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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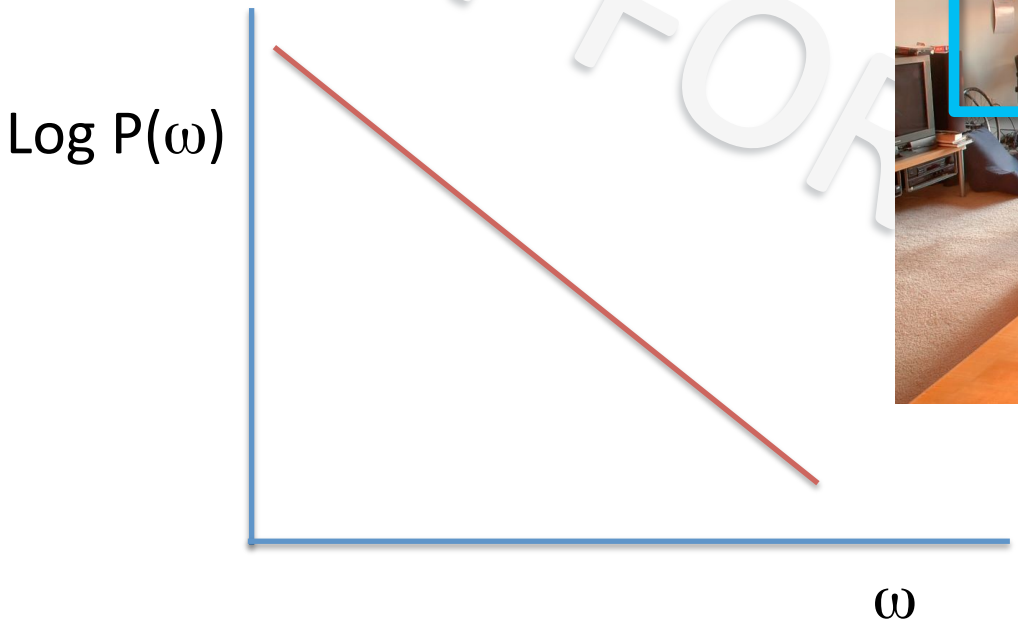
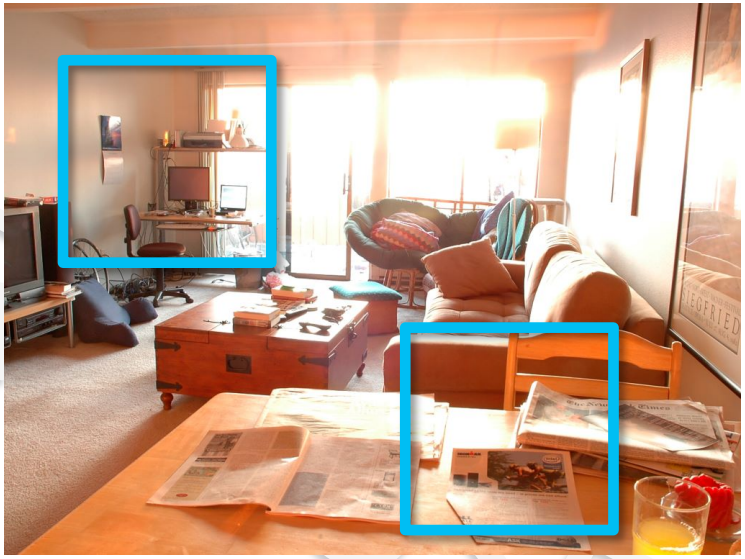
Natural stimuli

1. Huge dynamic range: variations over many orders of magnitude

2. Power law scaling

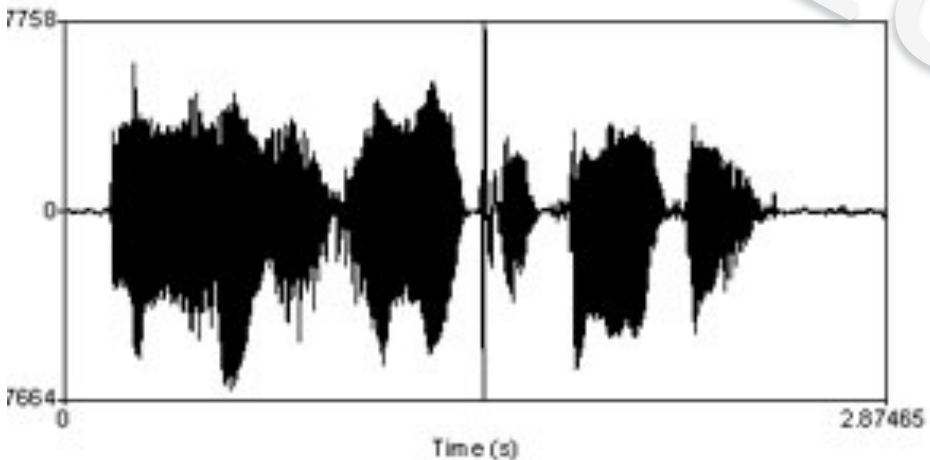




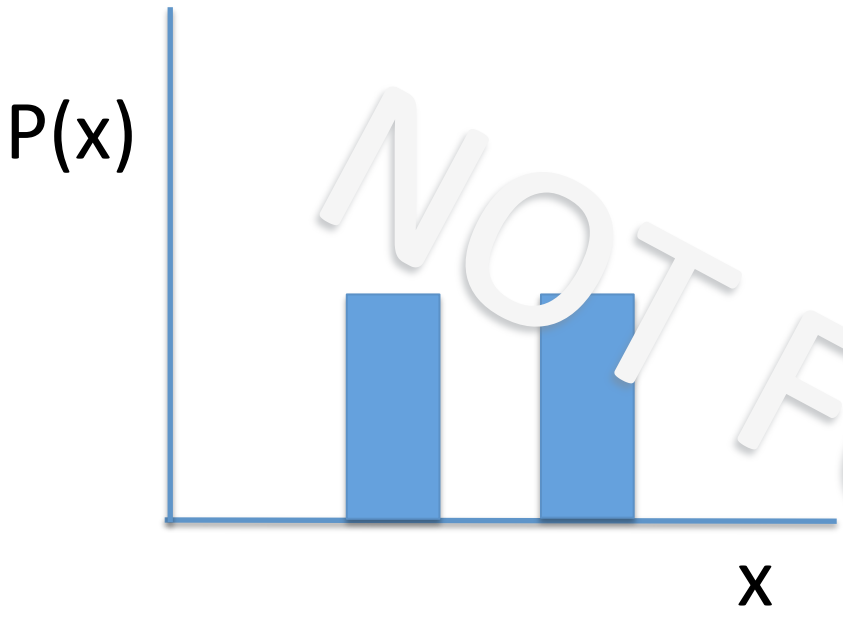
Natural stimuli

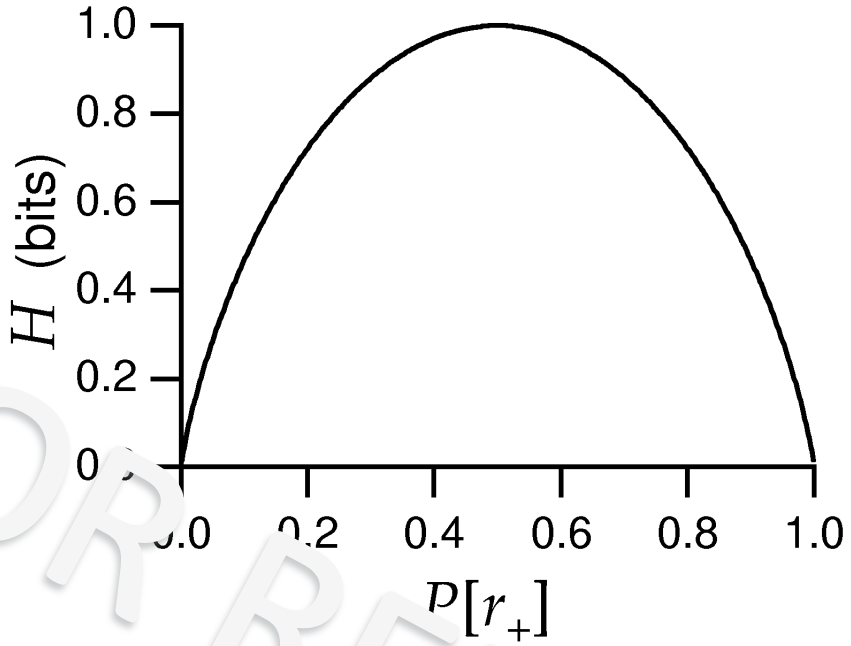
1. Huge dynamic range: variations over many orders of magnitude

2. Structure at many scales



What makes a good code?





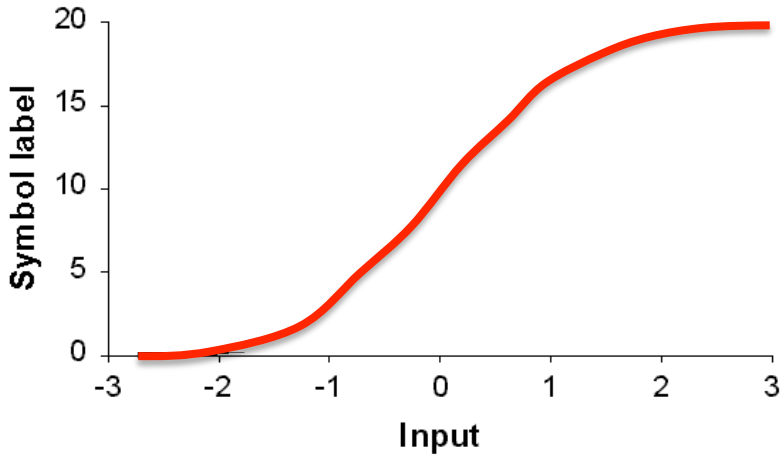
Entropy = $- \Sigma\, p_i \log_2 p_i$

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



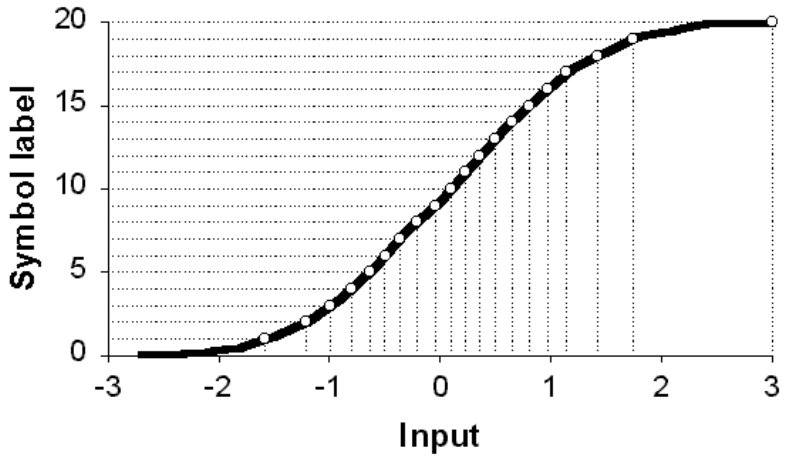
Maximize information:

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

Barlow, Attneave 1954

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

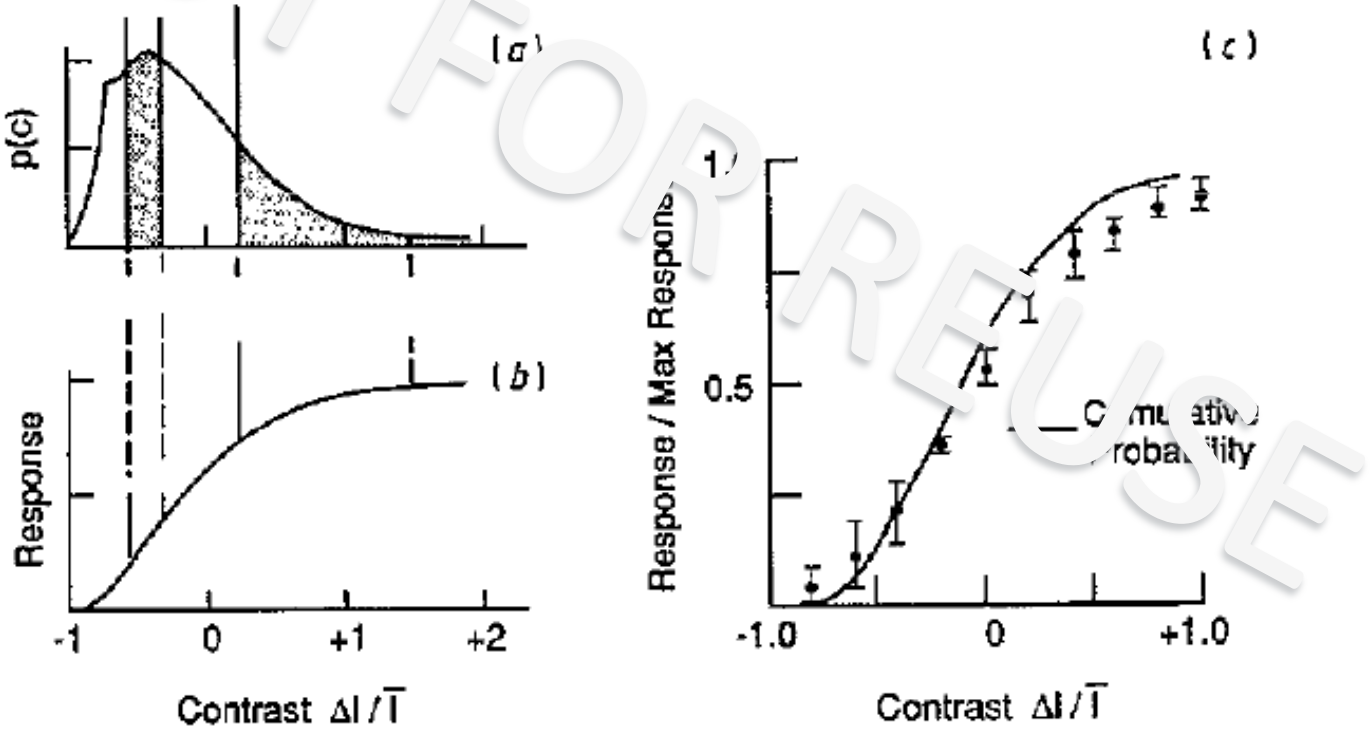
Optimizes **mutual information** between output and input

Barlow, Attneave 1954

Fly visual system

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

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

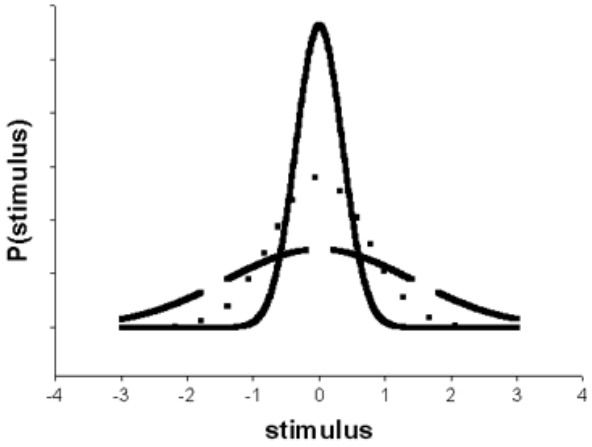


Laughlin, '81

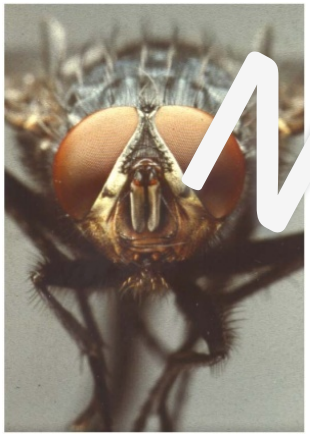
Variation in time

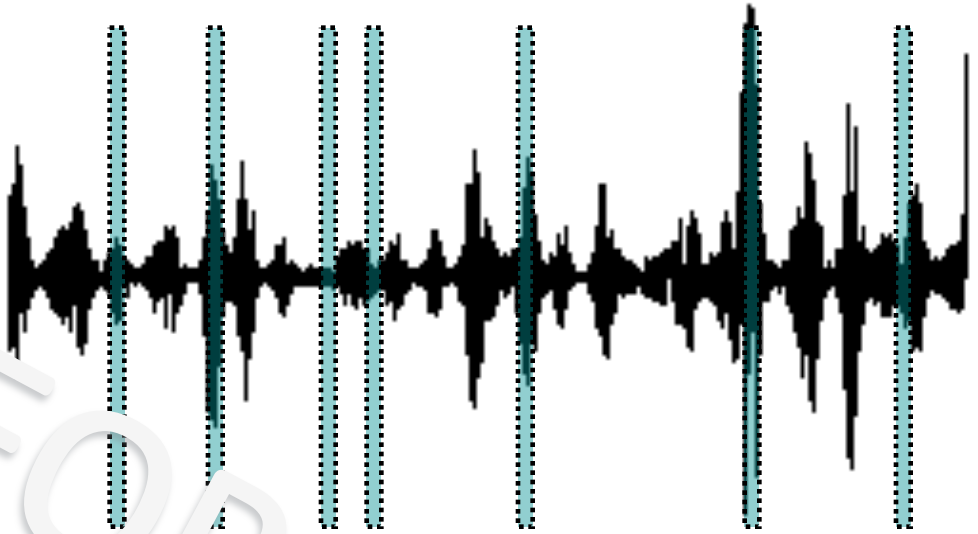
Contrast varies hugely in time.

Should a neural system optimize over evolutionary time or locally?

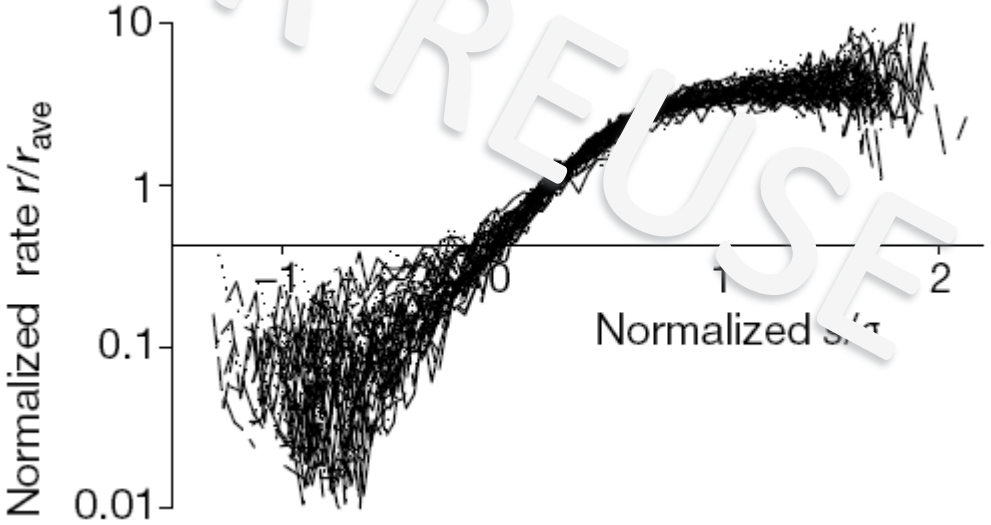


Time-varying stimulus representation



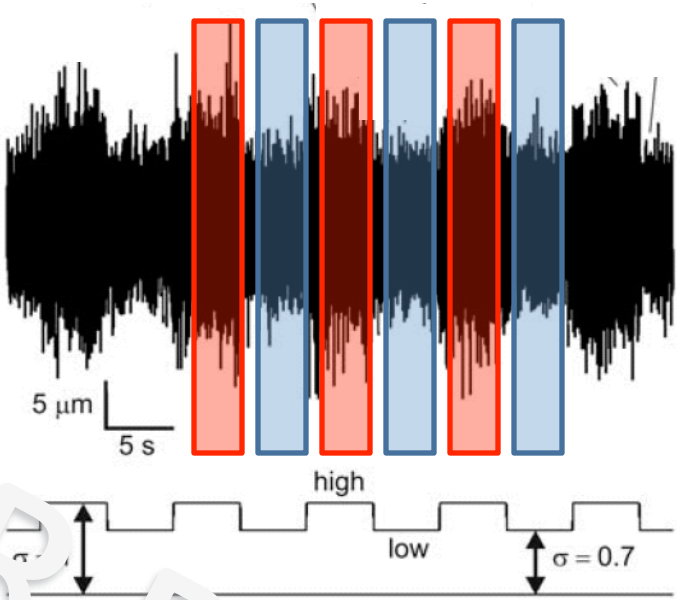


For fly neuron H1, determine the input/output relations throughout the stimulus presentation

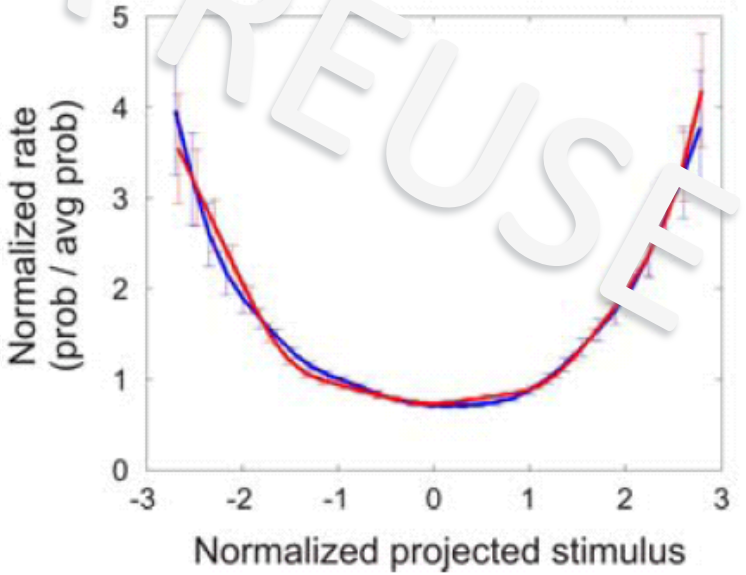


Fairhall, Lewen, de Ruyter and Bialek (2001)

Barrel cortex

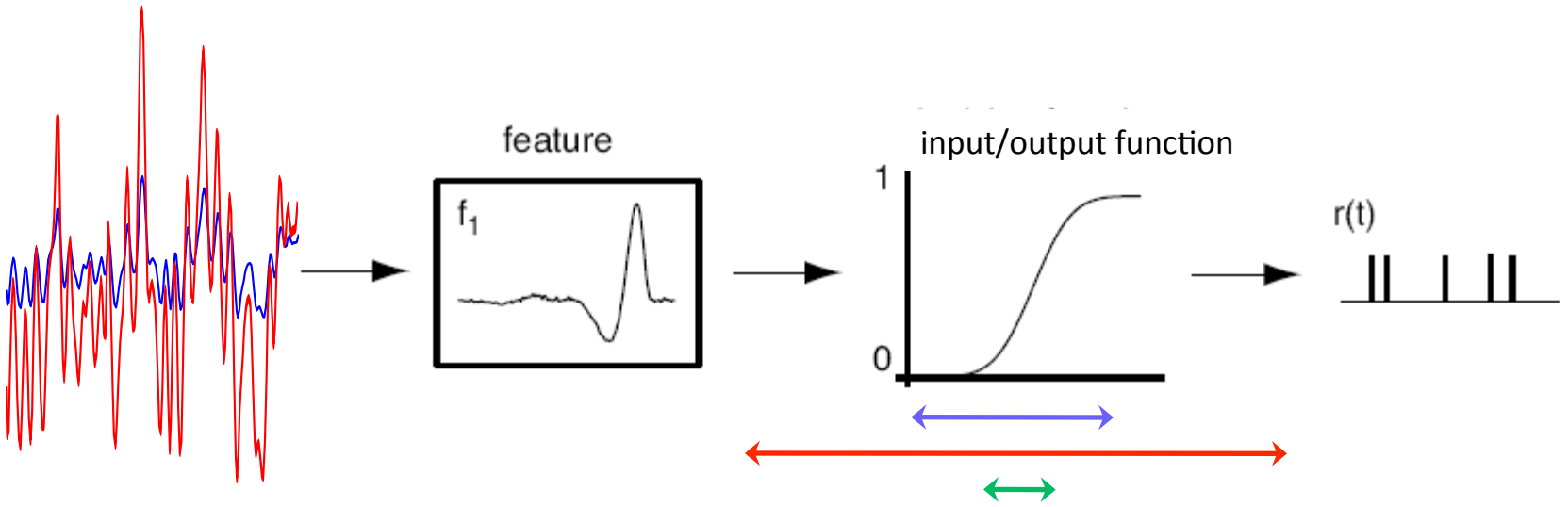


Extracellular *in vivo* recordings of responses to whisker motion in rat S1 barrel cortex in the anesthetized rat



M. Maravall et al., (2007)

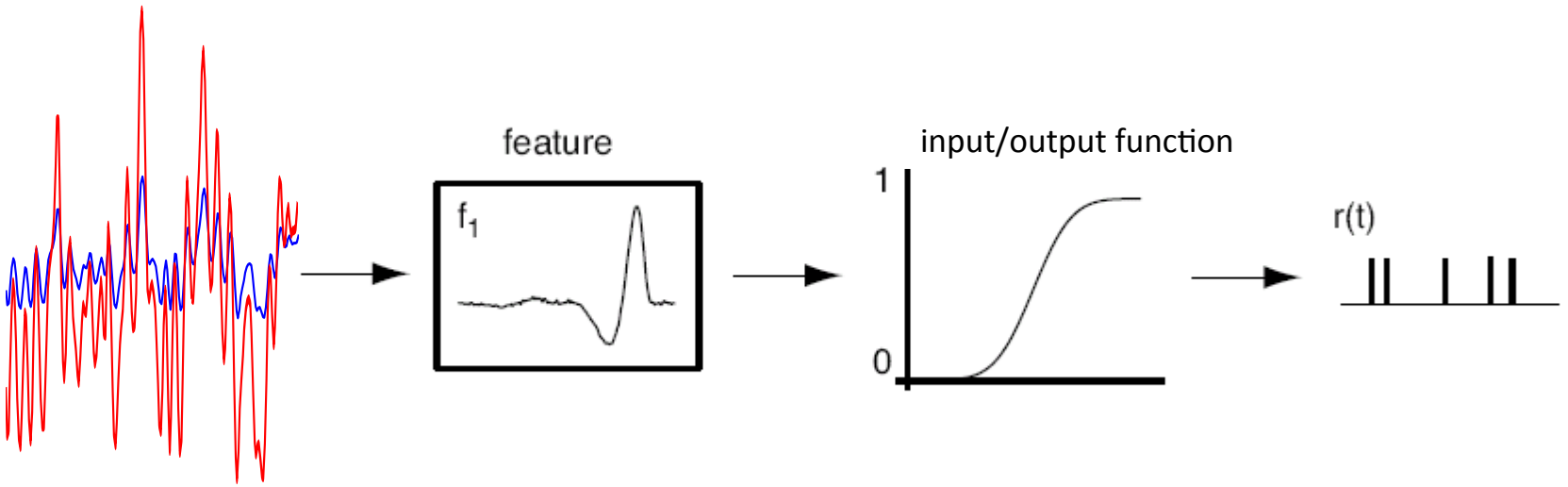
Adaptive representation of information



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

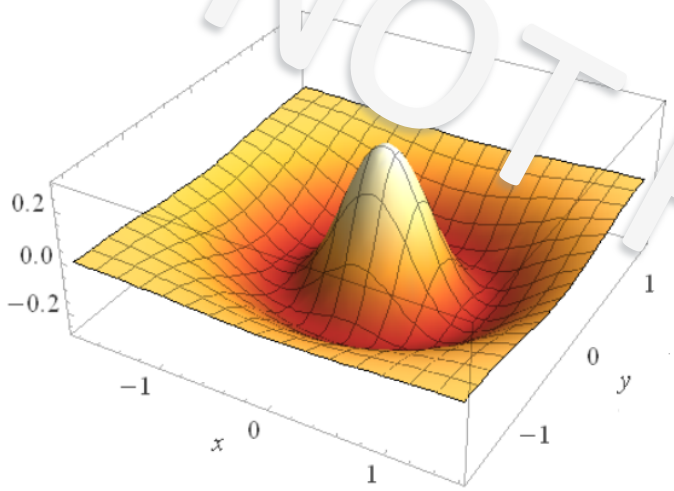
Barlow ’50s, Laughlin ‘81, Shapley et al, ‘70s, Atick ‘91, Brenner ‘00

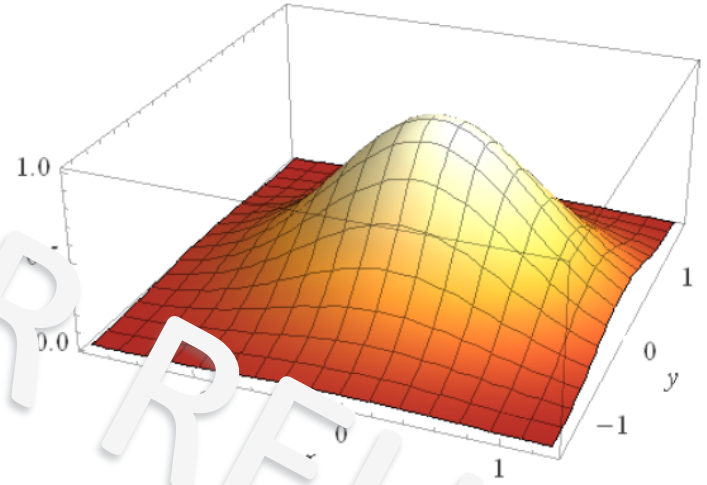
Feature adaptation



Barlow ’50s, Laughlin ‘81, Shapley et al, ‘70s, Atick ‘91, Brenner ‘00

Feature adaptation



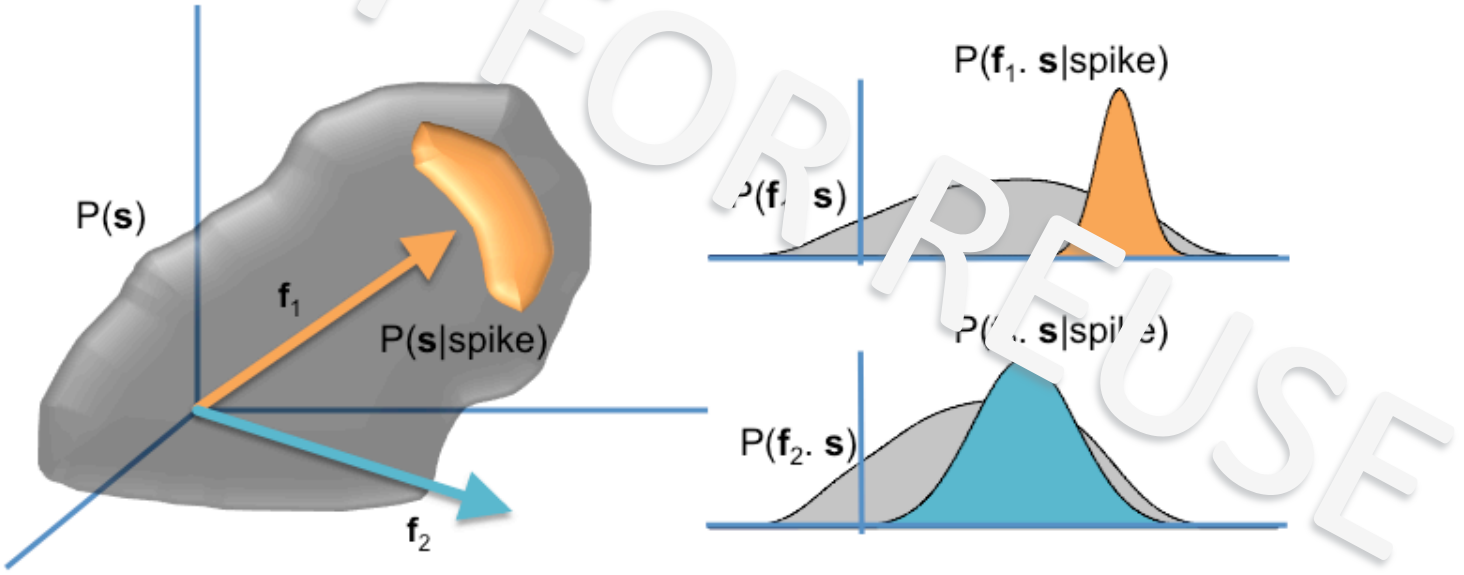


Atick and Redlich (‘90), Atick (‘92)

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.



Sharpee, Rust and Bialek, Neural Computation, 2004

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.

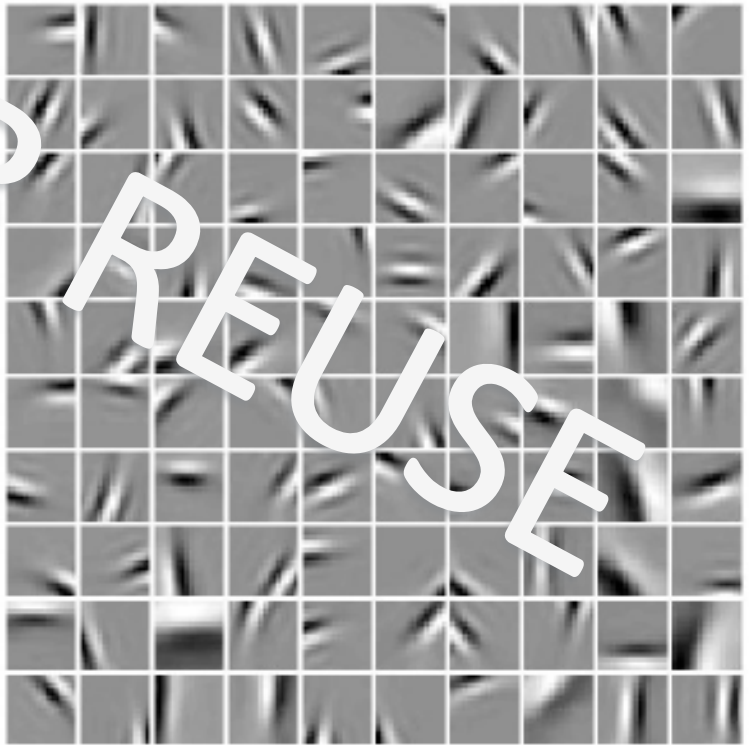
- Error correction and robust coding
- Correlations can help discrimination

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

Representing natural scenes sparsely

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

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



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…

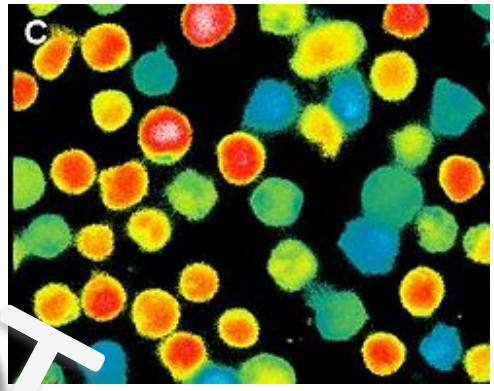
Classic and state of the art methods:

- 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?

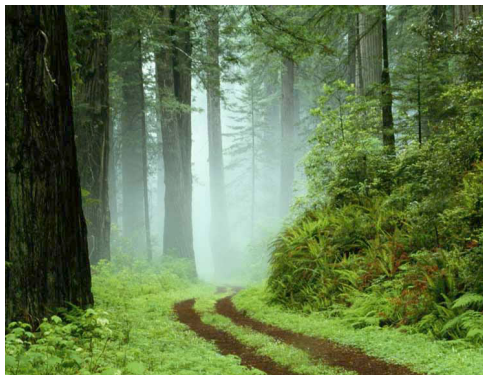
What features do animals extract to solve problems?

Neural activity

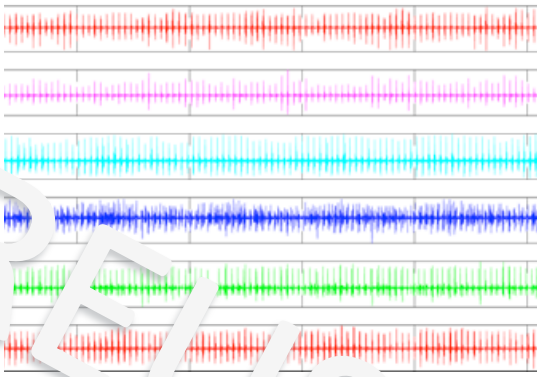


How is information synthesized to drive decisions?

Complex environments



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