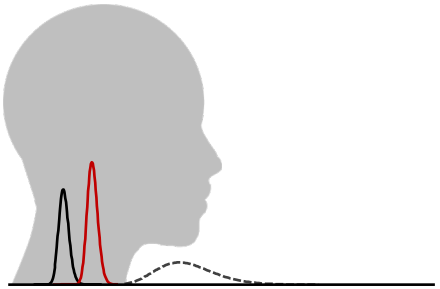
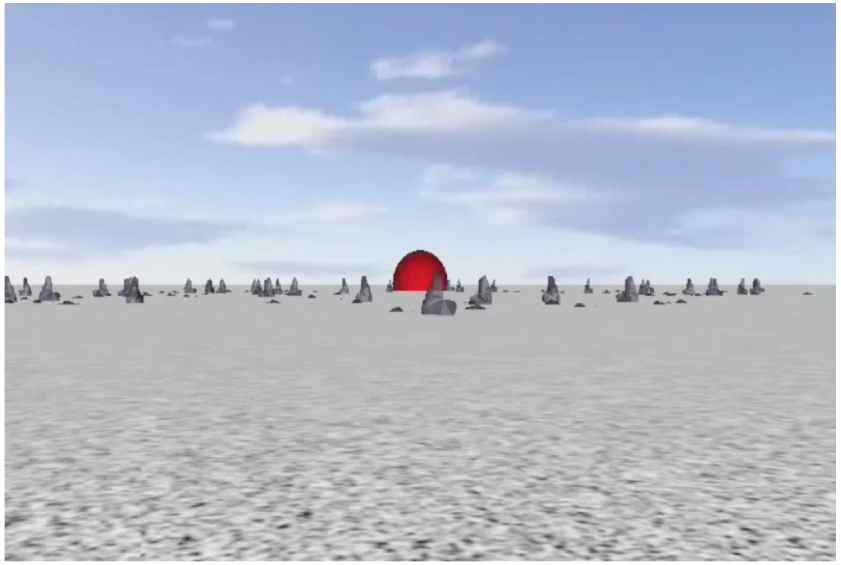


Perception as Bayesian Inference

Lecture

Dr. Frederike Petzschner



What is perception?

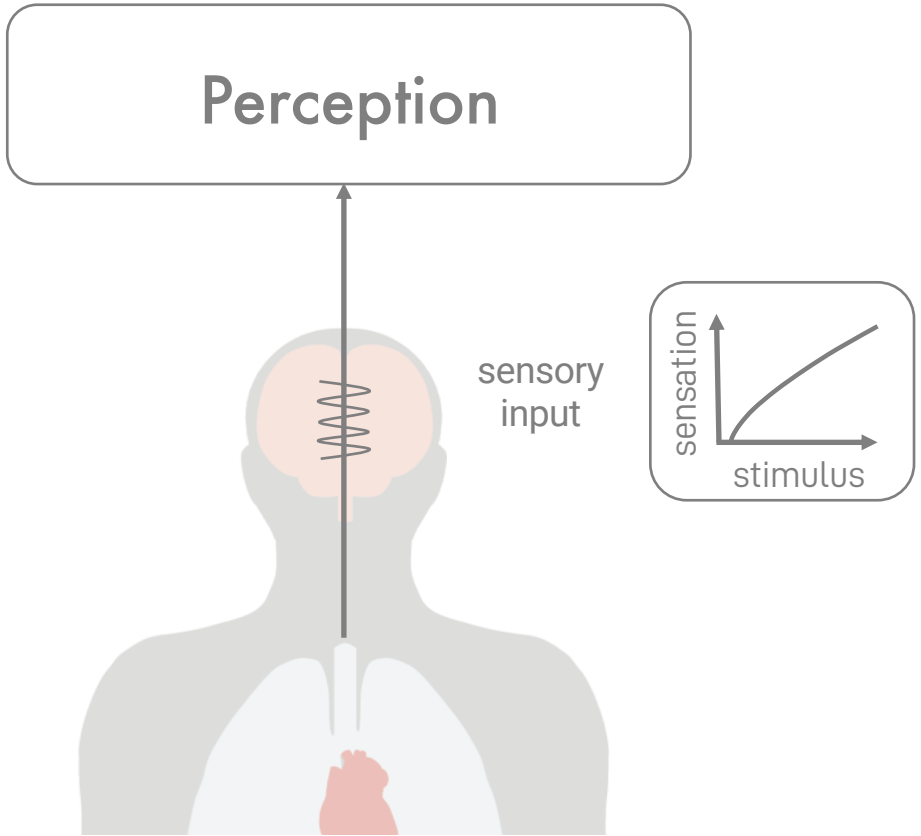
What is Bayesian inference?

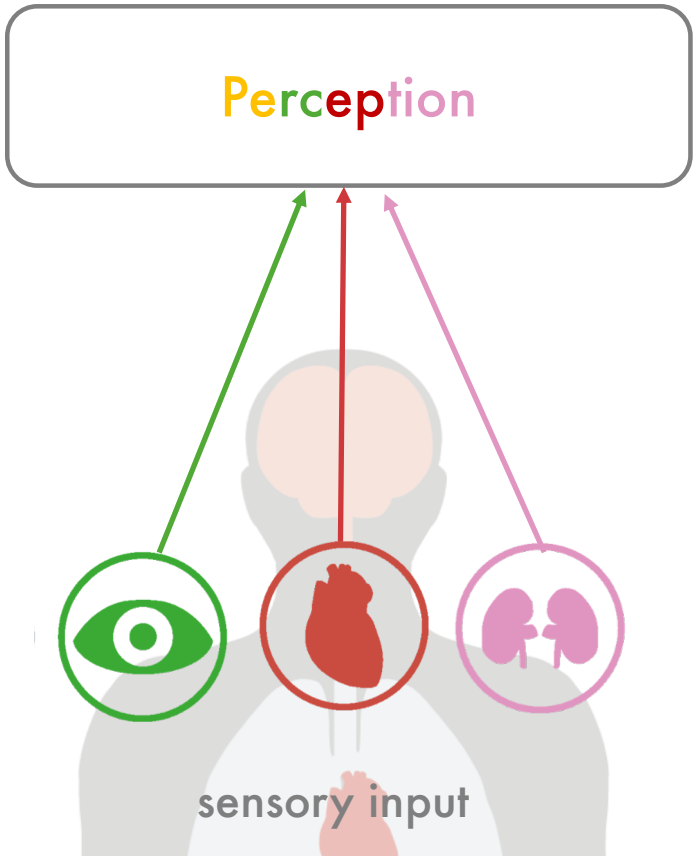
How to we integrate our senses?

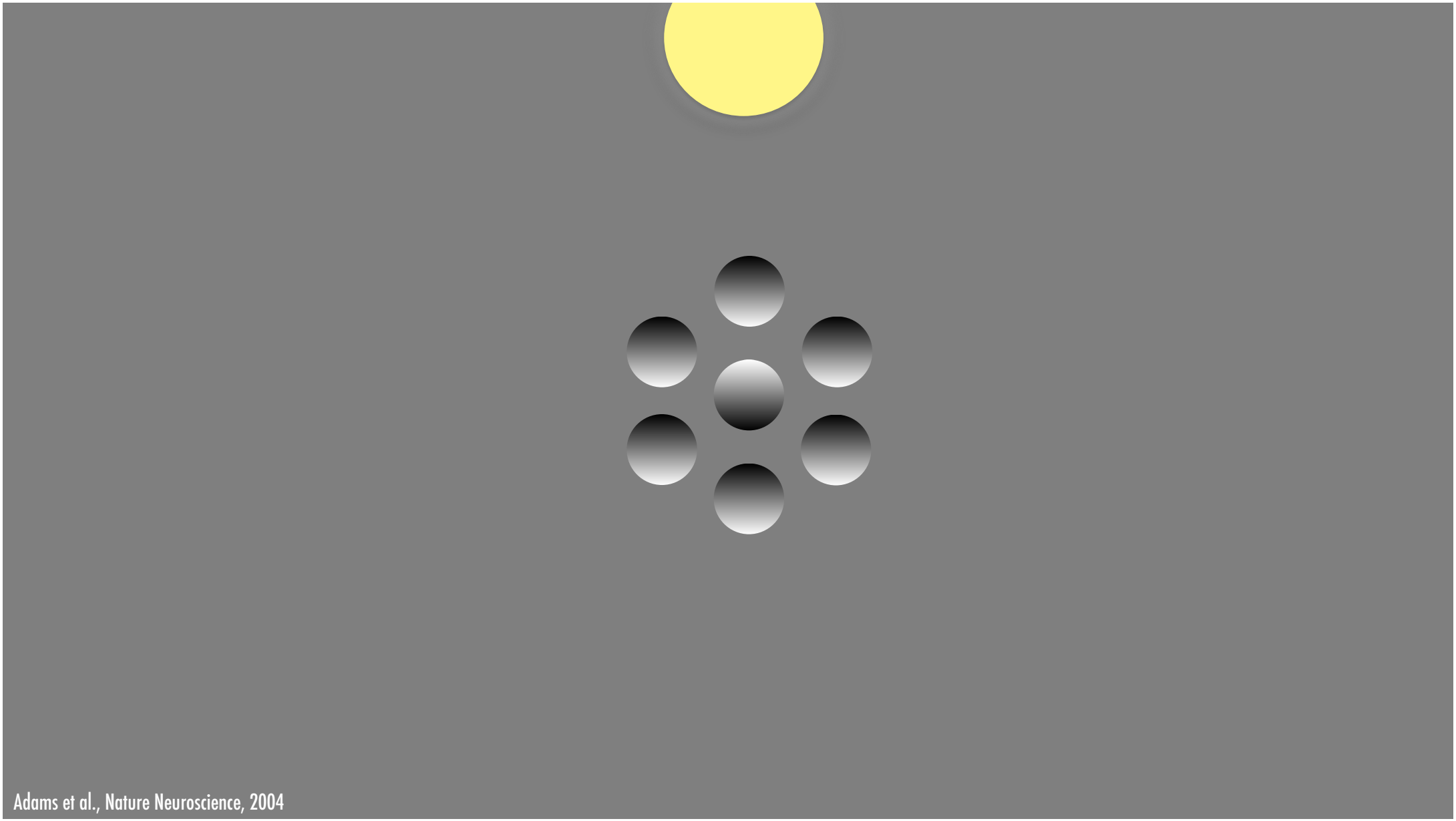
How to we form priors?

Critiques and interpretations

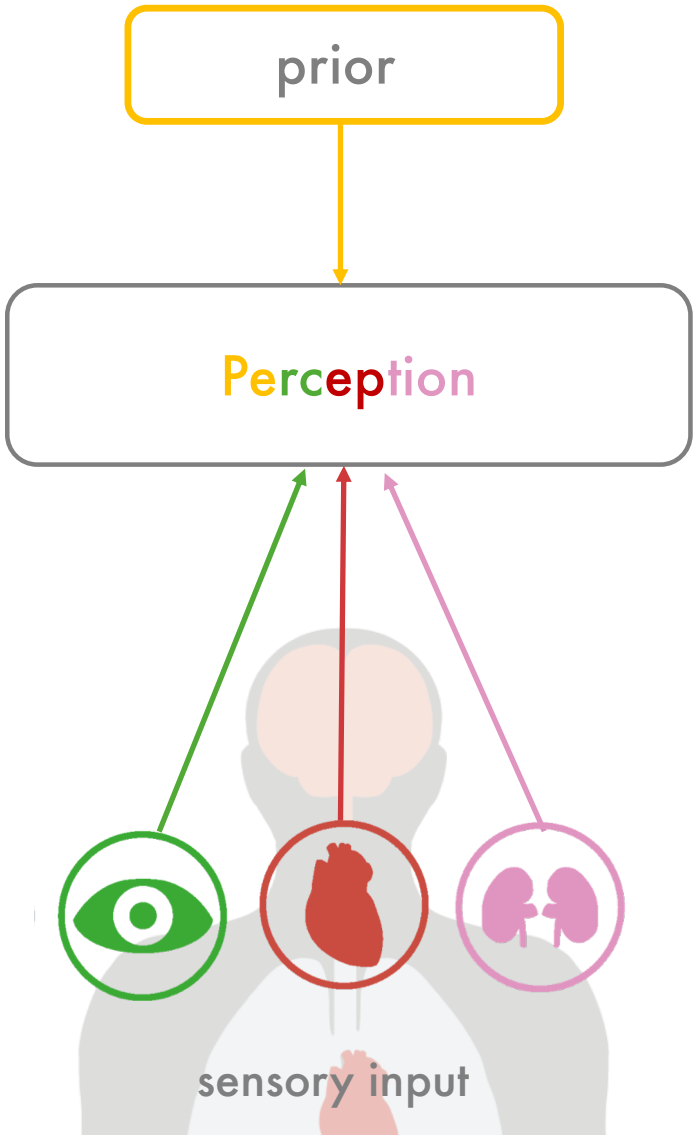
What is perception?


Perception
sensory
input
sensation
stimulus


Perception
sensory input

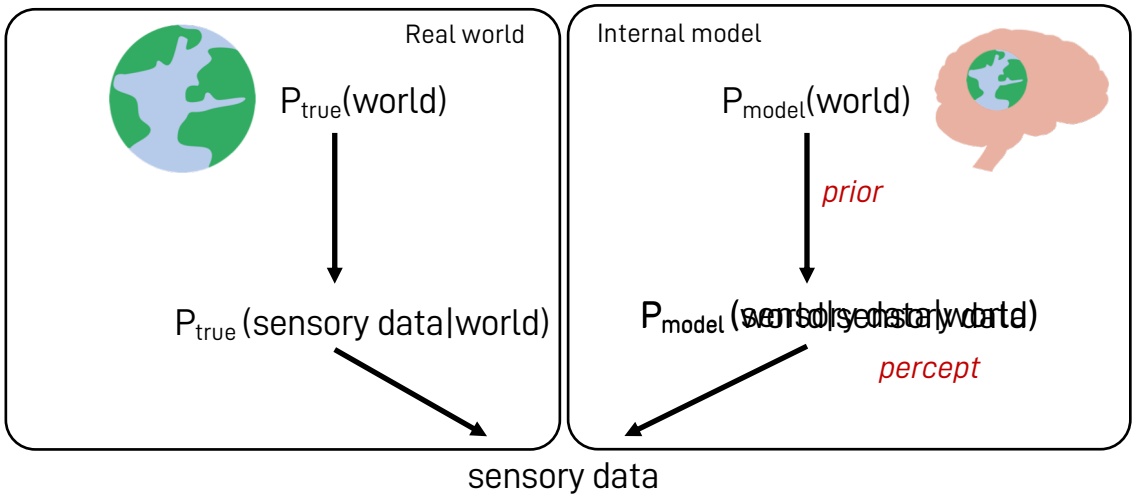


Adams et al., Nature Neuroscience, 2004


prior
Perception
sensory input

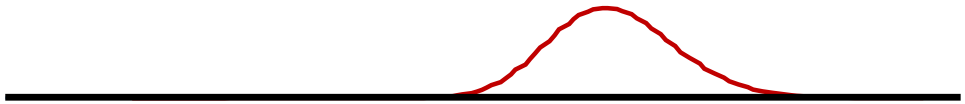
Bayesian inference?

Key idea

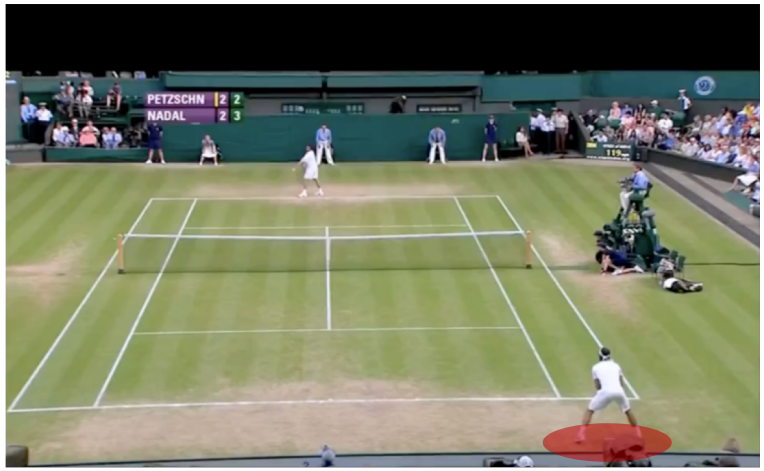

Real world
P_{true}(world)
P_{true} (sensory data|world)
Internal model
P_{model}(world)
prior
P_{model} (sensory data|world)
percept
sensory data

Example

Information extraction with Bayes' Rule

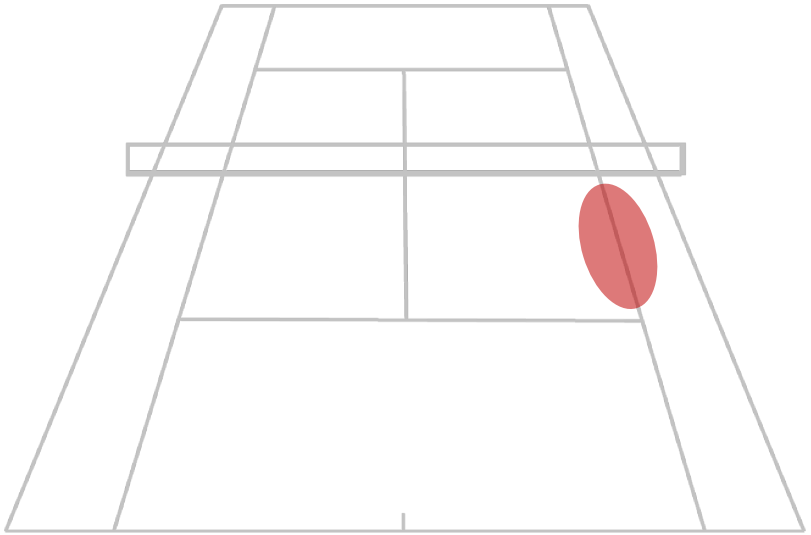


prior

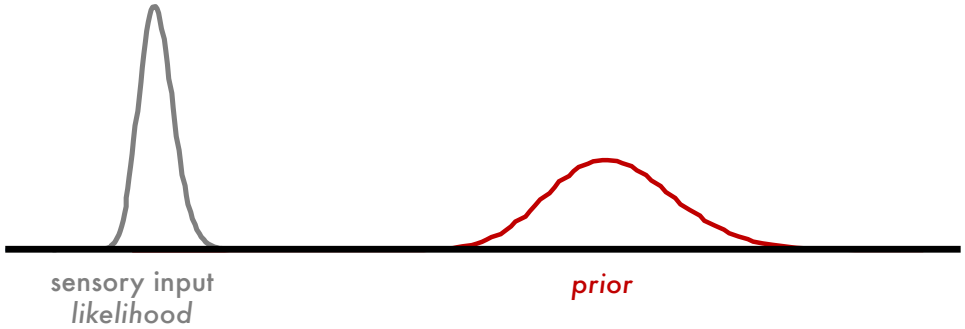


Bayes' Rule

$$\underset{\text{posterior}}{P(state|sensory\ input)} = \frac{\overset{\text{likelihood}}{P(sensory\ input|state)}\ \overset{\text{prior}}{P(state)}}{P(sensory\ input)}$$

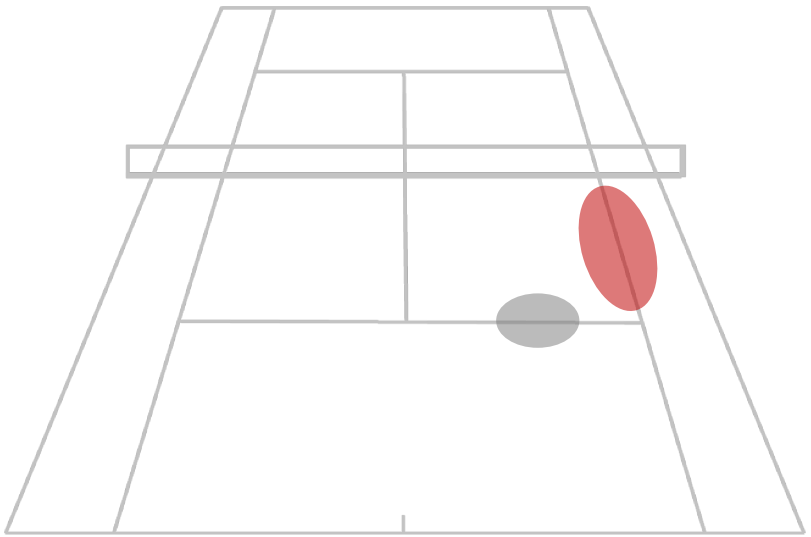


Information extraction with Bayes' Rule

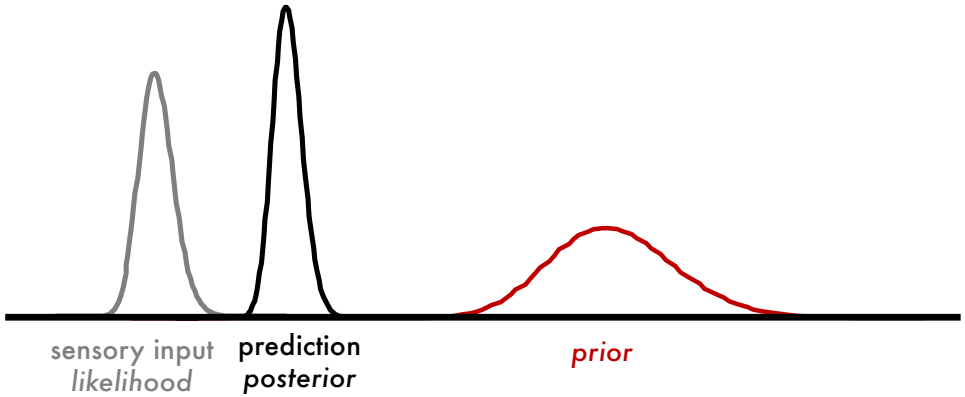


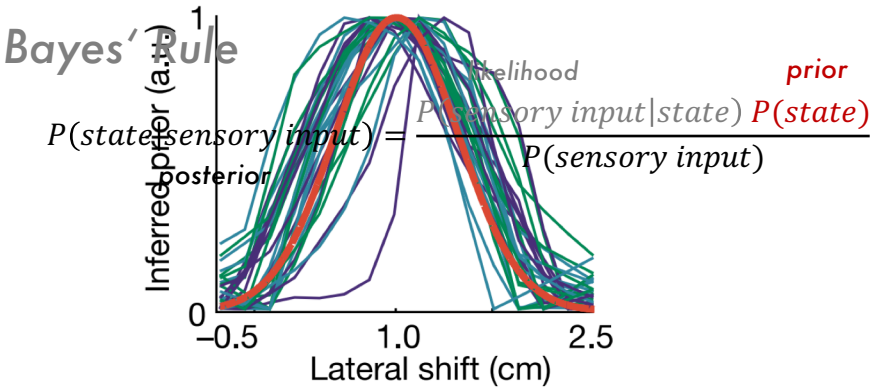
Bayes' Rule

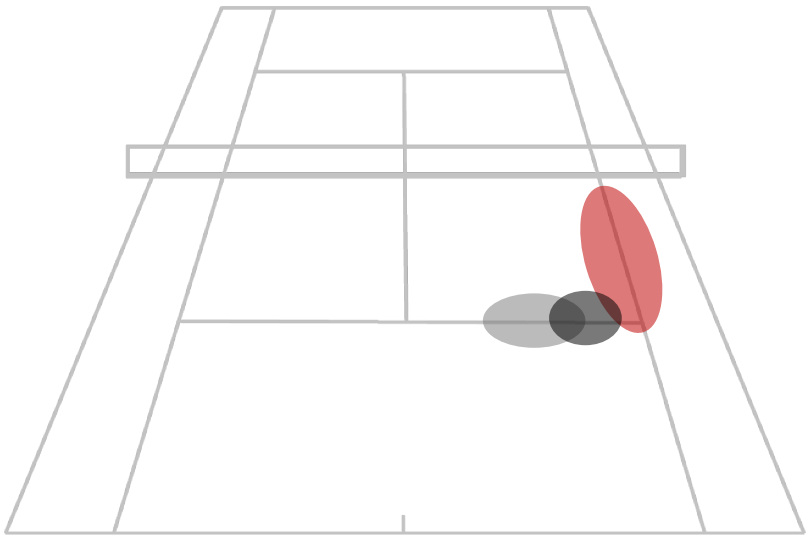
$$\underset{\text{posterior}}{P(state|sensory\ input)} = \frac{\overset{\text{likelihood}}{P(sensory\ input|state)}\ \overset{\text{prior}}{P(state)}}{P(sensory\ input)}$$



Information extraction with Bayes' Rule

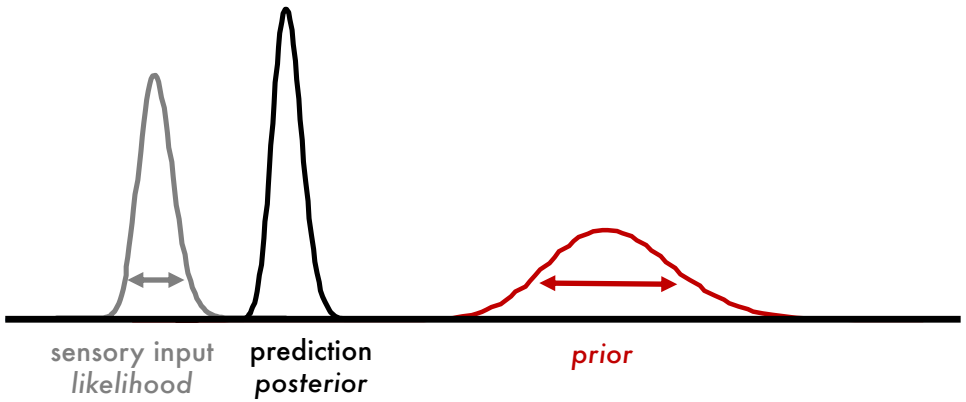


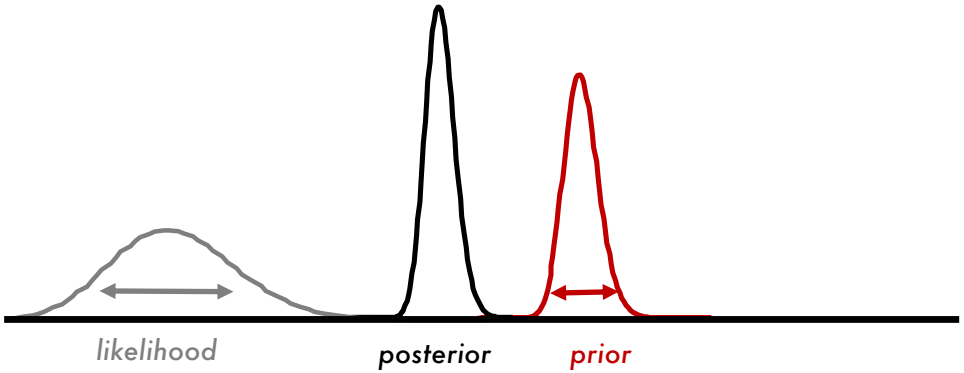




Körding & Wolpert, Bayesian integration in sensorimotor learning, Nature, 2004

How Bayes' Rule deals with uncertainty





Bayes Rule:
Optimal combination of uncertain information sources

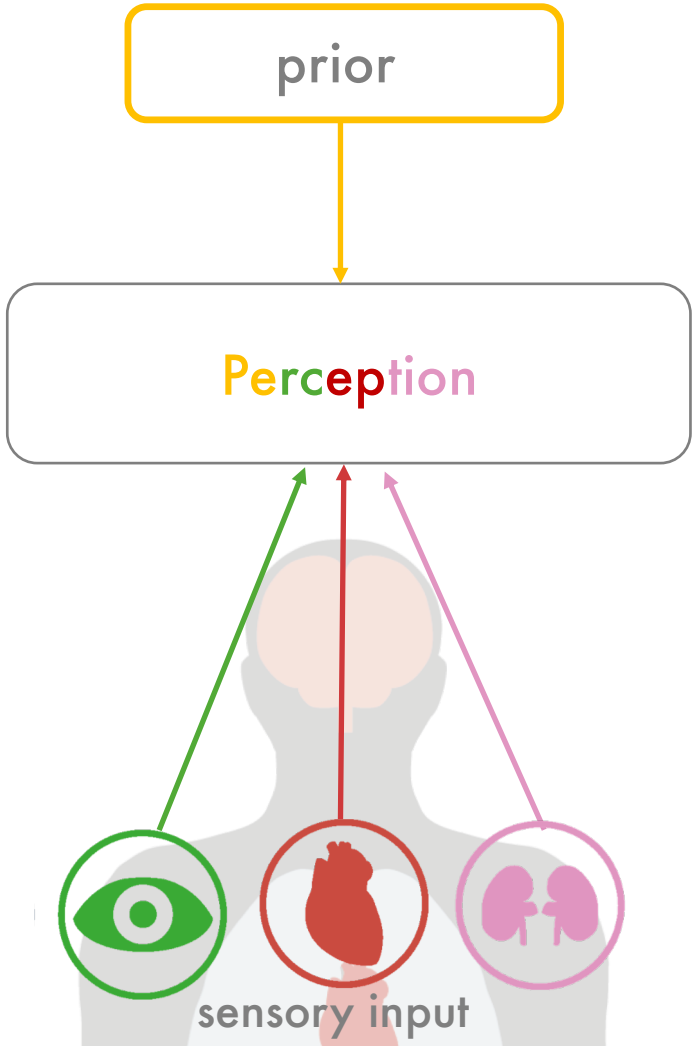
If Gaussian distributions:

$$\mu_{posterior} = w_{sens} \cdot \mu_{sens} + w_{prior} \cdot \mu_{prior}$$

$$\sigma^2_{posterior} = \frac{\sigma^2_{sens} \cdot \sigma^2_{prior}}{\sigma^2_{sens} + \sigma^2_{prior}}$$

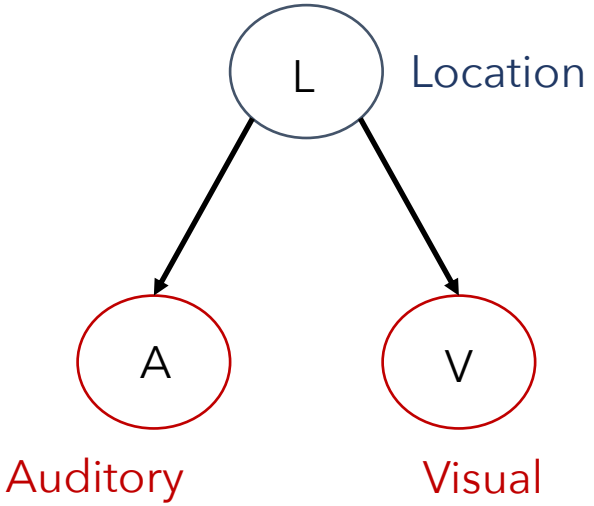
Perception as Bayesian inference

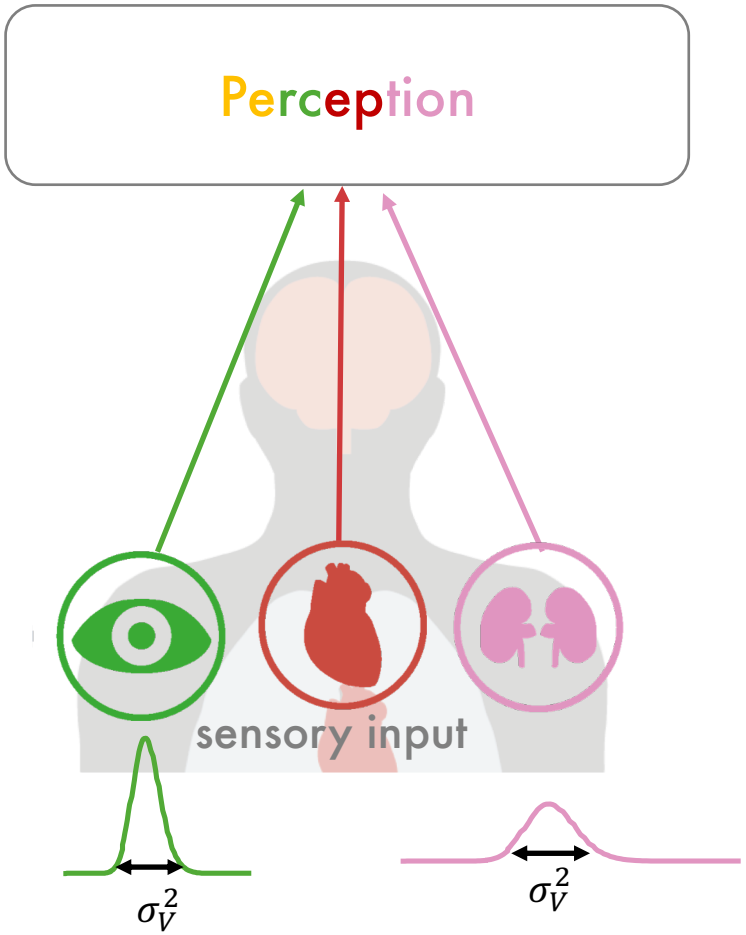
Perception is the result of a combination different types of noisy information in a statistical optimal manner



How to we integrate our senses?

Combination of visual and auditory information

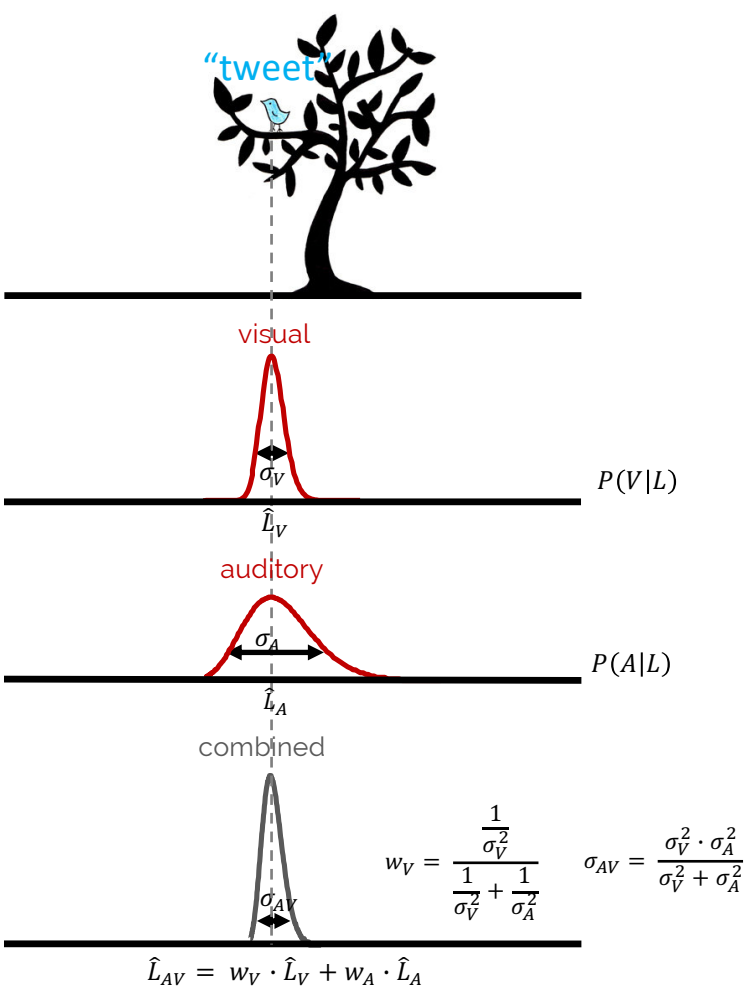


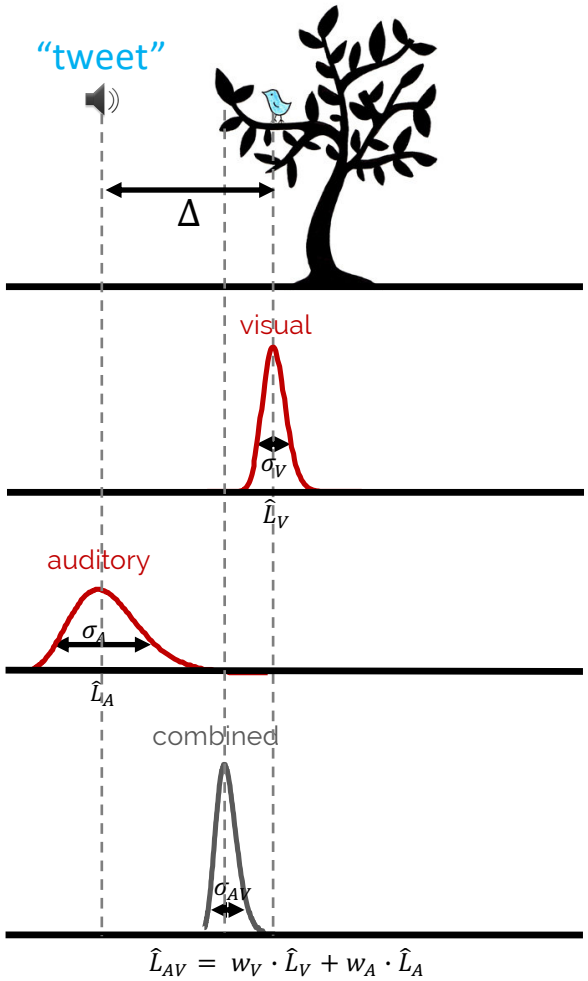


$$\mu_{AV} = w_V \cdot \mu_V + w_A \cdot \mu_A$$

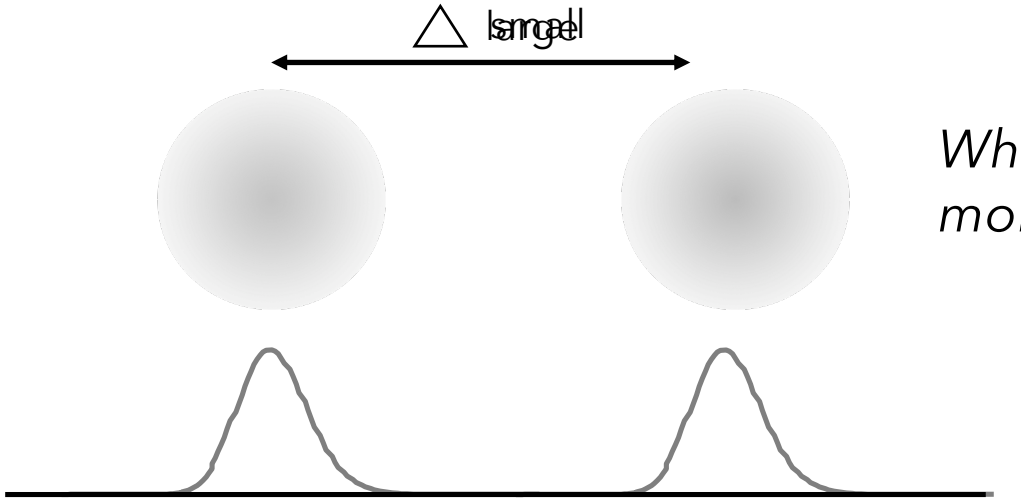
$$\sigma_{AV}^2 = \frac{\sigma_V^2 \cdot \sigma_A^2}{\sigma_V^2 + \sigma_A^2}$$

Combination of visual and auditory information: Ideal Observer

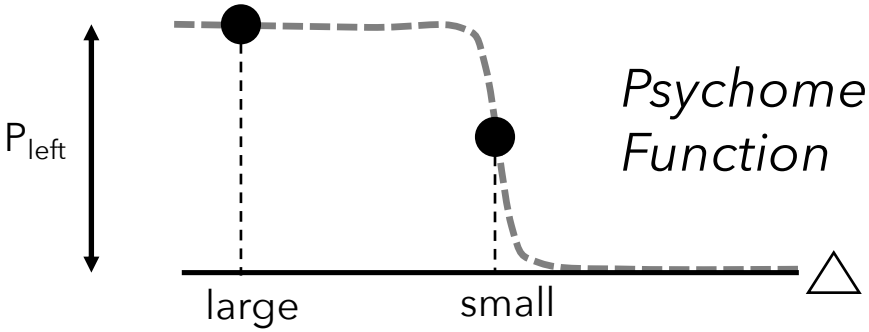




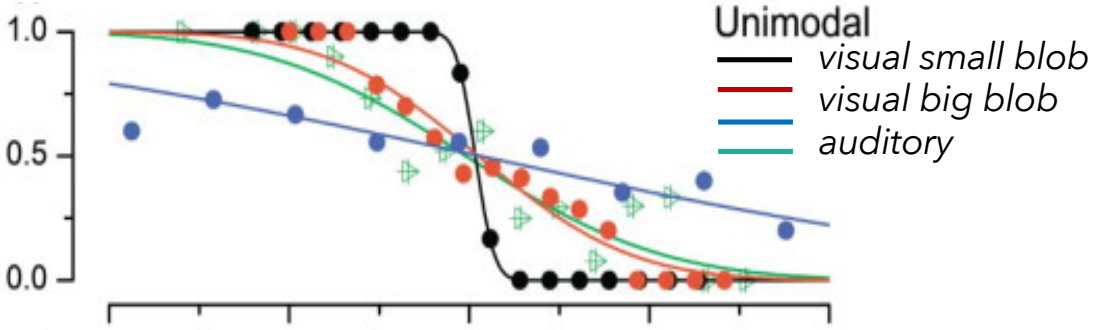
Reminder: The Psychometric Function



Which one was more left?

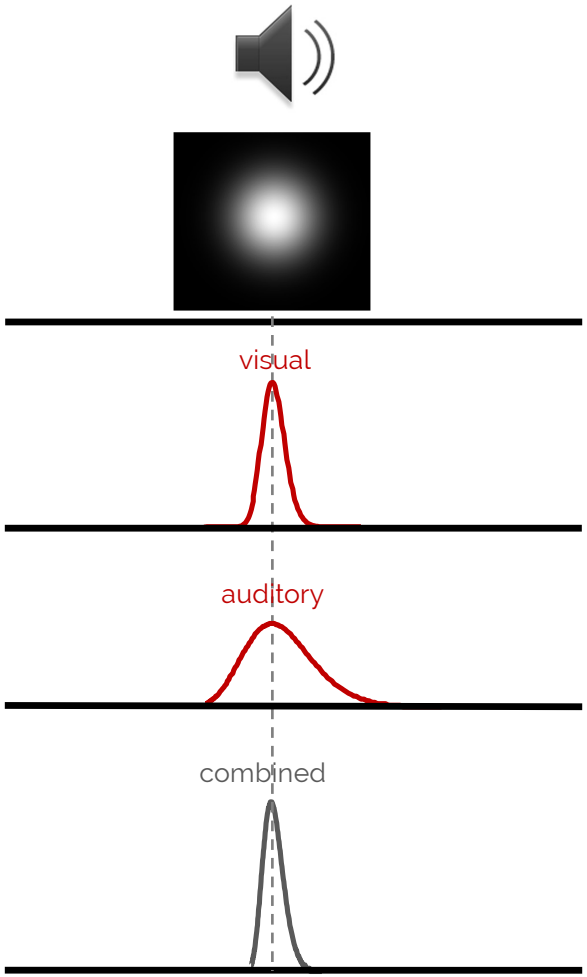


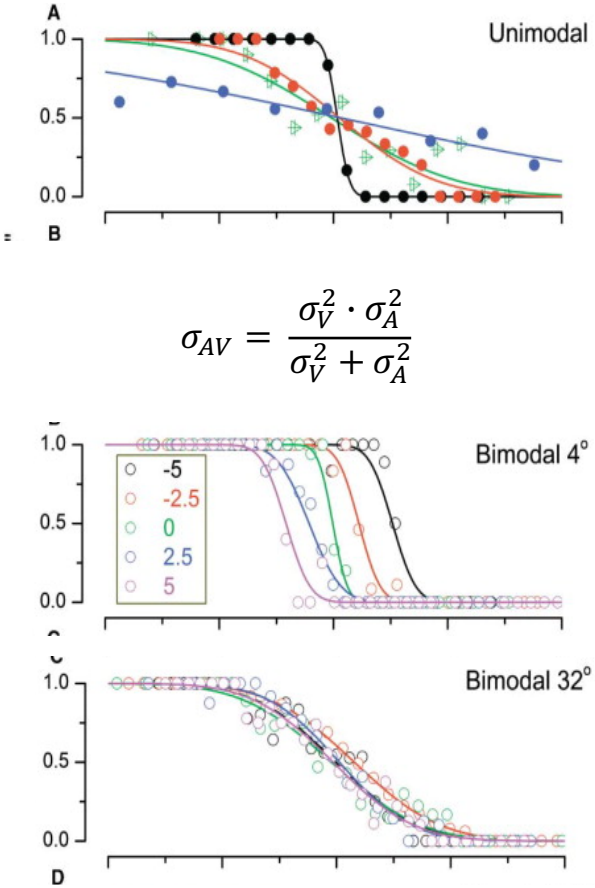
Psychometric Function



Alais & Burr, 2004

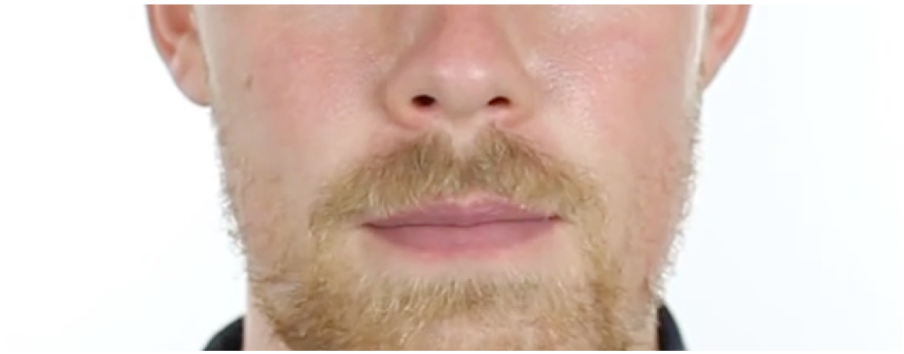
Combination of visual and auditory information: Human Observer





$$\sigma_{AV} = \frac{\sigma_V^2 \cdot \sigma_A^2}{\sigma_V^2 + \sigma_A^2}$$

Alais & Burr, 2004



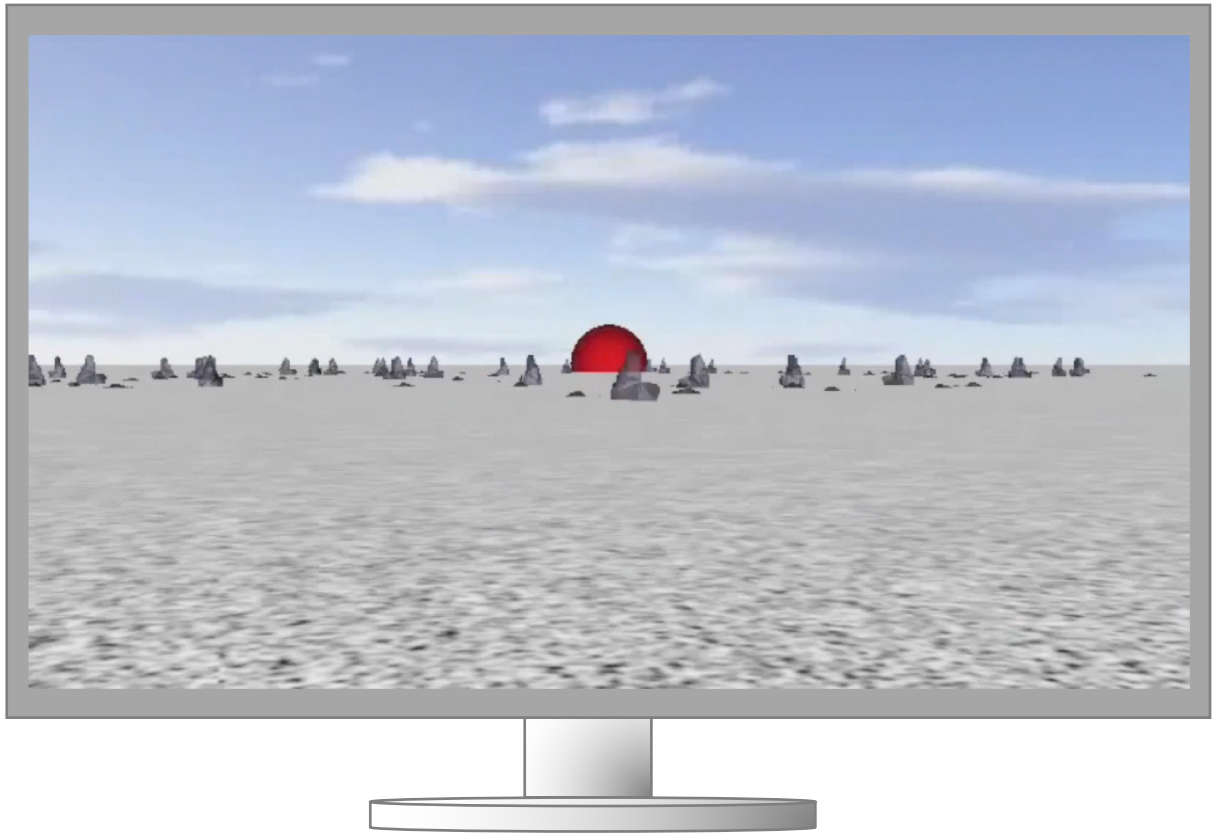
BAR

FAR

How do we form priors?

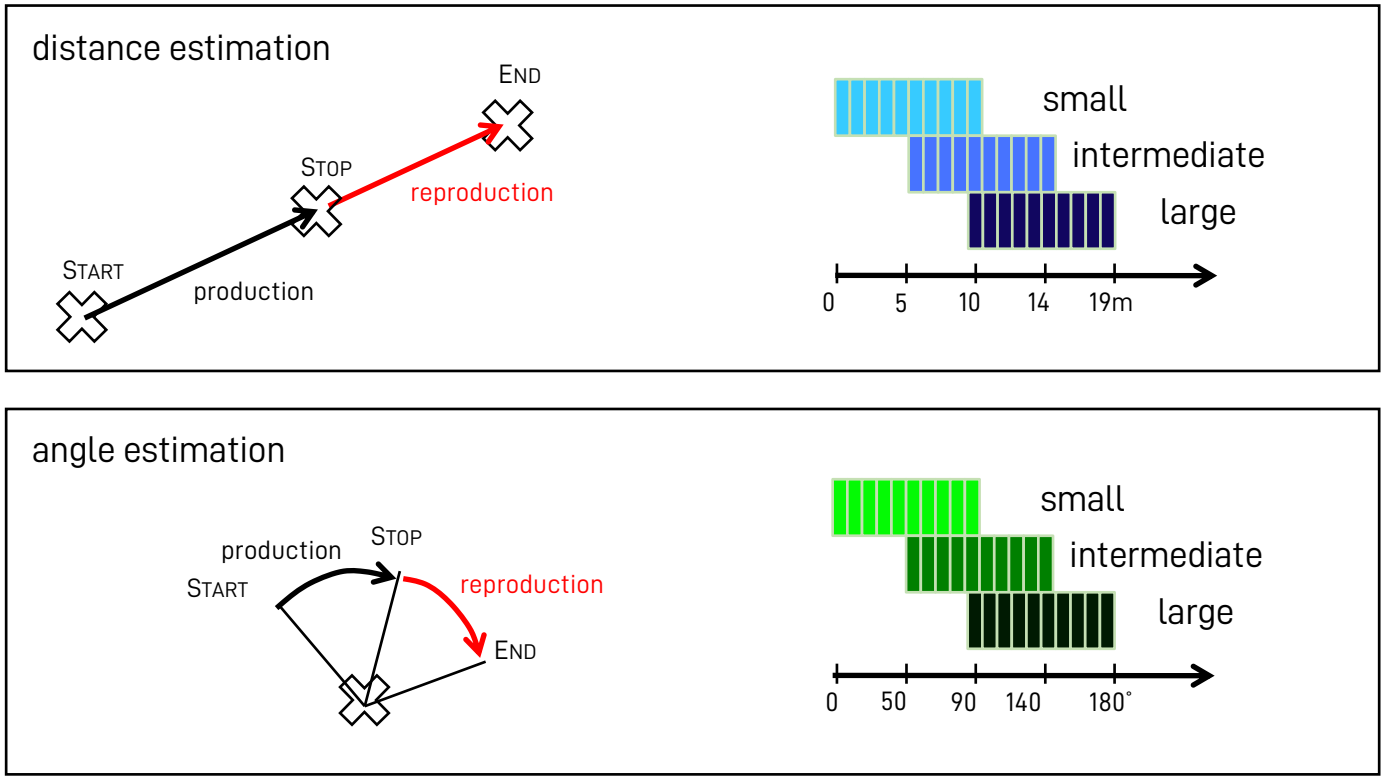
Priors can be learned…

“optimal errors” in magnitude estimation

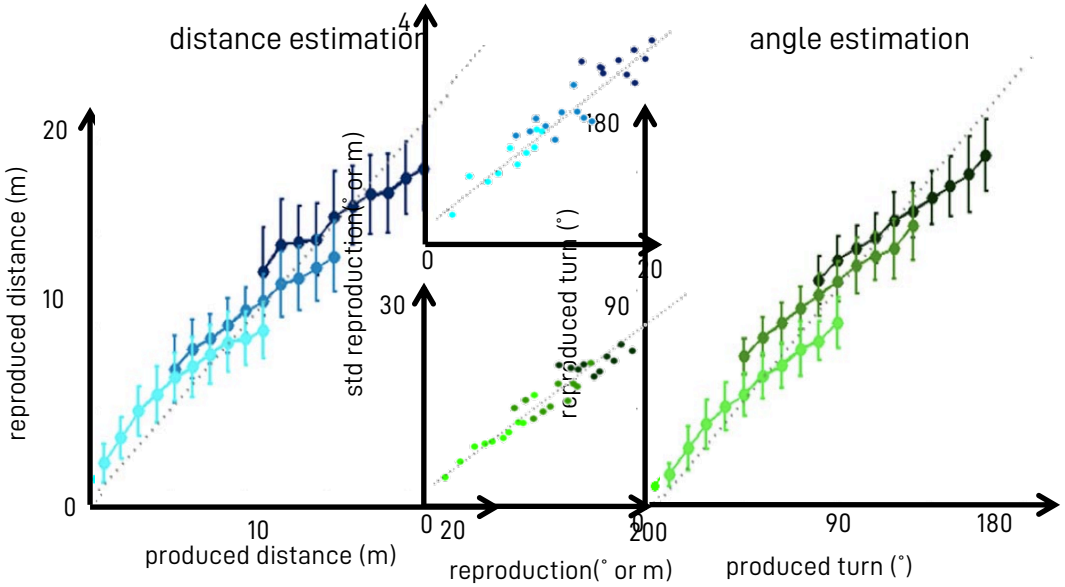


Petzschner & Glasauer, JoN, 2011

Varying the sample range

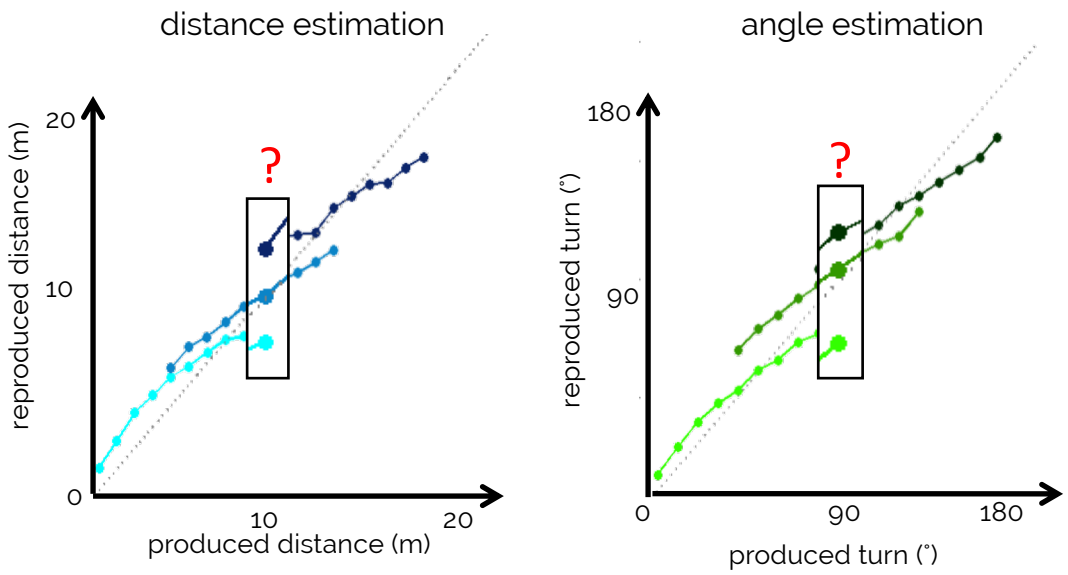


Petzschner & Glasauer, JoN, 2011



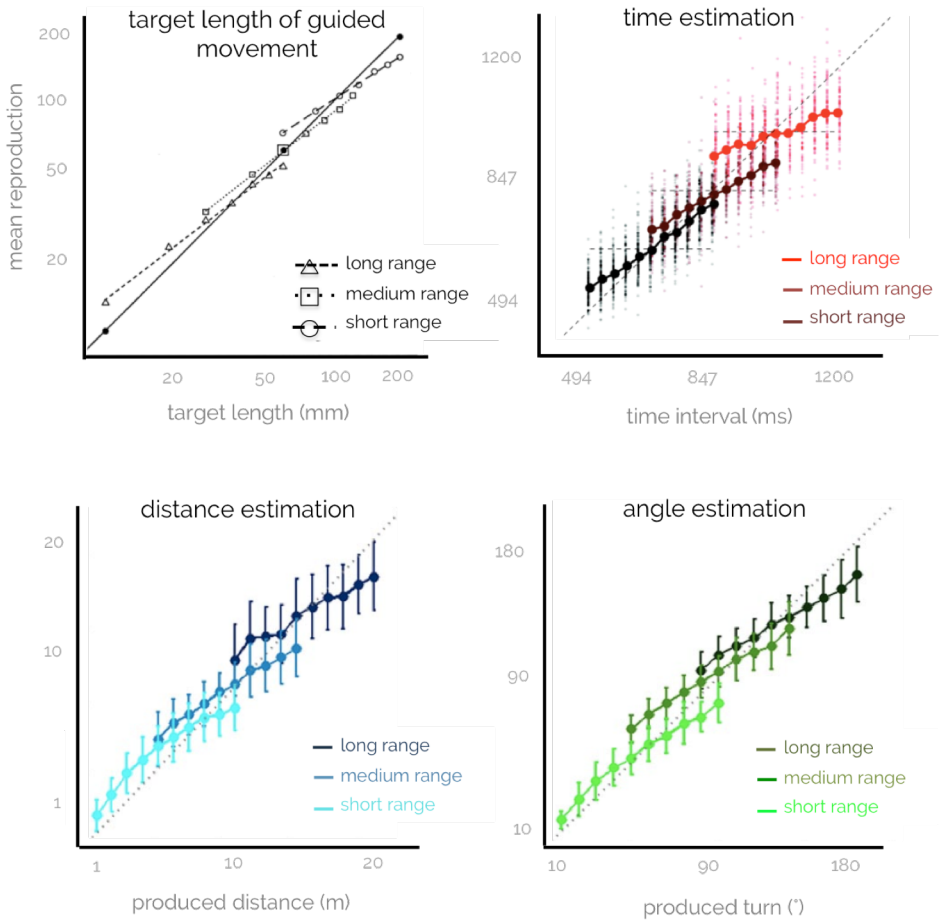
Petzschner & Glasauer, JoN, 2011

Prior knowledge: Experience



Petzschner & Glasauer, JoN, 2011

Let's take a look at the literature

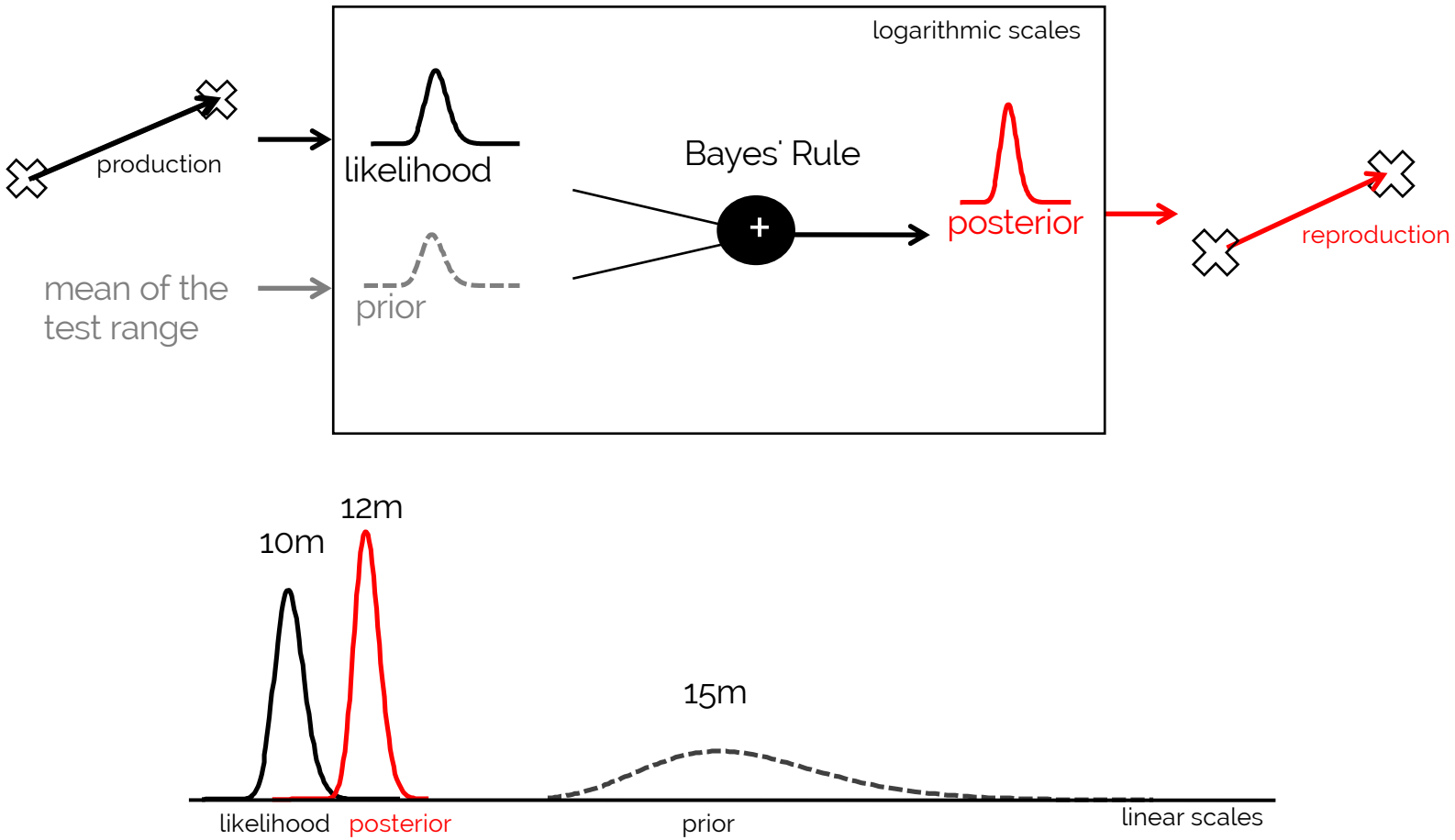


Petzschner et al, TiCS, 2015; Petzschner & Glasauer, JoN, 2011

A Bayesian Model for magnitude estimation

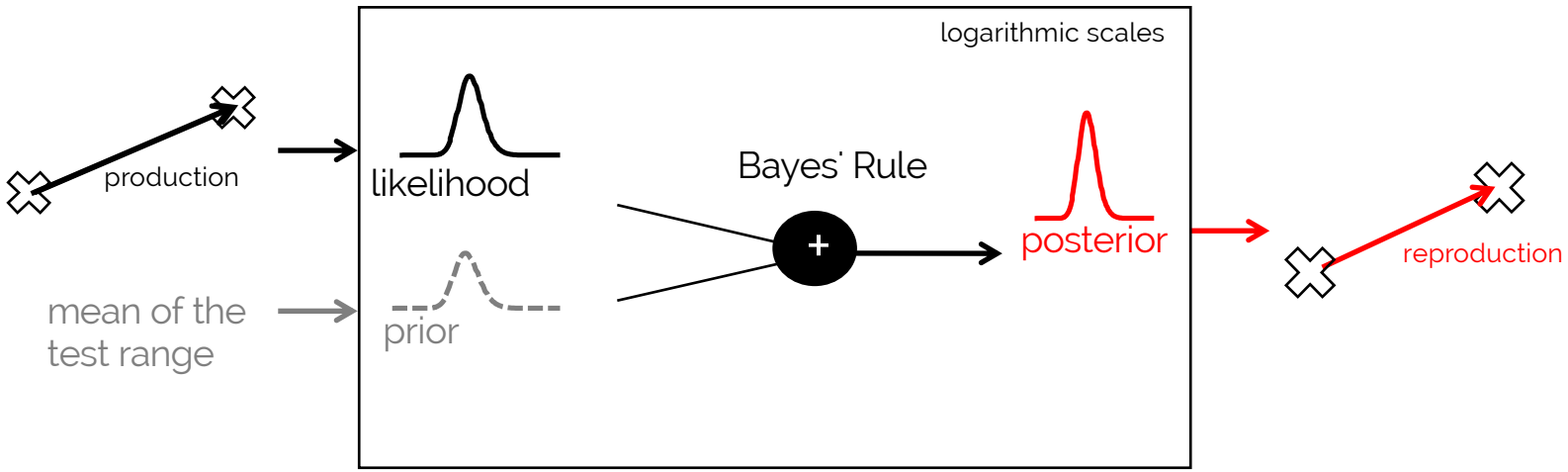
Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

A Bayesian Model for magnitude estimation



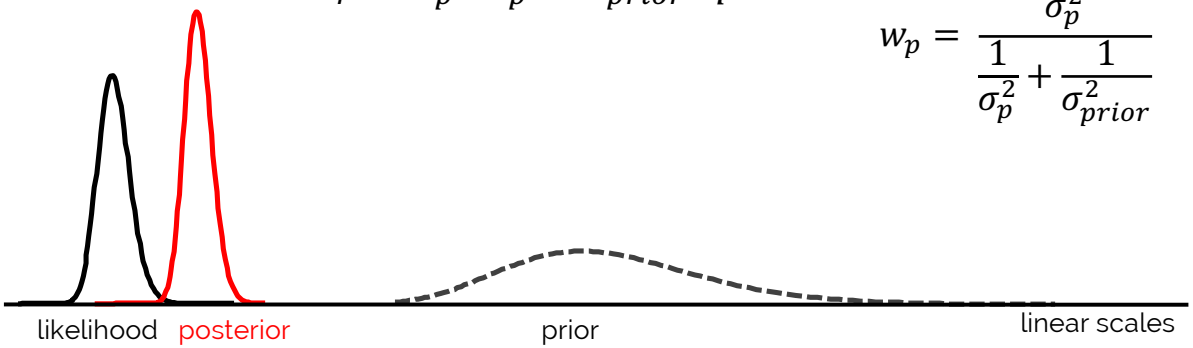
Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

A Bayesian Model for magnitude estimation



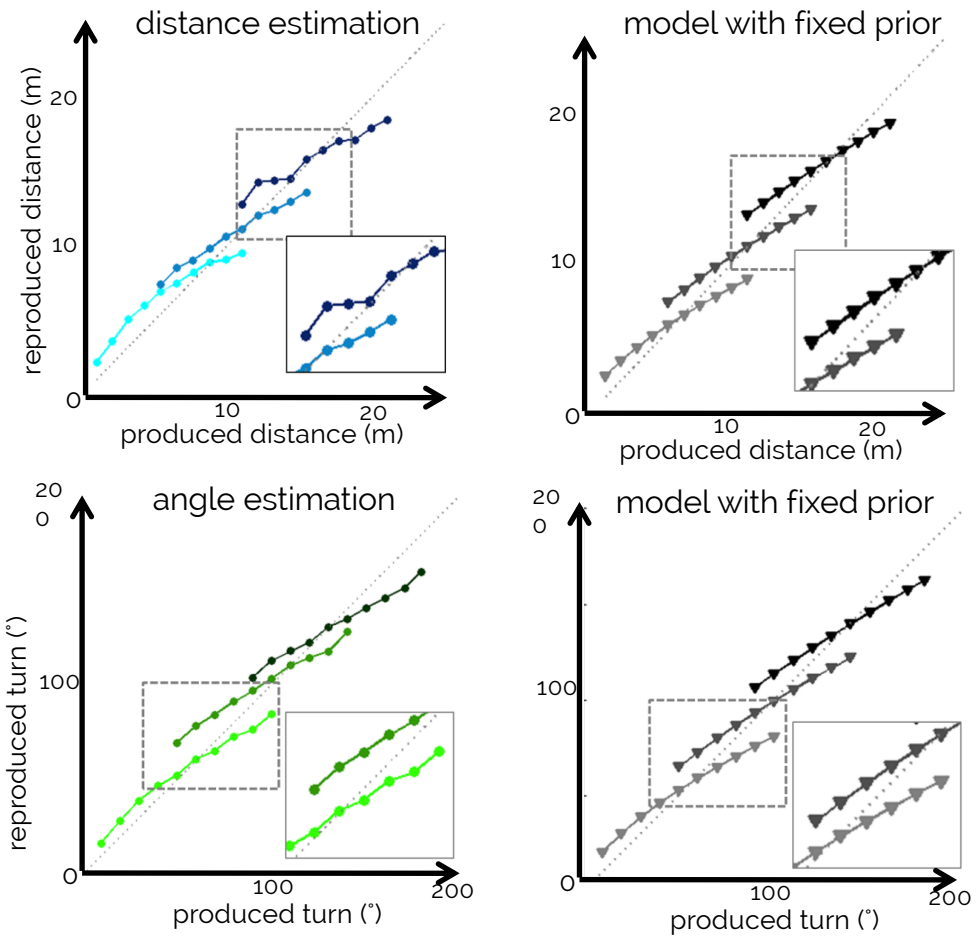
$$\widehat{d_r} = w_p \cdot d_p + w_{prior} \cdot prior$$

$$w_p = \frac{\frac{1}{\sigma_p^2}}{\frac{1}{\sigma_p^2} + \frac{1}{\sigma_{prior}^2}}$$



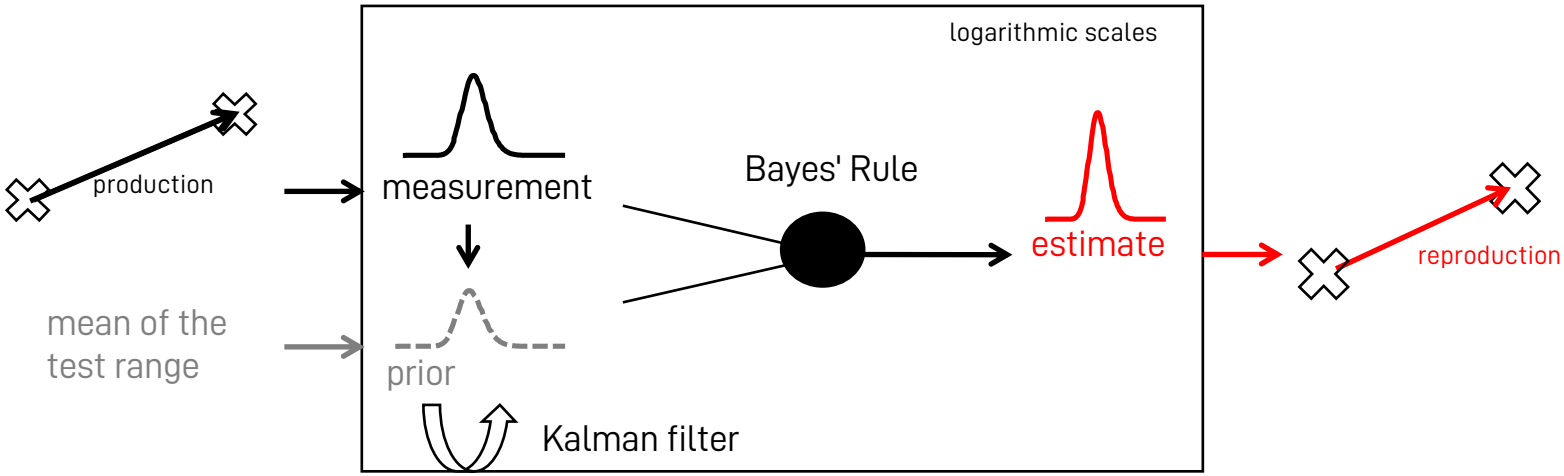
Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

Quantitative results



Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

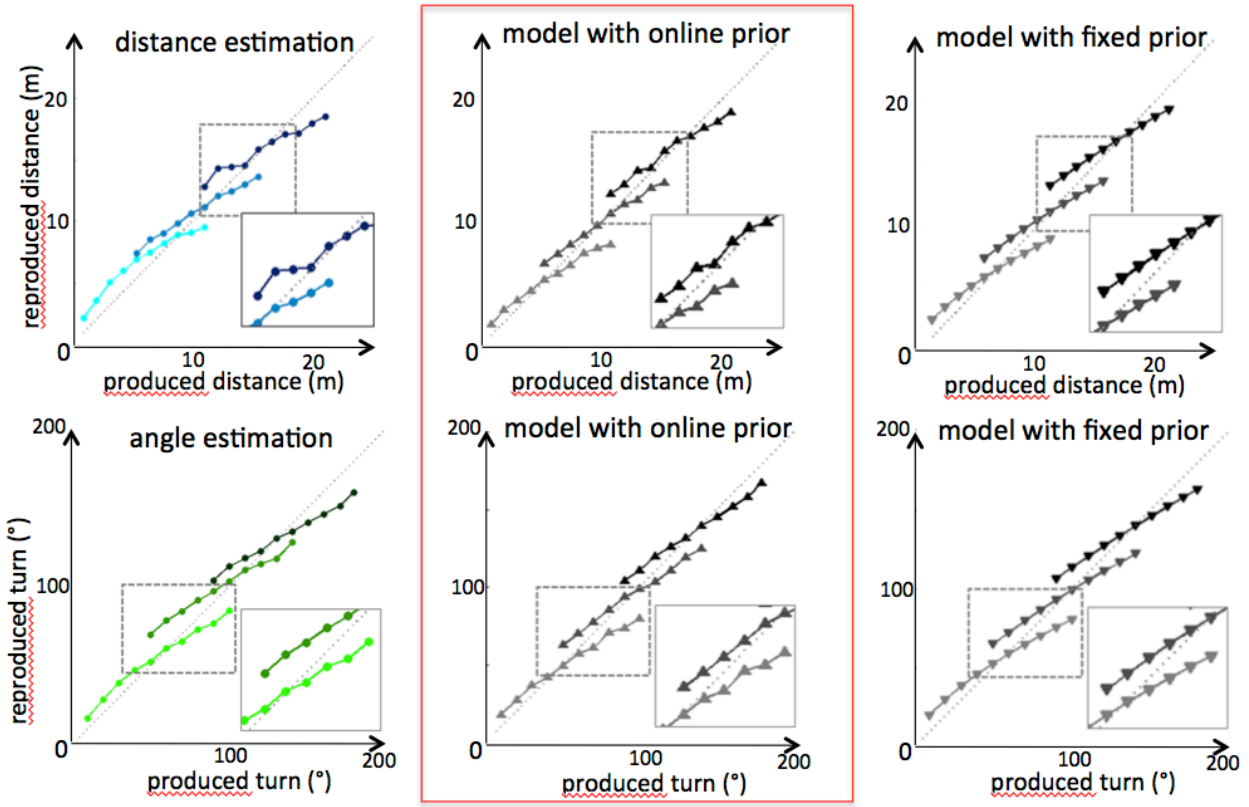
Bayesian Learning



"Todays posterior is tomorrows prior."

Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

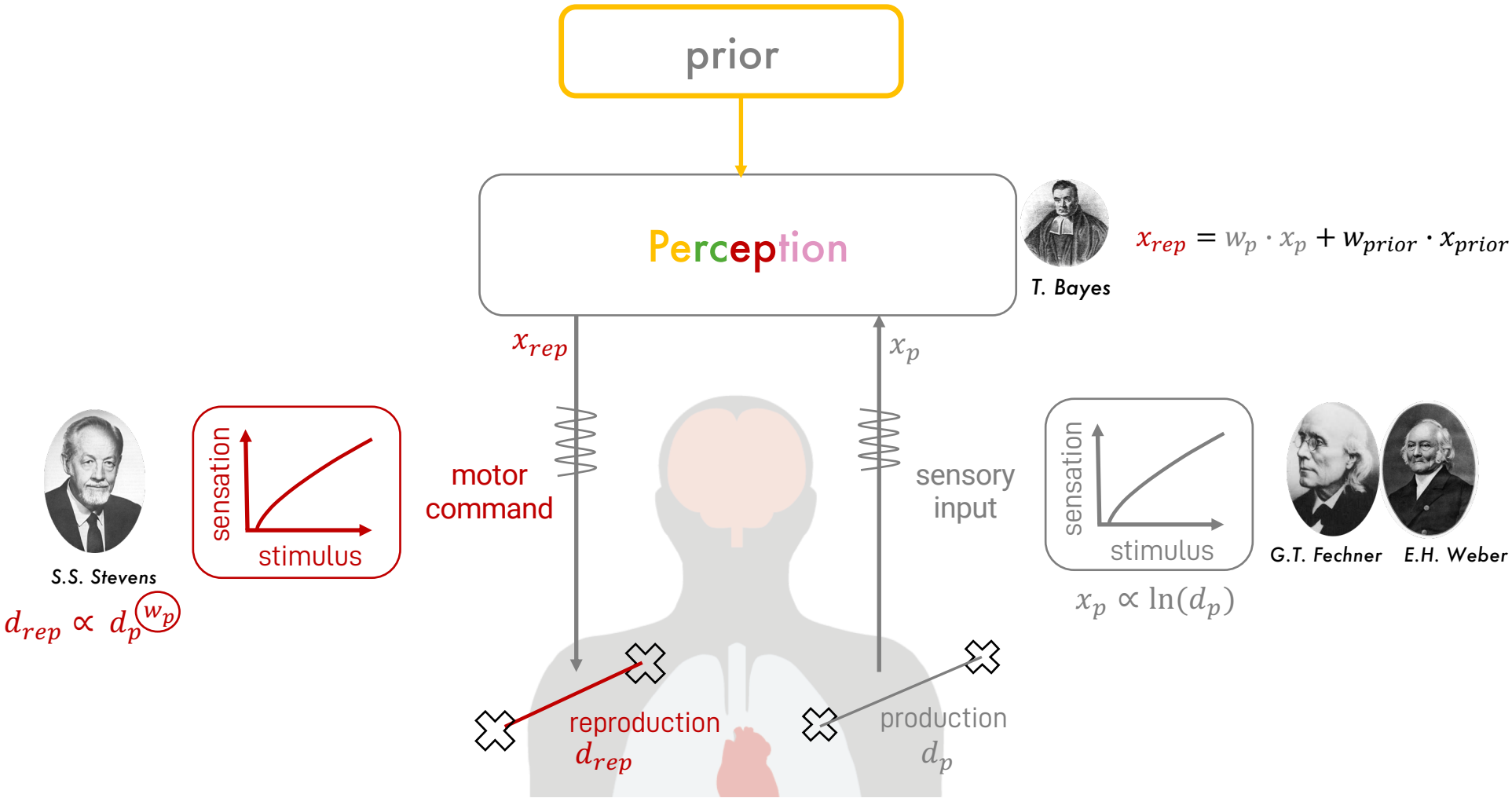
Bayesian Learning

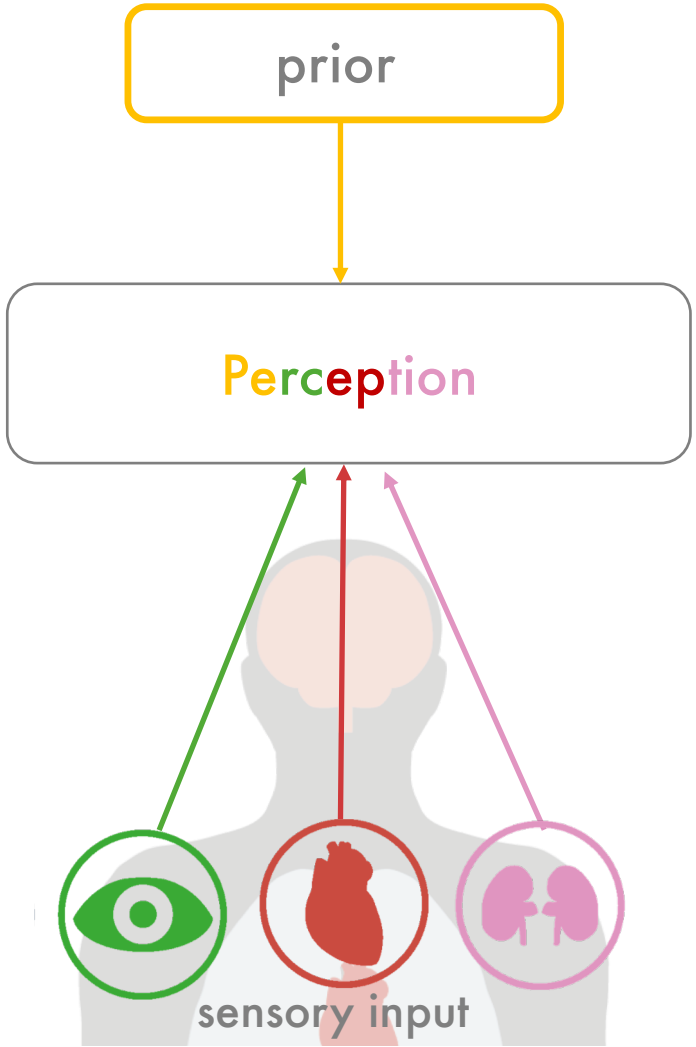


→ Talks on Learning this afternoon

Petzschner & Glasauer, JoN, 2011; Petzschner et al, TiCS, 2015

Back to psychophysics

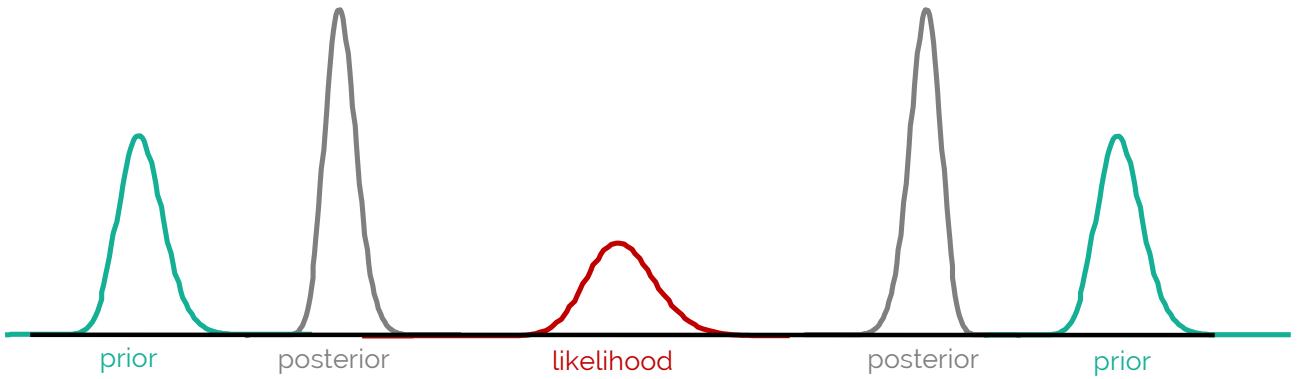



prior
Perception
sensory input

Critiques and interpretations

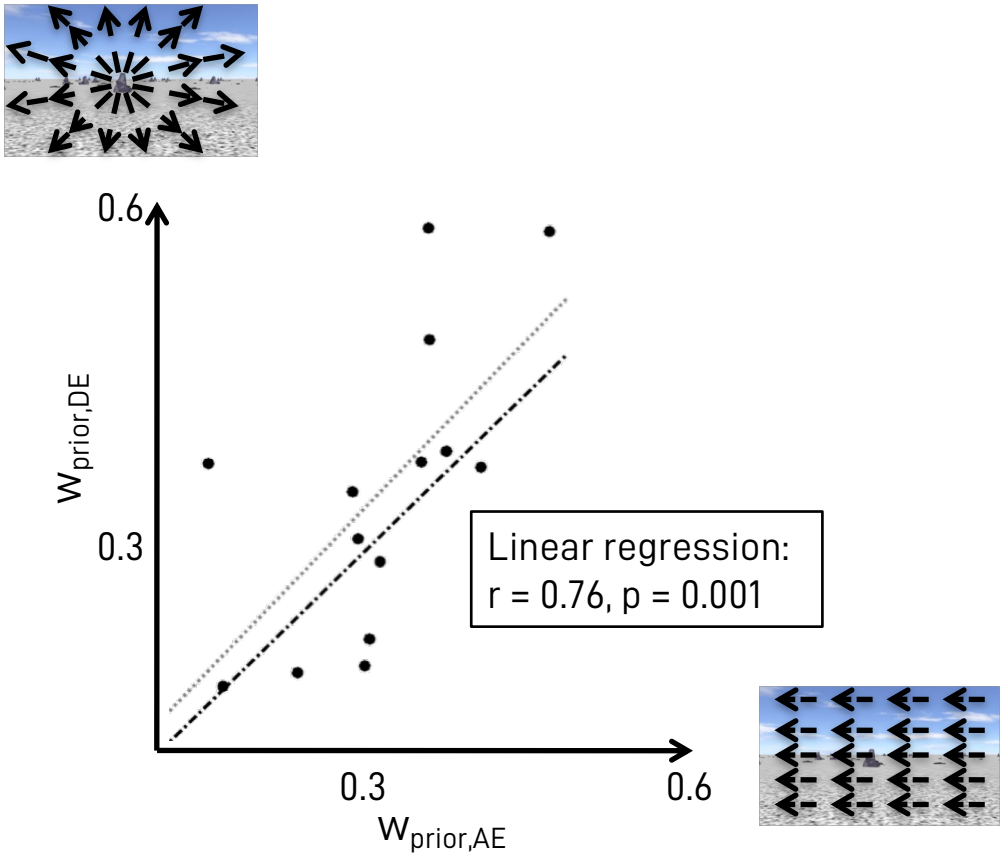
Critique

'there are too many arbitrary ways that priors, likelihoods, utility functions, etc., can be altered in a Bayesian theory post hoc'.



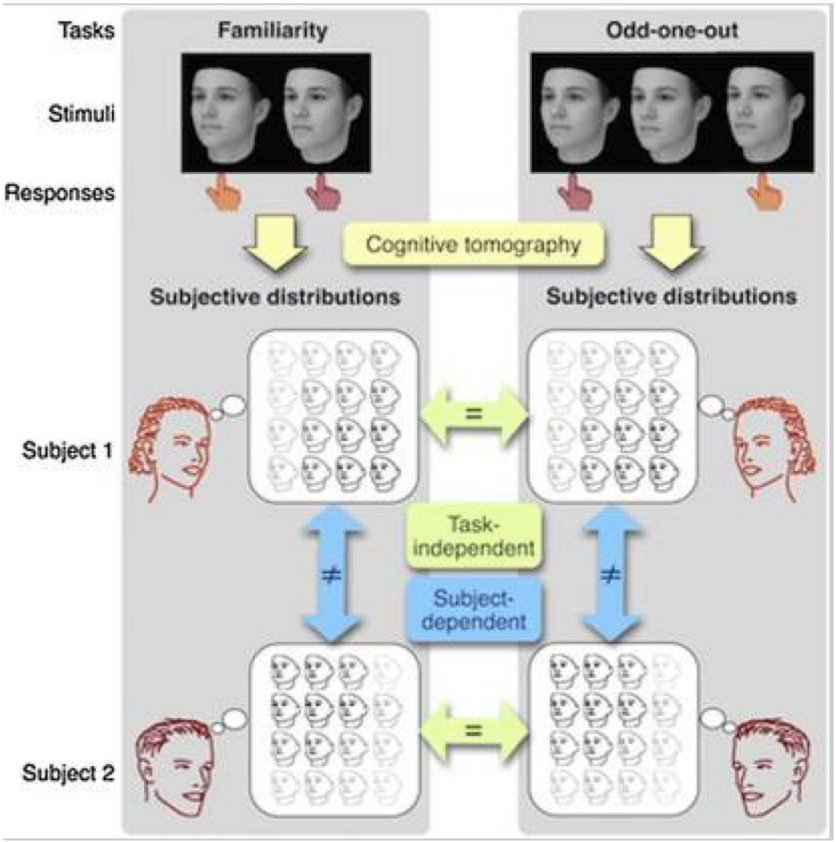
Bowers and Davis, 2012a,b; Griffiths et al., 2012, Colombo and Series, 2012; Jones and Love, 2011

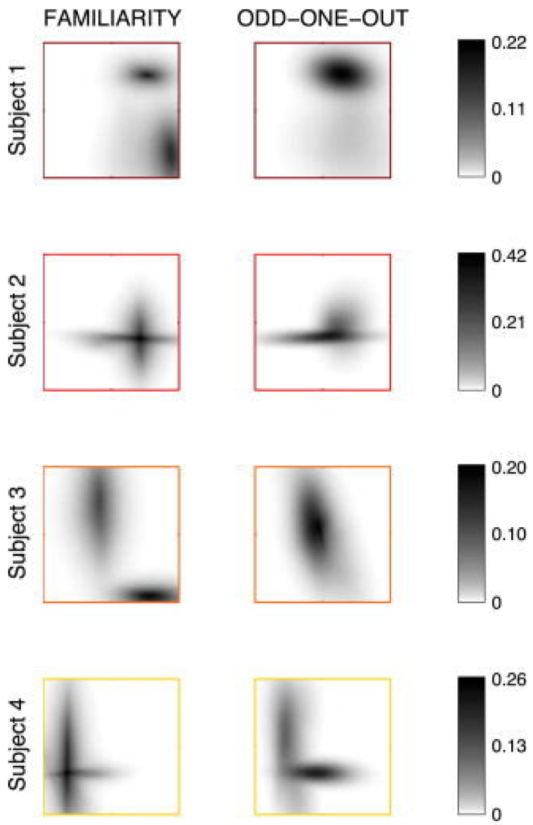
Do priors generalize?



Petzschner et al, TiCS, 2015; Petzschner & Glasauer, JoN, 2011

Do priors generalize?





Houlsby et al., Current Biology, 2013

Bayes in the brain

Marr's Three Levels of Analysis

- Computation:

  "What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?"

- Algorithm:

  Cognitive psychology

- Implementation: ***Berkes, et al., Science, 2011***

  Neurobiology

Bowers and Davis, 2012a,b; Griffiths et al., 2012, Colombo and Series, 2012; Jones and Love, 2011

Bayesian model across the literature

[Friston and Stephan, 2007; Knill and Pouget, 2004; Knill and Richards, 1996]

Magnitude perception [Shadlen, Kiani, Glasauer, Petzschner, ...]

Visual perception [Weiss, Simoncelli, Adelson, Richards, Freeman, Feldman, Kersten, Knill, Maloney, Olshausen, Jacobs, Pouget, ...]

Haptic perception [Ernst, Banks, ...]

Auditory perception [Alais, Burr, ...]

Language acquisition and processing [Brent, de Marken, Niyogi, Klein, Manning, Jurafsky, Keller, Levy, Hale, Johnson, Griffiths, Perfors, Tenenbaum, ...]

Motor learning and motor control [Ghahramani, Jordan, Wolpert, Kording, Kawato, Doya, Todorov, Shadmehr, ...]

Associative learning [Dayan, Daw, Kakade, Courville, Touretzky, Kruschke, ...]

Memory [Anderson, Schooler, Shiffrin, Steyvers, Griffiths, McClelland, ...]

Attention [Mozer, Huber, Torralba, Oliva, Geisler, Yu, Itti, Baldi, ...]

Categorization and concept learning [Anderson, Nosfosky, Rehder, Navarro, Griffiths, Feldman, Tenenbaum, Rosseel, Goodman, Kemp, Mansinghka, ...]

Reasoning [Chater, Oaksford, Sloman, McKenzie, Heit, Tenenbaum, Kemp, ...]

Causal inference [Waldmann, Sloman, Steyvers, Griffiths, Tenenbaum, Yuille, ...]

Decision making and theory of mind [Lee, Stankiewicz, Rao, Baker, Goodman, Tenenbaum, ...]

Optimal motor control [Wolpert, Körding ...]

Computational Psychiatry and Bayesian Models of Perception

When the world becomes 'too real': a Bayesian explanation of autistic perception

Elizabeth Pellicano[1,3] and David Burr[2,3]

Understanding why patients with schizophrenia do not perceive the hollow-mask illusion using dynamic causal modelling

Danai Dima [a,*], Jonathan P. Roiser [c], Detlef E. Dietrich [a,b], Catharina Bonnemann [a], Heinrich Lanfermann [d], Hinderk M. Emrich [a,b], Wolfgang Dillo [a]

No rapid audiovisual recalibration in adults on the autism spectrum

Marco Turi[1], Themelis Karaminis[2], Elisa R. Pellicano[2,4] & David Burr[3,4]

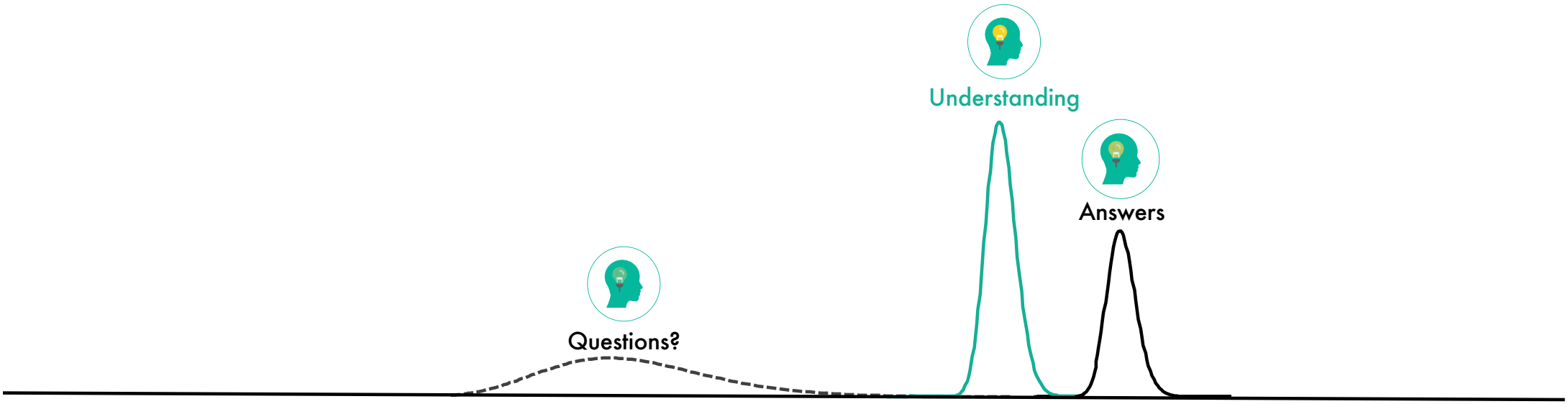
'Wrong' priors (bad experiences, maladaptive learning)
'Wrong' likelihood
'Wrong' Precision
'Wrong' execution/decision

Shift toward prior knowledge confers a perceptual advantage in early psychosis and psychosis-prone healthy individuals

Christoph Teufel[a,b,1], Naresh Subramaniam[b], Veronika Dobler[c,d], Jesus Perez[c,d], Johanna Finnemann[b,e], Puja R. Mehta[b], Ian M. Goodyer[c,d], and Paul C. Fletcher[b,d]

Depression: A Decision-Theoretic Analysis

Quentin J.M. Huys,[1,2] Nathaniel D. Daw,[3] and Peter Dayan[4]


Understanding
Answers
Questions?