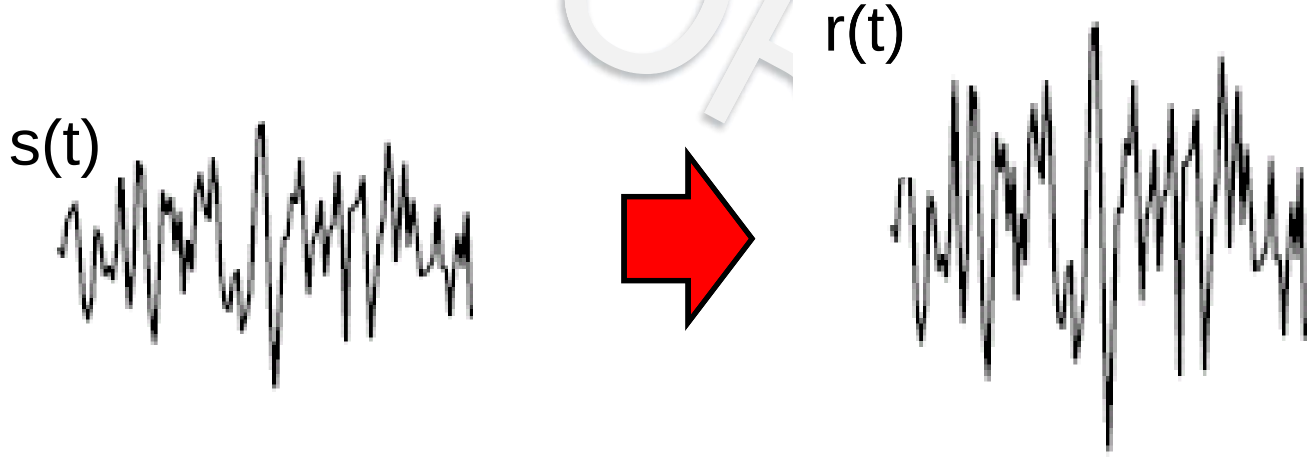
Constructing response models

$\boxed{\text{P(response | stimulus)} \rightarrow \text{r(t) given a stimulus } s}$

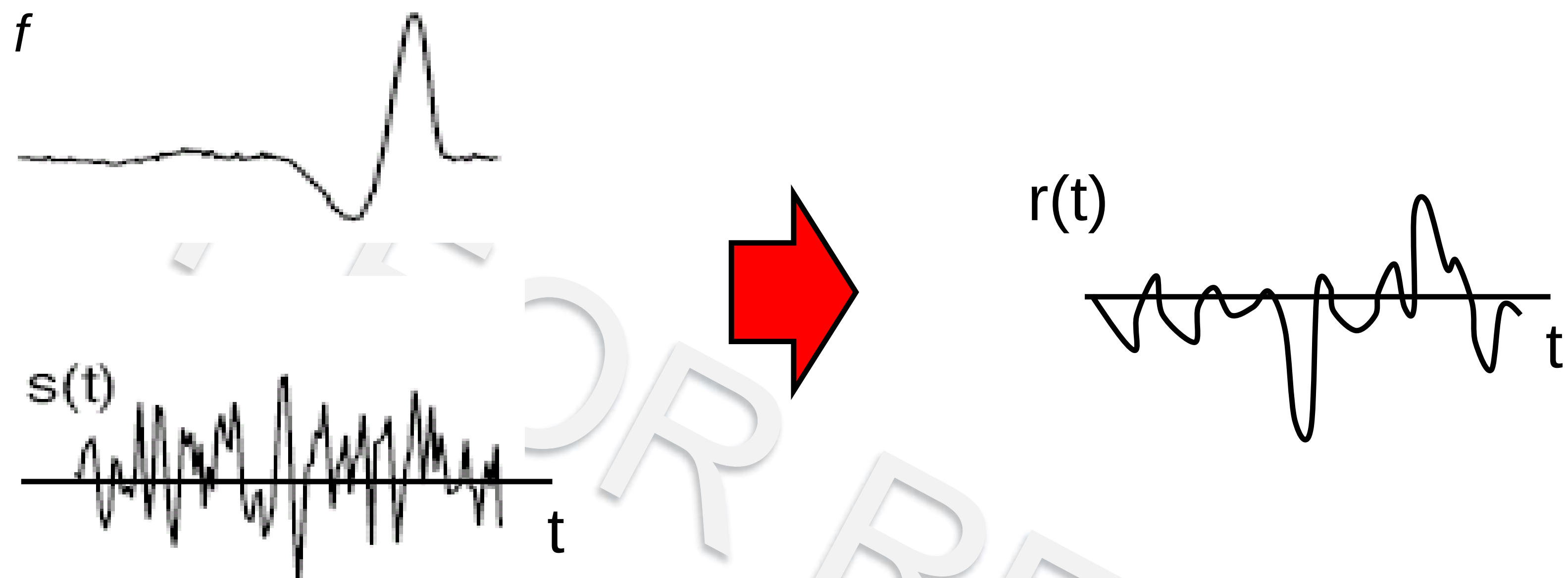
$\boxed{\text{P(response | stimulus)}}$

Basic coding model: linear response

$$r(t) = \phi\, s(t)$$



Basic coding model: temporal filtering



Linear filter:

$$r(t) = \sum_{k=0}^{n} s_{t-k} f_k$$

$$r(t) = \int_{-\infty}^{t} d\tau \, s(t-\tau) f(\tau)$$

Example I: running average

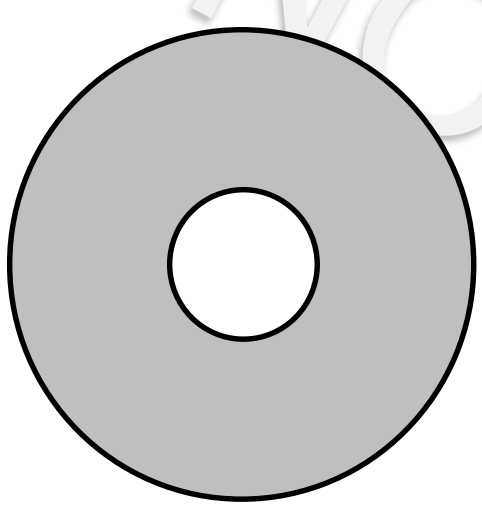
Linear filter: $$r(t) = \sum_{k=0}^{n} s_{t-k} f_k$$

Example II: leaky average

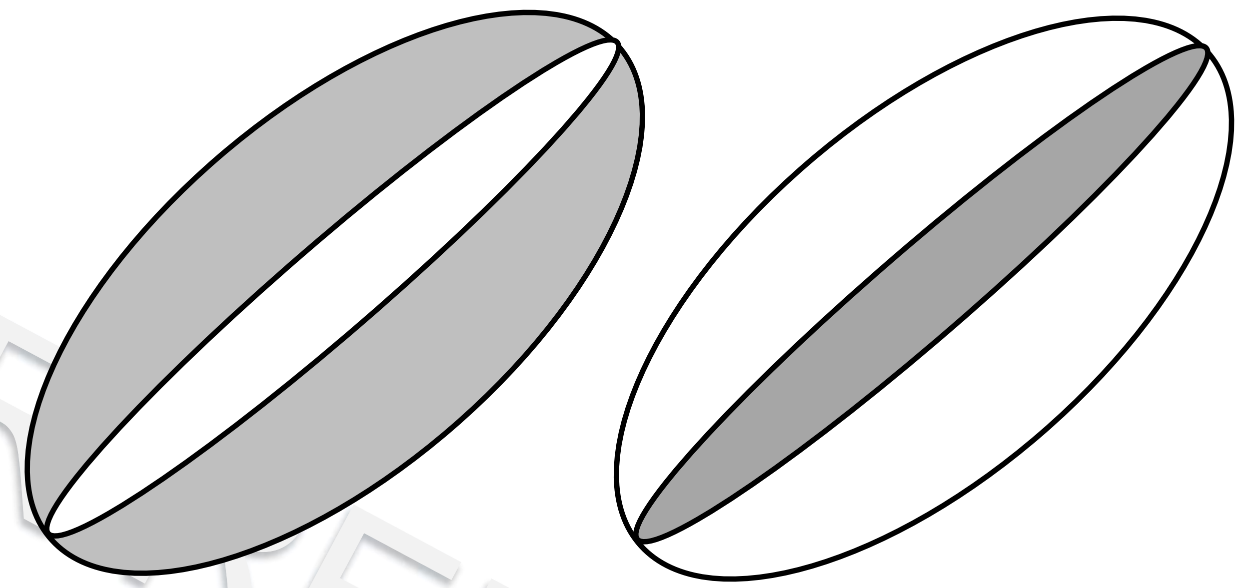
Linear filter: $$r(t) = \sum_{k=0}^{n} s_{t-k} f_k$$

Basic coding model: spatial filtering

Basic coding model: spatial filtering



retina



Visual cortex

Basic coding model: spatial filtering

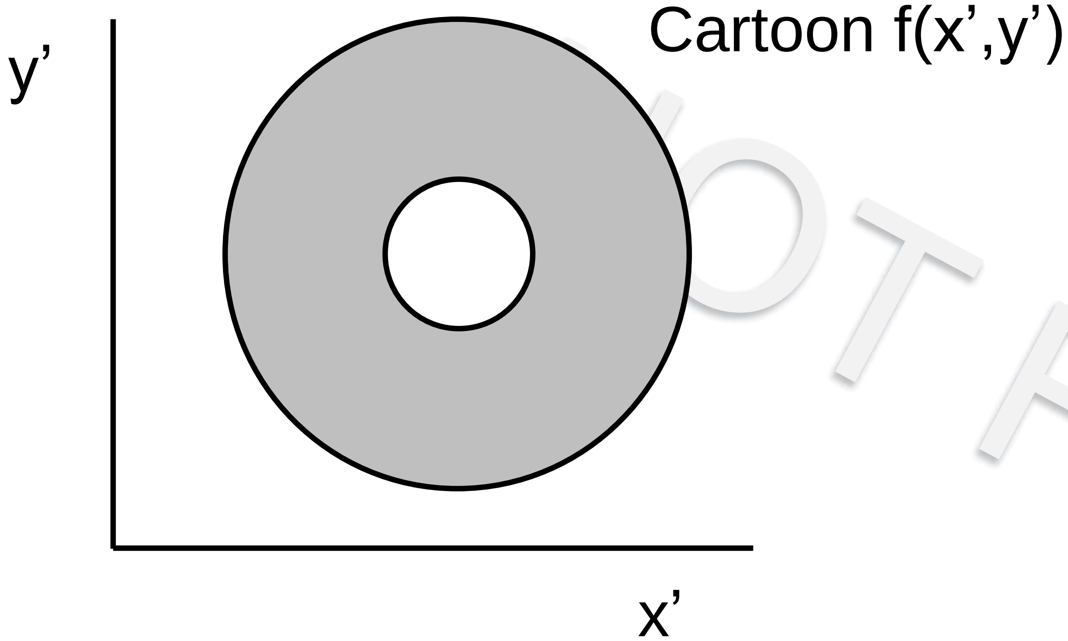
$$r(t) = \sum_{k=0}^{n} s_{t-k} f_k$$

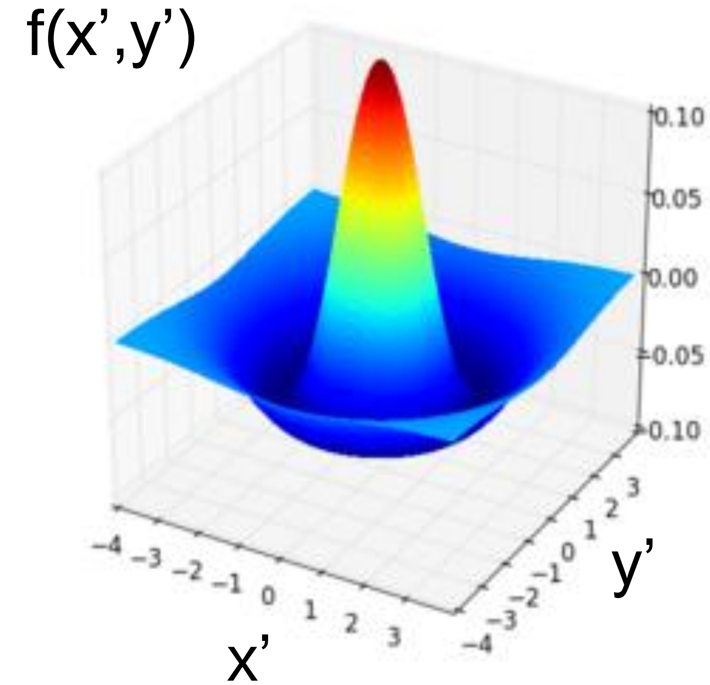
Temporal filter

$$r(x,y) = \sum_{x\prime=-n, y\prime=-n}^{n} s_{x-x\prime, y-y\prime} f_{x\prime, y\prime}$$

$$= \int_{-\infty}^{\infty} dx' dy' \, s(x-x', y-y') f(x', y')$$

Spatial filtering and retinal receptive fields

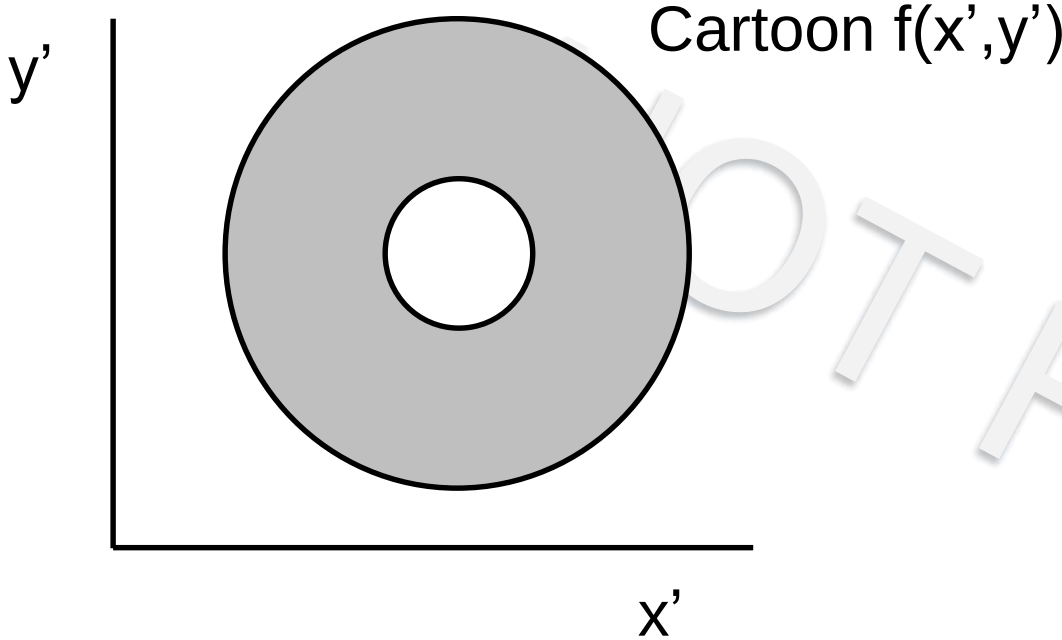


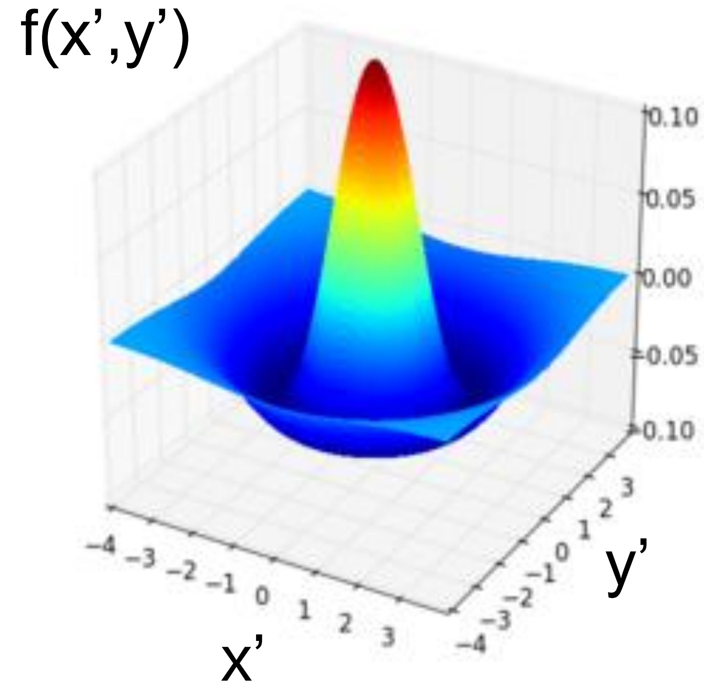


$$r(x, y) = \sum_{x'=-n, y'=-n}^{n} s_{x-x', y-y'} f_{x', y'}$$

http://en.wikibooks.org/wiki/Sensory_Systems/Visual_System

Spatial filtering and receptive fields

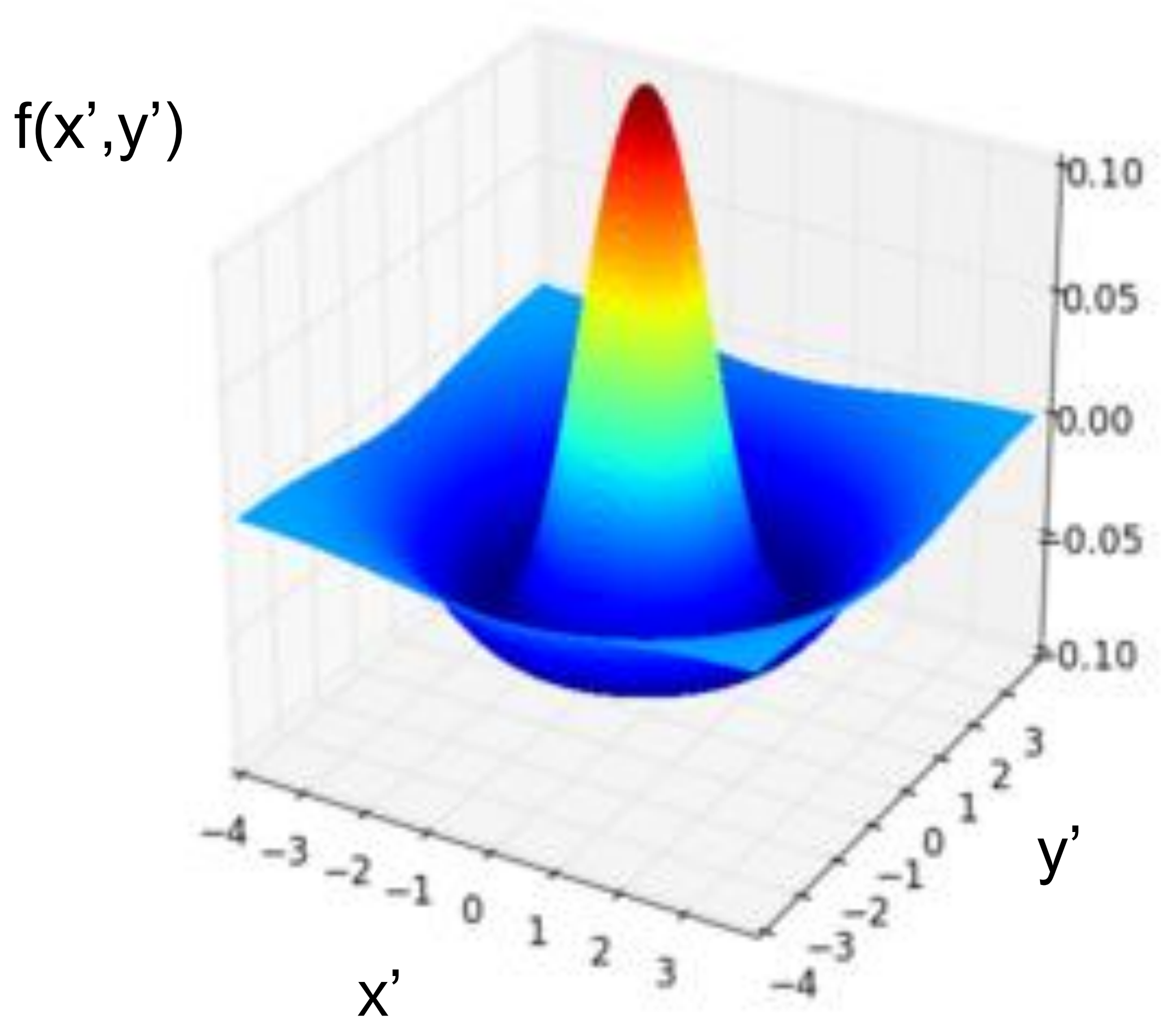




$$r(x,y) = \sum_{x'=-n,y'=-n}^{n} s_{x-x',y-y'} f_{x',y'}$$

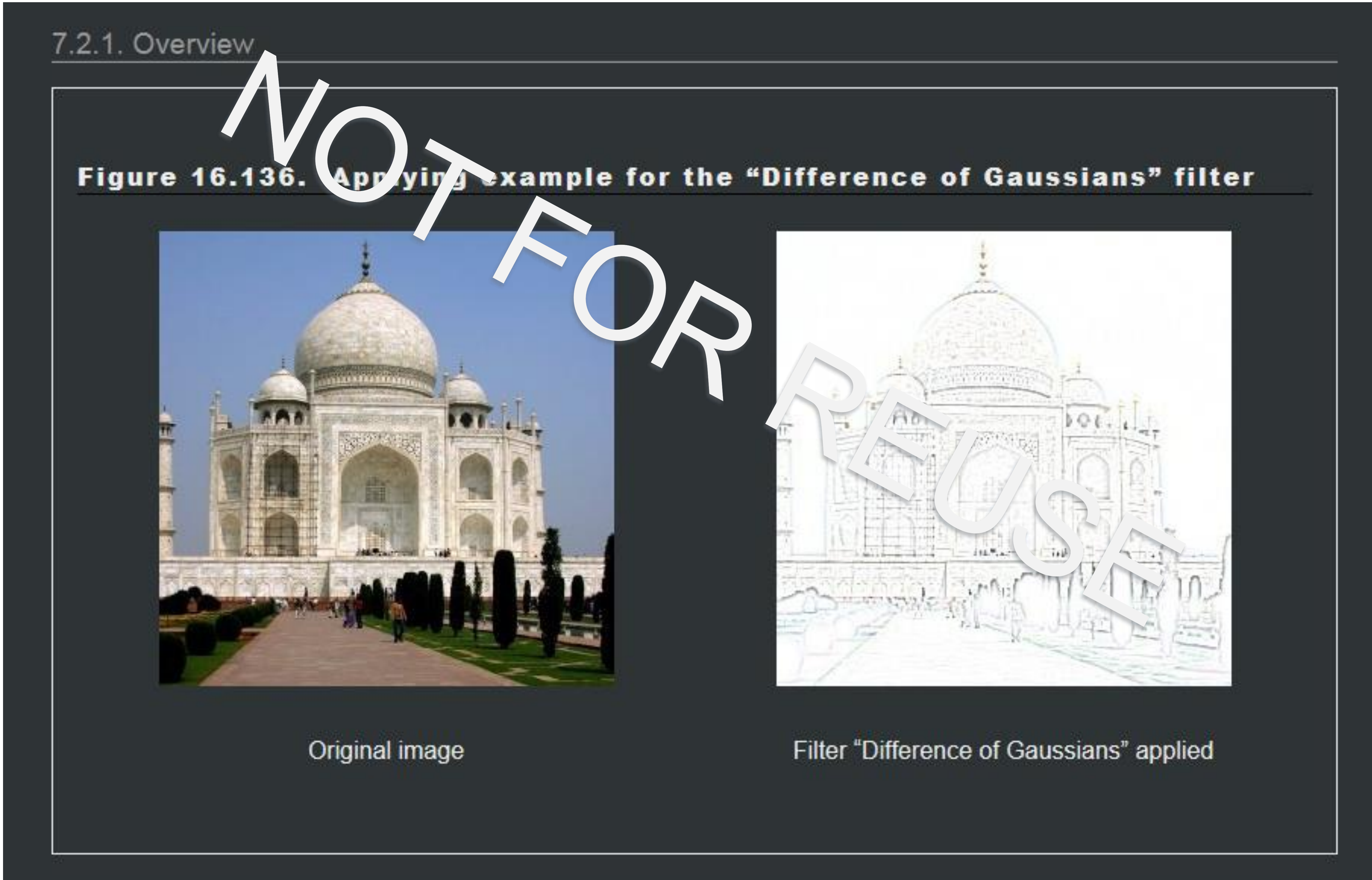
http://en.wikibooks.org/wiki/Sensory_Systems/Visual_System

Spatial filtering and receptive fields



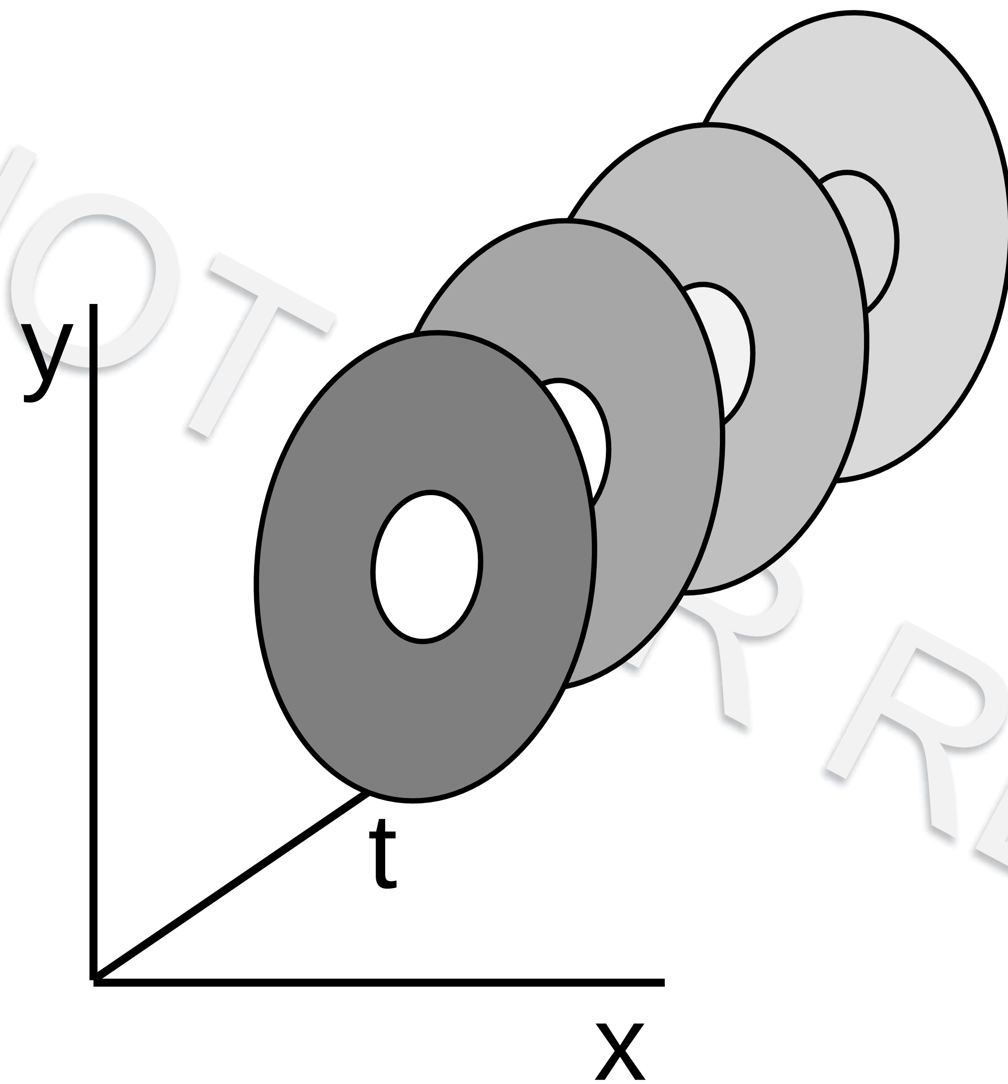
http://en.wikibooks.org/wiki/Sensory_Systems/Visual_System

Spatial filtering



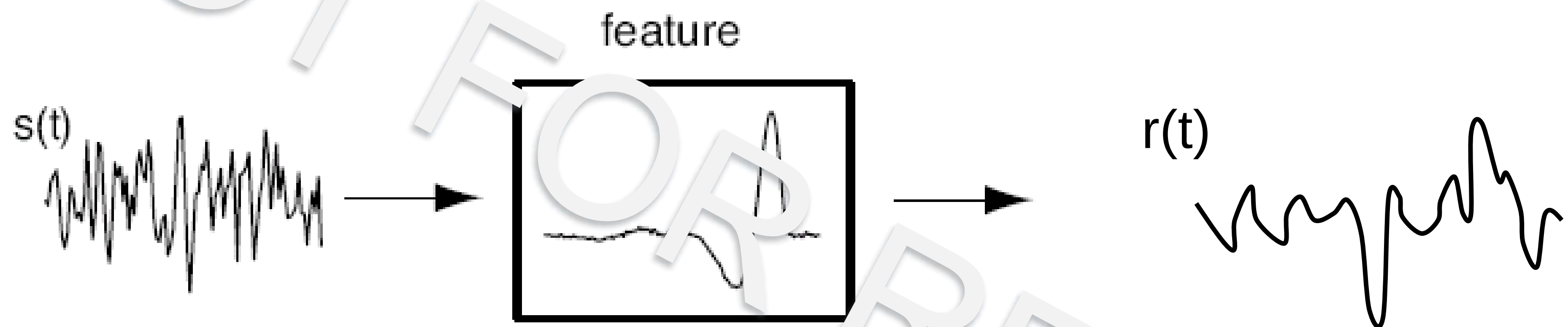
http://docs.gimp.org/2.6/en/plug-in-dog.html

Basic coding model: *spatiotemporal* filtering



$$r_{x,y}(t) = \iiint dx'\, dy'\, d\tau\; f(x',y',\tau)\; s(x-x',y-y',t-\tau)$$

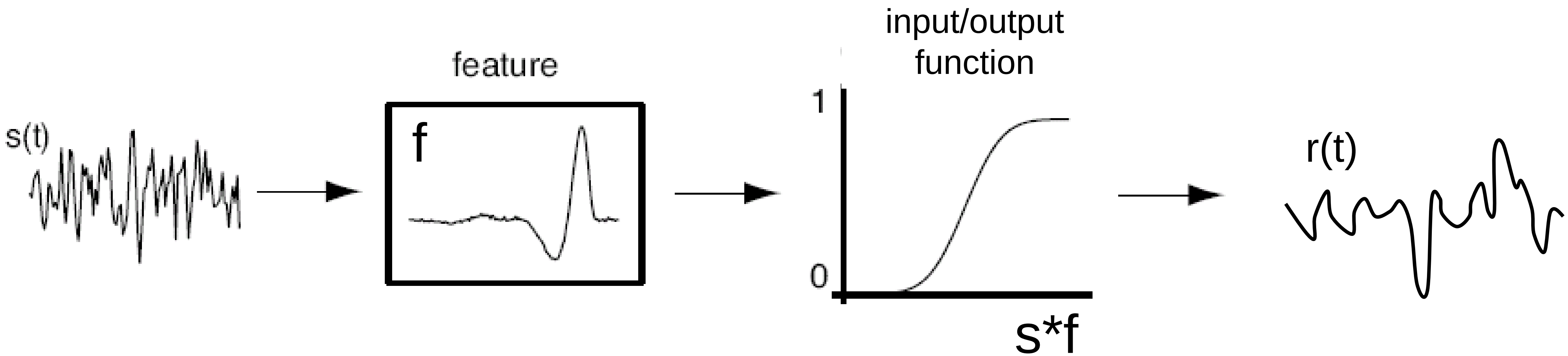
Basic coding model: temporal filtering



Linear filter: $r(t) = \int s(t-\tau)\, f(\tau)\, d\tau$

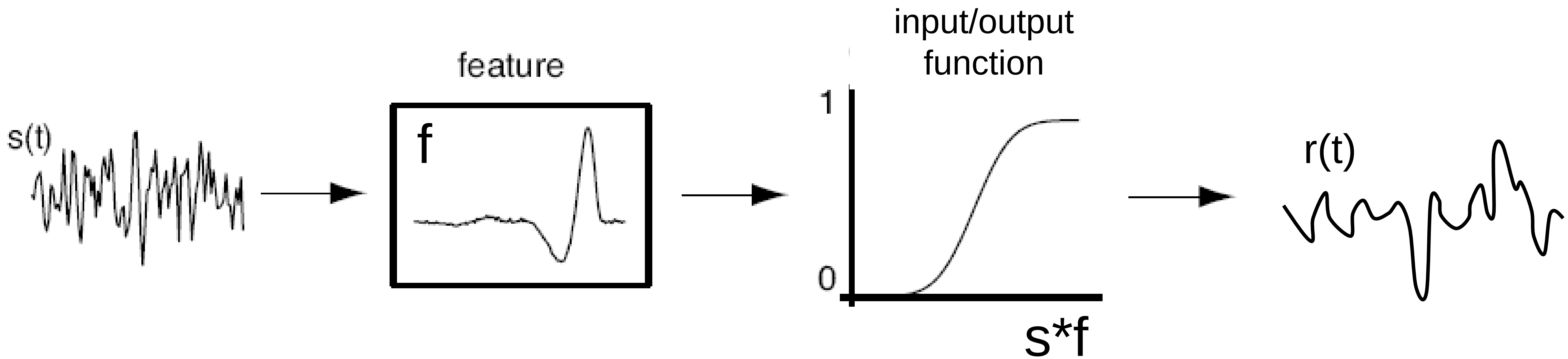
…shortcomings?

Next most basic coding model

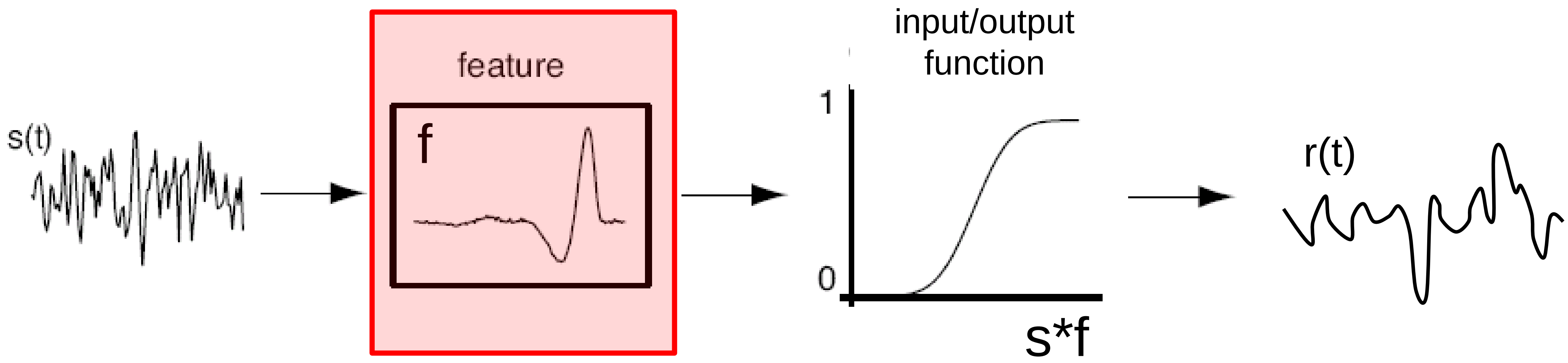


Linear filter & nonlinearity: $r(t) = g(\int s(t-\tau)\, f(\tau)\, d\tau)$

How to find the components of this model



How to find the components of this model



How to proceed?

P(response | stimulus)

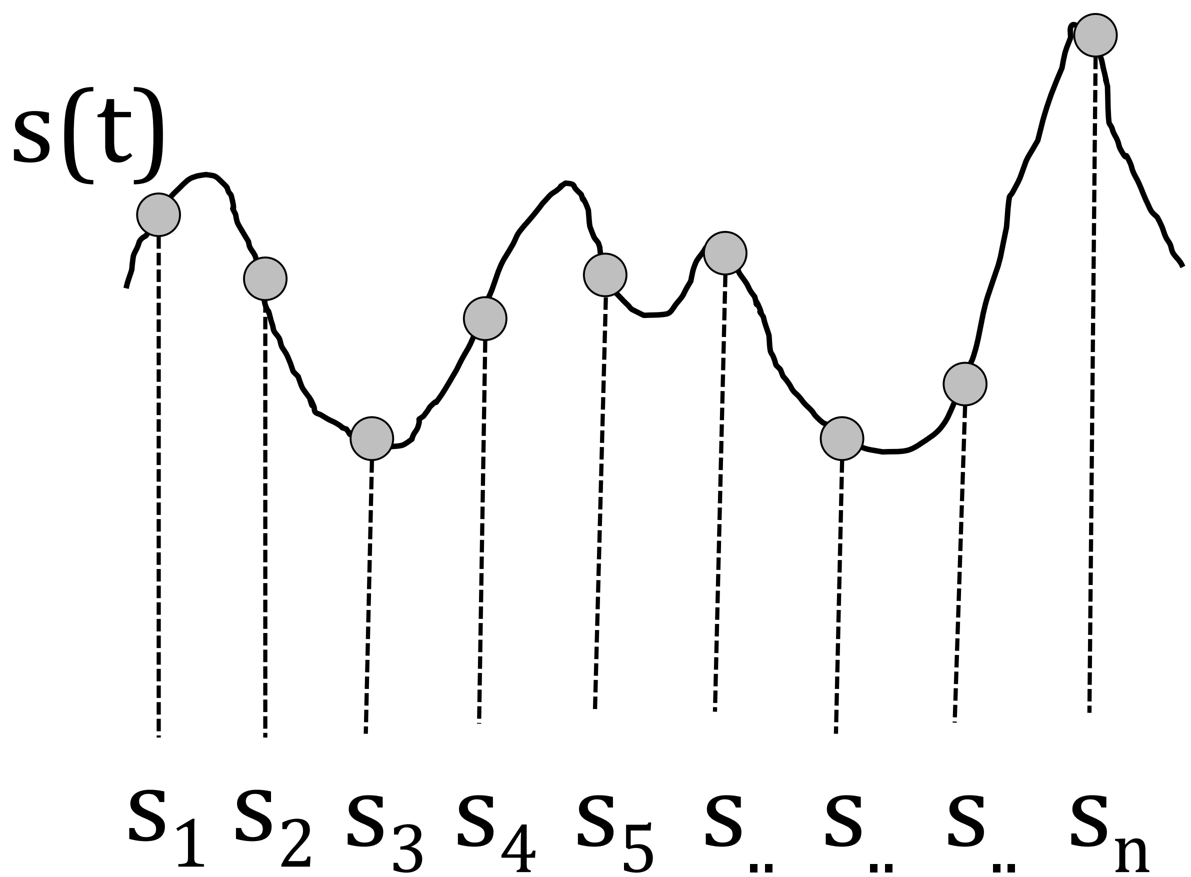
Our problem is one of dimensionality!

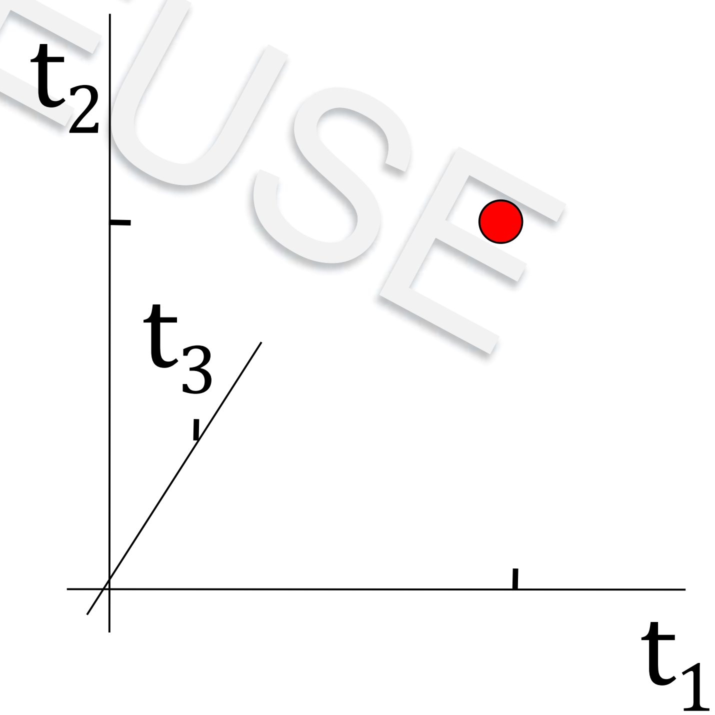
We want to sample the responses of the system to many stimuli so we can characterize what it is about the input that triggers responses.

P(response | stimulus) $\rightarrow$ P(response | s_1)

Dimensionality reduction

Start with a very high dimensional description
(eg. an image or a time-varying waveform)
and pick out a small set of relevant dimensions.





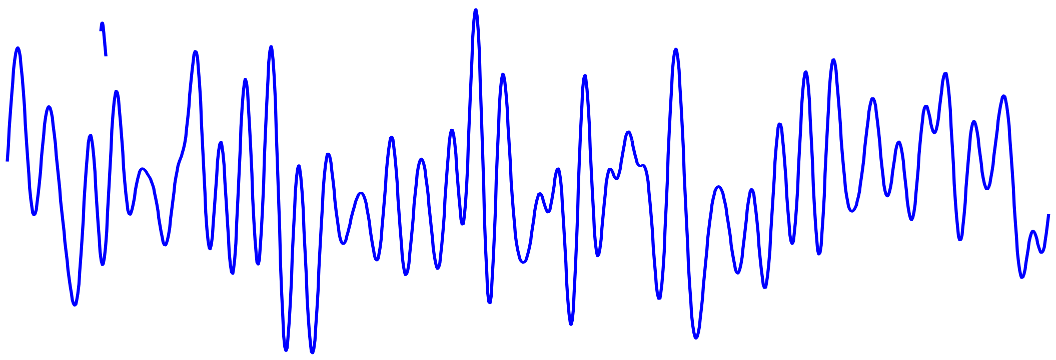
$s(t) = (s_{t1}, s_{t2}, s_{t3}, \ldots, s_{tn})$

What is the right stimulus to use?

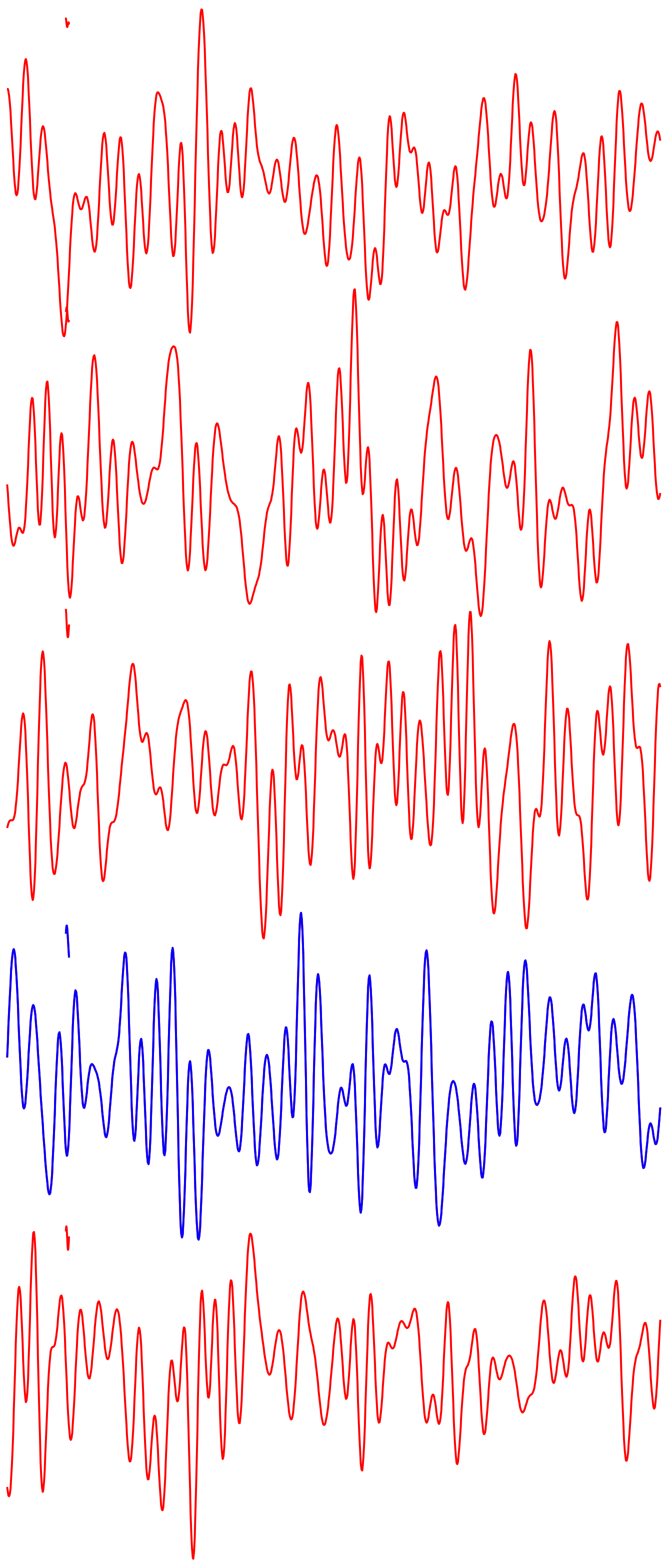
We want to sample the responses of the system to a variety of stimuli so we can characterize what it is about the input that triggers responses.

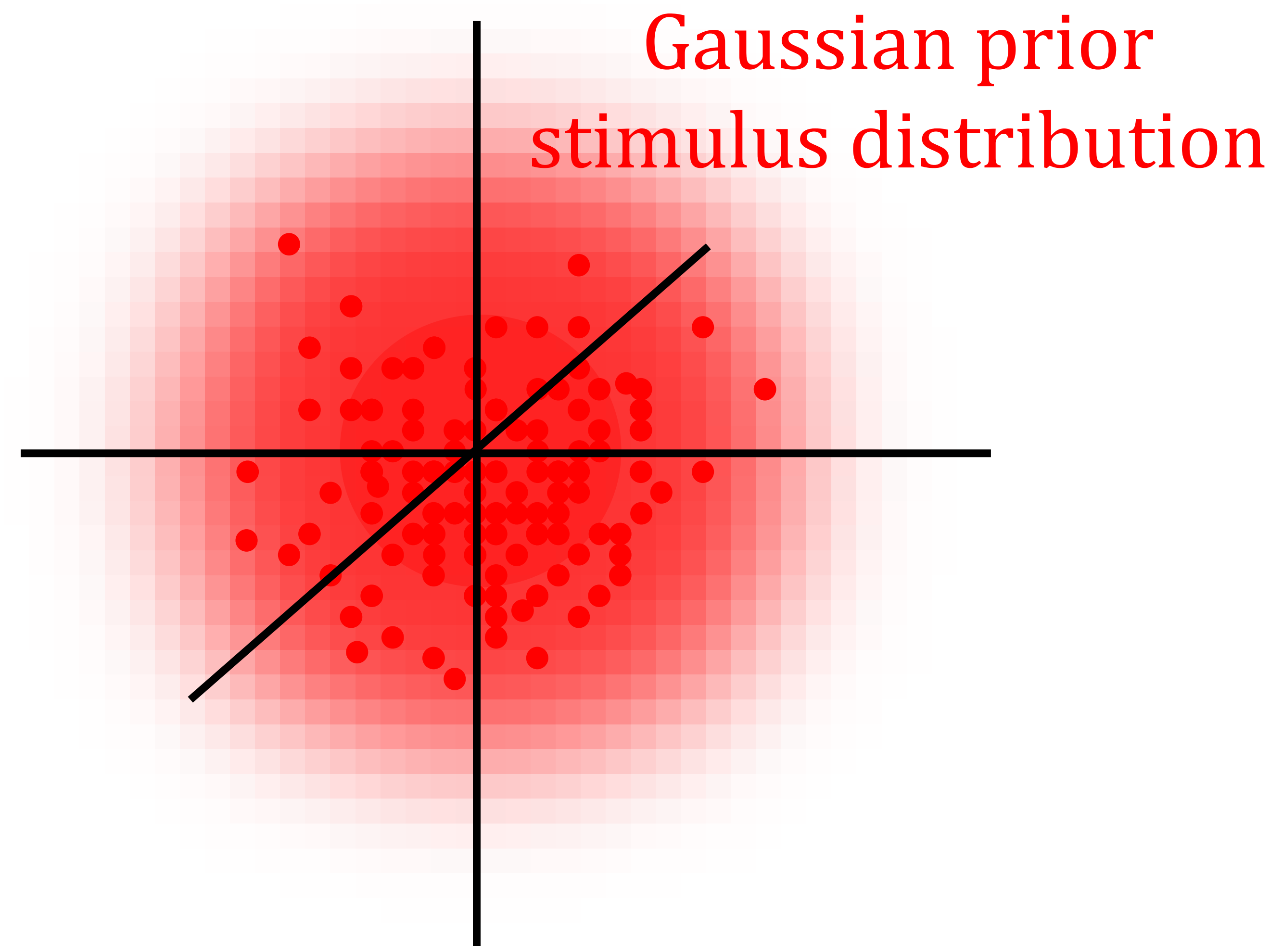
$$P(\text{response} \mid \text{stimulus}) \rightarrow P(\text{response} \mid s_1, s_2, .., s_n)$$

One common and useful method is to use **white noise**

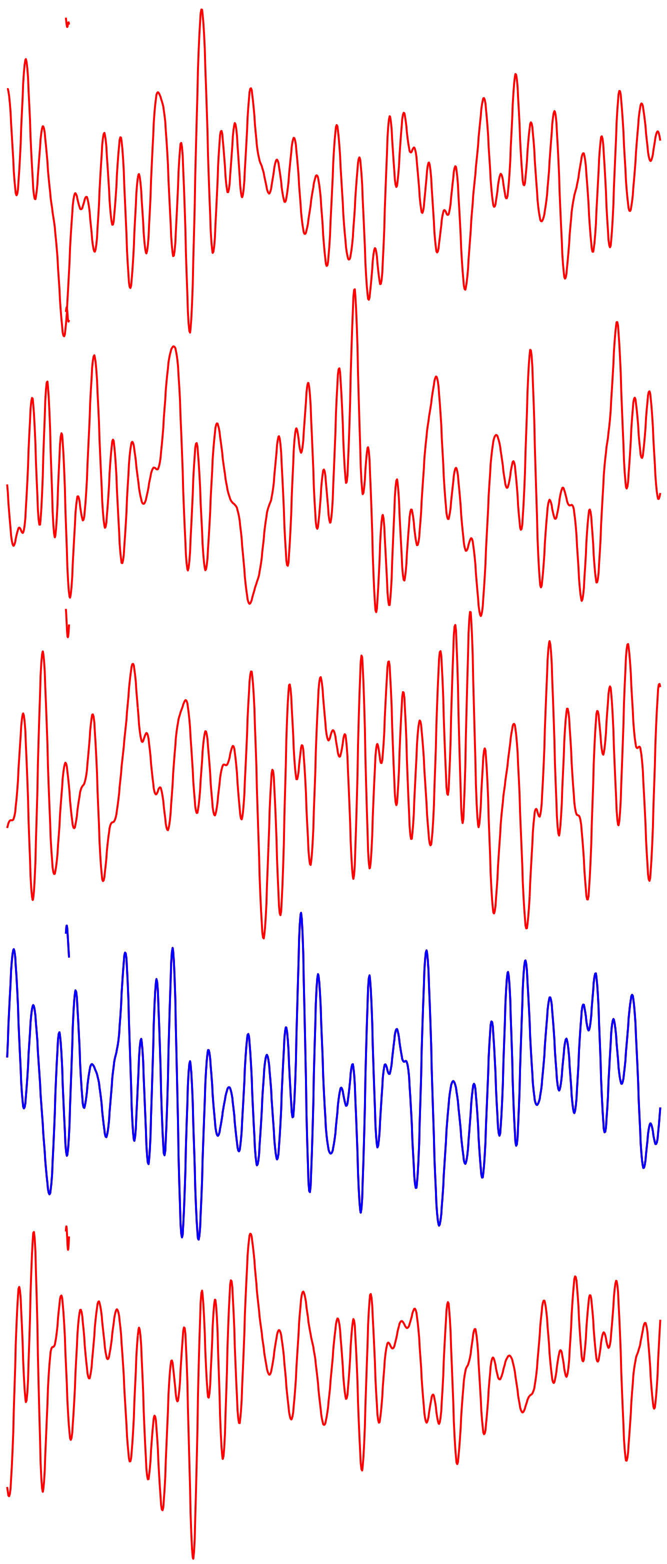


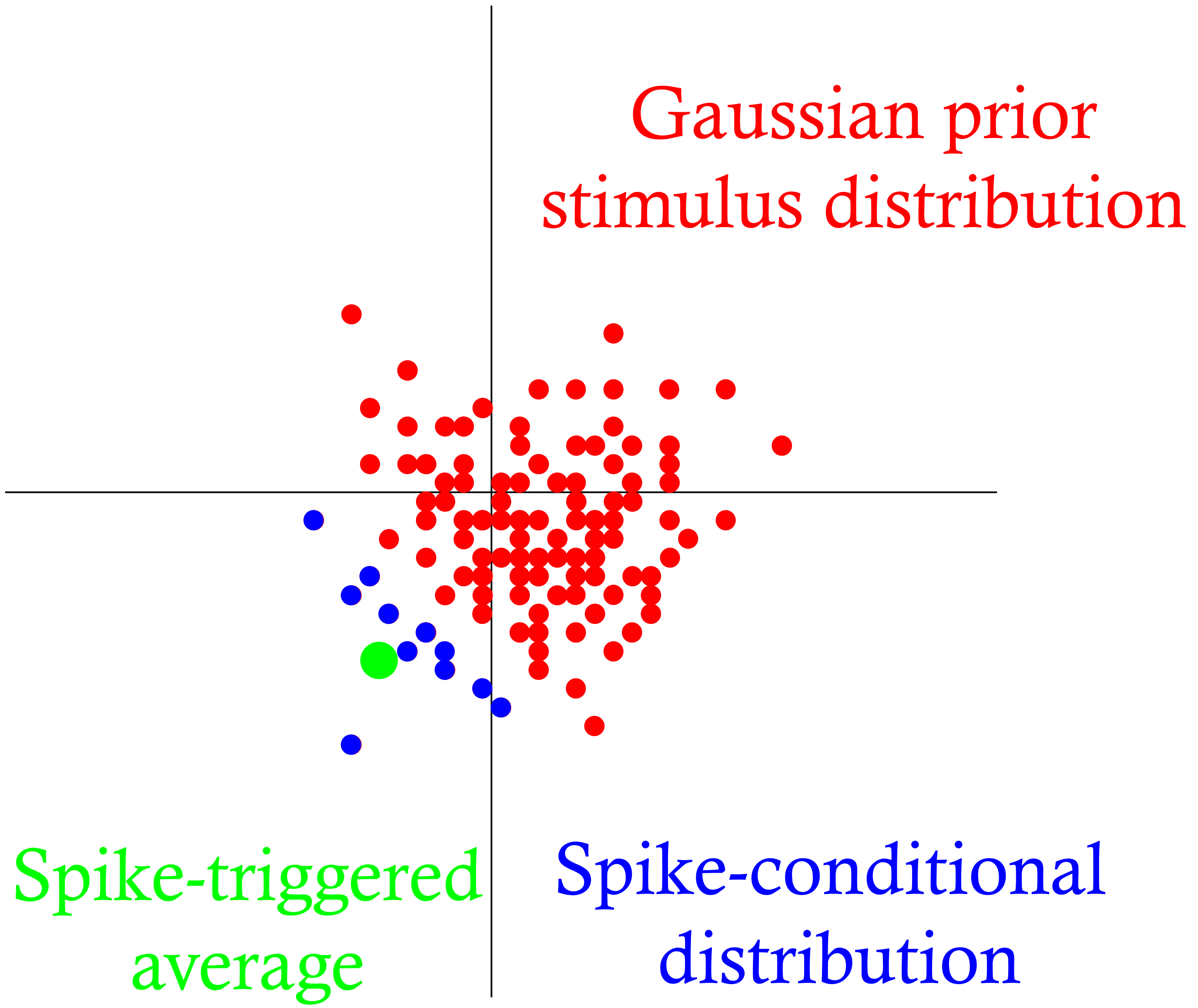
Determining multiple features from white noise





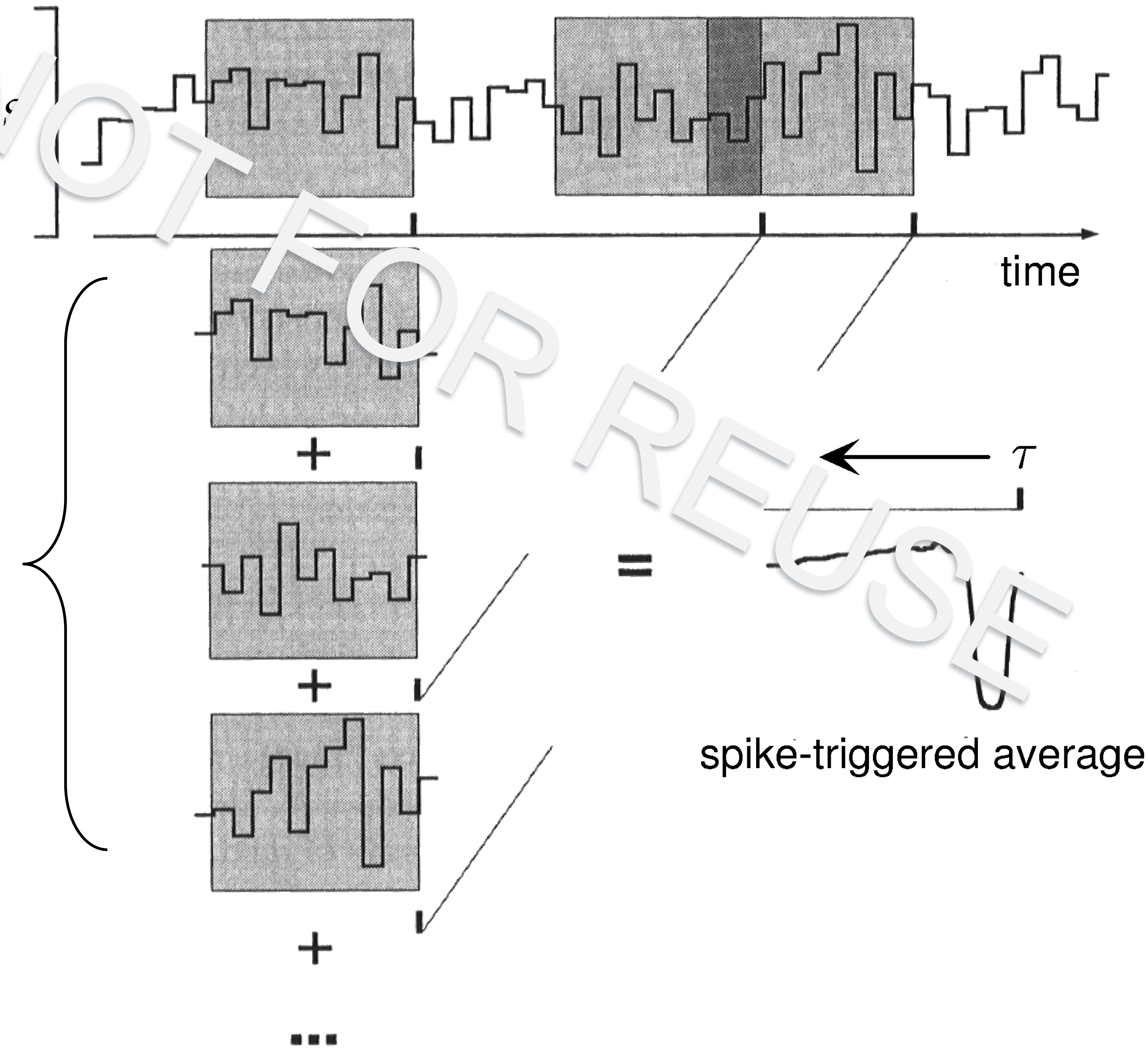
Determining linear features from white noise





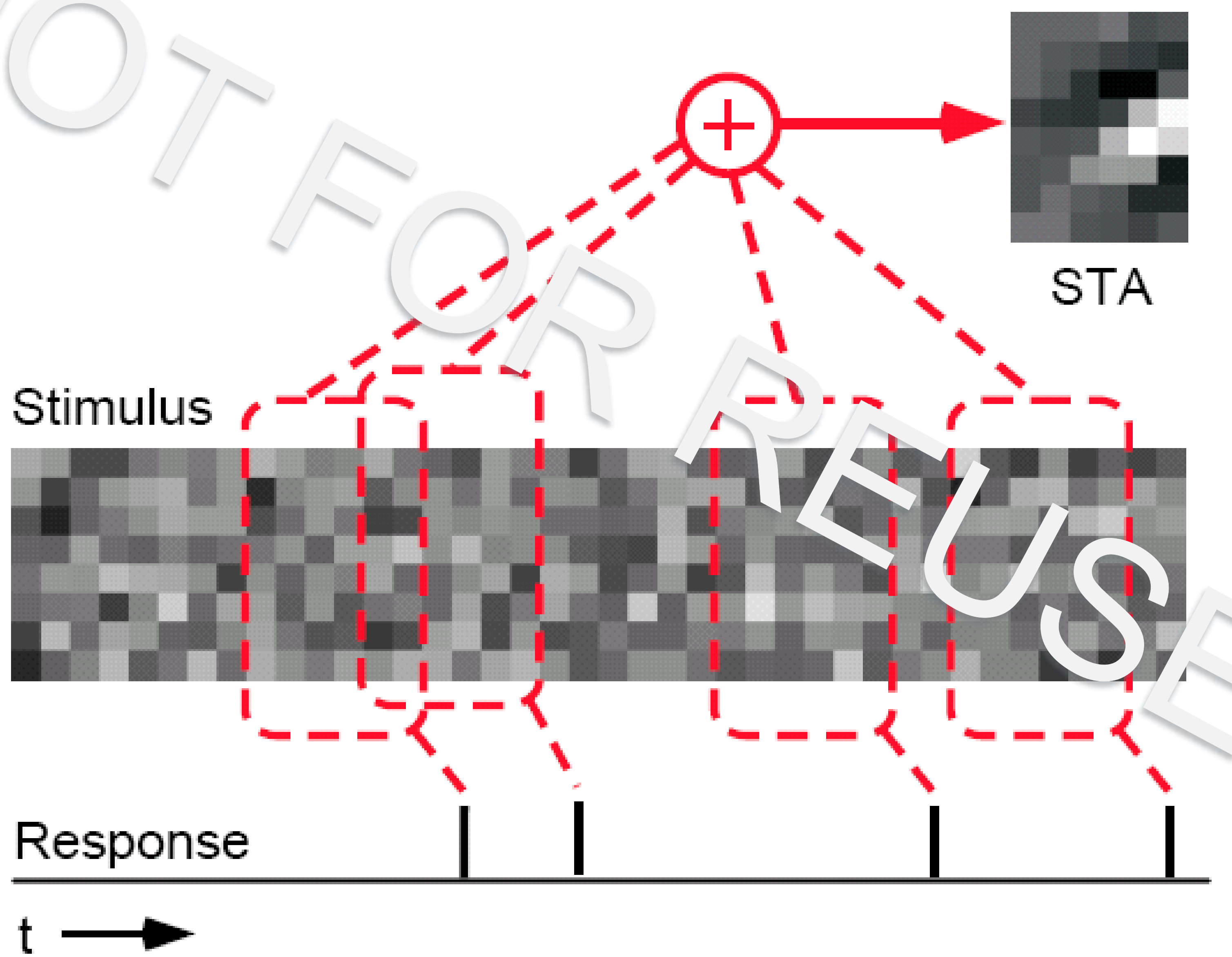
Reverse correlation: the spike-triggered average

Spike-
conditional
ensemble



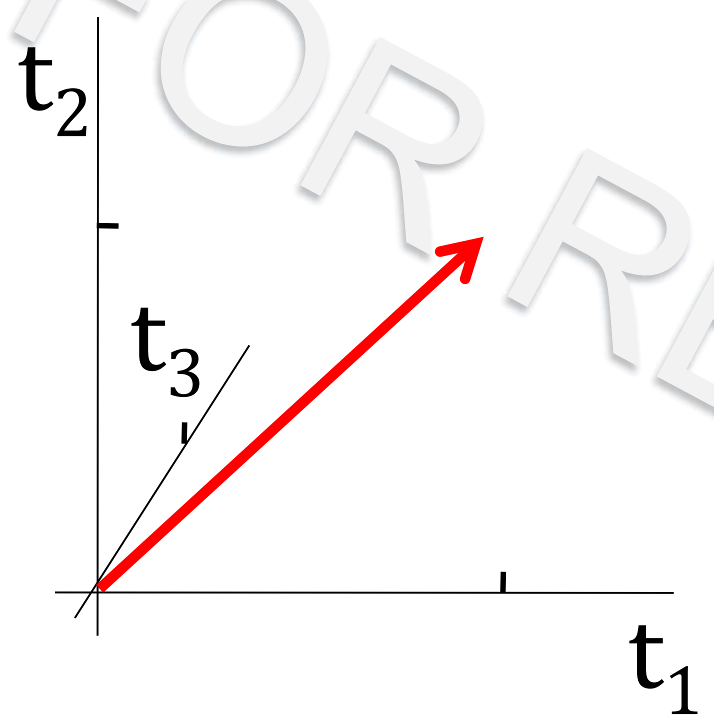
Dayan and Abbott, Theoretical Neuroscience

The spike-triggered average



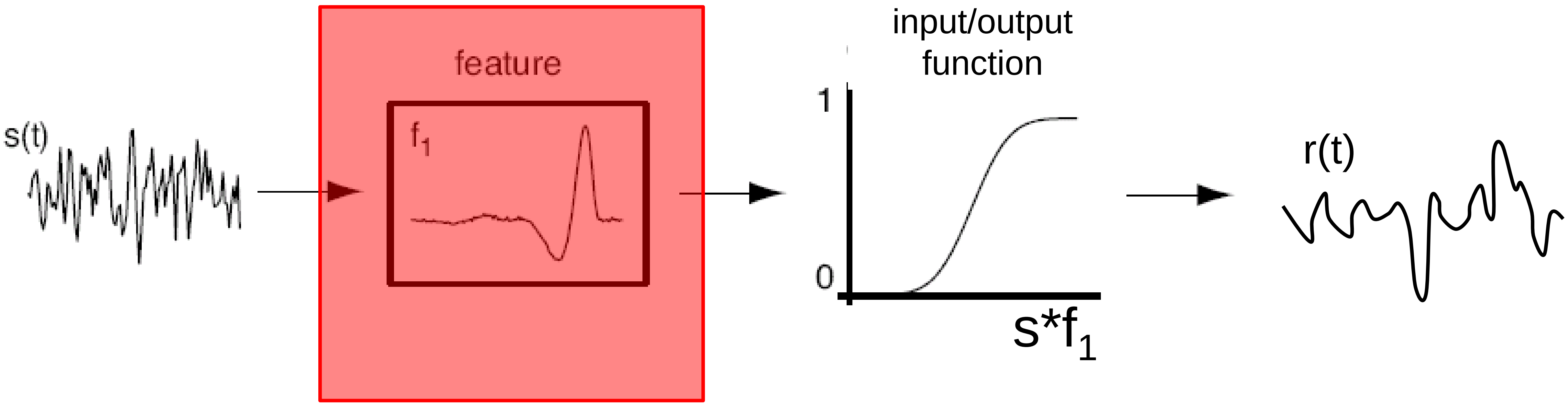
Linear filtering

Stimulus feature *f* is a vector in a high-dimensional stimulus space



Linear filtering = convolution = projection

How to find the components of this model



Determining the nonlinear input/output function

The input/output function is:

$$P(\text{spike}|\text{stimulus}) \Rightarrow P(\text{spike}|s_1)$$

This can be found from data using Bayes' rule:

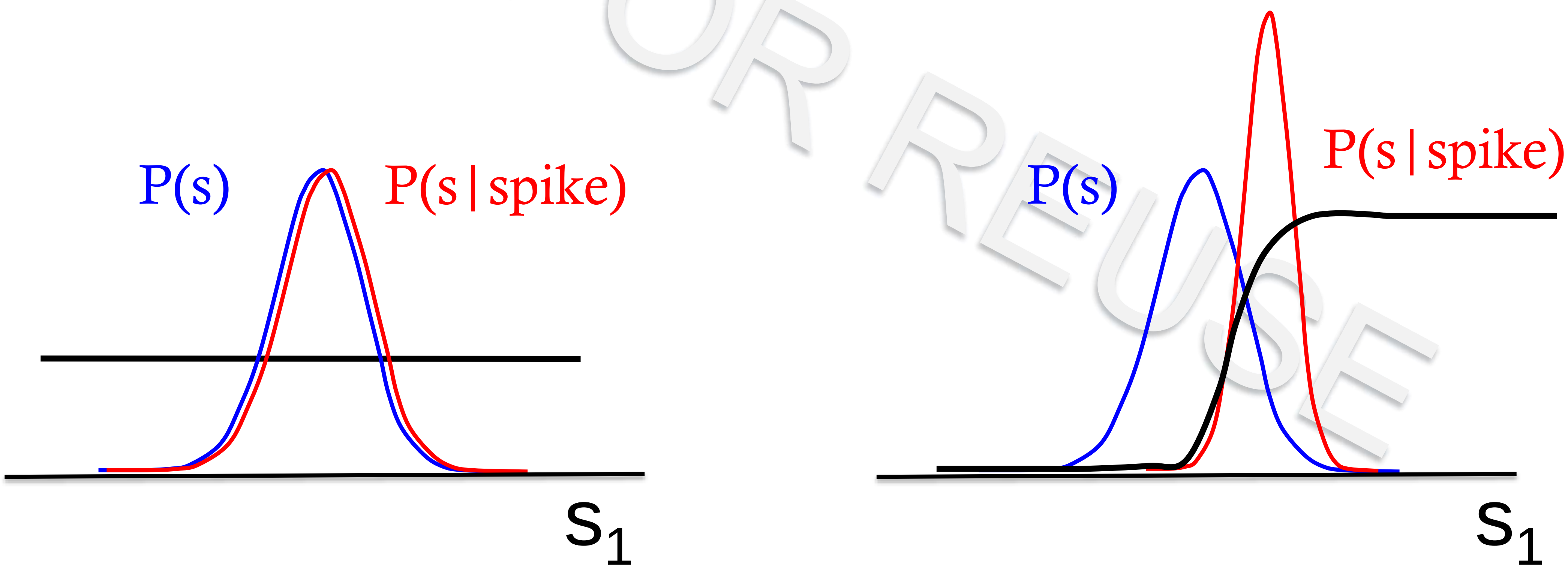
$$P(\text{spike}|s_1) = \frac{P(s_1|\text{spike})P(\text{spike})}{P(s_1)}$$

$P(s_1)$

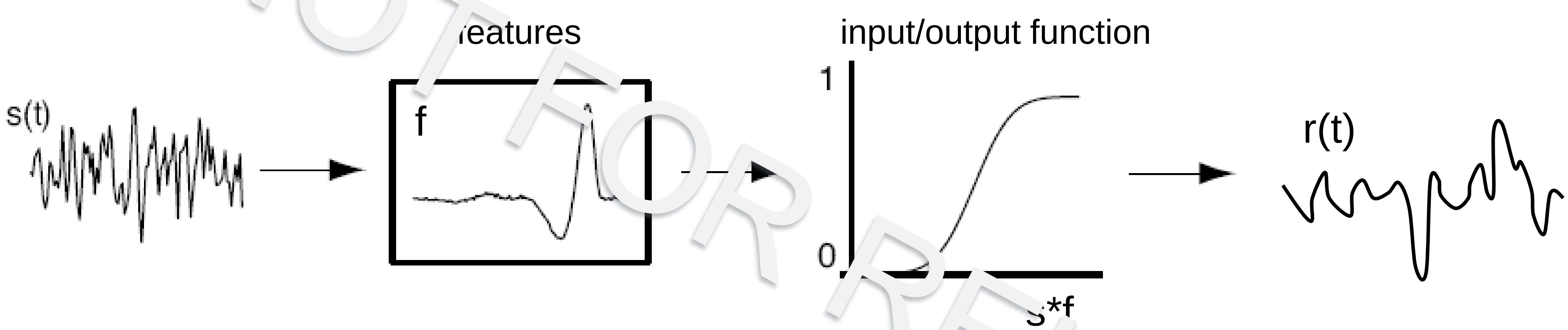
$P(s_1|\text{spike})$

Nonlinear input/output function

$$P(\text{spike} \mid s_1) = P(s_1 \mid \text{spike})\, P(\text{spike}) \,/\, P(s_1)$$

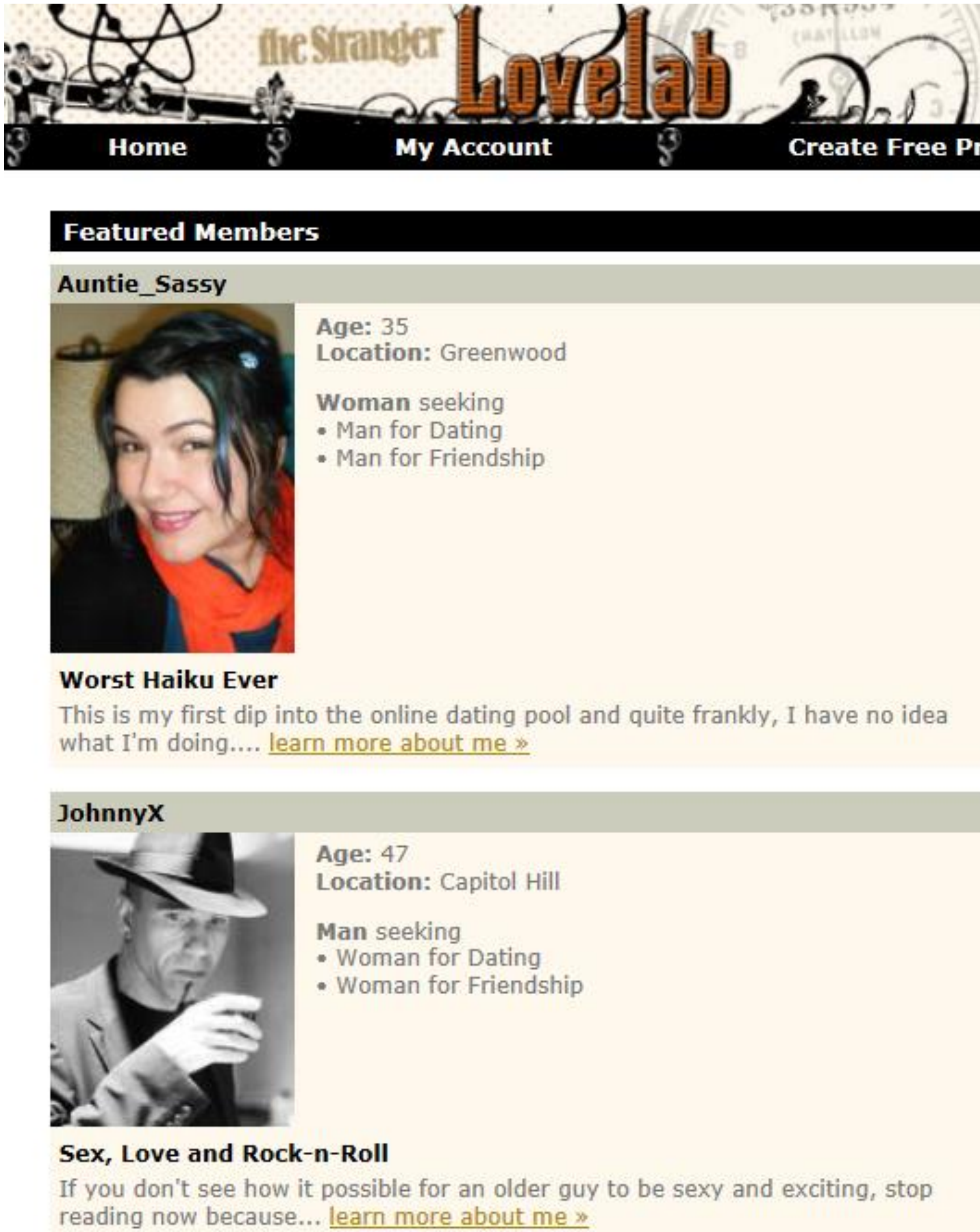


Linear/nonlinear models

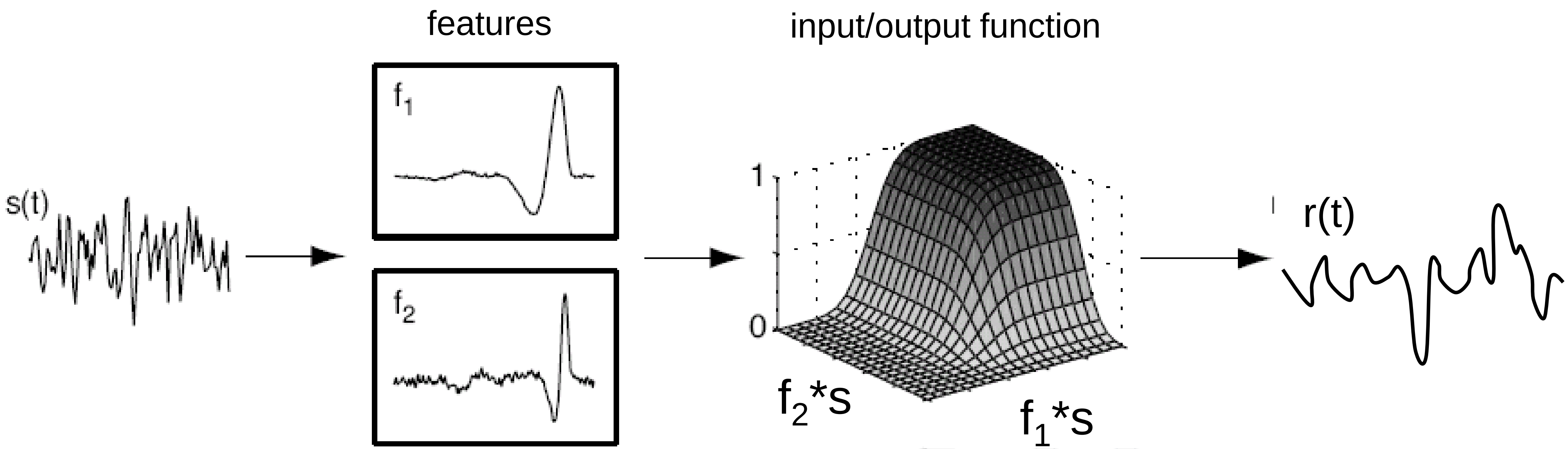


Linear filter & nonlinearity: $r(t) = g(\int f(t-\tau)\, s(\tau)\, dt)$

High-dimensional feature selection

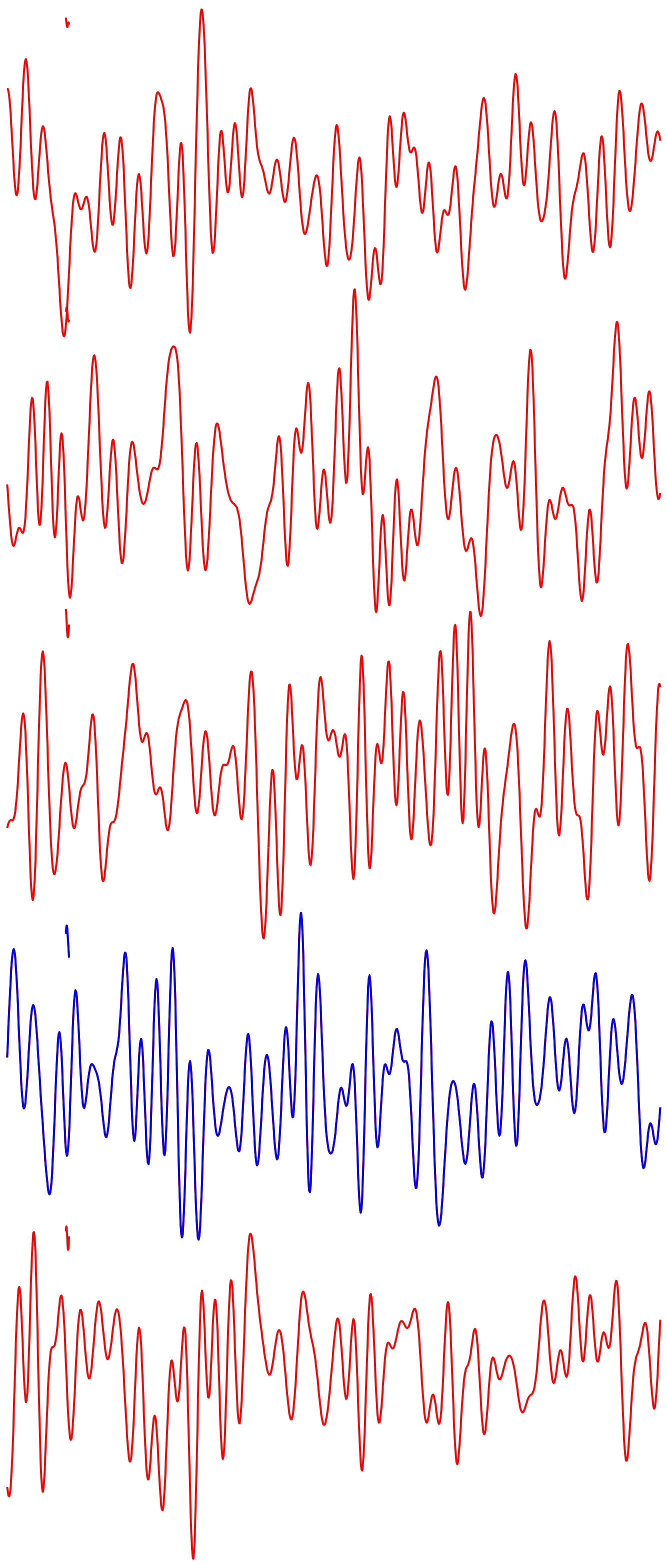


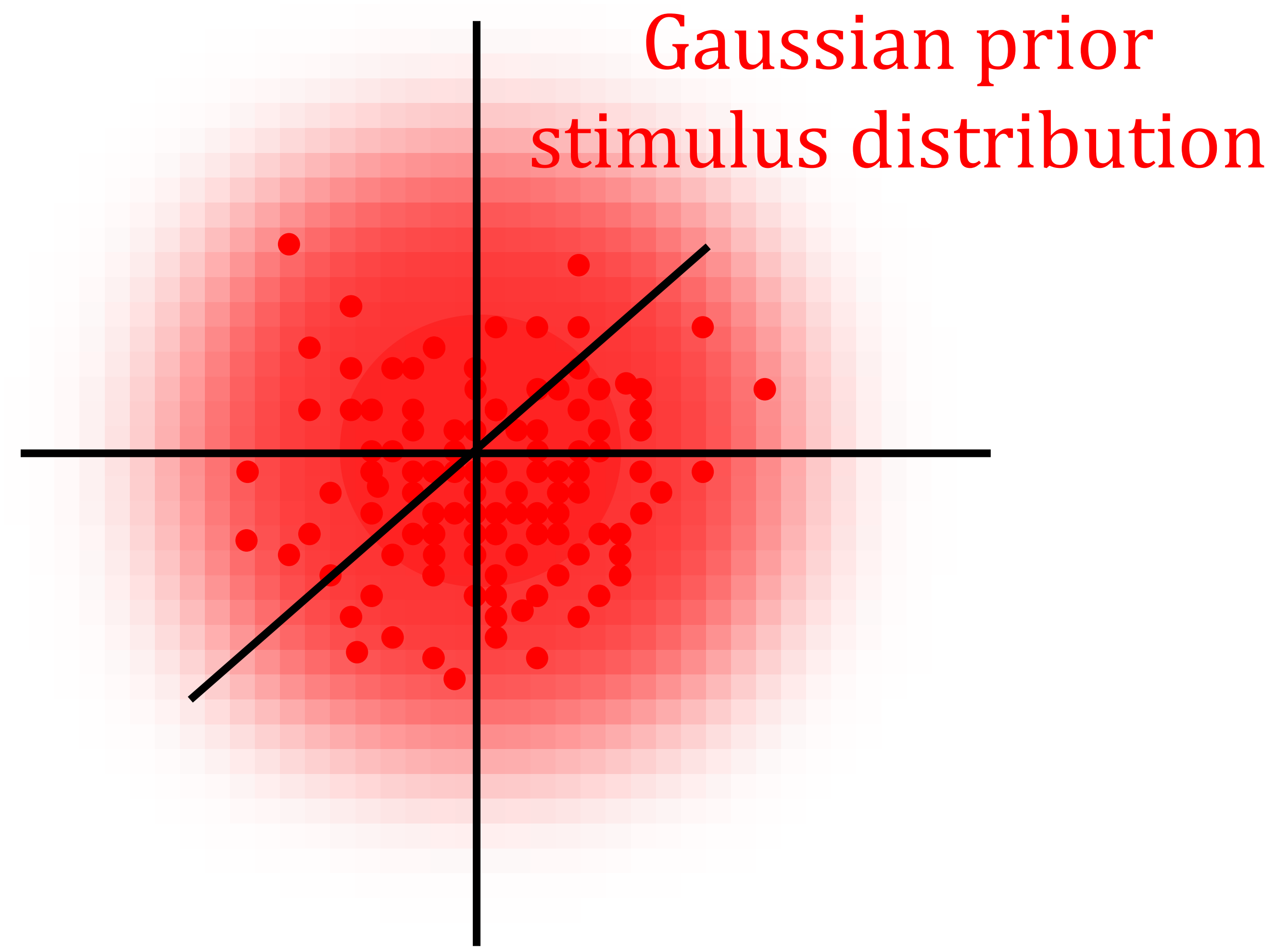
Less basic coding models



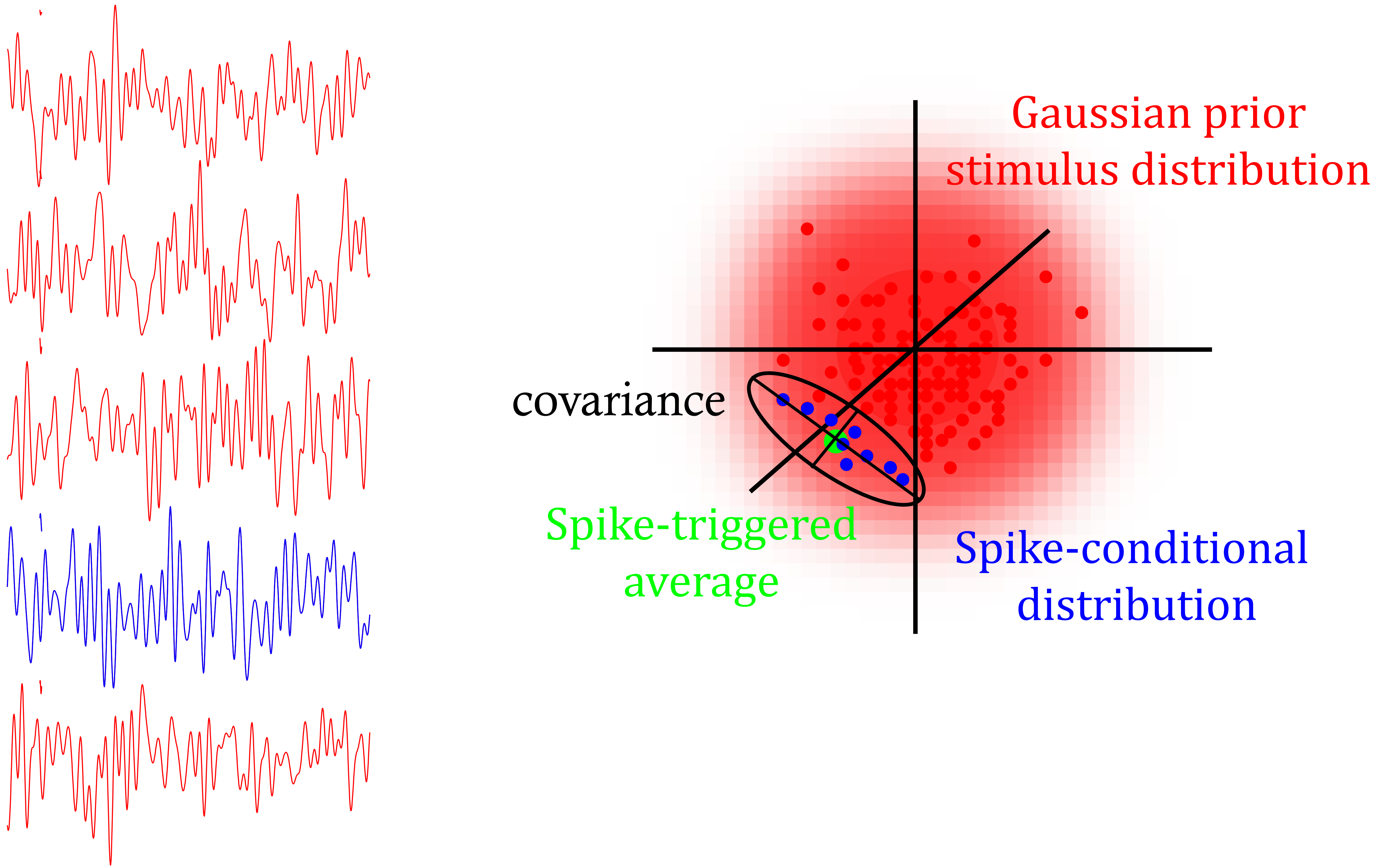
Linear filter*s* & nonlinearity: $r(t) = g(f_1 * s, f_2 * s, \ldots, f_n * s)$

Determining multiple features from white noise

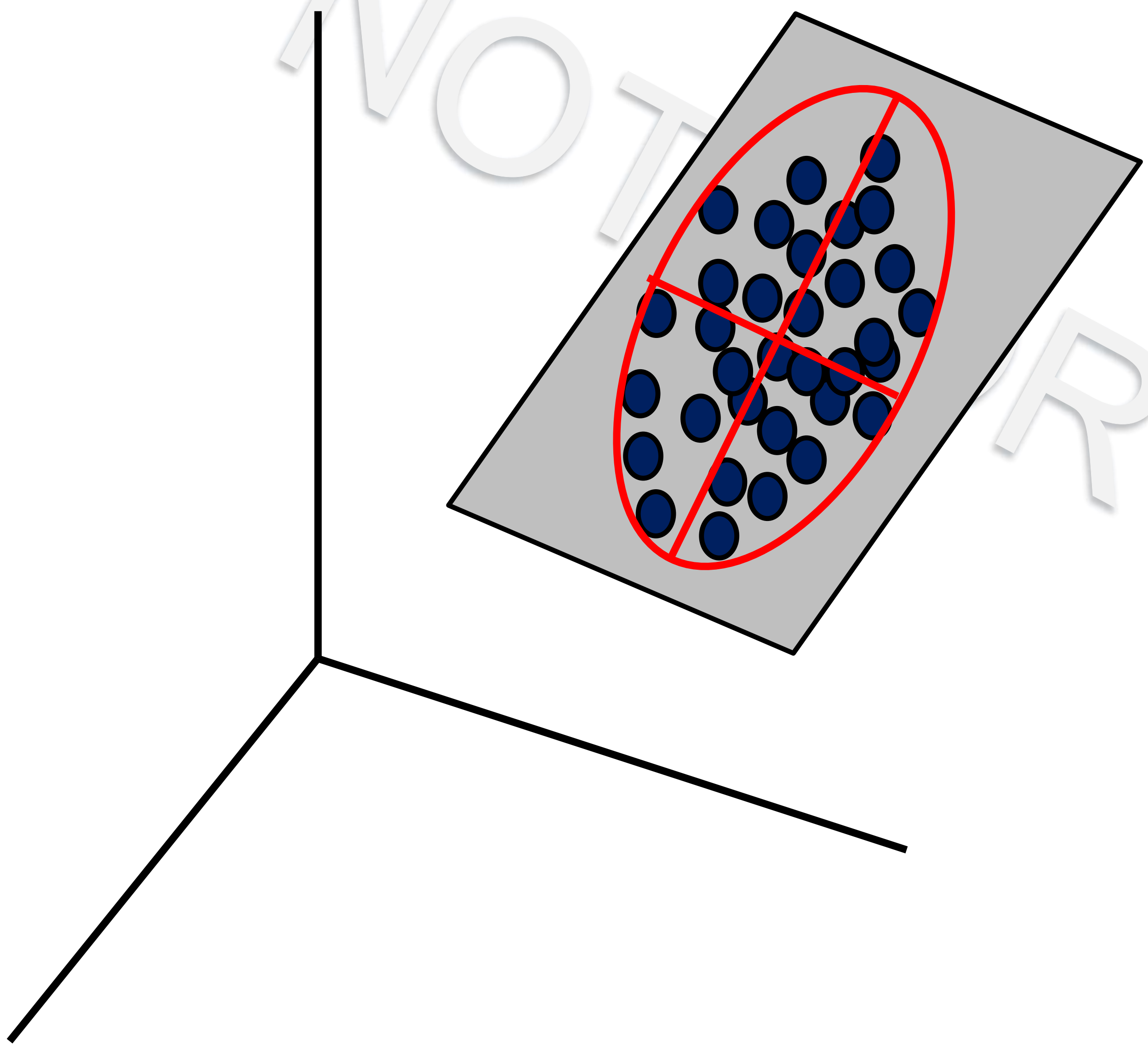




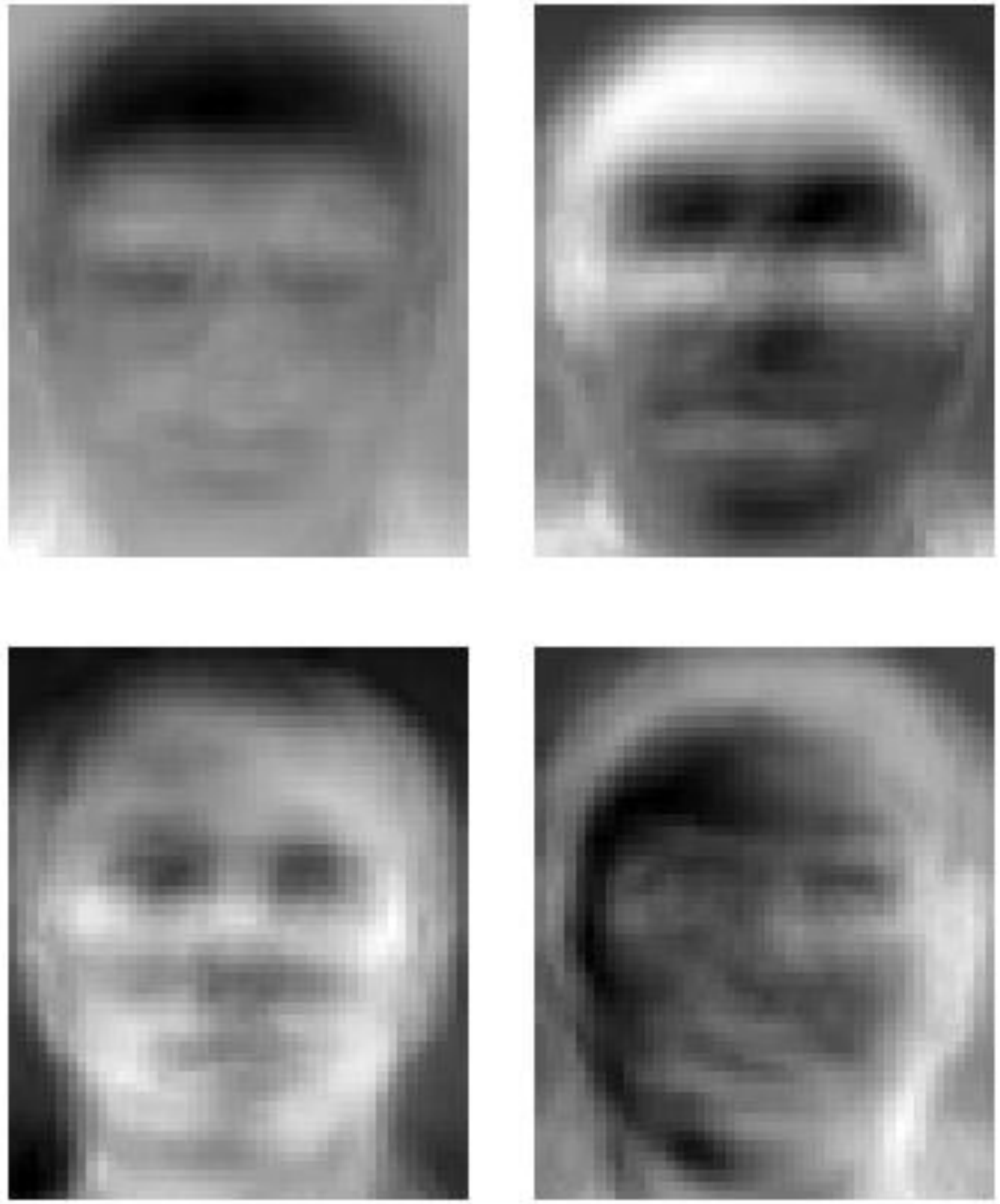
Determining multiple features from white noise



Principal component analysis

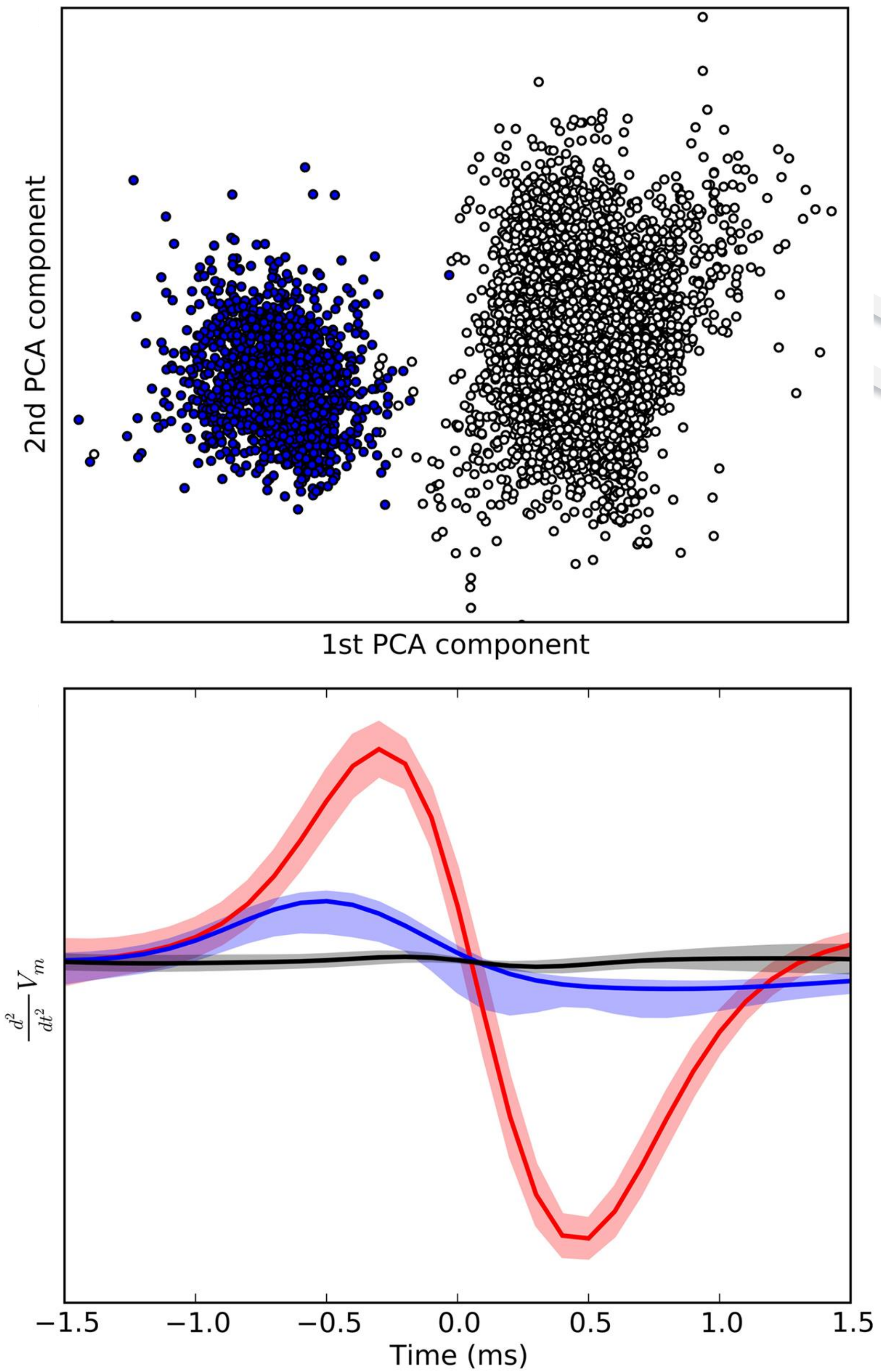


Principal component analysis: eigenfaces



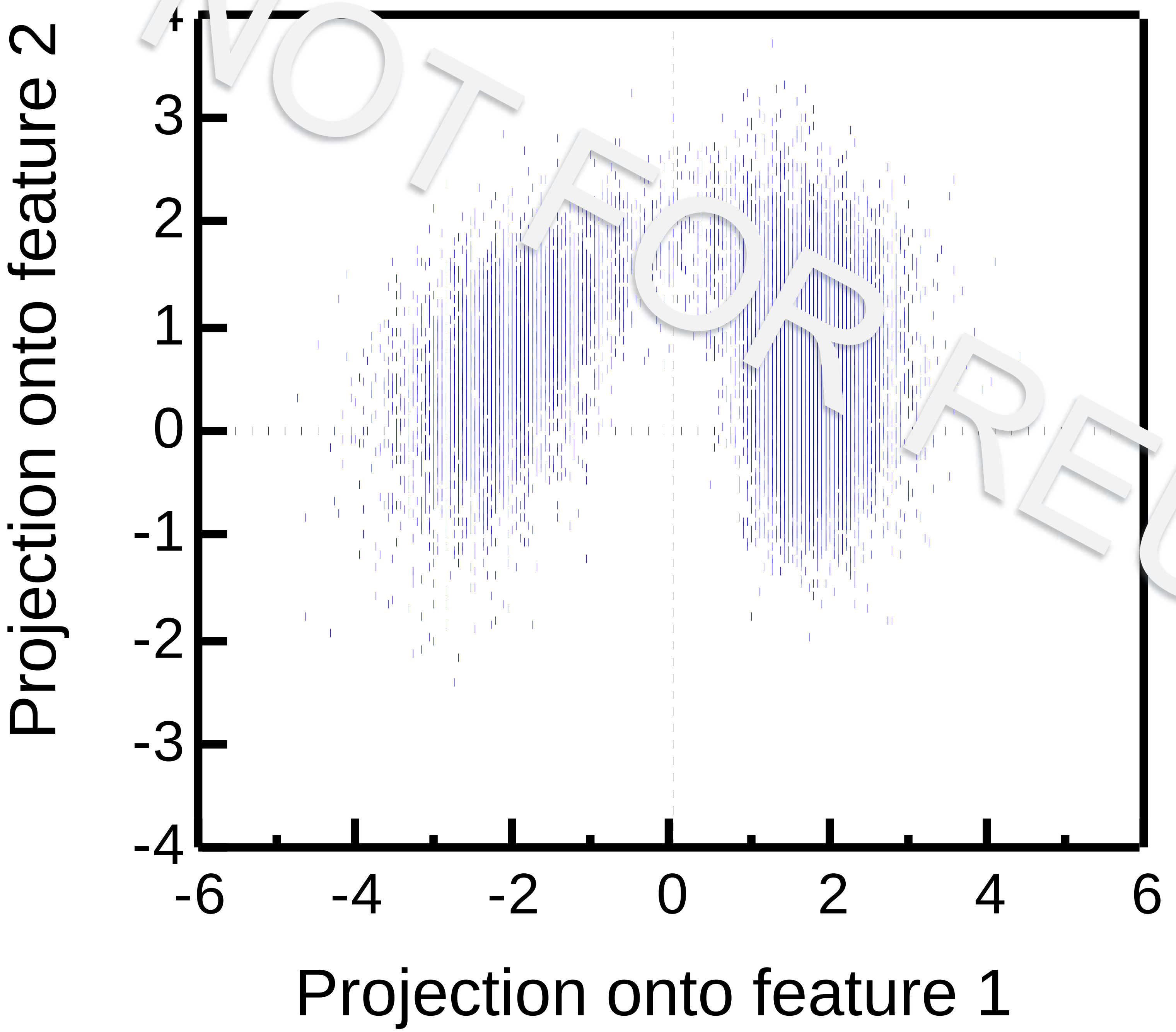
ATT Labs, Cambridge (via Wikipedia)

Principal component analysis: spike sorting



Koepsell et al., Front. Syst. Neurosci., 2009

Finding interesting features in the retina



Fairhall et al., J. Neurophysiol., 2007