

Information and coding efficiency

- 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 dark, moody interior scene, likely a control room or studio. In the foreground, there's a large, dark, curved object, possibly a reel or a piece of equipment. To the left, a desk is visible with various electronic components and cables. Large windows dominate the background, showing a bright sunset or sunrise over rolling hills and a body of water. The overall atmosphere is dramatic and atmospheric.



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A dark, atmospheric 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 seat is visible in the foreground. The overall mood is moody and dramatic.

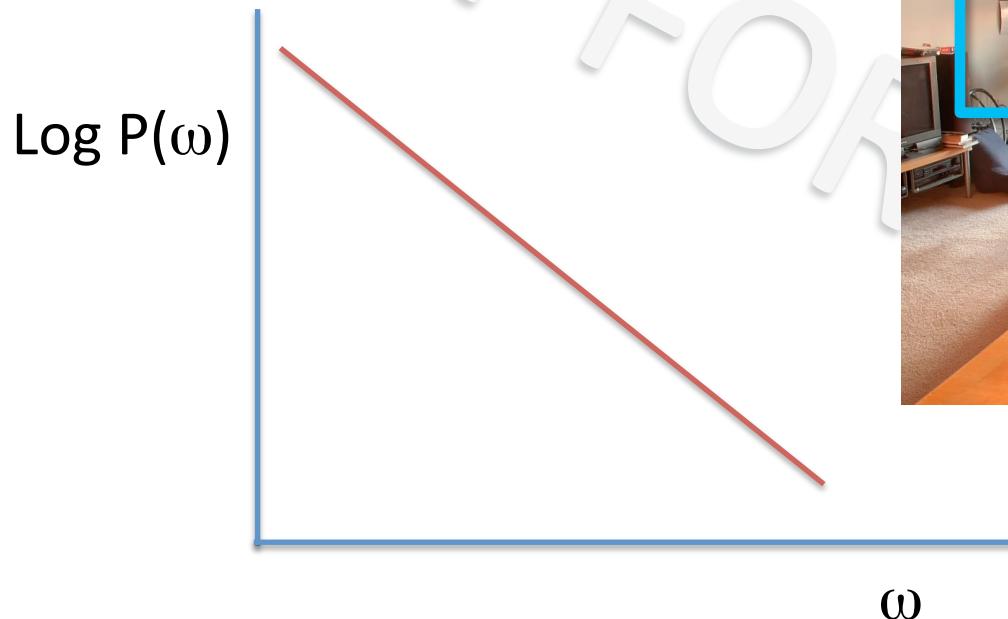
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A dark, moody photograph of an interior space, likely a control room or observatory, featuring large windows that look out onto a forest at sunset. The scene is mostly in shadow, with light from the windows creating a dramatic silhouette effect. In the foreground, there's a desk with some equipment and papers. A large, semi-transparent white text overlay reads "NOT FOR REUSE" diagonally across the image.

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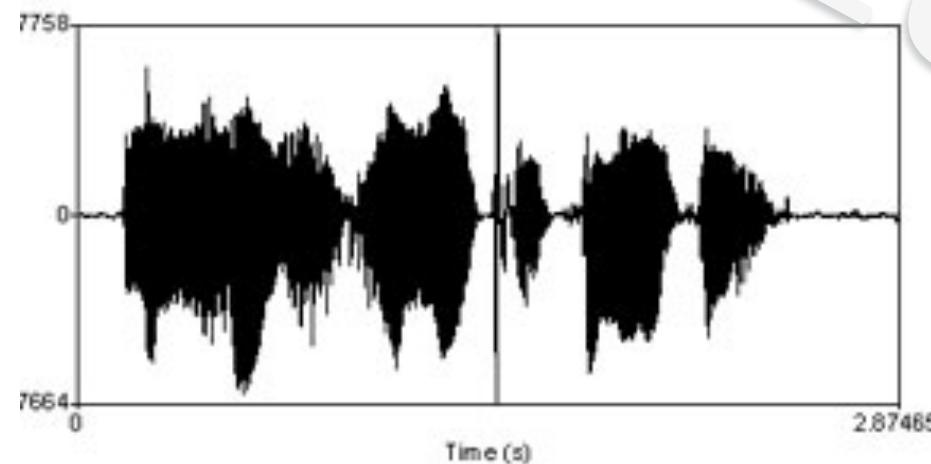
Natural stimuli

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

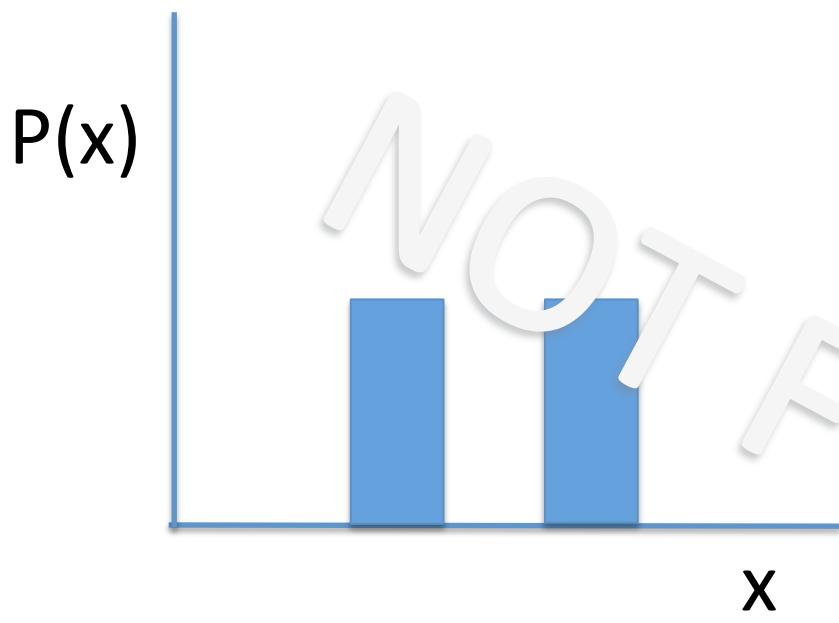


Natural stimuli

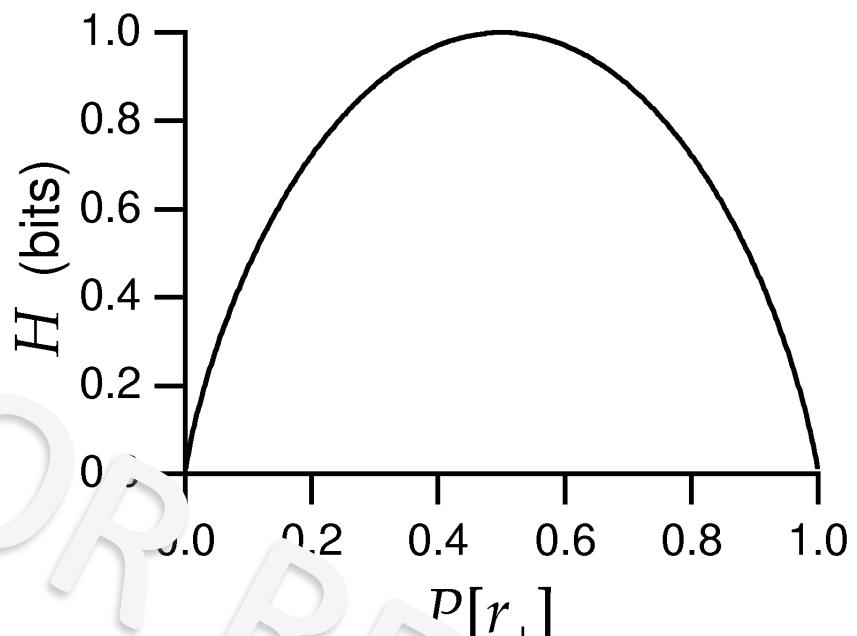
1. Huge dynamic range: variations over many orders of magnitude
2. Structure at many scales



What makes a good code?



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

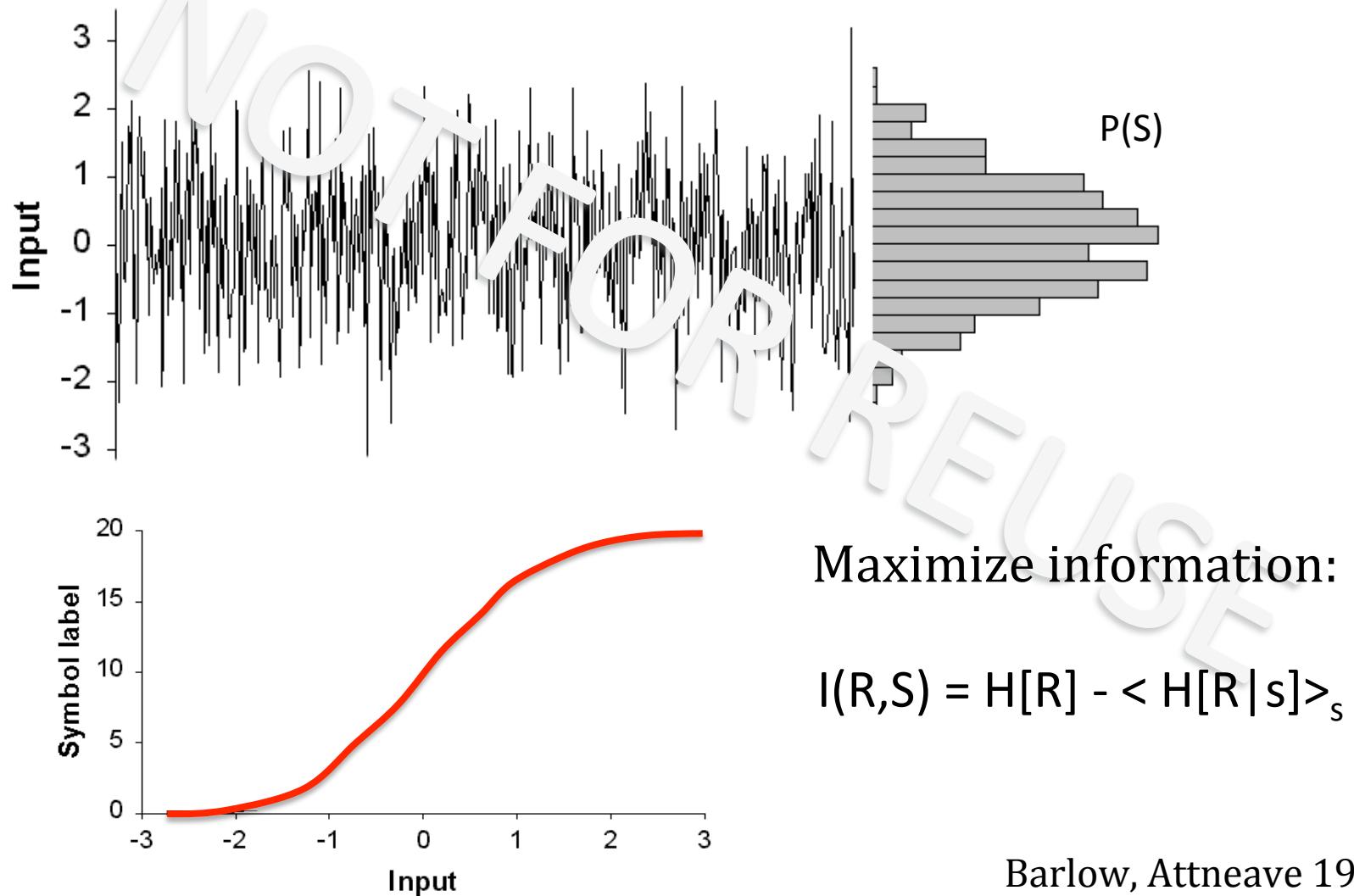


Maximize information

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

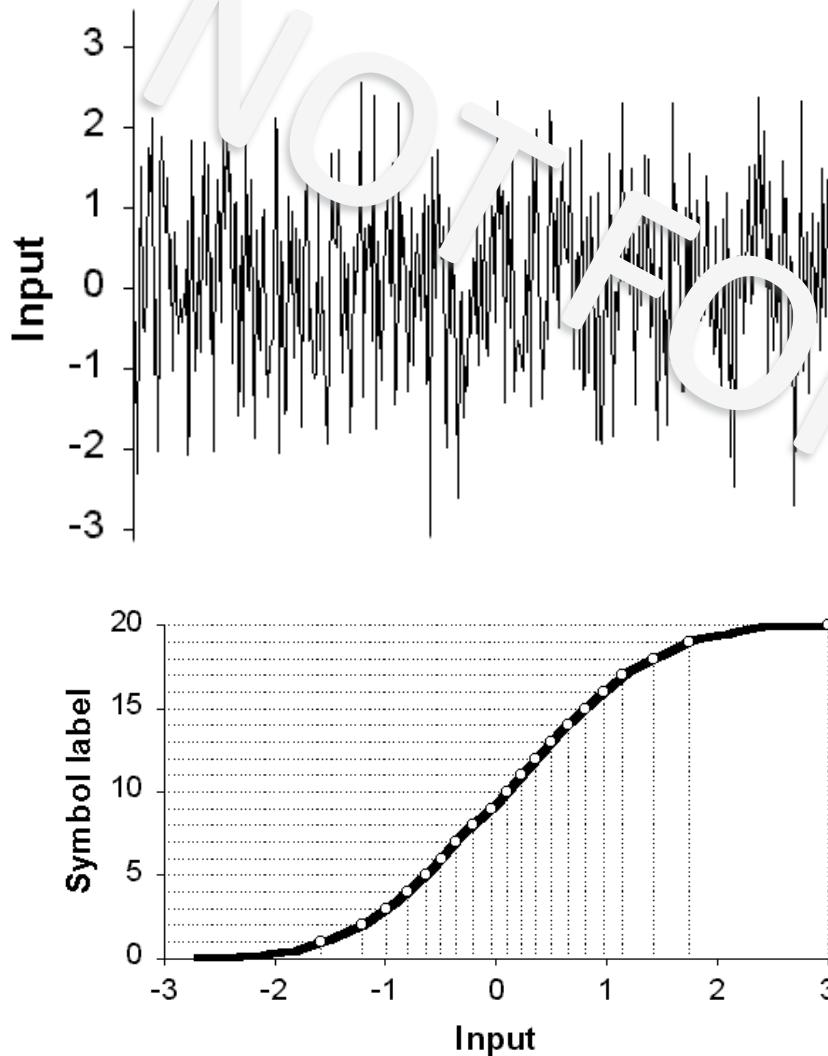
Efficient coding

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



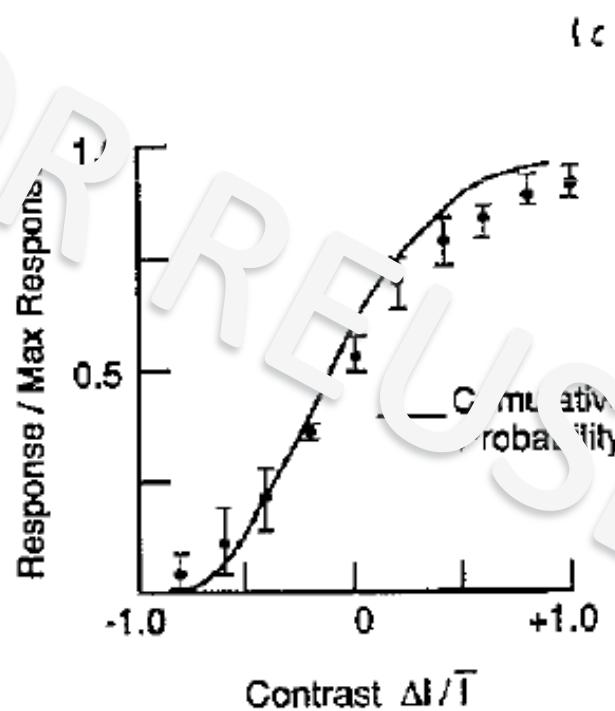
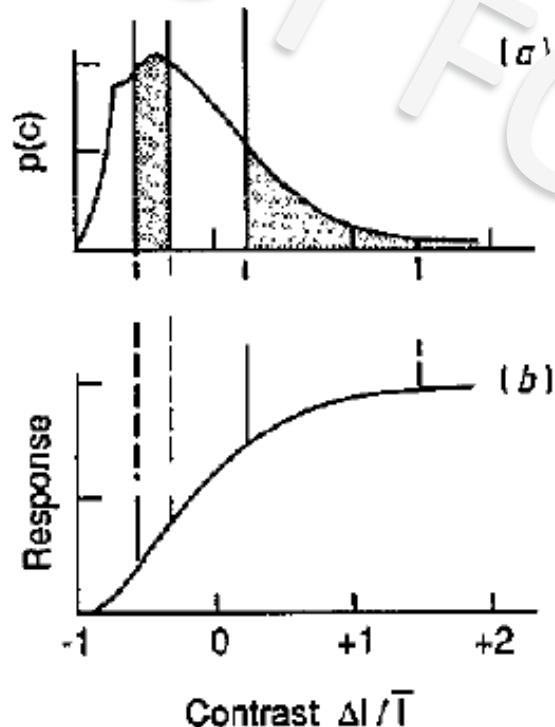
The input/output function should be determined by the distribution of natural inputs

Optimizes **mutual information** between output and input

Fly visual system

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

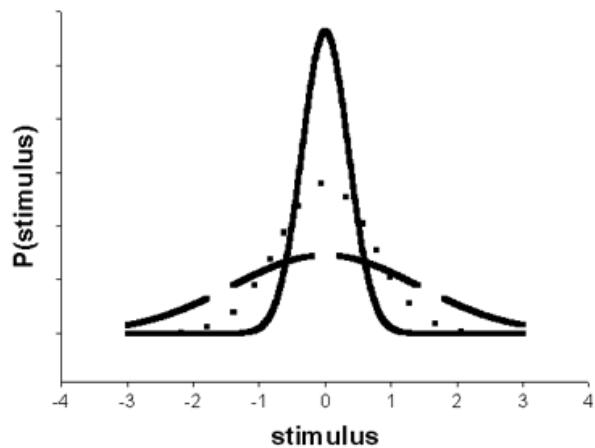
$$r = g(s) = \frac{1}{\alpha} \int_{-1}^s ds' P(s').$$



Variation in time

Contrast varies hugely in time.

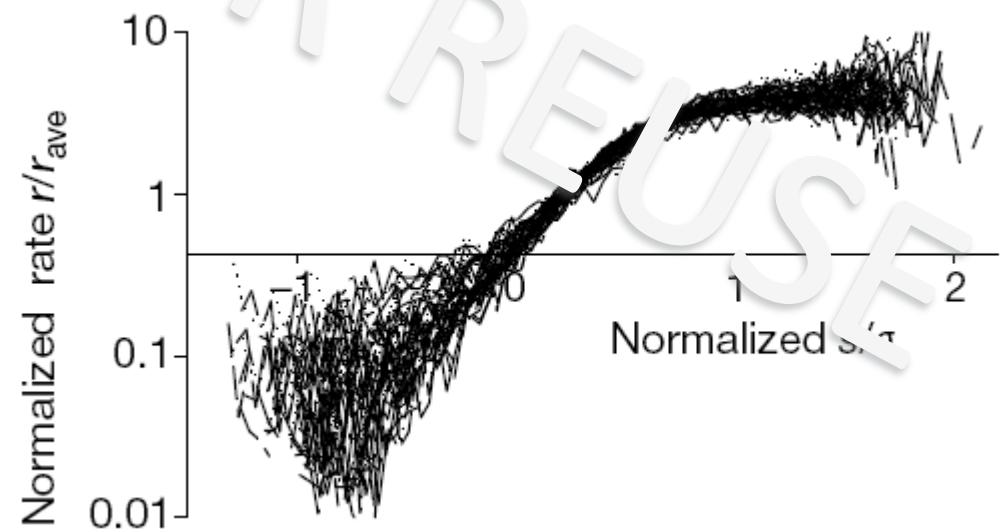
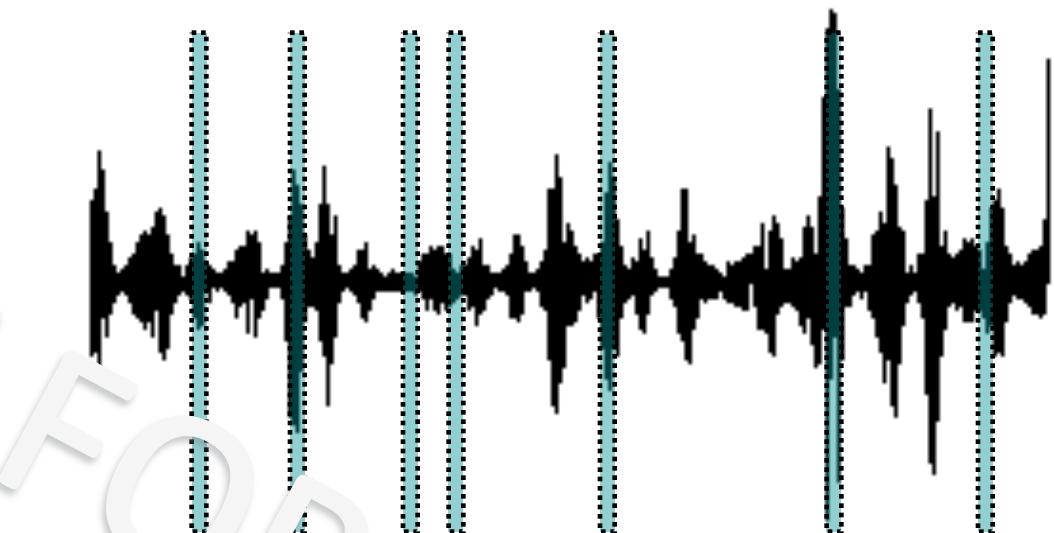
Should a neural system
optimize over evolutionary
time or locally?



Time-varying stimulus representation



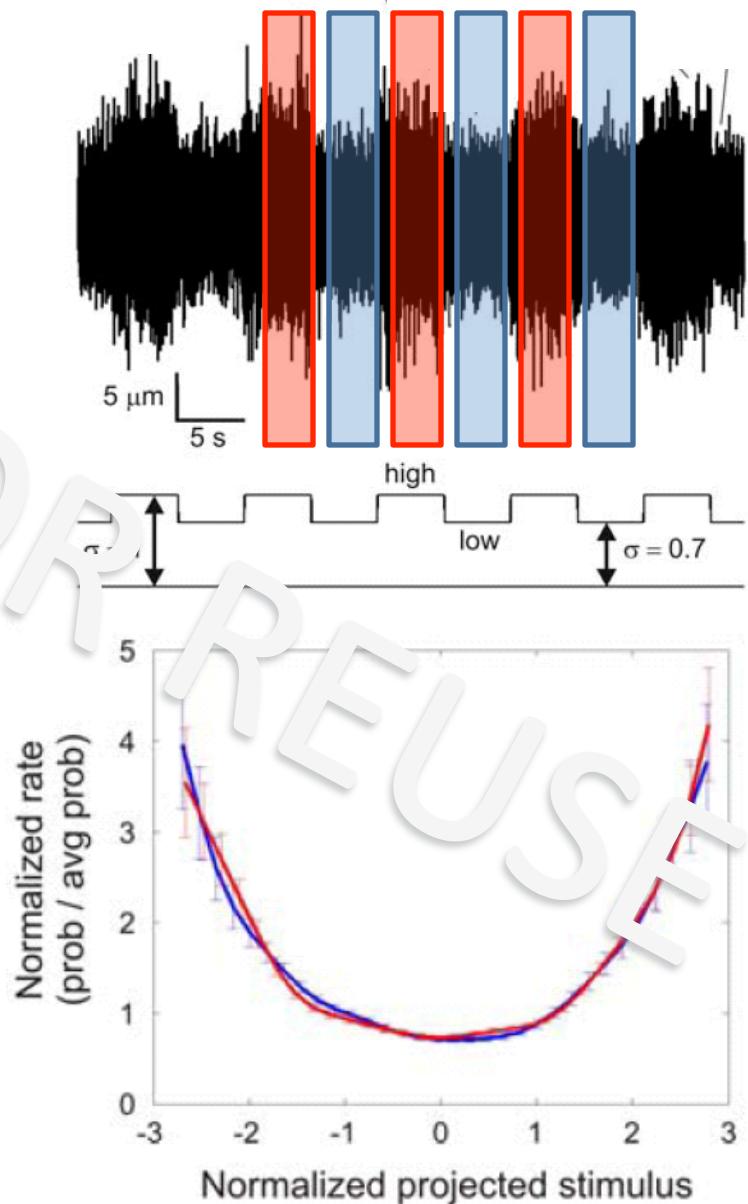
For fly neuron H1,
determine the input/output
relations throughout the
stimulus presentation



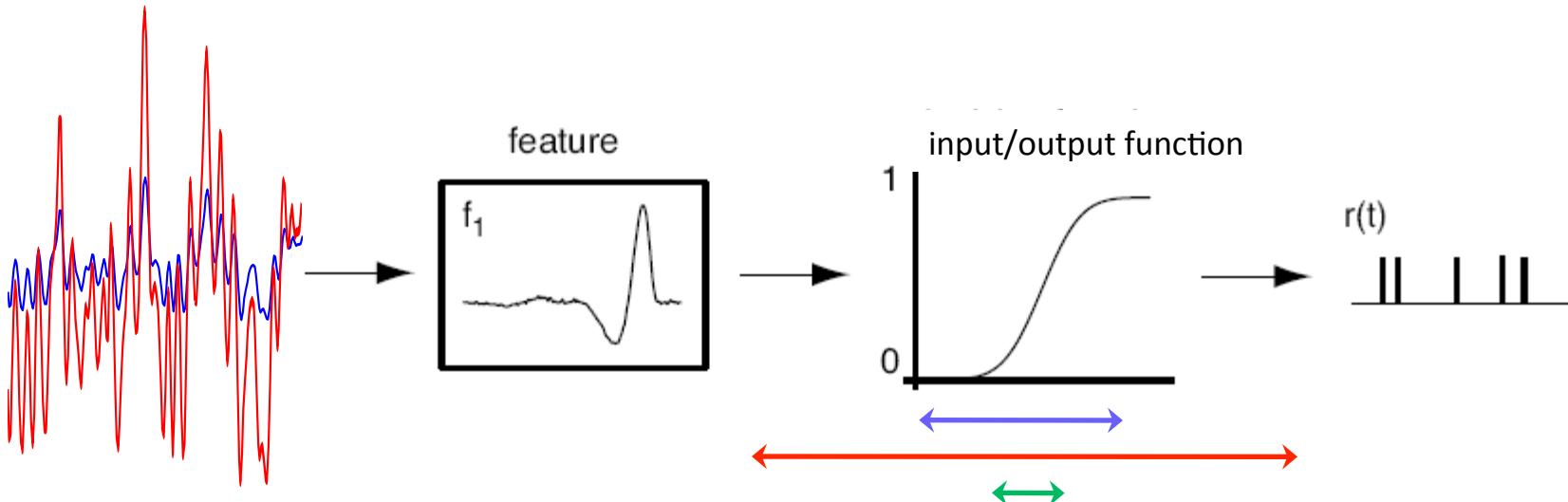
Barrel cortex



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

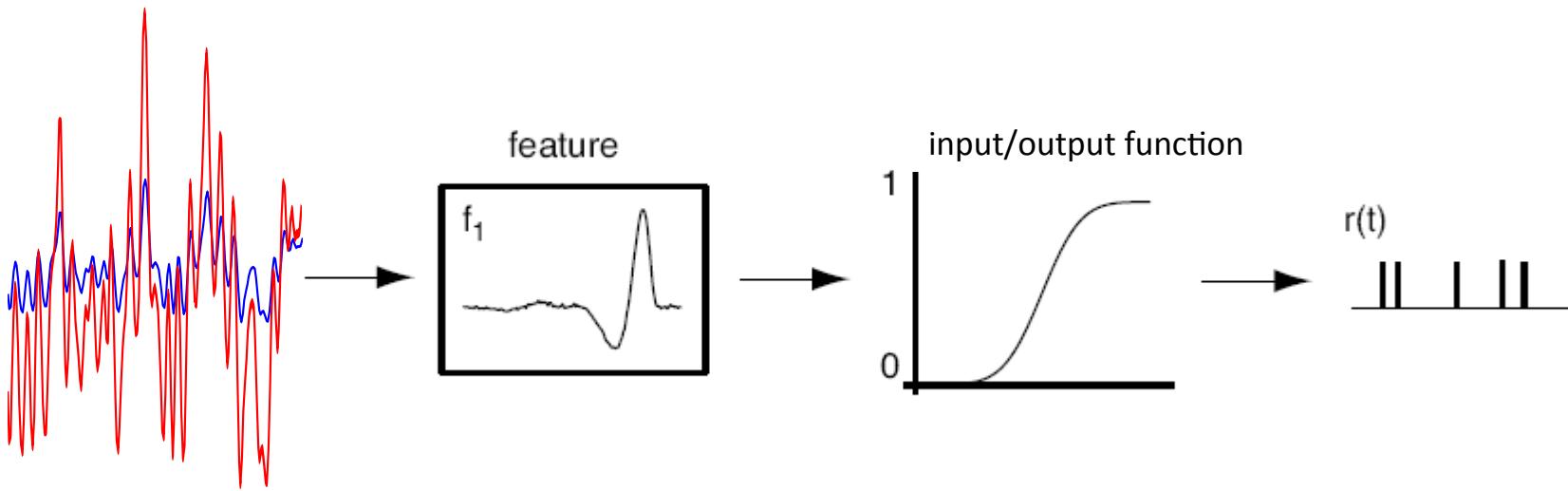


Adaptive representation of information

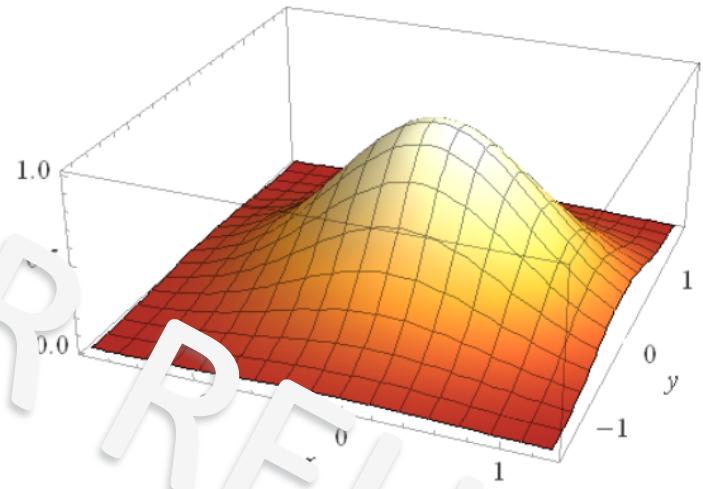
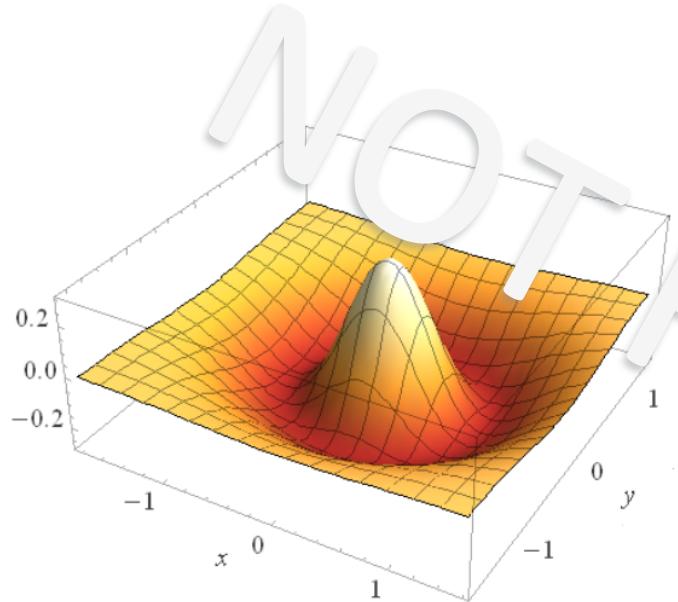


As one changes the characteristics of $s(t)$, changes can occur in the *input/output function* and in the encoded *feature*.

Feature adaptation



Feature adaptation

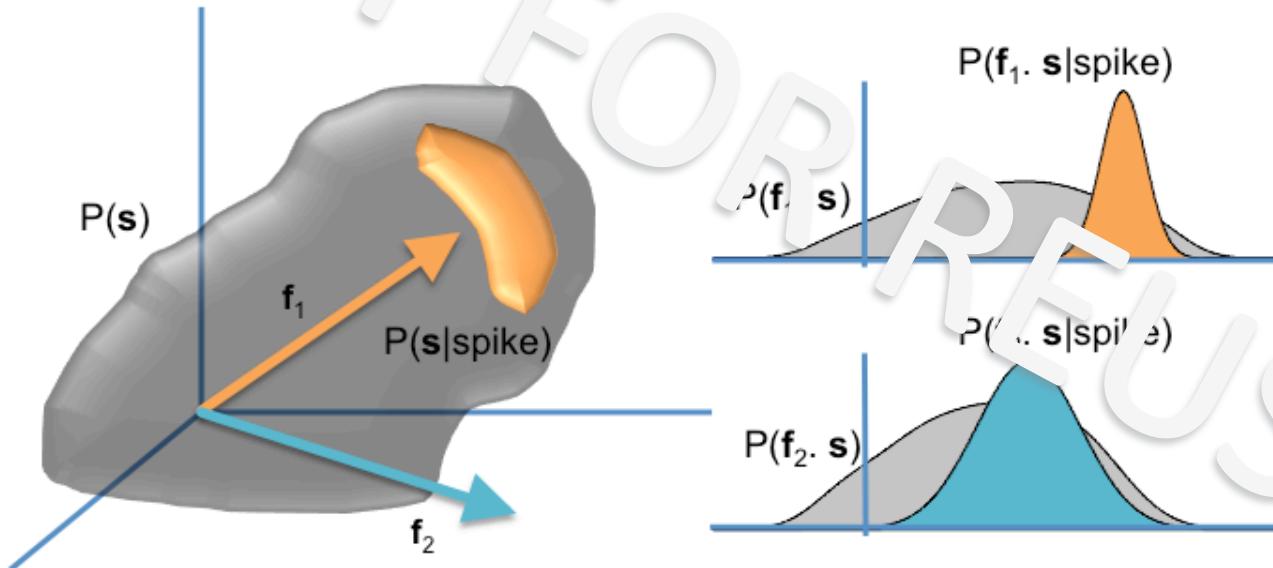


Atick and Redlich ('90), Atick ('92)

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

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)

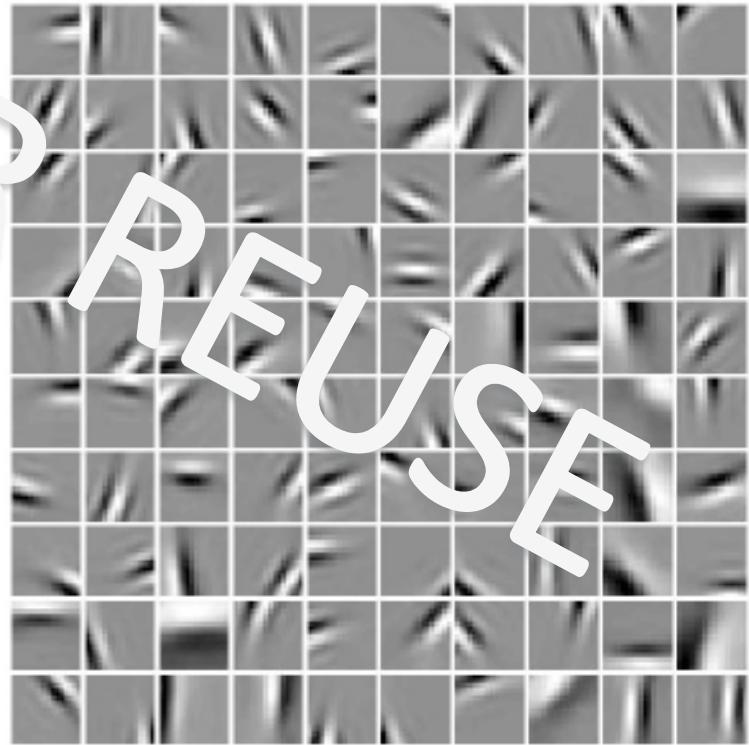
Representing natural scenes sparsely

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

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



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

Coding principles

- Coding efficiency
- Adaptation to stimulus statistics
- Sparseness

And so to the end of coding...

Classic and state of the art methods:

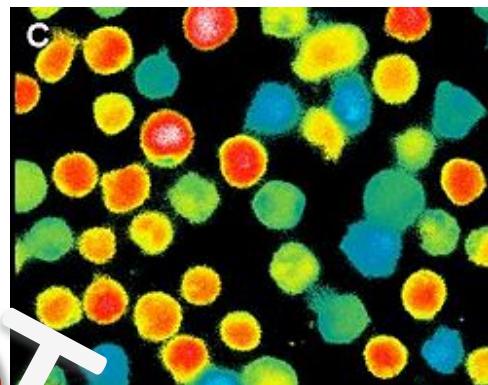
- Models for predicting how stimuli are coded in spikes
- Models for decoding stimuli from neural responses
- Information theory and how it is used to evaluate coding schemes
- A very quick glance at how coding strategies might be shaped by the statistics of natural inputs

What have we missed?

What features do animals extract to solve problems?



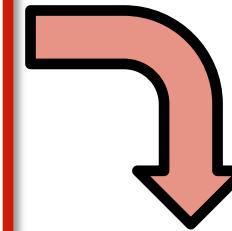
Neural activity



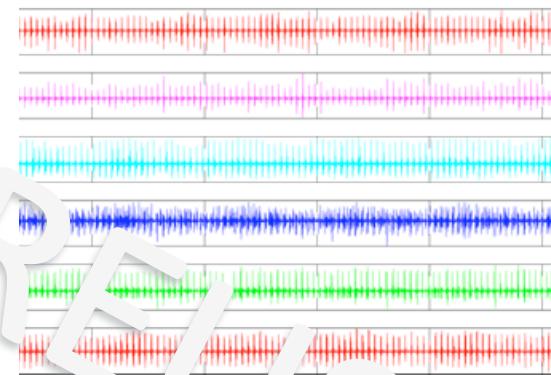
Complex environments



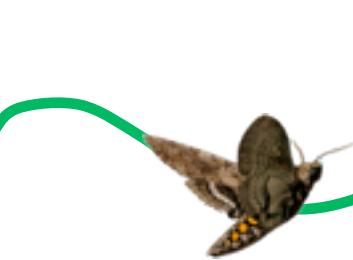
How is information synthesized to drive decisions?



Motor activity



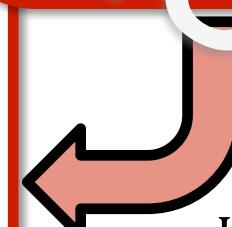
Behavioral output



How does action affect subsequent sensation?



How do muscles work together to perform actions?



Next week

A brief introduction to the biophysics of coding

- Neuronal excitability
- Simplified models that capture neuronal firing