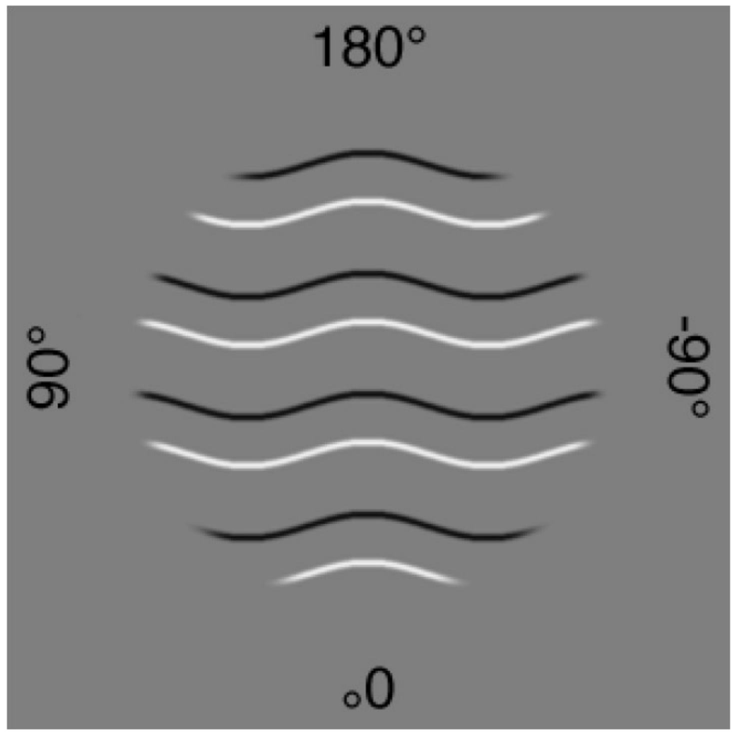
Visual priors

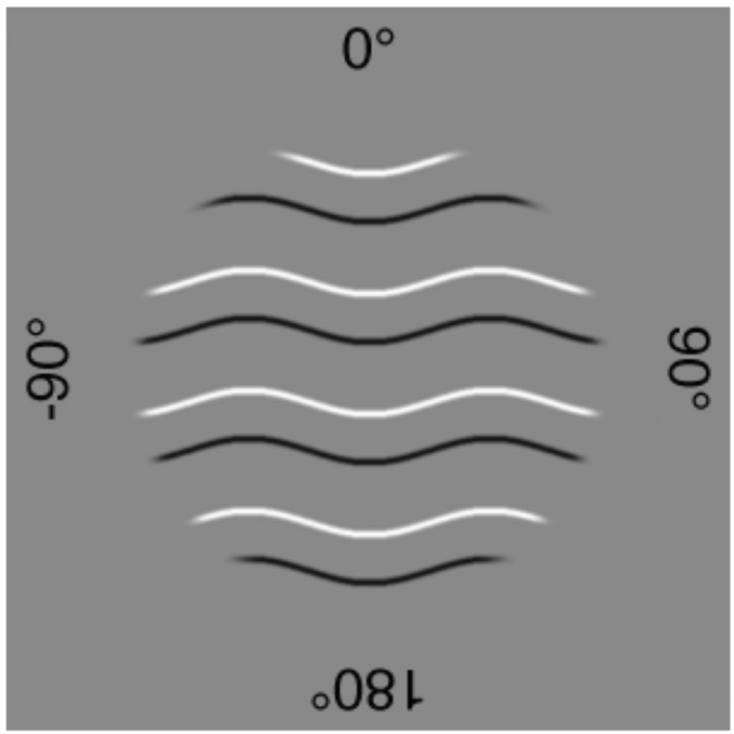
CS786

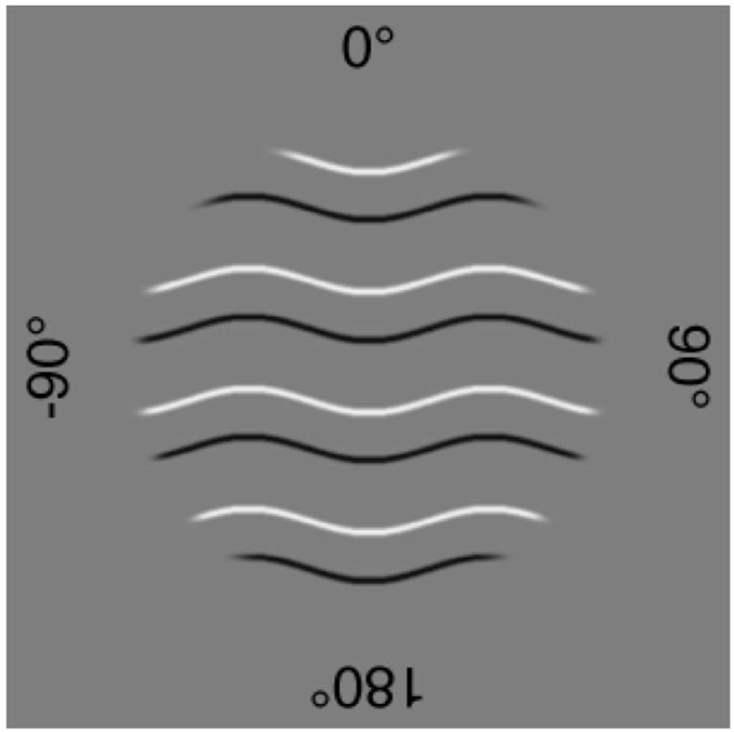
September 24th 2024

Which curves are raised?



Which curves are raised?

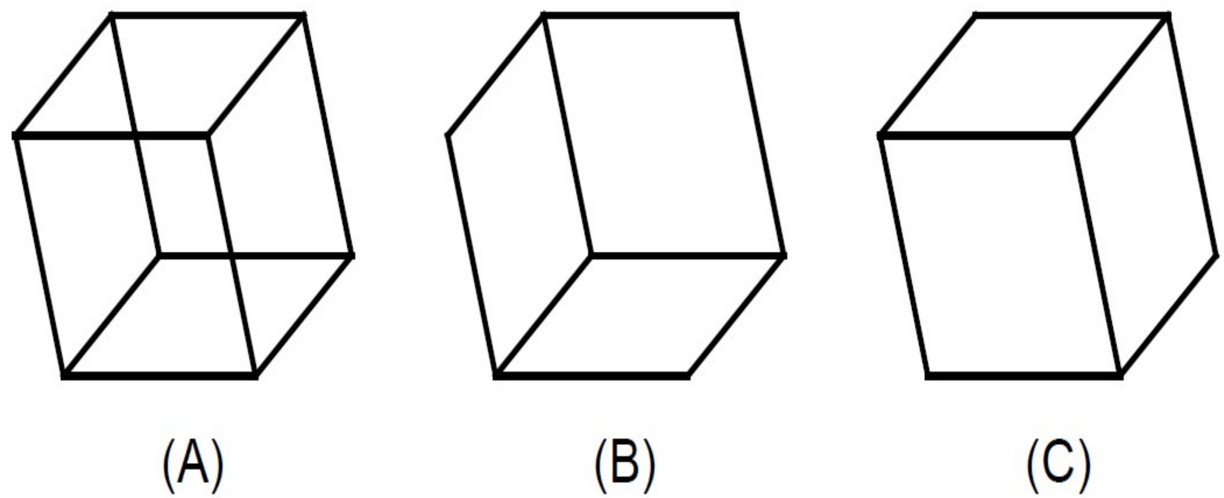




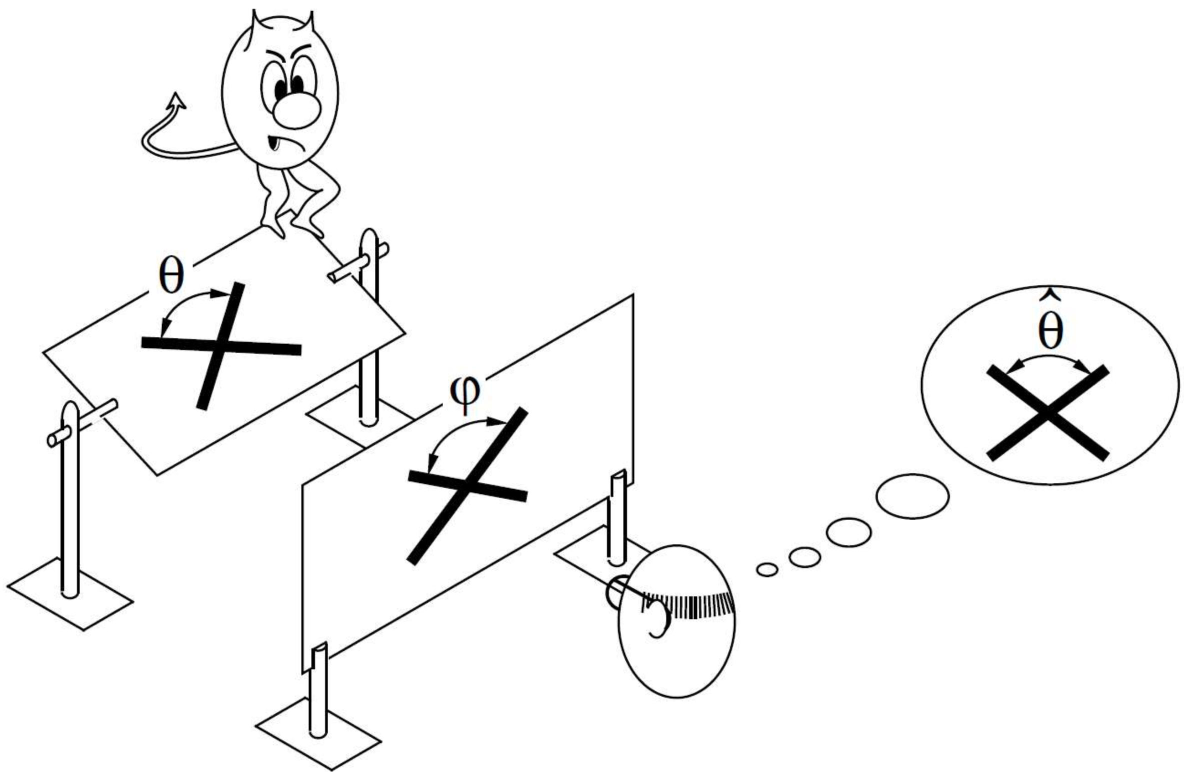
http://www.psych.nyu.edu/maloney/MamassianLandyMaloney.MITPress2003.pdf

Vision uses more information than impacts the retina

- What you see isn't exactly what you get



Perception as inference



Want to know θ, get to see ϕ

Bayesian visual perception

- Observer constructs $p(\theta|\phi)$ using
  - $p(\phi|\theta)$, physiologically determined likelihood
  - $p(\theta)$, visual priors on percepts
- Bayesian revolution in perception (Knill, 2004)
  - Using Bayesian analysis to estimate visual priors using behavior responses

Bayesian prior estimation

- Regular sequential Bayes
    - Update prior by multiplying with likelihood
    - Obtain posterior
    - Use posterior as prior for next time step
- Inverse procedure
    - Know posterior distribution given all data
    - Divide posterior by data likelihood sequentially
    - Each obtained prior serves as posterior for earlier time step
    - Finally left with original prior

Bayes 101

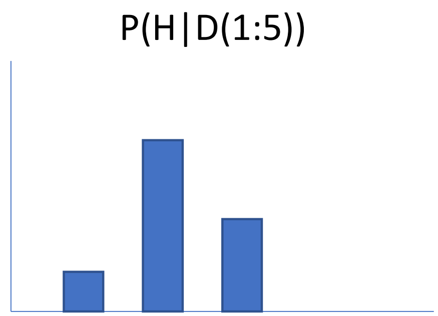
- $P(H|D)$ proportional to $p(H)p(D|H)$
  - Basic Bayes claim
- We have a bunch of data D
- And there are several possible h that can potentially account for the data
- With a Bayesian analysis, we can construct a probability $p(H|D)$
  - Which hypothesis is most likely, given we've seen the data D

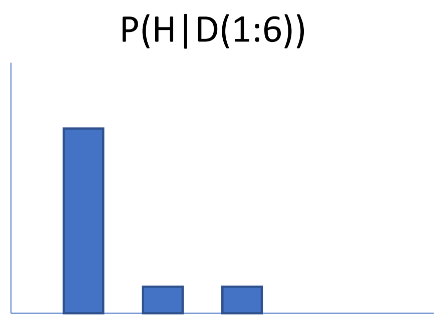
Sequential Bayes 101

- Let's assume that the data are sequential D = {d1, d2, ….. dn}
- P(H|D(1:n)) proportional to p(H|D(1:n-1))p(dn|H)
  - Prior is p(H|D(1:n-1))
  - Likelihood is p(dn|H)

Bayesian analysis

- 1,2,4,8,16 ....
- All natural numbers
- All powers of two
- Members of the table of two
- d6 = 31



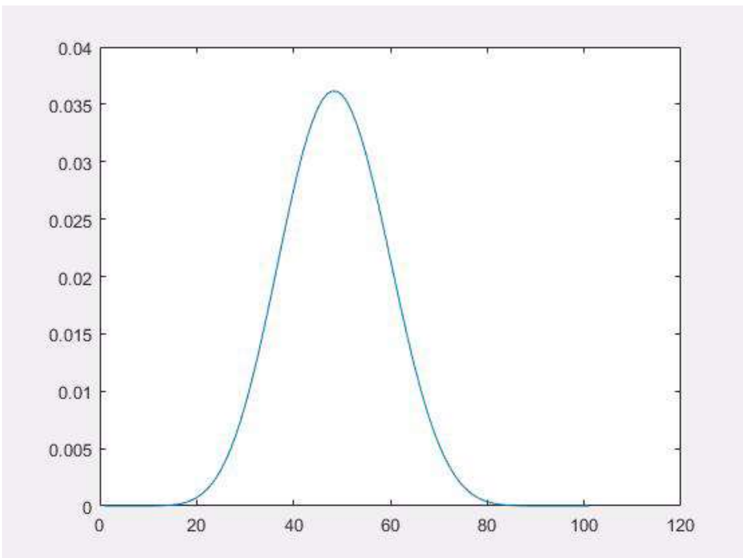


Bayesian parameter estimation

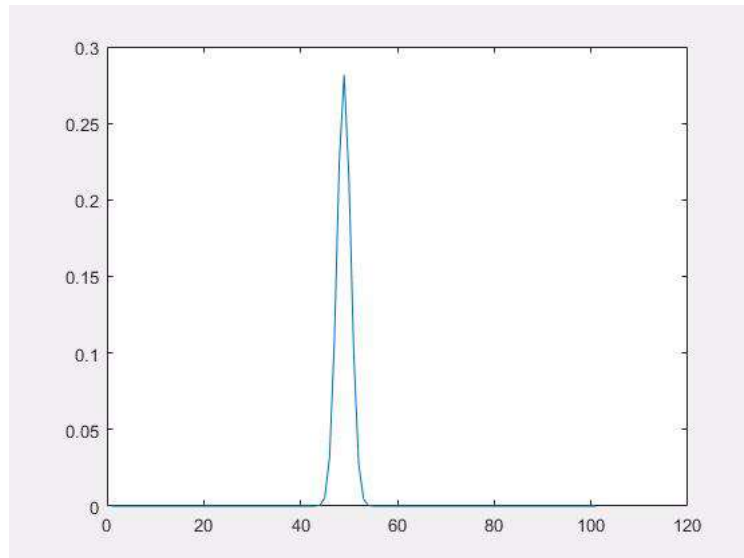
- Typically hard to obtain likelihoods for multiple sequential updates in closed form
- Alternative procedure
  - Generate posterior distributions using different parameters determining the prior
  - Find parameters that yield posterior distributions that best fit the true distribution
  - Frequently have to use some form of MCMC sampling

Demo

String of binary observations modeled using binomial likelihood and beta prior

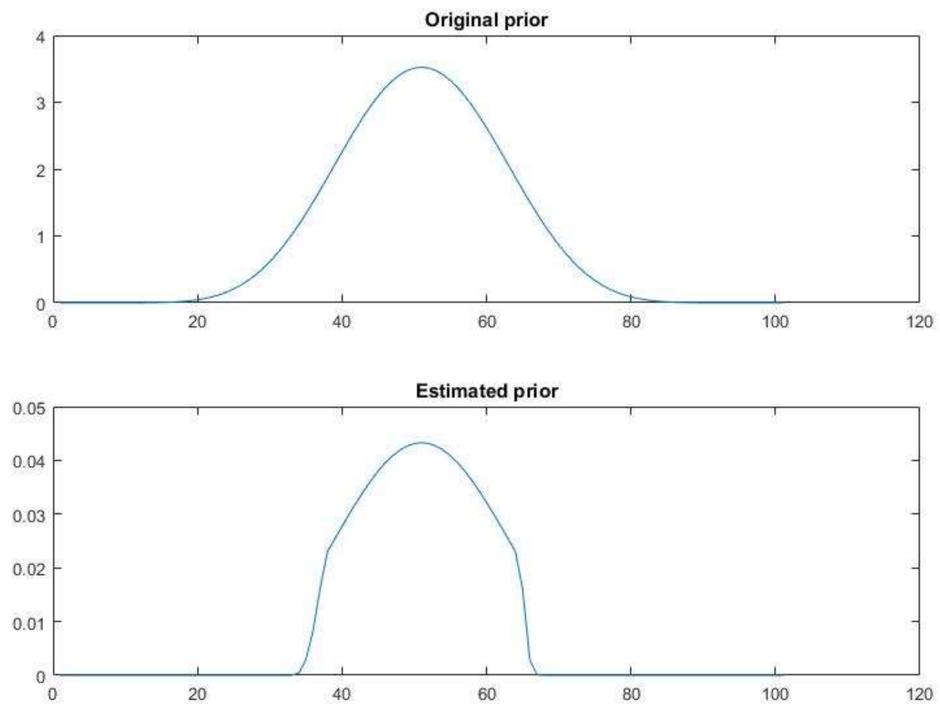


Posterior update

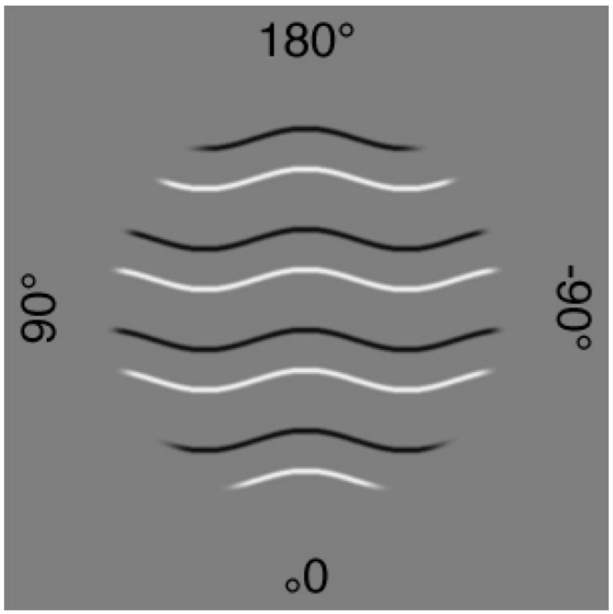


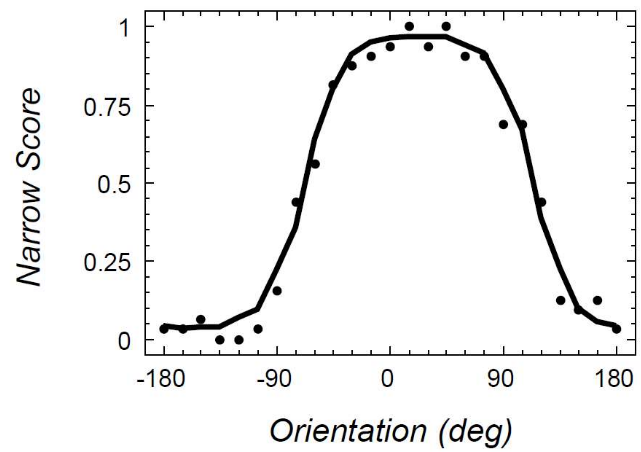
Prior estimation

Prior estimation



Applied to vision data





Narrow score = proportion of times image is described with bulging narrow ridges

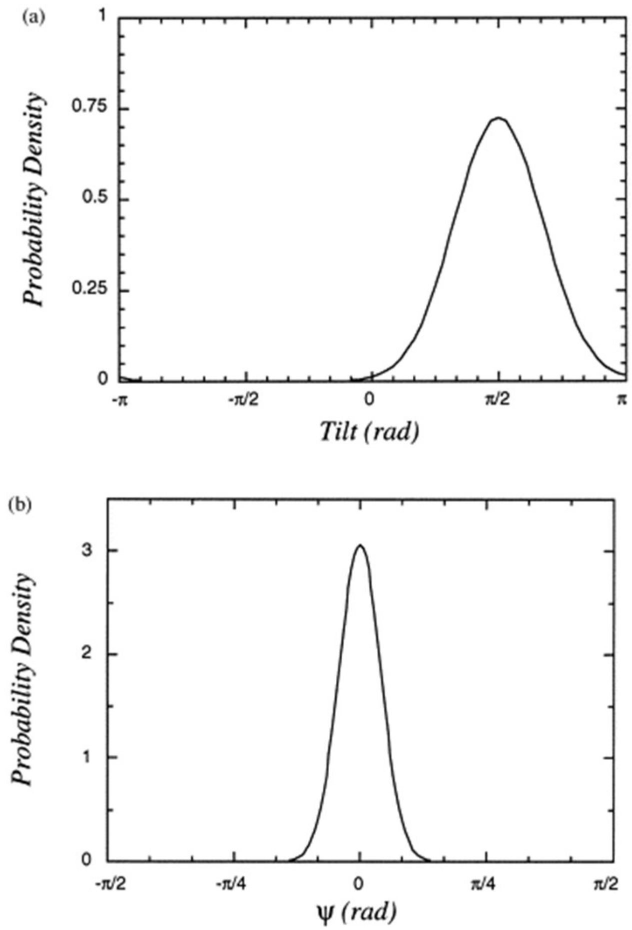
http://www.psych.nyu.edu/maloney/MamassianLandyMaloney.MITPress2003.pdf

Simplifying assumptions

- Response proportions assumed to reflect posterior probability p(narrow|image)
- Prior biases assumed to influence response independently
- Model illumination and viewpoint as drawn from a normal distribution on the respective angles

$$\int p(narrow, illumination, viewpoint \mid stimulus)\, d(illumination) d(viewpoint).$$

Findings



- Illumination angles are *a priori* assumed to be above and to the left
  - Increasing shading contrast reduces the variance of the illumination prior
  - Increasing contour contrast reduces the variance of the viewpoint prior
- In other experiments, shown that
  - People think they are looking at objects from above
  - People think angles are *a priori* likely to be right angles
  - And many more

What does it mean?

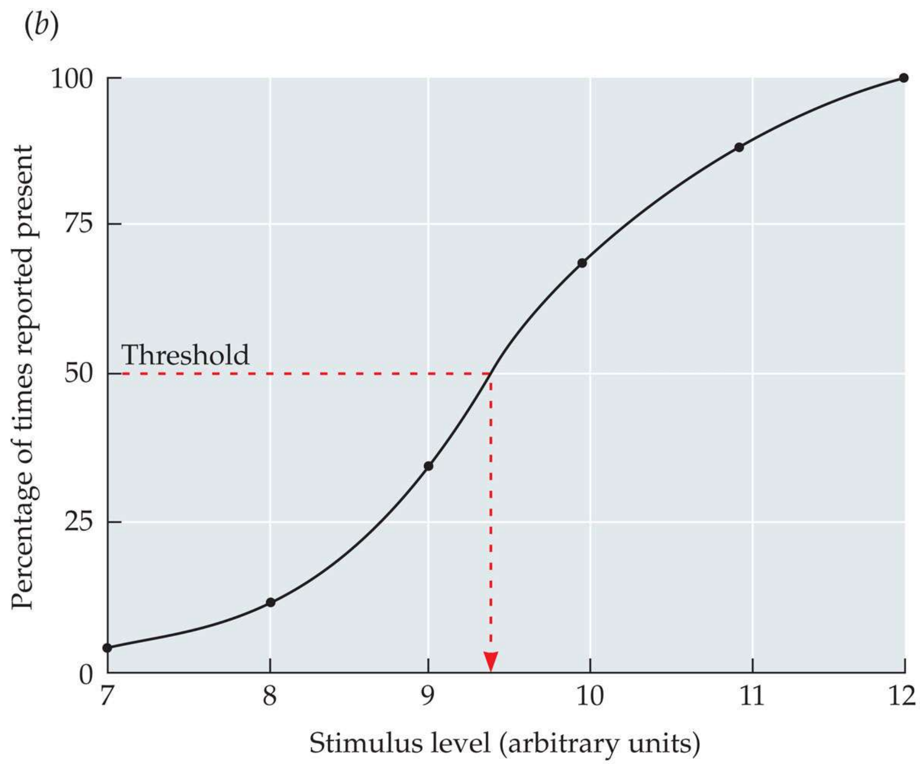
- Bayesian models of visual perception give us a way of *describing* the priors that people use
- But they don't explain *how* the priors come to be the way they are
- Positives: can describe both perceptual and cognitive priors
- Negatives: Hard to characterize the true provenance of empirically determined priors

Perceptual Learning

From priors to posteriors

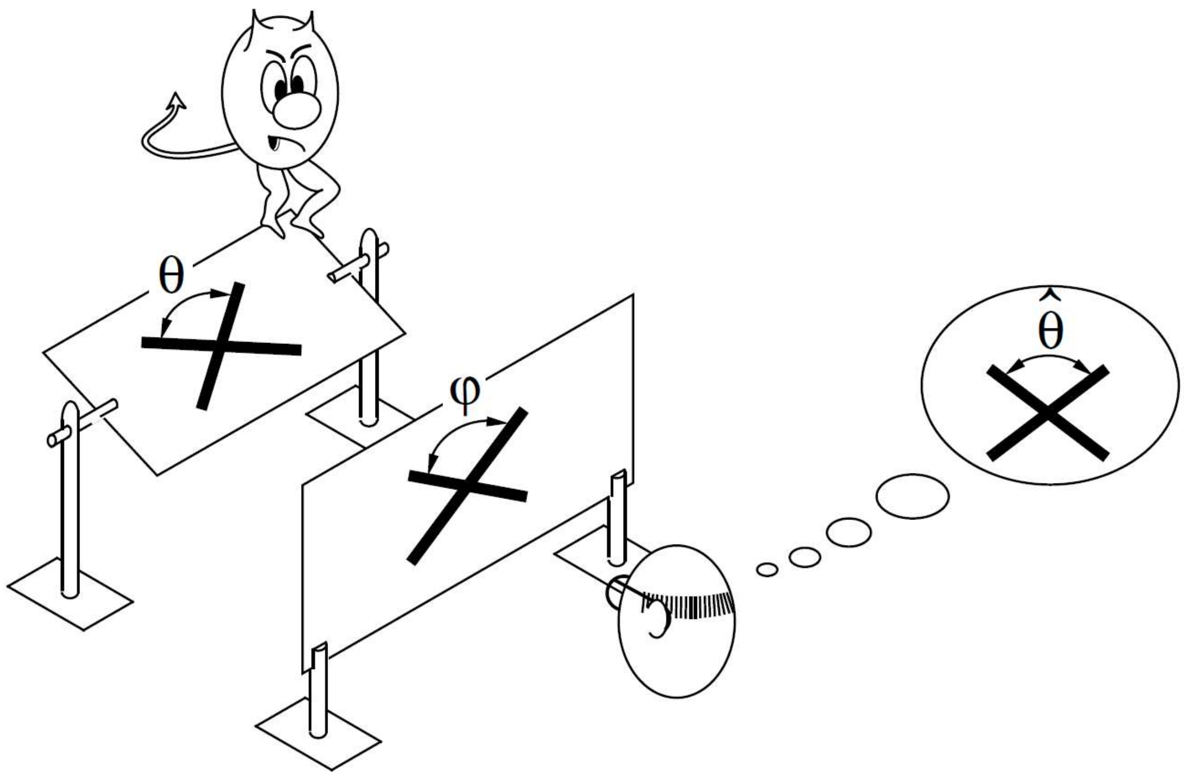
Absolute Thresholds

Psychometric function demonstrating the probabilistic (statistical) nature of the threshold



SENSATION & PERCEPTION 4e, Figure 1.6 (Part 2)

Perception as inference



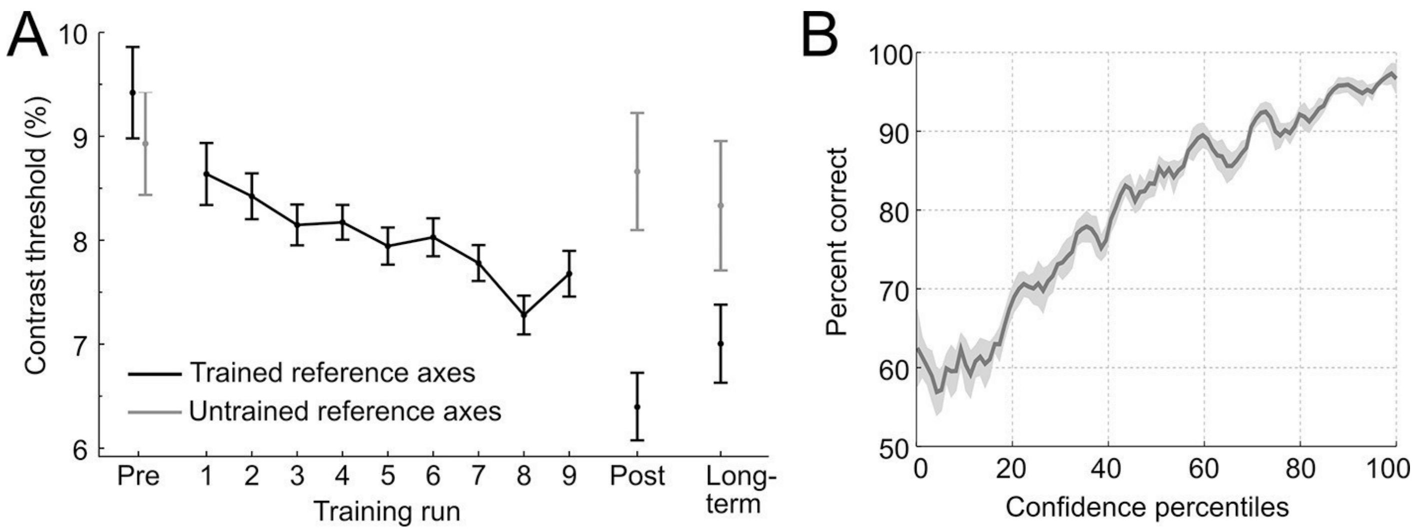
Want to know θ, get to see ϕ

Can perceptual ability improve?

- Classic psychophysics imagined perception to be governed by absolute limits
- Signal detection theory was developed to measure these limits
- Visual perception research shows
  - Perception strongly influenced by prior knowledge
  - Question: how does this influence work?
- Evidence for perceptual learning presents some hypotheses

Perceptual learning

- Perceptual discrimination improves with training



(Guggenmos, Wilbertz, Hebart & Sterzer, 2016)

Practice makes perfect

- https://www.youtube.com/watch?v=Qzhs1Z8Rwnk

Hypotheses

- Attentional weighting
  - Observers learn to attend to discriminative features of stimuli
- Stimulus imprinting
  - Detectors developed that are specialized for stimuli
- Differentiation
  - Perceptual adaptation by the development of increasingly differentiated object representations
- Unitization
  - Development of sensory units that are triggered when a complex configuration occurs

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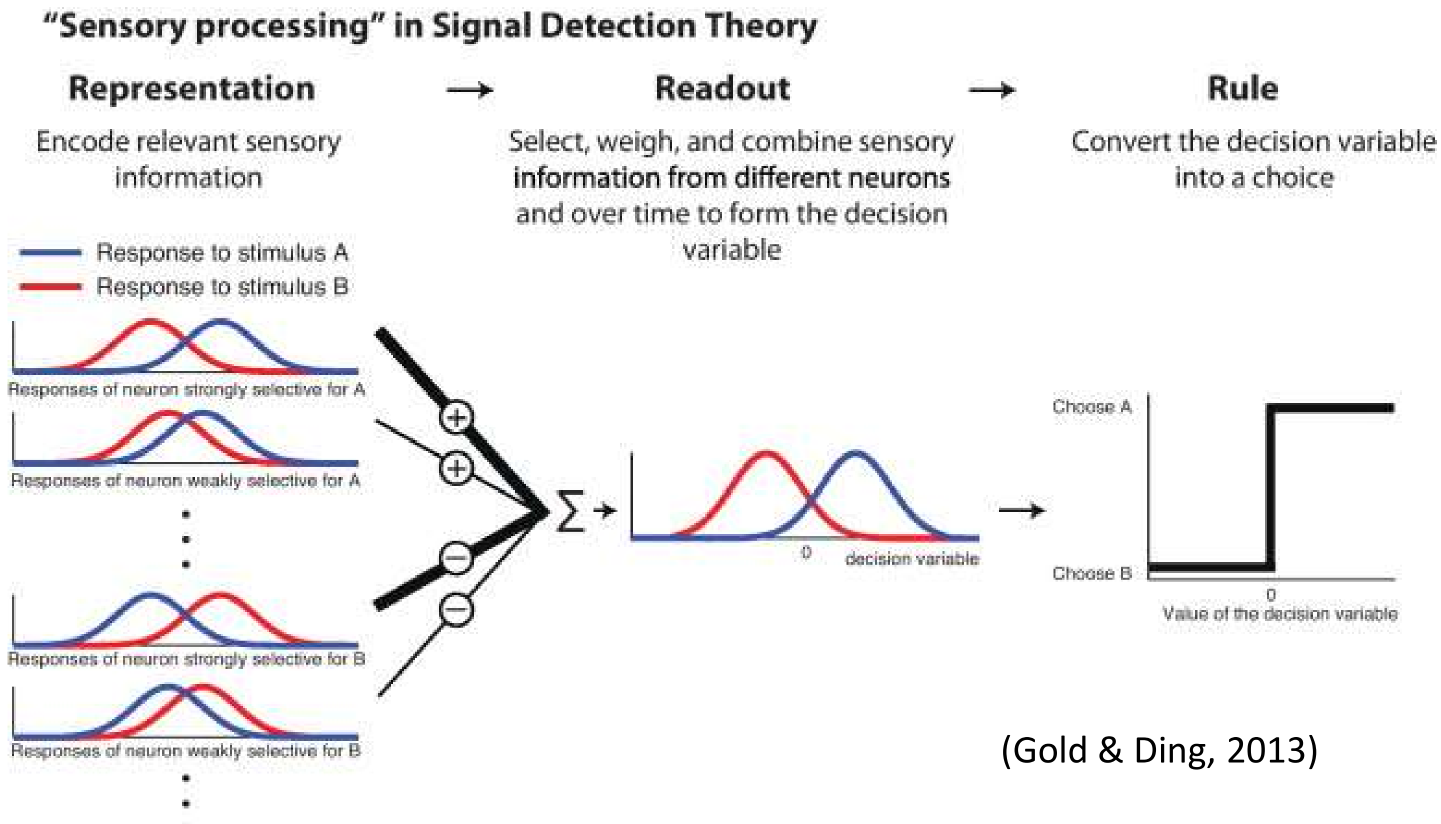
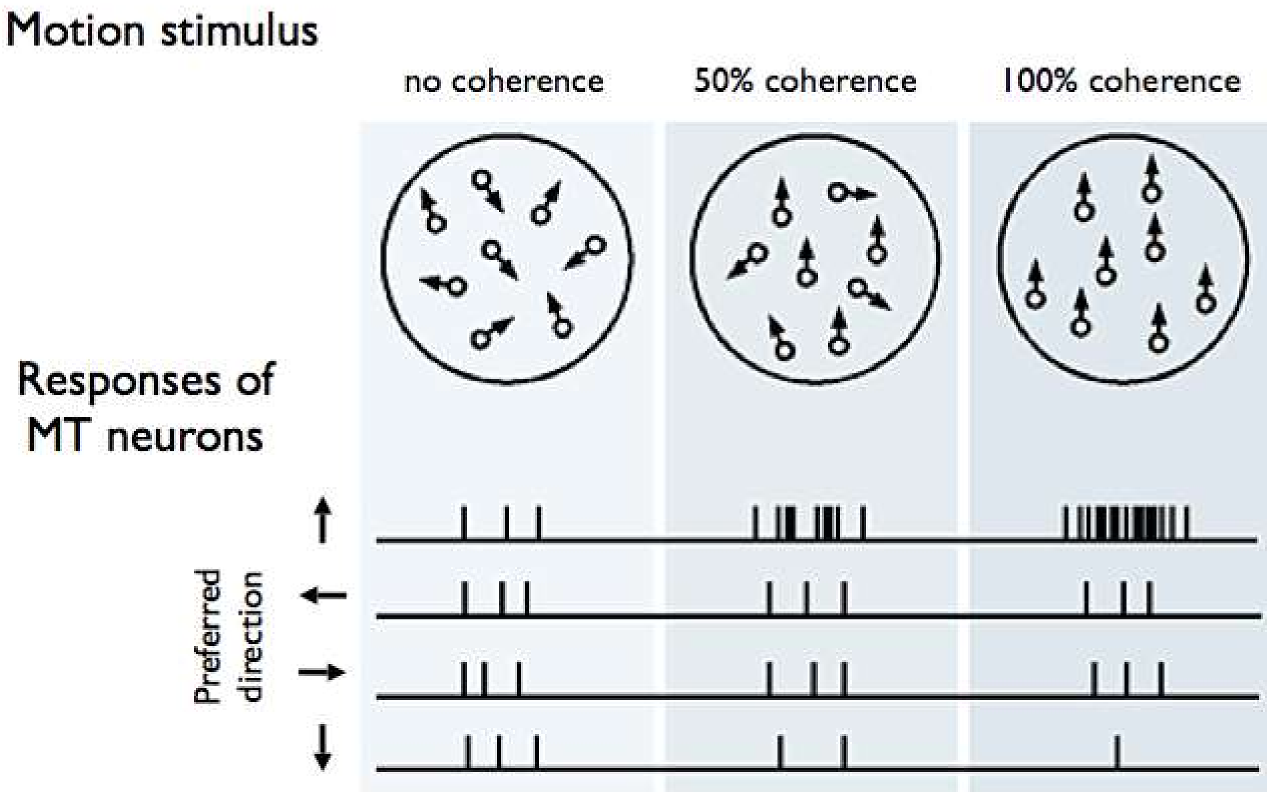
Perceptual learning as improved decision-making



(Gold & Ding, 2013)

Motion coherence and MT neurons



The dataset

- Recorded spiking response of neurons in monkey LIP cortex
- Neurons responsive to different motion directions
- Measured behavioral and neural data across multiple sessions (e.g. 165 sessions over 645 days for monkey C)