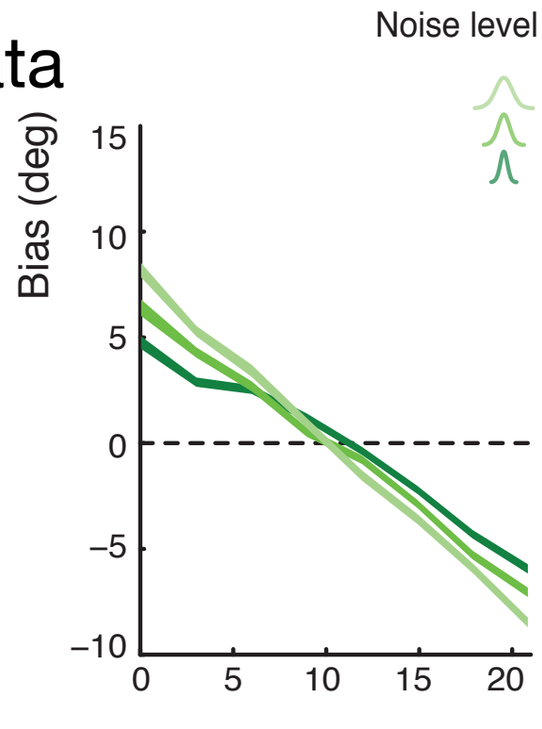


Experiment 3: self-inferred vs. given choice

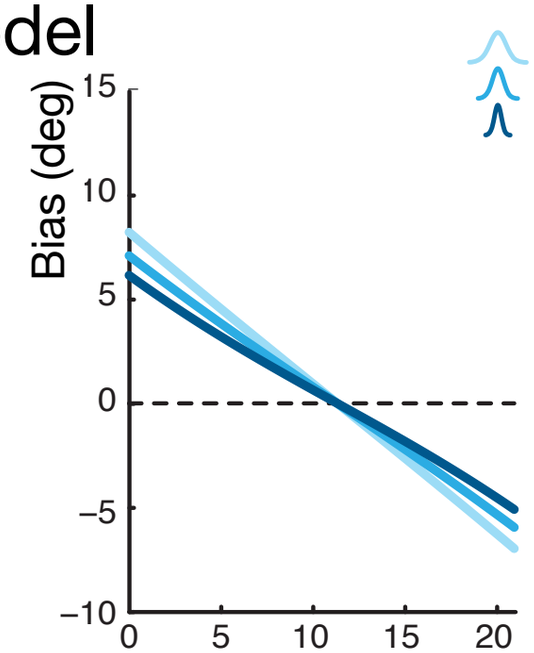


Results

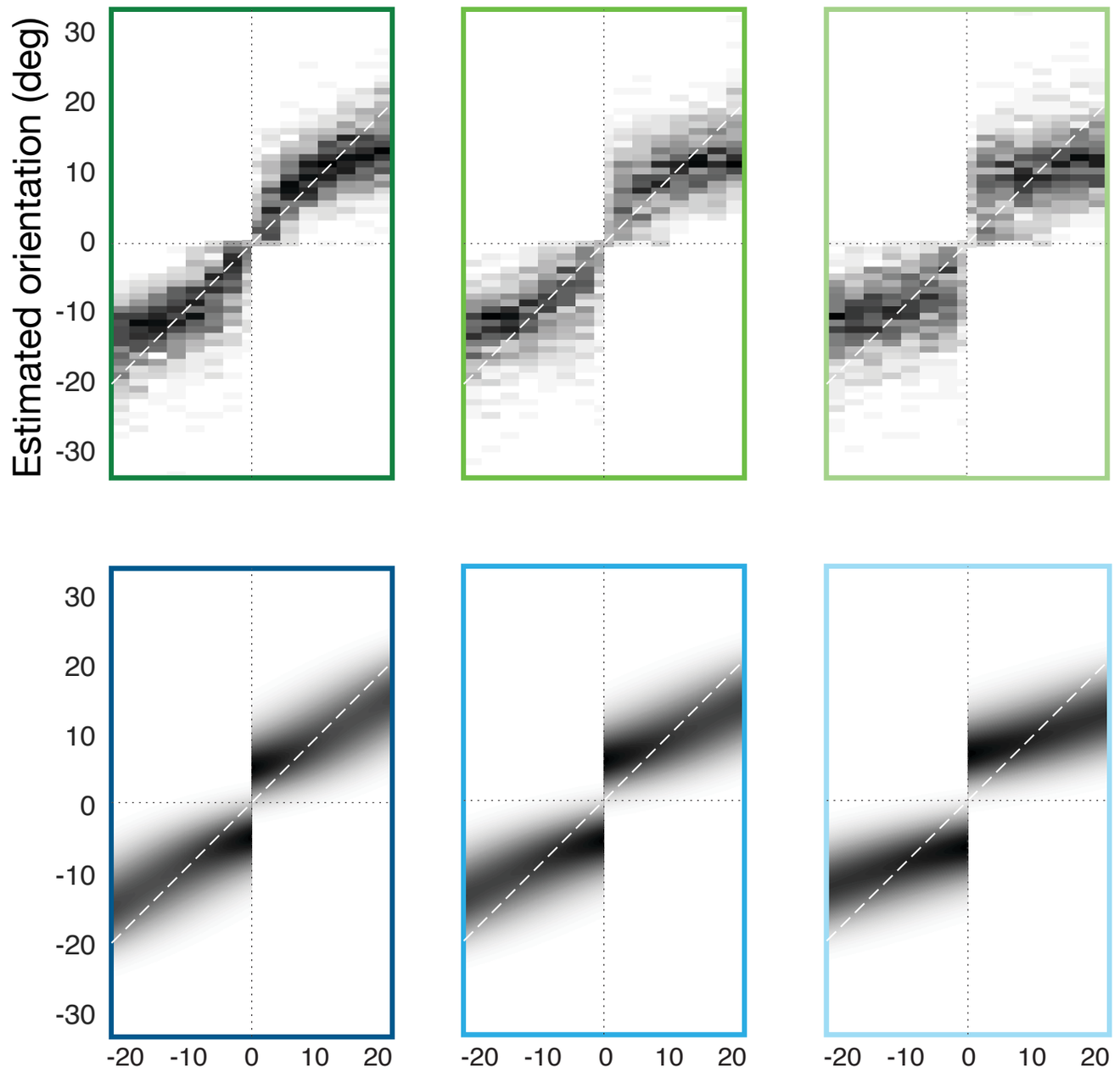
Data



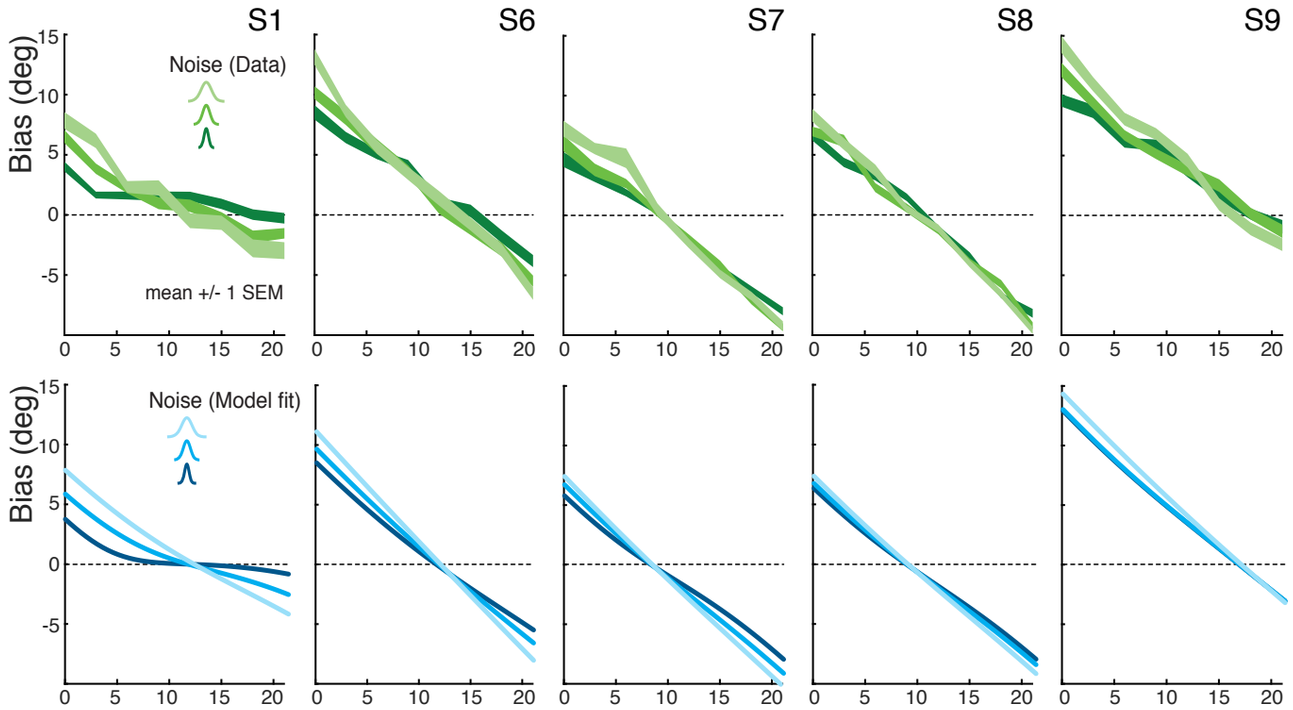
Model



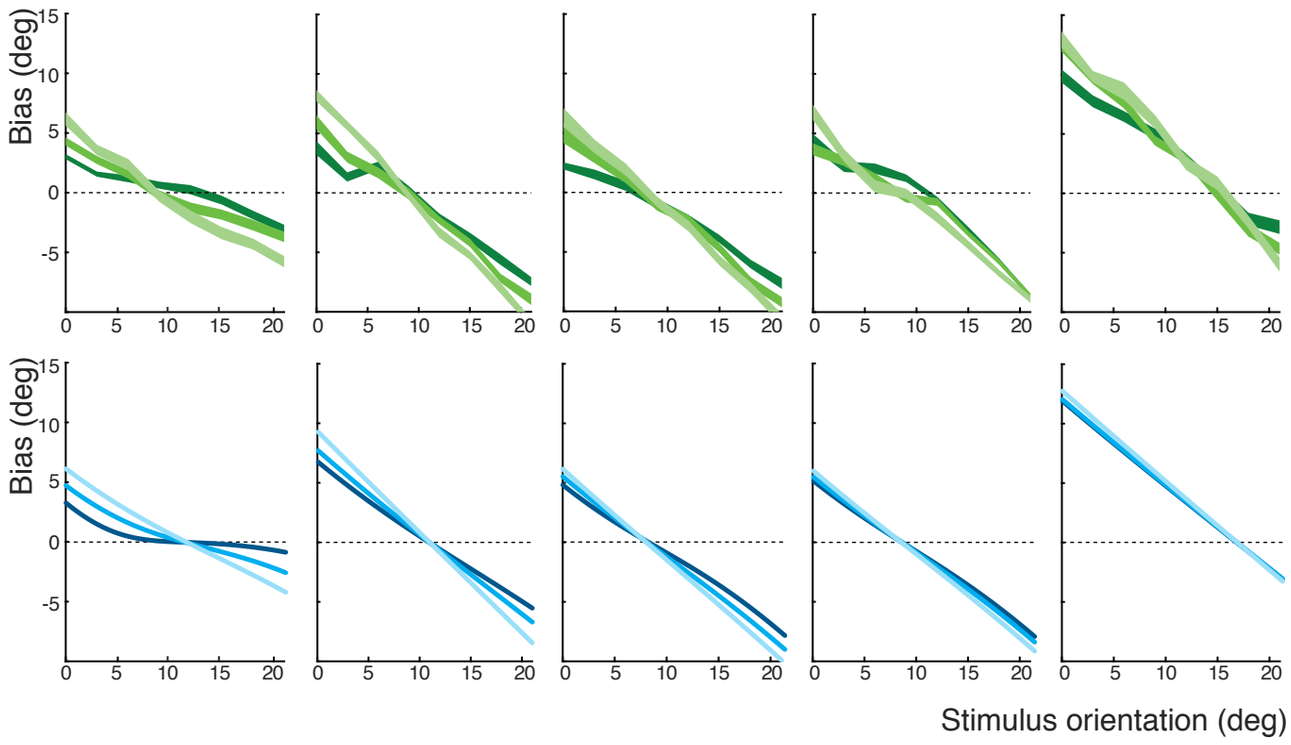
combined subject (N=5)



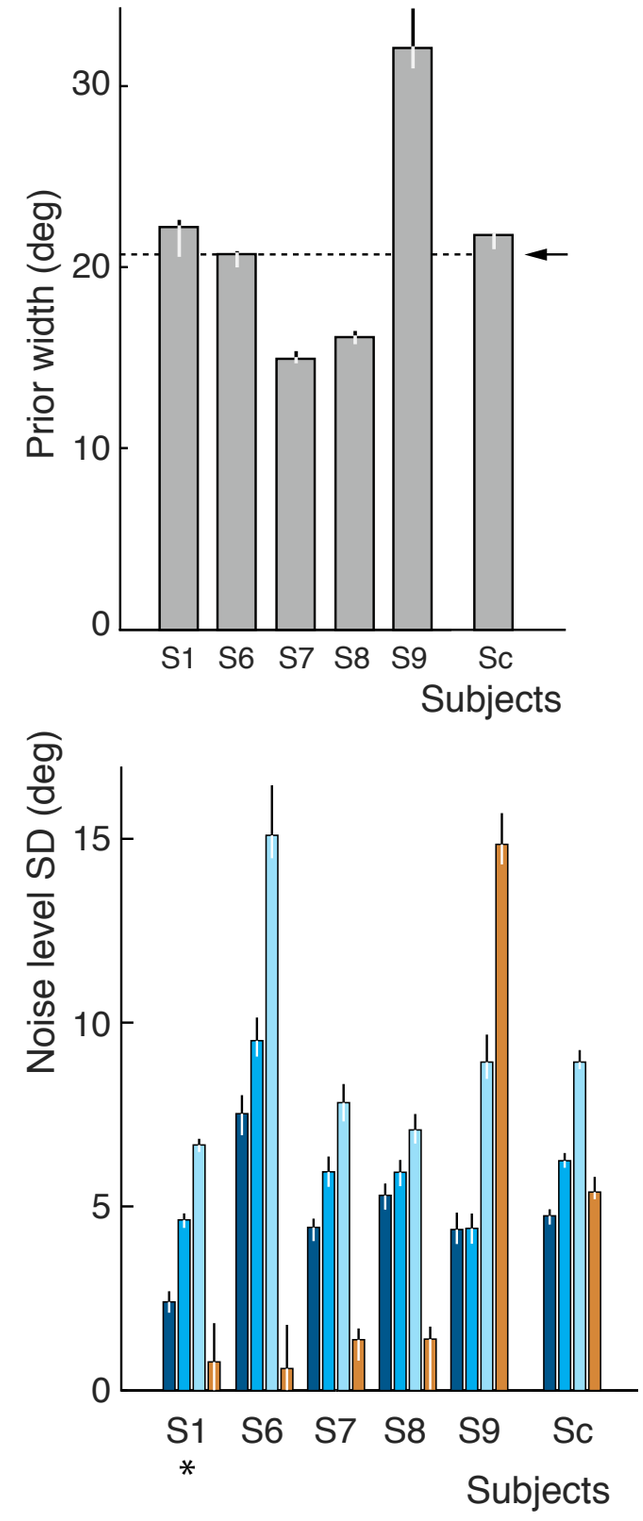
Experiment 2



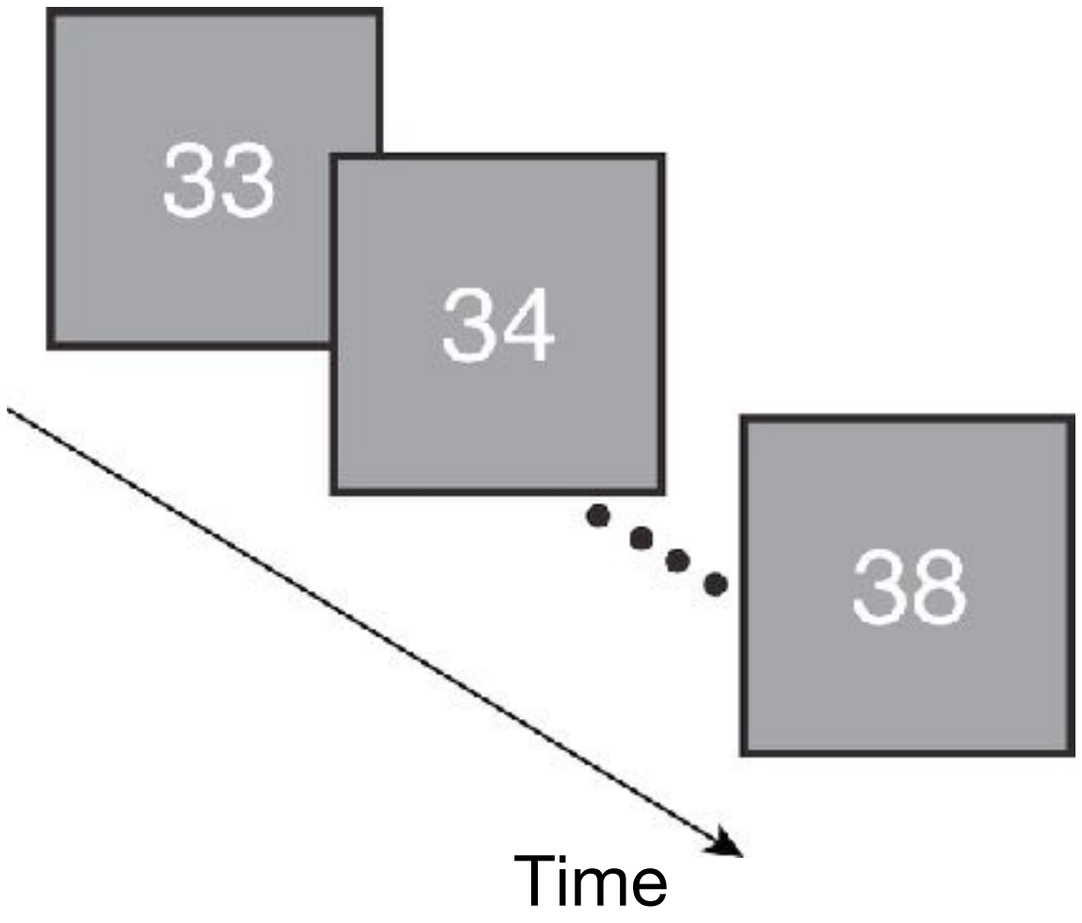
Experiment 3



joint fit (same subjects)



Numerosity (number sense)

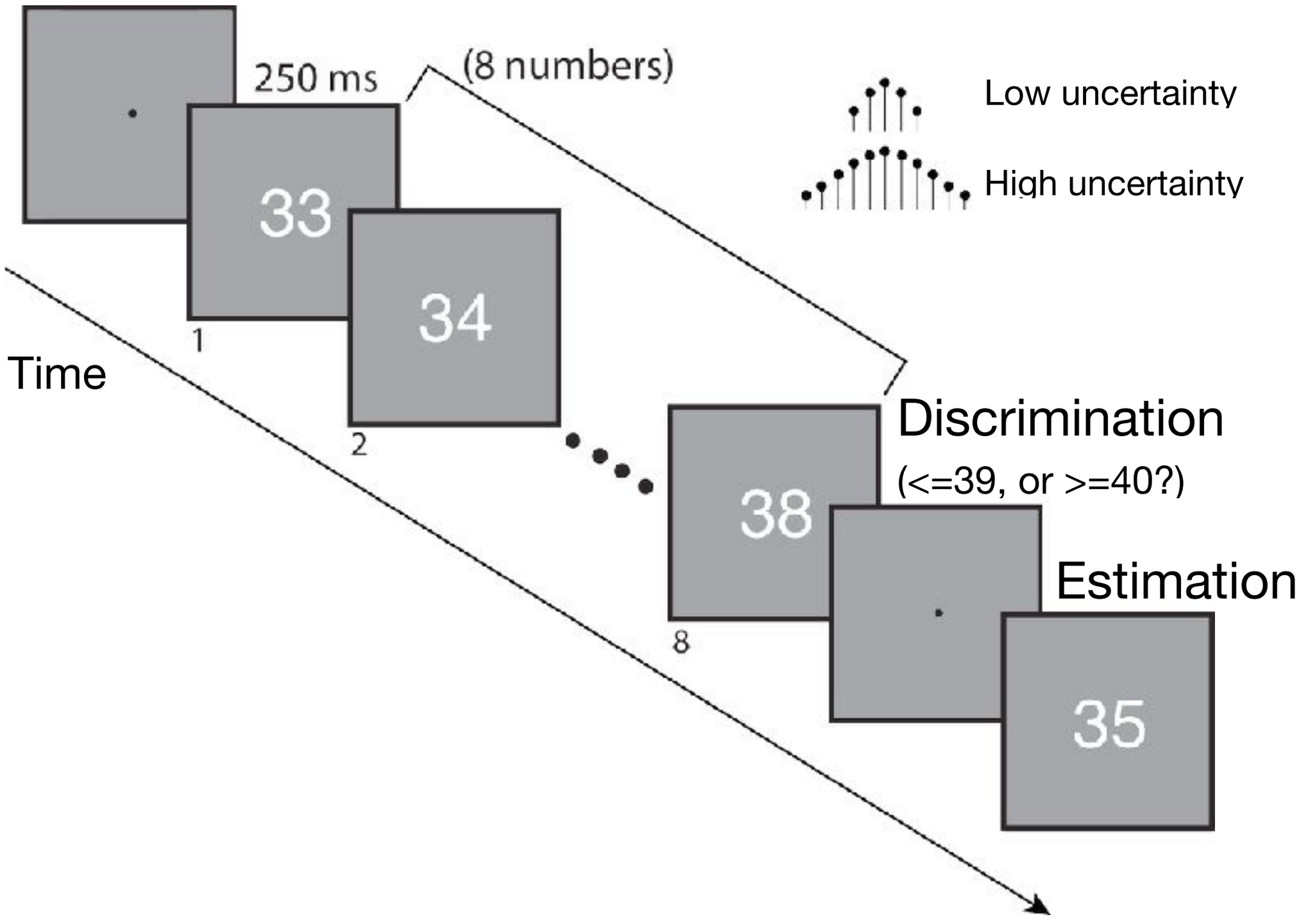


Symbolic representation:

low-level features have minimal influence on numerical percept.

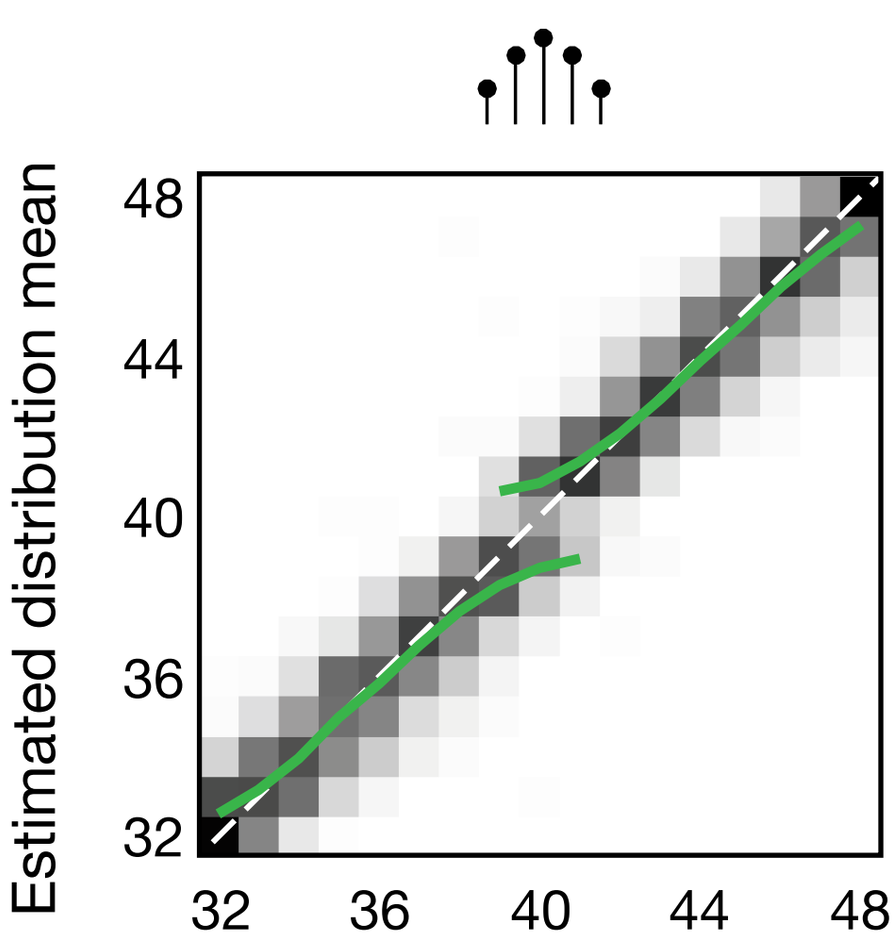
Uncertainty:
external (sampling)

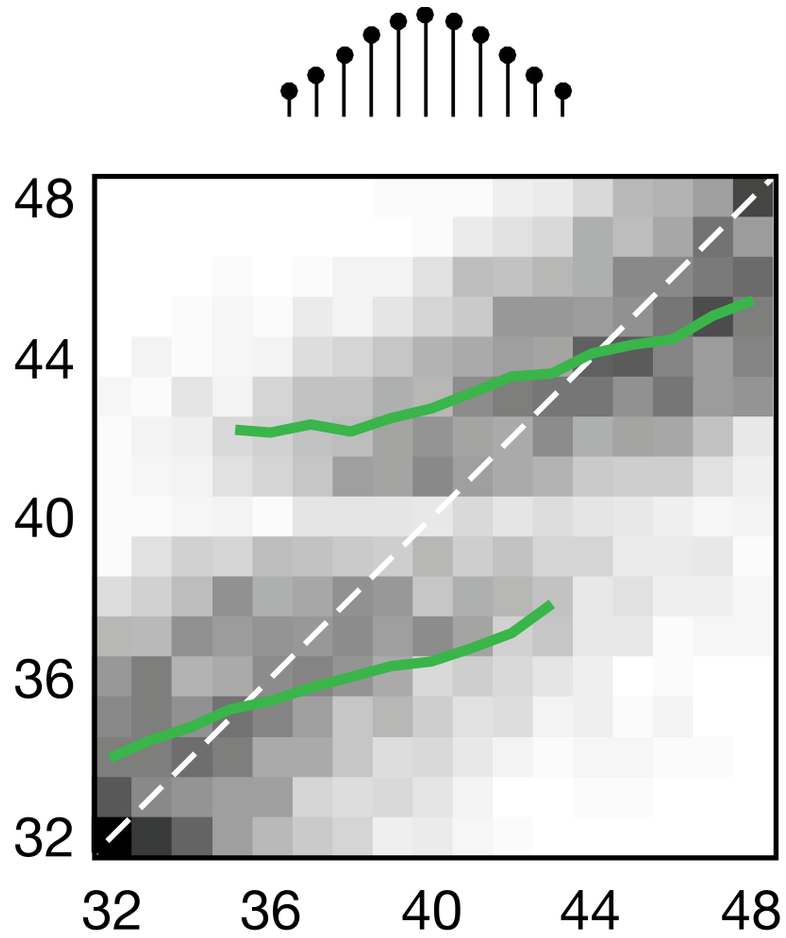
Experiment


250 ms
(8 numbers)
33
34
1
2
38
8
35
Time
Low uncertainty
High uncertainty
Discrimination
(<=39, or >=40?)
Estimation

Choice-induced biases in number stimulus

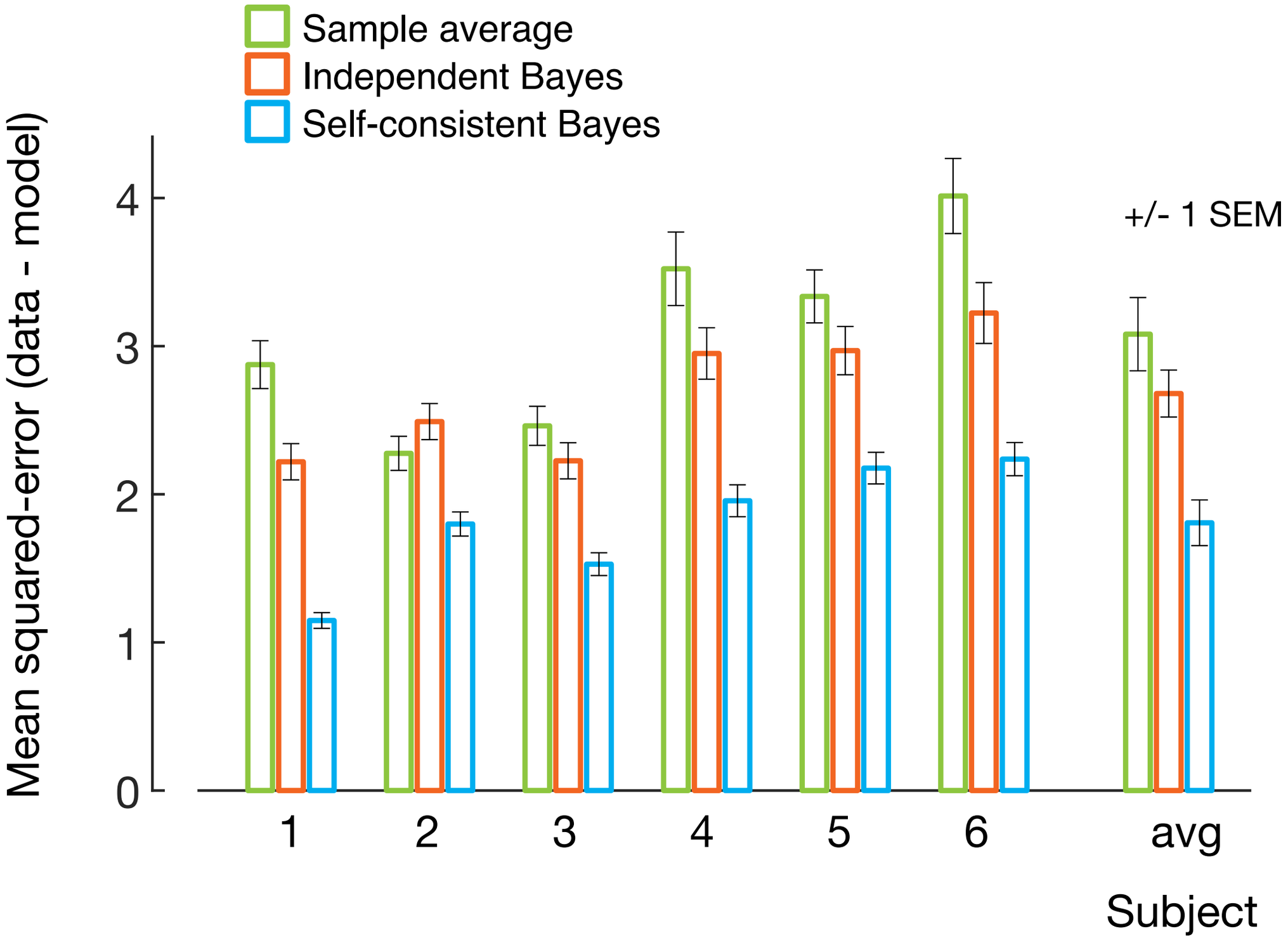
Data (combined subject, N=6)





Trial-by-trial predictions

Prediction errors of the different models



Value-based inference

How attractive
are these kitchen appliances?

Brehm 1956

...

...

Score: 4 6.5 6.5

Discrimination: pick the more attractive item from two possible choices.

Brehm 1956

Score:	4	6.5	6.5

Estimation: re-evaluate the attractiveness

Brehm 1956

Score: ~~4~~ **4** ~~6.5~~ **7.5** ~~6.5~~ **5.5**

Cognitive dissonance

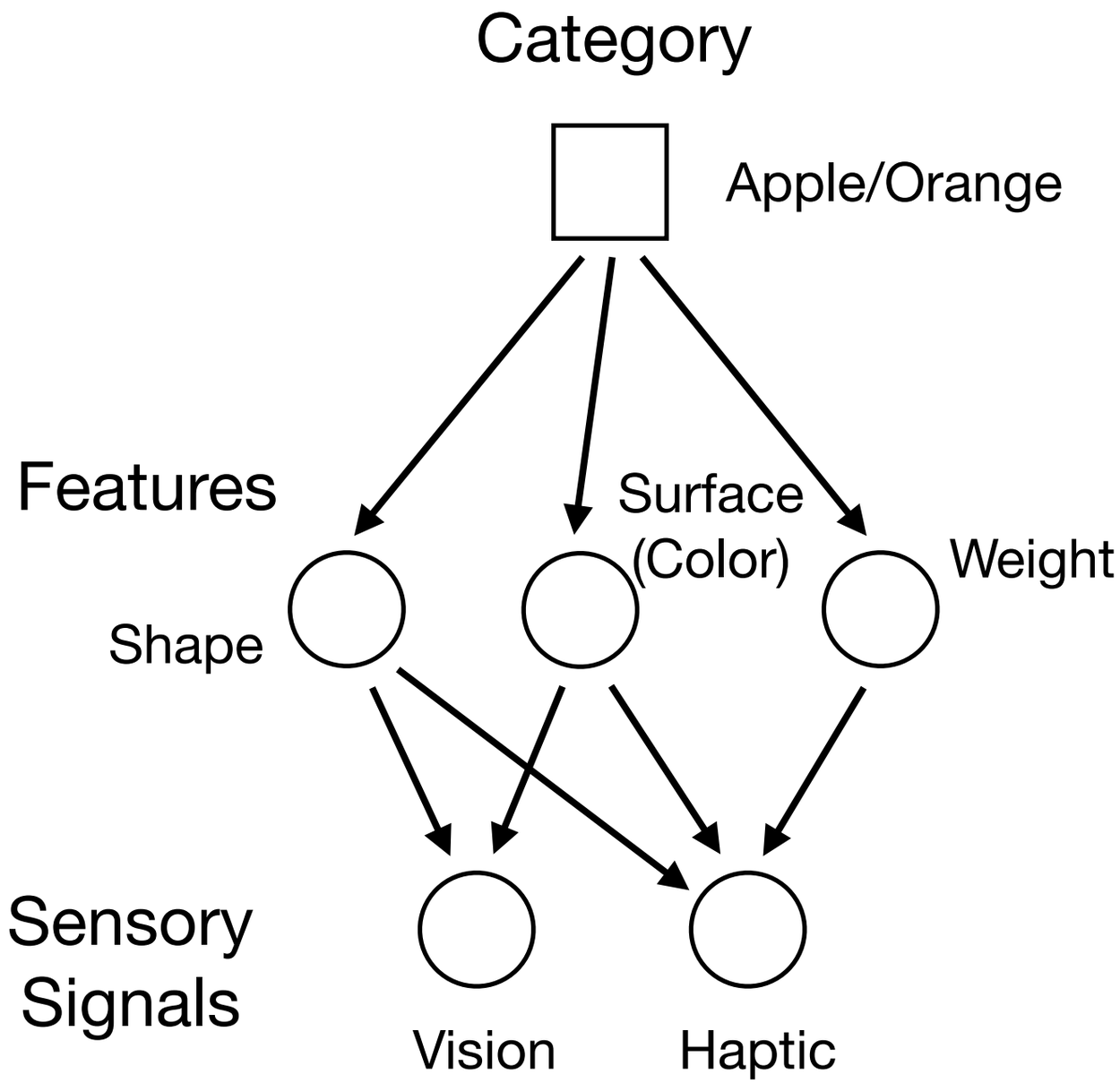
Summary and conclusions

- Humans show choice-induced biases in sequential perceptual inference tasks.
- Self-consistent bayesian observer model
  - full account of data.
  - subjects treat their own decisions as if they were correct.
- General behavior/model (perceptual, cognitive, and value-based inference tasks).

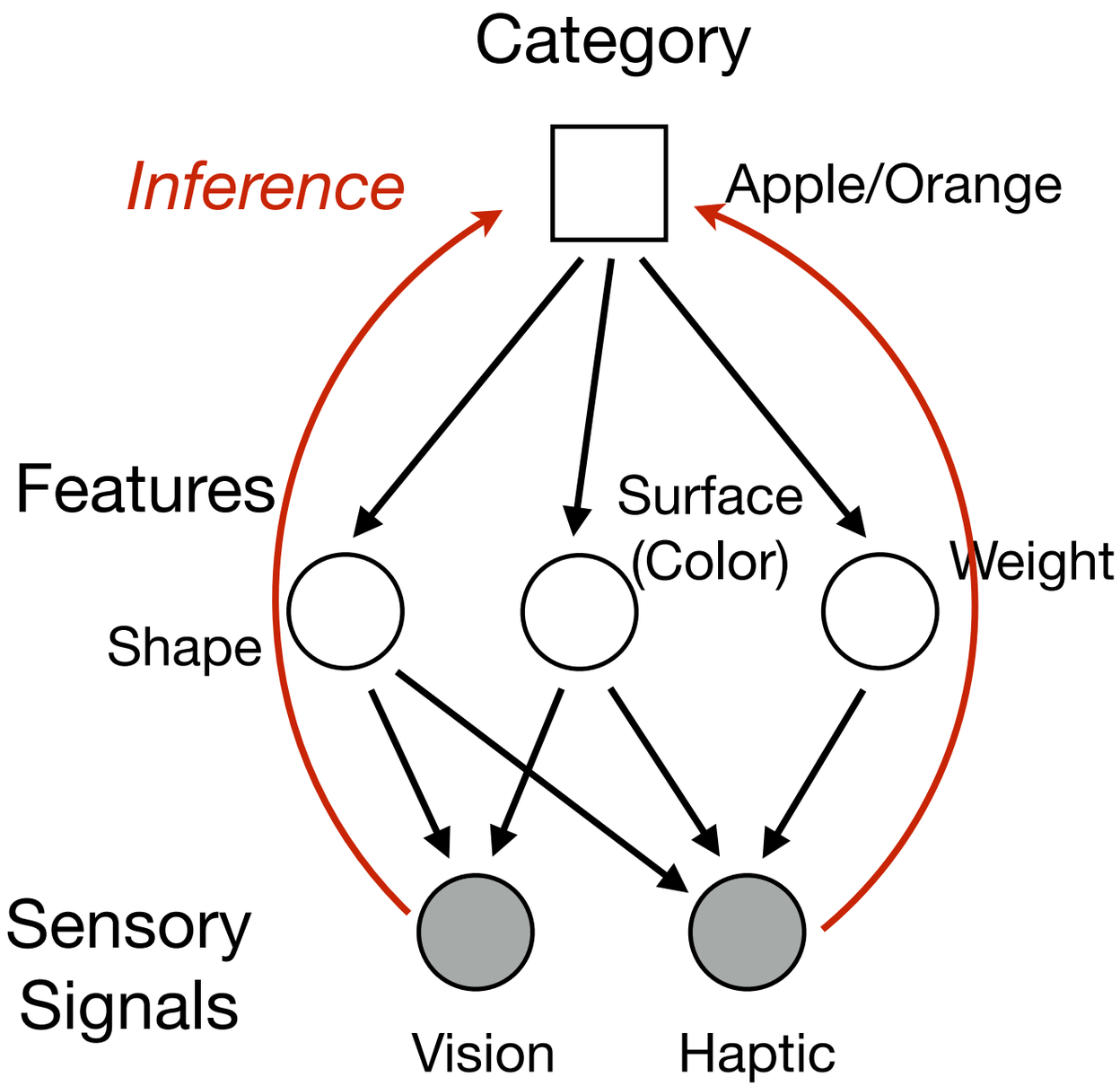
Open questions

- Does self-consistent inference intrinsically happen in perception/cognition or only when forced to commit to an outcome? (e.g. object recognition)

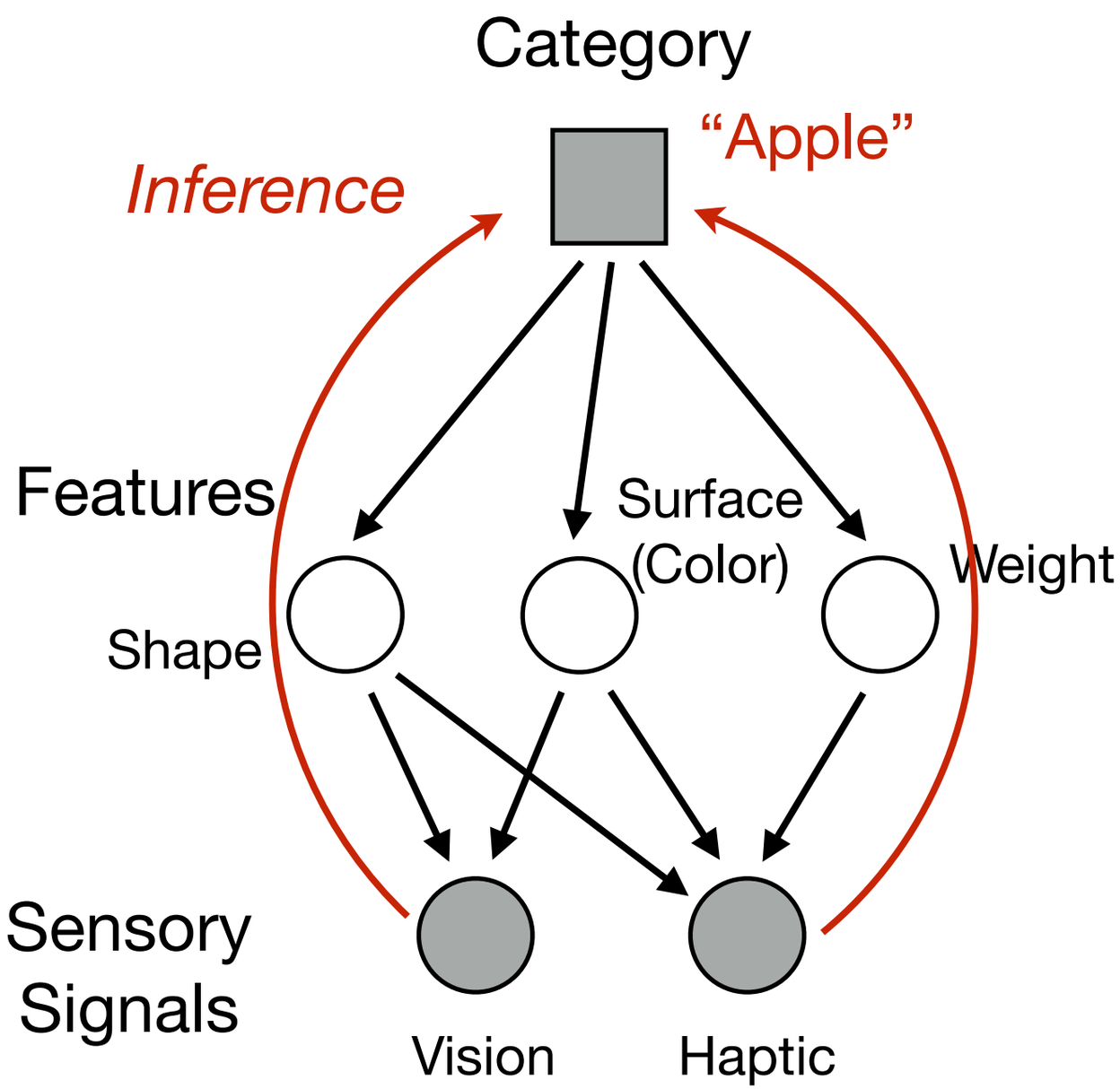
Proposal


Category
Apple/Orange
Features
Surface
(Color)
Weight
Shape
Sensory
Signals
Vision
Haptic

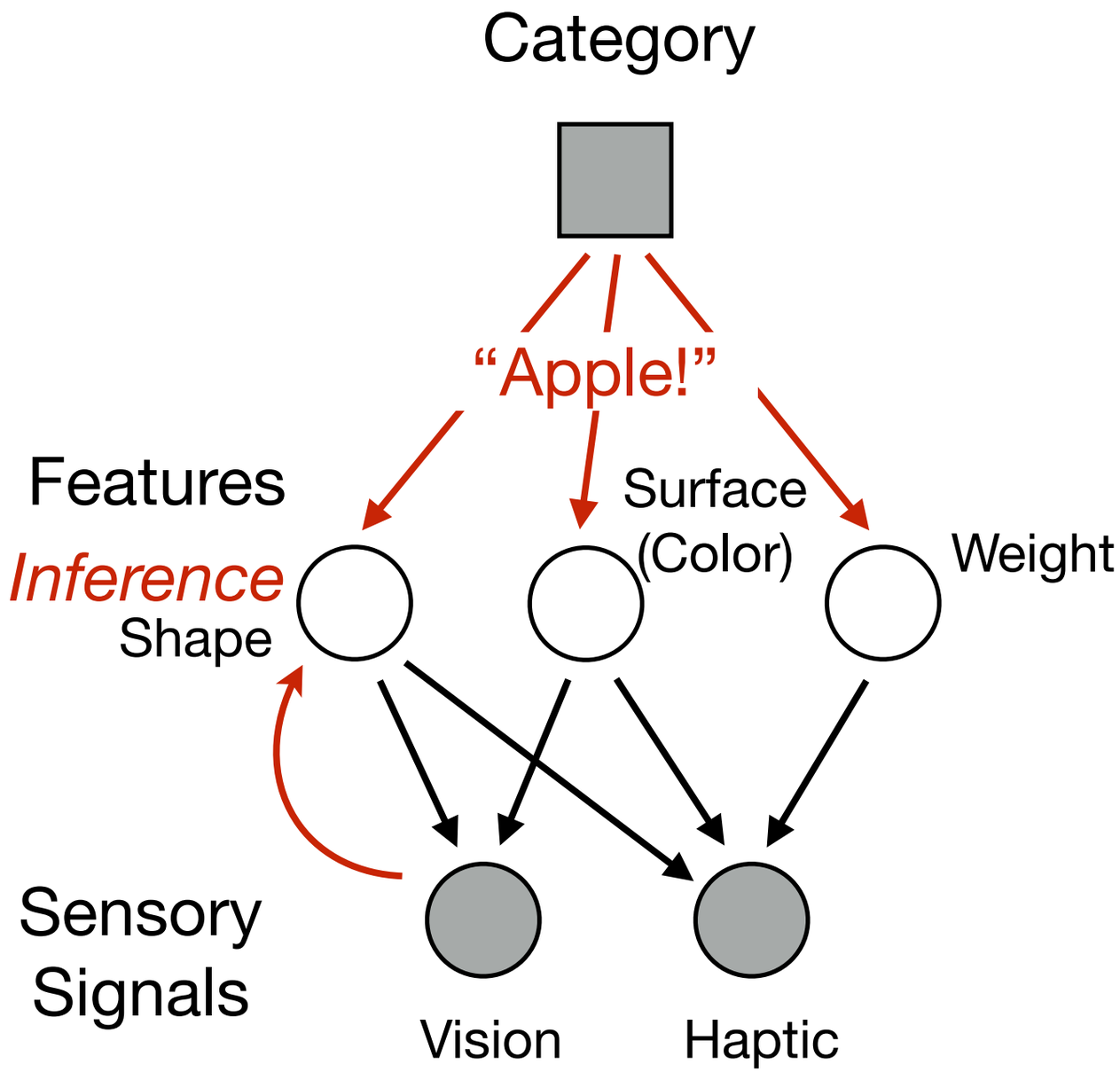
Proposal


Category
Inference
Apple/Orange
Features
Surface
(Color)
Weight
Shape
Sensory
Signals
Vision
Haptic

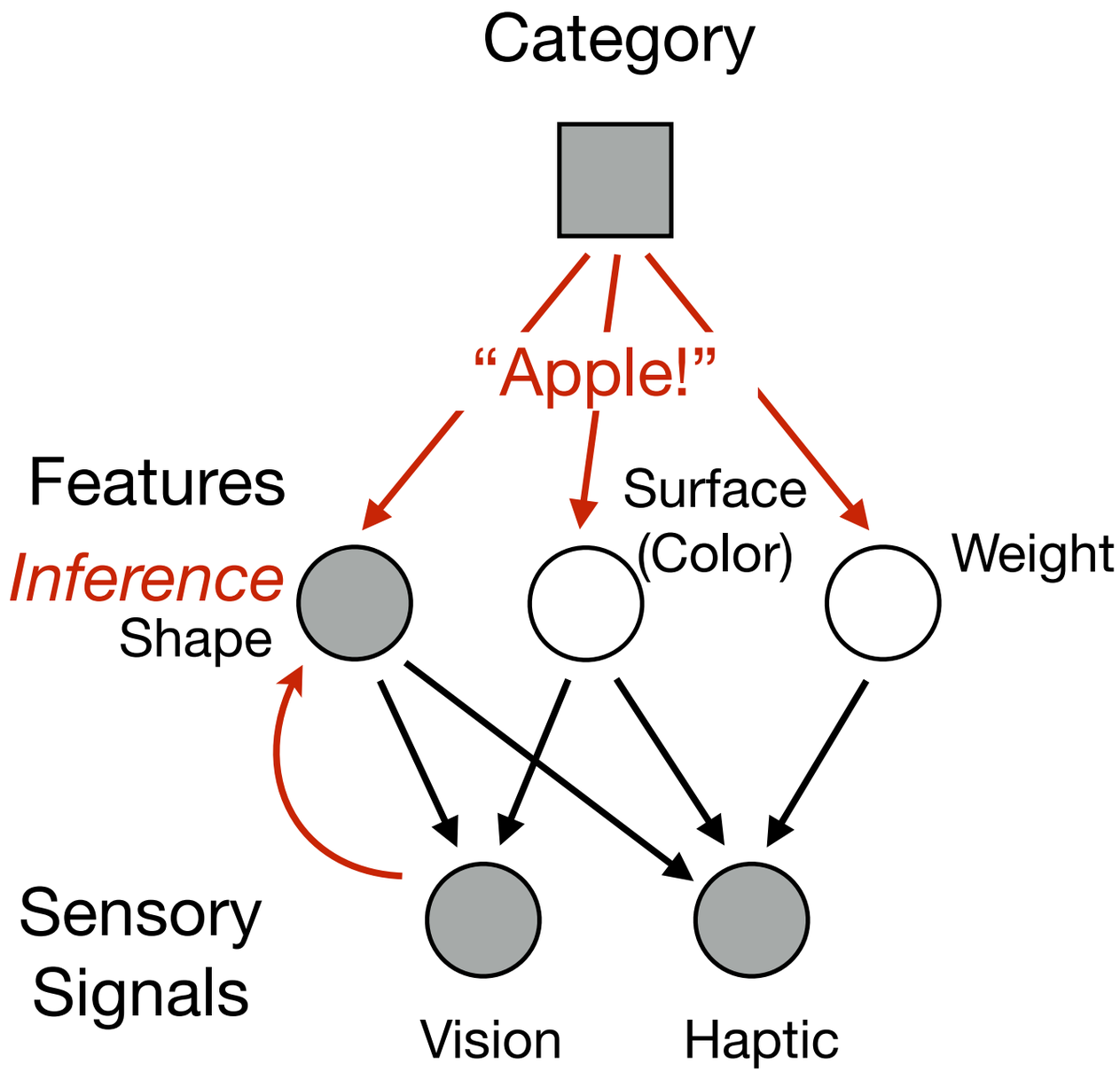
Proposal


Category
“Apple”
Inference
Features
Surface
(Color)
Weight
Shape
Sensory
Signals
Vision
Haptic

Proposal


Category
"Apple!"
Features
Surface
(Color)
Weight
Inference
Shape
Sensory
Signals
Vision
Haptic

Proposal

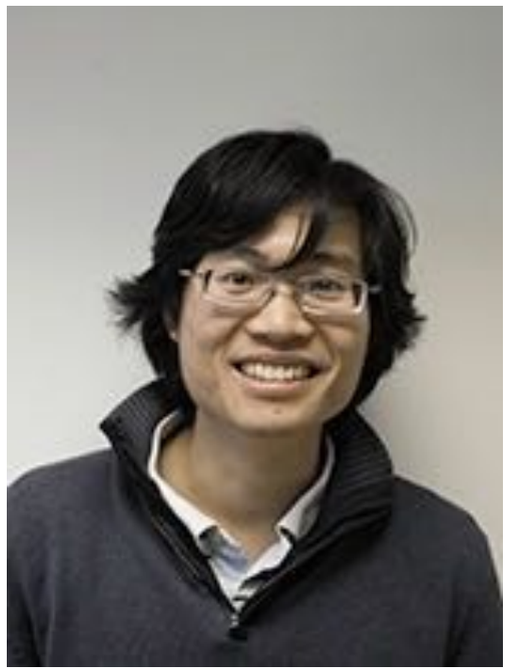

Category
“Apple!”
Features
Surface
(Color)
Weight
Inference
Shape
Sensory
Signals
Vision
Haptic

Open questions

- Does self-consistent inference intrinsically happen in perception/cognition or only when forced to commit to an outcome? (e.g. object recognition)
- Self-consistent inference is sub-optimal behavior (in terms of plain performance): can we find a quantitative formulation for its rationality?
- Are reported decision-feedback signals in the brain there to ensure self-consistency? Nienborg/Cumming 2009, Siegel et al 2015

thank you and …

Long Luu



5th year graduate student, UPenn