‘Bayesian’ theories of perception, cognition and mental illness (part 2 - CCN Lecture 15)

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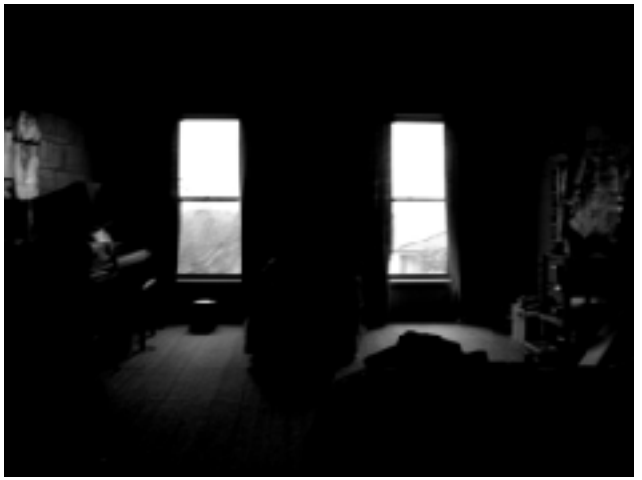
1) Do People behave as Bayesian Observers?

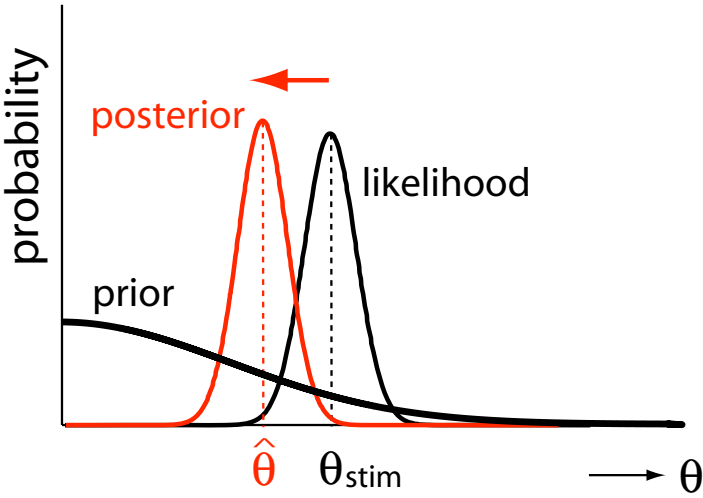
a) Do brains take into account measurement uncertainty when combining different (simultaneous) information? Combine different sources optimally?

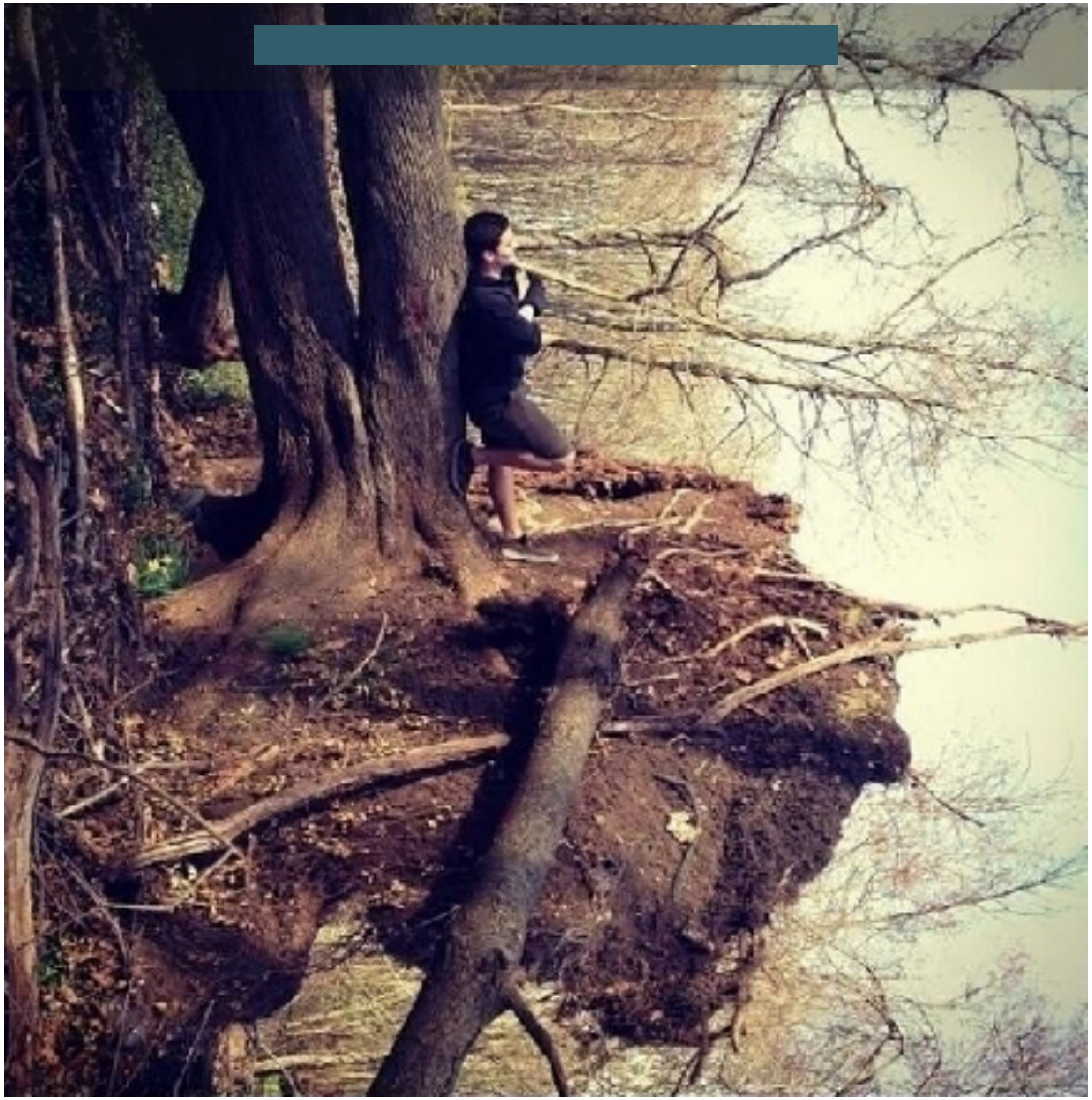
b) **Do brains form a representation of the past statistics of the environment (priors) and combine it optimally with current information?**

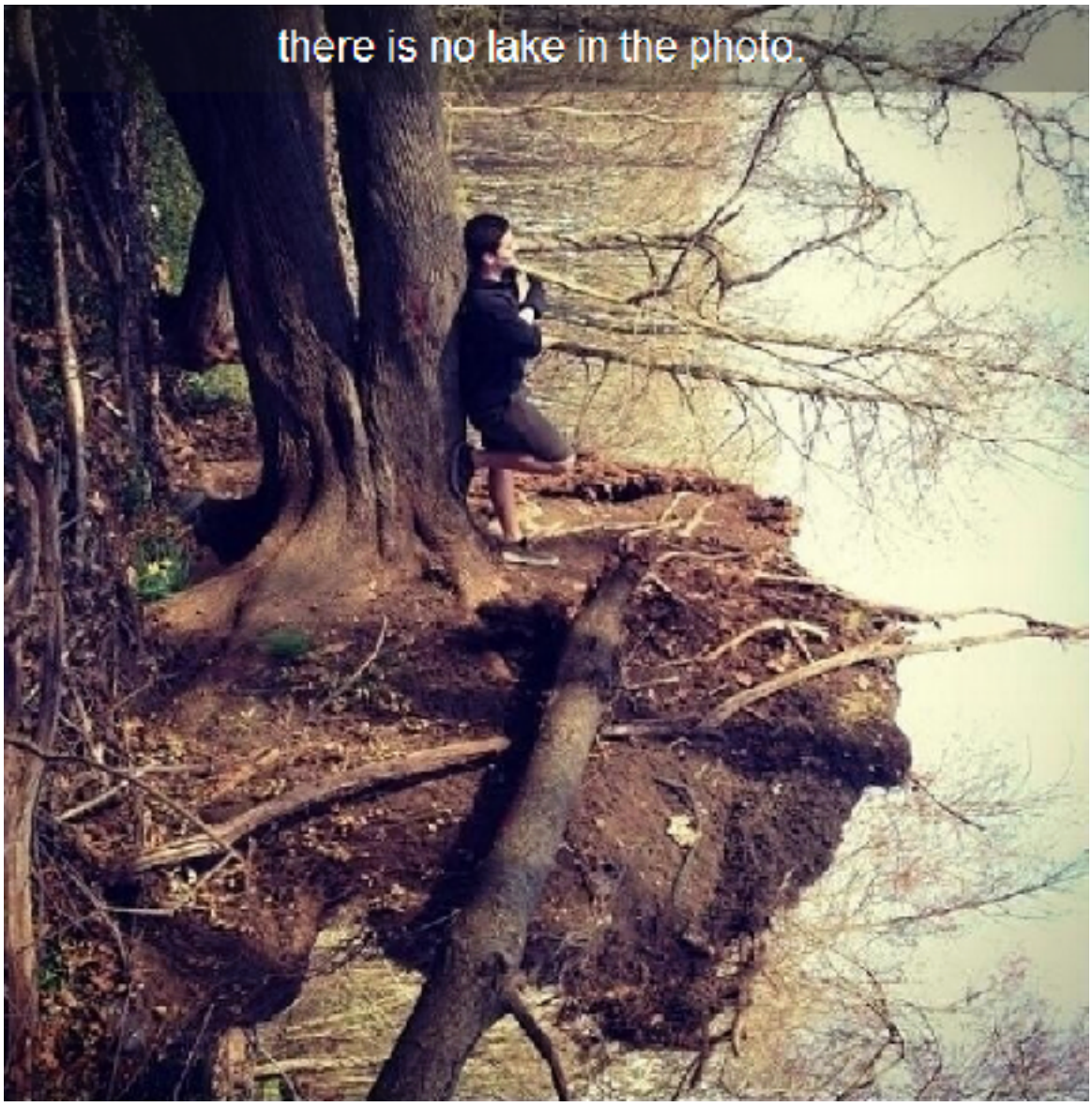
A Bayesian theory of the Brain: Priors

- How is the brain making use of previous knowledge? what priors?
- Prediction 1: the more uncertain the data, the more prior information should influence the interpretation.
- Prediction 2: The priors should reflect the statistics of the sensory world (on which time-scale?).



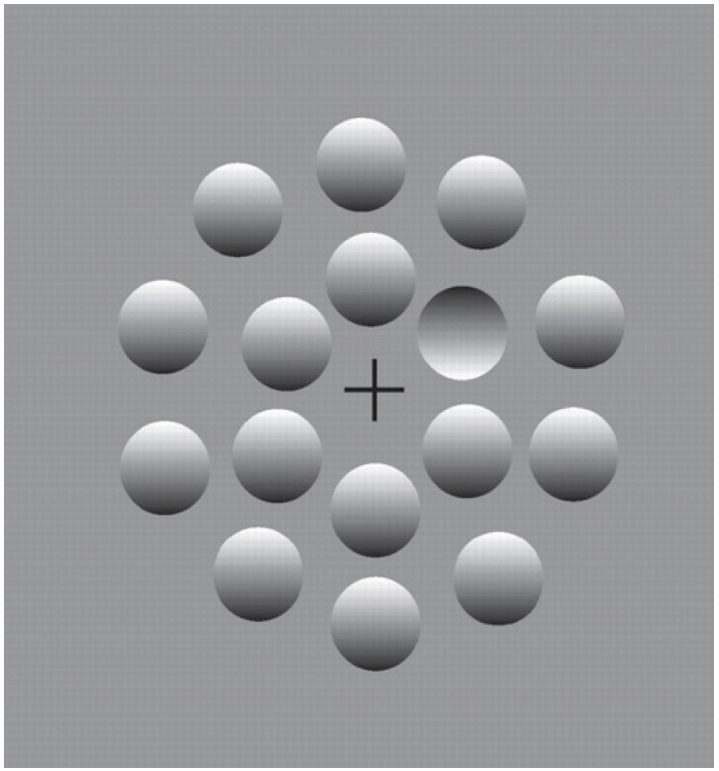





there is no lake in the photo.

Long-term “structural” priors

Visual illusions : insight into what sort of assumptions the visual system makes.



- Light comes from above
- Cardinal orientations are more frequent [Gershick et al 2011]
- smoothness [Geisler et al 2001]
- symmetry [Knill 2007]
- Objects don’t move or only slowly

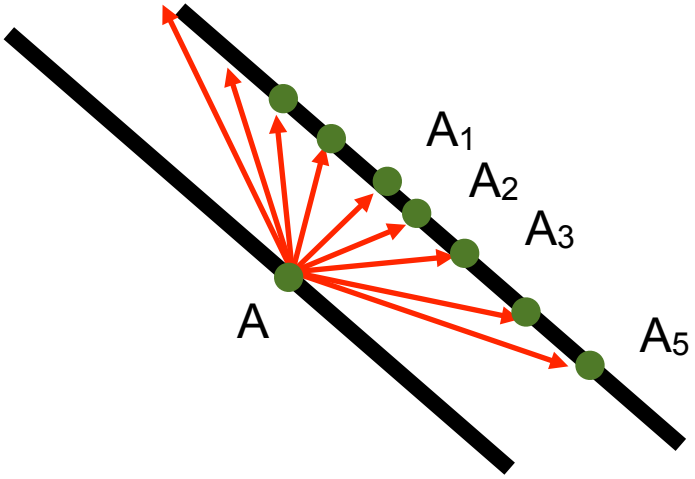
[Weiss et al 2001; stocker & Simoncelli 2006]

... recently formalized in Bayesian terms

[T. Adelson, E. Simoncelli, O. Schwartz, Y. Weiss]

Interpreting motion : A Prior on Low Speeds (1)

- Motion shown in an aperture is fundamentally ambiguous; it can be interpreted in an infinite number of ways
- which one is chosen? why?



Interpreting motion : A Prior on Low Speeds (2)

- Hypothesis: humans tend to favour slower motions
- Use a (gaussian) prior on low speeds (centred at 0).
- Explain great variety of data -- elegant unifying explanation

articles

Motion illusions as optimal percepts

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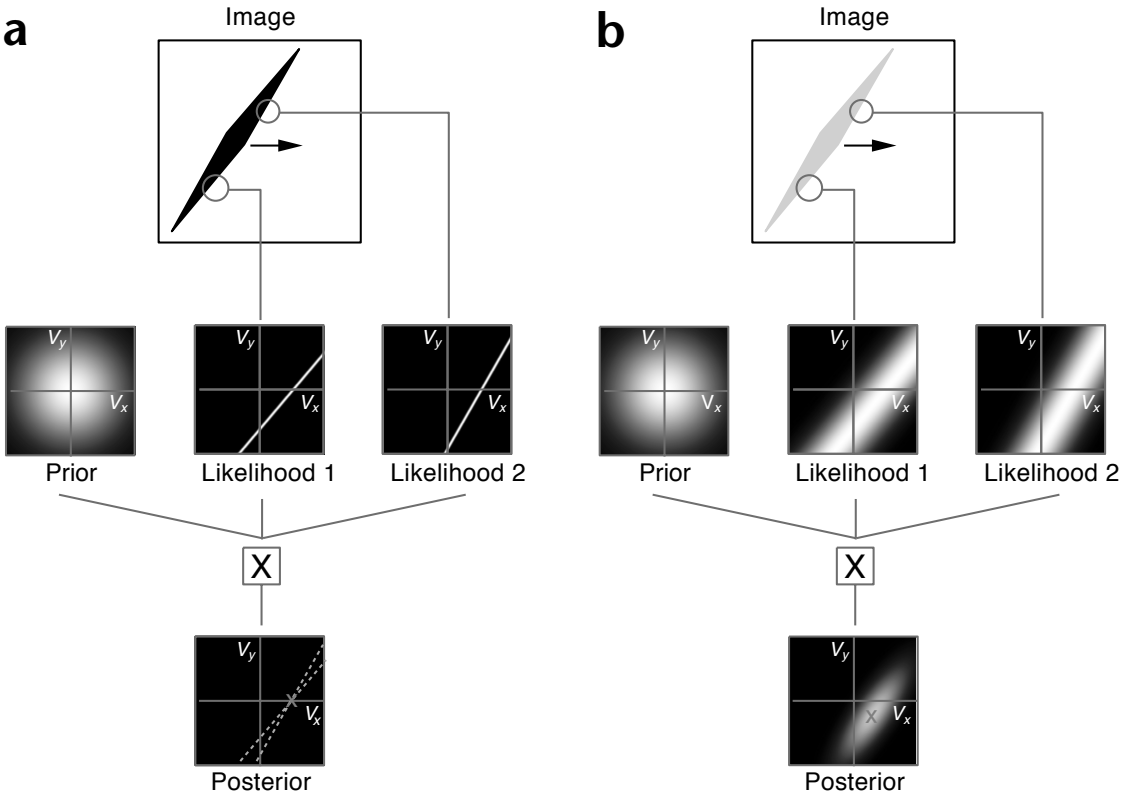
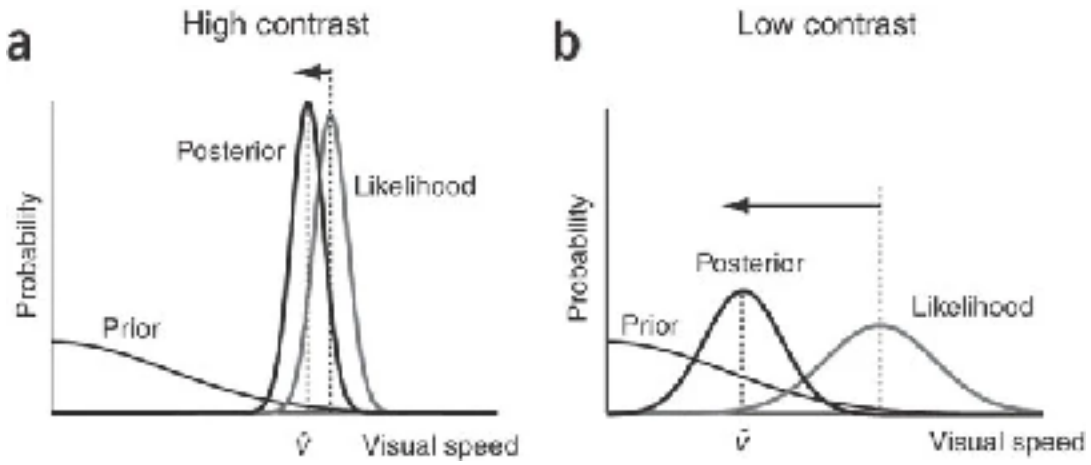
The pattern of local image velocities on the retina encodes important environmental information. Although humans are generally able to extract this information, they can easily be deceived into seeing incorrect velocities. We show that these 'illusions' arise naturally in a system that attempts to estimate local image velocity. We formulated a model of visual motion perception using standard estimation theory, under the assumptions that (i) there is noise in the initial measurements and (ii) slower motions are more likely to occur than faster ones. We found that specific instantiation of such a velocity estimator can account for a wide variety of psychophysical phenomena.

Weiss, Adelson & Simoncelli, *Nat Neuro*, 2002

http://www.cs.huji.ac.il/~yweiss/Rhombus/rhombus.html



Interpreting motion : A Prior on Low Speeds (1)



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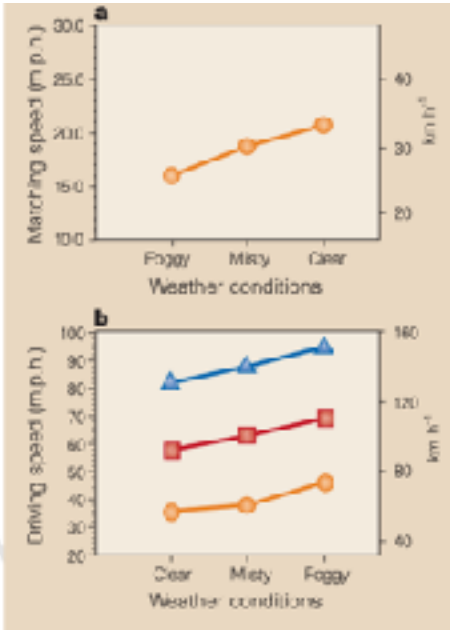
Speed perception fogs up as visibility drops

Many horrendous vehicle accidents occur in foggy weather. Drivers know they should slow down because fog reduces visibility, but many still drive too quickly[1]. The 'blame' for many such accidents may be due to a perceptual quirk: it appears that drivers think they are driving far more slowly than they actually are in foggy conditions, and therefore increase their speed.

We used a virtual-environment driving

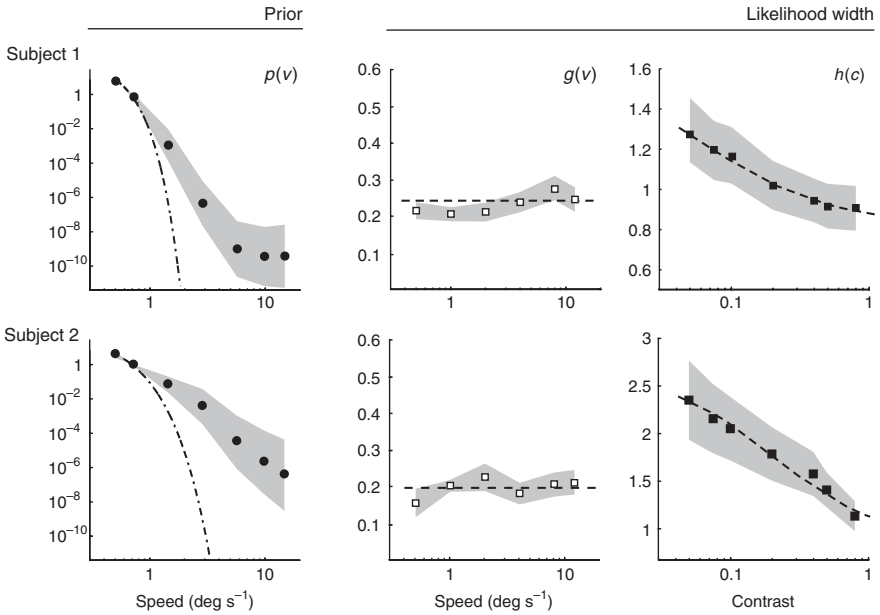


- The brain expects speed to be 0 or slow.
- Prior on low speed will influence the estimation of speed, mostly at very low contrast.
- This is proposed to be the explanation why drivers might misestimate their speed in the fog.

Can we measure people's prior experimentally?

- We can reverse engineer the shape of the prior from people's perceptual data
- Speed discrimination task at different contrast levels -- measure both bias and variability + fit Bayesian model --> recover speed prior and likelihood in individuals

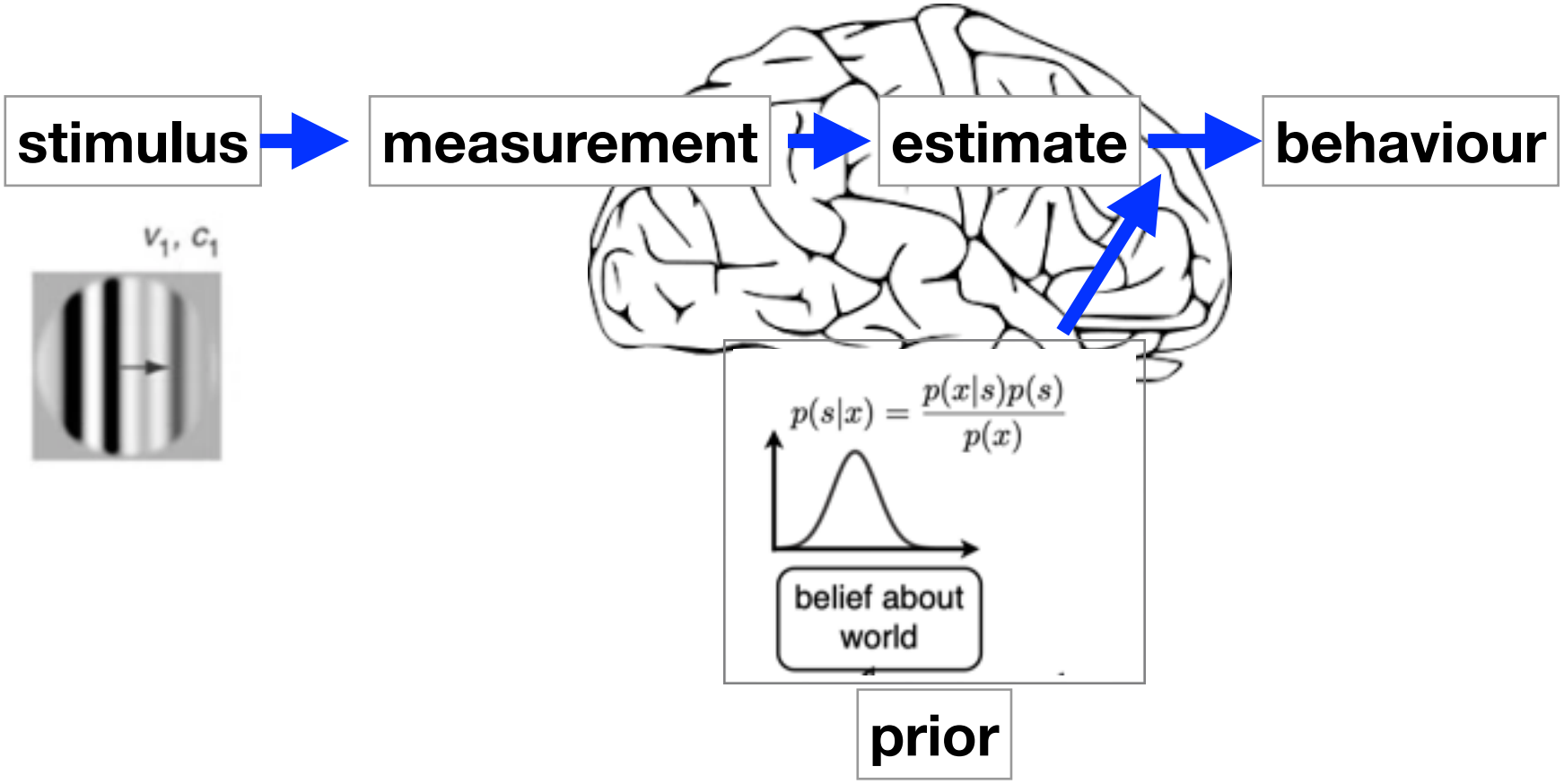
- reveals inter-individual variability in the prior different people use
- Speed prior not Gaussian



Stocker & Simoncelli, Nat Neuro, 2006

A way to discover people's beliefs?

- Reverse engineering Bayesian models as a way to discover people's priors/ beliefs/expectations and measure then quantitatively



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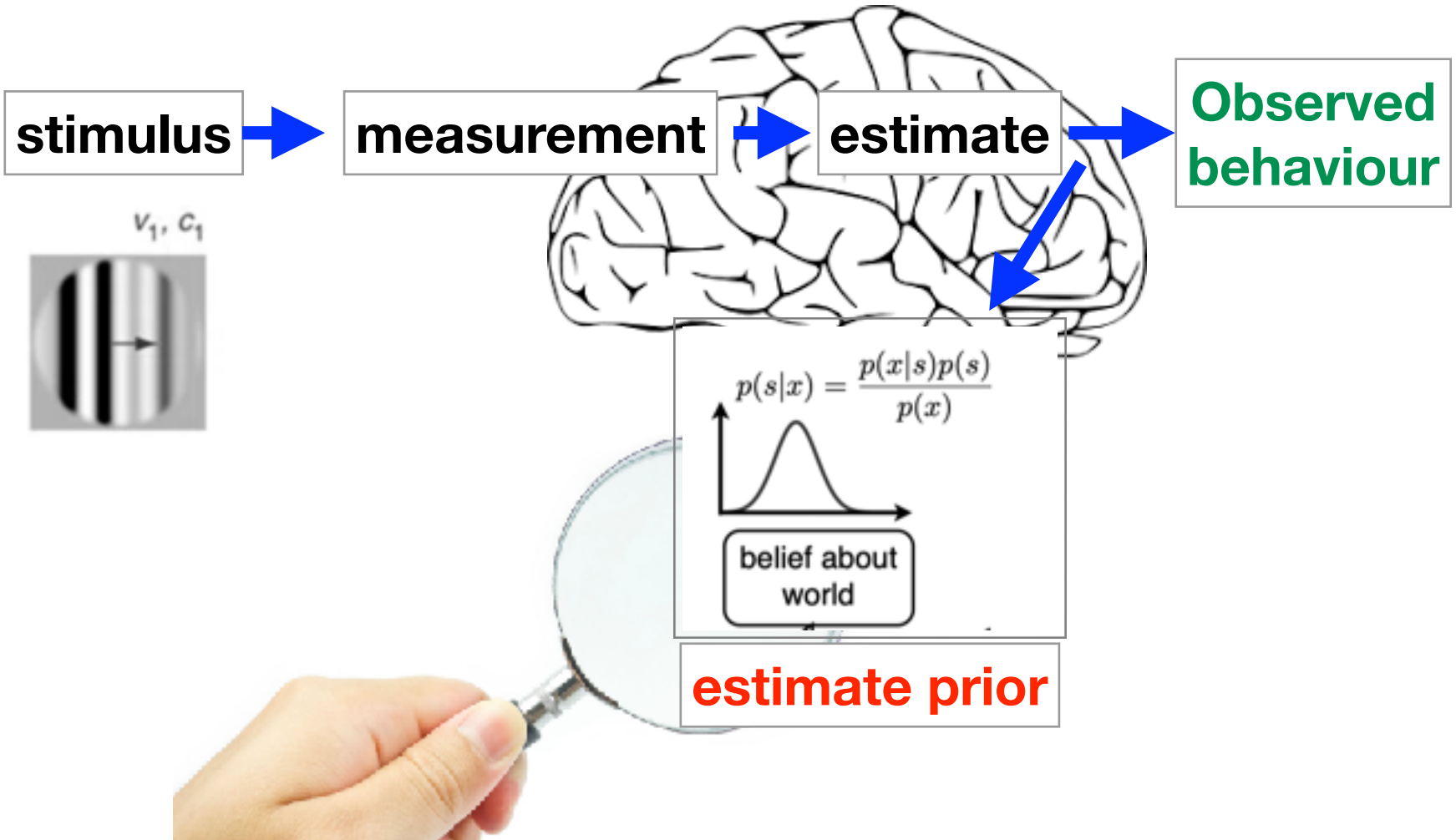
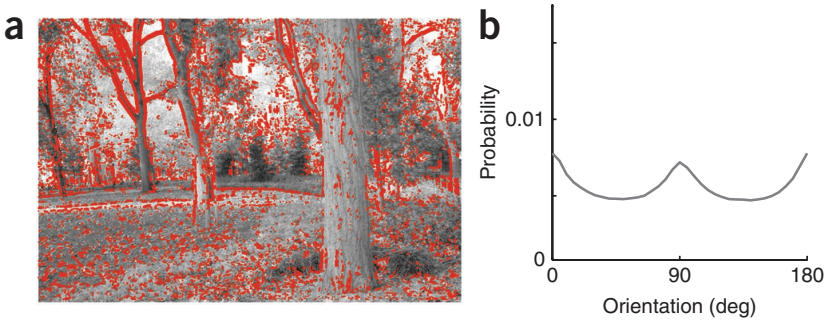


Do such priors correspond to the environment statistics?

- Difficult to assess for speed prior, but easier for orientation.

- Orientation judgments are more accurate at cardinal (horizontal and vertical) orientations.
- And Biased toward cardinal orientations.

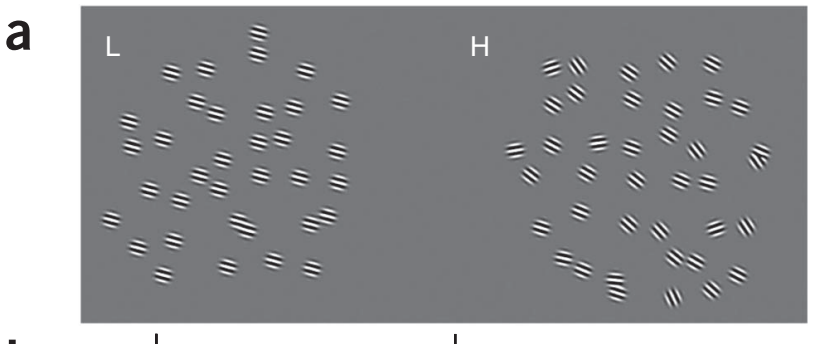
- Prior towards cardinal orientation, as estimated through reverse engineering behaviour, match orientation distribution measured in photographs.



Cardinal rules: visual orientation perception reflects knowledge of environmental statistics

Ahna R Girshick[1,2], Michael S Landy[1,2] & Eero P Simoncelli[1–4]

Humans are good at performing visual tasks, but experimental measurements have revealed substantial biases in the perception of basic visual attributes. An appealing hypothesis is that these biases arise through a process of statistical inference, in which information from noisy measurements is fused with a probabilistic model of the environment. However, such inference is optimal only if the observer's internal model matches the environment. We found this to be the case. We measured performance in an orientation-estimation task and found that orientation judgments were more accurate at cardinal (horizontal and vertical) orientations. Judgments made under conditions of uncertainty were strongly biased toward cardinal orientations. We estimated observers' internal models for orientation and found that they matched the local orientation distribution measured in photographs. In addition, we determined how a neural population could embed probabilistic information responsible for such biases.



is L stimulus CW or CCW compared to H?

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