Stimulus-dependent Activity

- No class next week. We'll catchup the following week!

Stimulus-dependent variability

- In most sensory-related circuits, it is assumed that information processing is ‘deterministic’.
- The variability of a response (e.g. noise in spike production) limits the extent to which it can be ‘decoded’, and hence perceived.

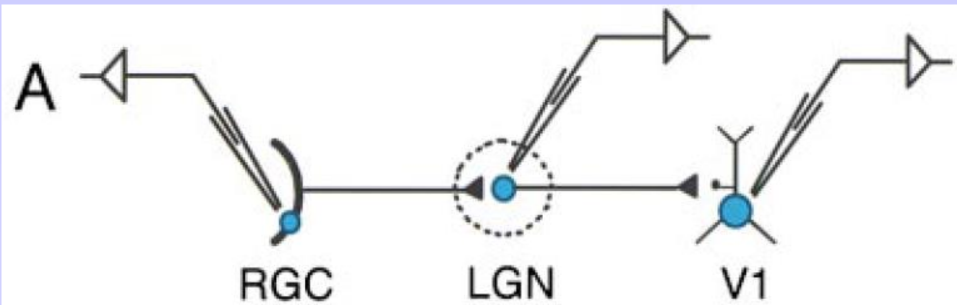
Stimulus A ←→ Response A (i.e. spike train A)

- In higher cognitive circuits (e.g. decision making, face-perception, memory) information processing is generally not deterministic (?). Phenomena of adaptation, learning, memory (re)consolidation
- The neural code for a specific item changes, from presentation to presentation.

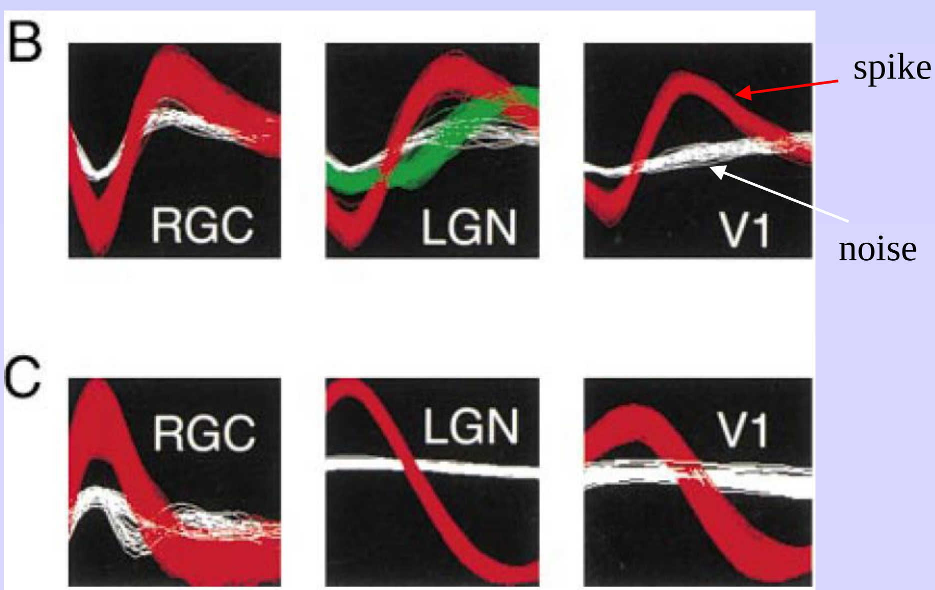
Stimulus A → Response A1
Stimulus A → Response A2
Stimulus A → Response A3
Stimulus A → Response B
…

Fano Factor – Part 2

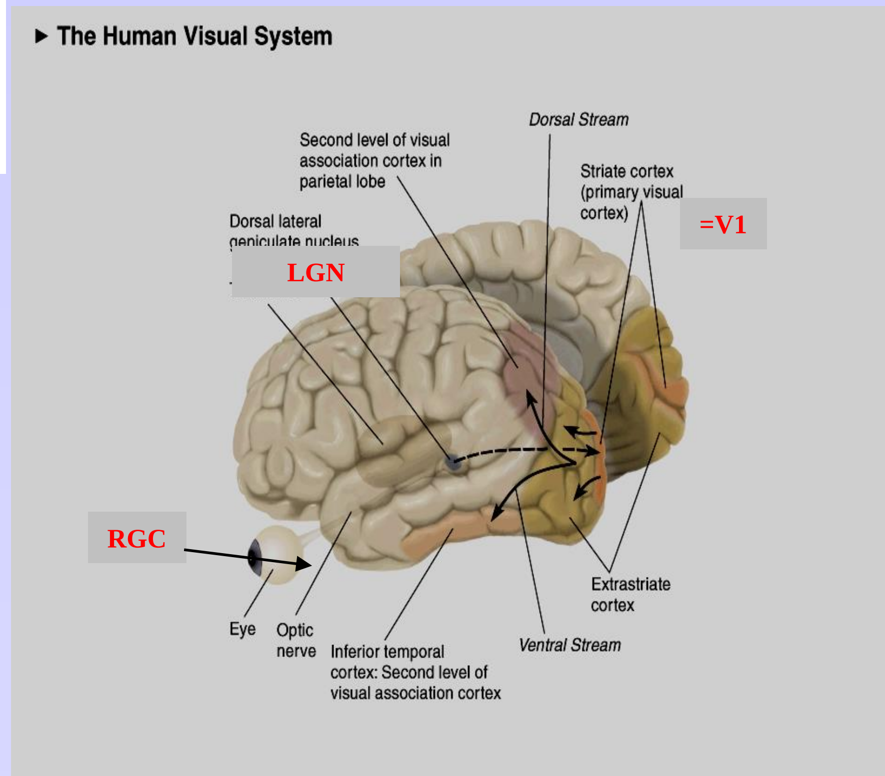
- Measure of reliability (variability) of a response *across* multiple presentations of a stimulus.



RGC= Retinal Ganglion Cell

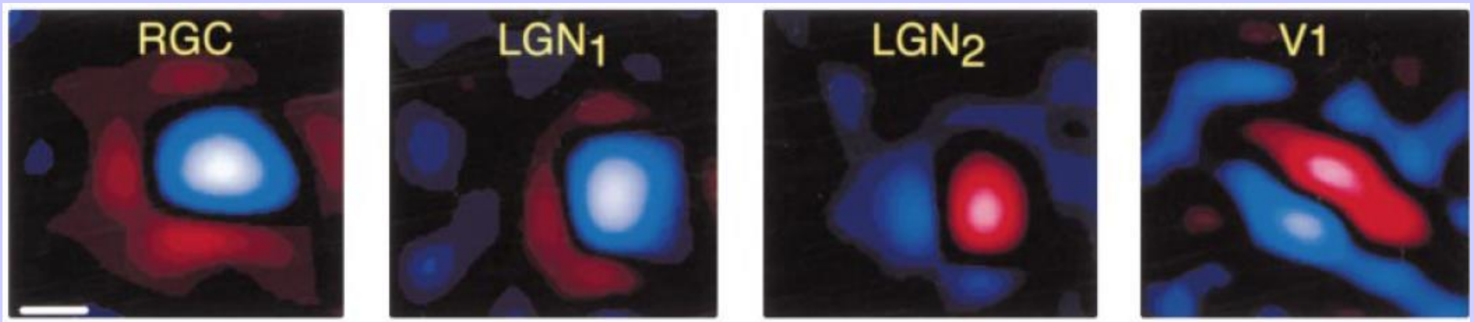


(Kara et. al. 2000)



Fano Factor – Part 2

Overlapping Receptive fields



0.8°

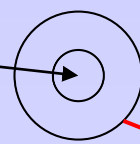
Off-center

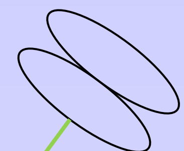
Off-center

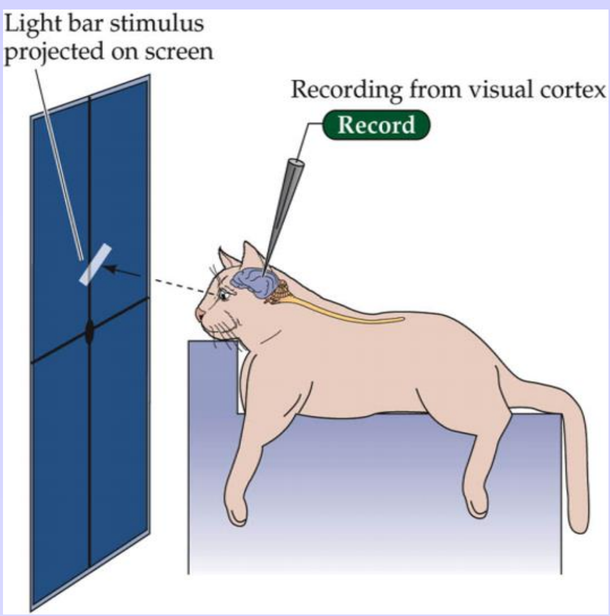
On-center

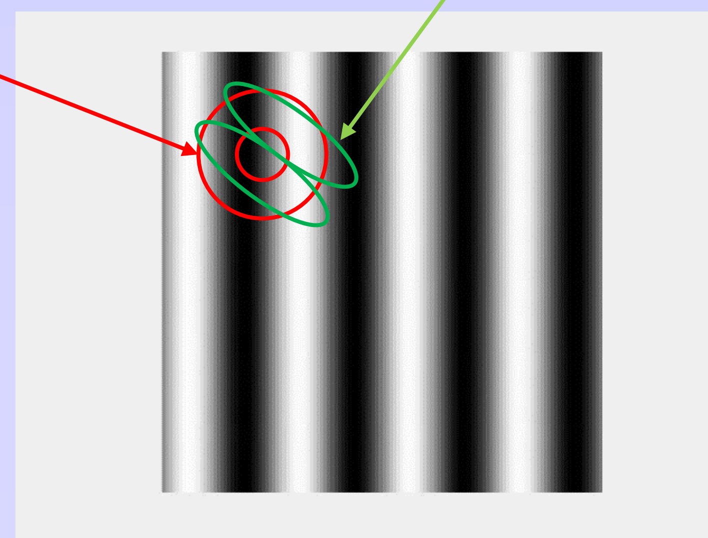
Simple cell

‘center’







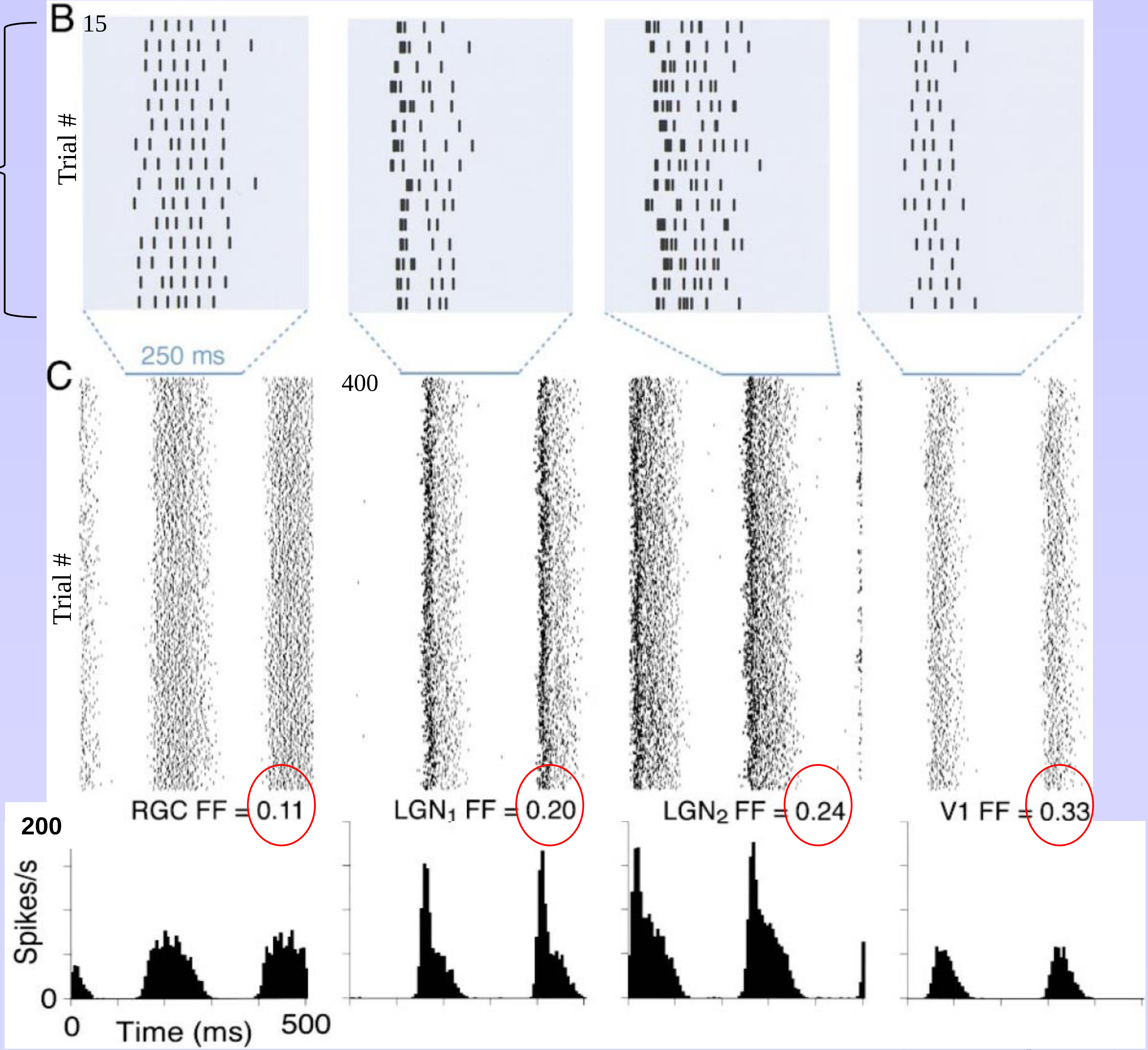


stimulus

Fano Factor – Part 2

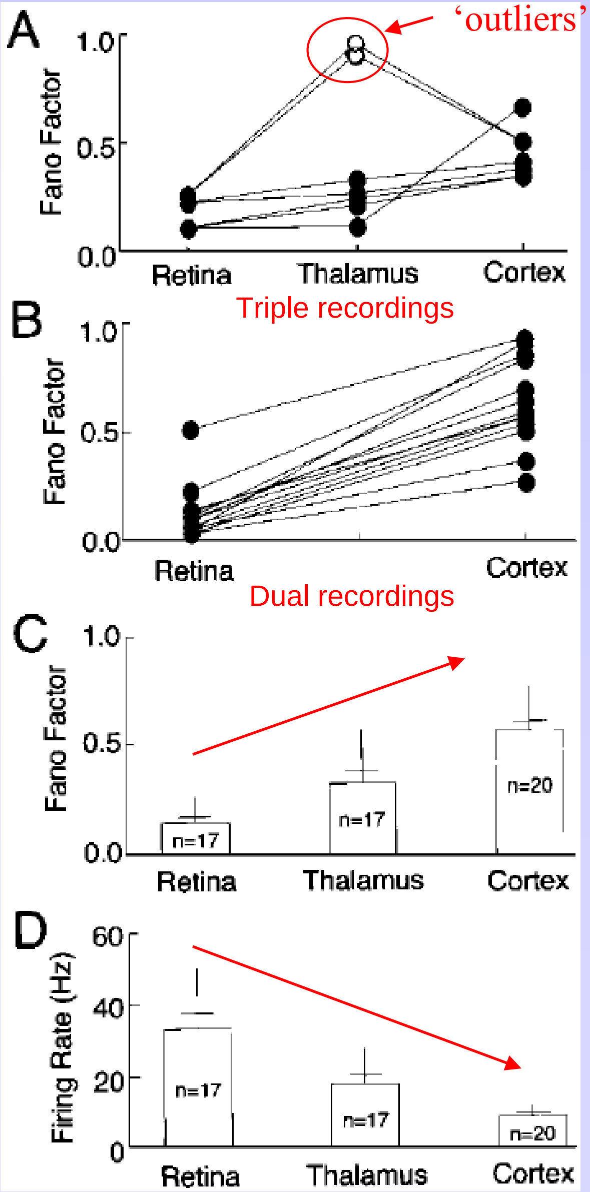
Variability of spike count across trials?

Stimulus-evoked Fano Factor across trials.
→The 'bin' is the trial
T=Trial length=250 ms



(Kara et. al. 2000)

Fano Factor – Part 2

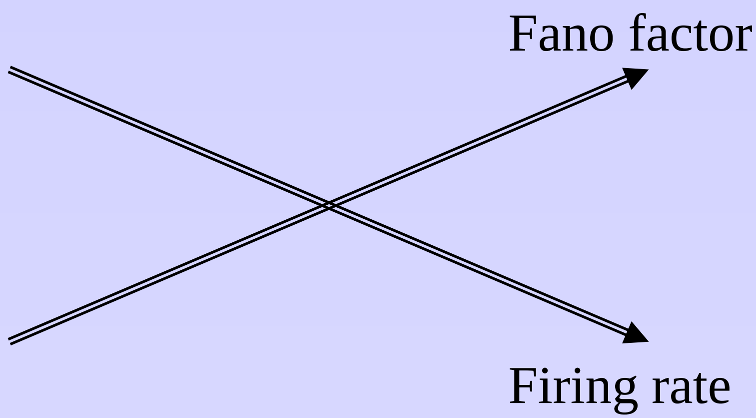


(Kara et. al. 2000)

Fano factor increases from retina to cortex

More irregularity in response to the same stimulus

More 'information'/'processing'

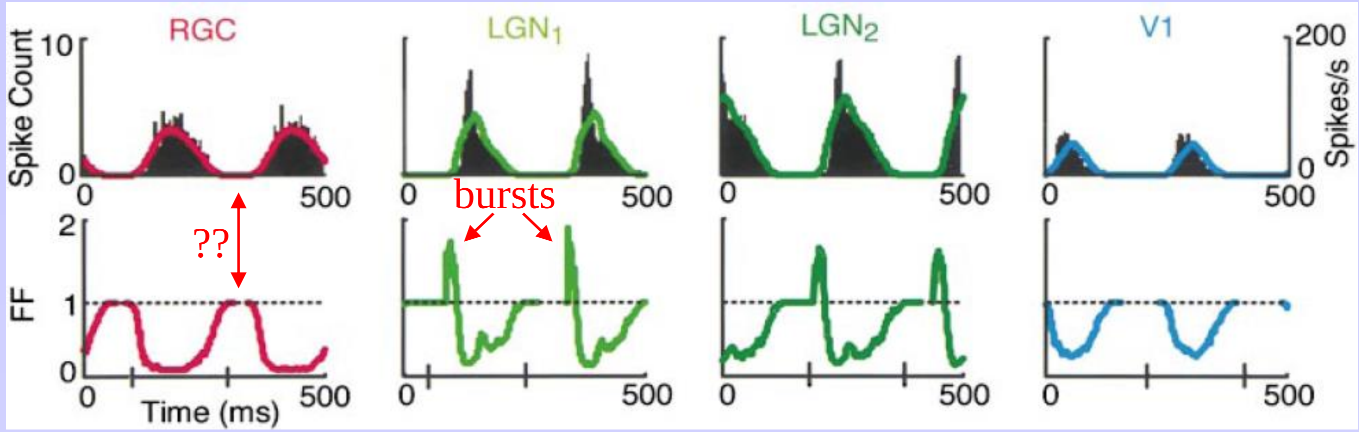


➔ 'Quick' way to estimate information content

Fano Factor – Part 2

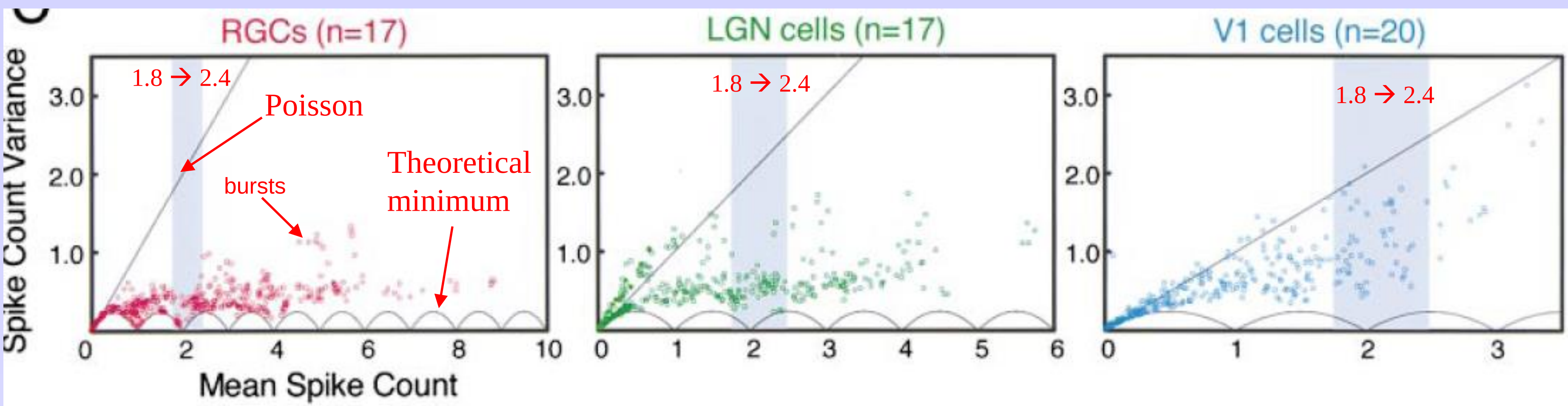
- FF only makes sense for non-zero firing rates
- FF is anticorrelated with firing rate

Spike count / FF in sliding 50ms windows



No bursts → *Bursts* → *No bursts*

Variance Vs. mean spike count in sliding 50ms windows, 25ms overlap (all cells)

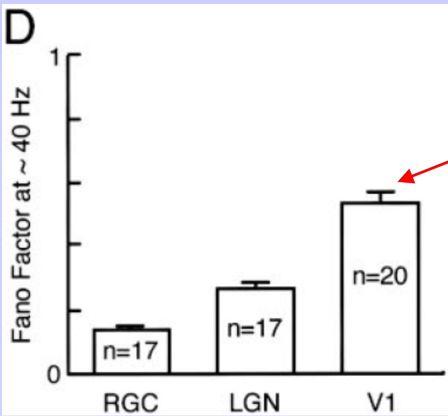


RGC close to minimum variance, bursts (FF>1) > diagonal

(Kara et. al. 2000)

Fano Factor – Part 2

1.8 → 2.4 mean spike count in a 50 ms window ➔ ~40Hz (gamma oscillations, STDP)



Standard Error (of the mean)

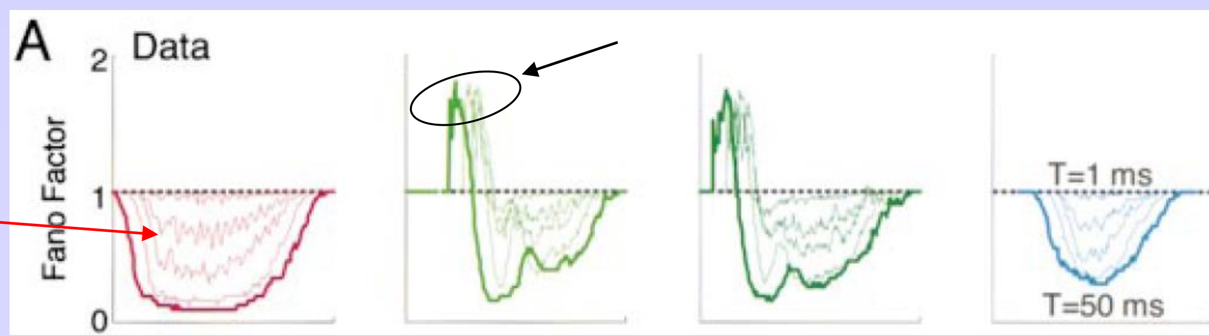
Vs

Standard deviation (σ)

$$SE = \frac{\sigma}{\sqrt{n}}$$

More irregular (i.e. meaningful?) 40Hz events from RGC to V1

T=1,5,10,25,50 ms



(Kara et. al. 2000)

Fano factor does depend on the width of the counting window (but qualitatively the same)

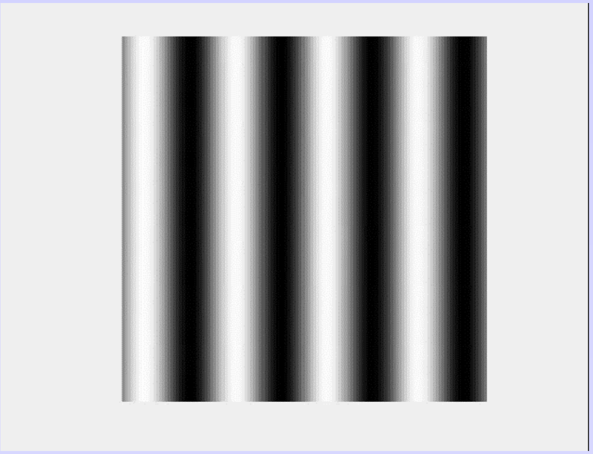
Stimulus Dependent Activity

-What kind of stimulus? Experimentally tractable Vs Natural stimuli

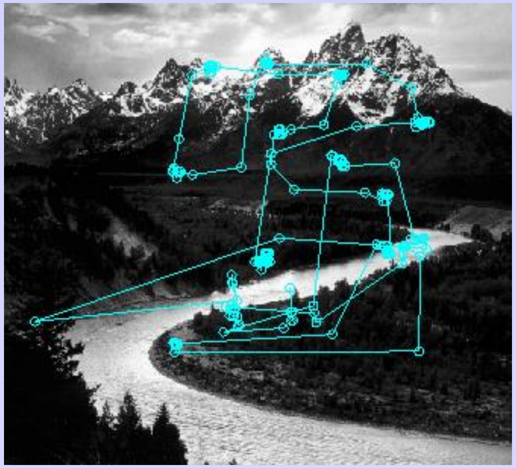
Ex: Vision: moving bars/gratings Vs Natural scenes
Audition: pure tone Vs human voice
Olfaction: one chemical Vs one odor
…

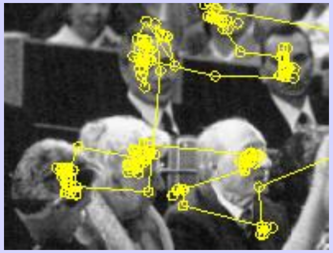
- How long does the response of a neuron depends on a stimulus?

Stimulus *driven* Vs. Stimulus *triggered*



Vs.





(Reinagel)

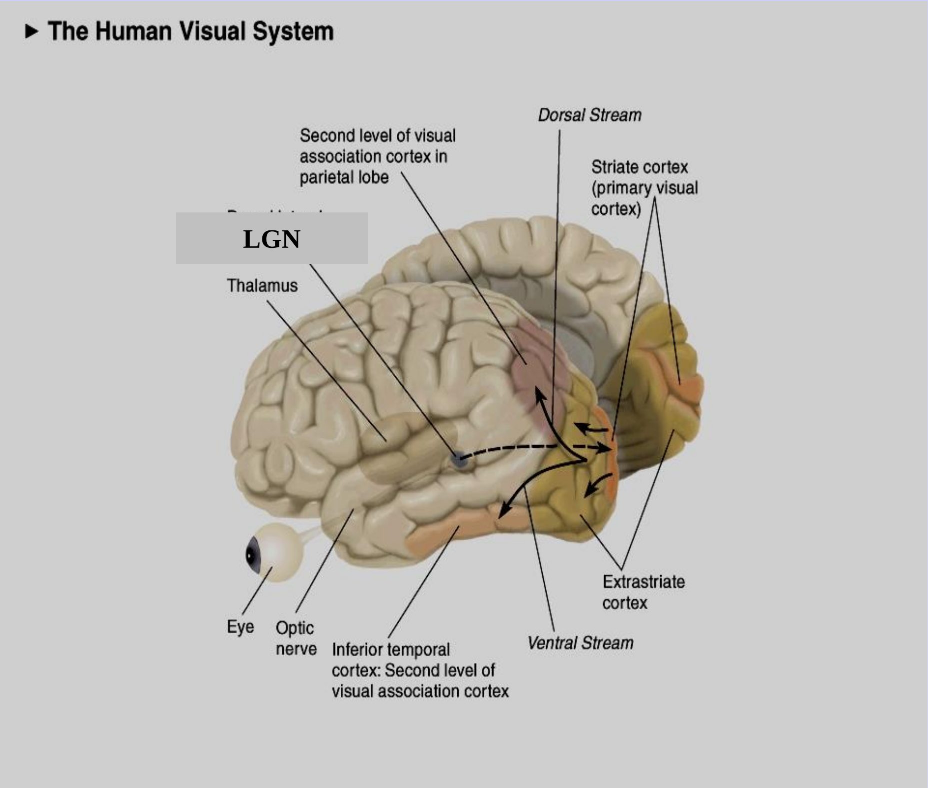
Simple? Complex?

Stimulus Driven Activity: Vision

- What visual stimulus makes a neuron fire?
- How reproducible (reliable) is the response?

Receptive Field

Neuron in cat LGN (Reinagel, UCSD)

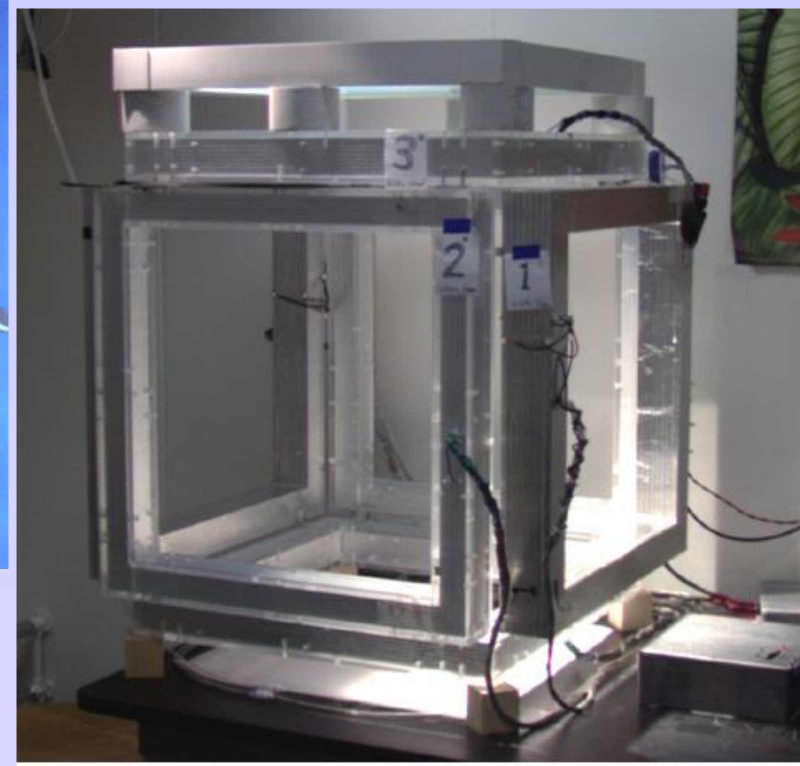


Problem: is it really what the cat would ‘see’ !?

Stimulus Driven Activity: H1

- H1: Motion sensitive neuron of the blowfly: Procedure

  Record flight → infer what fly sees → record from a fly watching movie



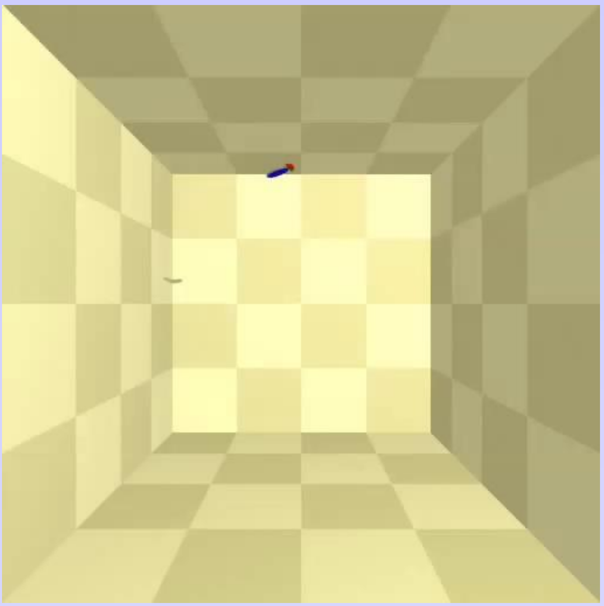
3 pairs of field coils (of approximately 45 cm diameter), producing magnetic fields at 50, 68, and 86 kHz. On top of the setup is a heat filter for the illumination.

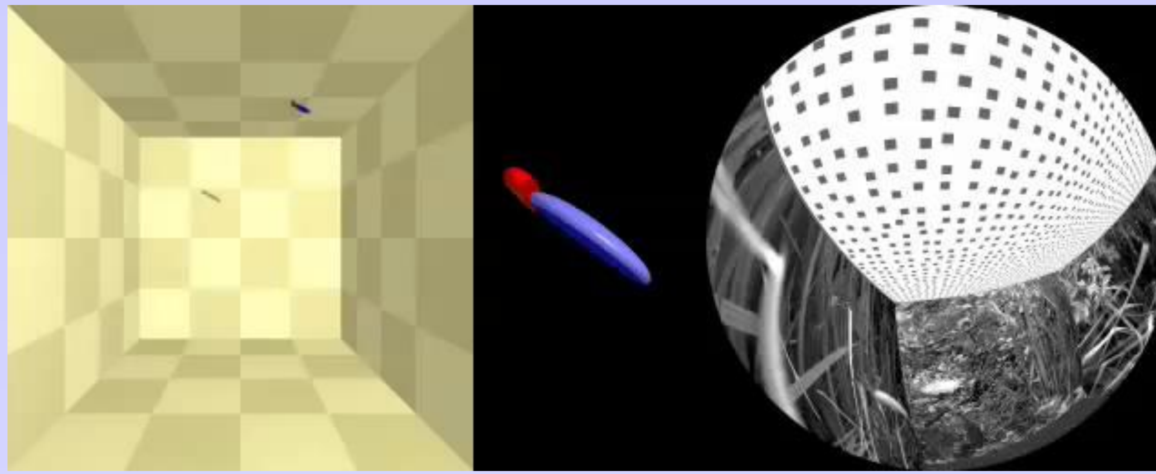
http://hlab.phys.rug.nl/demos/optic_flow/index.html

Stimulus Driven Activity: H1

H1: Motion sensitive neuron of the blowfly:

Recording flight ➔ reconstructing visual inputs





(Van Hateren)

Record + replay flight

Infer what fly 'sees'

Quasi-natural/complex stimuli…

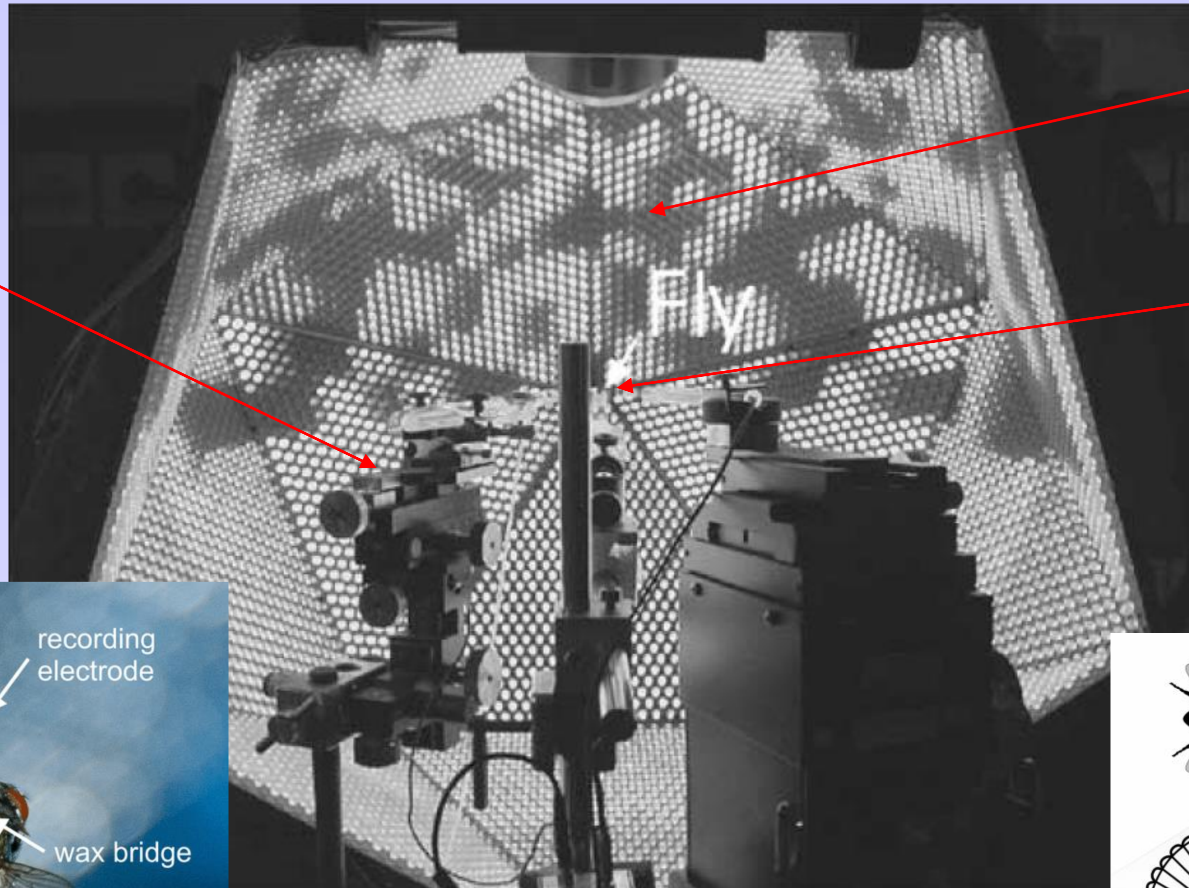
Stimulus Driven Activity: H1

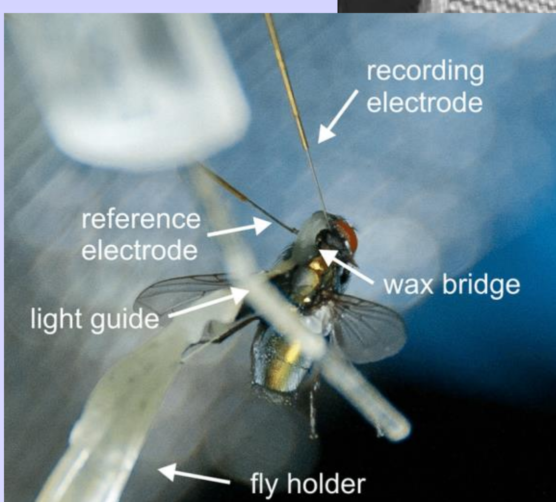
- Record from a fly watching a (simple) movie: Apparatus

Micromanipulator

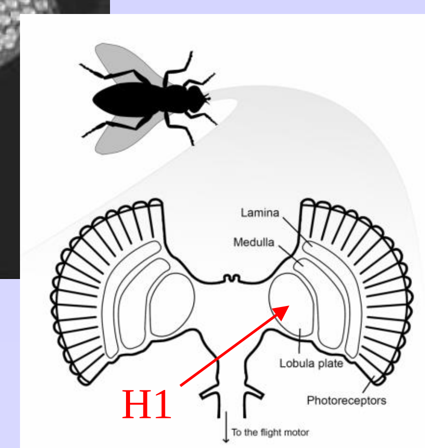
‘screen’

The fly



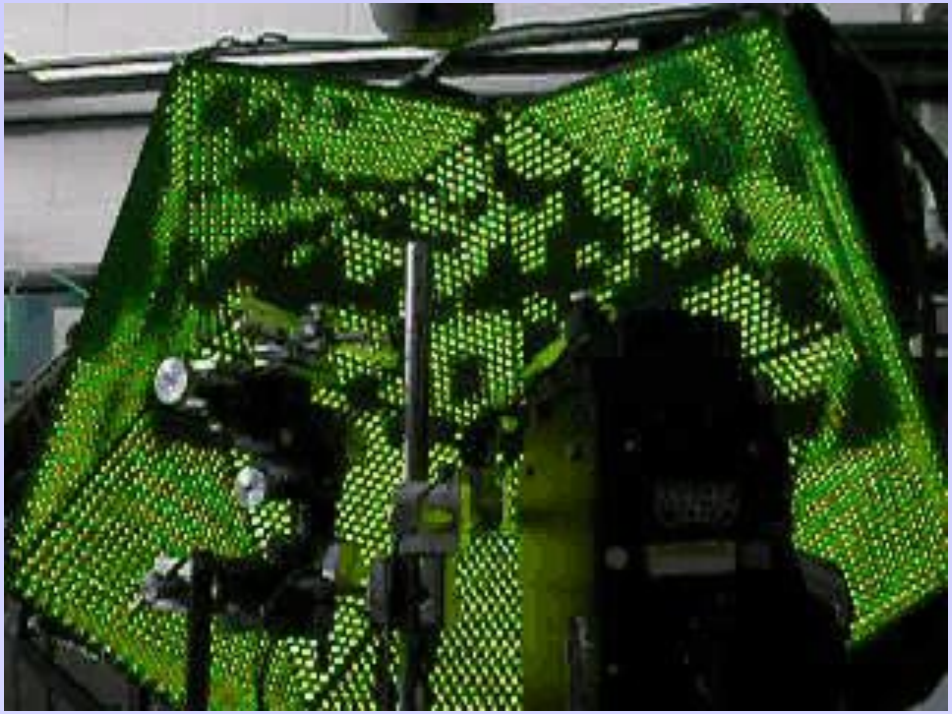


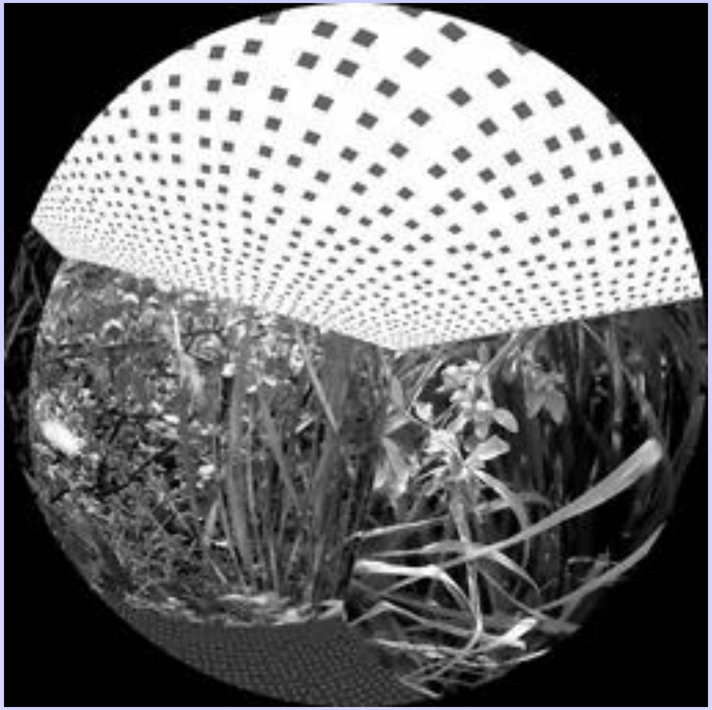
(Lindemann et al, 2003)



Stimulus Driven Activity: H1

Recording from a fly watching a movie: The data



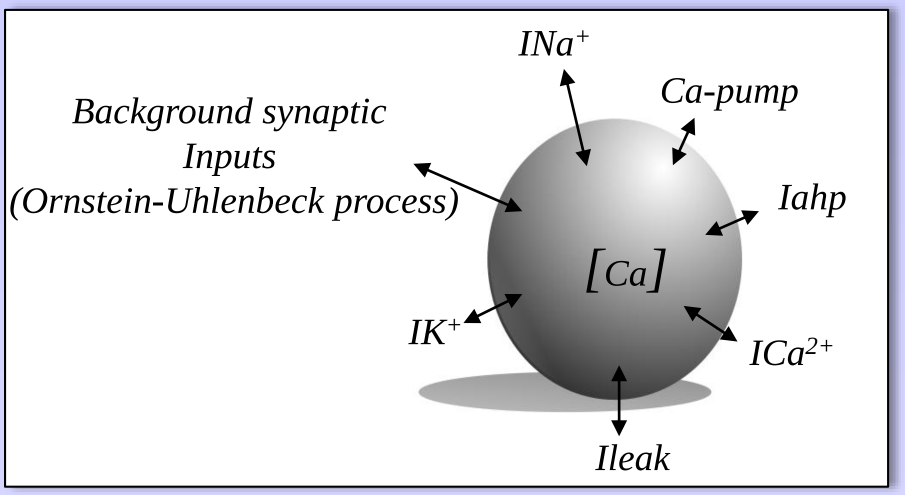


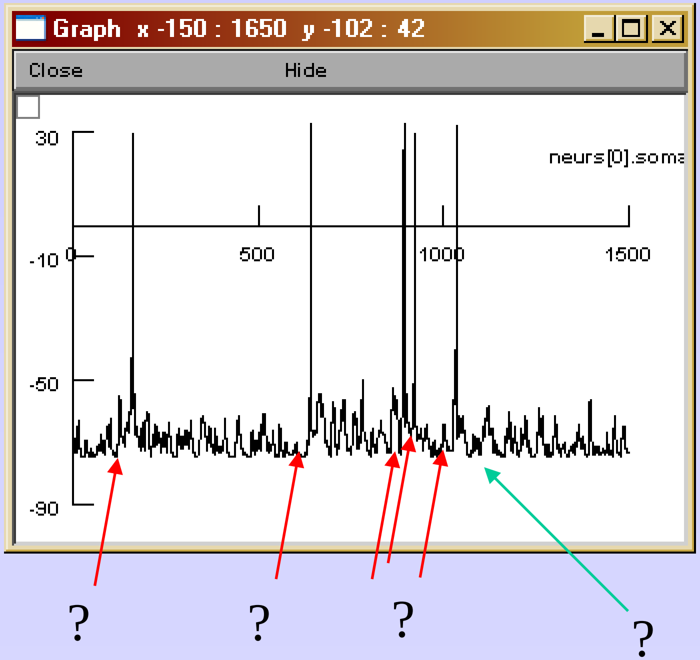
2 H1 neurons (left + right speakers)

… more soon….see Homework 3…

Stimulus Driven Activity: Spike Triggered Average

- The 'spike' as a stimulus….
- Is there anything in the membrane potential that 'predicts' or 'follows' a spike. I.e. is a spontaneous spike 'truly' a random occurrence?



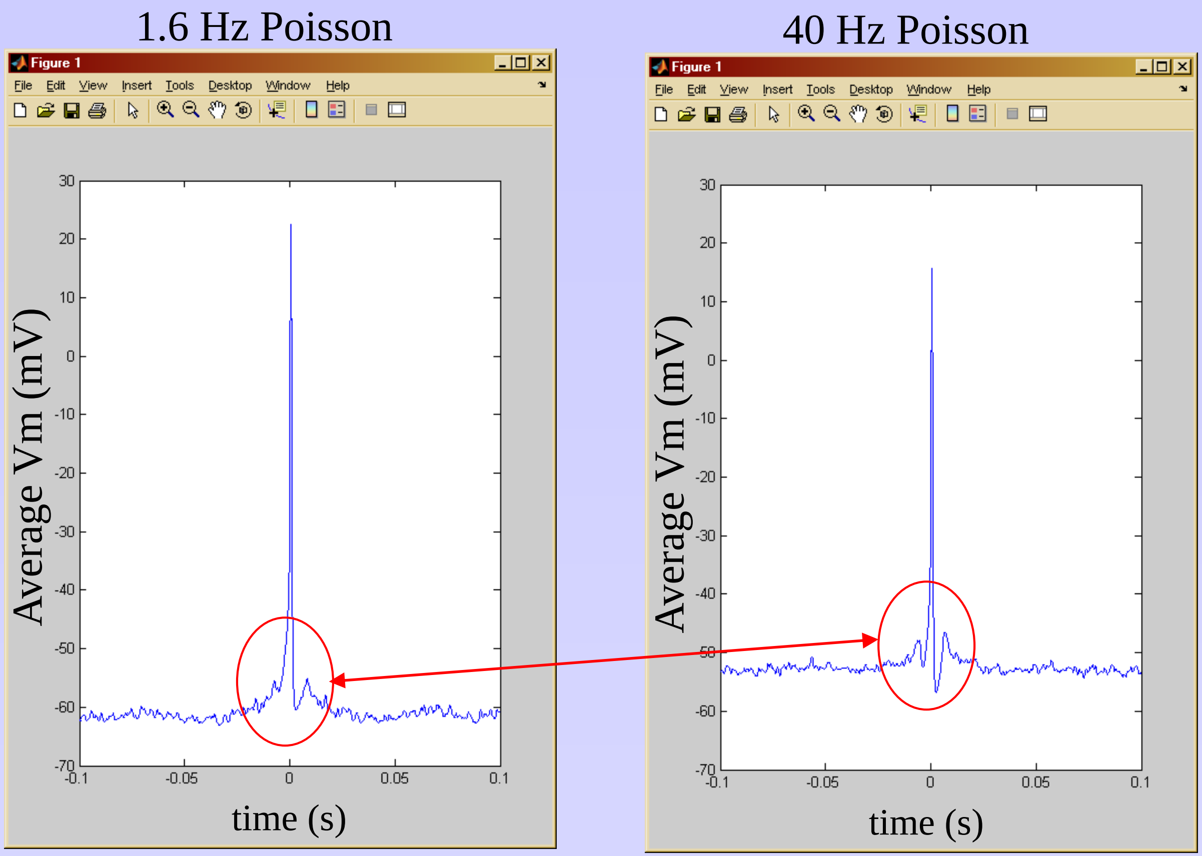


Complex dynamical system…
Cannot be solved analytically…

➔ Spike triggered average of the membrane potential

Stimulus Driven Activity: **S**pike **T**riggered **A**verage

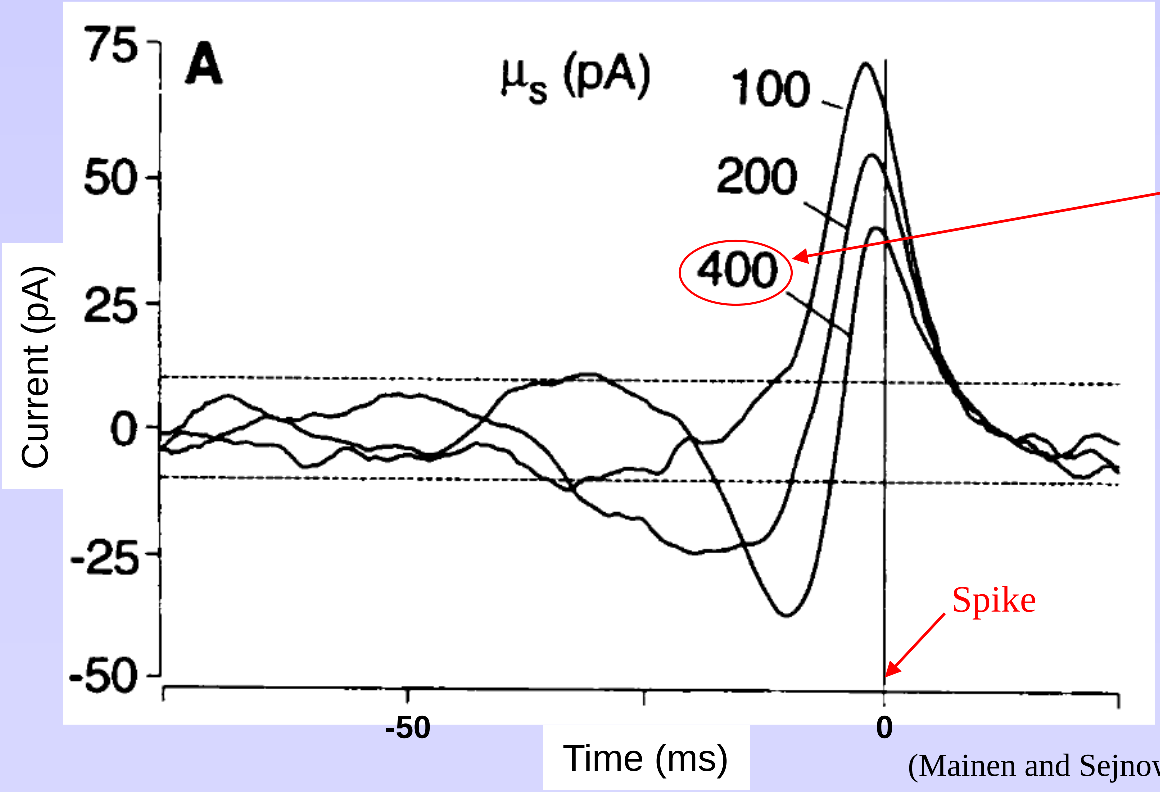
e.g. 100 ms window, Simple neuron model, spontaneous activity



- STA= Average of the membrane potential around each spike (‘context’)
- Assumptions: all spikes are the ‘same’ -- there is only one type of ‘context’

Spike triggered average: In vitro

- In *vitro*
- Stimulus = injected current (random waveform)
- Spike triggered average of the injected current



Best (most reliable) way to fire a cell

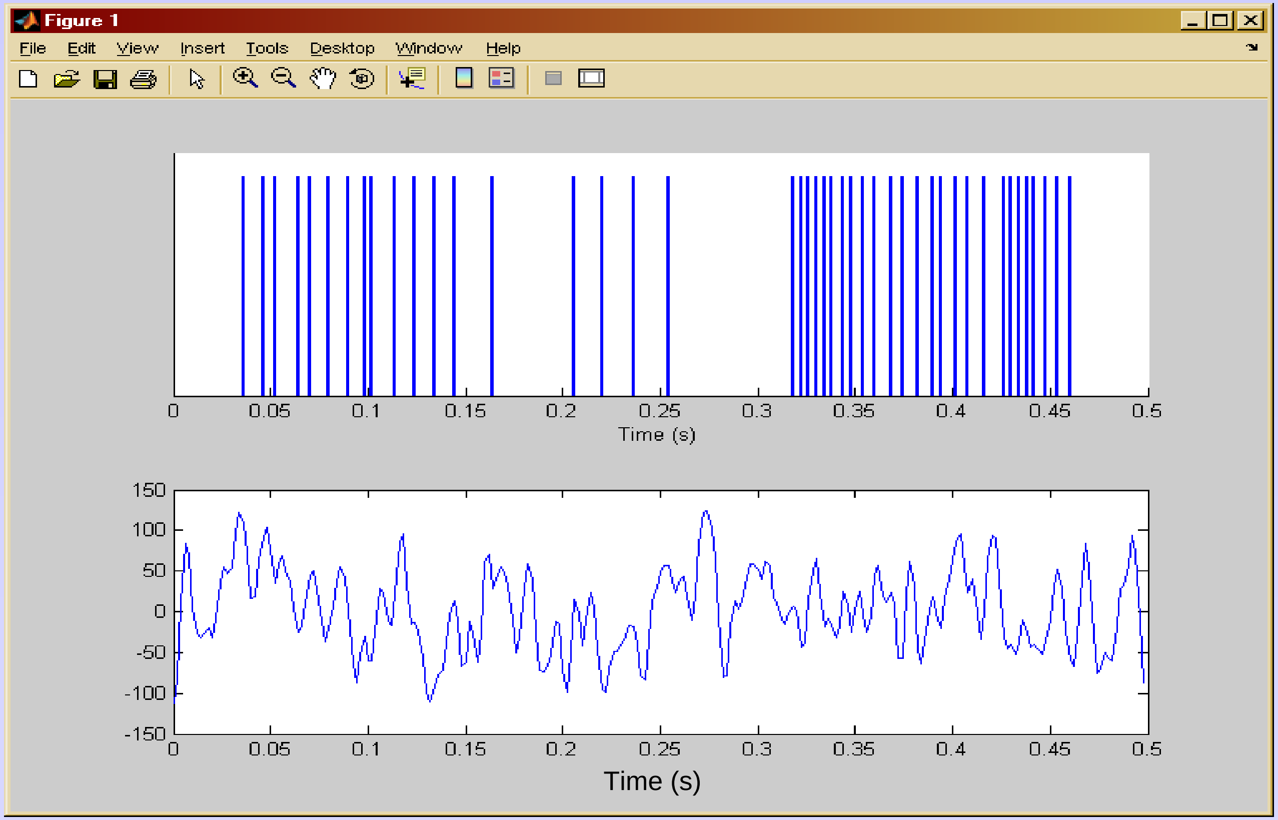
(Mainen and Sejnowski, 1995)

➔ The best way to fire a cell (*in vitro*) is to inhibit it first!

Stimulus Driven Activity: Spike Triggered Average

- Is there anything in the stimulus that 'predicts' or 'follows' a spike
- Stimulus = visual inputs/patterns

White noise visual stimulus (random horizontal velocities)

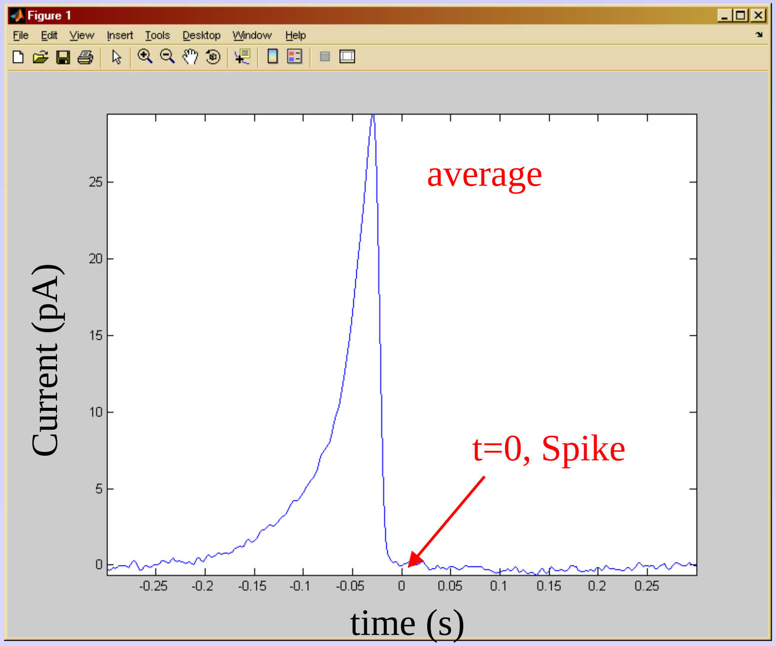


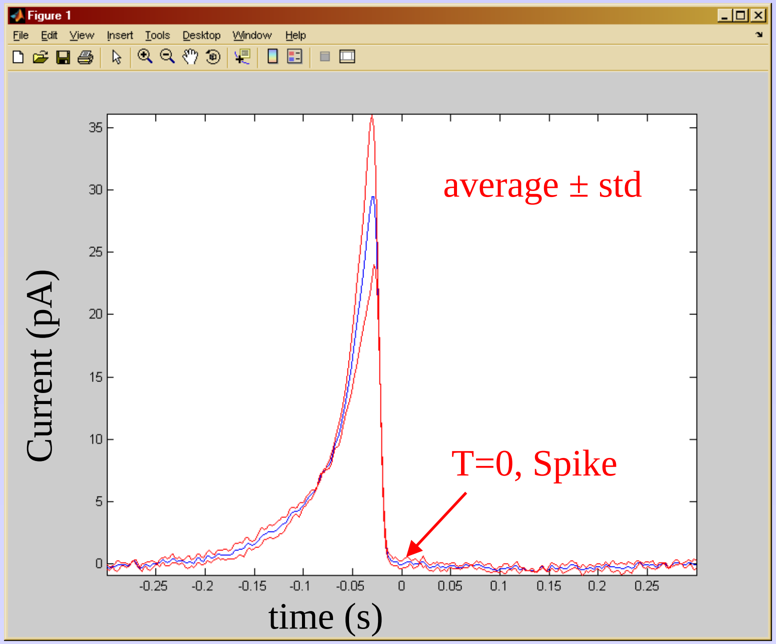
(R de Ruyter van Steveninck)

➔ Spike triggered average of stimulus – a.k.a 'Reverse correlation'

Stimulus Driven Activity: Spike Triggered Average

- H1 Spike triggered (stimulus) average: ± 300 ms time window.
- Stimulus = **white visual noise movement**

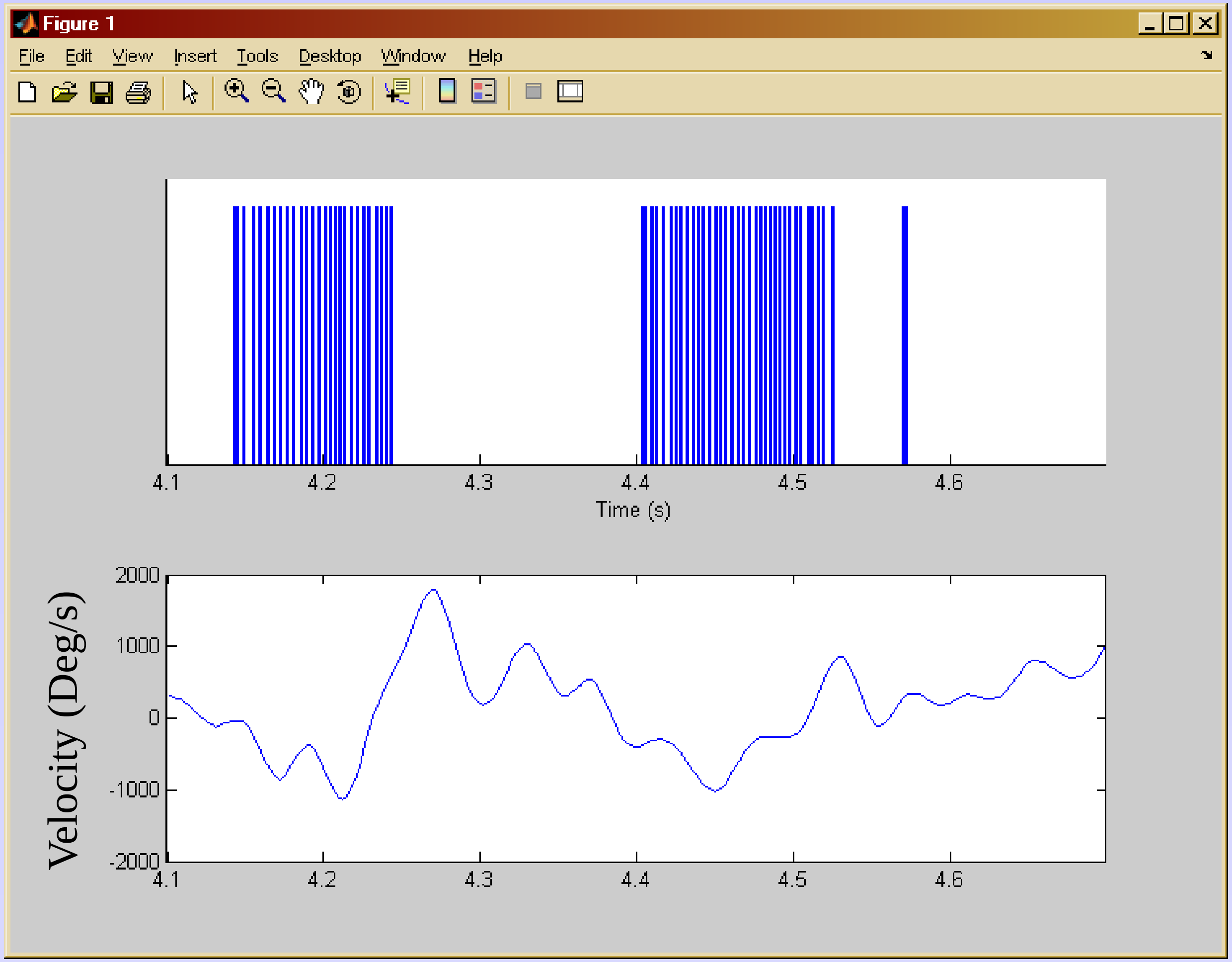


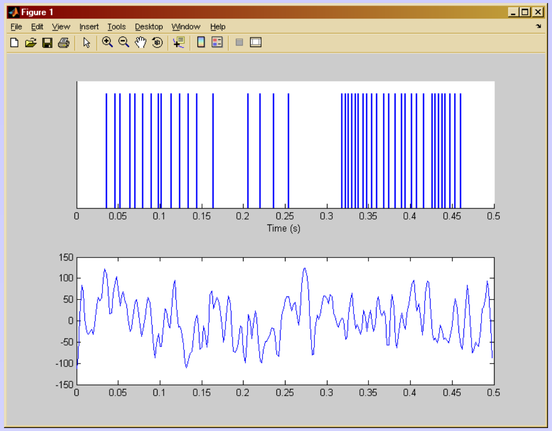


Is this significant?

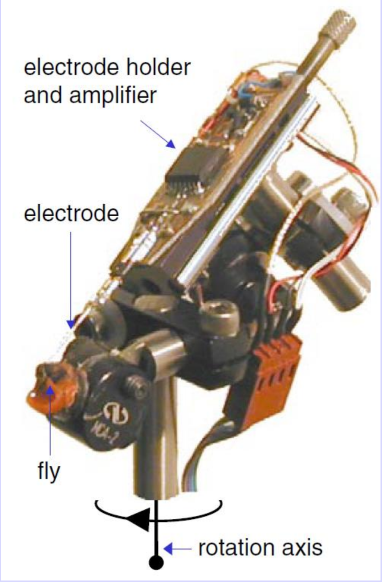
Stimulus Driven Activity: Spike Triggered Average

- Reconstructed visual stimulus: Natural horizontal velocities. Outdoor extracellular recordings





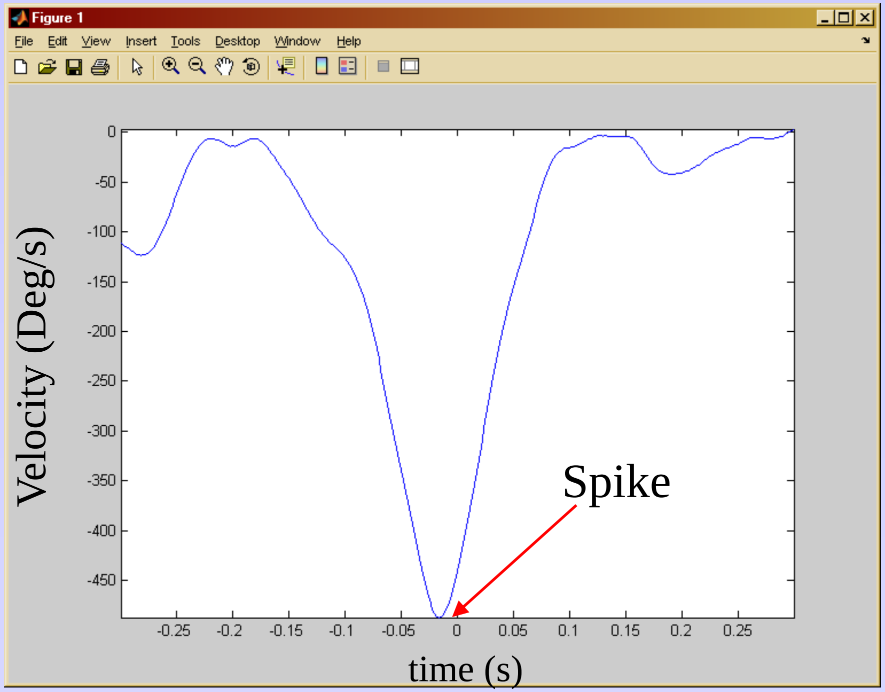
Reminder: white noise

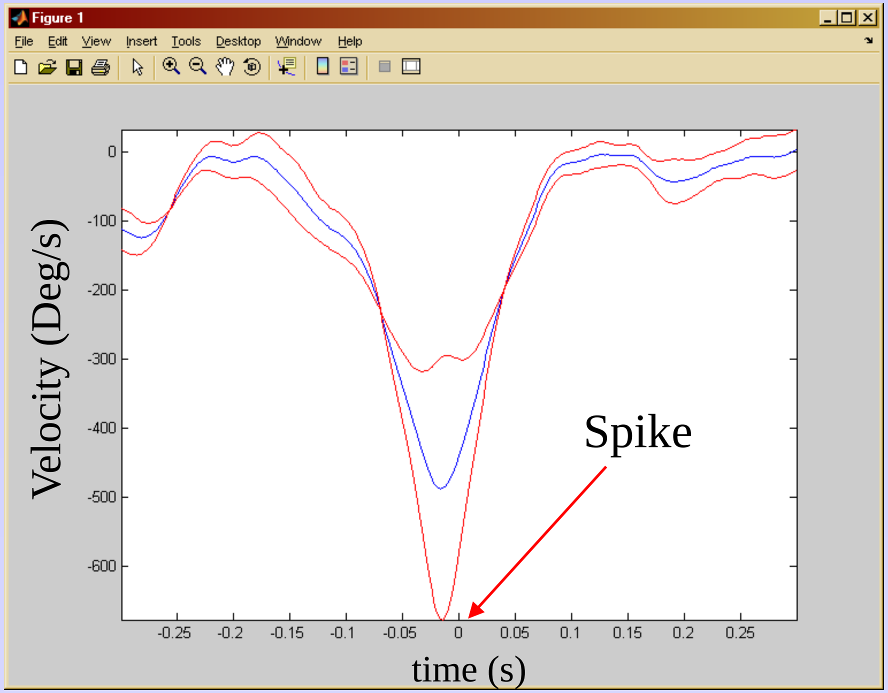


(R de Ruyter van Steveninck; Lewen et al. 2001)

Stimulus Driven Activity: Spike Triggered Average

- Spike triggered (stimulus) average: 300 ms time window. Visual stimulus.



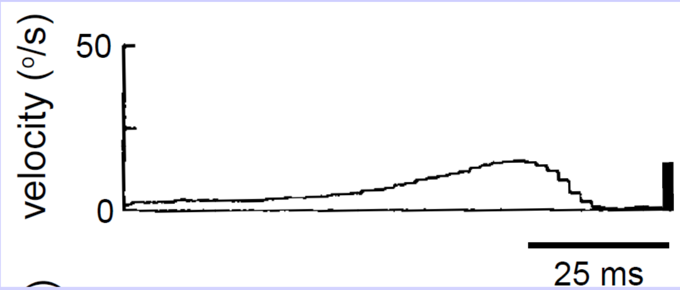


- Note: Confidence interval: ± standard deviation at each point in the waveform

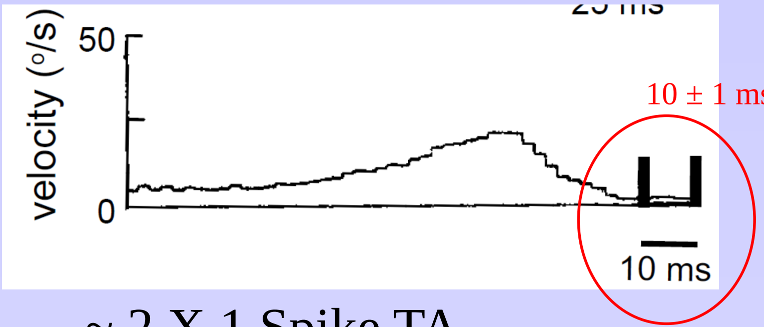
Multi-Spike Triggered Average

- Can N (>1) spikes tell you more about which part of the stimulus is 'important'?
- H1 neuron in the fly (velocity triggered neuron)

Spike-triggered (t=0) stimulus average

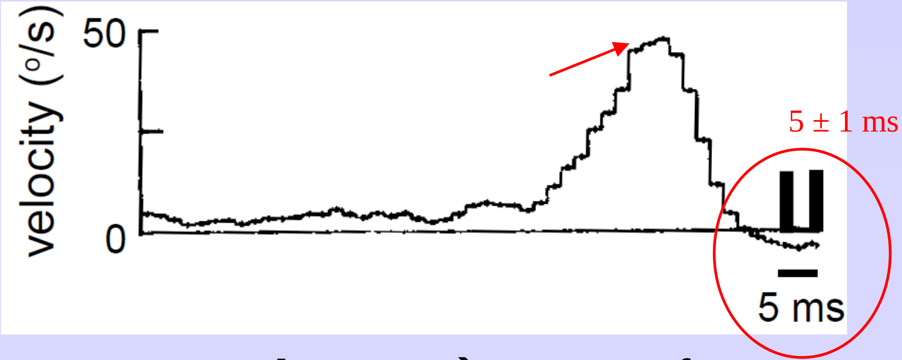


Doublet-triggered stimulus average



~ 2 X 1 Spike TA.
→No extra information with
2 spikes 10ms apart

Burst-triggered stimulus average



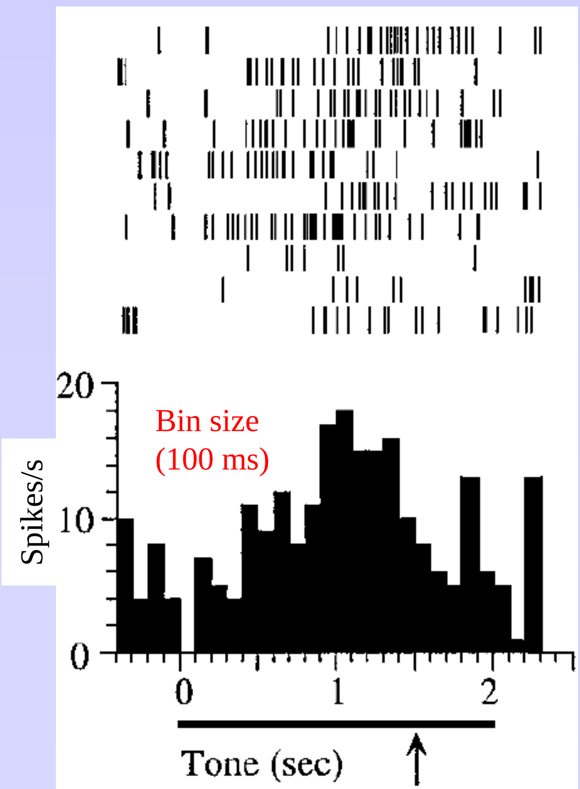
> 2 X 1 Spike TA! → Extra information

(Rieke et al, 1997; Dayan and Abbot 2003, Fig 1.10)

PeriStimulus Time Histogram

- Analyze the firing of a neuron when driven/stimulated at a specific time.
- Peri-Stimulus Time Histogram. ‘Peristimulus’ = ‘around stimulus’
  ➔ Need: time ‘zero’, multiple trials and a bin size.

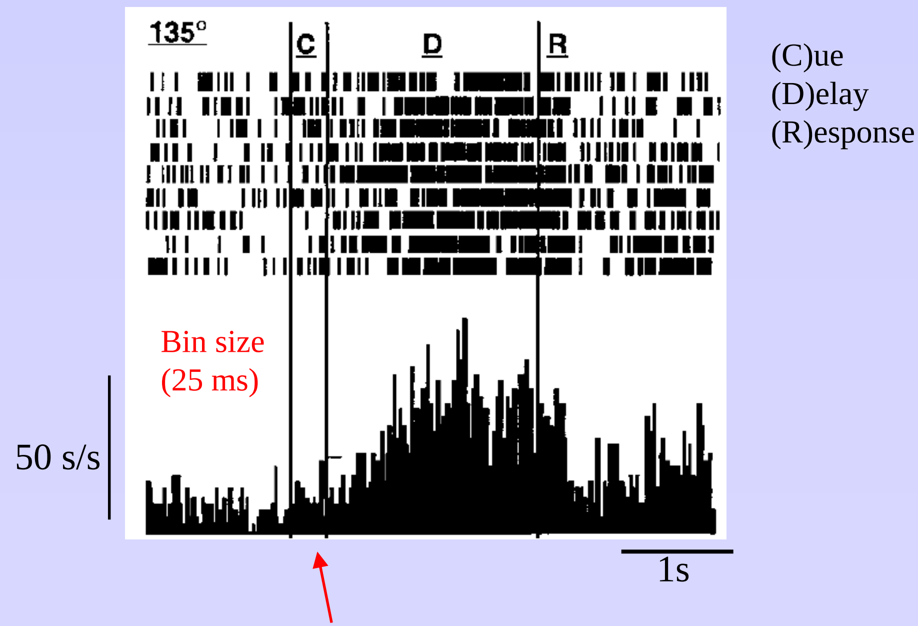
Stimulus ‘driven’



Stimulus drives the response

V.s.

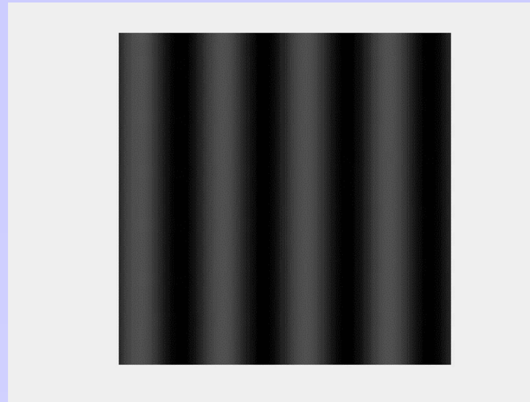
Stimulus ‘triggered’



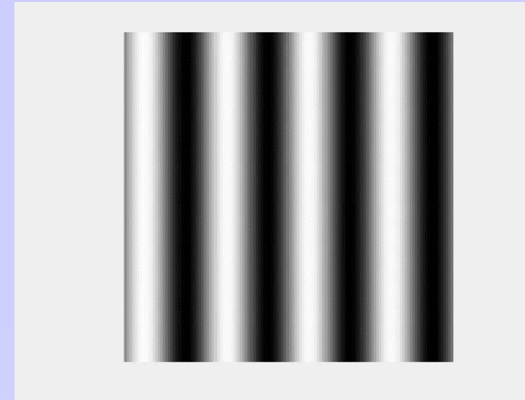
Stimulus (Cue=C) triggers the (delayed=D) response

PeriStimulus Time Histogram

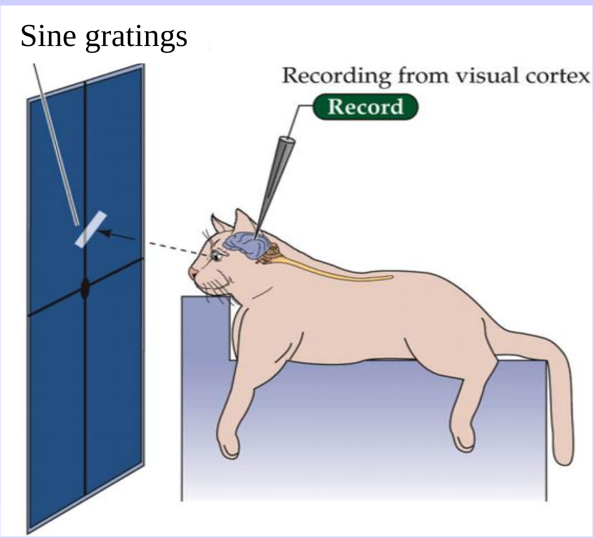
Need a large number of 'trials'
→ Repeat the stimulus

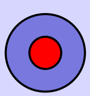


32% contrast

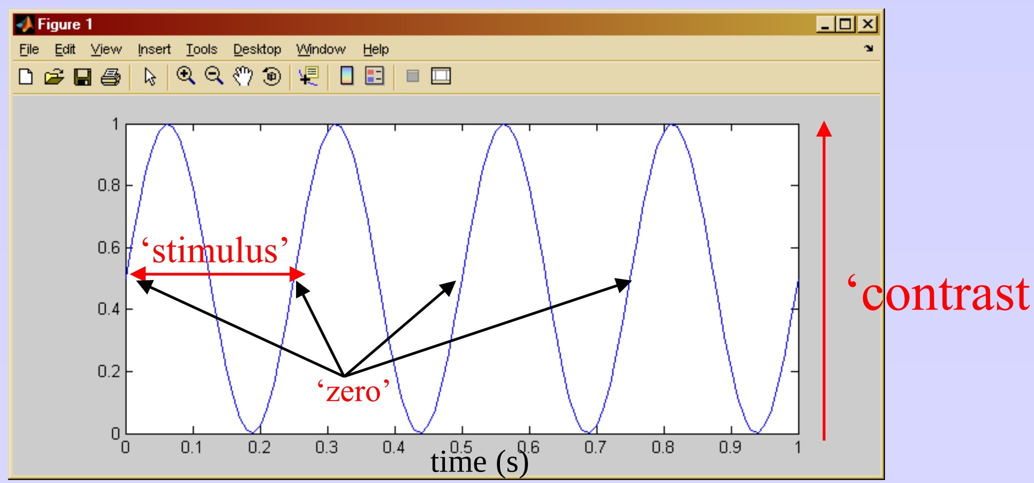


100% contrast





LGN/RGC
Receptive fields

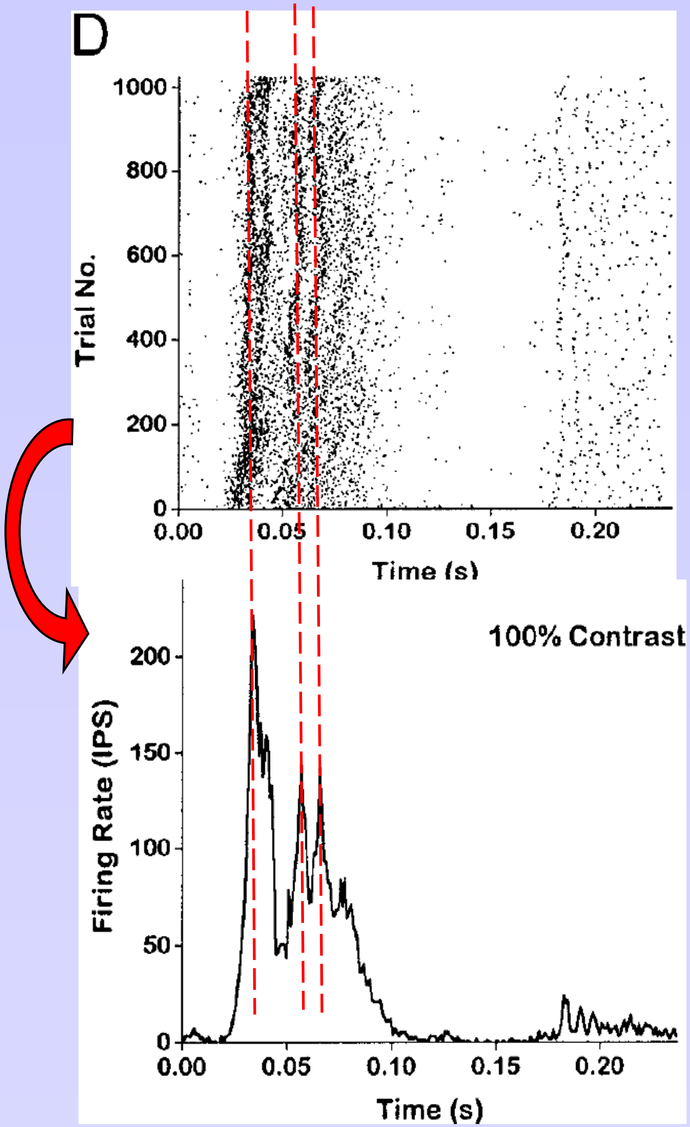


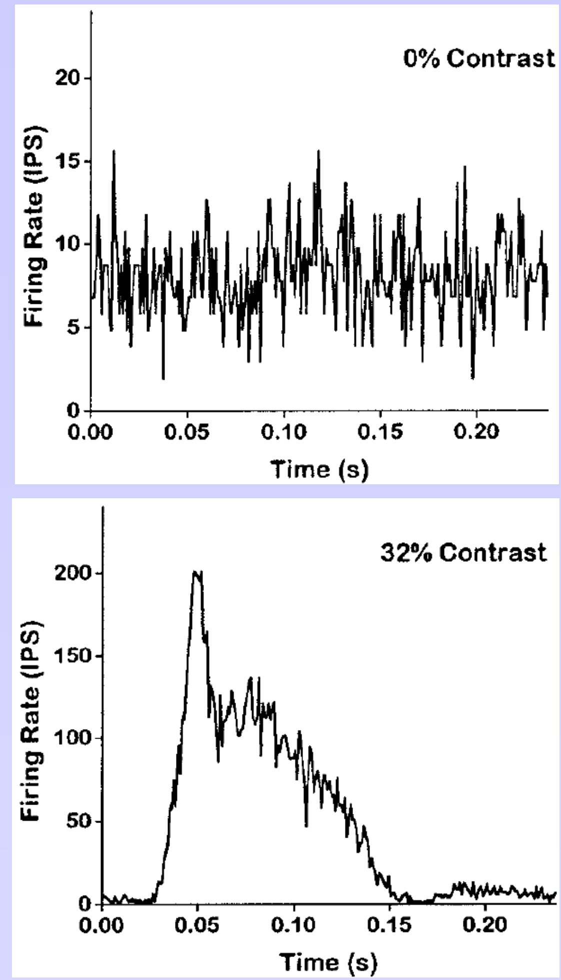
4 Hz → 250 ms stimulus length
1 cycle ↔ 1 'trial'

PeriStimulus Time Histogram

LGN On-center cell

1 ms bins



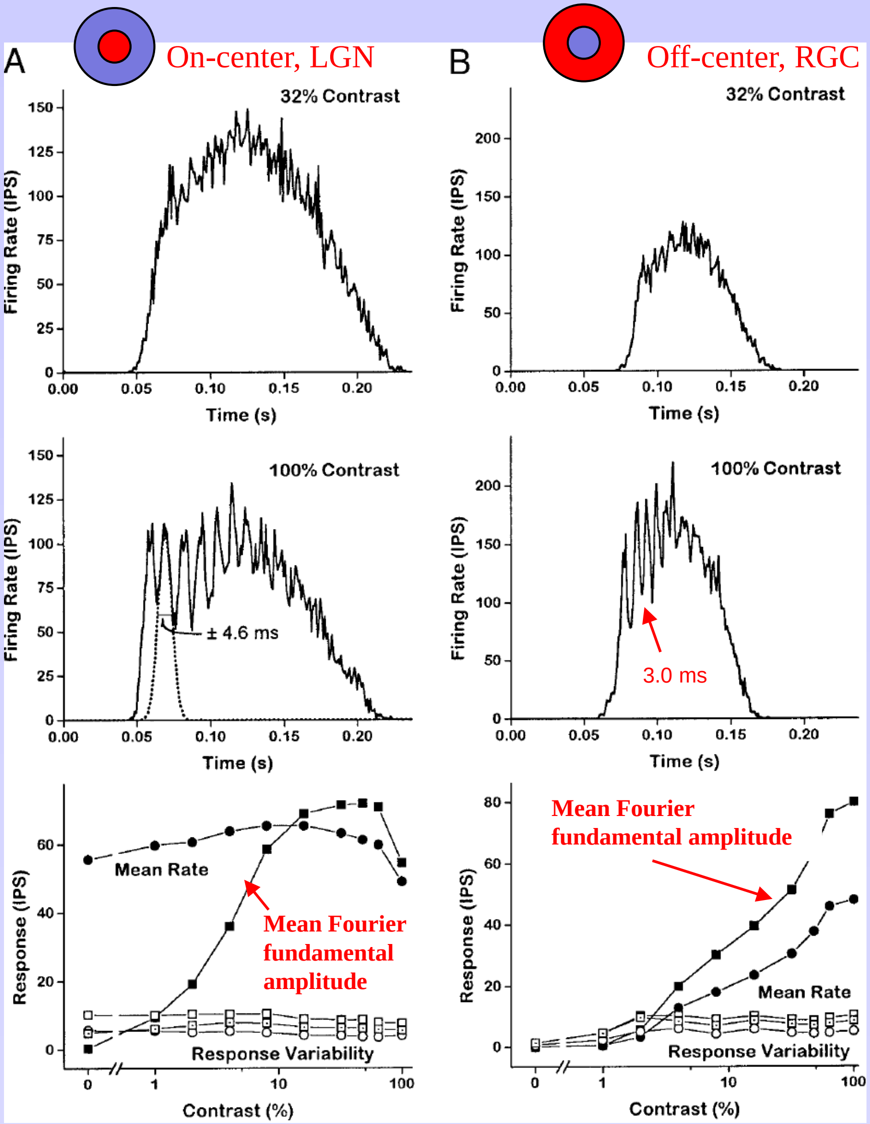


(Reich et. al. 1997)

- ‘Drift errors in PSTH estimation’ – beware of non-stationarity

PeriStimulus Time Histogram

- Same stimulus: LGN Vs Retinal Ganglion Cell. Stimulus driven PSTH.



(Reich et. al. 1997)

- Firing ‘precision’ is ~4.6 ms for On-center, ~3ms for off-center.

  See more on ‘precision’ later in the class…
- Fourier dominant frequencies of the average firing rate was ~90Hz (A), ~120 Hz (B)
- Beware of:

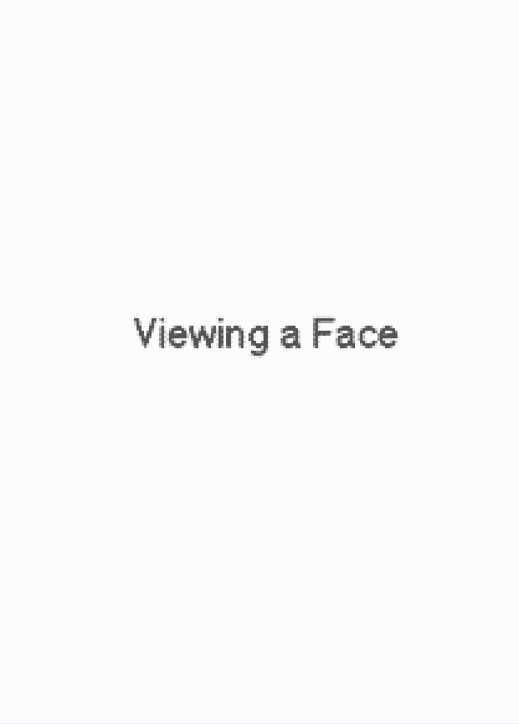
  Power spectrum peaks ←→ oscillations

  See more on this later in the class…

Fano factor/CV – Part 2

- Typical vision experiments: multiple repeated presentations of a stimulus
- Eye movements (every ~200ms) as a source of variability?

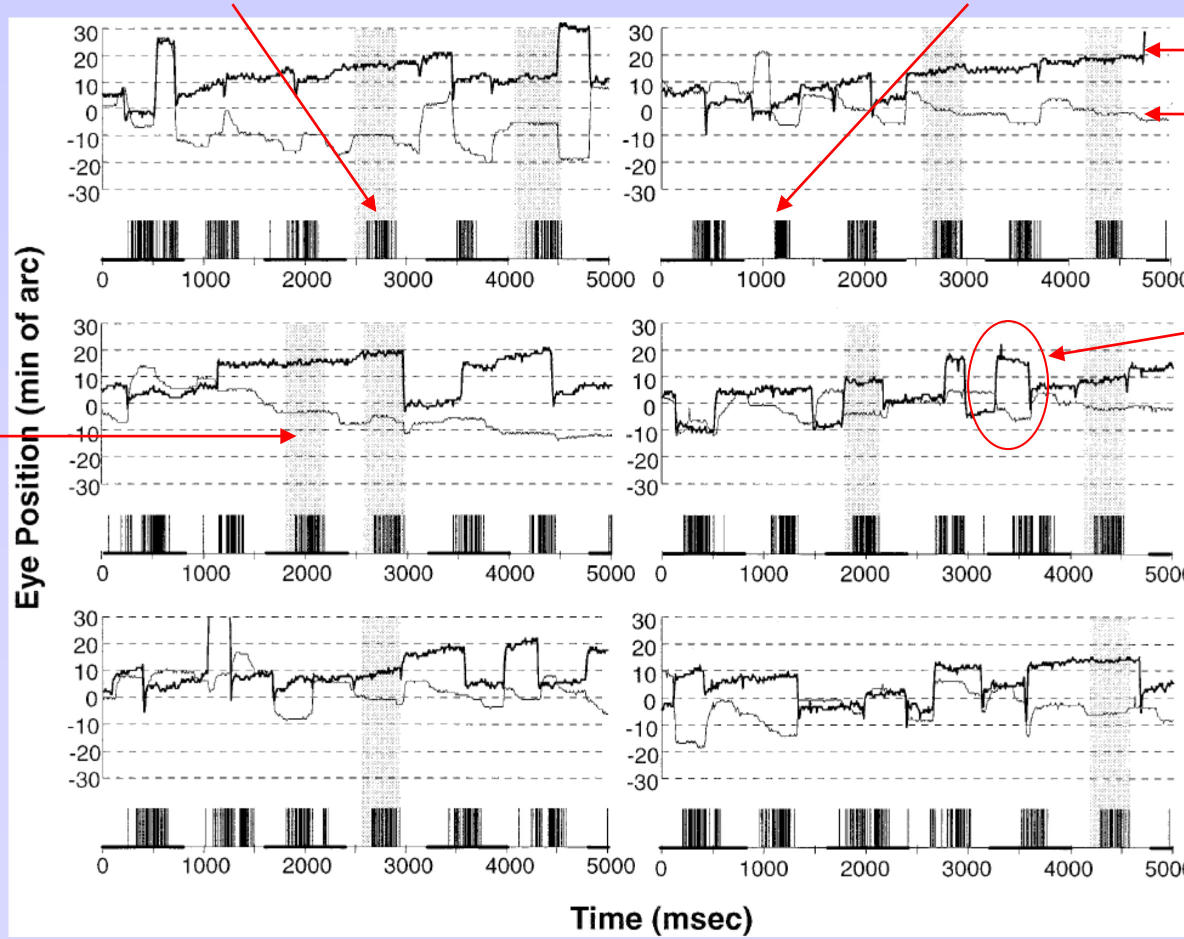
→ Understanding the cause(s) of variability



Fano factor/CV– Part 2

- 6 sweeps of a bar, recordings in monkey V1.
- What is the contribution of eye movements to neural variability?

μ=38.9 Hz, **σ²=21.2** ← Vs → μ=40.4 Hz, **σ²=189.4**



Vertical eye mvt

Horizontal eye mvt

saccade

Negligible eye movements epochs during response

(Gur et al, 1997)

Fano factor/CV– Part 2

- For single cells: Variance not *apparently* correlated with mean
  - ➔ CV decreases with mean…

Linear regression/fit

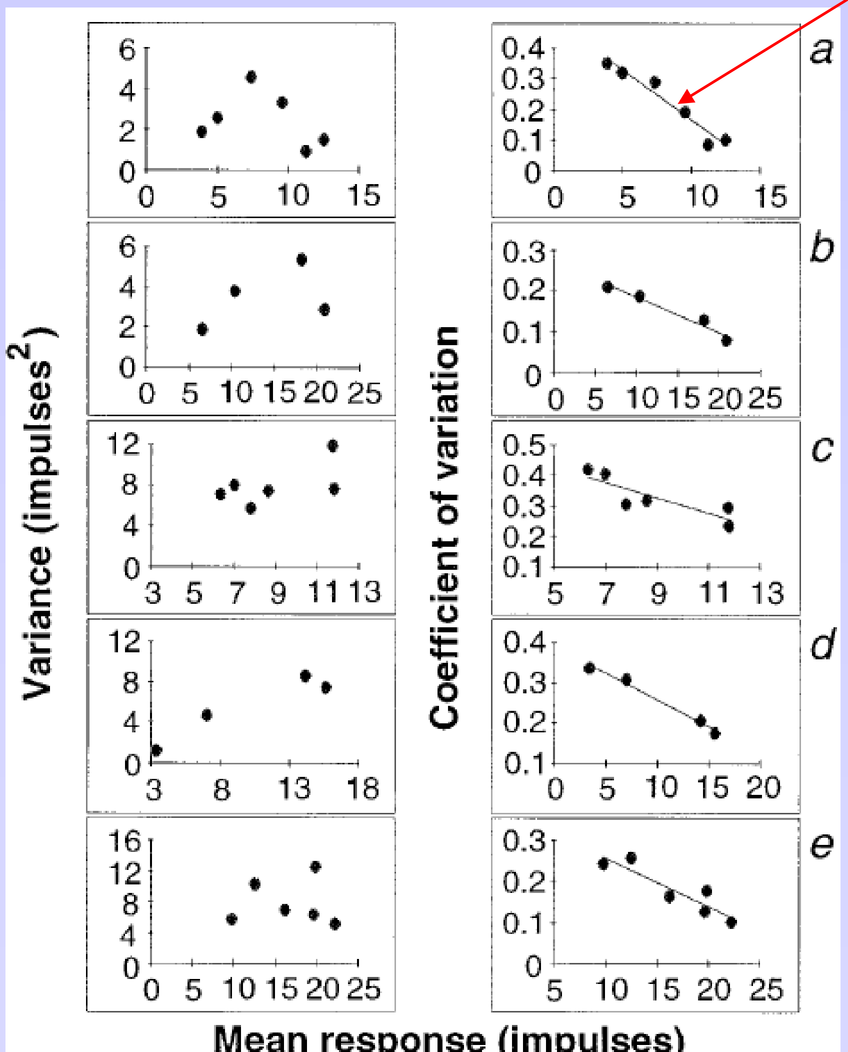
Cell 1

Cell 2

Cell 3

Cell 4

Cell 5



≠ Contrasts → ≠ Mean FR

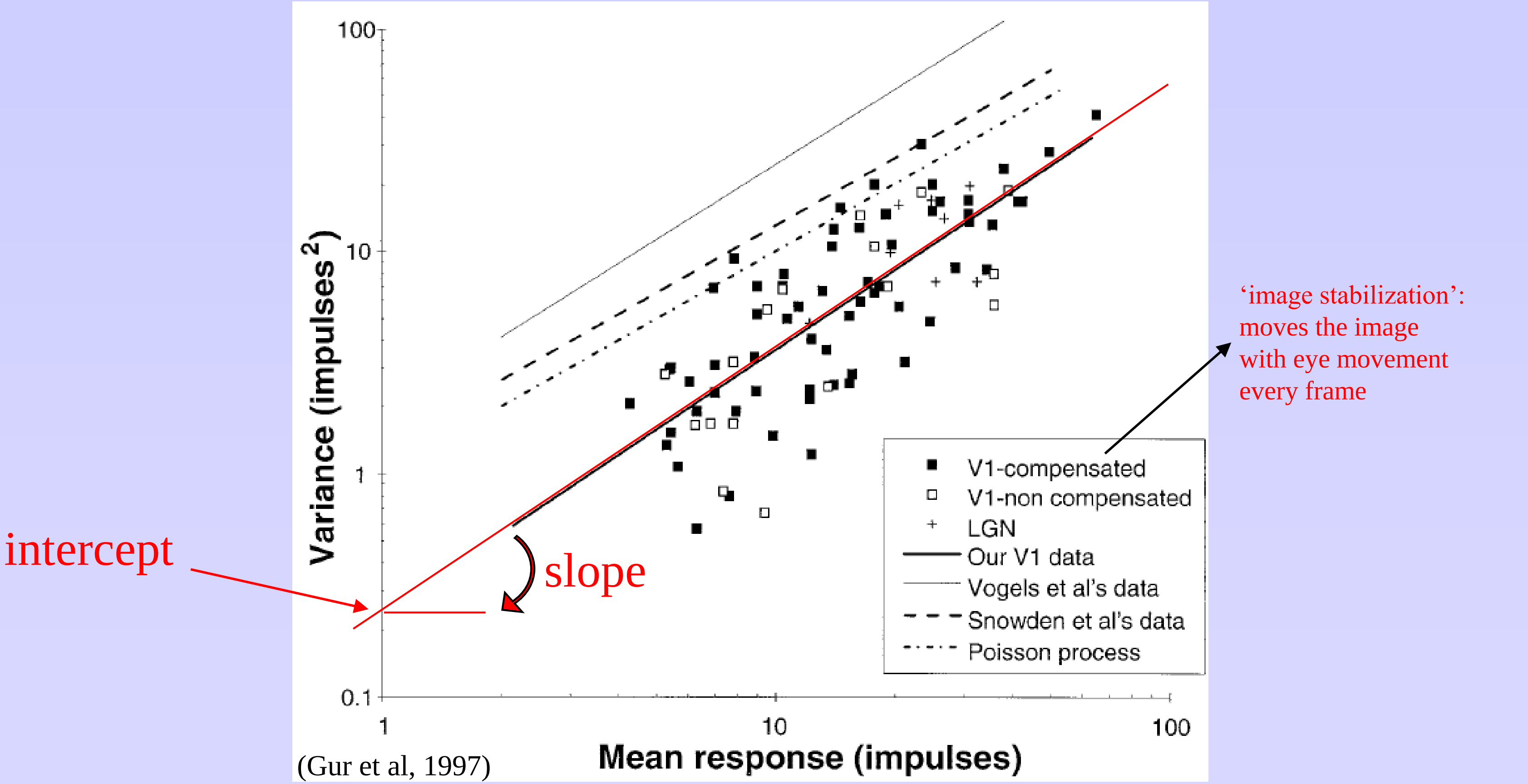
≠ Orientations → ≠ Mean FR

(Gur et al, 1997)

Regression line in log-log plot

- Population analyses (no eye movement epochs)

$$\sigma^2 = a\,\mu^b \;\Rightarrow\; \mathrm{Log}(\sigma^2) = \log(a) + b\,\log(\mu)$$

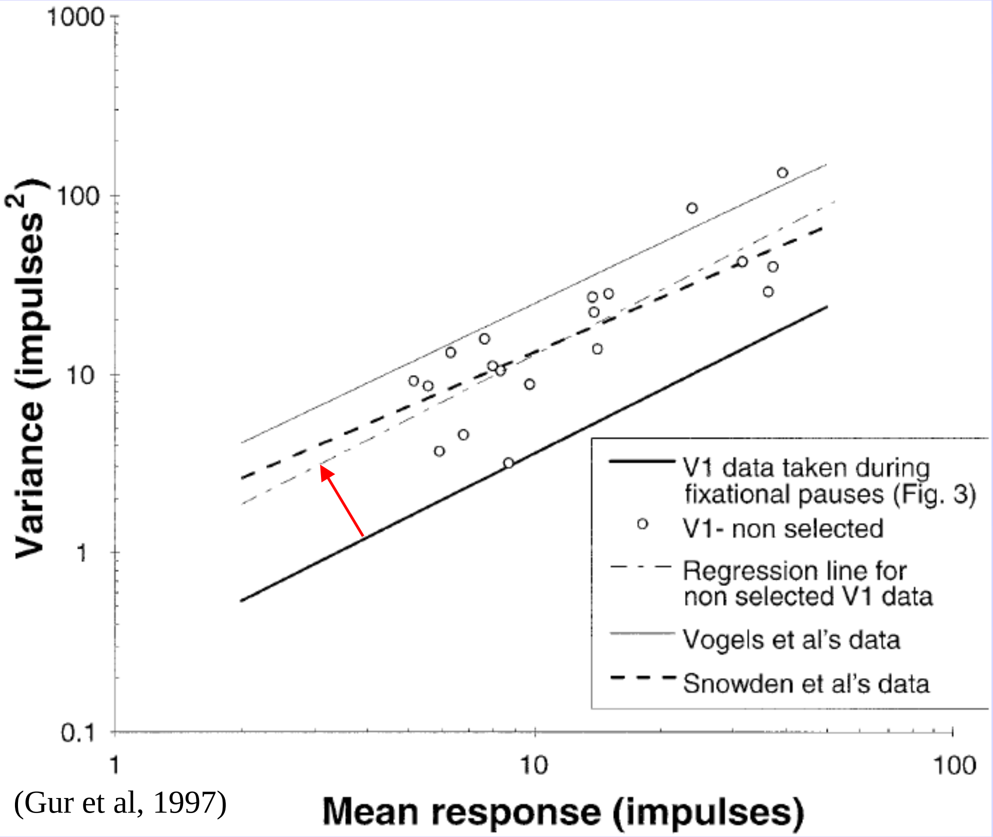


(Gur et al, 1997)

Other data: same slope… but greater intercept ➔ greater overall variance (*because* of eye movements)

Regression line

- Towards causality….. Due to eye movement?
  → Random selection of cells (irrespective of eye movements)



With eye movements: same slope… but greater intercept ➔ greater overall variance

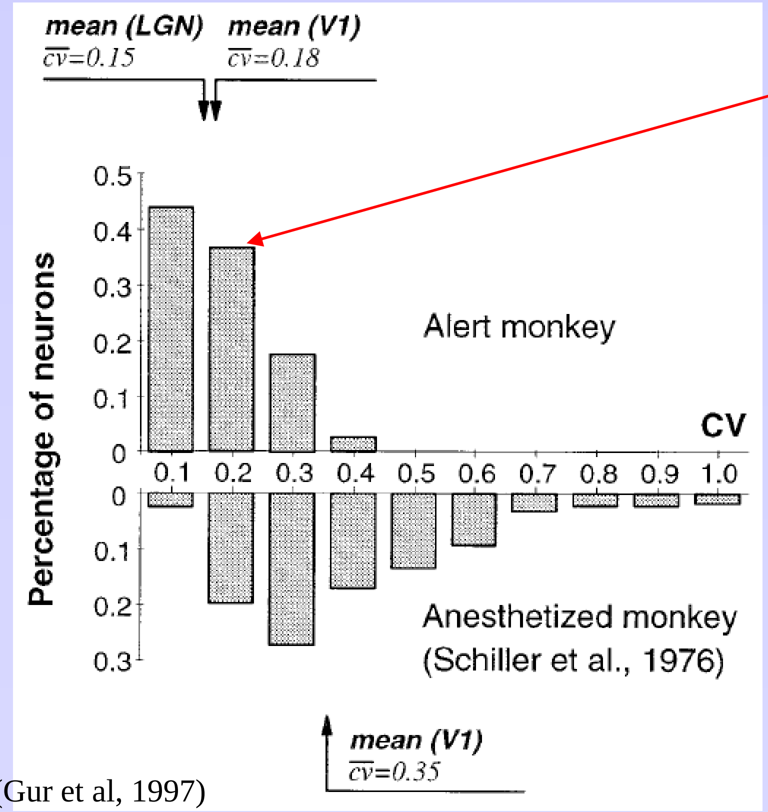
Corrected CVs

- Conclusions: V1 and LGN are much more reliable/regular than previously thought → contain/carry less information than previously thought
  → Is the goal of eye movements to increase information about the stimulus?

Good example of: Data analyses → new hypotheses

CV < 0.2

Corrected for eye movements



CV > 0.3

(Gur et al, 1997)

Good example of comparisons/advances from previous publications