

# Functional analysis of cortical activity statistics

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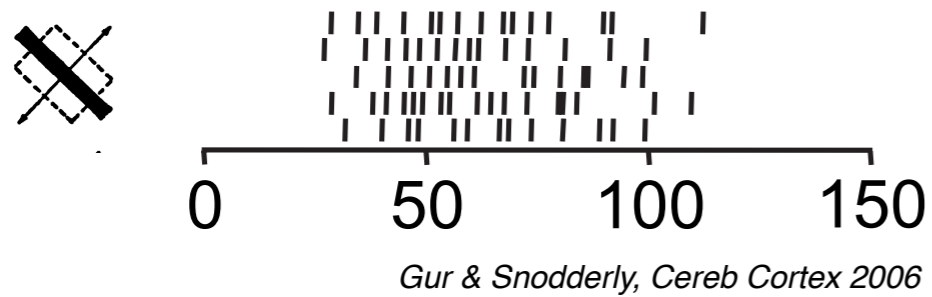
Neuroinformatics 2018.

# Computational Systems Neuroscience Lab

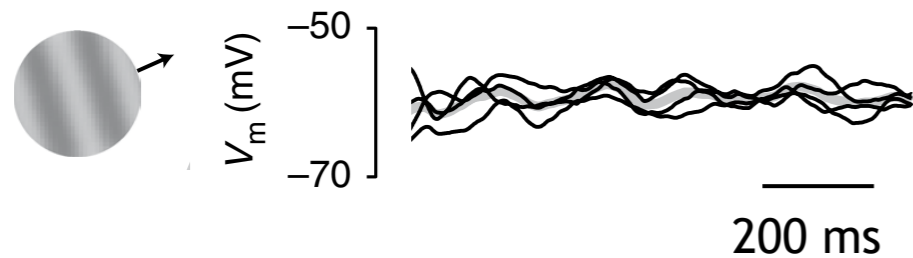
- Wigner Research Centre for Physics
- Department of Computational Sciences
- modelling of neural computations
- modelling human behaviour
- <http://golab.wigner.mta.hu/>

# Variability in the activity of neurons

## V1 spike train-variability

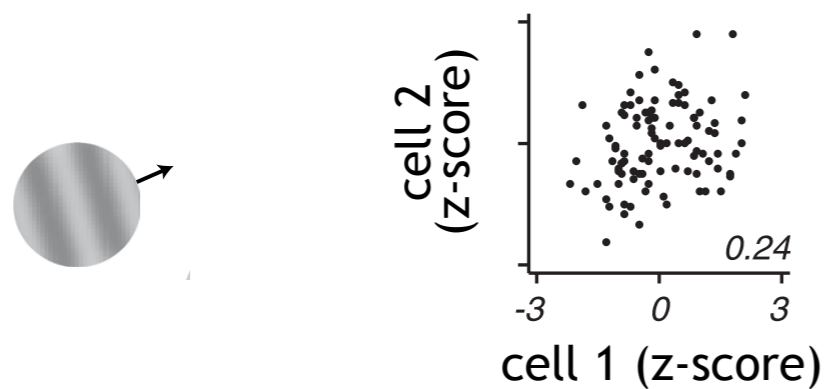


## V1 membrane potential variability



*Finn et al, Neuron 2007; Churchland et al, Nat Neurosci 2010*

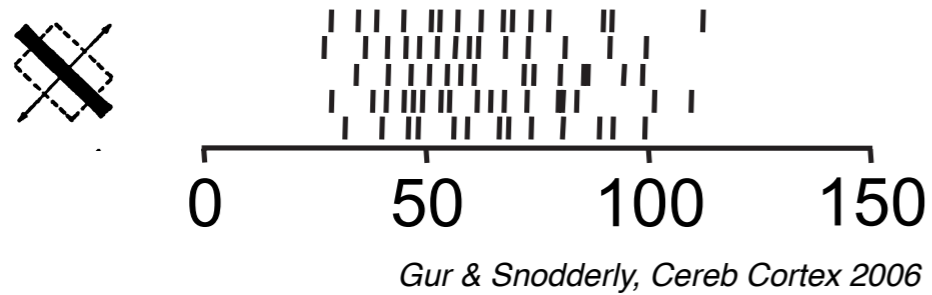
## V1 spike count covariability



*Kohn & Smith, J Neurosci 2005*

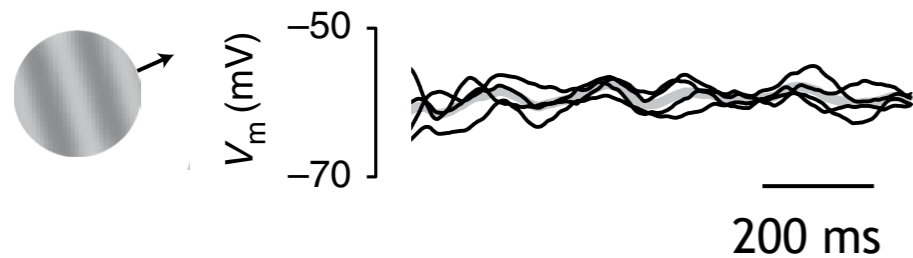
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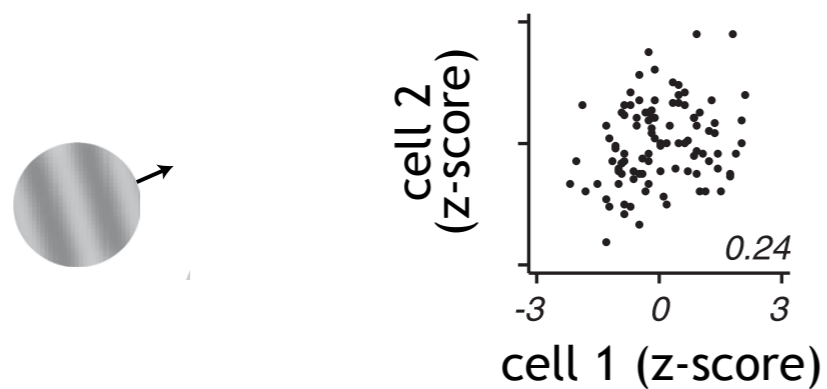
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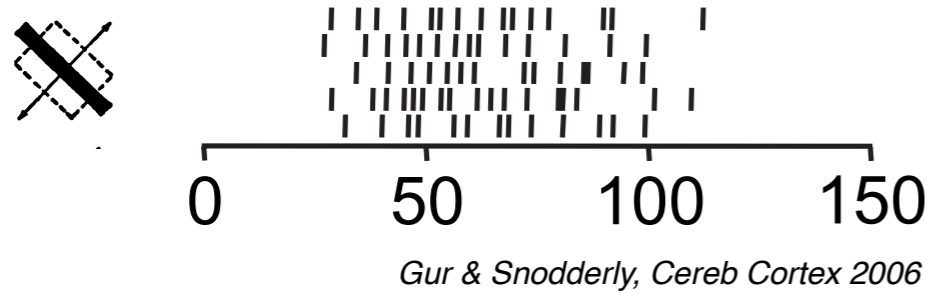


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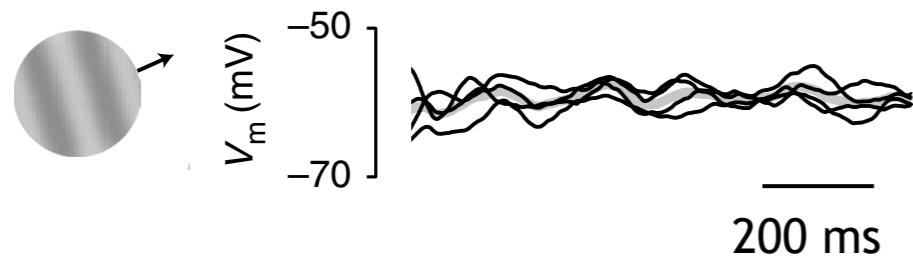
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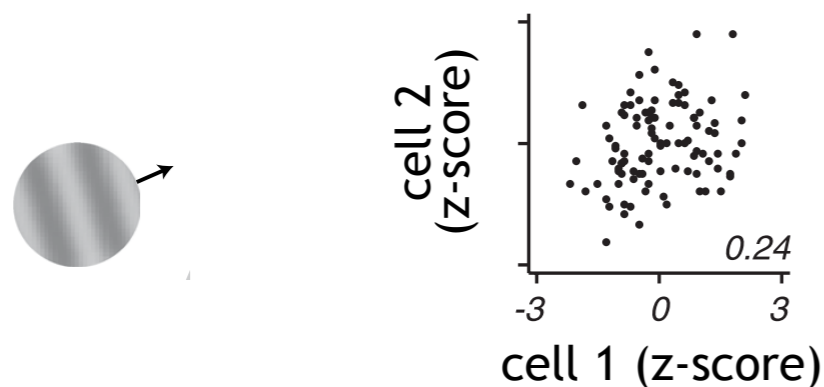
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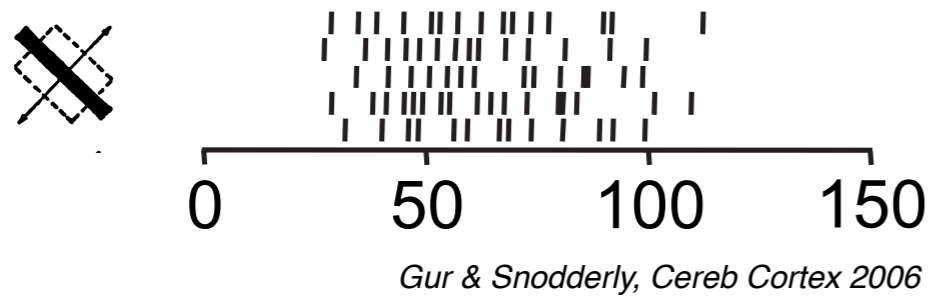
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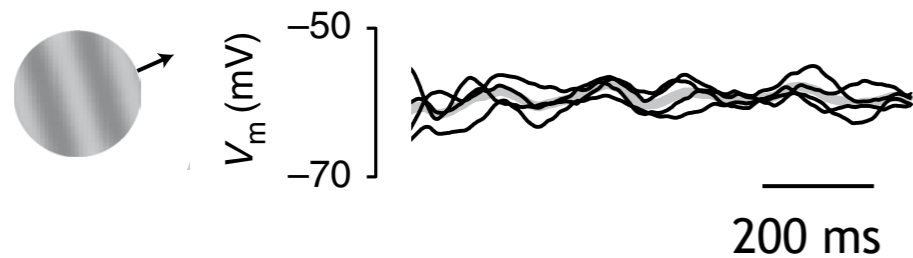
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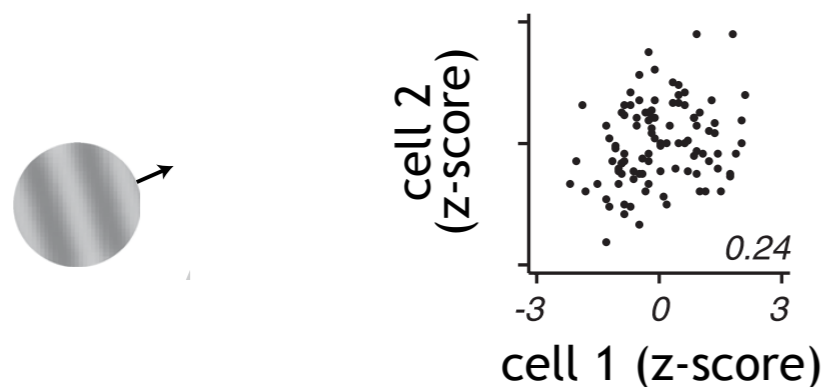
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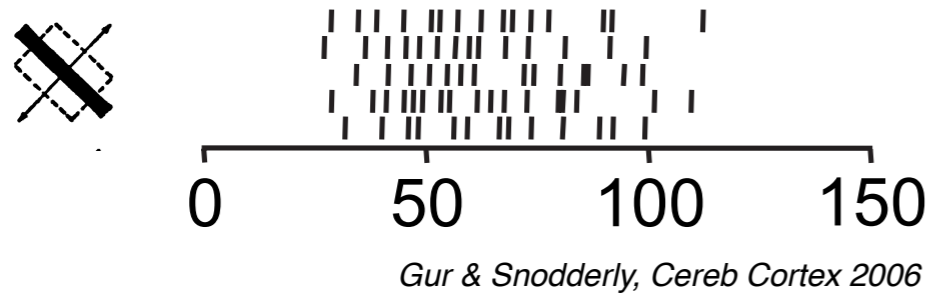
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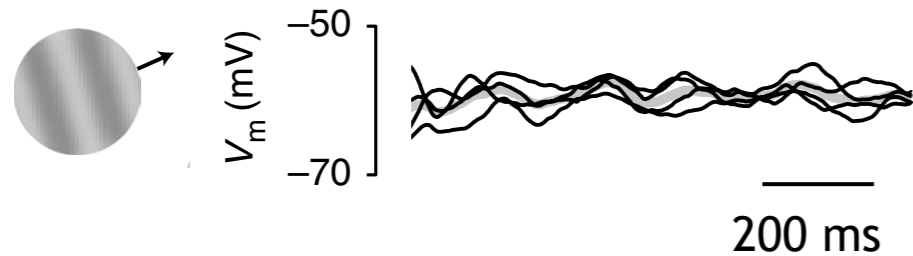
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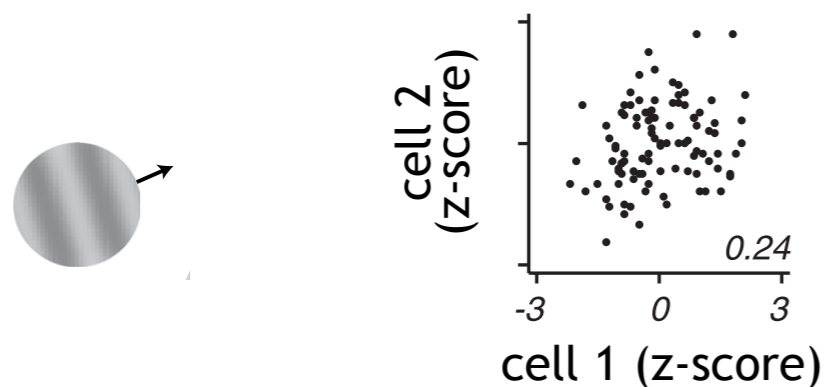
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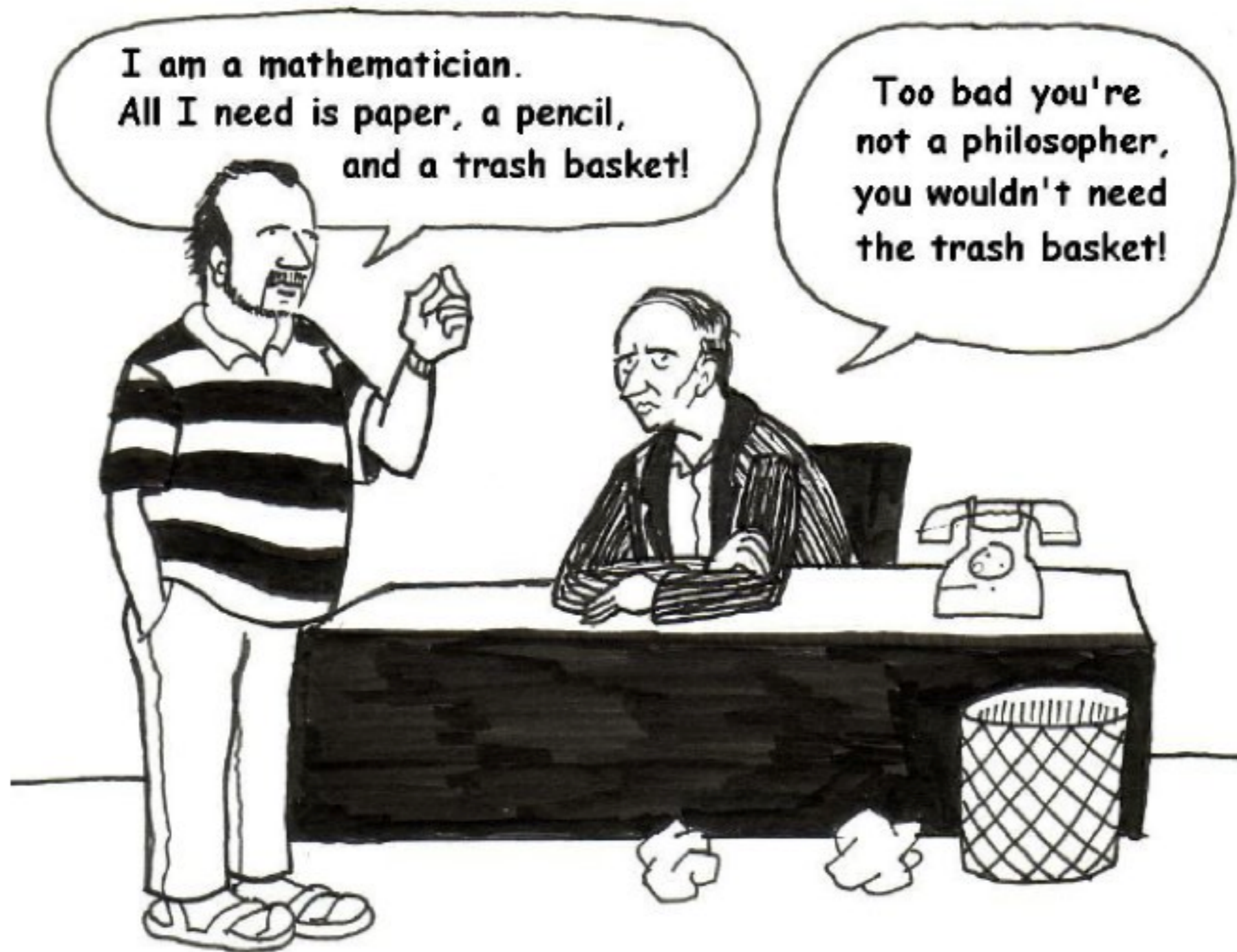
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## V1 spike count covariability



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- Could the nervous system use this variability for something?



– Eugene M. Izhikevich: *Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting*



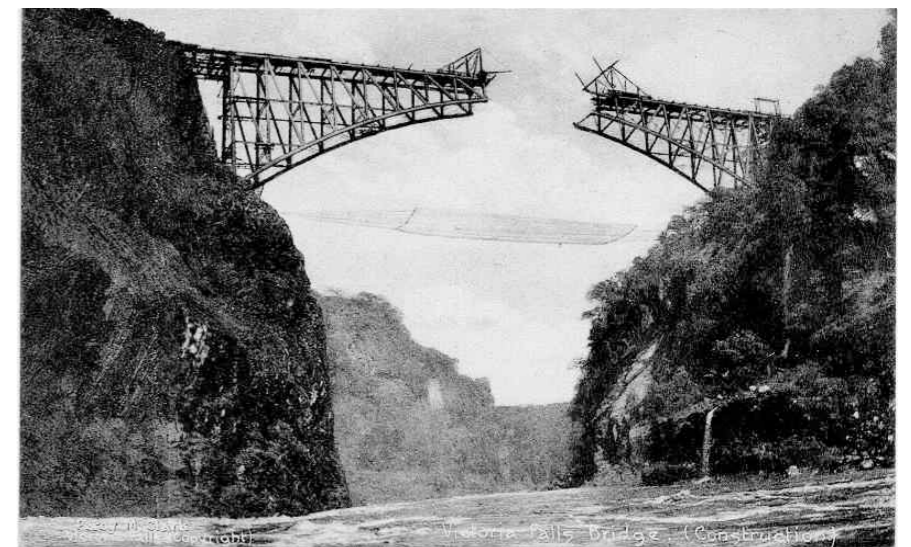
# Formulating functional hypotheses

Levels of abstraction in neuroscience according to David Marr:

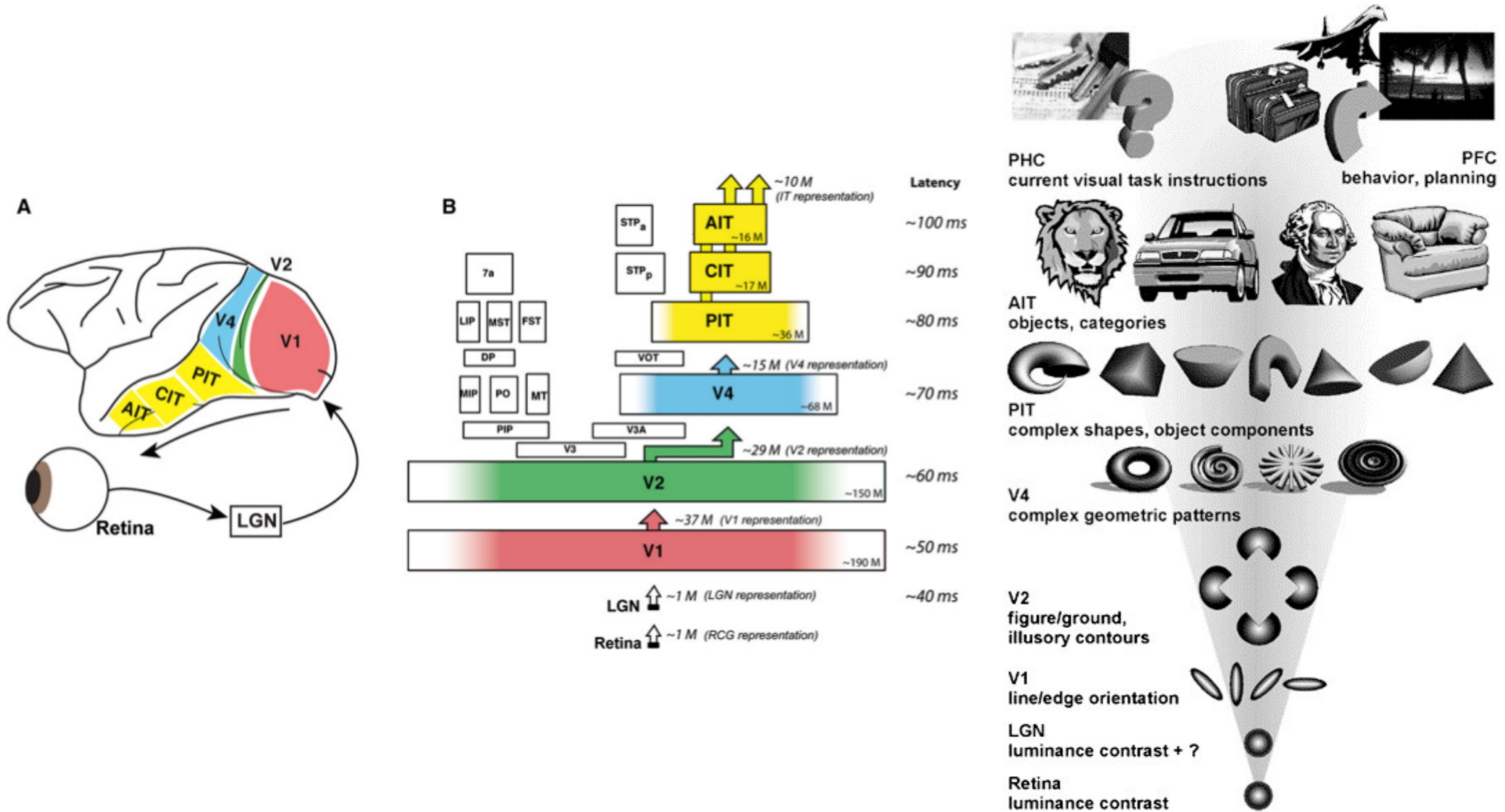
- **Computation** - specification of the brain function as an input-output mapping
- **Algorithm** - a step-by-step mathematical description of how to calculate the mapping
- **Implementation** - realisation of the algorithm by biological structures and their dynamical properties

“A wing would be a most mystifying structure if one did not know that birds flew.”

*Horace Barlow*

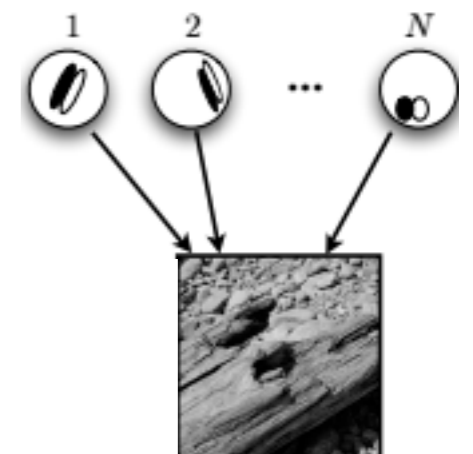
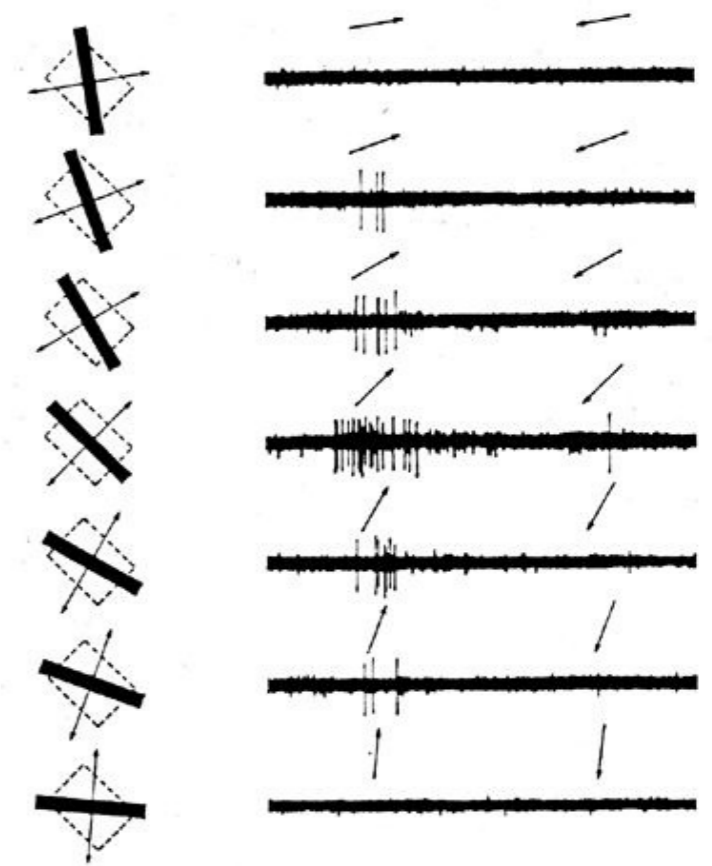


# Hierarchy of object recognition



# Relating environmental quantities to biophysics

- receptive field: range of some parameters defining a stimuli in which the cell shows increased firing activity
- V1 simple cells: localised oriented edges
- can be used to predict the average number of spikes generated by a cell in response to the repeated presentation of a stimulus



# The role of variability



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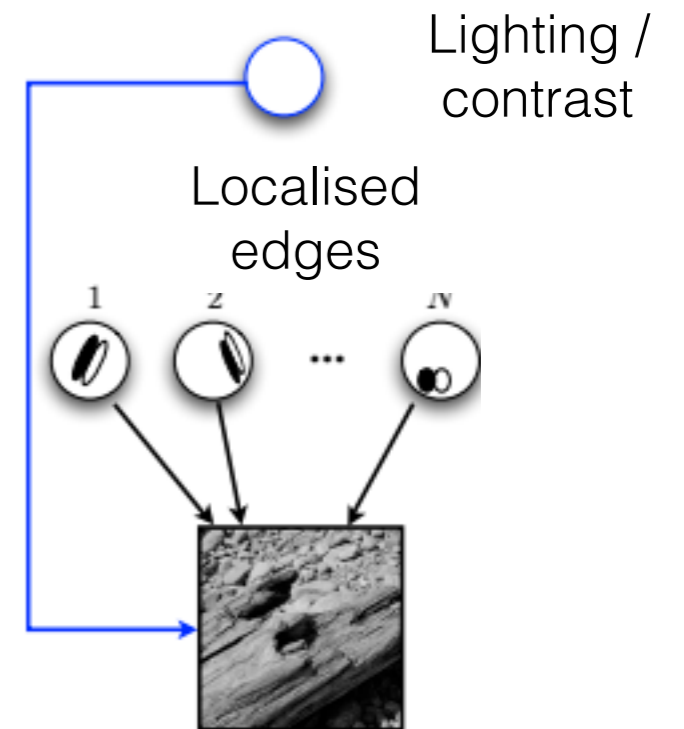
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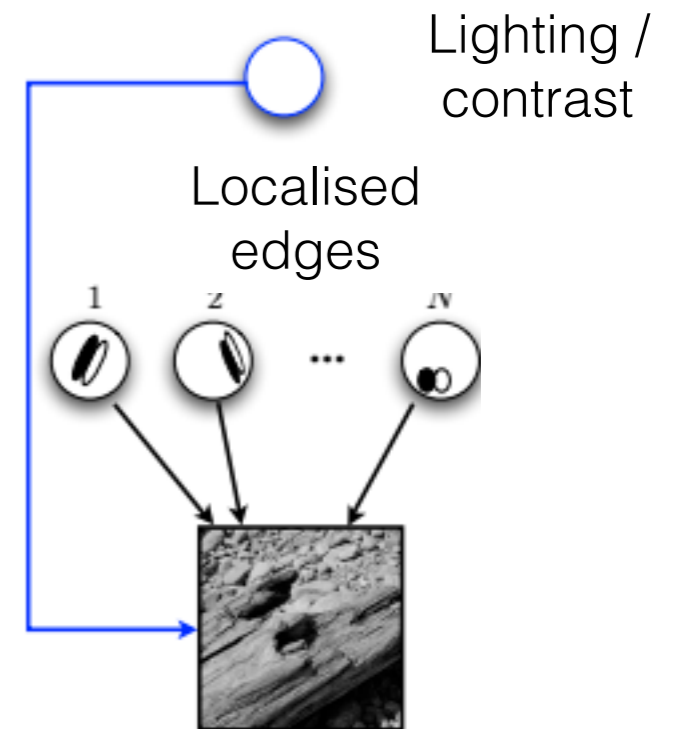
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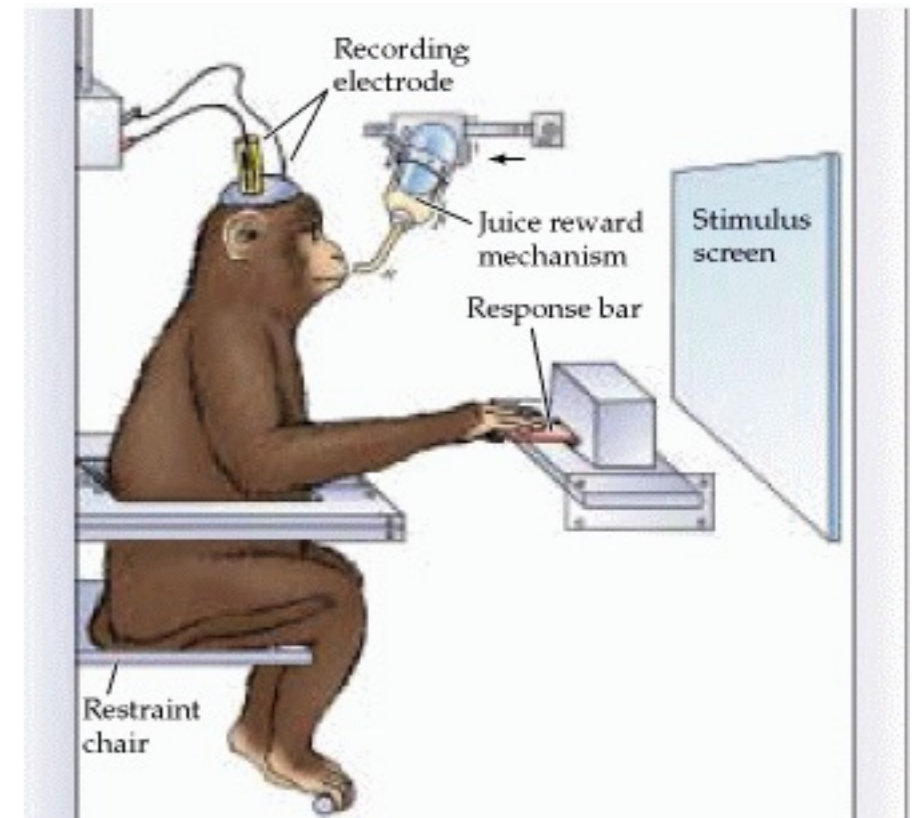


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- Prediction: higher contrast -> lower variability

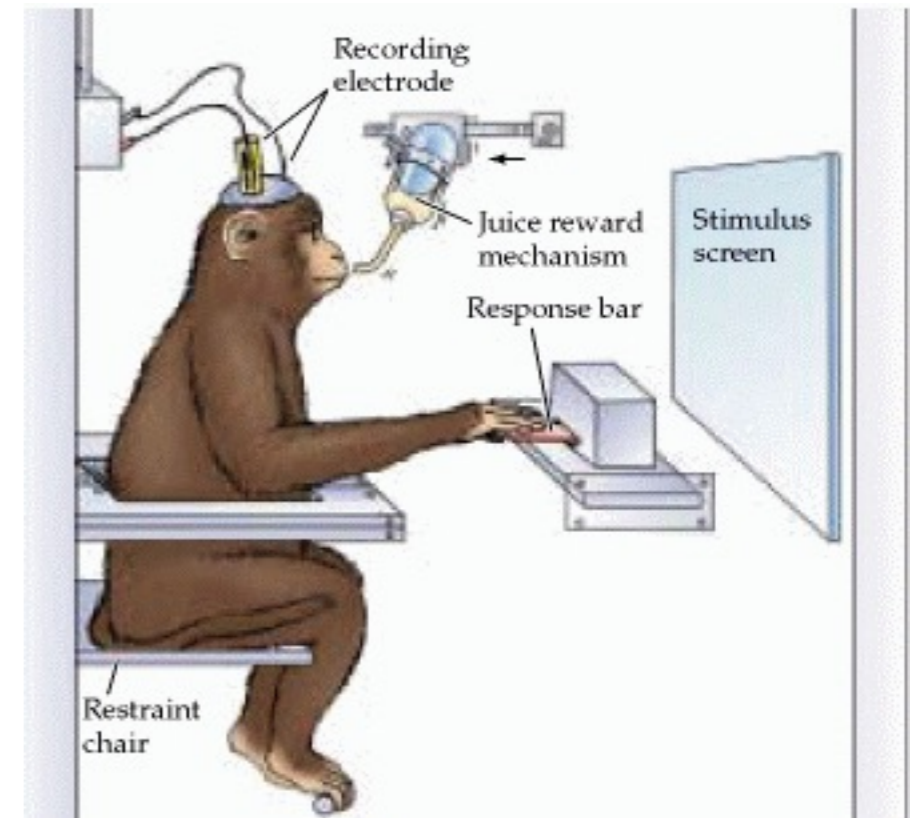


# Electrophysiological experiments with awake monkeys



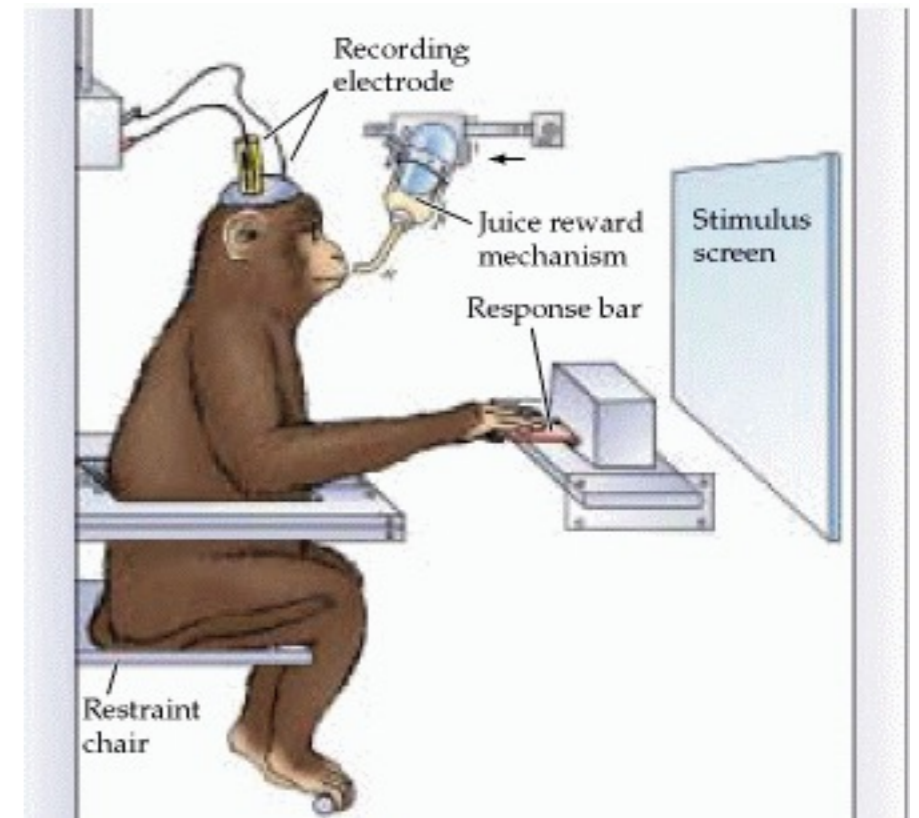
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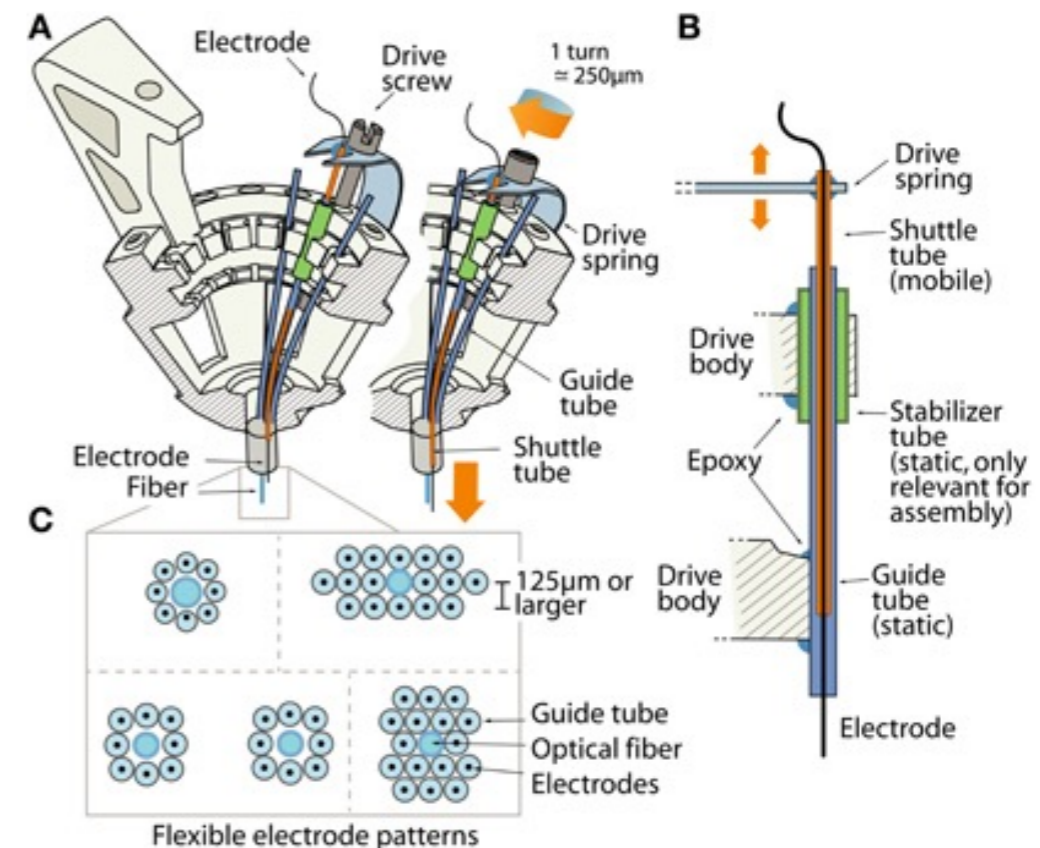
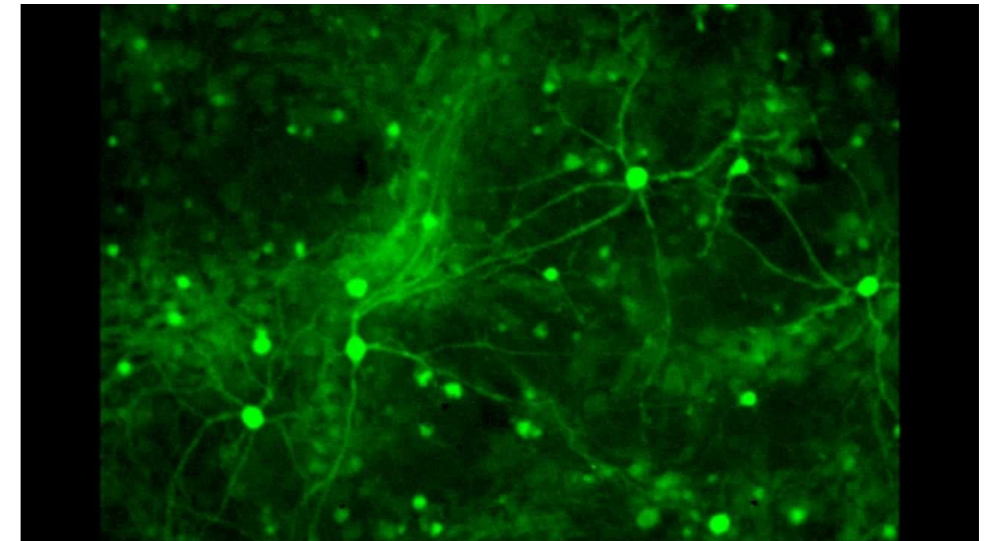
- you can teach a monkey to fixate, as opposed to almost any other animal
- one can measure under anesthesia, but different anesthetics will modulate neural response statistics in arbitrary ways (acting as a common input to cells, it especially disrupts response correlations)





# Measurable quantities in the nervous system

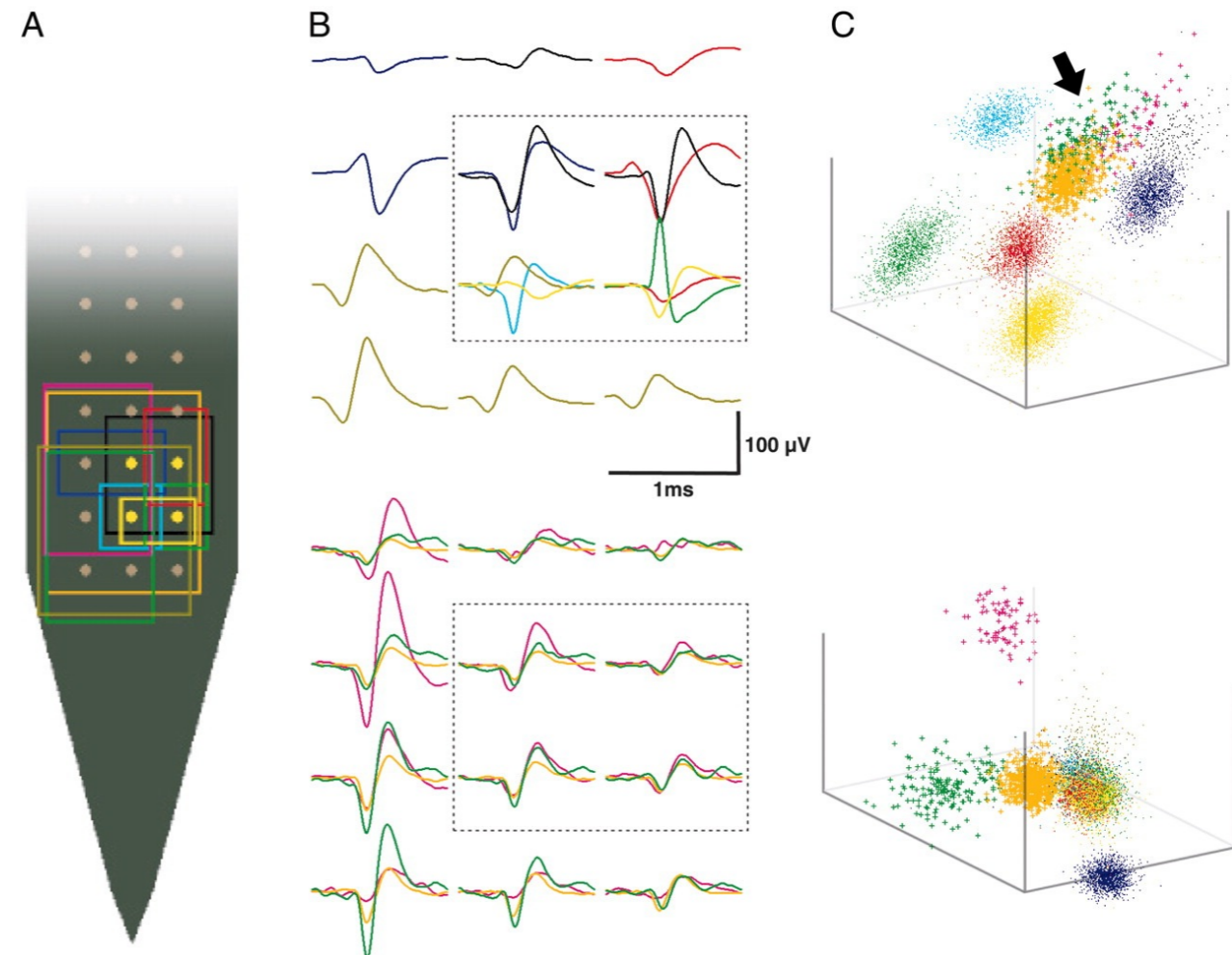
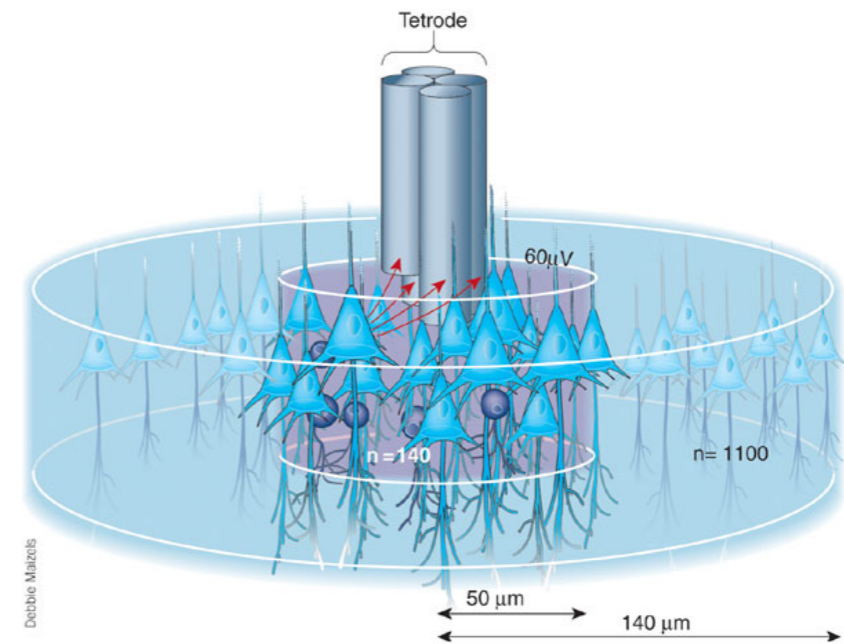
- we would like to measure a lot of cells at once (for our simple example it's not really required, but very often it is)
- calcium imaging
  - low temporal resolution
- extracellular electrodes
  - mixed signal coming from multiple cells





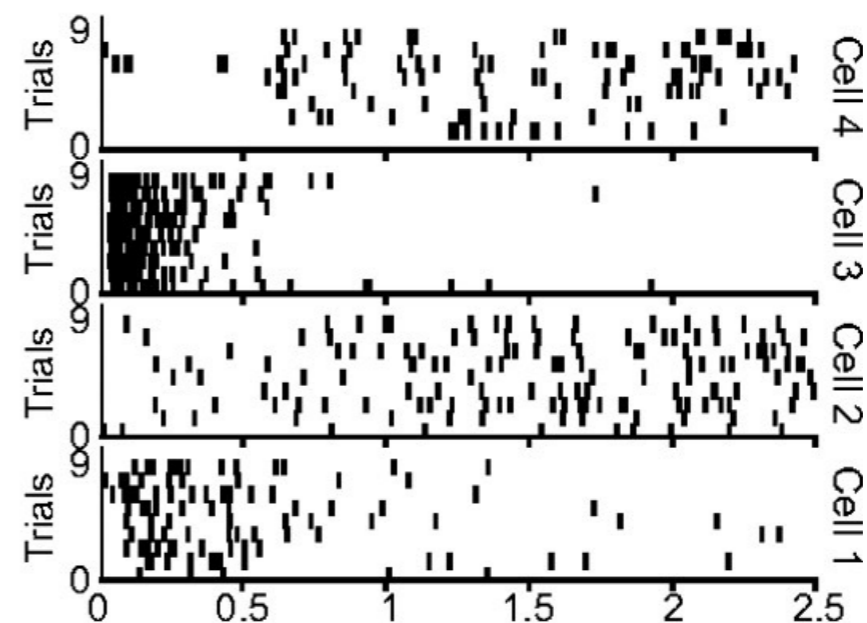
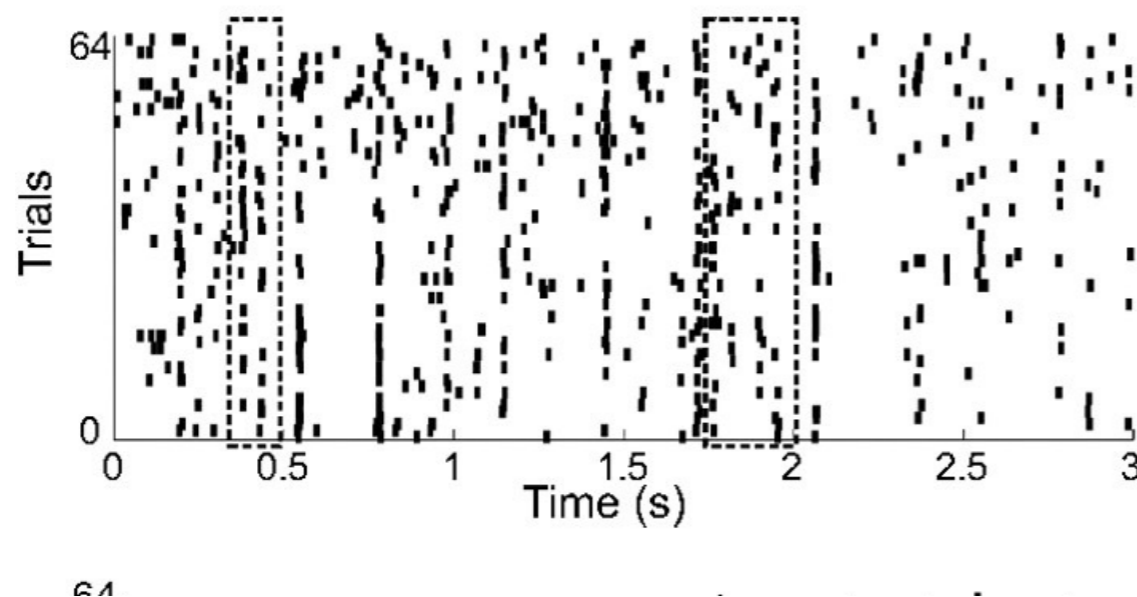
# Sorting the signals coming from single neurons

- clustering
- we can recover spike times
- not many ground truth datasets (patch-clamp or juxtacellular parallel with extracellular)
  - however, a big parallel dataset has just been released, so it may change quickly
- it introduces confounds to the response statistics that are hard to characterise



# How to measure variability?

- the base quantity number of spikes in a single time window
- variability can be measured in standard deviation of spike counts in all windows, or its square, variance
- if we present a single stimuli for a long time, adaptation makes a lot of our data useless -> we rather record a lot of short trials, each showing on elf our stimuli, in randomised order
- spike count variance can be measured over the trials showing the same stimulus, always in the same time window



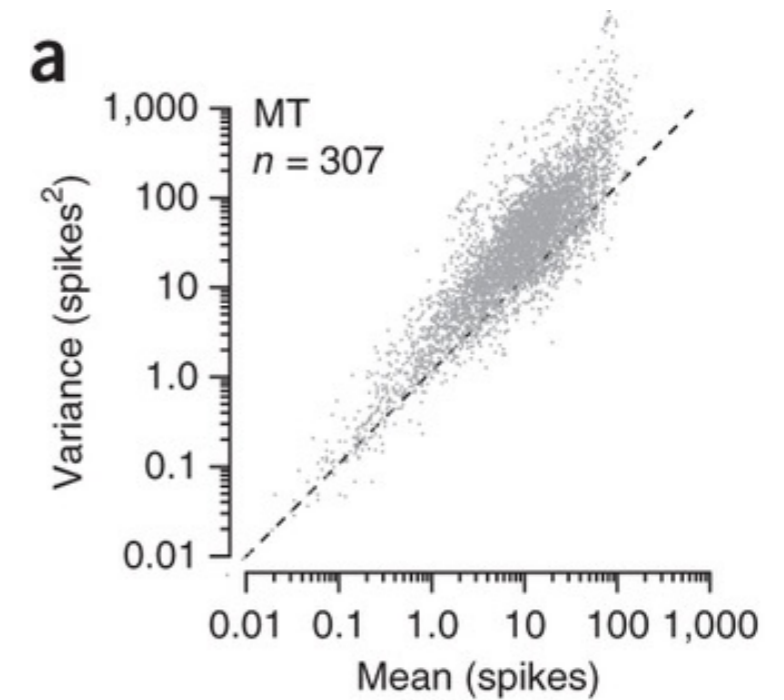
# Reliability of variance estimation

- statistical measures are random variables themselves
- uncertainty in them depends on the sample size
- how many trials we need?

<http://www.rmki.kfki.hu/~banmi/sote/spikingVariability.ipynb>  
<https://colab.research.google.com/>

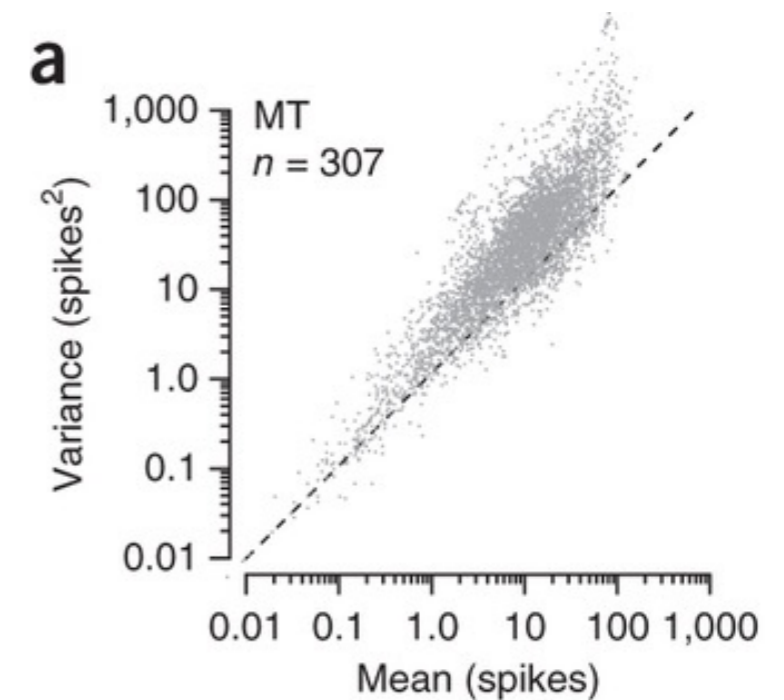
# Characteristics of neural spiking statistics

- the mean and the variance of the spike count tend to change together



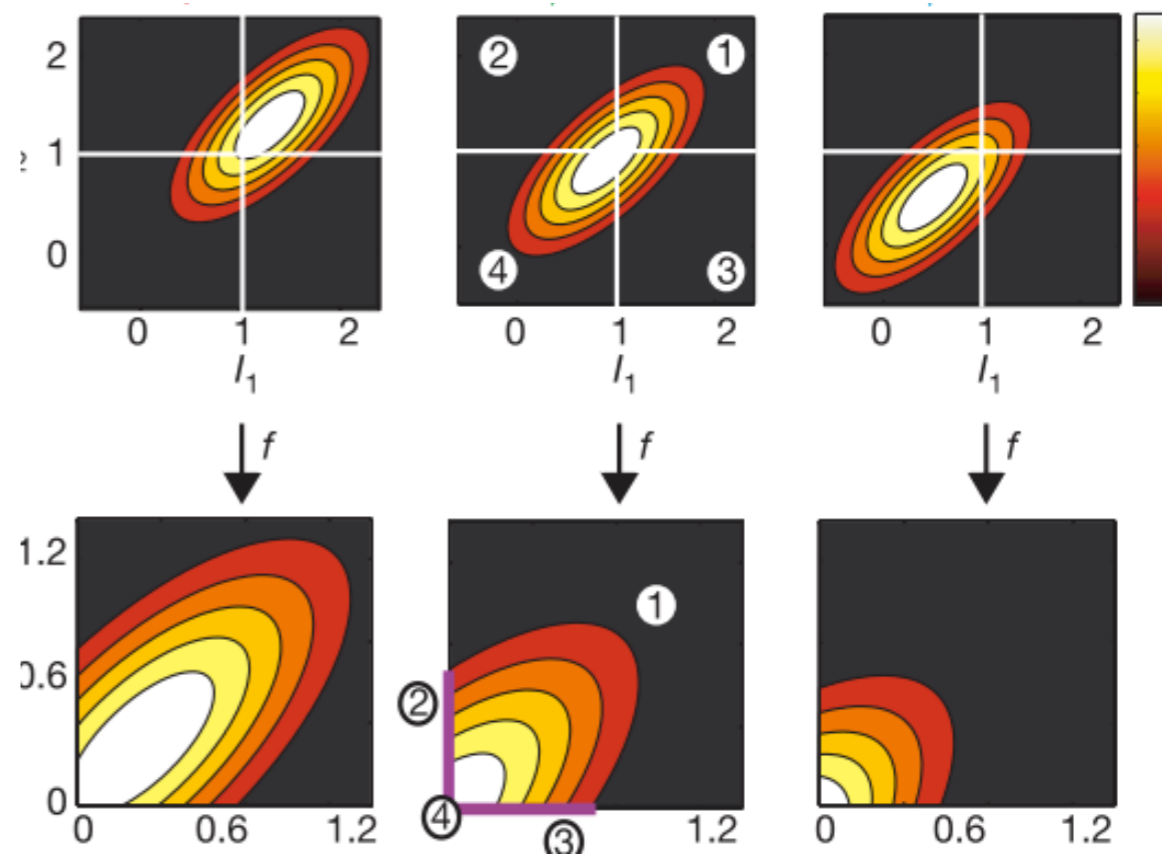
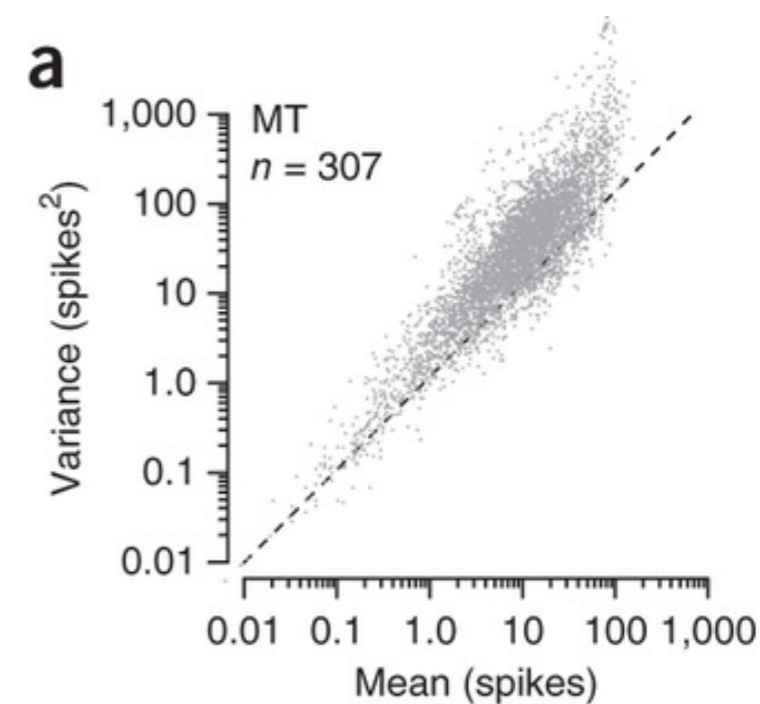
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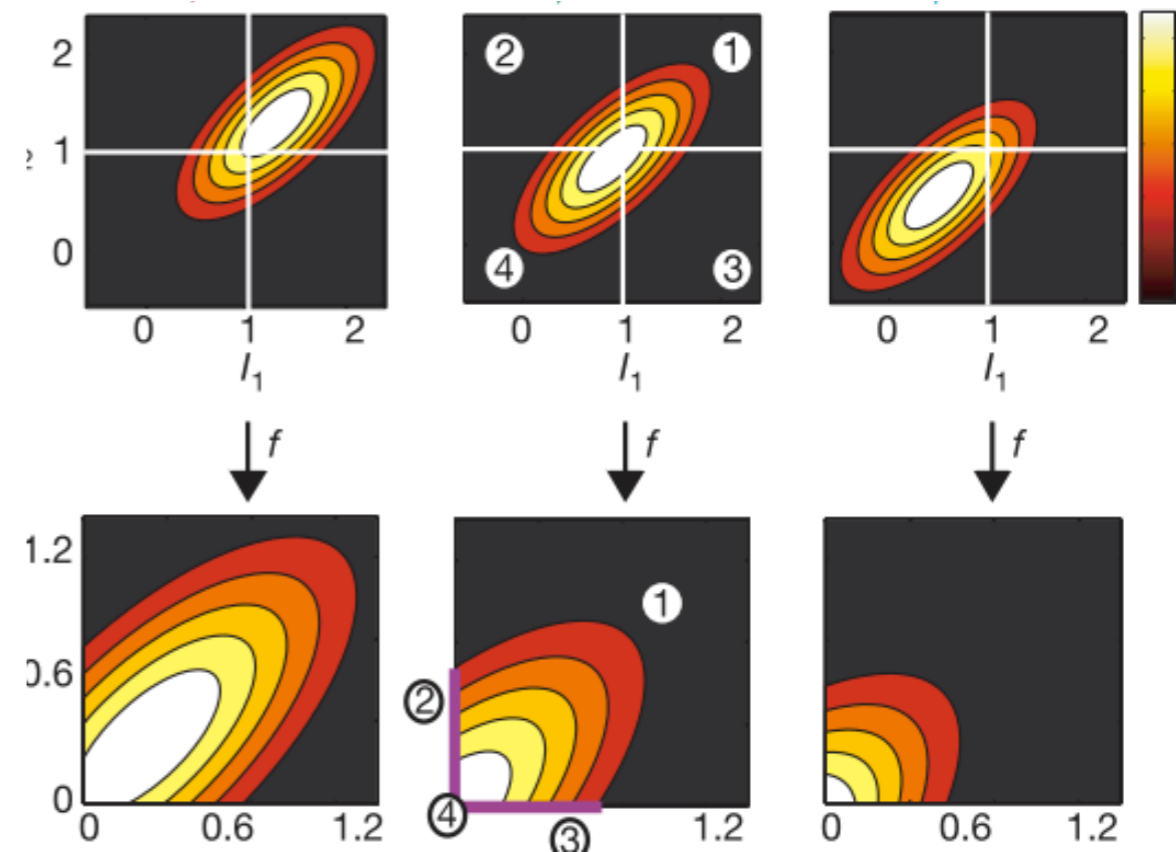
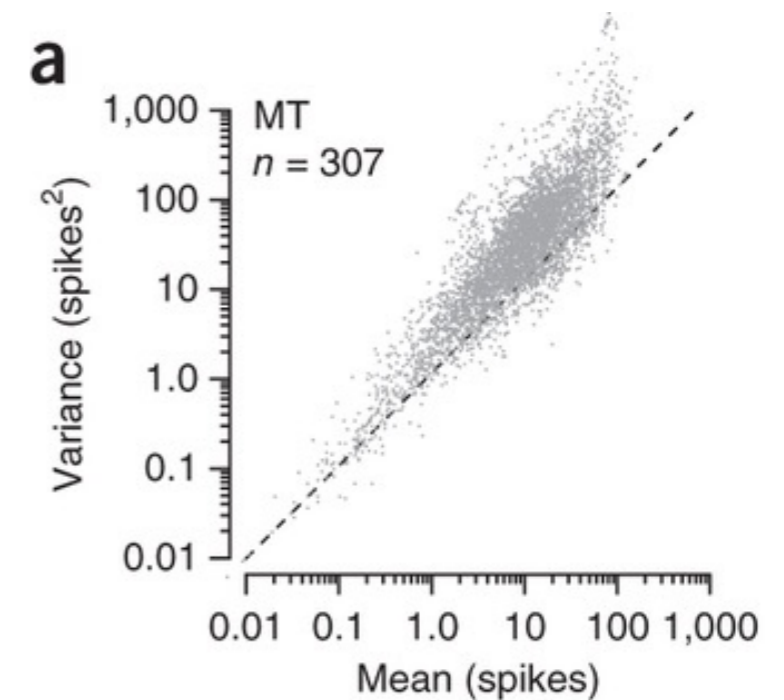
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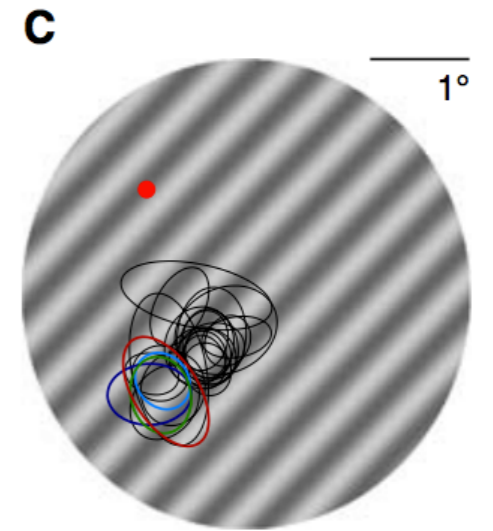
# Characteristics of neural spiking statistics

- the mean and the variance of the spike count tend to change together
- this may follow from a Poisson-distributed spike generation procedure
- or simply the effect of the firing threshold
- we are interested in the excess variability relative to the mean -> Fano factor = variance / mean



# Publicly available data

- <http://bethgelab.org/datasets/v1gratings/>
- Awake monkeys
- Multielectrode recording from V1
- Clustered spikes
- Static grating stimuli (they have moving too)
- Stimuli with low and high contrast levels



<http://www.rmki.kfki.hu/~banmi/sote/spikingVariability.ipynb>

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Further possible controls

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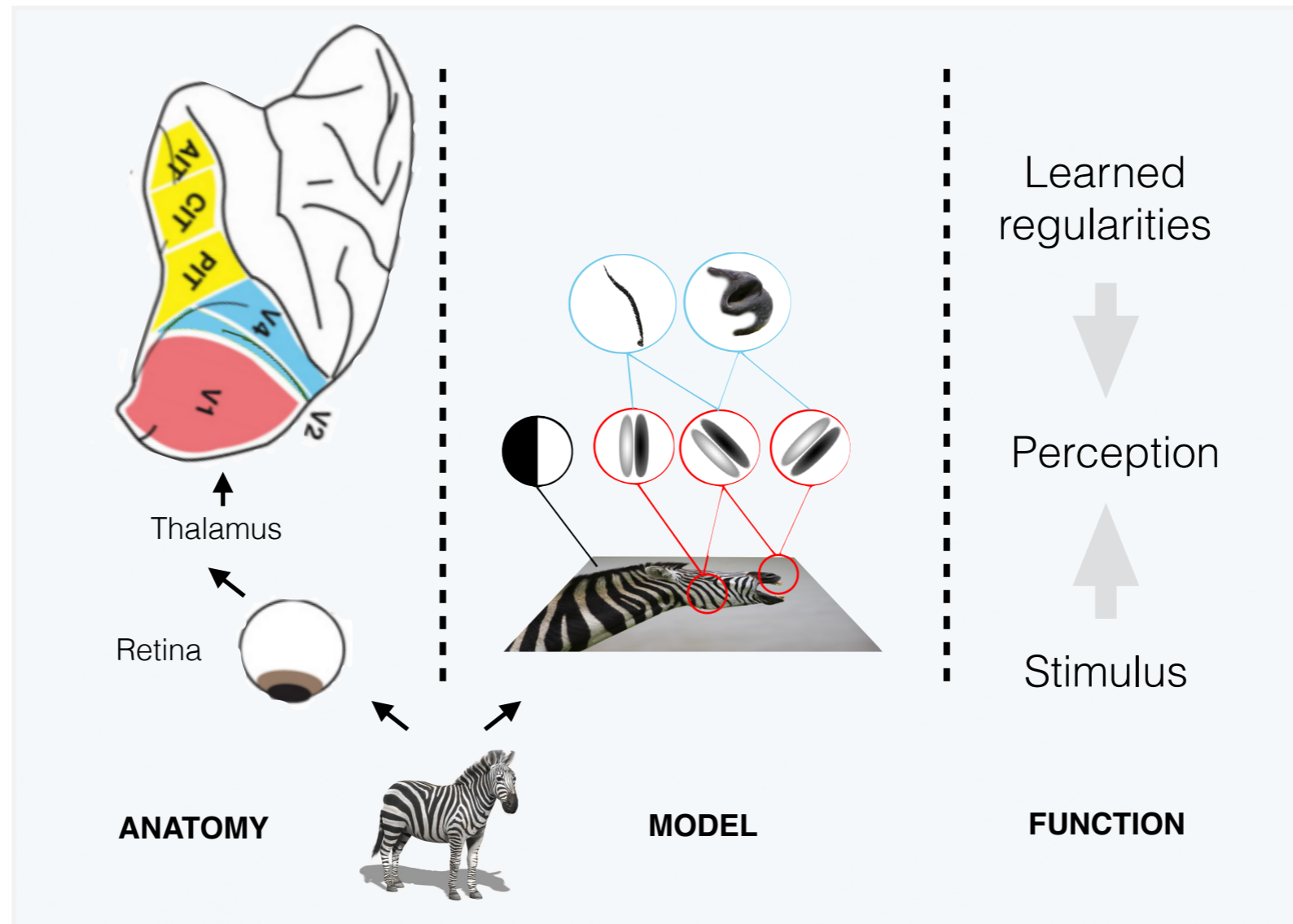
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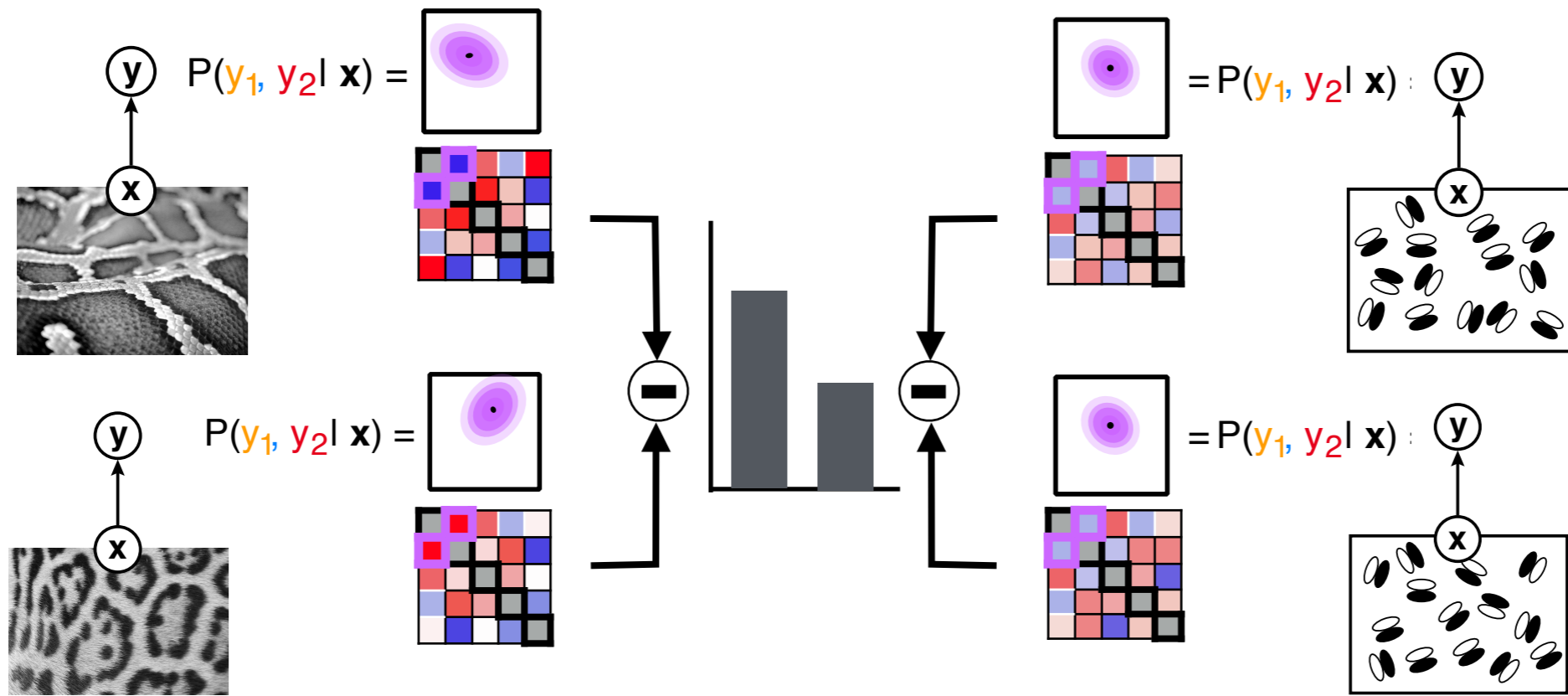
- We can throw out units deemed unreliable by the clustering algorithm
- Units with low firing rates may be filtered out, as few spikes mean unreliable statistics
- As changing contrast causes the mean and the variance change together, we may try to separate effects of the changing mean on the Fano factor

# Functional hypotheses about co-activation statistics

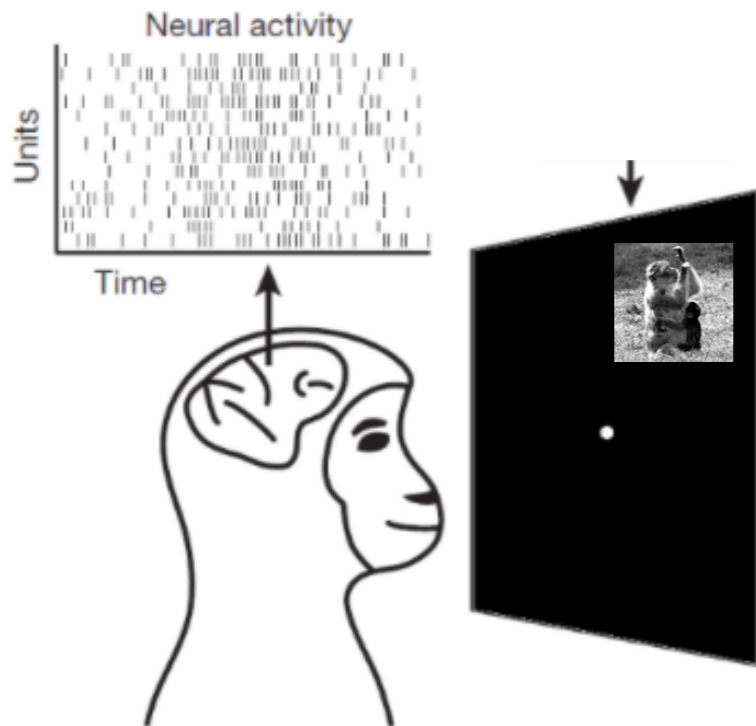
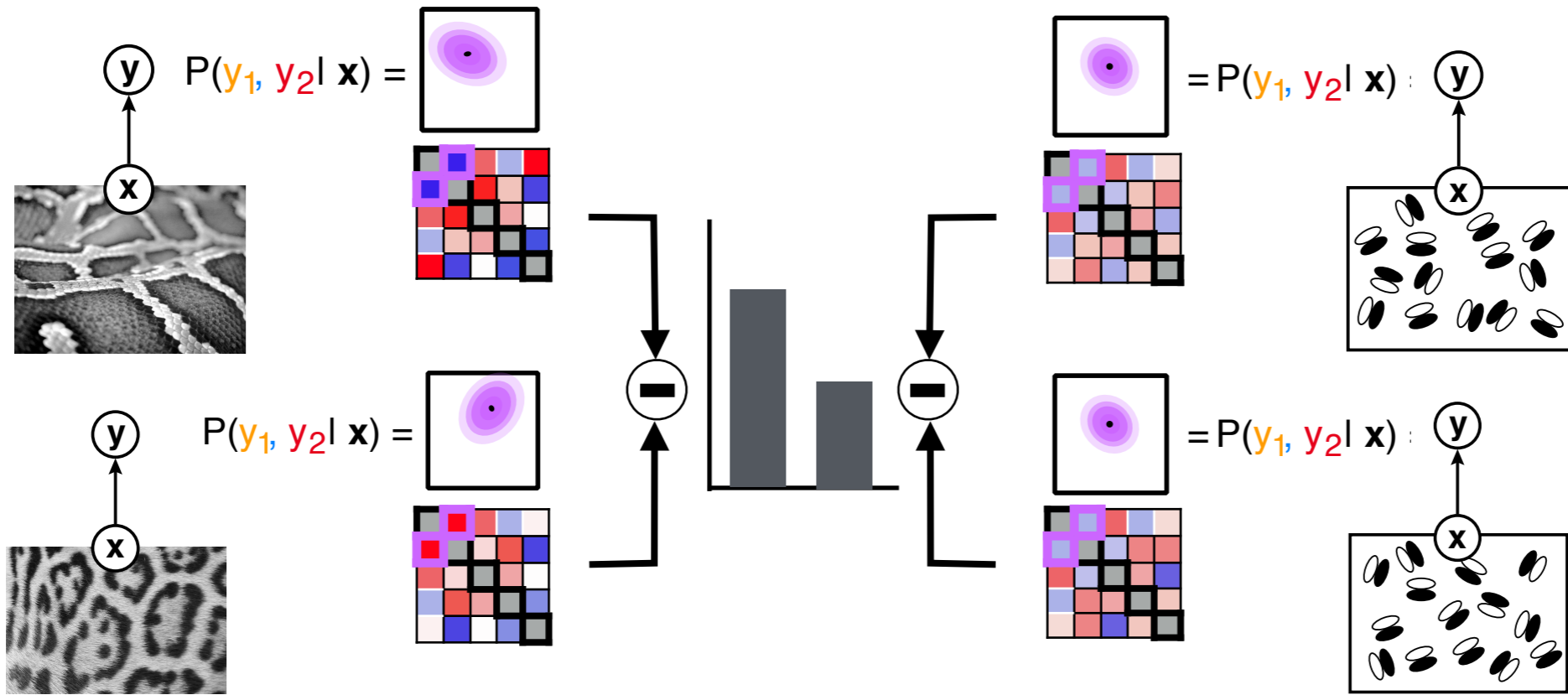
- Combination of edges -> texture/contour detection  
-> object recognition



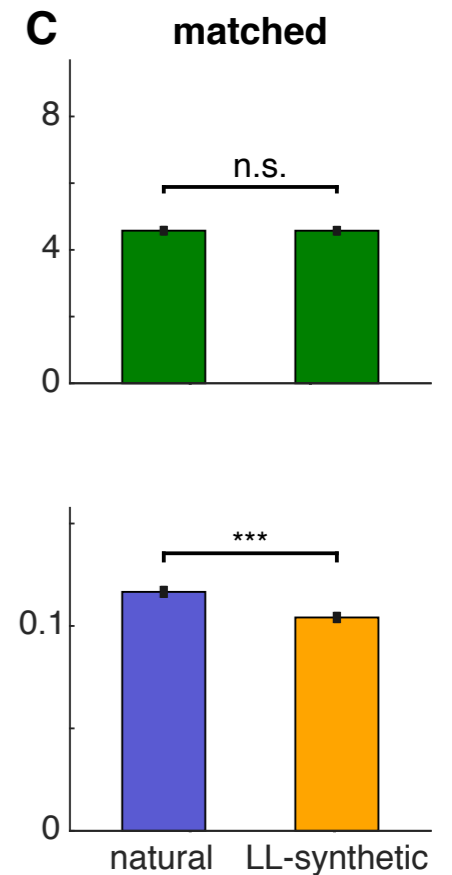
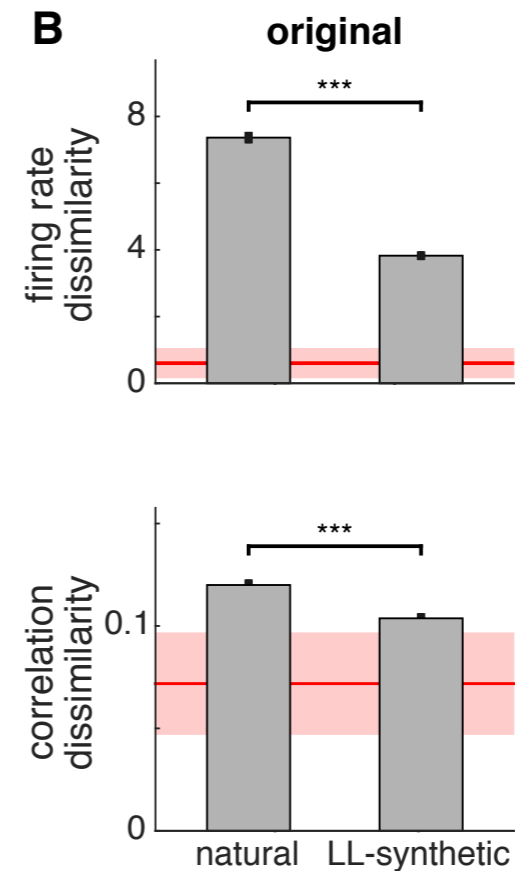
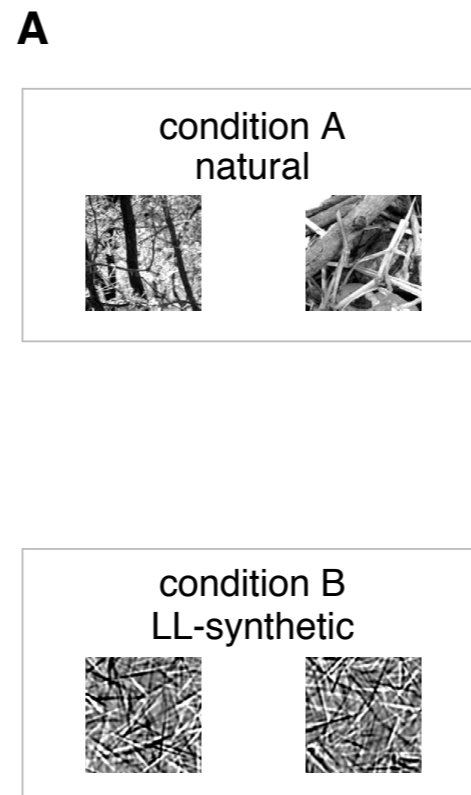
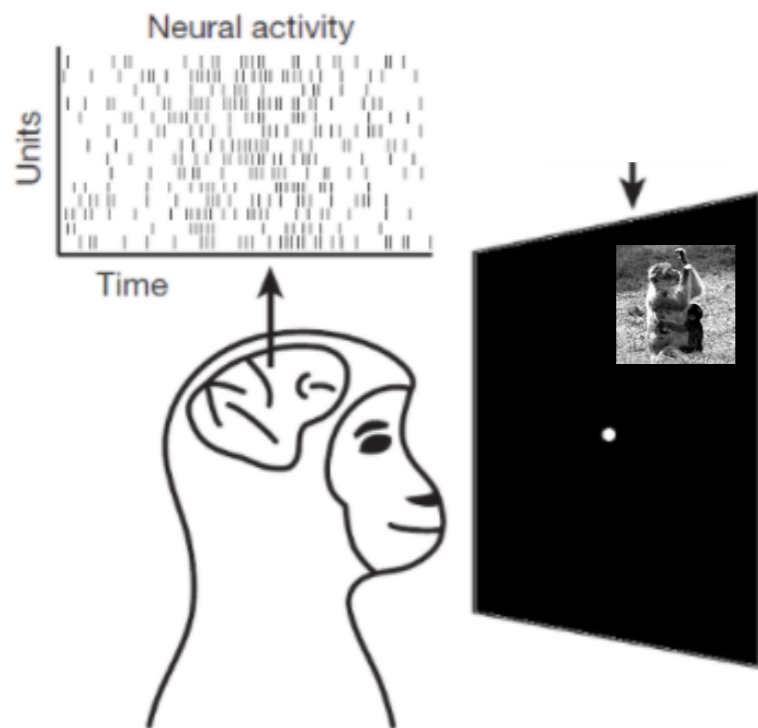
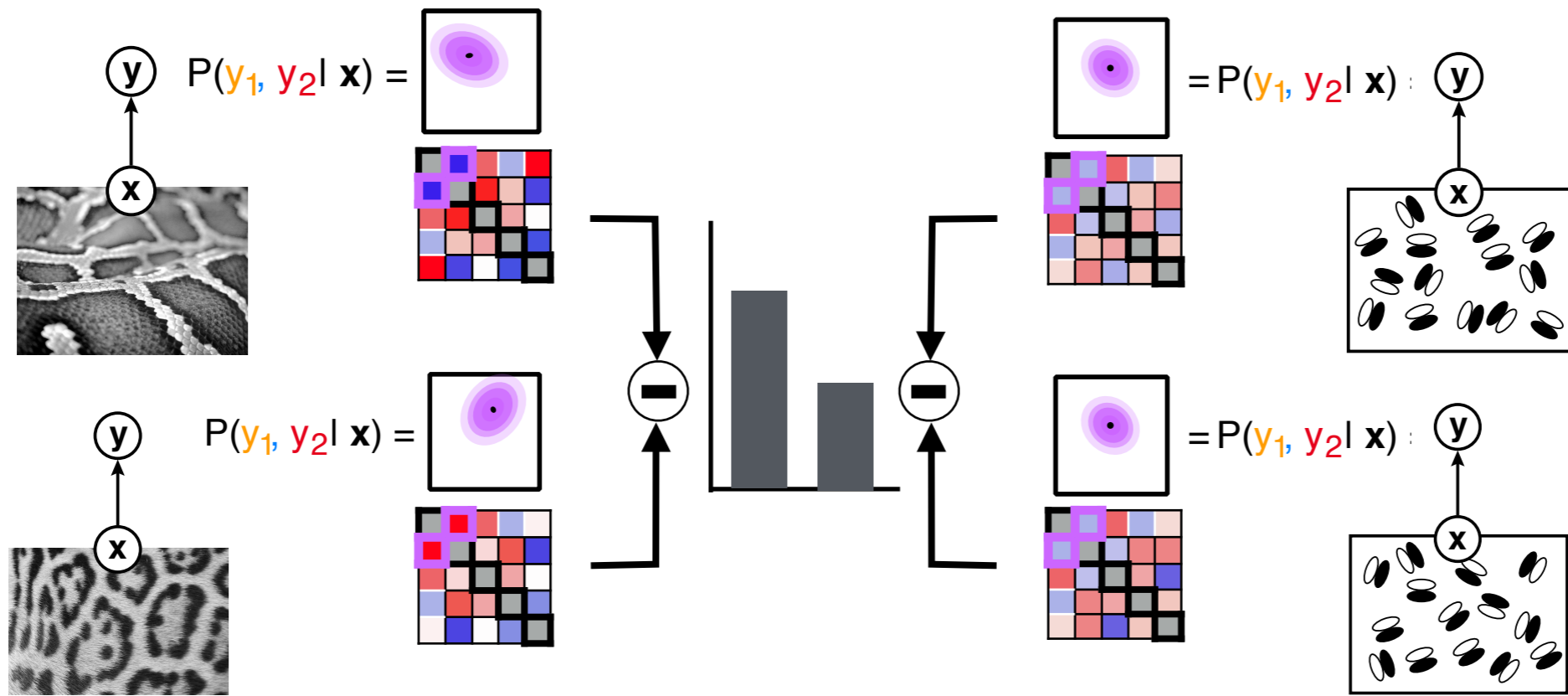
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- covariability reflects expectations about the co-occurrence of features
- perception, all the way up to object recognition can be formalised as probabilistic inference of unobserved quantities (features, objects) based on observed ones (pixels, retinal activations)
- probabilistic models provide a unifying framework for understanding many brain functions and make connections to artificial intelligence solutions