NEURAL DATA ANALYSIS

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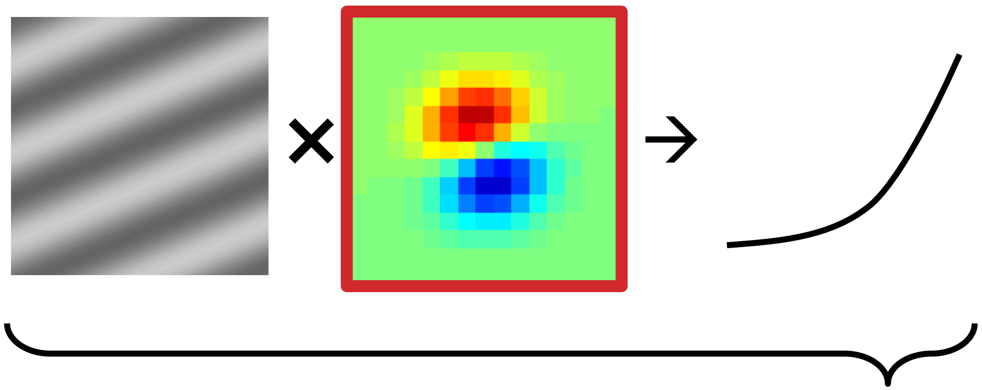
COMPUTATIONAL VISION AND
NEUROSCIENCE GROUP

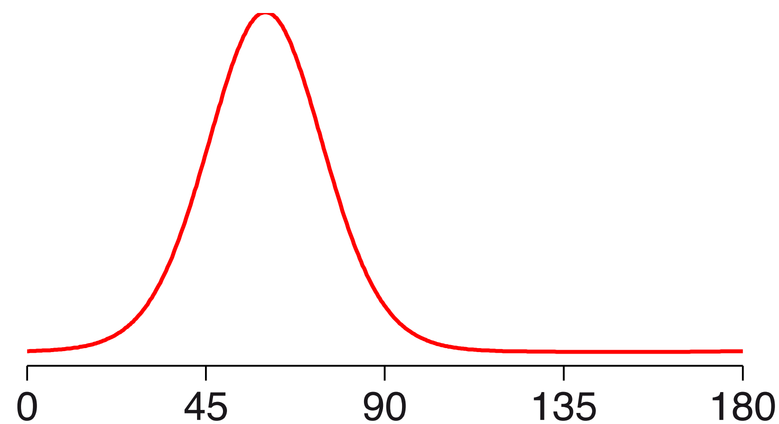
RECEPTIVE FIELDS

WHAT MAKES A NEURON FIRE? WHERE?



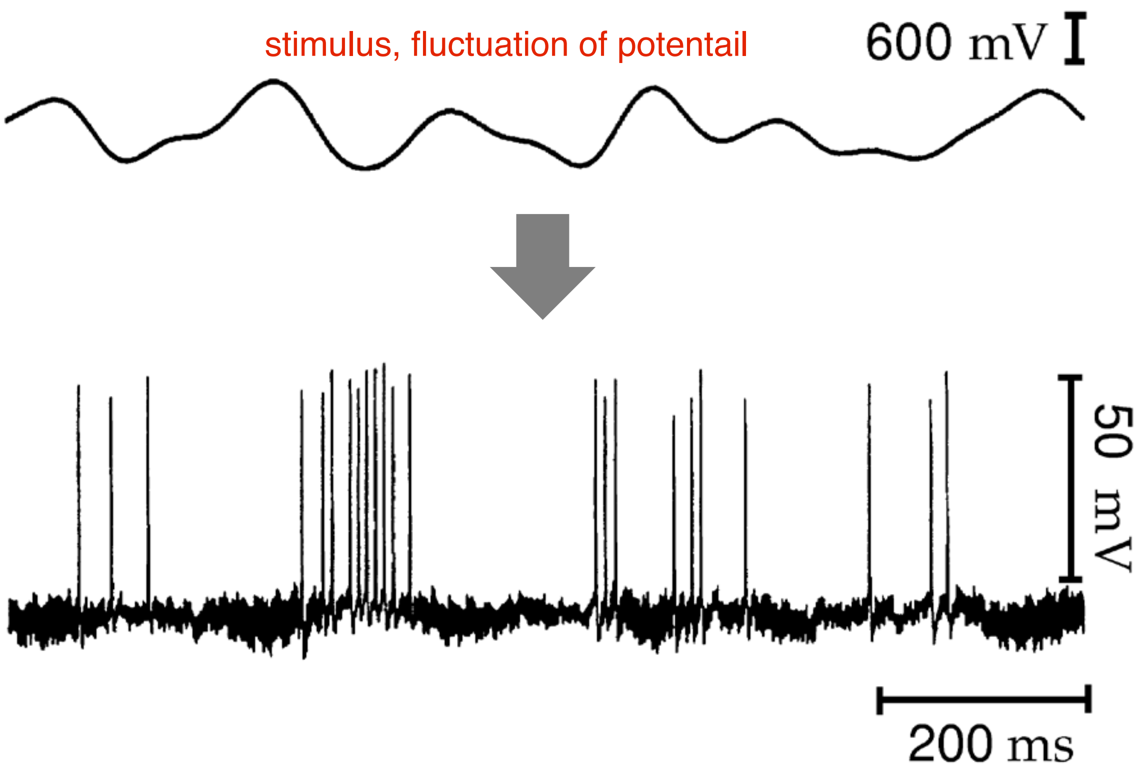
$$f(\theta) = \exp[\alpha + \kappa(\cos(2(\theta - \phi)) - 1)]$$

von Mises Model

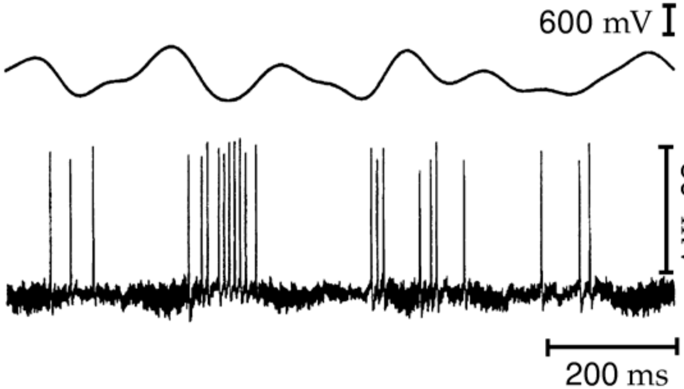


WHAT MAKES A NEURON FIRE WHEN?

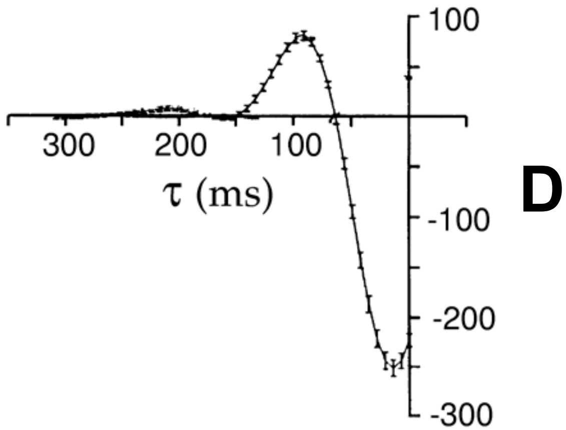
Example: weakly electric fish electrosensory lateral-line lobe



LINEAR MODEL



spike-triggered average



$$r_{est}(t) = \int_0^{\infty} D(\tau)\, s(t-\tau)\, d\tau$$

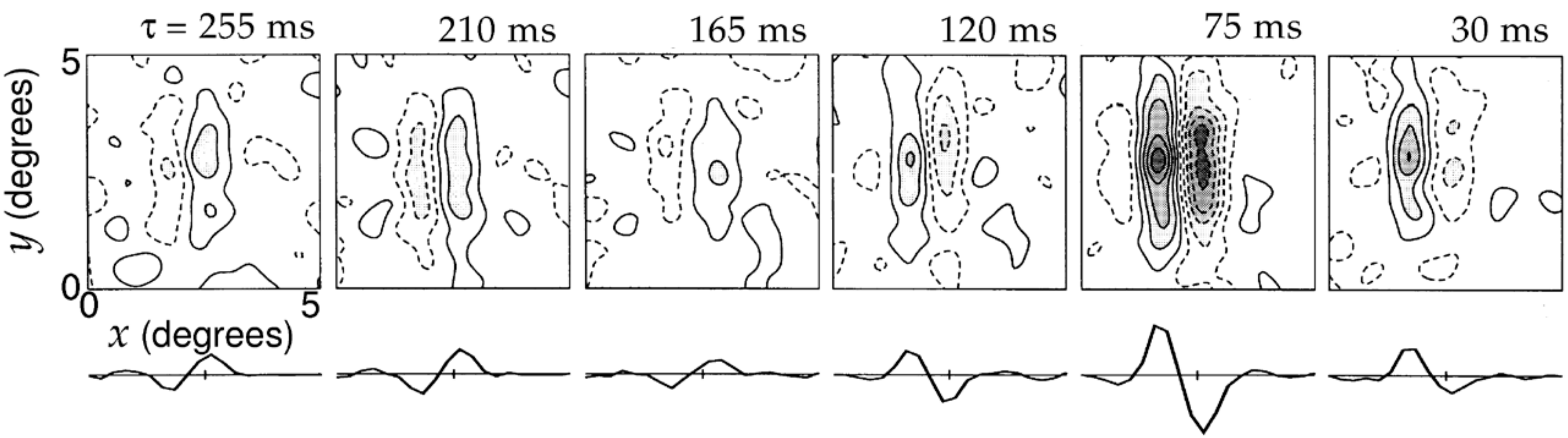
Receptive field kernel

Stimulus

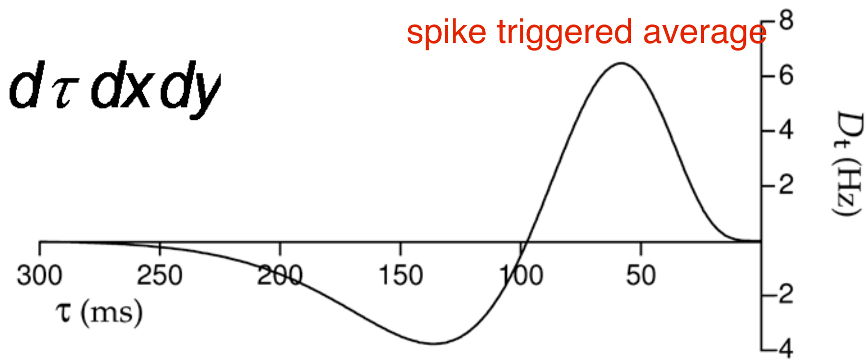
WIENER/VOLTERRA EXPANSION

$$
\begin{aligned}
r_{est}(t) = r_0 &+ \int D(\tau)s(t-\tau)\,d\tau \\
&+ \int D(\tau_1,\tau_2)s(t-\tau_1)s(t-\tau_2)\,d\tau_1\,d\tau_2 \\
&+ \int D(\tau_1,\tau_2,\tau_3)s(t-\tau_1)s(t-\tau_2)s(t-\tau_3)\,d\tau_1\,d\tau_2\,d\tau_3 \\
&+ \ldots
\end{aligned}
$$

V1 SIMPLE CELL



$$r_{est}(t) = \int D(x,y,\tau)s(x,y,t-\tau)\,d\tau\,dx\,dy$$



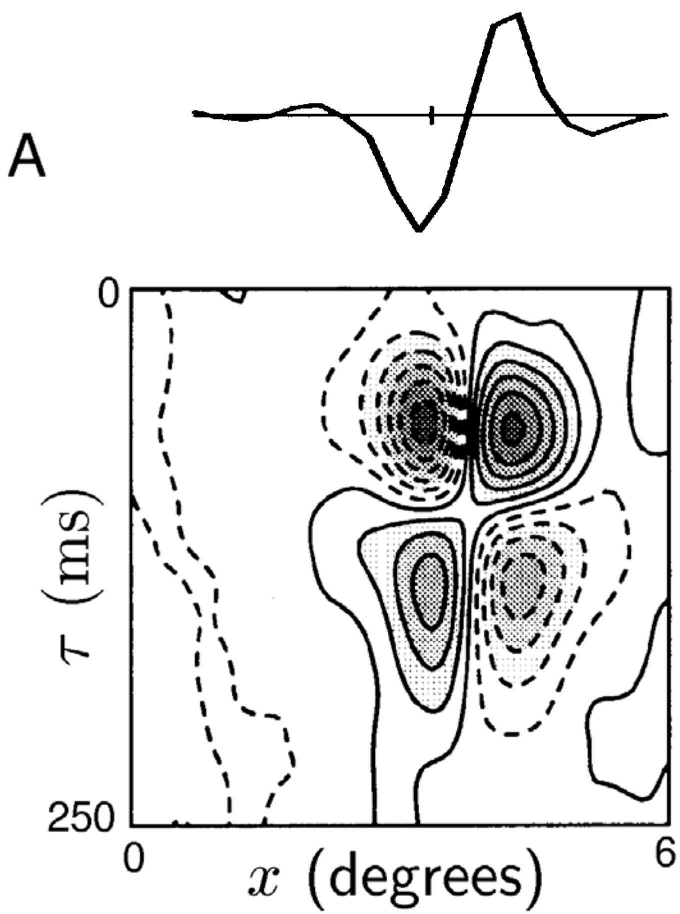
Dayan & Abbott, 2001

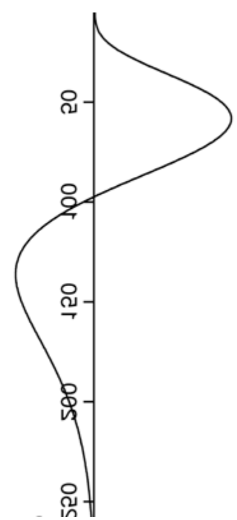
SPACE-TIME SEPARABLE RECEPTIVE FIELD

Spatial kernel

$$D(x, y, \tau) = D_s(x, y) D_t(\tau)$$

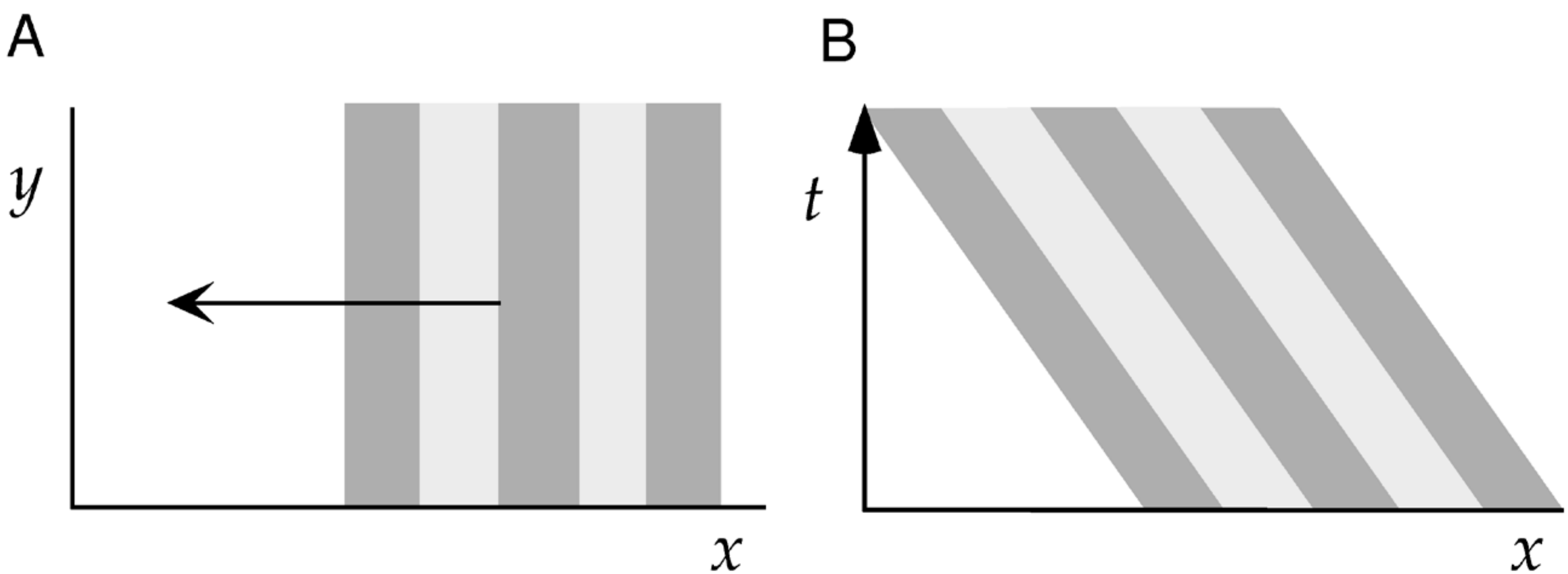
Temporal kernel





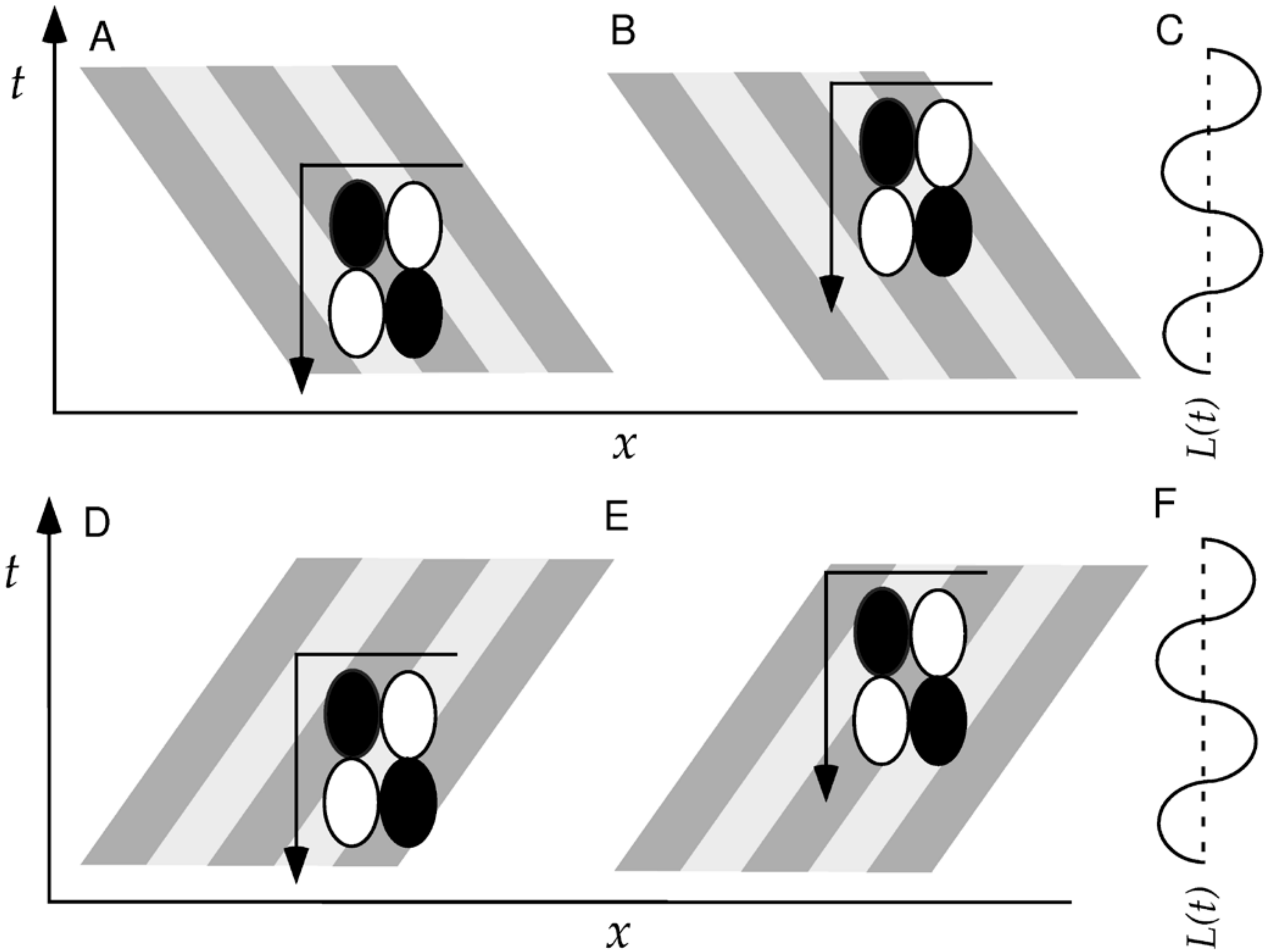
Dayan & Abbott, 2001

MOVING GRATING IN SPACE-TIME DIAGRAM



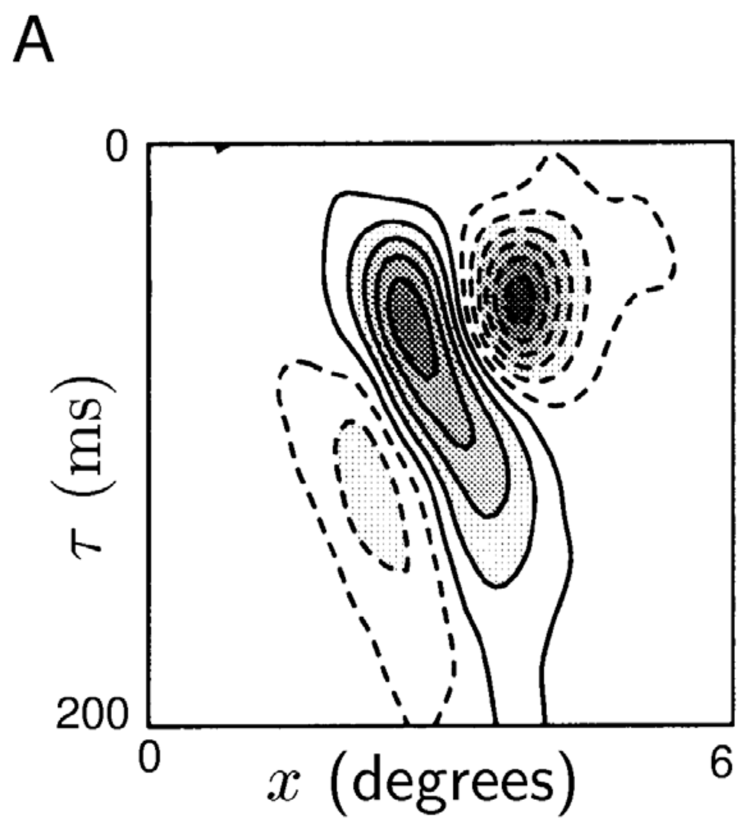
Dayan & Abbott, 2001

SPACE-TIME SEPARABLE RESPONSE



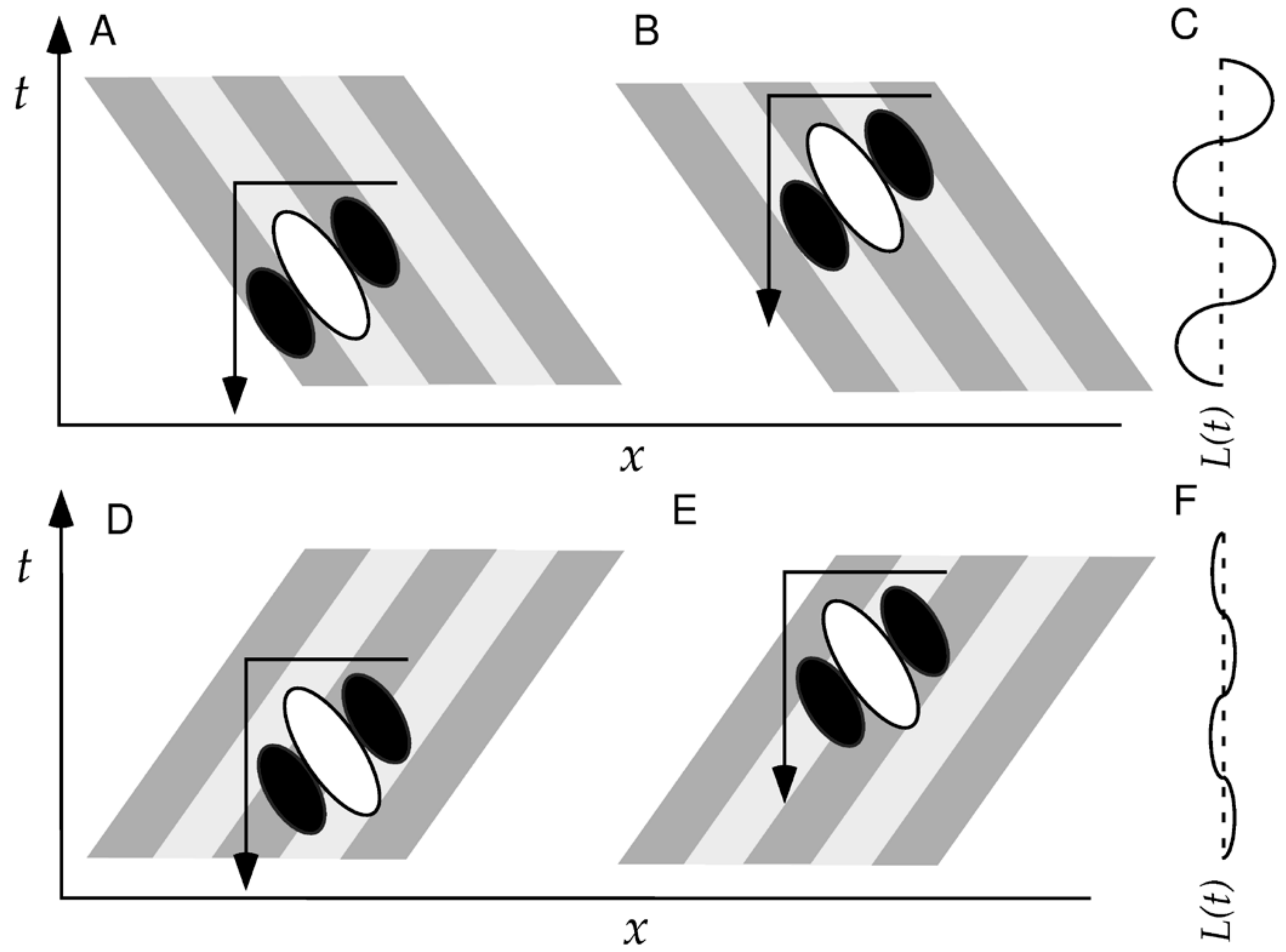
Dayan & Abbott, 2001

NON-SEPARABLE: DIRECTION SELECTIVITY



Dayan & Abbott, 2001

NON-SEPARABLE RESPONSE

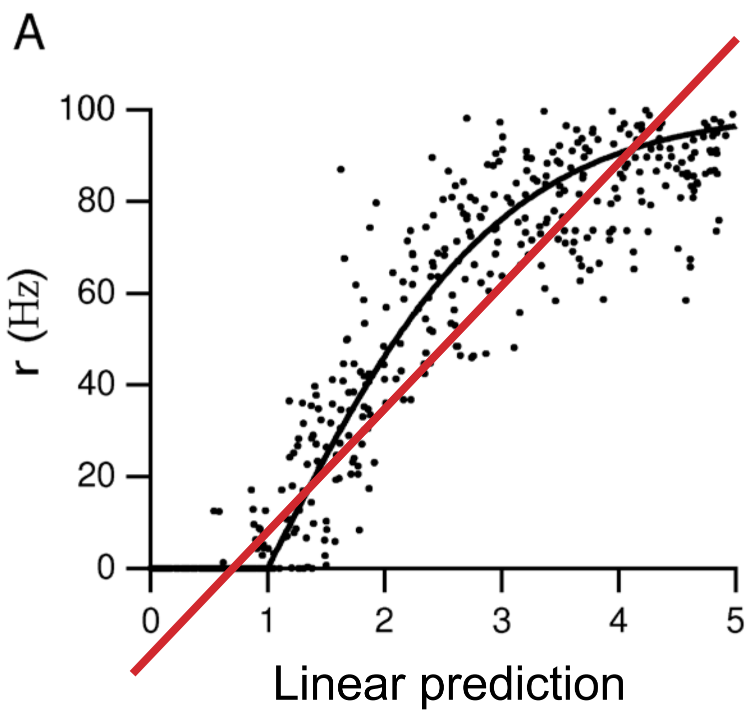


Dayan & Abbott, 2001

BEYOND LINEAR

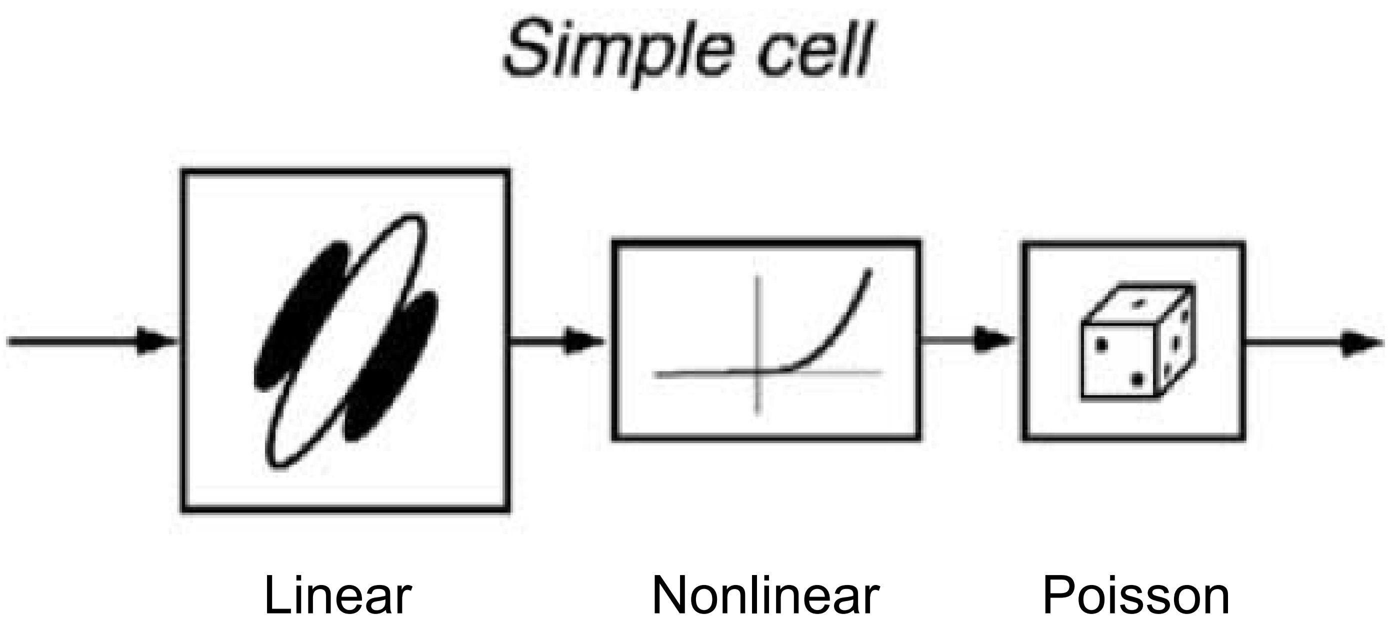
1. Linear-nonlinear-Poisson (LNP) model
2. Energy model (complex cells)

LNP MODEL: STATIC NONLINEARITY



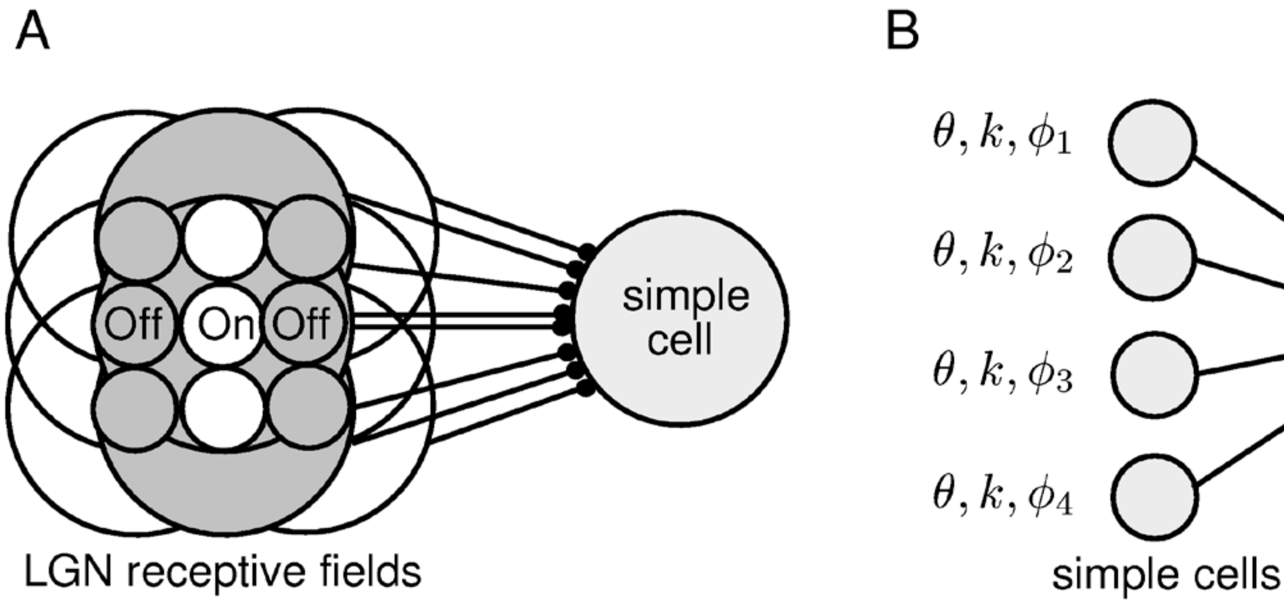
Dayan & Abbott, 2001

THE LNP MODEL



$$y \sim \text{Poisson}(\exp(r))$$

COMPLEX CELLS: HUBEL & WIESEL MODEL



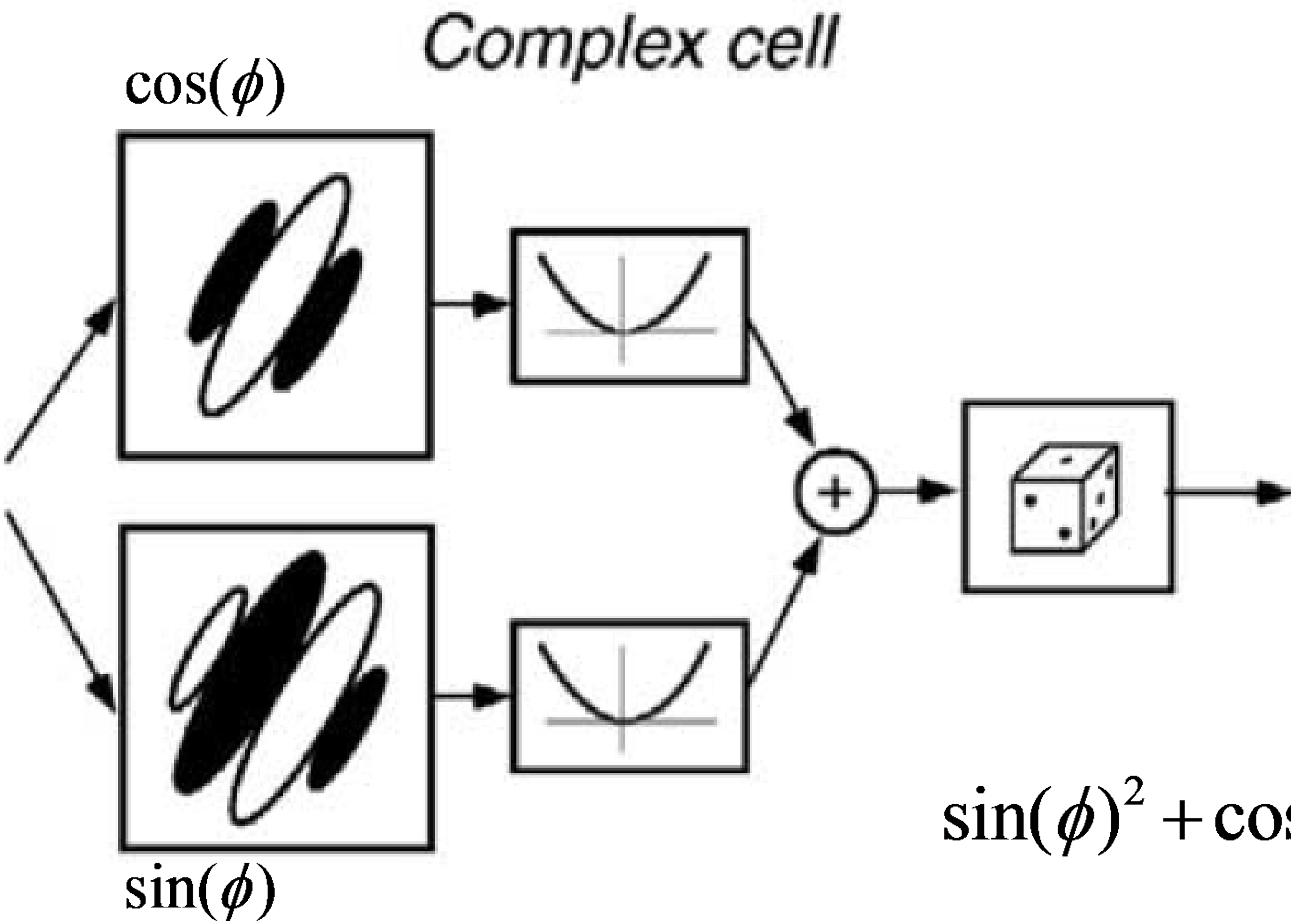
capture edge contrast

capture light on and off

Theta : hidden variables of Poisson.
k : estimate of spikes counts.
phi : the tuning angle

Dayan & Abbott, 2001

COMPLEX CELLS: THE ENERGY MODEL



$$\sin(\phi)^2 + \cos(\phi)^2 = 1$$

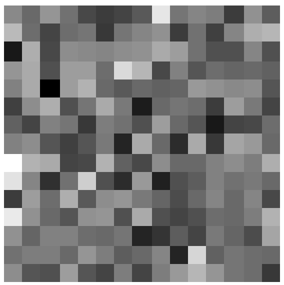
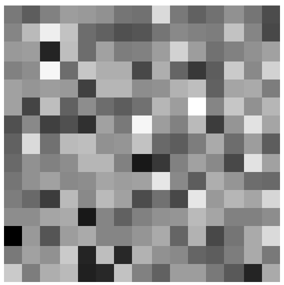
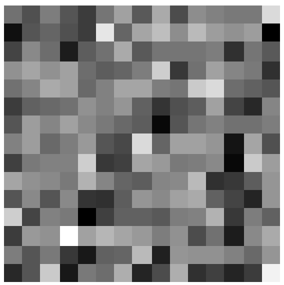
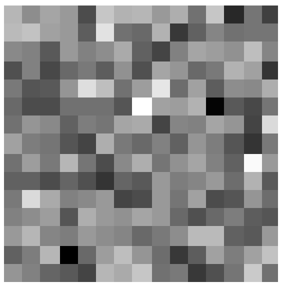
LEARNING RECEPTIVE FIELDS

LEARNING RECEPTIVE FIELD MODELS

1. Spike-triggered average
2. Maximum likelihood
3. Spike-triggered covariance

SPECIAL CASE

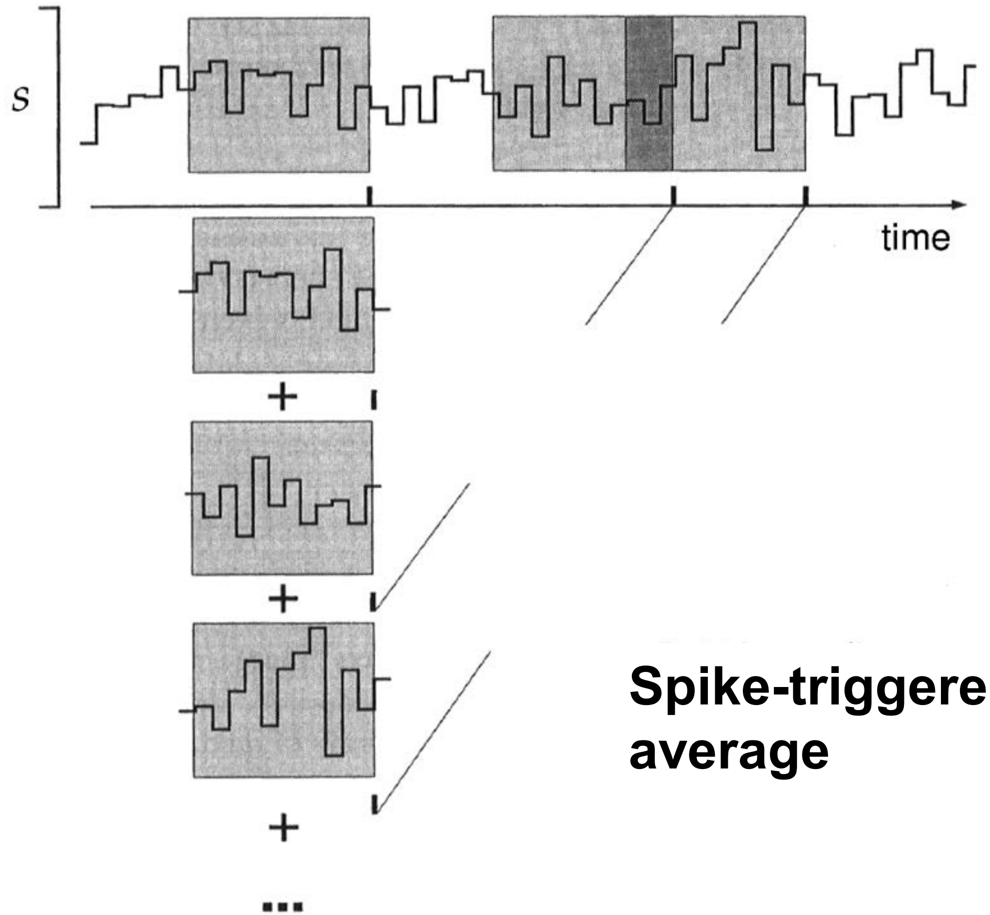
1. **White noise stimulus**

 →  →  →  → …

2. **Linear receptive field**

$$\Rightarrow \quad D(\tau) \sim C(\tau), \qquad C(\tau): \text{ Spike-triggered average (STA)}$$

SPIKE-TRIGGERED AVERAGE



Spike-triggered average

$$C(\tau) = \left\langle \frac{1}{n} \sum_{i=1}^{n} s(t_i - \tau) \right\rangle$$

Dayan & Abbott, 2001

ESTIMATING RECEPTIVE FIELDS

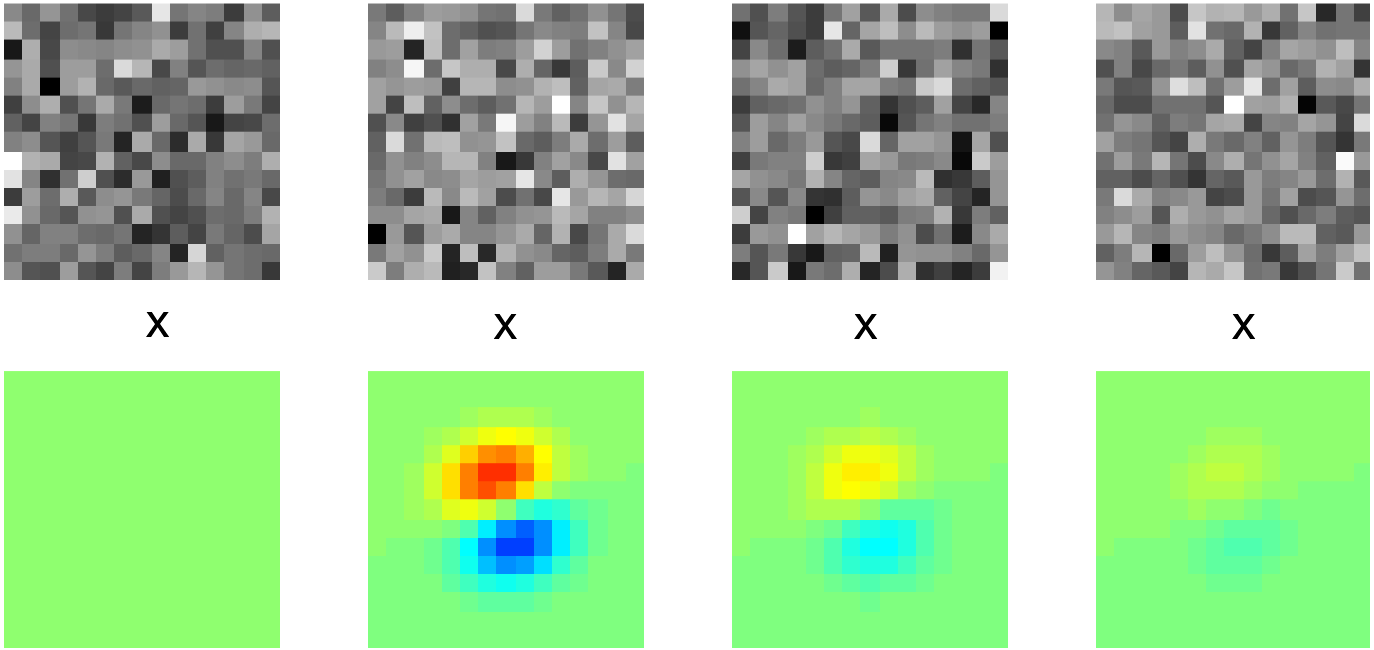
Continuous representation (integrals)

$$r_{est}(t) = \int D_s(x,y) D_t(\tau) s(x,y,t-\tau)\, d\tau\, dx\, dy$$

Discretize space and time (sums)

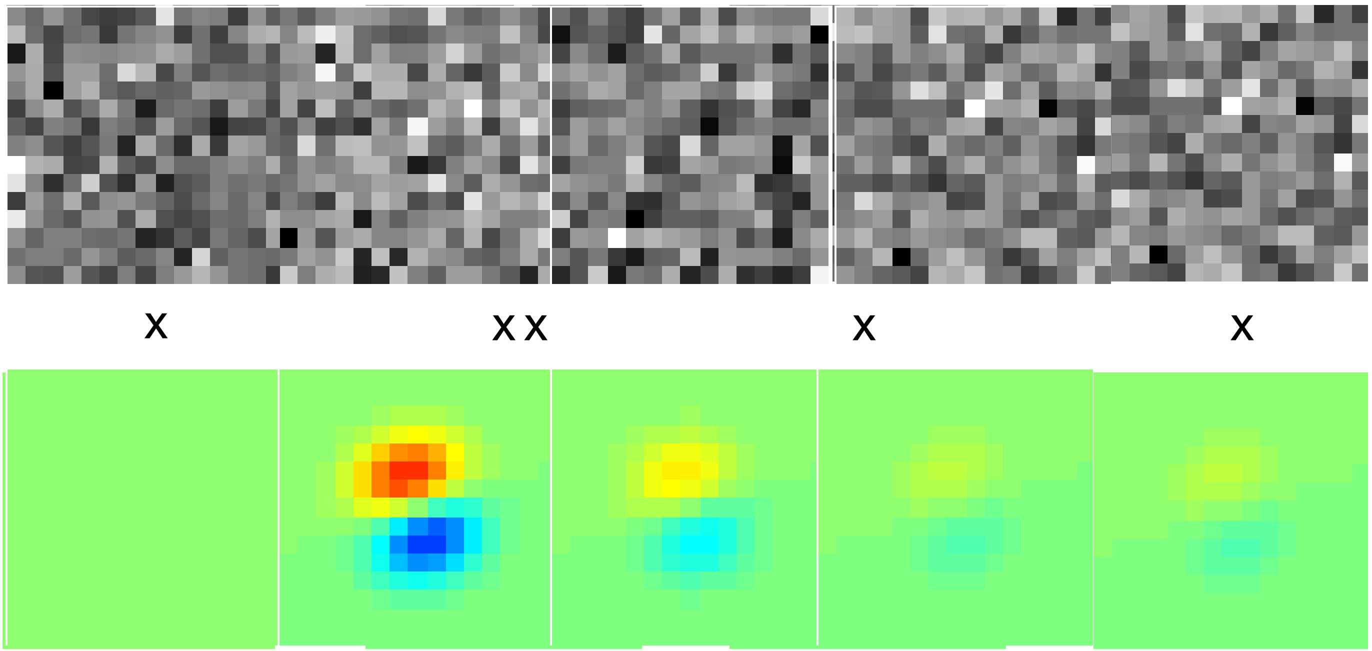
$$r(t) = \sum_i \sum_j \sum_k D_{ijk} s_{ijk}(t)$$

SPATIO-TEMPORAL RECEPTIVE FIELDS



$\Delta t = 0$ $\Delta t = -1$ $\Delta t = -2$ $\Delta t = -3$

SPATIO-TEMPORAL RECEPTIVE FIELDS



$$\Rightarrow \quad r_t = w^{\mathrm{T}} s_t$$

ESTIMATING RECEPTIVE FIELDS

Maximum likelihood: minimize the negative log-likelihood

$$y_t \sim \text{Poisson}(\lambda), \qquad \lambda = \exp(w^{\mathrm{T}} s_t)$$

$$P(y_t \mid w) = \frac{\lambda^{y_t}}{y_t!} \exp(-\lambda)$$

Negative log-likelihood:

$$\begin{aligned} L(w) &= -\log P(y_t \mid w) \\ &= -y_t \log \lambda + \log(y_t!) + \lambda \end{aligned}$$

$$\frac{\partial L(w)}{\partial w} = \ldots$$

SPIKE-TRIGGERED COVARIANCE

SPIKE-TRIGGERED COVARIANCE

e.g. Rust et al. (2005), Neuron

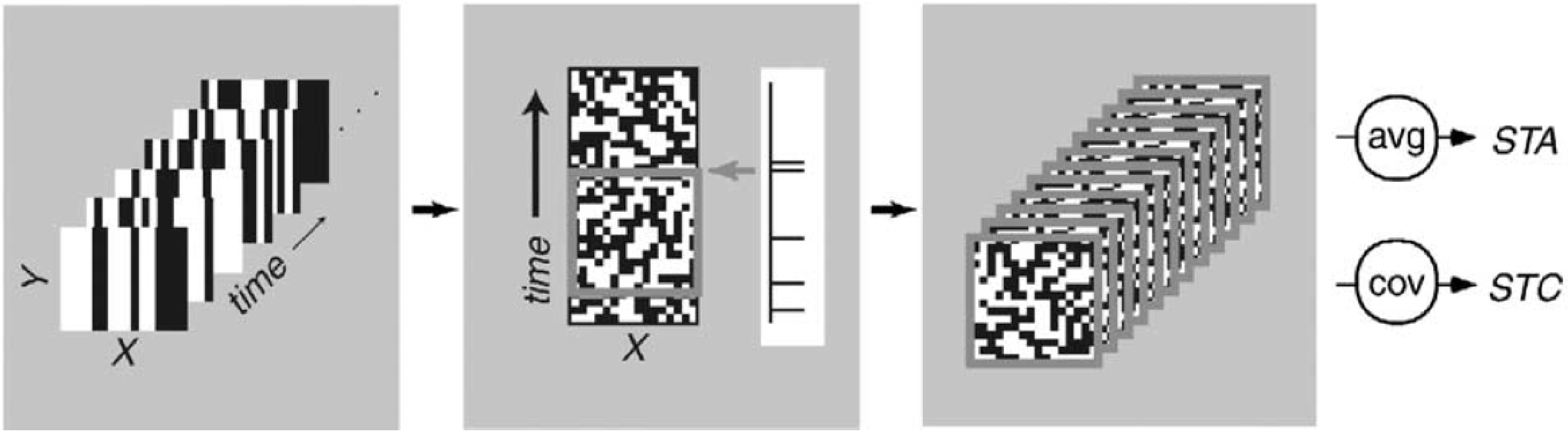
Spike-triggered covariance: $$C_{ij}(\tau) = \left\langle \frac{1}{n} \sum_t s_i(t-\tau) s_j(t-\tau) \right\rangle$$

Visualize eigenvectors of C_{ij} with largest (smallest) variance

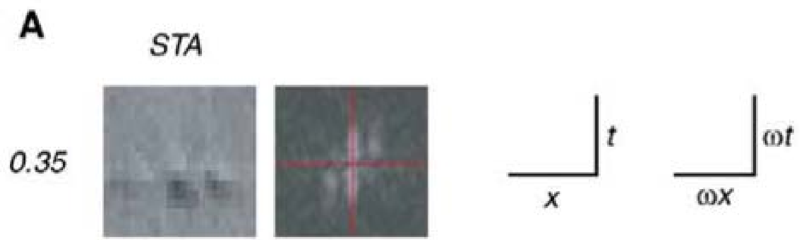
→ Capture non-linear response properties (e.g. complex cell)

what the fuck?

SPIKE-TRIGGERED COVARIANCE (RUST 2005)



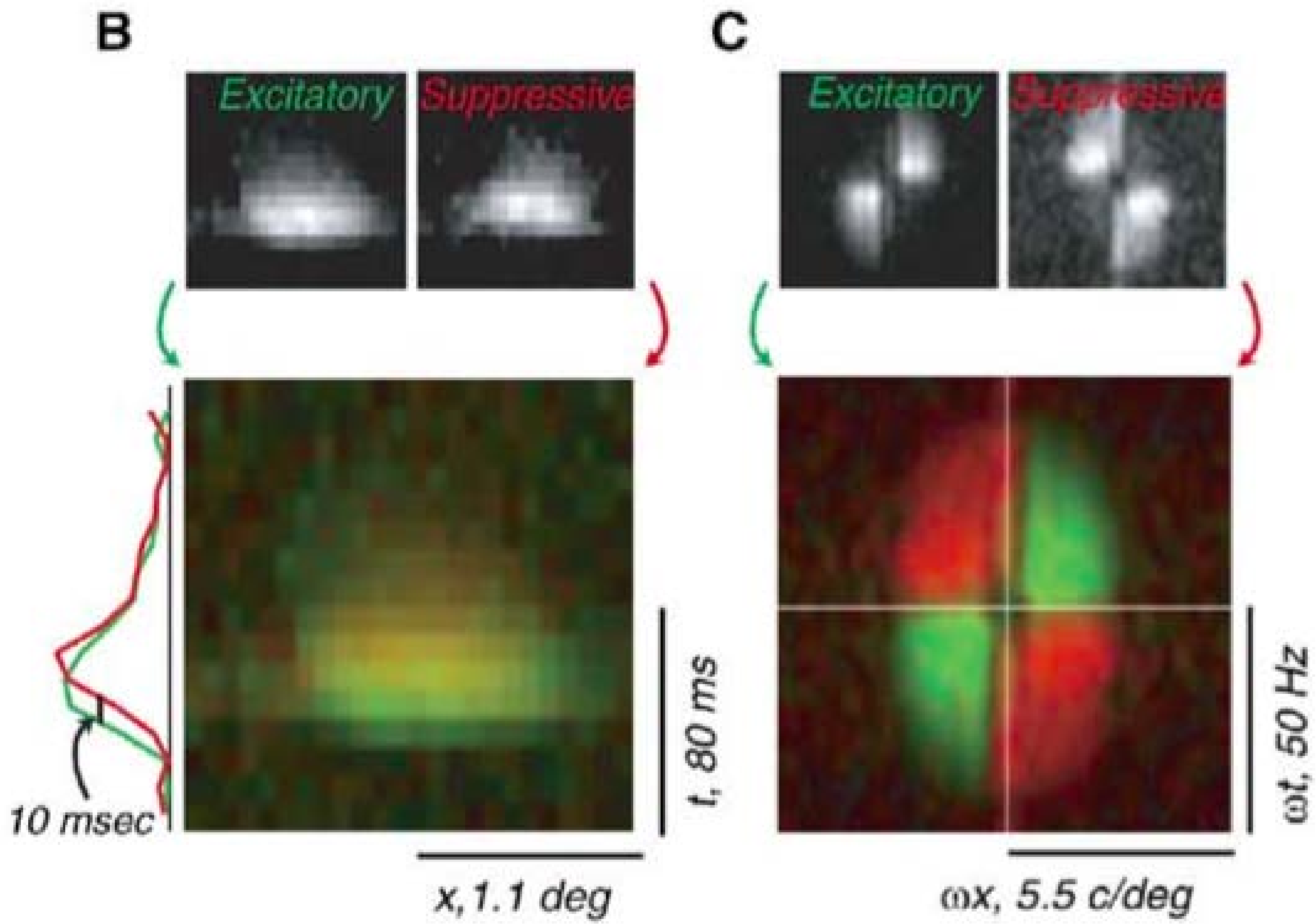
SPIKE-TRIGGERED COVARIANCE (COMPLEX CELL)



what the fuck

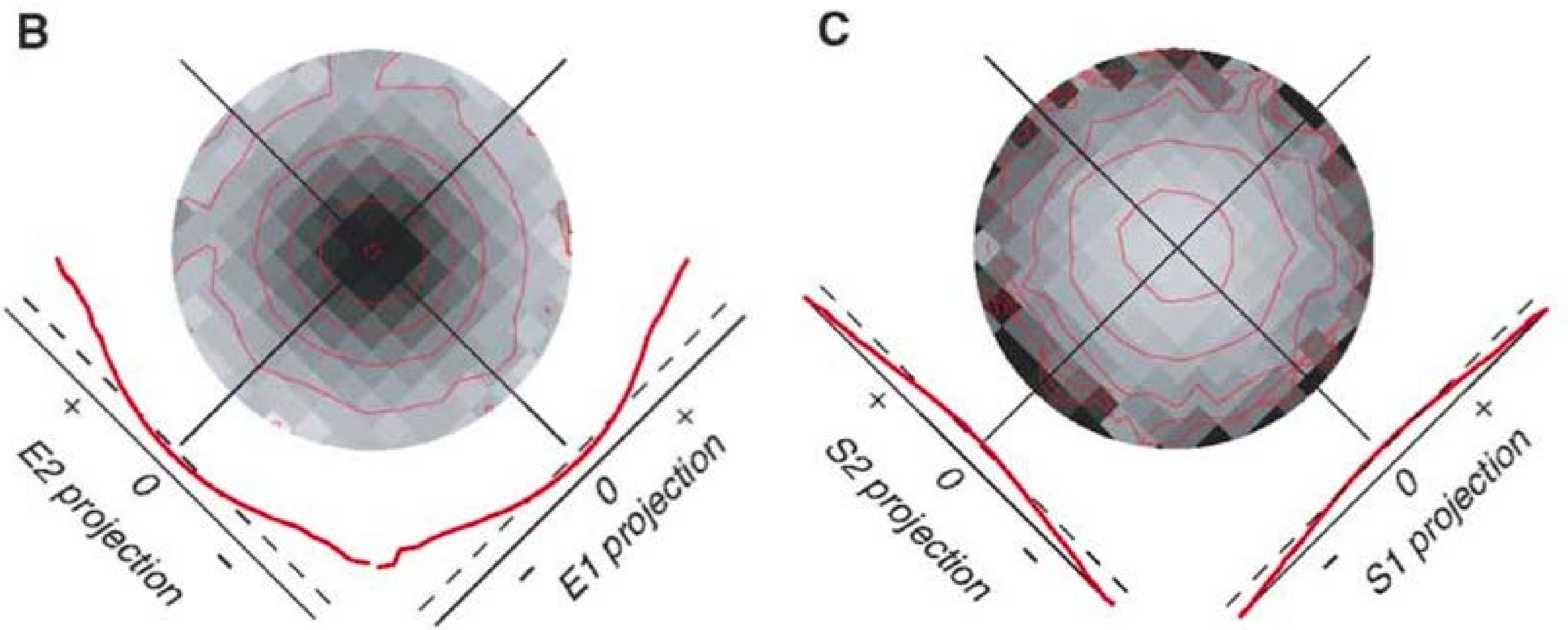
Rust et al. 2005

SPIKE-TRIGGERED COVARIANCE (RUST 2005)



Rust et al. 2005

SPIKE-TRIGGERED COVARIANCE (RUST 2005)



excitatory

suppressive

Rust et al. 2005