The Bayesian Brain:
an evolutionary approach to cognition

"Nothing in biology makes sense except in the light of evolution."

T. Dobzhansky (1973).

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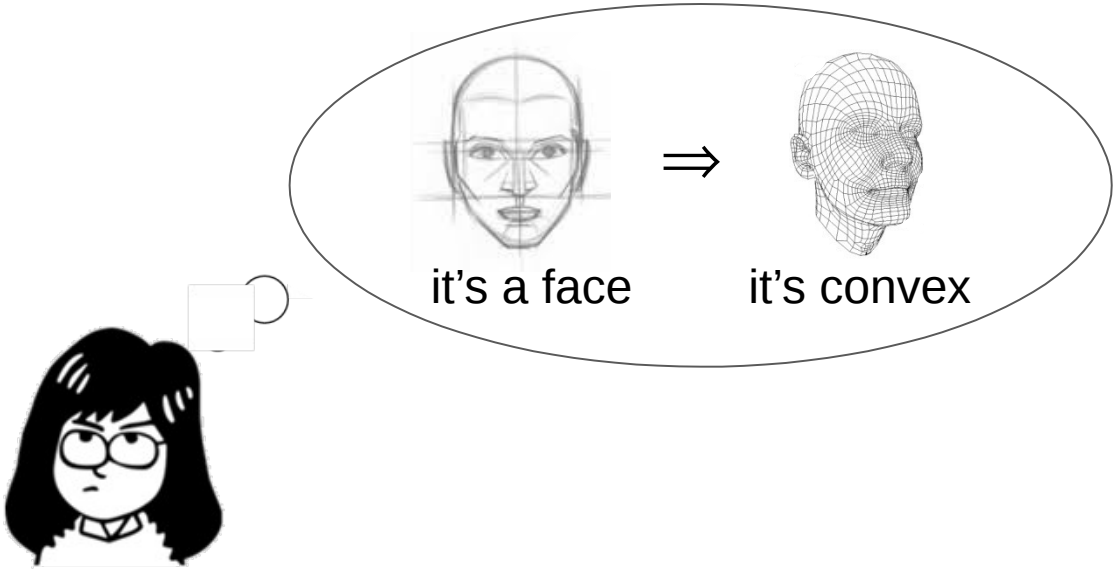
ETH, Zurich, Switzerland

The “bayesian brain” hypothesis



- ✓ Cerebral information processing was optimized through natural selection
- ✓ Cerebral information processing (i) is optimal *on average*, but (ii) can induce systematic *biases*

Overview of the talk

- ✓ *Optimality principles and Bayesian decision theory*
- ✓ *What is optimal about perception?*
- ✓ *Motor control and the corollary discharge*
- ✓ *Neural code efficiency and predictive coding*
- ✓ *Discussion*

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Optimality principles

Are optimality principles amenable to mathematical modelling?

✓ Information theory:

- describes *optimal propagation of information/uncertainty*
- relies on probability calculus (***Bayes' rule***)
- models of perception, memory and learning

✓ Decision theory:

- describes *optimal use of information for action*
- relies on ***utility/loss functions***
- models of decision making and motor control

✓ Bayesian Decision Theory = information theory + decision theory

Optimality principles

Marr's tri-level description of cognitive processes

✓ Computational level:

- what problem does the system solve?
- why does it solve this problem?

BDT

✓ Algorithmic/representational level:

- how does the system do what it does?
- what representations does it use and what processes does it employ to build and manipulate the representations?

neural code

✓ Implementational level:

- how is the system physically realized?
- what neurobiological mechanisms implement the algorithmic level?

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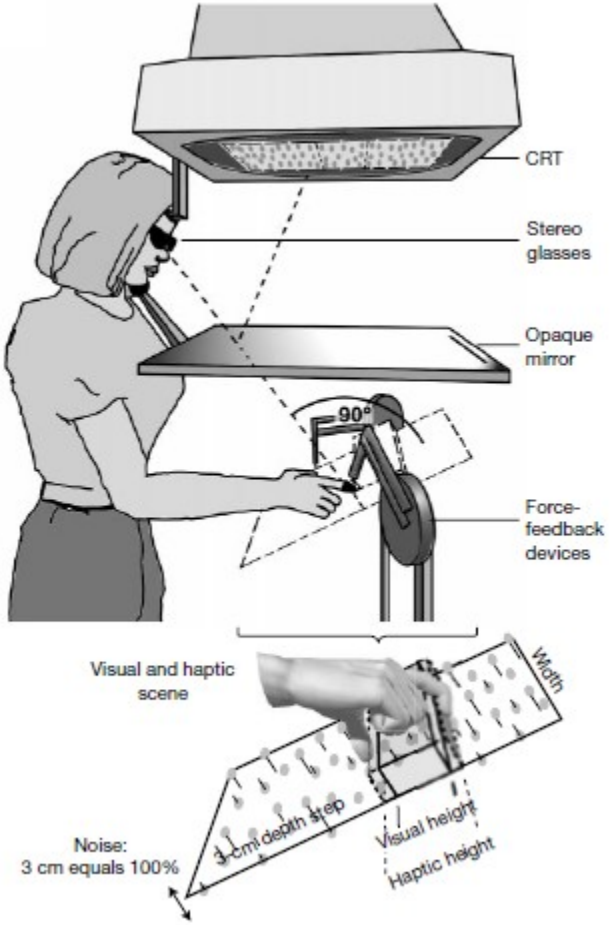
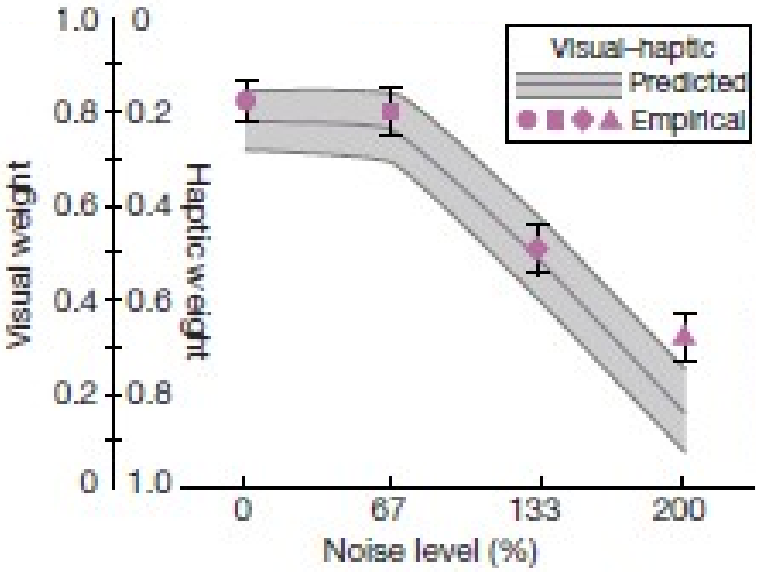
What is optimal about perception?

precision-weighted multisensory integration

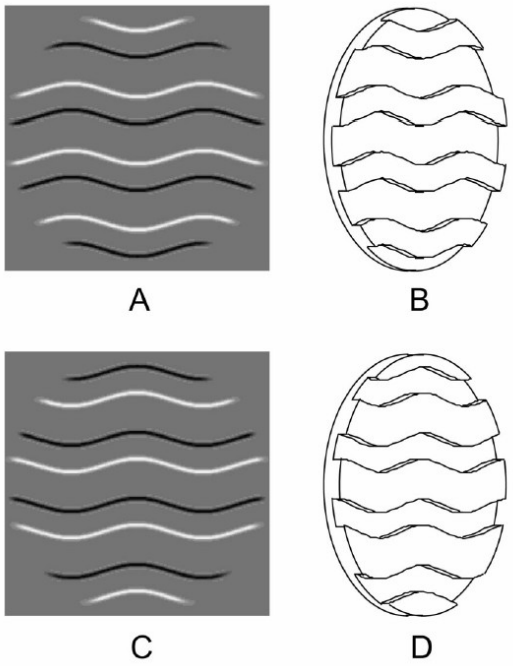


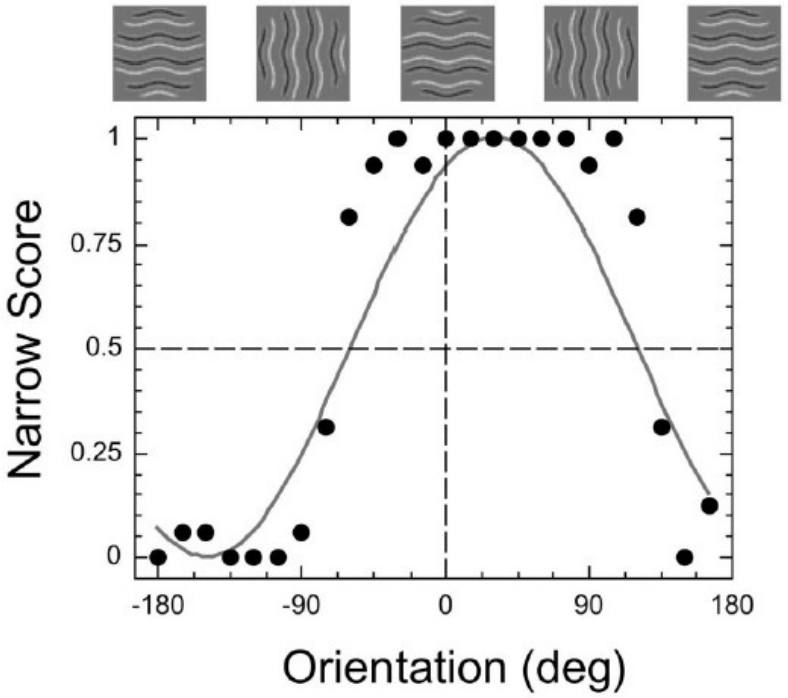


Ernst & Banks (2002)

What is optimal about perception?

can visual illusions reveal the priors of the visual system?

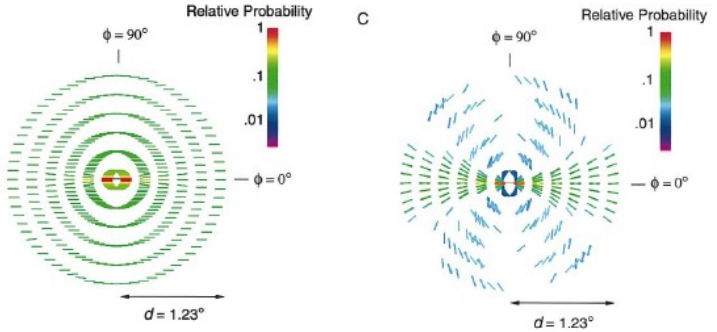


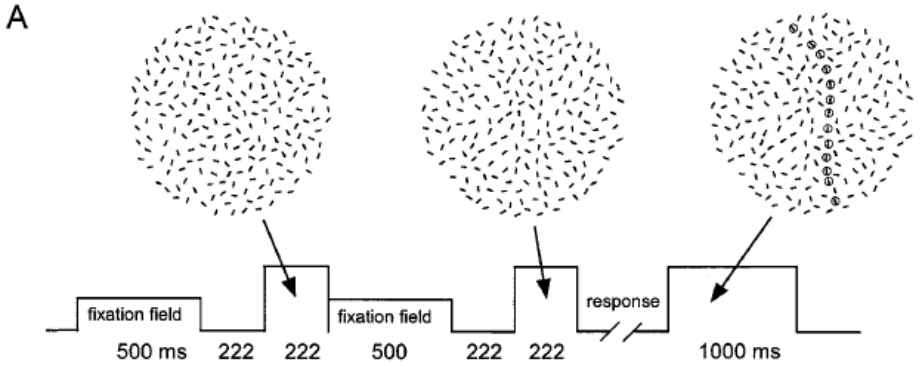


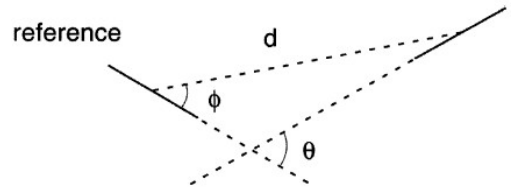
Mammassian & Goutcher (2001)

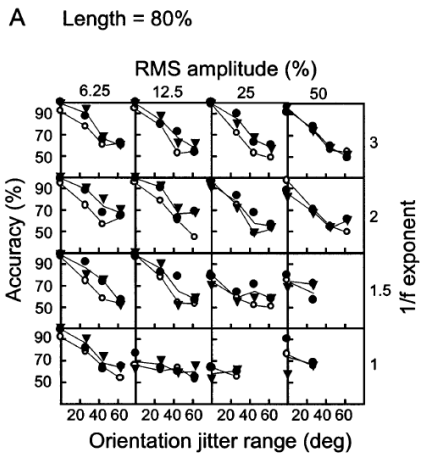
What is optimal about perception?

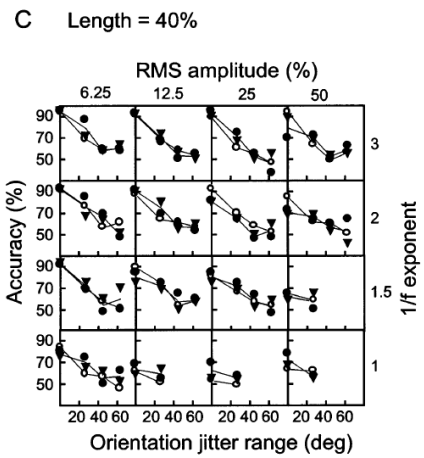
does the visual system use priors that capture natural scenes' statistics?











Geisler et al. (2001)

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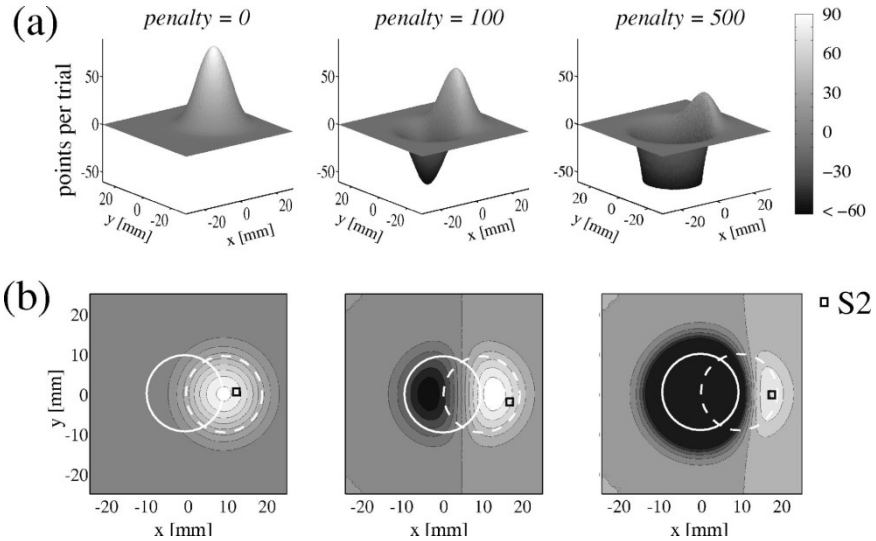
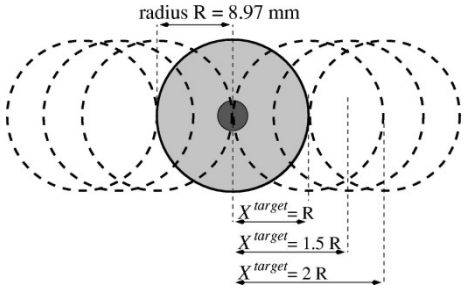
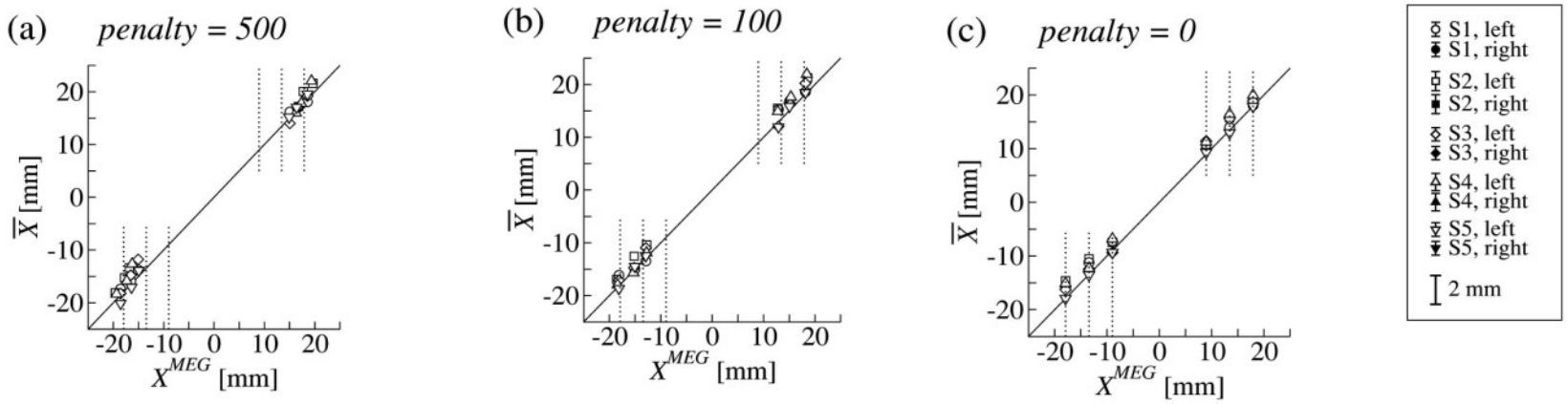
Motor control and the corollary discharge

movement planning under risk



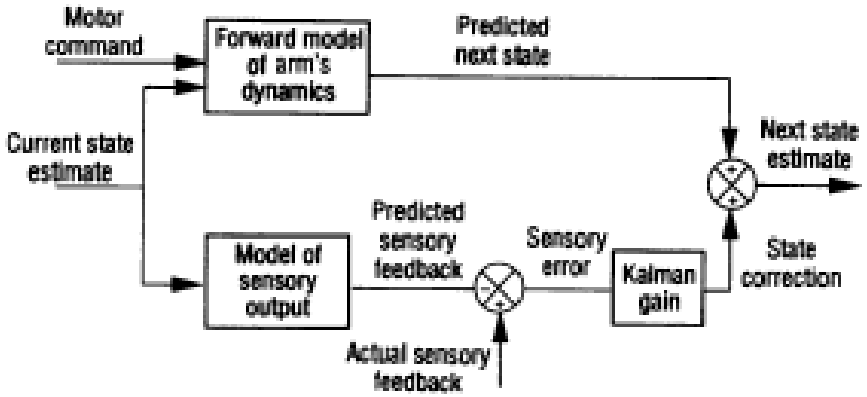


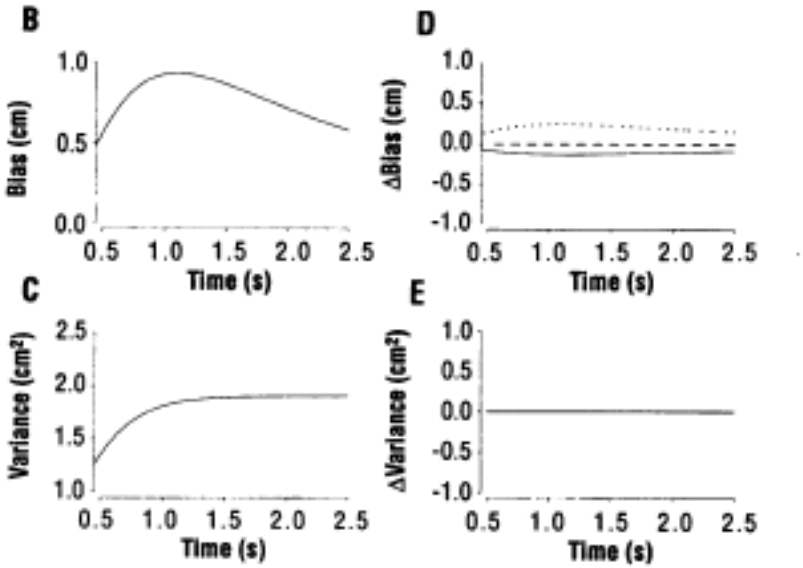


Trommershauser et al. (2003)

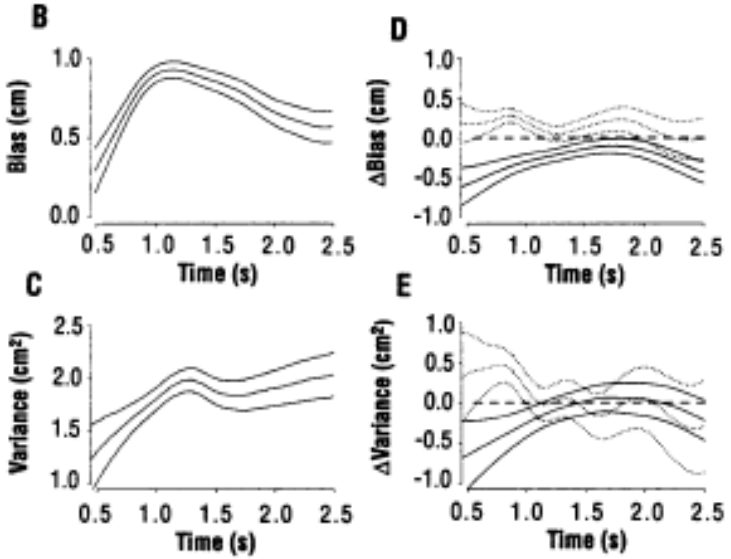
Motor control and the corollary discharge

an internal model for sensorimotor integration?





model simulations

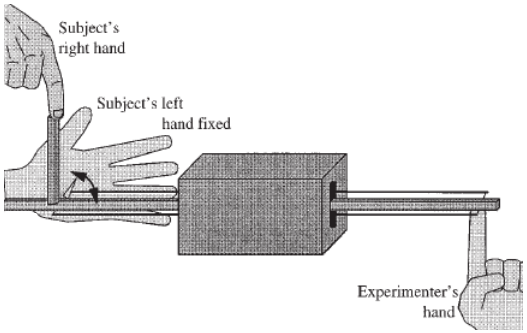


empirical data

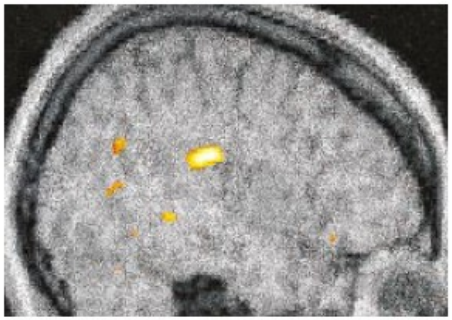
Wolpert et al. (1995)

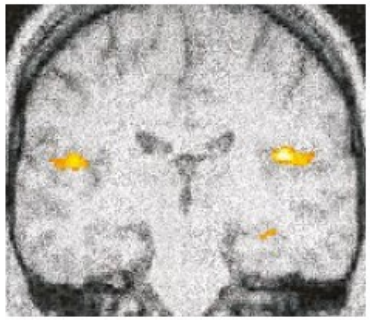
Motor control and the corollary discharge

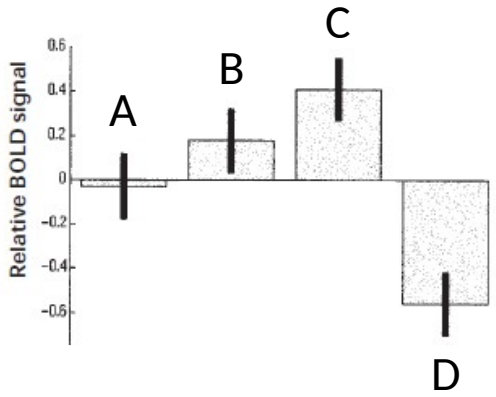
is there a prediction error signal in the brain?



	Tactile stimuli	No tactile stimuli
Self-generated movement	A, Self-produced tactile stimuli	B, Self-produced movement without tactile stimuli
No self-generated movement	C, Externally produced tactile stimuli	D, Rest







Blakemore et al. (1998)

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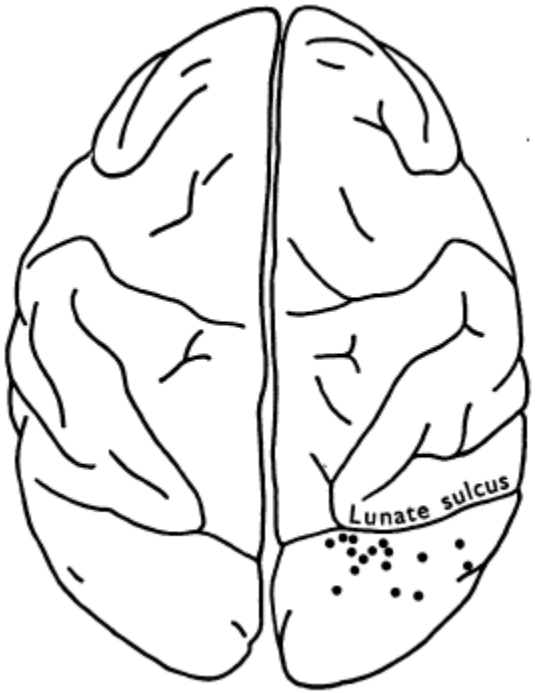
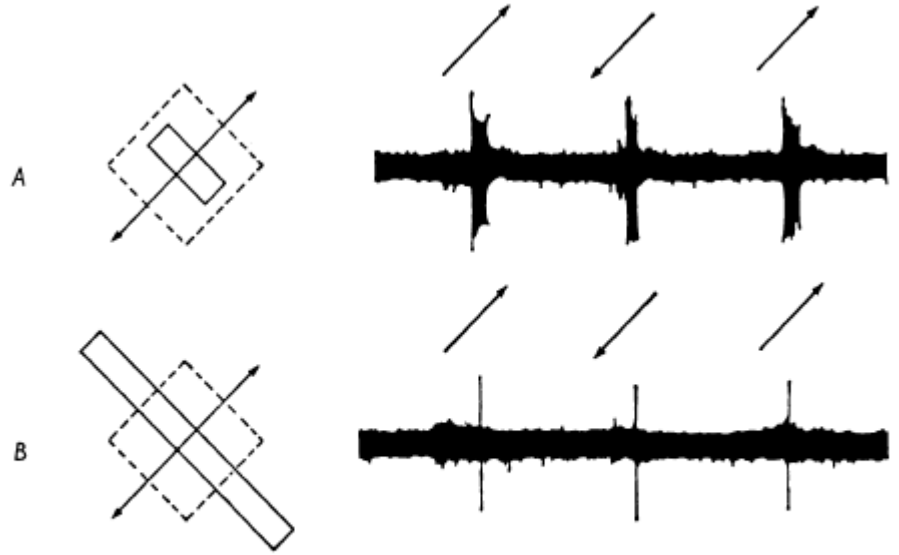
Neural code redundancy and predictive coding

extra-classical receptive field effects



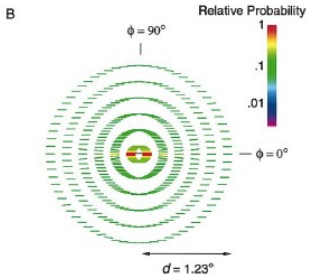


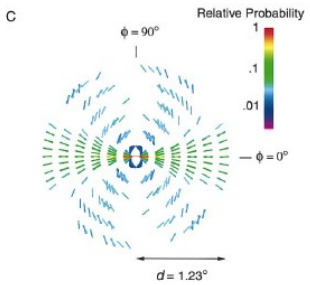
Text-fig. 4. Hypercomplex cell recorded from right striate cortex, layer II. *A*: stimulus of left eye by moving slit within activating region ($\frac{1}{4} \times \frac{3}{8}°$); *B*: similar stimulation with slit extending beyond activating region. Background, log 0·0 cd/m²; stimulus, log 1·3 cd/m². Duration of each record 10 sec.

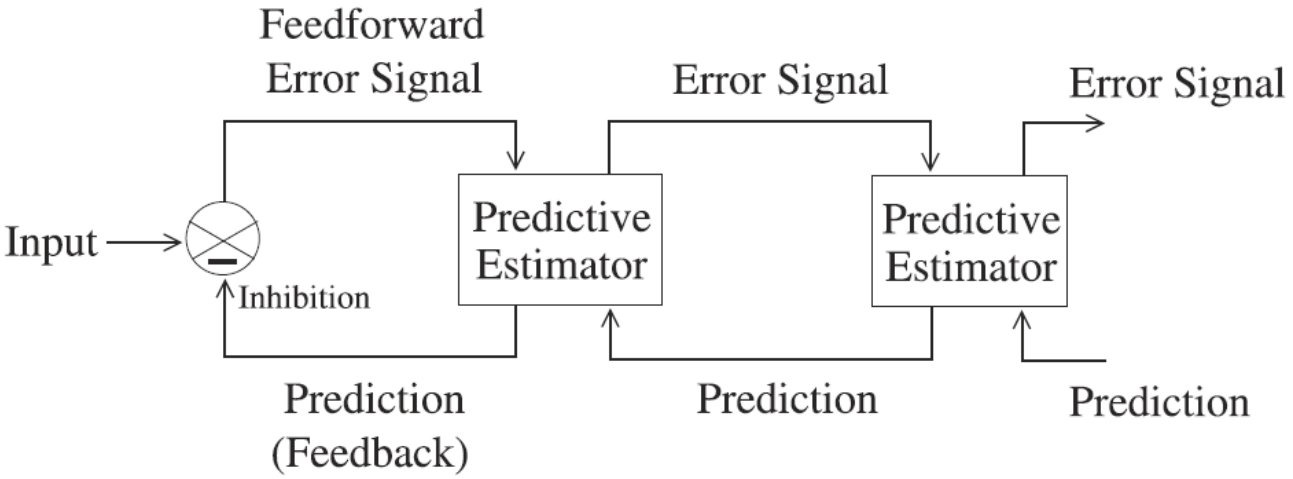
Hubel & Wiesel (1968)

Neural code redundancy and predictive coding

can input correlations be exploited to minimize redundancy in the neural code?



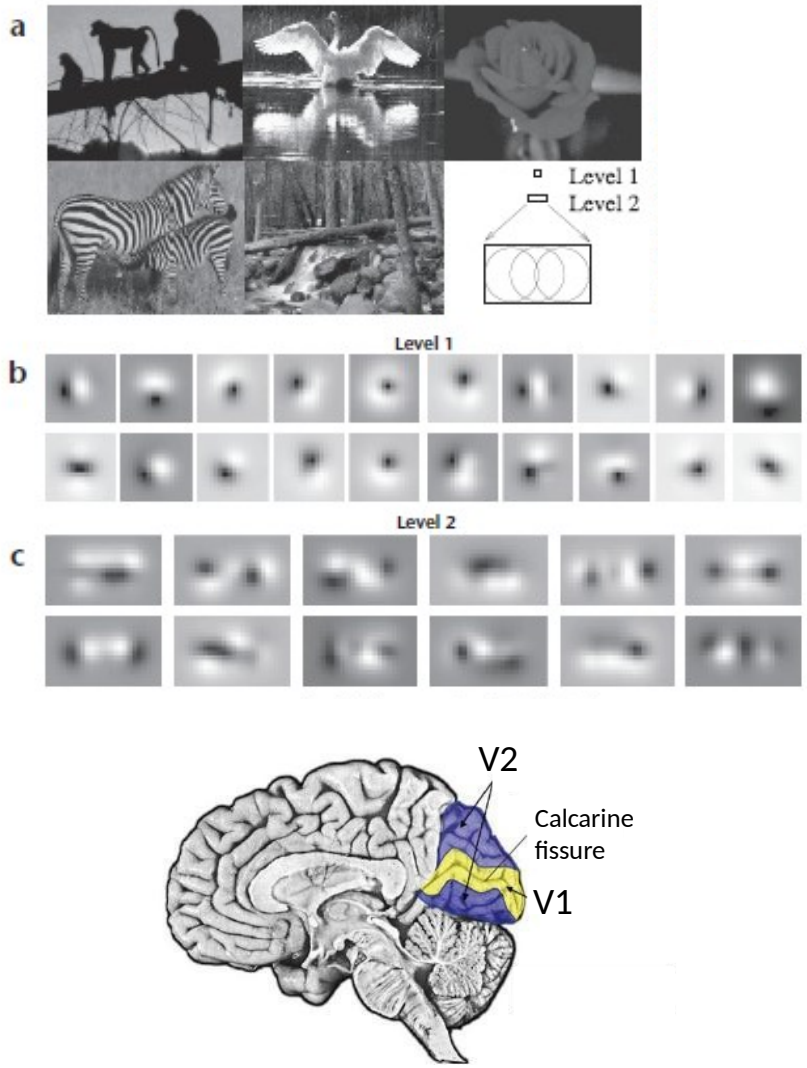


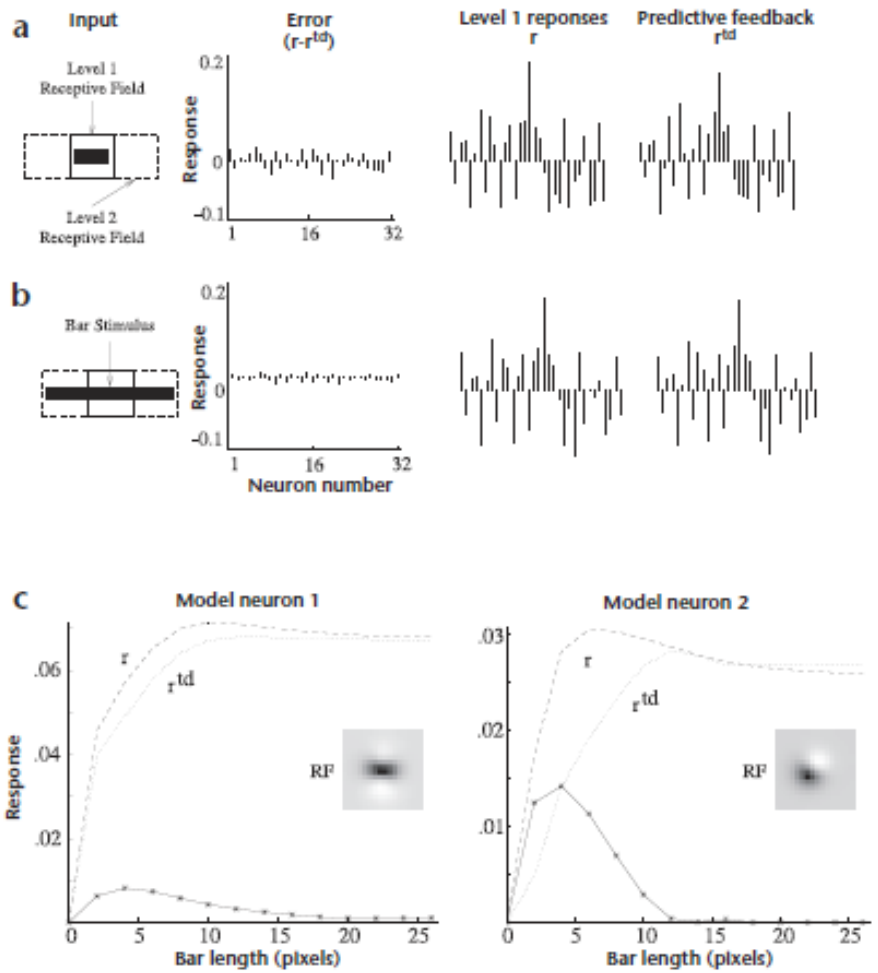


Rao & Ballard (1999)

Neural code redundancy and predictive coding

the emergence of functional segregation





Rao & Ballard (1999)

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Conclusion

- ✓ Bayesian brain = specialized, precise, efficient, flexible…
  - optimality = stigma of an important (computational) problem
  - optimality is only guaranteed *on average*
- ✓ What about “higher-level” cognitive functions?
  - attention (allocation of limited processing resources)
  - motivation (decision biases)
  - consciousness
  - …
- ✓ Questions?