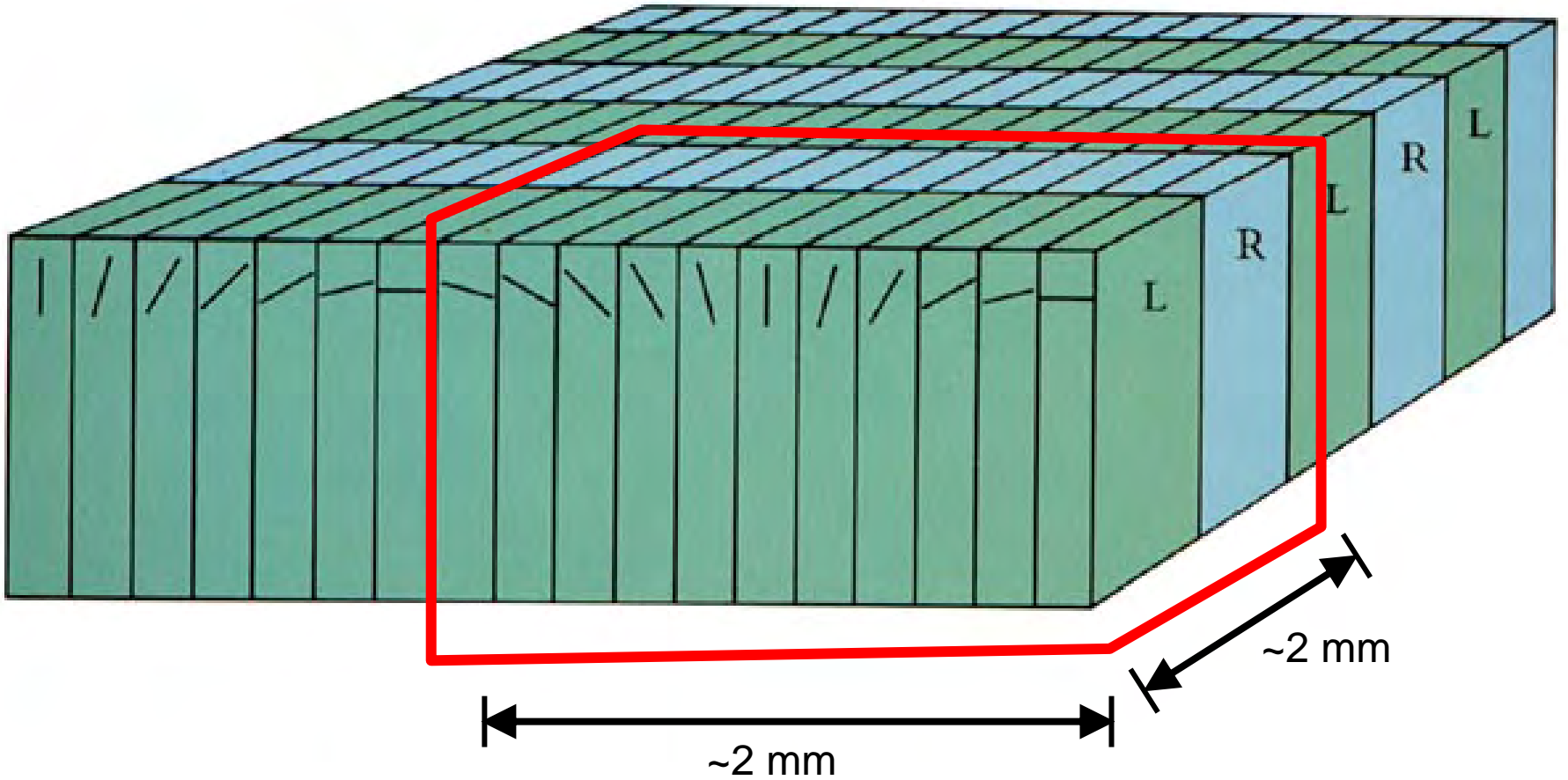
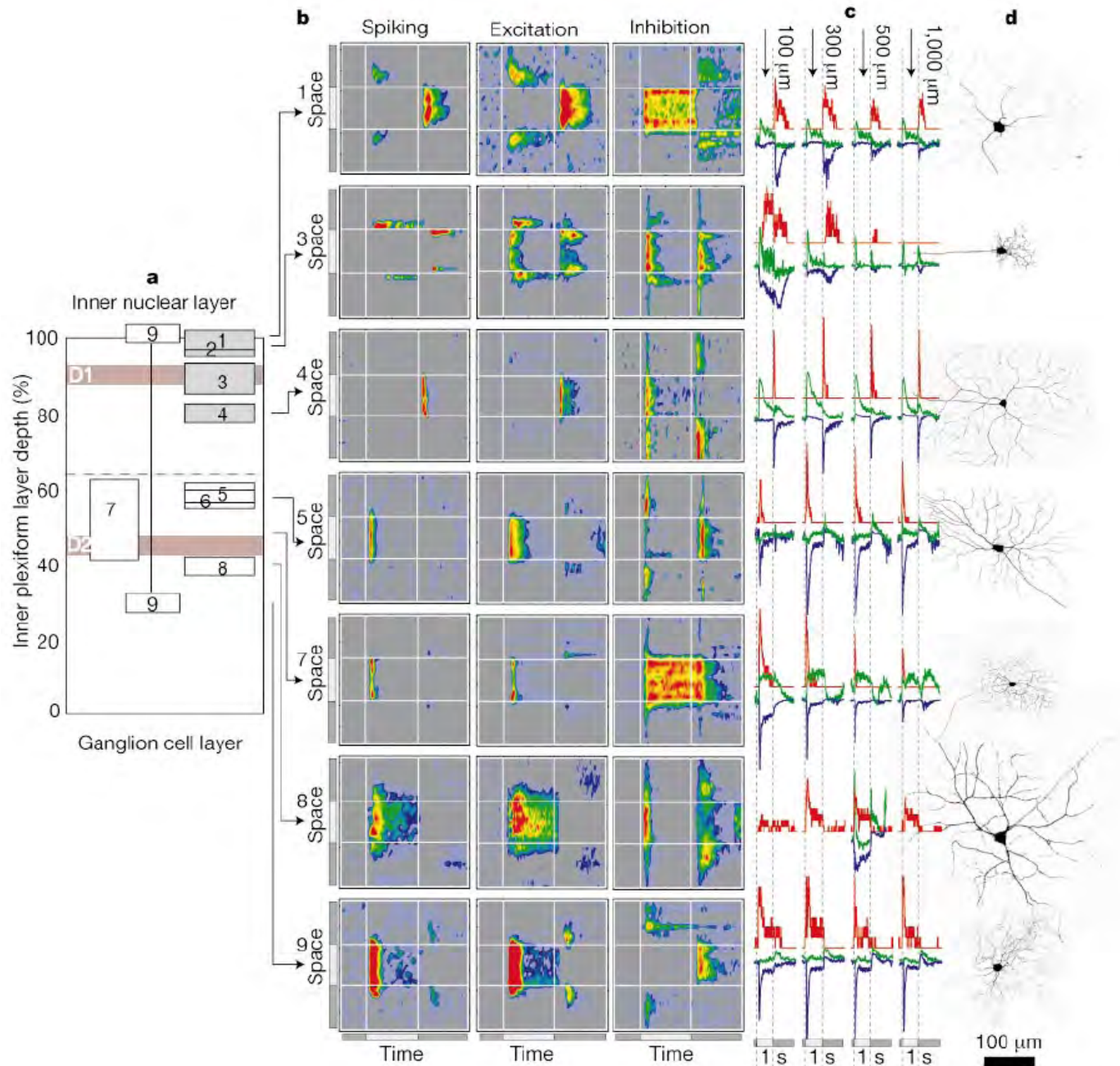


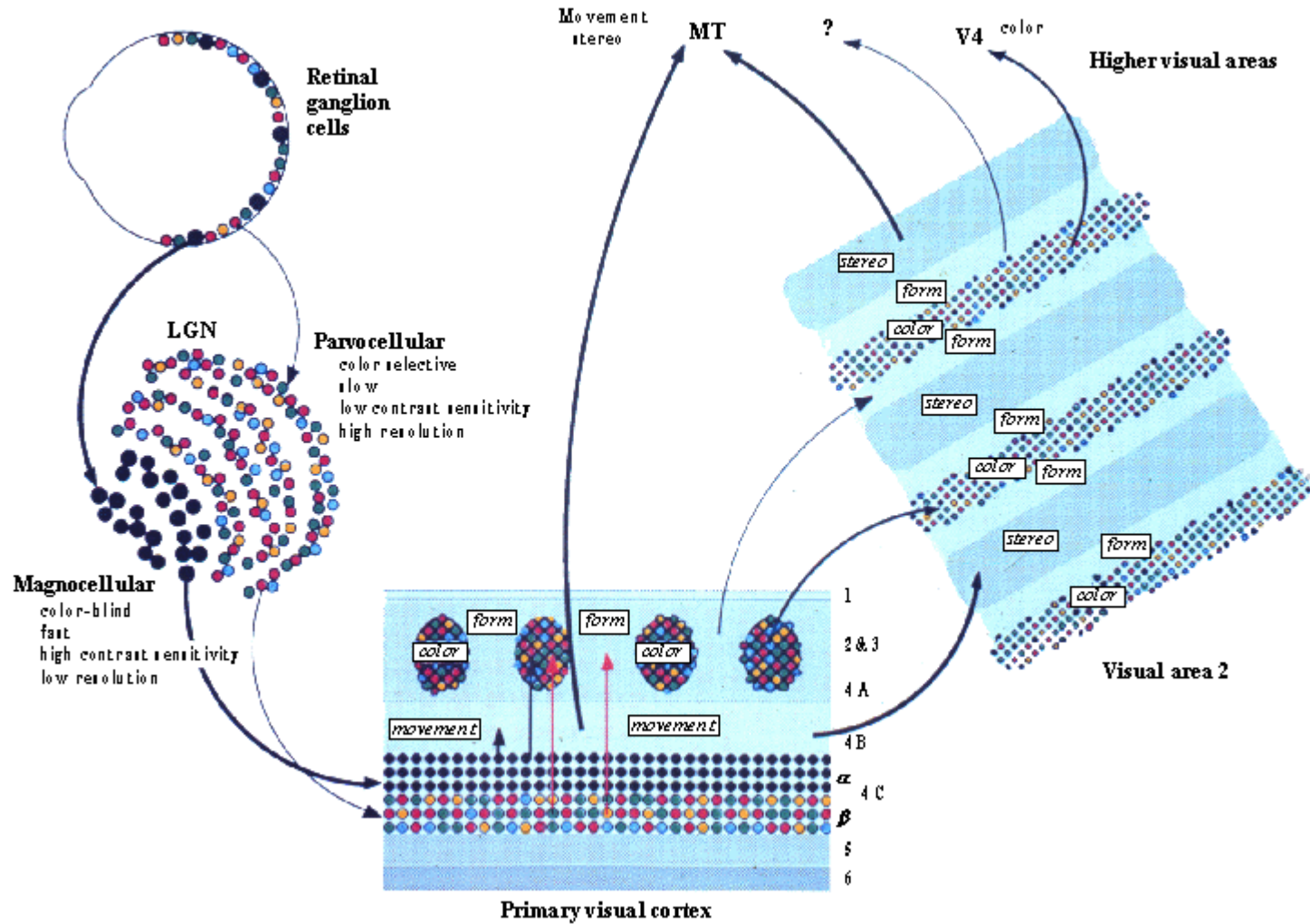
# “Hypercolumn”



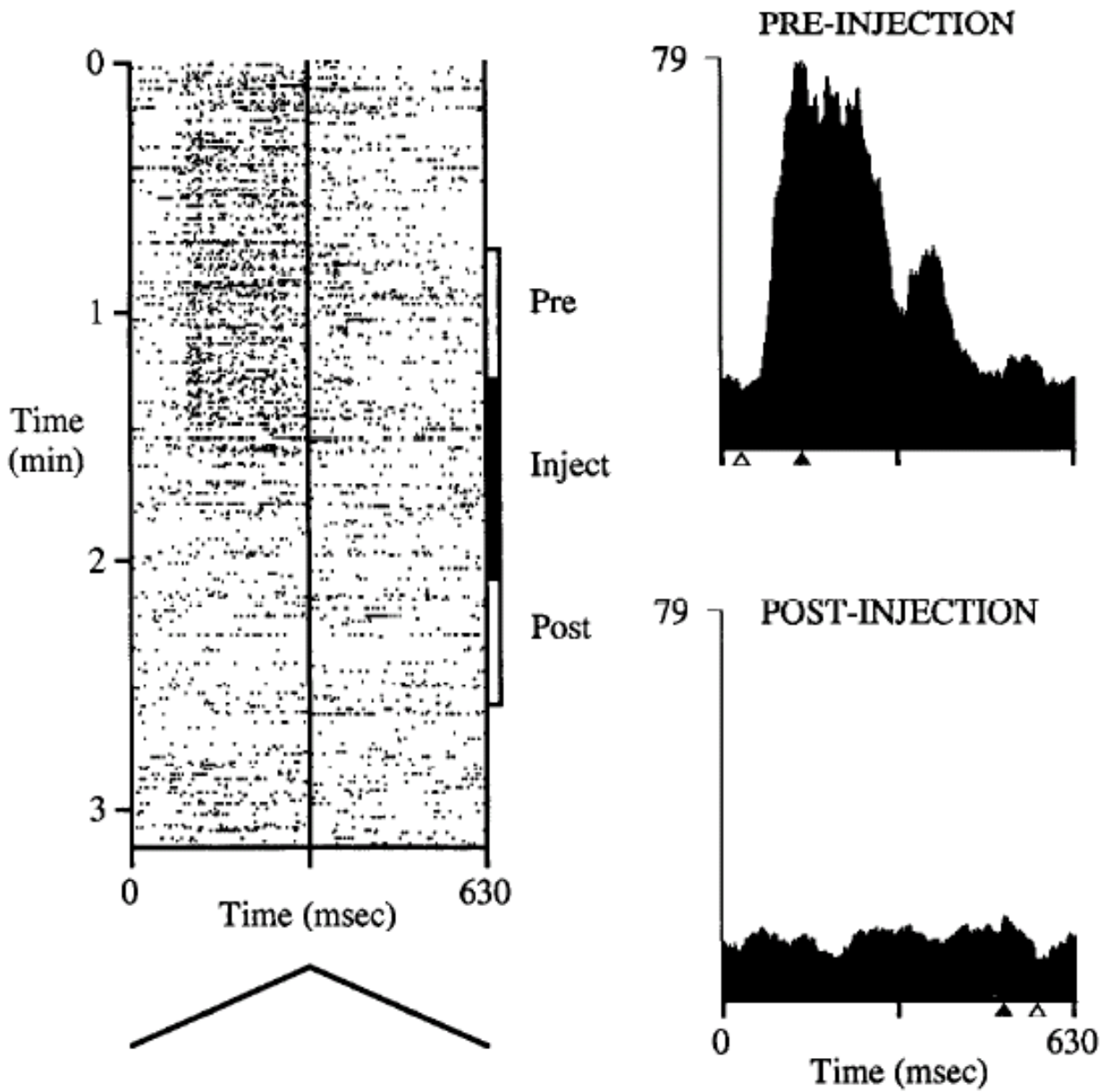
after Hubel & Wiesel 1962



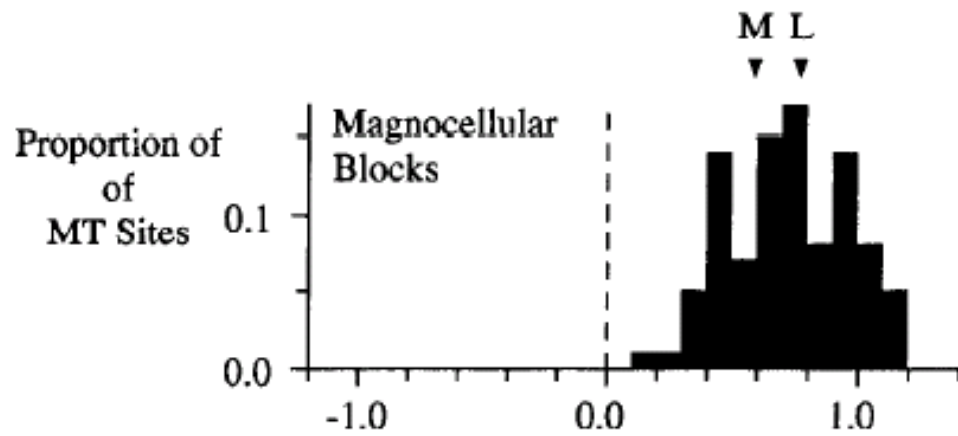
# Parallel Processing in the Monkey Visual System



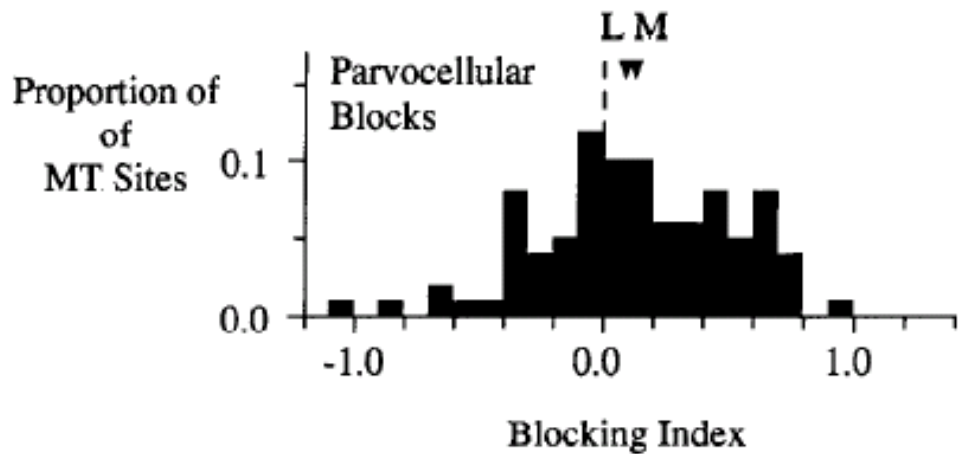
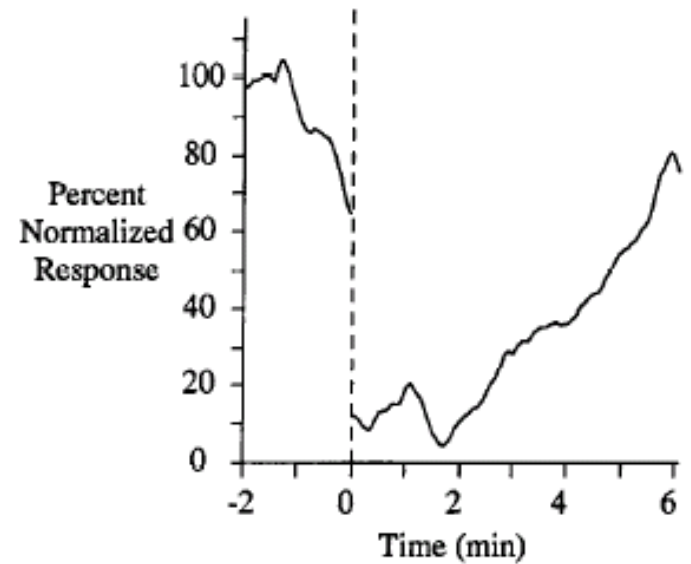
# magno dominates MT



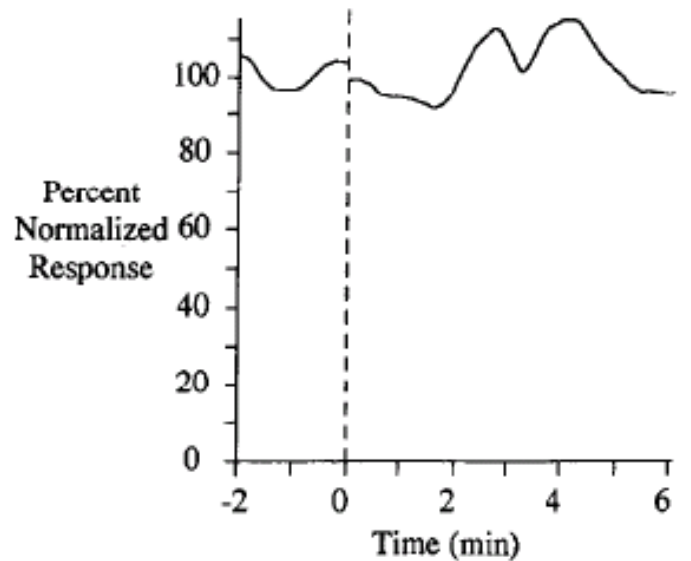
# magno dominates MT



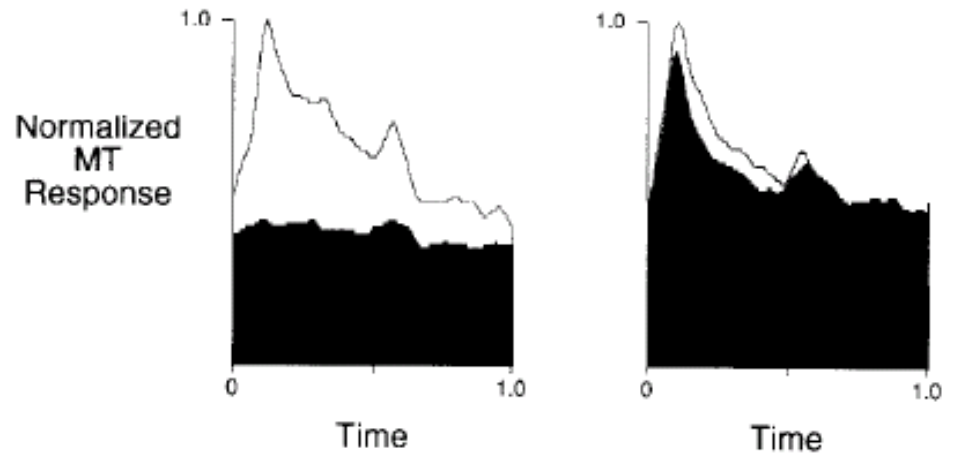
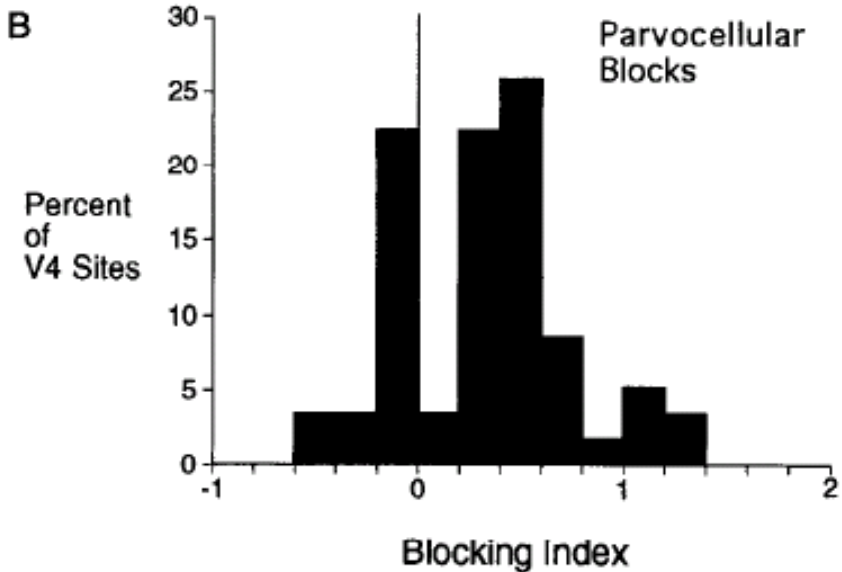
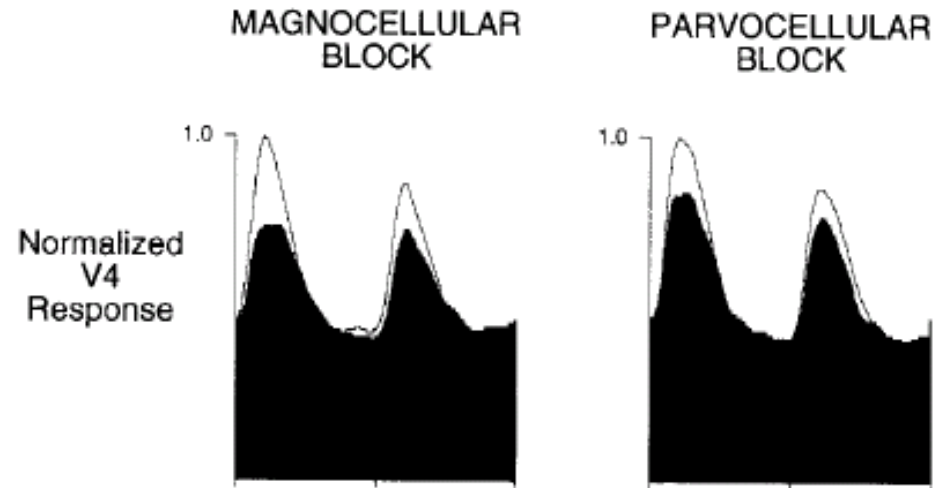
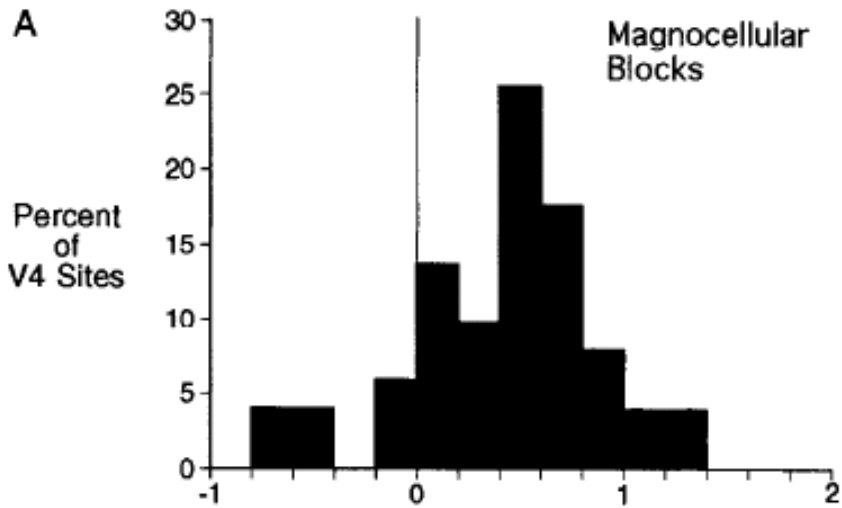
**MAGNOCELLULAR BLOCKS**



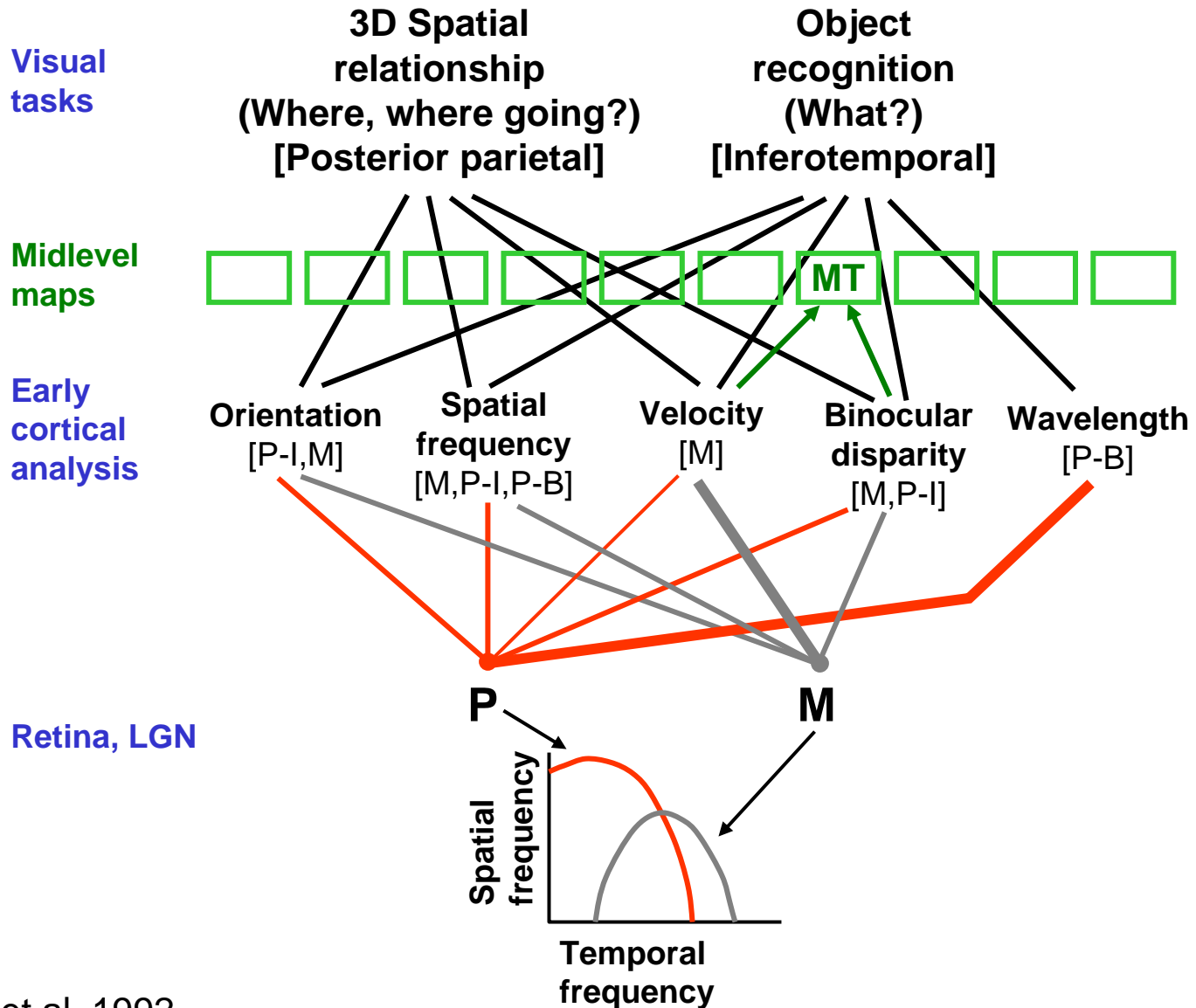
**PARVOCELLULAR BLOCKS**



# V4 inputs are mixed M/P

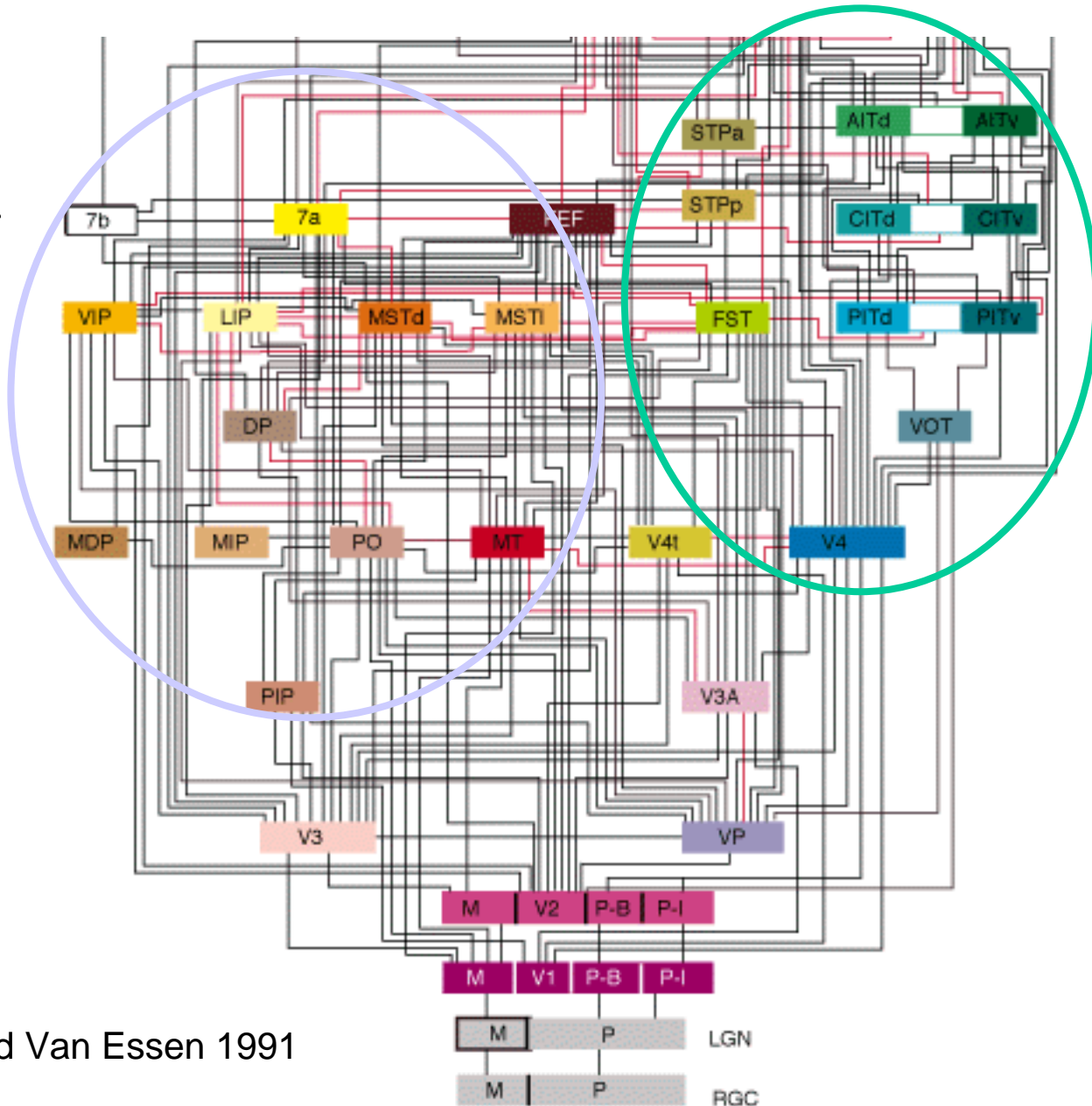


# computational flexibility



# Clusters of Areas: Processing Streams

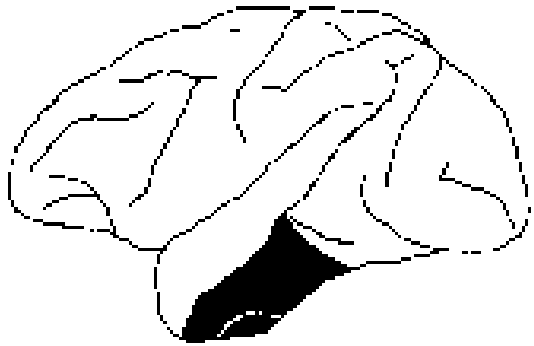
Posterior  
Parietal  
Cluster



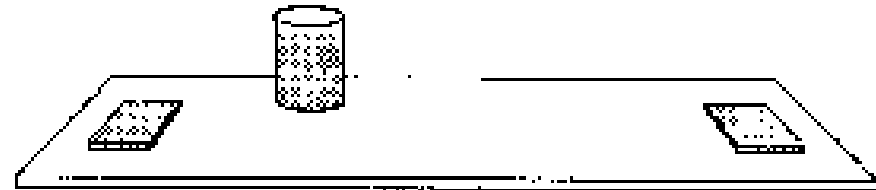
Inferior  
Temporal  
Cluster

# What? *versus* Where?

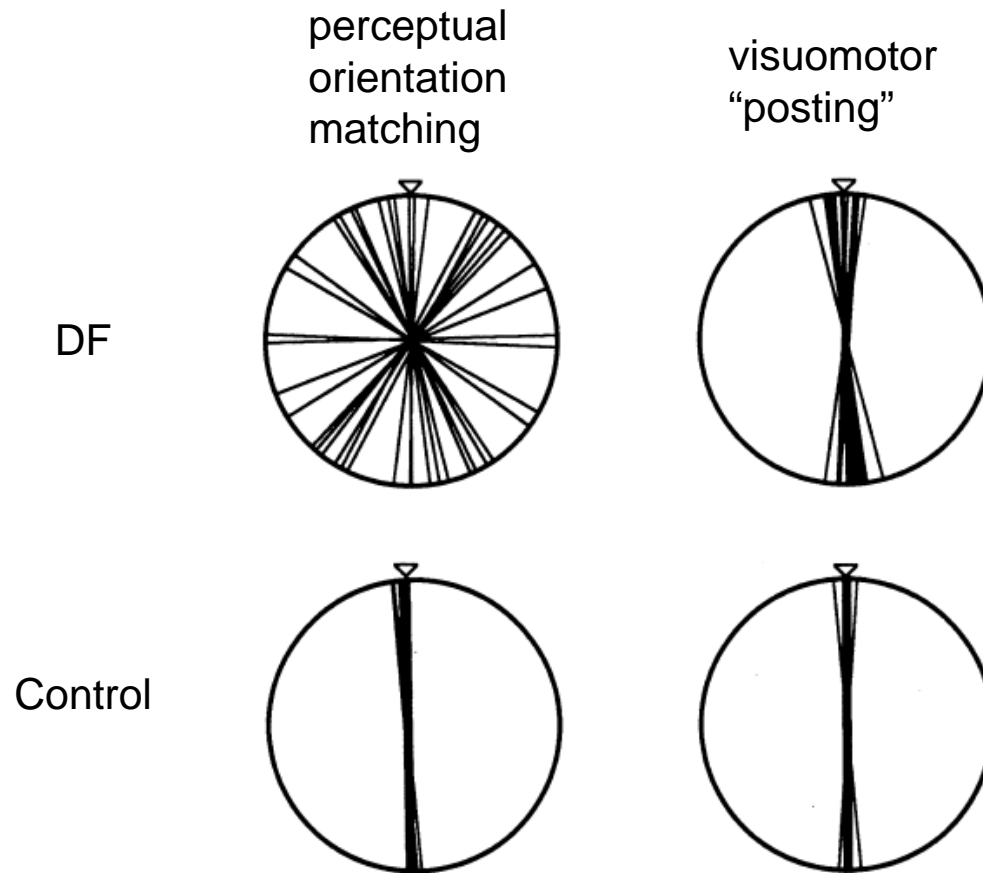
A.

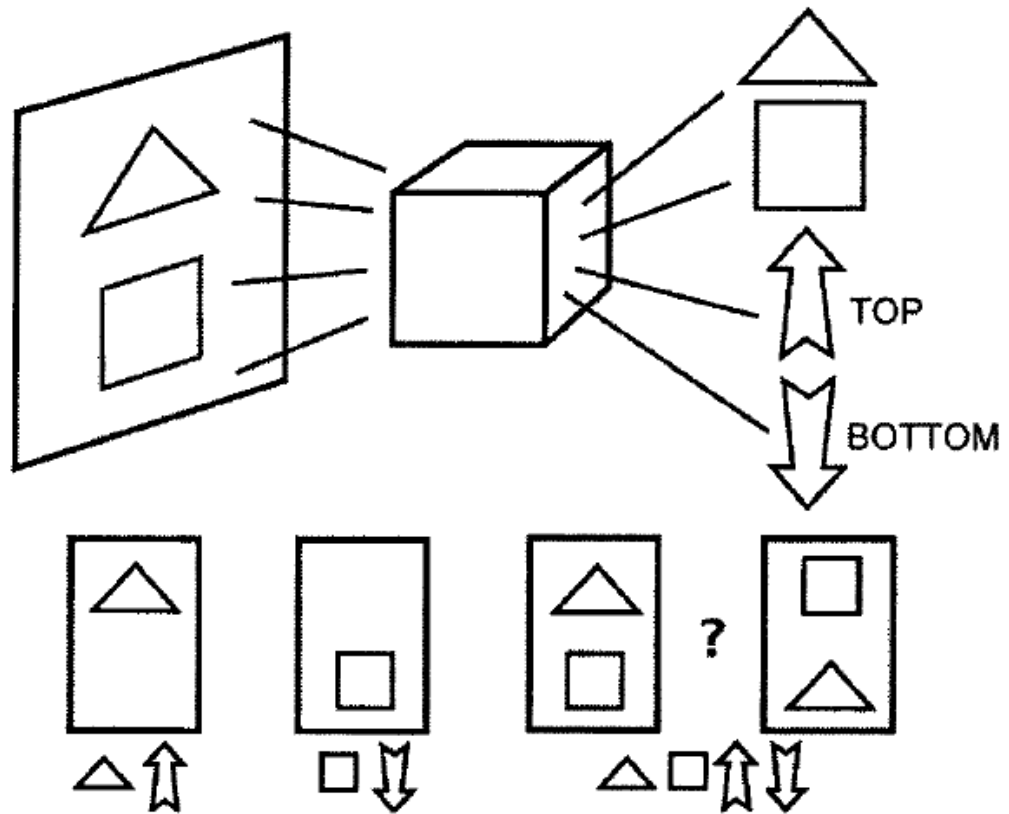


B.

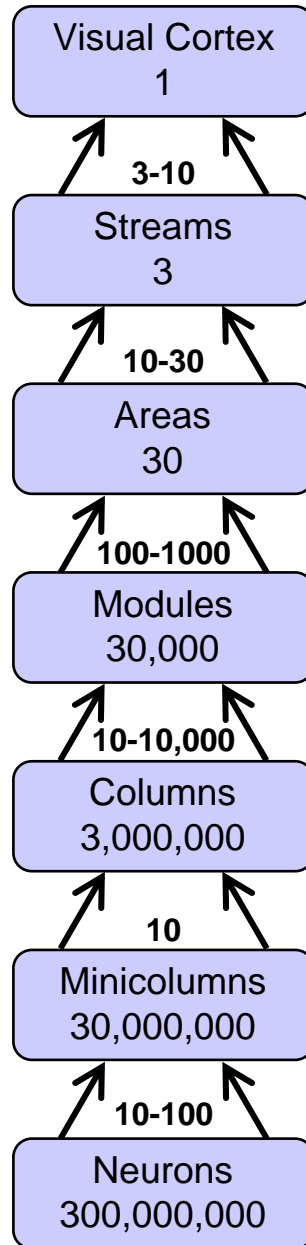


# Perception *versus* Action





# Monkey Visual Cortex



# “Cardinal Cells”?

(Barlow 1972)



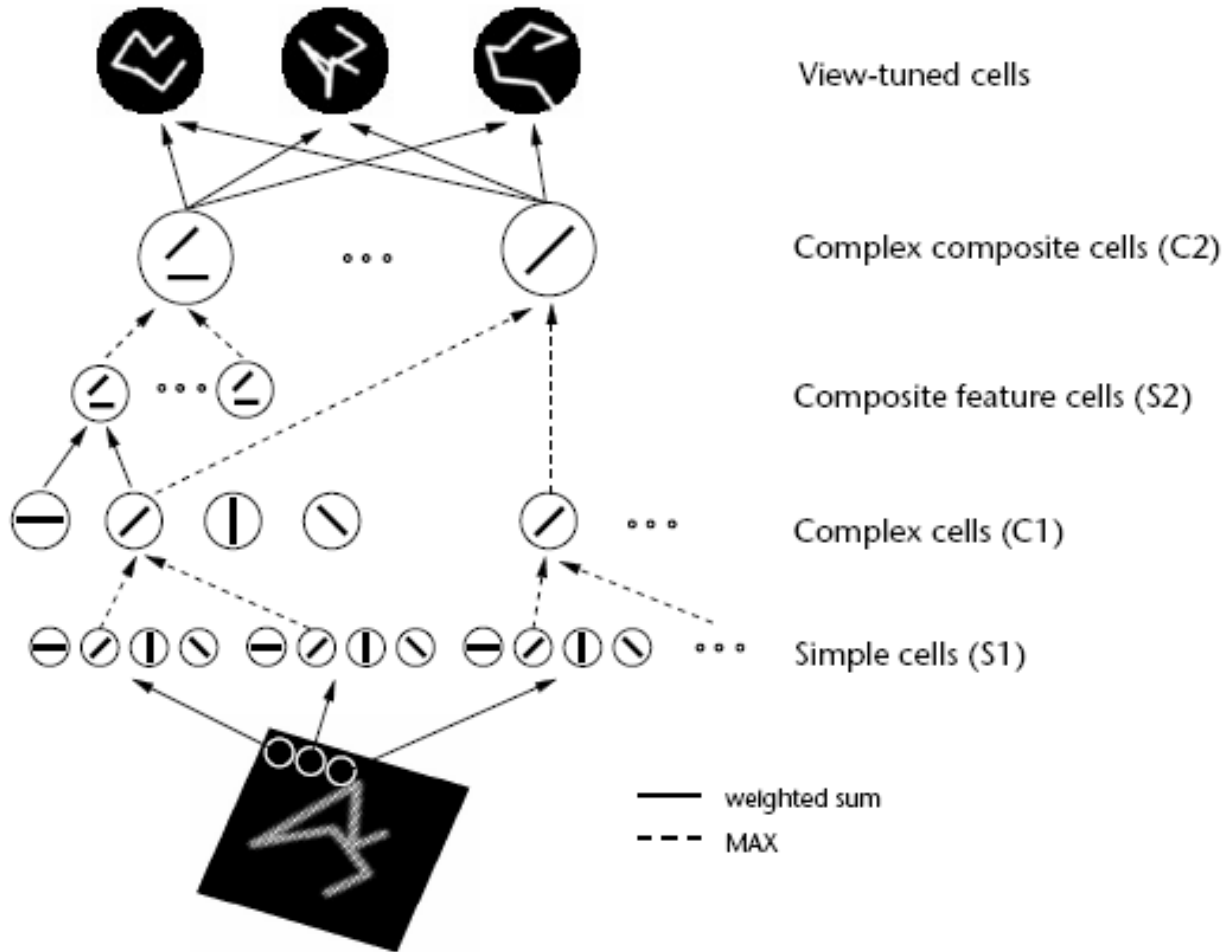
**selectivity**

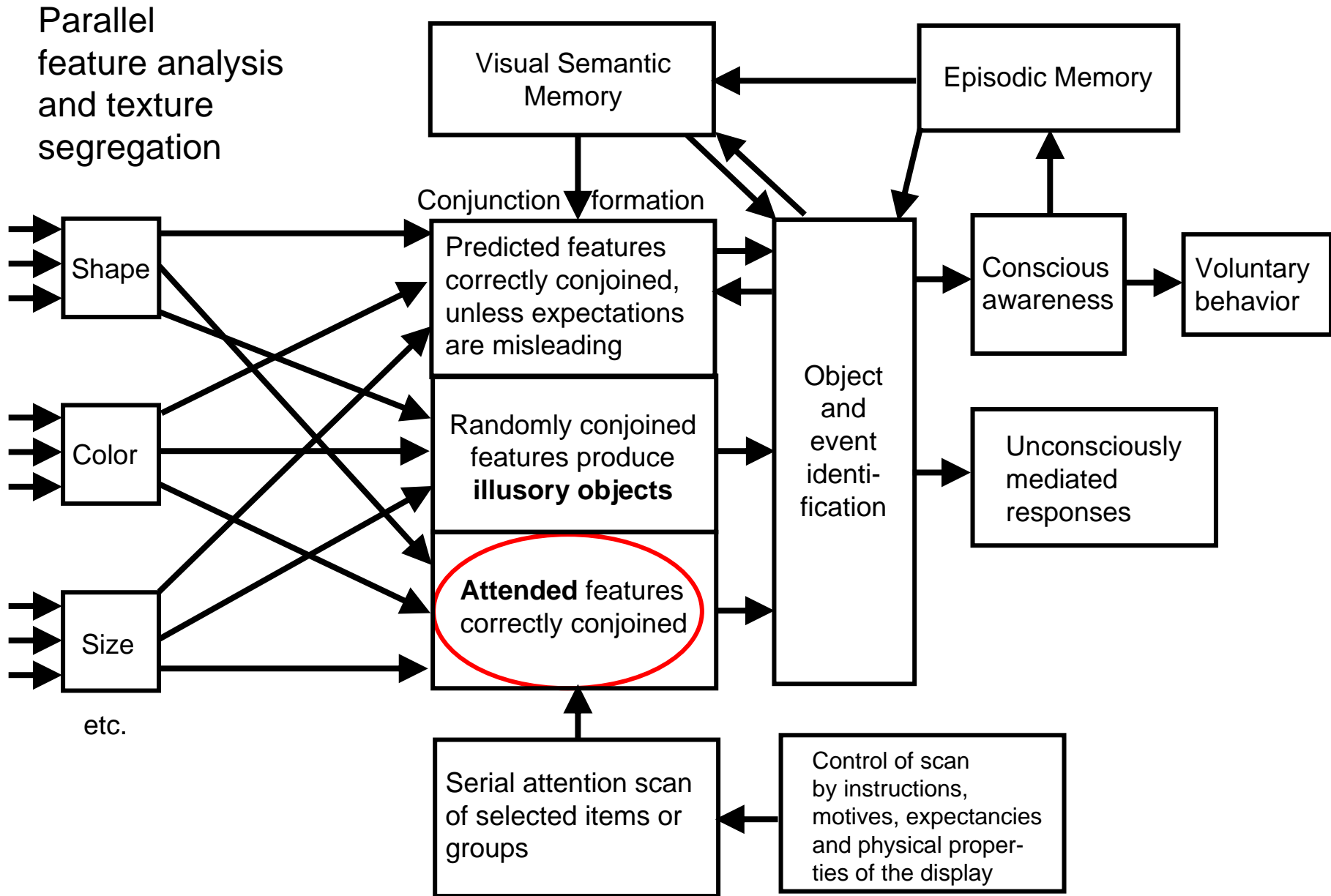
**generalization**

**selectivity**

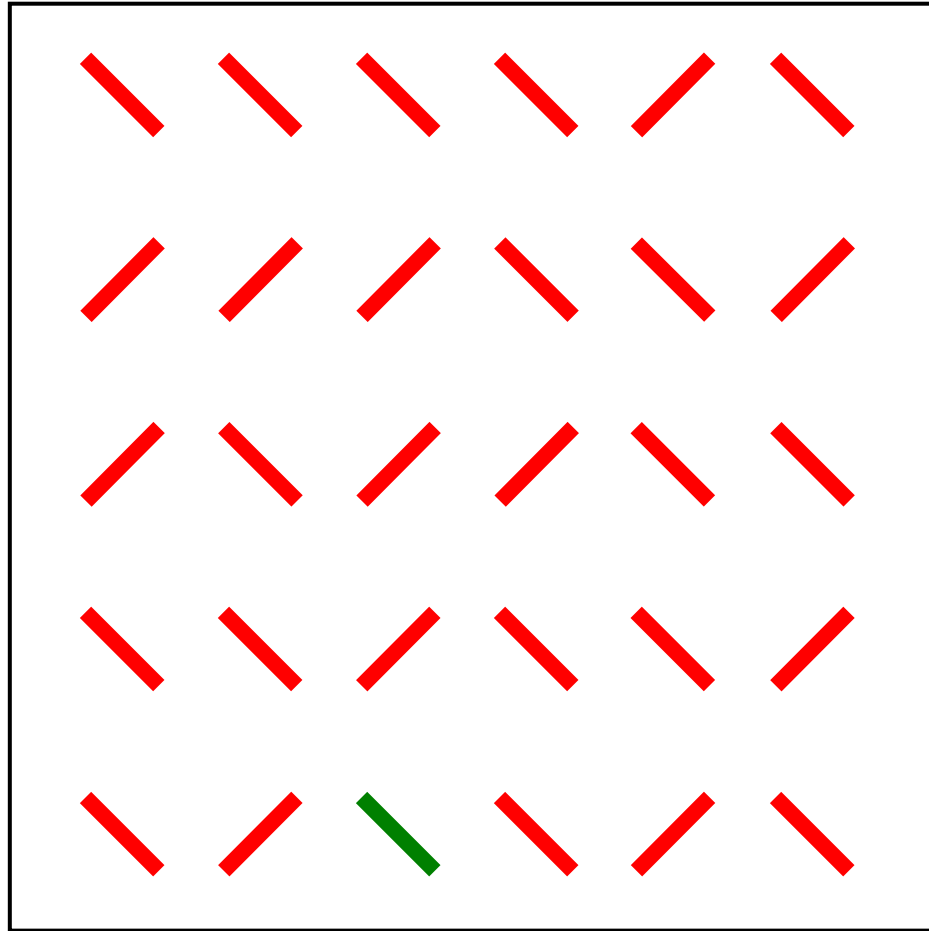
**generalization**

**selectivity**

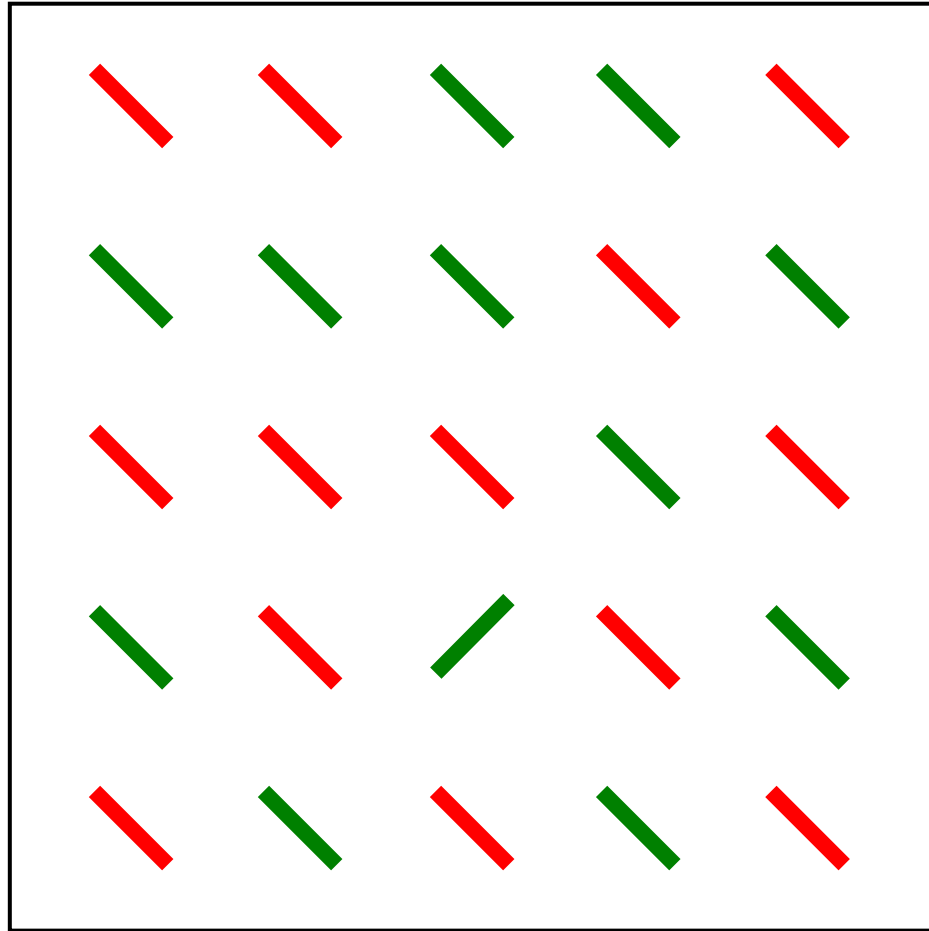




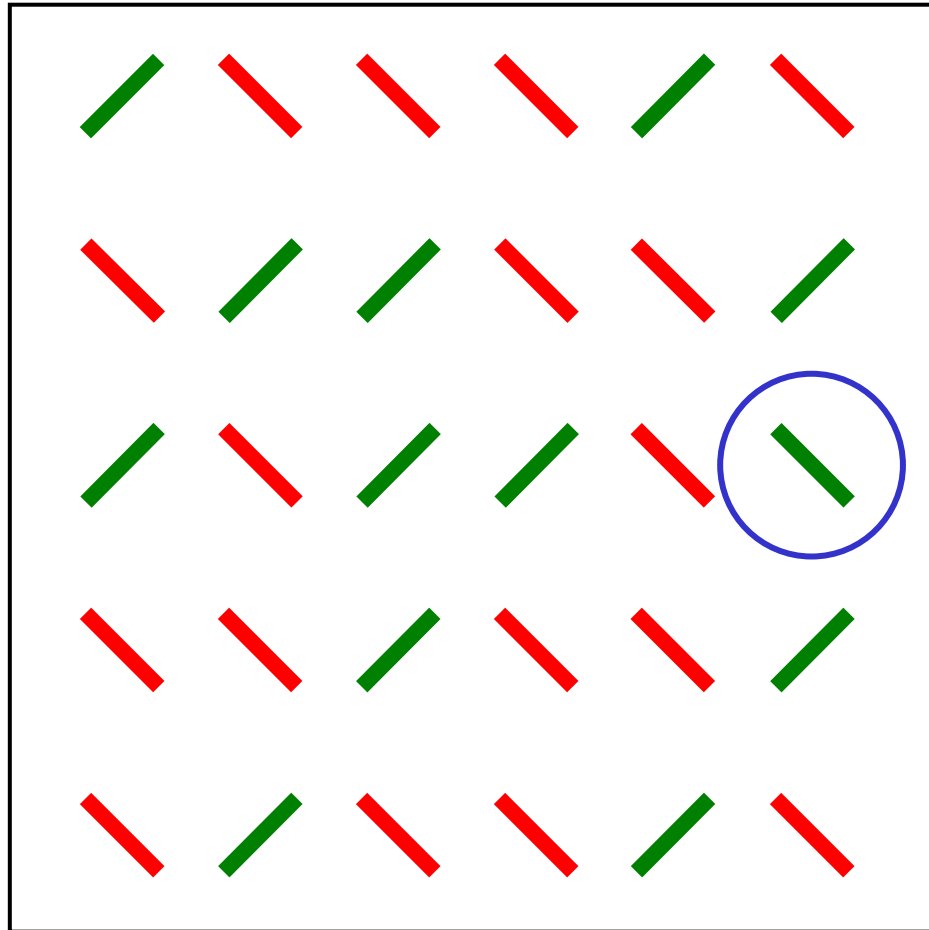
pop out



pop out



pop out

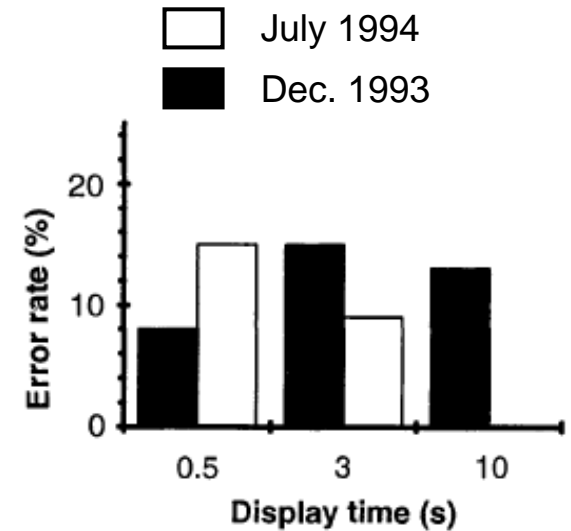
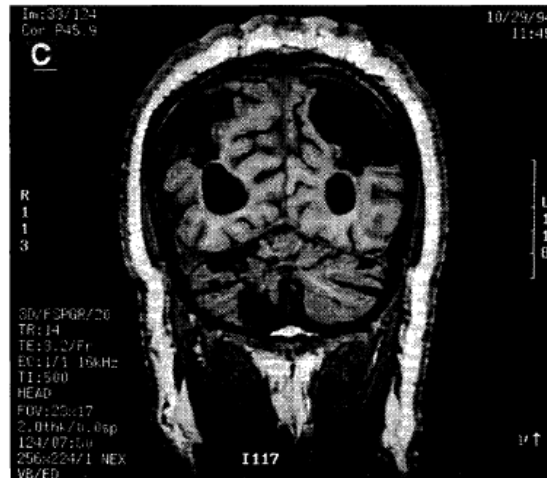
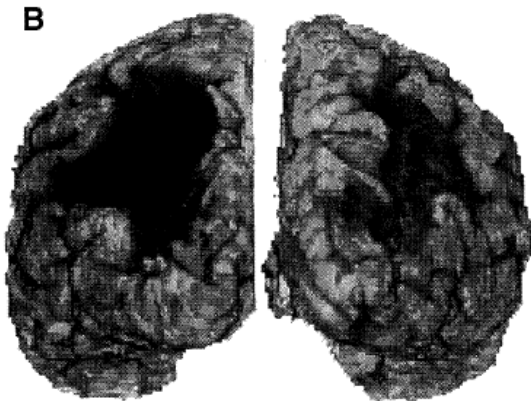
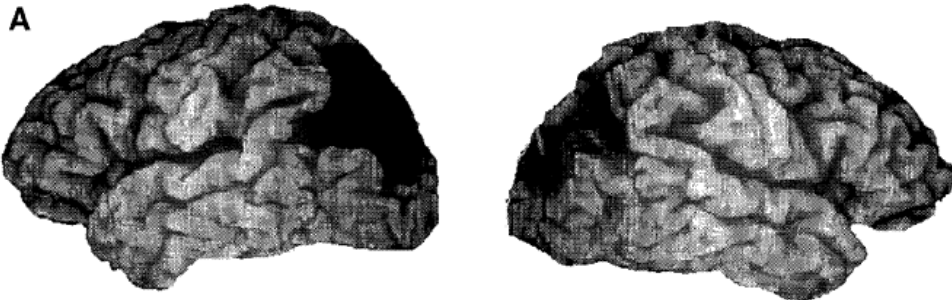


# illusory conjunctions

3 O X T 9

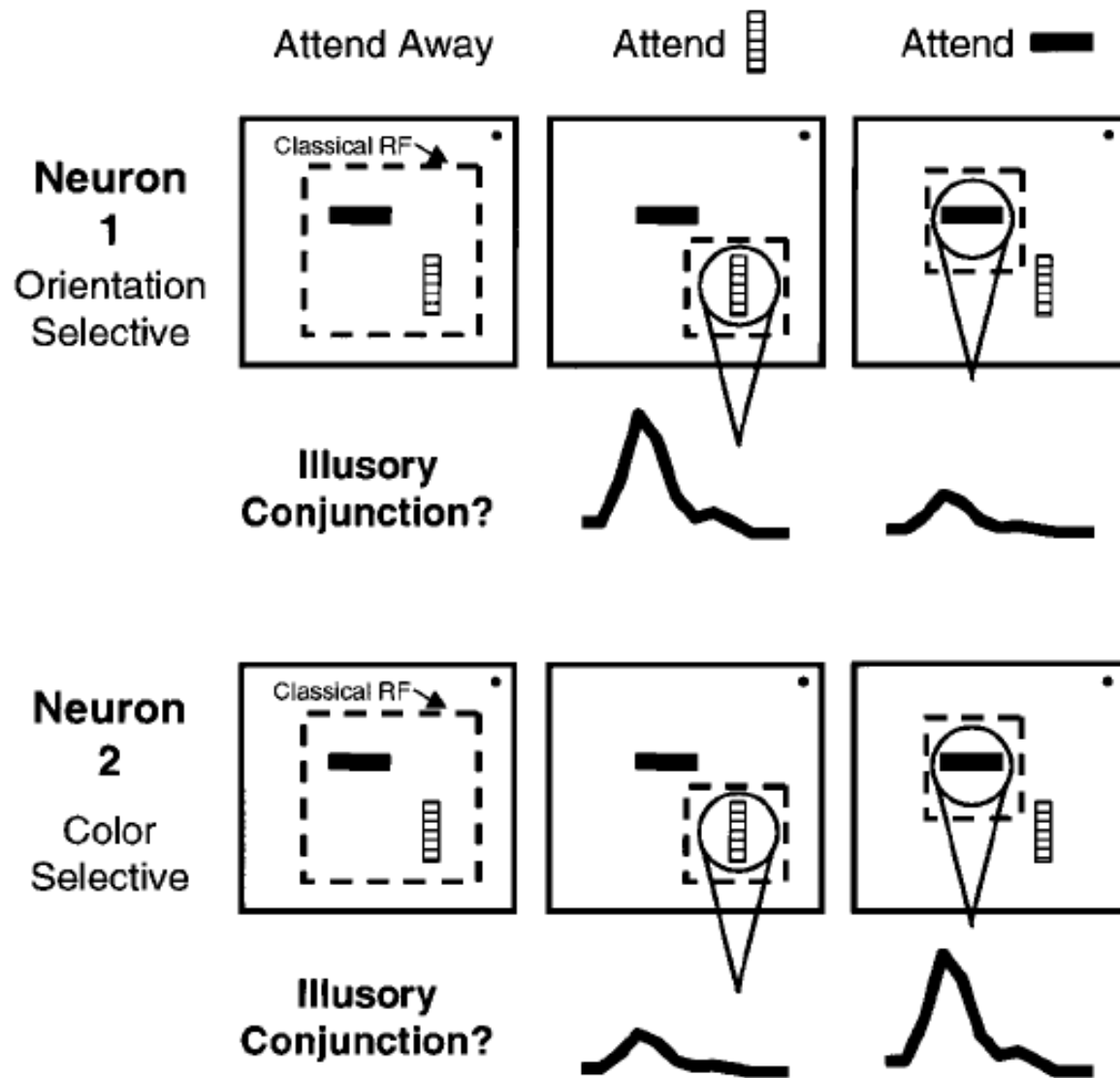
# Balint's Syndrome

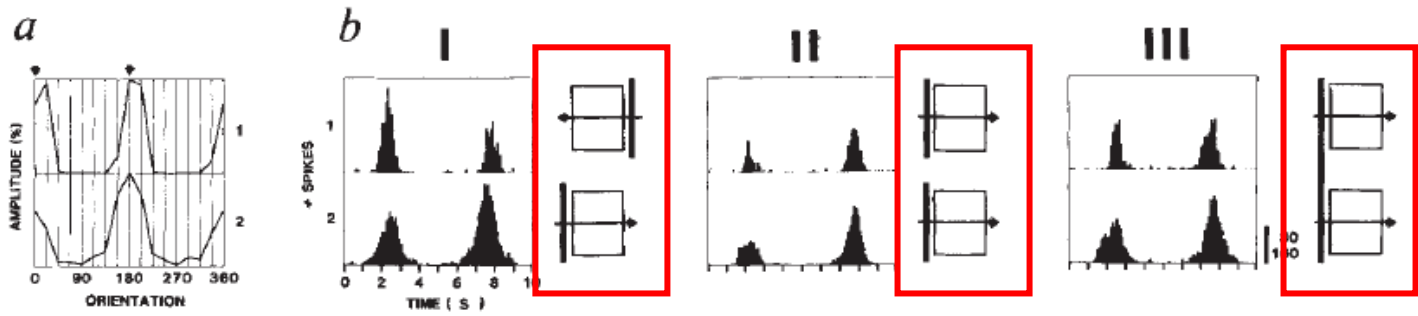
Patient R.M.



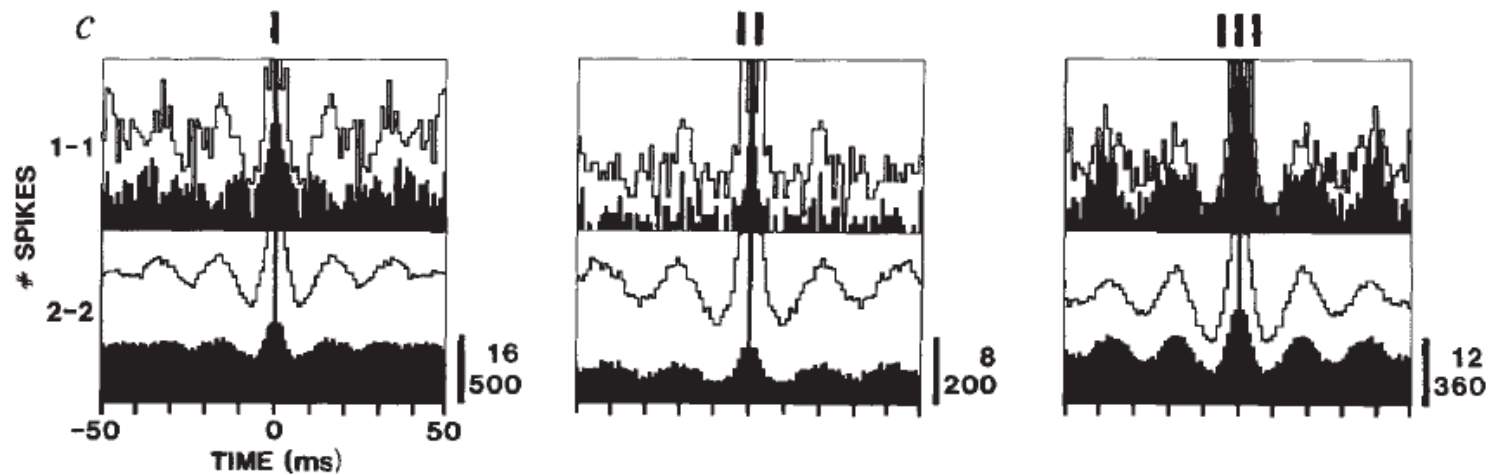
X T

“Report the name and the color of the first letter you see.”

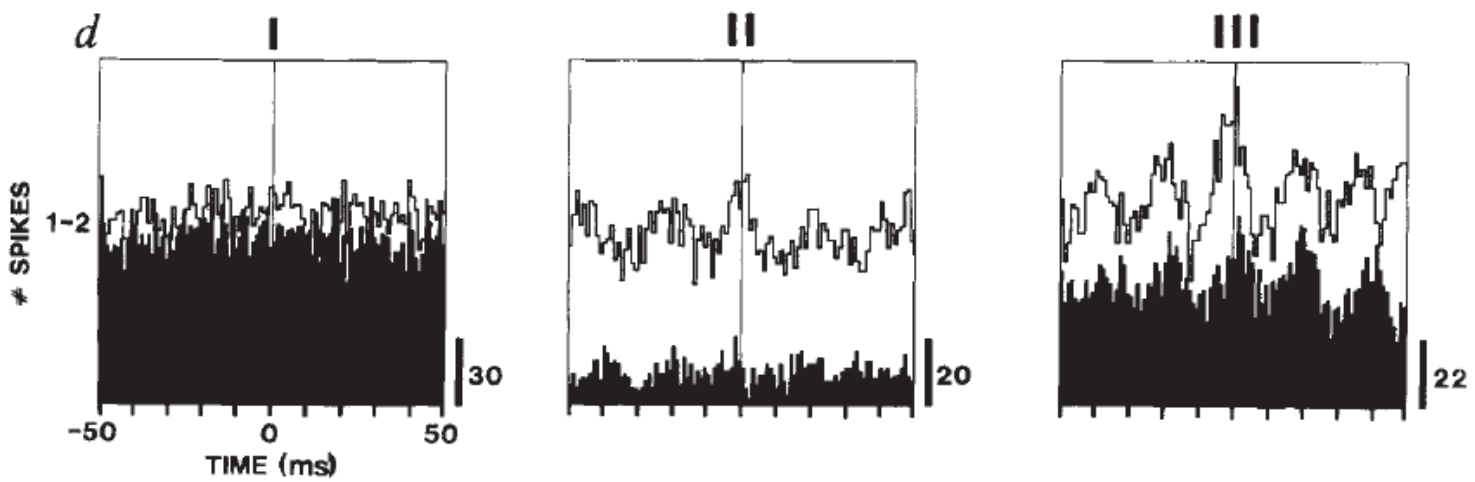




auto



cross



# Problems with Synchrony

1. Spike timing is also used to encode temporal variations in visual stimuli.  
(e.g. Shadlen & Newsome 1994; following slide)

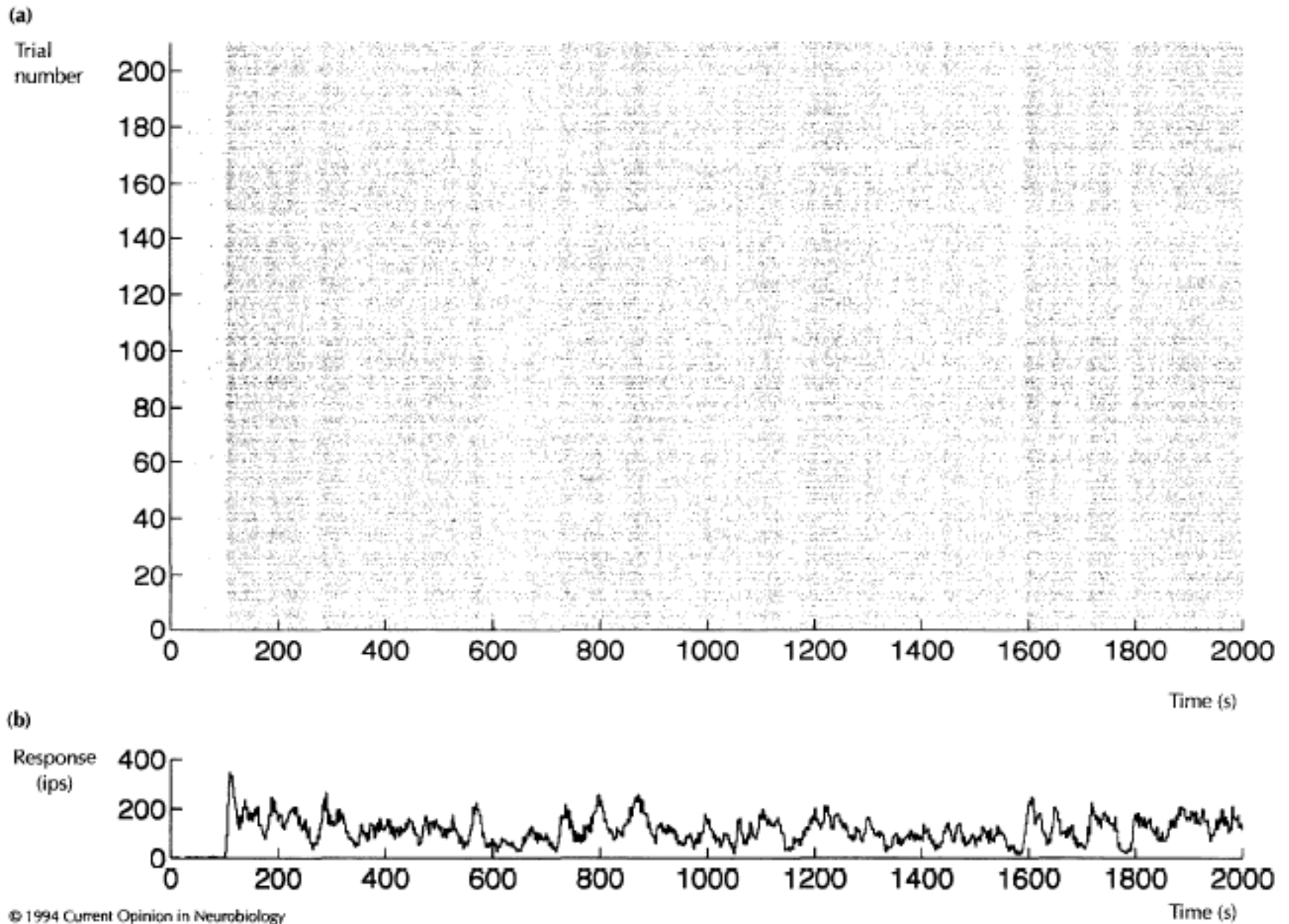
How does the brain distinguish stimulus-induced synchrony from binding synchrony?

2. Variable latencies across different cortical areas.  
(e.g. Nowak & Bullier 1997; 2<sup>nd</sup> slide following)

How can precise timing be coordinated across areas?

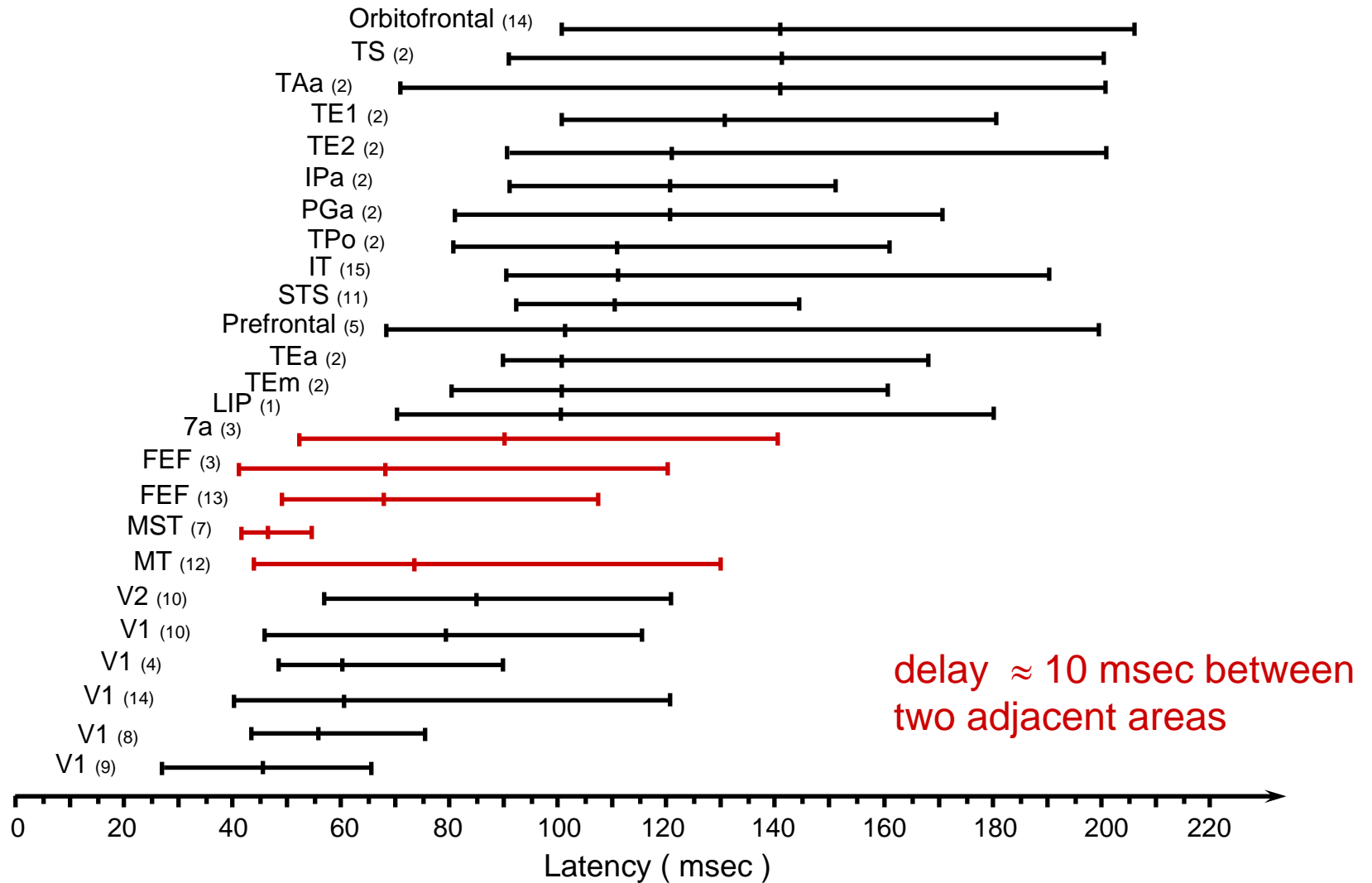
3. Large number of inputs to cortical neurons makes read-out a challenge.  
(e.g. Shadlen & Movshon 1999)

How can random coincidences be distinguished from those used to signal binding?

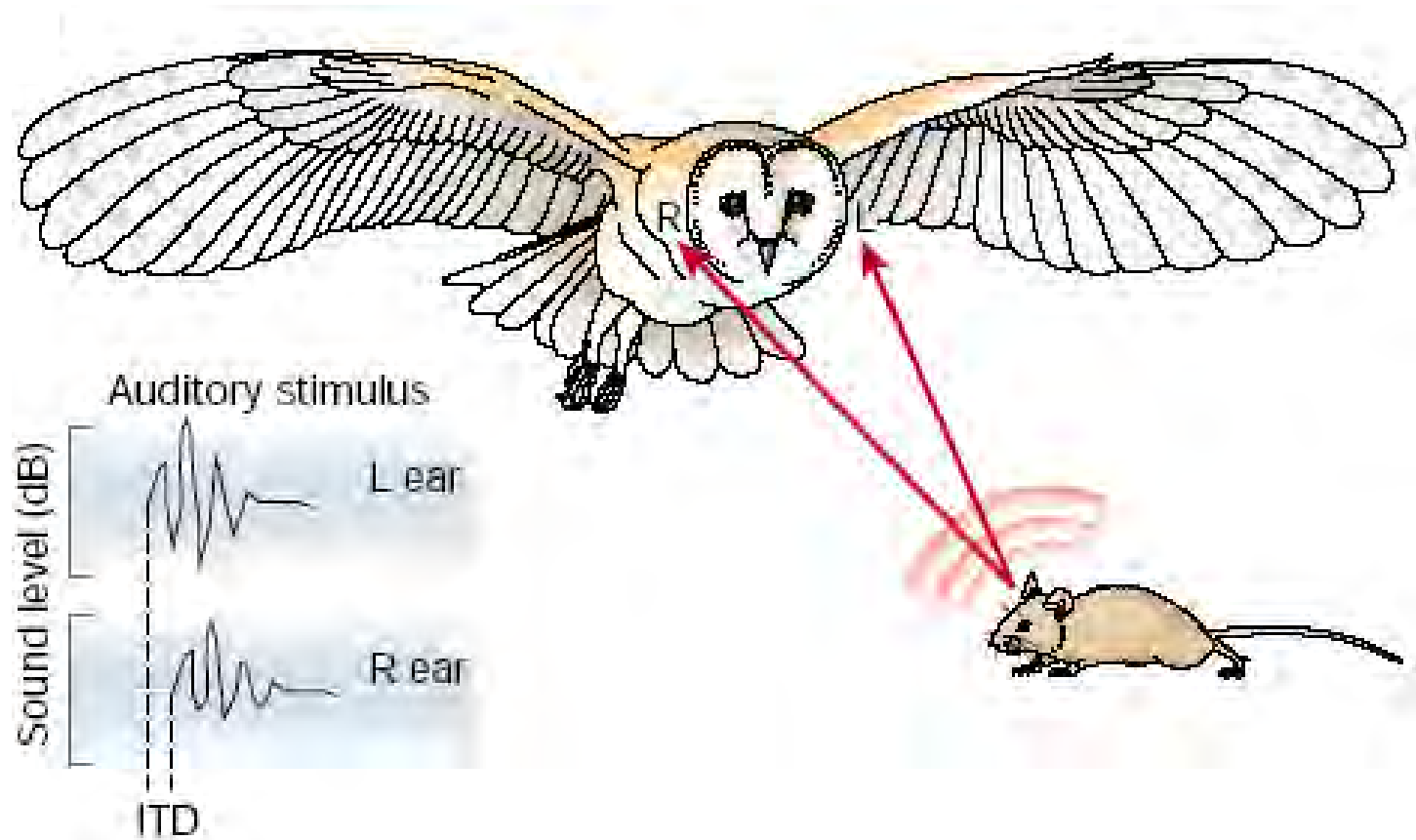


© 1994 Current Opinion in Neurobiology

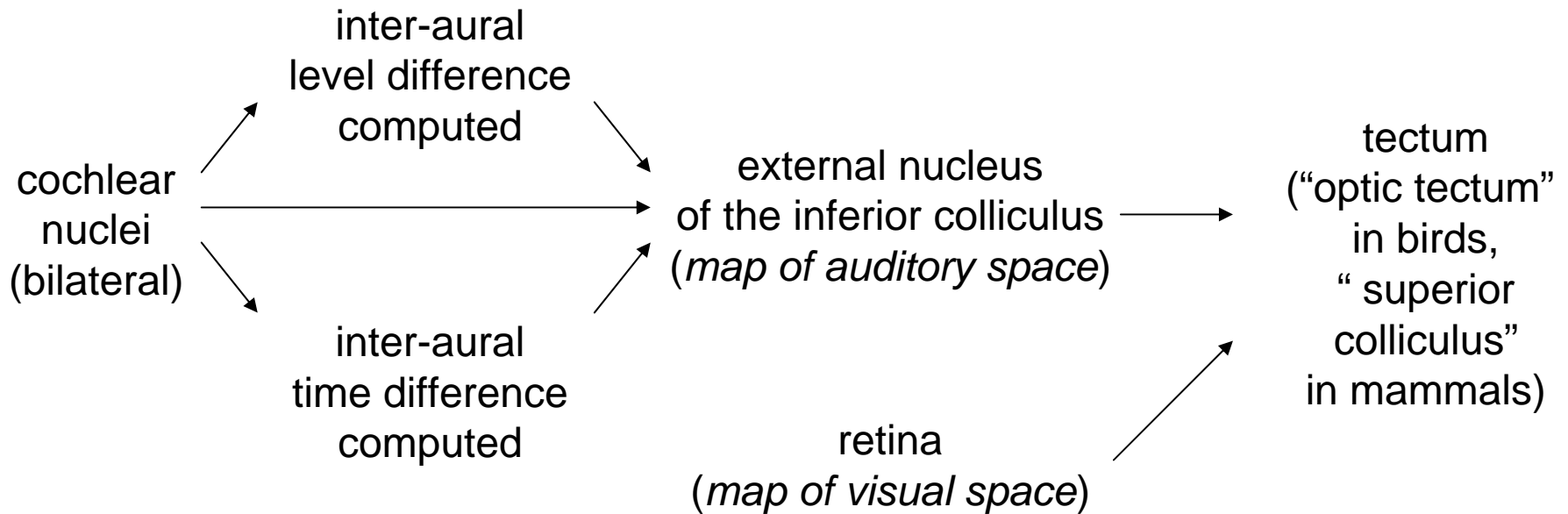
# Cortico-cortical Connections : Response Latency



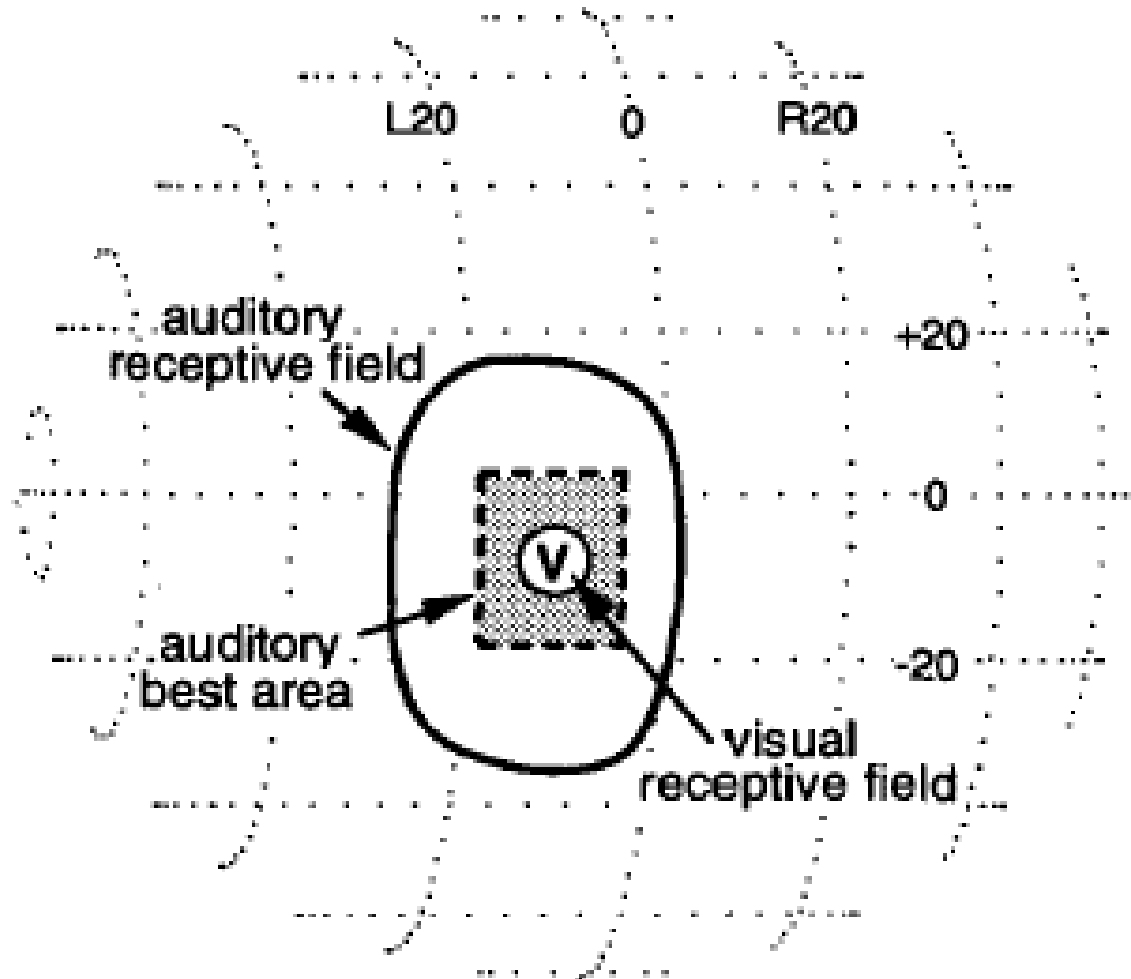
# Many behaviors require integrating visual and auditory information



# Tectum contains maps of auditory and visual space



# Bimodal neurons in the tectum have congruent receptive field locations



In the tectum, auditory and visual spatial information has been transformed into a common **coordinate space**.

Why might this be useful?

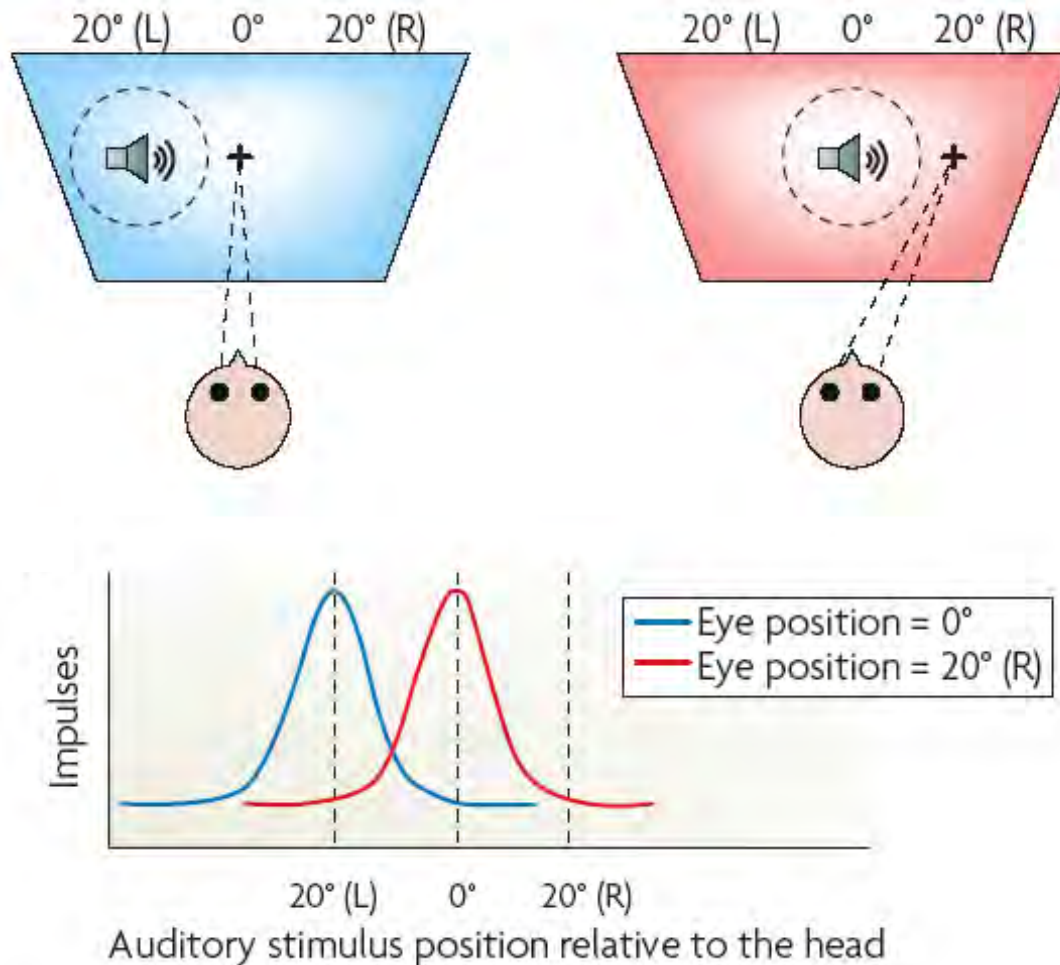
1. Multimodal neurons with congruent audio-visual receptive field locations trigger the same behavior even when one source of information is absent (e.g., if the prey is momentarily silent or out of sight).
2. Auditory and visual information can be seamlessly combined when both are present, improving the estimate of the spatial location of the stimulus.

# Don't eye movements throw everything out of whack?

1. Eye movements are often rapidly followed by head movements.
2. The eyes and ears (pinna) can move congruently.
3. Eye position can modify auditory receptive fields!  
(This is equivalent to a new coordinate transform.)

# Keeping the coordinate system aligned:

eye position modifies the auditory receptive fields of neurons in the superior colliculus



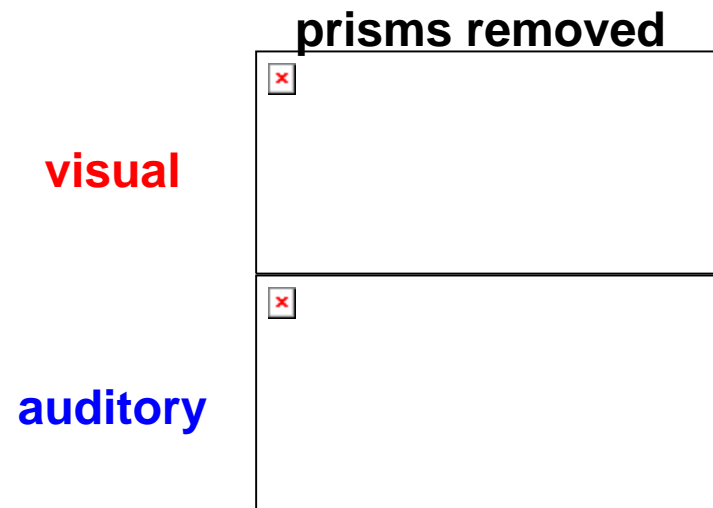
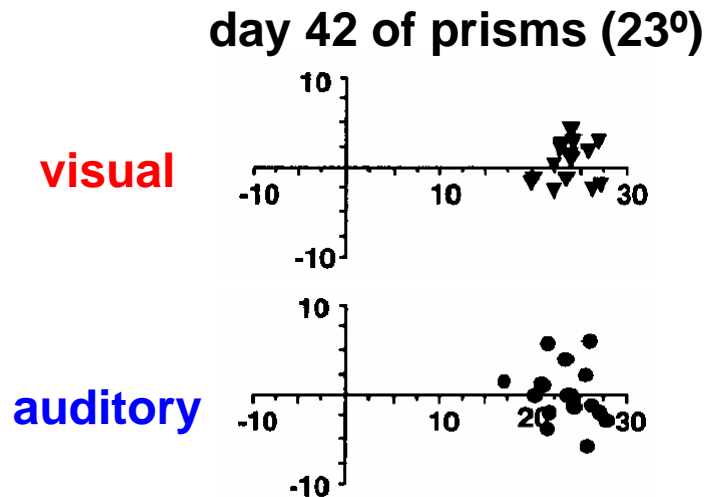
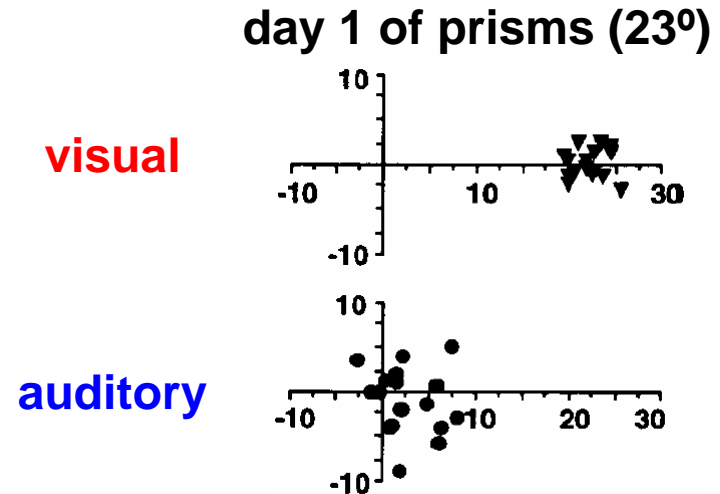
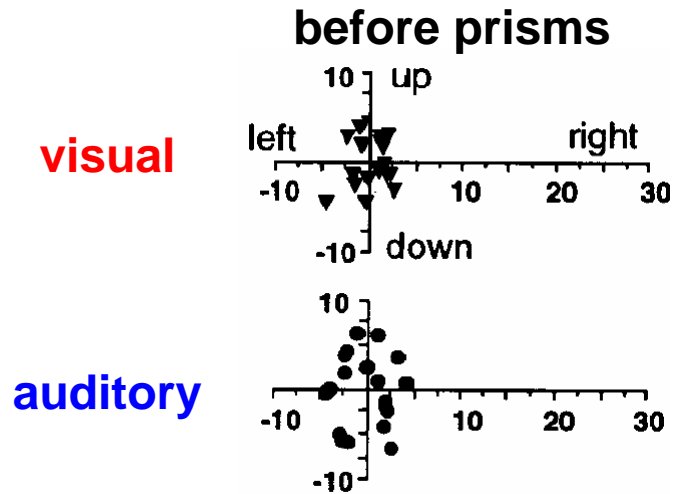
In the tectum, auditory and visual spatial information has been transformed into a common **coordinate space**.

Why might this be useful?

1. Multimodal neurons with congruent audio-visual receptive field locations trigger the same behavior even when one source of information is absent (e.g., if the prey is momentarily silent or out of sight).
2. Auditory and visual information can be seamlessly combined when both are present, improving the estimate of the spatial location of the stimulus.
3. Multimodal maps can provide error-correction mechanisms for each other.

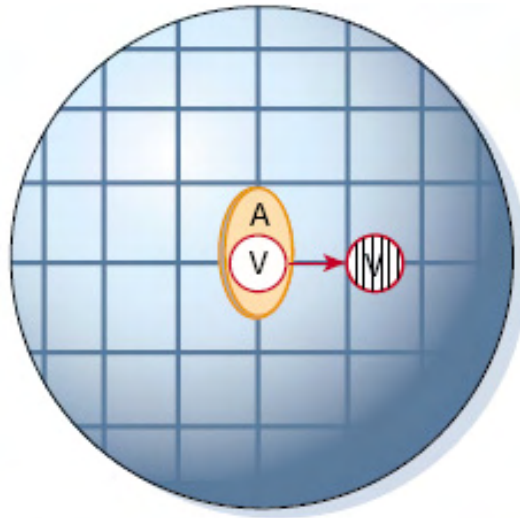


# Plasticity of auditory-evoked head turns in the owl

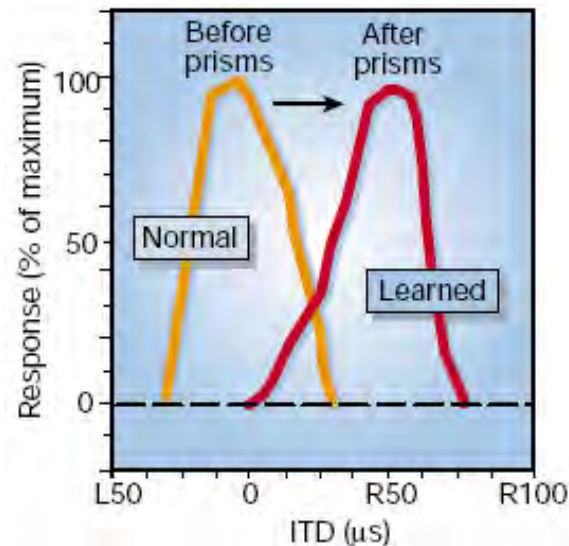
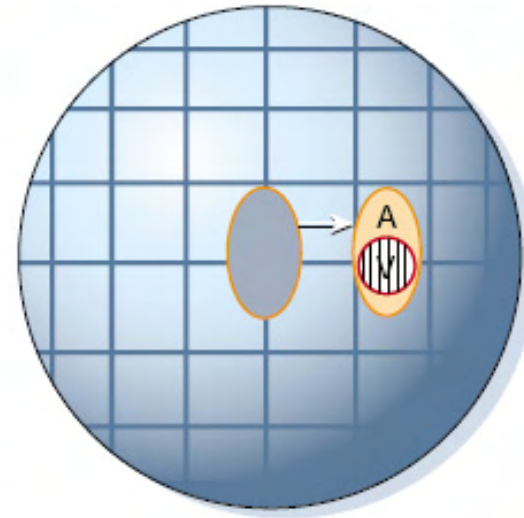


# Plasticity of auditory receptive fields in the owl tectum

before → after prisms (23°)



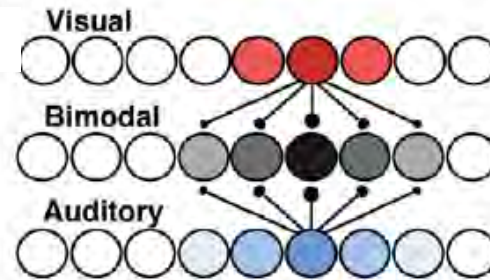
after 8 weeks of prisms



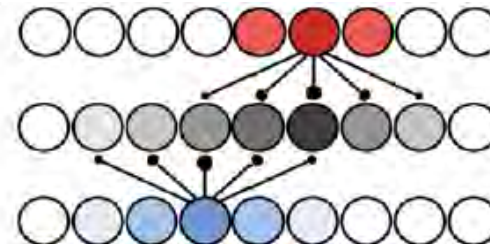
# Why do auditory receptive fields shift toward visual receptive fields?

If visual responses are stronger and/or more reliable, then a Hebbian mechanism is sufficient to explain this.

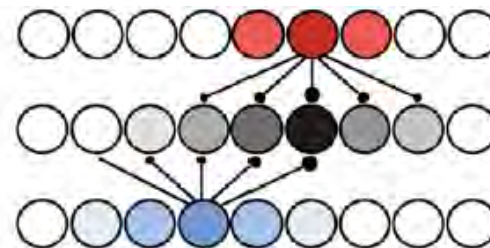
before prisms



just after prisms on



after plasticity



Old hypothesis: The dominance of one cue over another (e.g., vision over audition) is hard-wired into the brain.

New hypothesis: Neural circuits weight more heavily whatever source of information is more reliable at the moment.

Framework: “Bayesian inference”, a formalization of the optimal way to integrate multiple sources of current and stored information.



**Thomas Bayes**  
**1701?-1761**

## Bayes' rule:

$$P(s|o) = \frac{P(o|s)P(s)}{P(o)}$$

$P(s|o)$

The probability of the stimulus having a certain value after taking into account the observation (the *posterior distribution*).

$P(s)$

The probability of the stimulus having a certain value (the *prior*).

$P(o)$

The probability of the observation occurring.

$P(o|s)$

The probability of this observation given the stimulus having a certain value.

Suppose your patient has just tested positive for a disease.  
How likely is it that he actually has the disease?

We have to consider:

The probability of testing positive if you have the disease.

The probability of testing positive if you are healthy.

The probability that anybody has the disease.

Suppose your patient has just tested positive for a disease.  
How likely is it that he actually has the disease?

What if:

the probability of testing positive if you have the disease is 95%,  
the probability of testing positive if you are healthy is 5%,  
but the disease is rare, so the probability that anybody has it is 1%.

$$\begin{aligned} P(\textit{sick}|+) &= \frac{P(+|\textit{sick})P(\textit{sick})}{P(+)} \\ &= \frac{P(+|\textit{sick})P(\textit{sick})}{P(+|\textit{sick})P(\textit{sick}) + P(+|\textit{healthy})P(\textit{healthy})} \end{aligned}$$

$$P(+|\textit{sick}) = 0.95$$

$$P(+|\textit{healthy}) = 0.05$$

$$P(\textit{sick}) = 0.01$$

$$P(\textit{healthy}) = 0.99$$

$$P(\textit{sick}|+) = 16\%$$

## The multimodal case:

$$P(s|o) = \frac{P(o|s)P(s)}{P(o)}$$

Similarly, for a combination of visual and auditory observations,

$$P(s|v, a) = \frac{P(v, a|s)P(s)}{P(v, a)}$$

# The multimodal case:

If visual and auditory estimates of the stimulus are independent, meaning

$$P(v, a|s) = P(v|s)P(a|s)$$

and if the posterior distributions are Gaussian, then one can show that the optimal weighting is

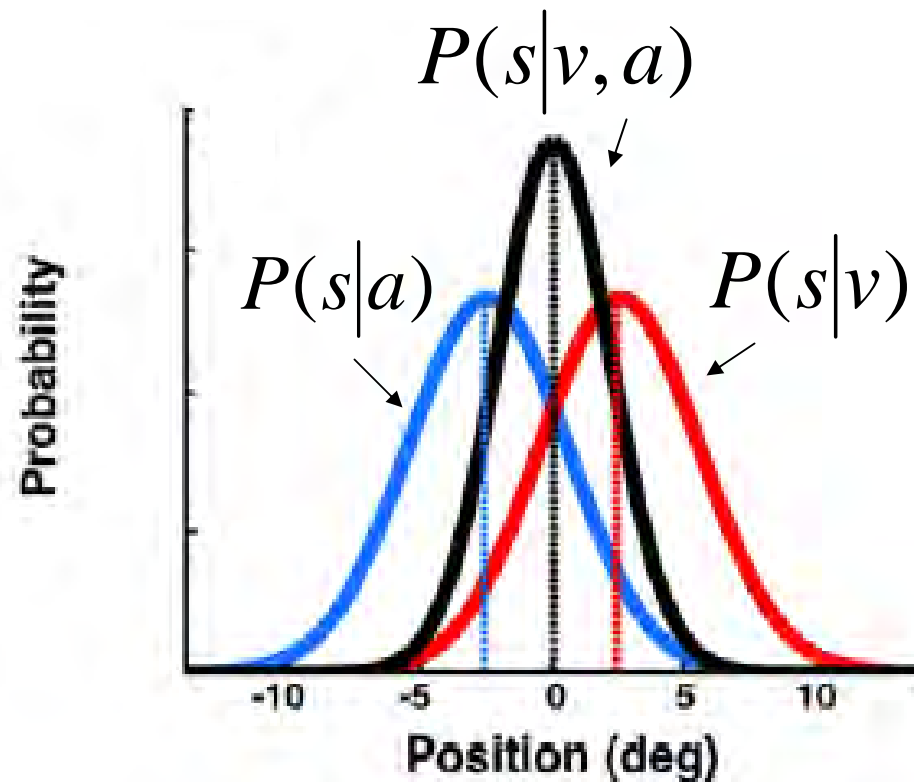
$$\hat{S}_{\text{bimodal}} = \hat{S}_v w_v + \hat{S}_a w_a$$

where  $\hat{S}_{\text{bimodal}}$ ,  $\hat{S}_v$ , and  $\hat{S}_a$  are the optimal estimates of the stimulus based on bimodal, visual, and auditory information.

and the weights are related to the variance of the posterior distributions:

$$w_v = \frac{1/\sigma_v^2}{1/\sigma_v^2 + 1/\sigma_a^2} \quad ; \quad w_a = \frac{1/\sigma_a^2}{1/\sigma_v^2 + 1/\sigma_a^2}$$

If visual and auditory estimates are equally reliable, then weight them equally:



Note that the variance of the bimodal posterior distribution (black) is smaller than that of either of the unimodal distributions (blue, red). This is always true.

If the auditory estimate is less reliable, then it should receive less weight:

