

# Information and coding efficiency

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- What are the challenges posed by natural stimuli?
- What do information theoretic concepts suggest that neural systems should do?
- What principles seem to be at work in shaping the neural code?

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A photograph of a dark room, likely a ship's bridge or control room, featuring large windows that look out onto a landscape of hills under a sunset sky. Inside, there are various pieces of equipment, including what appears to be a desk with electronic components and a chair. A prominent white diagonal watermark reading "NOT FOR REUSE" is overlaid across the center of the image.

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A photograph of a dark room, likely a control room or studio, featuring a large window that looks out onto a landscape at sunset. The room contains a desk with a computer setup, including a monitor and keyboard. The large window offers a panoramic view of a forested hillside under a warm, orange sky.

A dark, moody interior scene, likely a control room or studio, featuring large windows that look out onto a landscape at sunset. The sky is a warm orange and yellow. Inside, there are various pieces of equipment, including what looks like a control panel with multiple buttons and a computer monitor. A large, curved sofa or chair is visible in the foreground. The overall atmosphere is dramatic and atmospheric.

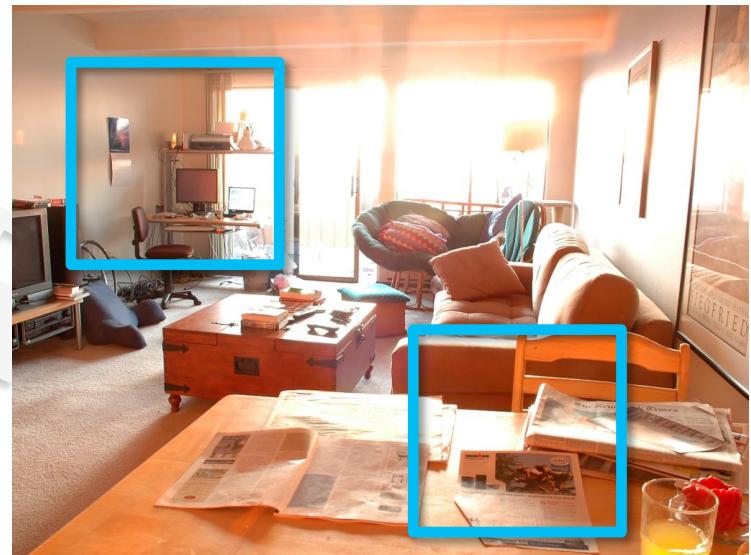
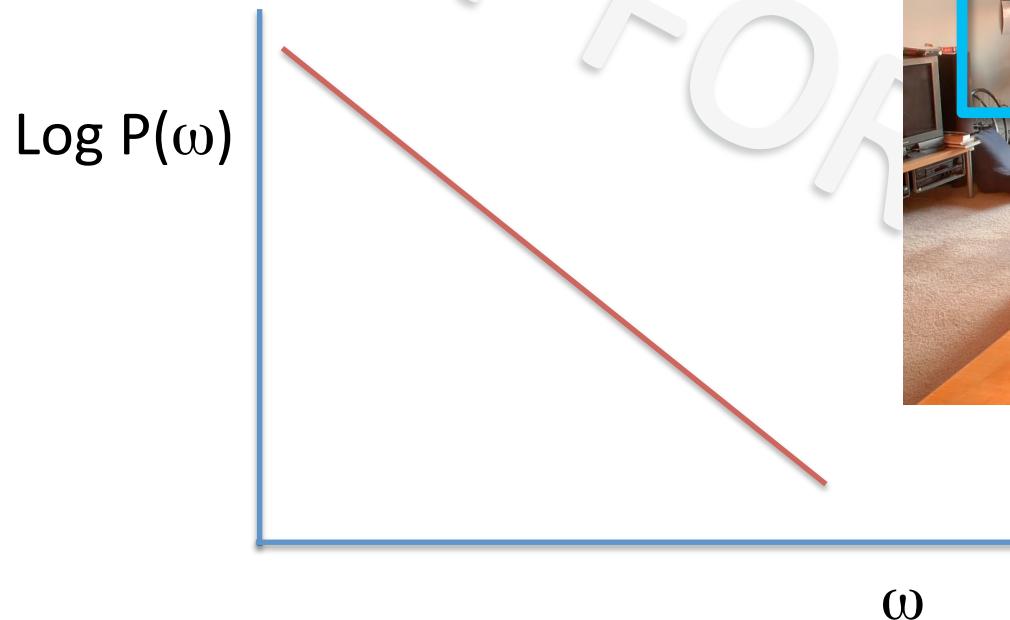
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A dark, moody photograph of an interior space, likely a control room or observatory, featuring large windows that look out onto a landscape at sunset. The windows are divided into multiple panes. In the foreground, there's a desk with some equipment and papers. The overall atmosphere is mysterious and contemplative.

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# Natural stimuli

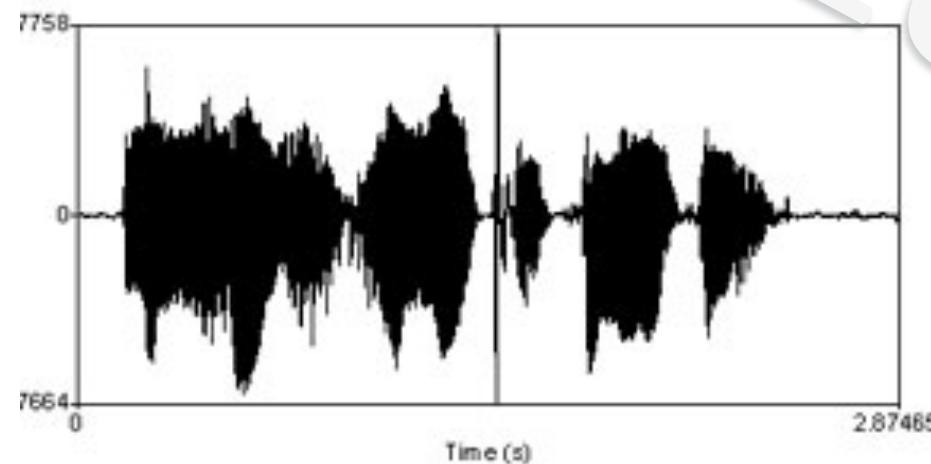
1. Huge dynamic range: variations over many orders of magnitude
2. Power law scaling



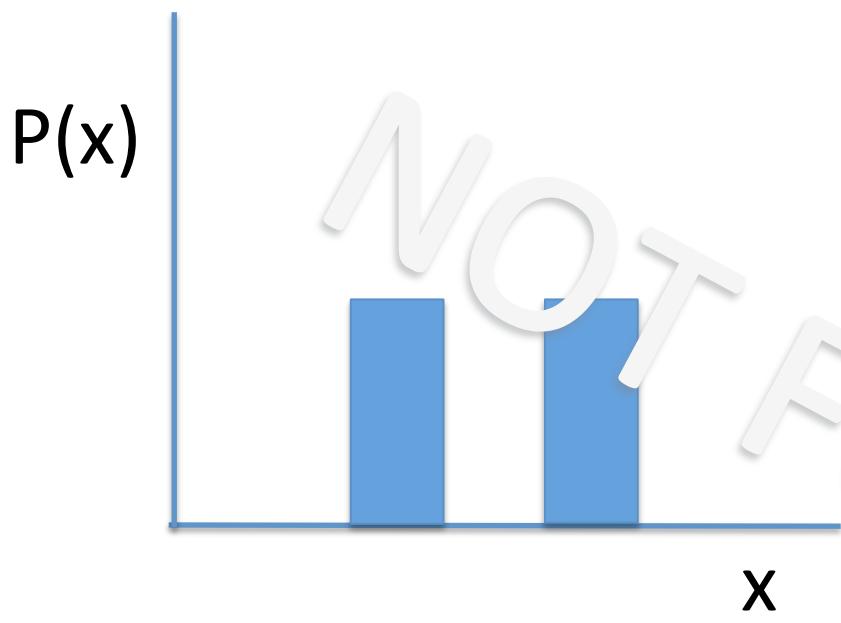
# Natural stimuli

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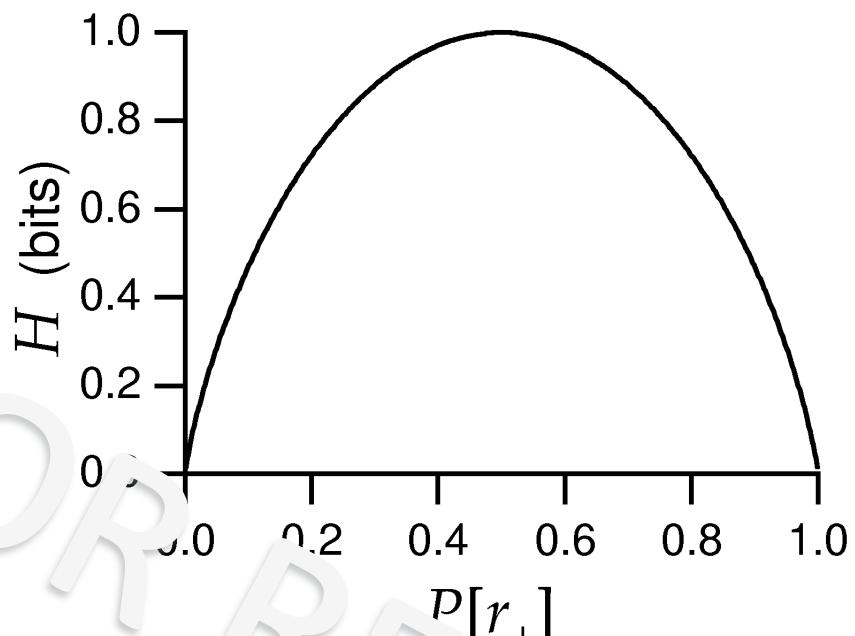
1. Huge dynamic range: variations over many orders of magnitude
2. Structure at many scales



# What makes a good code?



$$\text{Entropy} = - \sum p_i \log_2 p_i$$

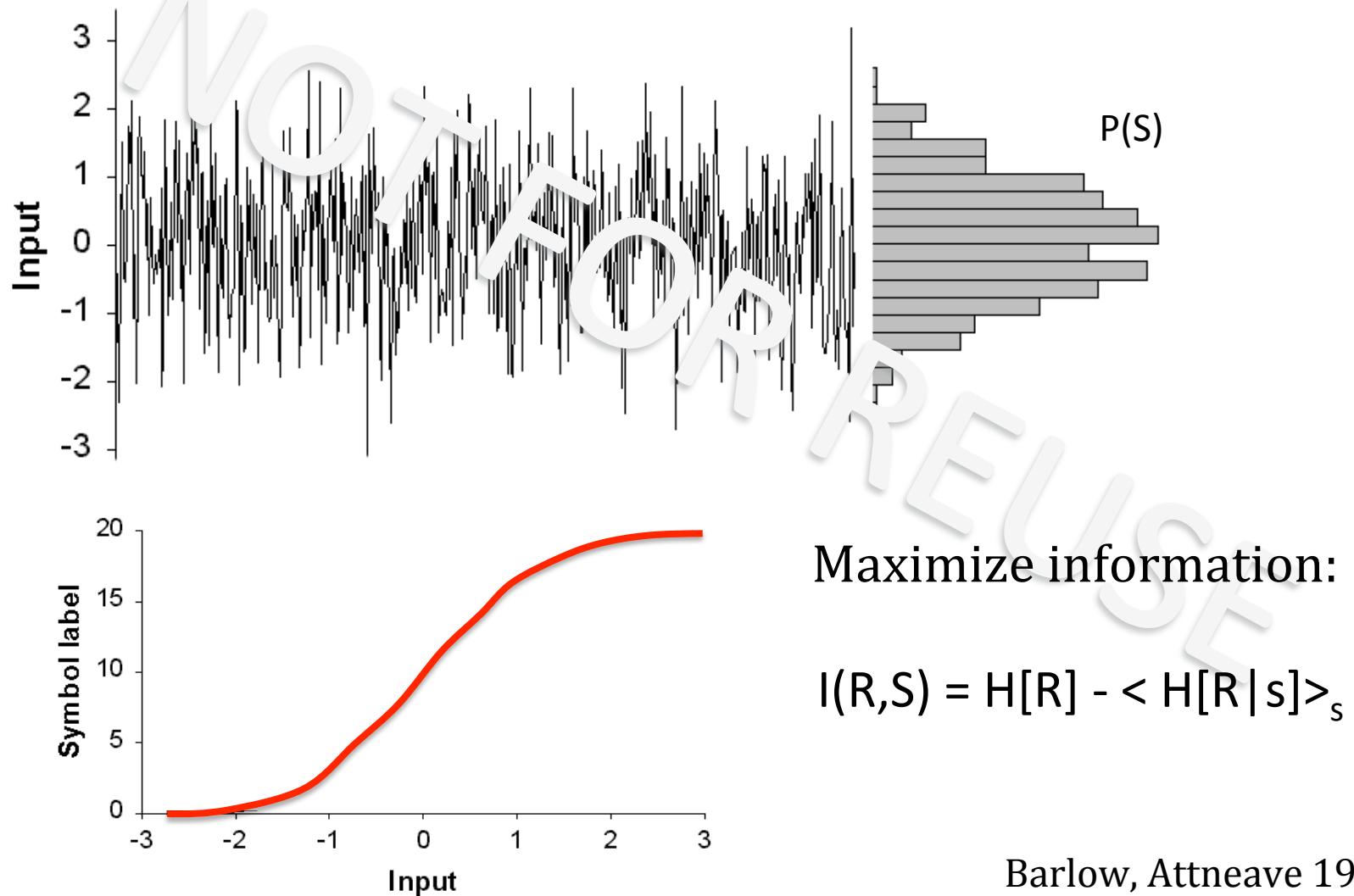


Maximize information

$$I(R,S) = H[R] - \langle H[R|S] \rangle_S$$

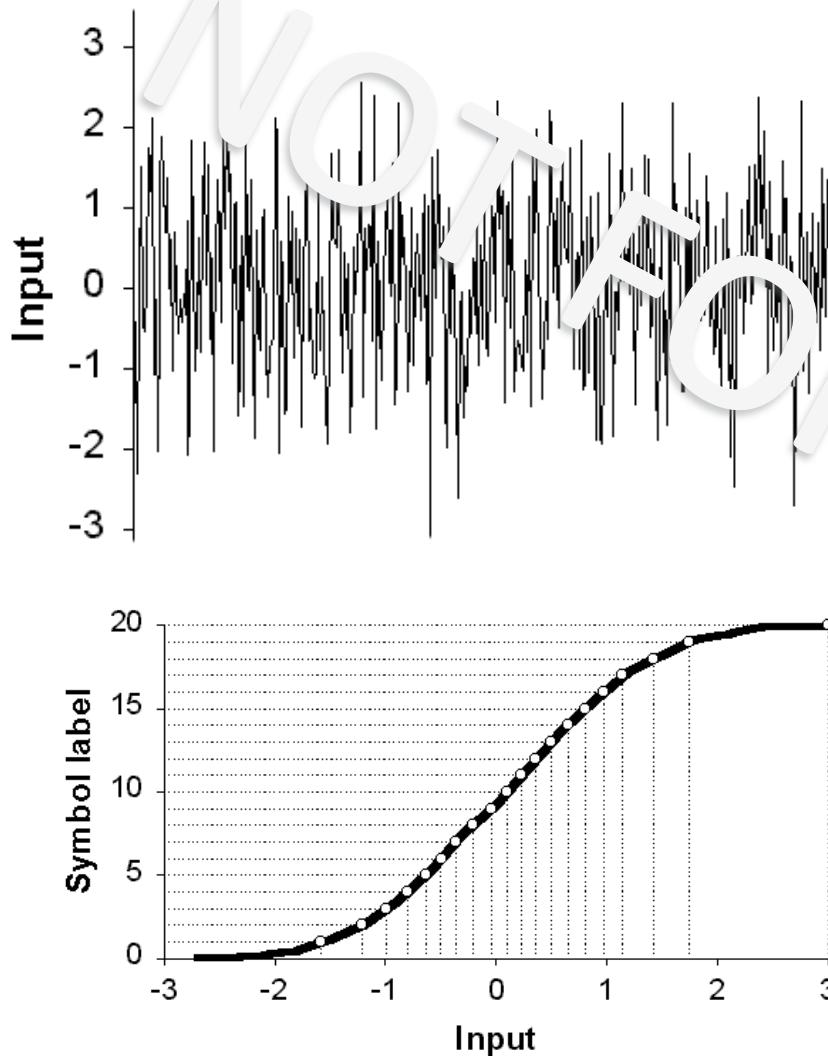
# Efficient coding

In order to have maximum entropy output, a good encoder should match its outputs to the distribution of its inputs



# Efficient coding

In order to encode stimuli effectively, an encoder should match its outputs to the statistical distribution of the inputs



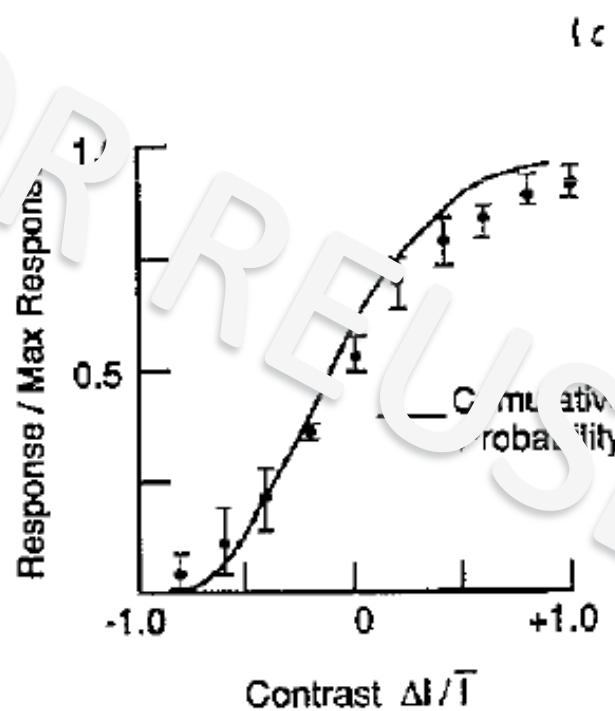
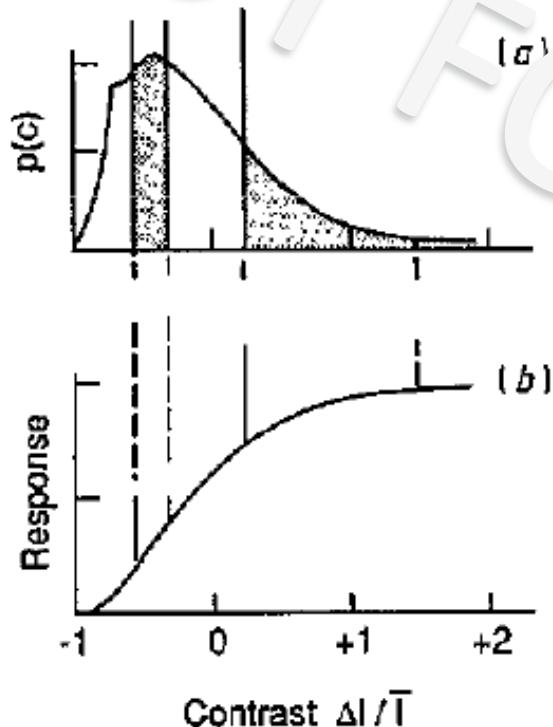
The input/output function should be determined by the distribution of natural inputs

Optimizes **mutual information** between output and input

# Fly visual system

$$P(r)dr = P(s)ds$$

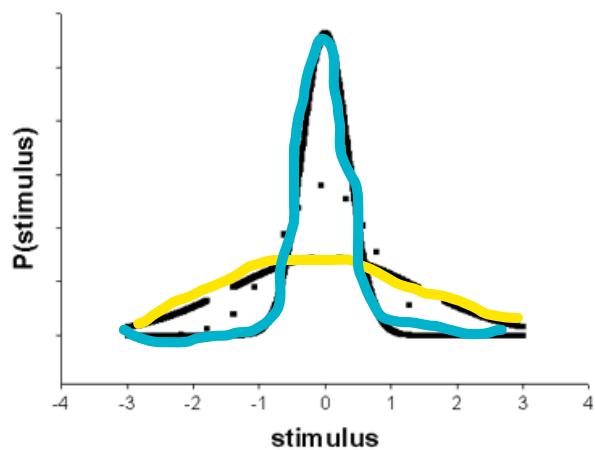
$$r = g(s) = \frac{1}{\alpha} \int_{-1}^s ds' P(s').$$



# Variation in time

Contrast varies hugely in time.

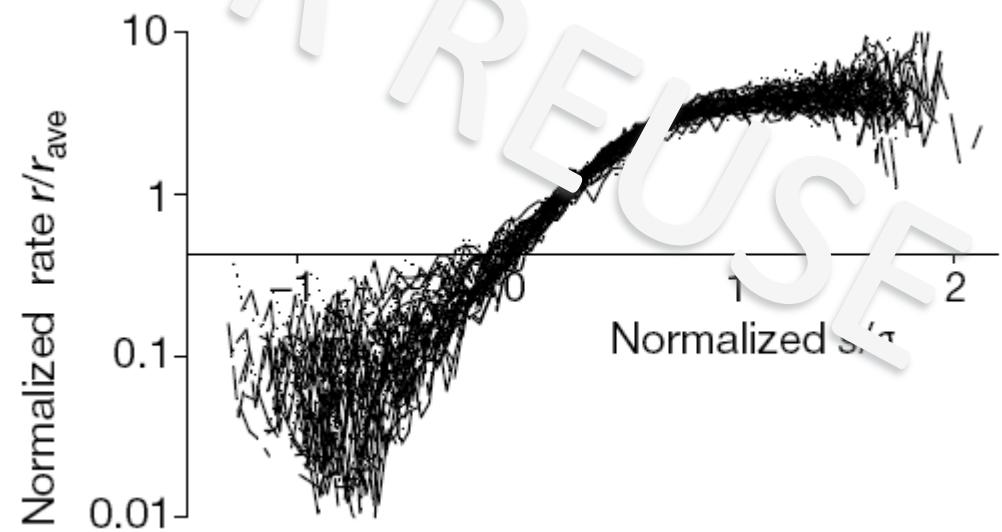
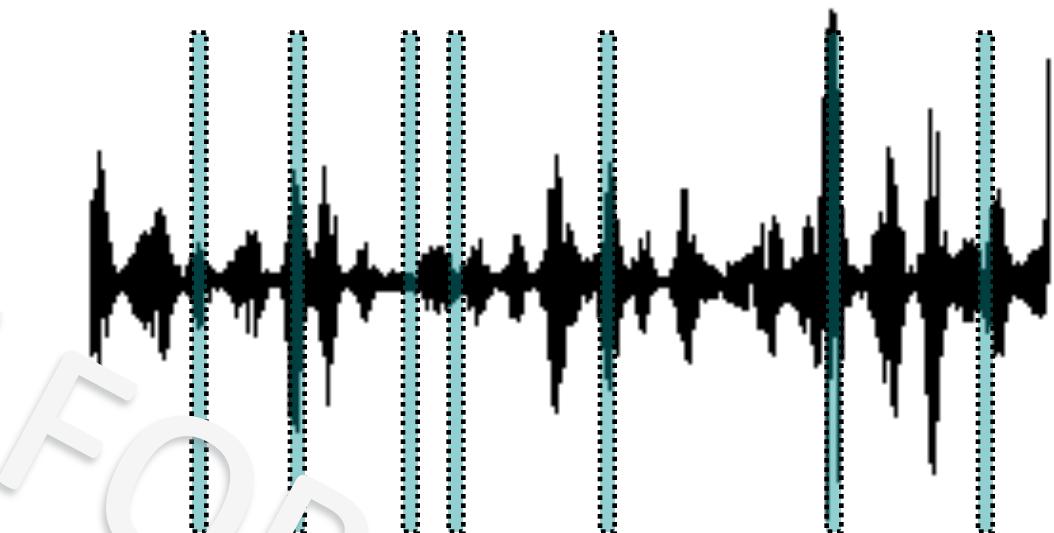
Should a neural system  
optimize over evolutionary  
time or locally?



# Time-varying stimulus representation



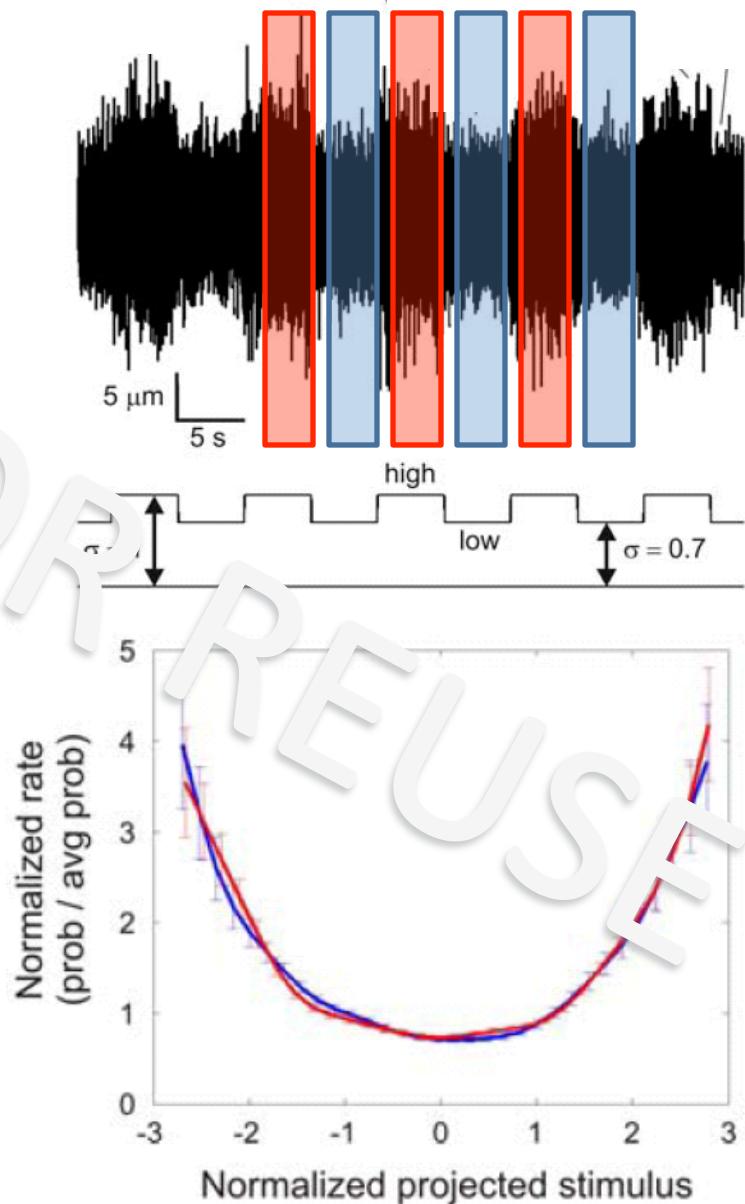
For fly neuron H1,  
determine the input/output  
relations throughout the  
stimulus presentation



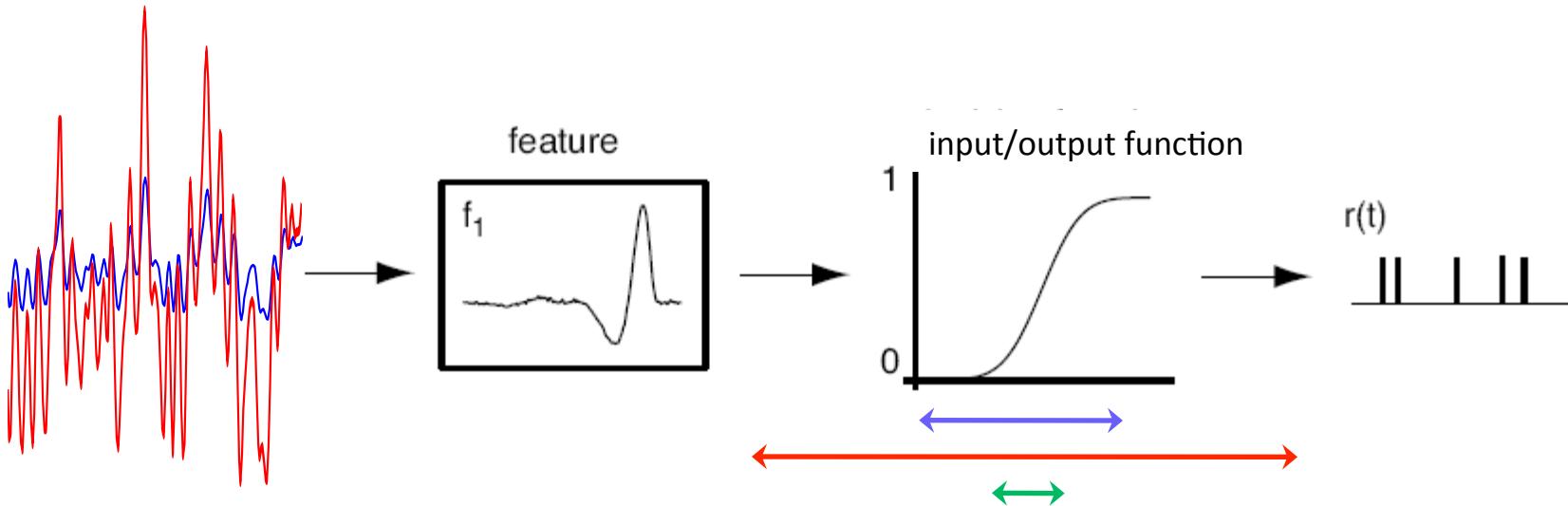
# Barrel cortex



Extracellular *in vivo* recordings  
of responses to whisker motion  
in rat S1 barrel cortex in the  
anesthetized rat

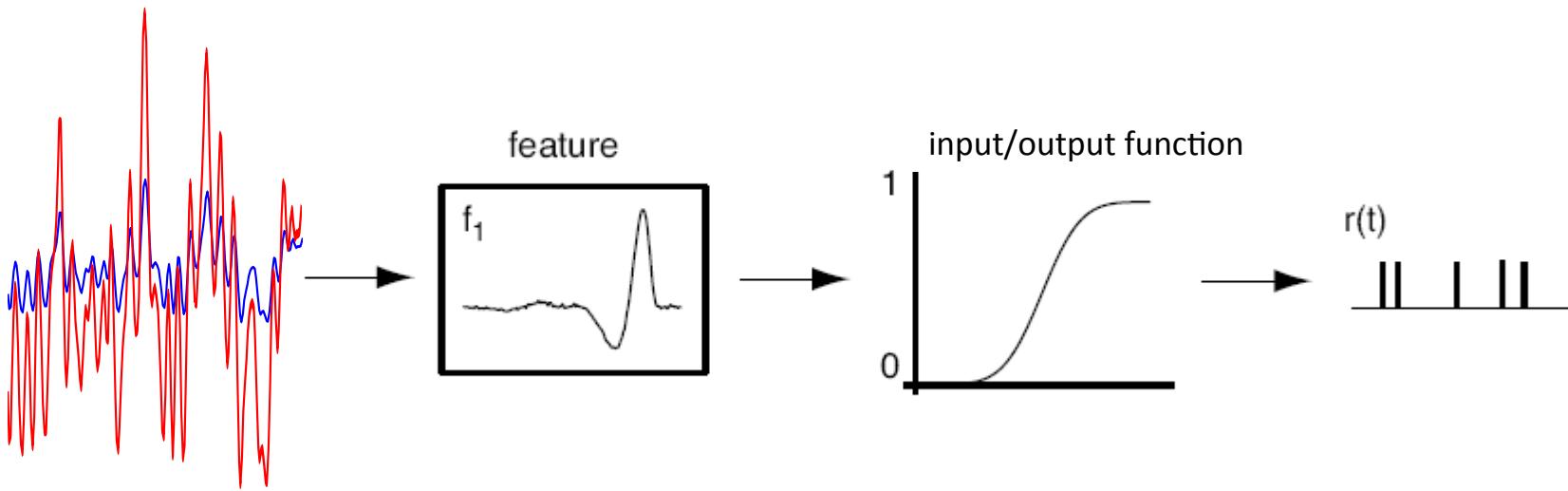


# Adaptive representation of information

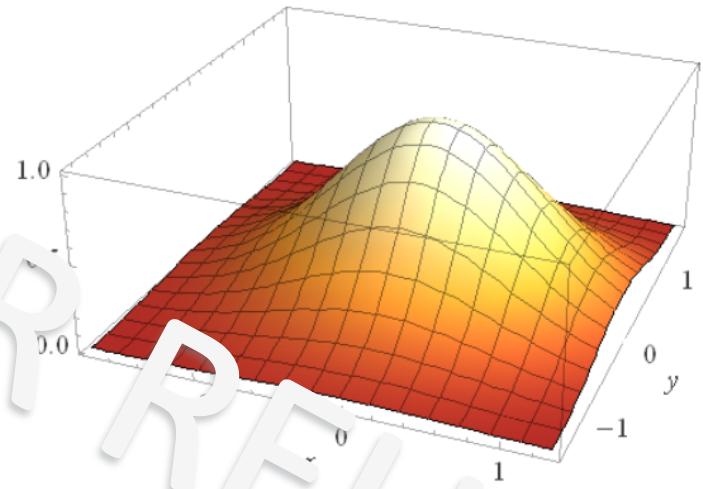
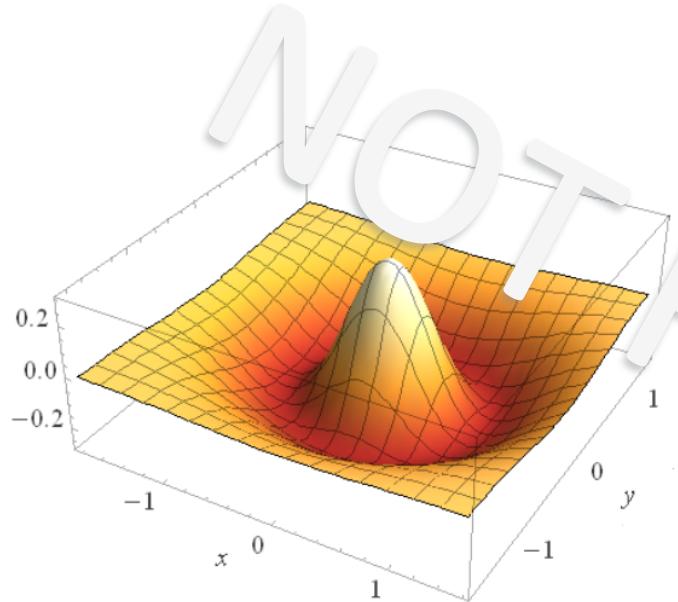


As one changes the characteristics of  $s(t)$ , changes can occur in the *input/output function* and in the encoded *feature*.

# Feature adaptation



# Feature adaptation

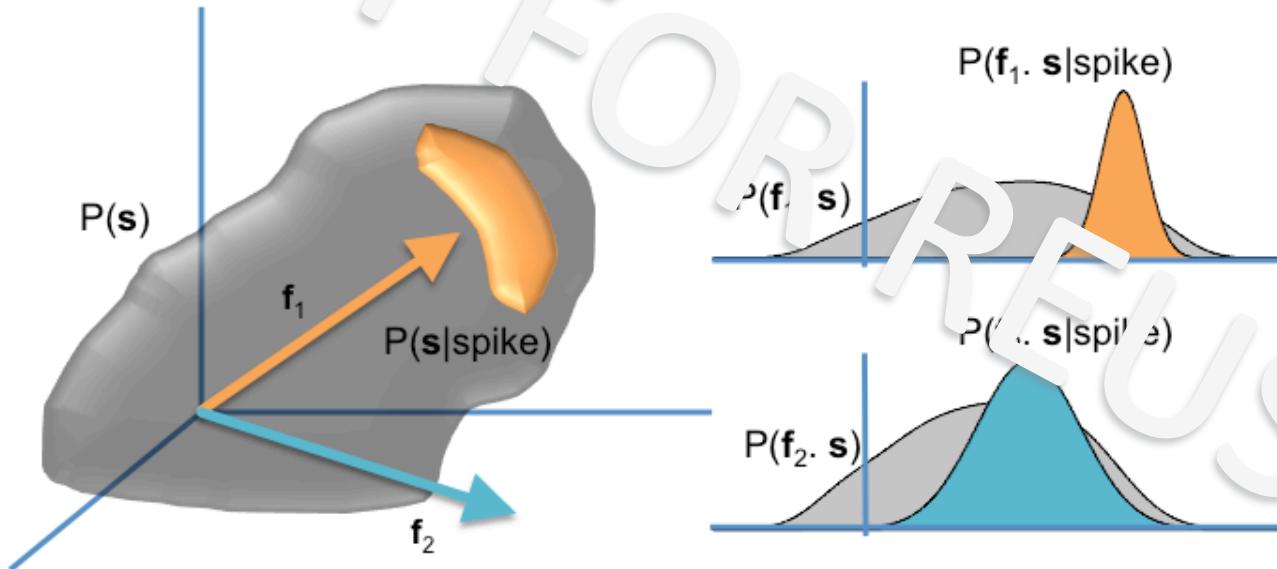


Atick and Redlich ('90), Atick ('92)

# Feature adaptation

Choose filter in order to maximize  $D_{KL}$  between spike-conditional and prior distributions.

Equivalent to maximizing information that the spike provides about the stimulus.



# Redundancy reduction

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Population code:  $P(R_1, R_2)$

$$H[R_1, R_2] \leq H[R_1] + H[R_2]$$

However.. correlations can be good.

- Error correction and robust coding
- Correlations can help discrimination

Indeed, neurons in the retina are observed to be redundant (Berry, Chichilnisky)

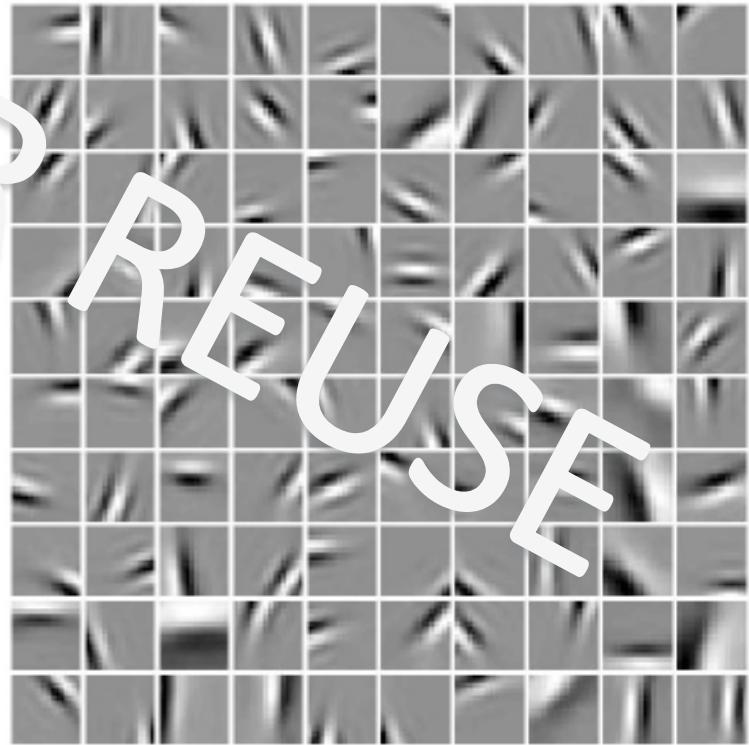
# Representing natural scenes sparsely

$$I(\vec{x}) = \sum_i a_i \phi_i(\vec{x}) + \epsilon(\vec{x})$$

$$E = \sum_{\vec{x}} \left[ I(\vec{x}) - \sum_i a_i \phi_i(\vec{x}) \right]^2 + \lambda \sum_i C(a_i)$$



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Olshausen; Olshausen and Field (1996), Bell and Sejnowski (1995)

# Coding principles

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- Coding efficiency
- Adaptation to stimulus statistics
- Sparseness

# And so to the end of coding...

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Classic and state of the art methods:

- Models for predicting how stimuli are coded in spikes
- Models for decoding stimuli from neural responses
- Information theory and how it is used to evaluate coding schemes
- A very quick glance at how coding strategies might be shaped by the statistics of natural inputs

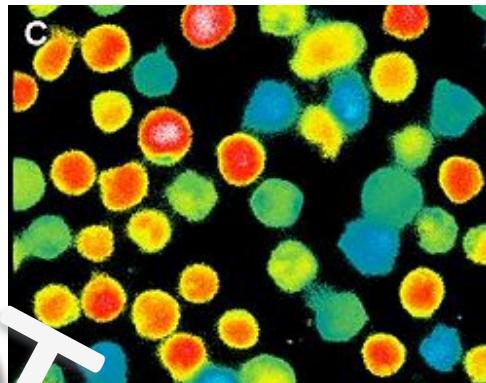
# What have we missed?

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What features do animals extract to solve problems?



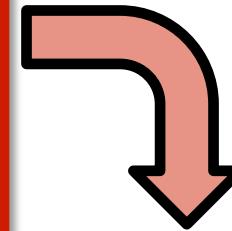
Neural activity



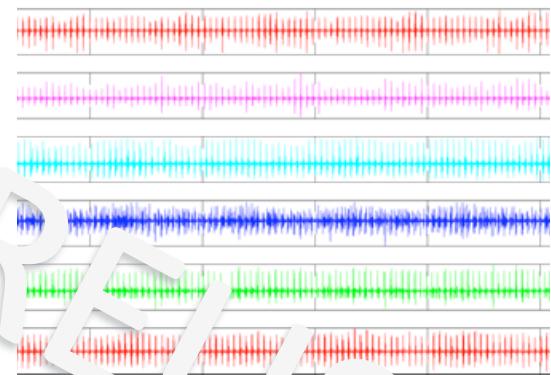
Complex environments



How is information synthesized to drive decisions?



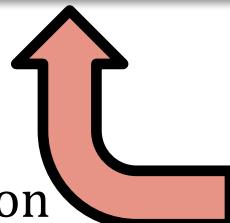
Motor activity



Behavioral output



How does action affect subsequent sensation?



How do muscles work together to perform actions?



# Next week

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A brief introduction to the biophysics of coding

- Neuronal excitability
- Simplified models that capture neuronal firing