

# **“POPULATION CODING IN SOMATOSENSORY CORTEX”**

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A review article by Petersen et al. (2002)

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Demille O.

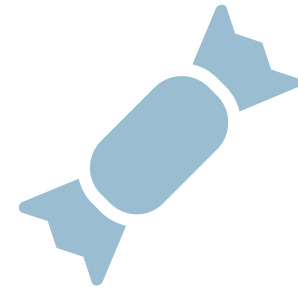
Paul I.



Individual neurons code for a different set of stimulus values



Individual neurons work together to encode all possible stimuli



**Analogy:** Jelly beans!

# Population Coding Refresher



# 50 Official Flavors

DIRECTIONS: FOR TRUE JELLY BELLY FLAVOR, EAT ONE BEAN AT A TIME OR GET CREATIVE AND COMBINE FLAVORS FOR A REAL GOURMET TREAT.



Natural & Artificial Flavors

# Jelly bean neurons: population coding!

## JELLY BELLY® RECIPES

### Banana Kiwi Pudding



### Mud Pie



### Chocolate Covered Cherries



### Pink Lemonade

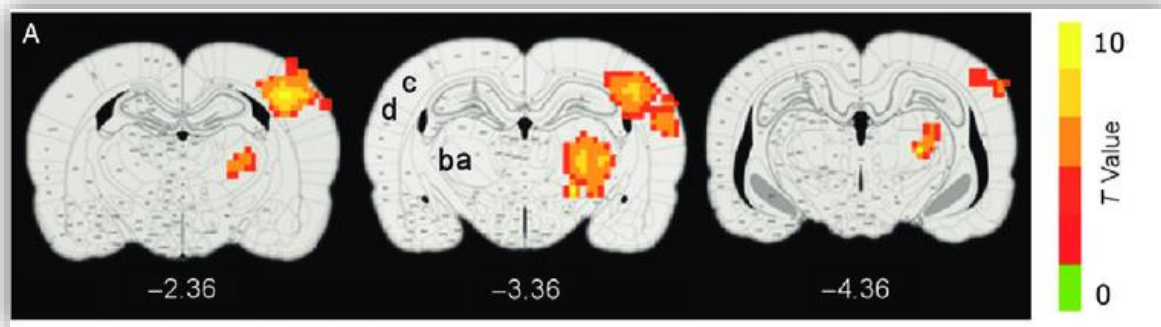


### Mango Pineapple Salsa

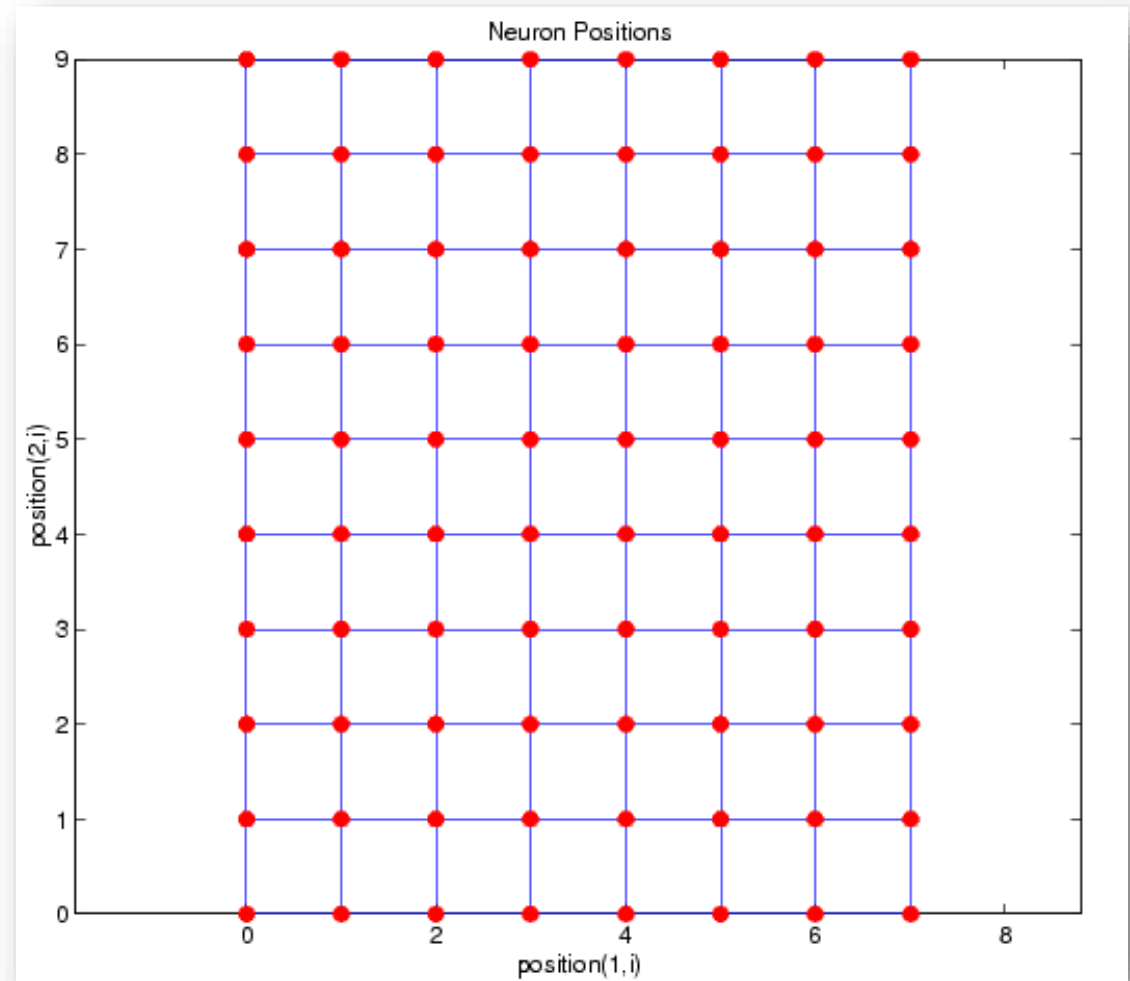


# Background

- Neuronal representations of discriminated stimuli must also be distinct
- Stimuli coded as temporo-spatial activation patterns



From: [https://www.researchgate.net/figure/fMRI-response-to-rat-whisker-barrel-cortex-stimulation-A-Group-statistical-activation\\_fig4\\_267272836](https://www.researchgate.net/figure/fMRI-response-to-rat-whisker-barrel-cortex-stimulation-A-Group-statistical-activation_fig4_267272836)



From: <http://matlab.izmiran.ru/help/toolbox/nnet/selfor11.html>

# Paper Overview

Goal: Compare candidate cortical population codes

- How?
  - Identify features of neural responses that might underlie stimulus discrimination
  - Systematically quantify the contribution of these features to the cortical population code

# Discussion points

Code  
features

```
graph TD; A[Code features] --- B[Spatial organization]; A --- C[Spike timing]; A --- D[Spike correlation];
```

Spatial  
organization

Widespread network vs  
restricted subset of neurons

Spike timing

Number of spikes over long  
time interval vs precise  
position of spike in time

Spike  
correlation

Are the spikes independent  
or is their correlation  
important?



# **BUILDING A FRAMEWORK:**

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Quantifying neural codes

# Characterize how a cell codes a set of stimuli:

Repeat each stimulus many times

Measure the response:

The number of spikes per trial evoked in a post-stimulus window

Evaluate whether the responses to the stimuli differ according to a statistical test

A significant result is achieved

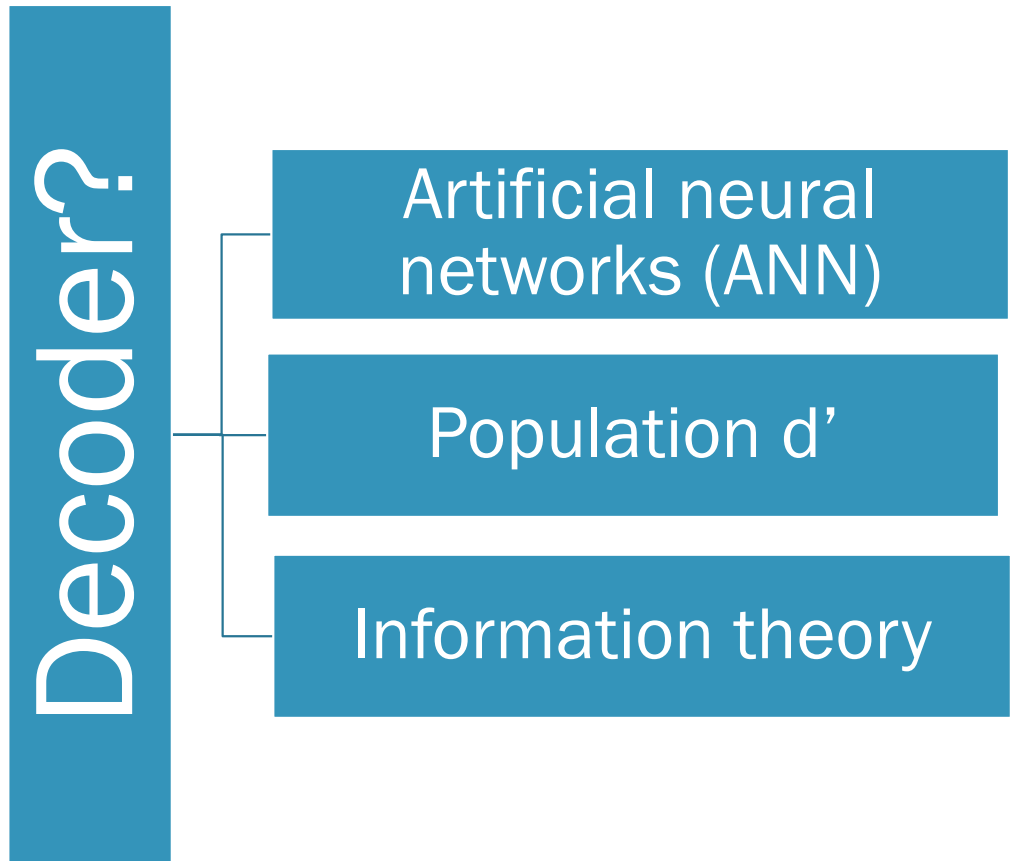
The neural representations of the stimuli are distinct

The neuron could contribute to stimulus discriminability



# An “ideal decoder”

- Monitors the neuronal ensemble activity
- Judges stimulus identity for each trial
- Can quantify the performance of how the decoder varies
  - Depends on what components of population activity are available to it



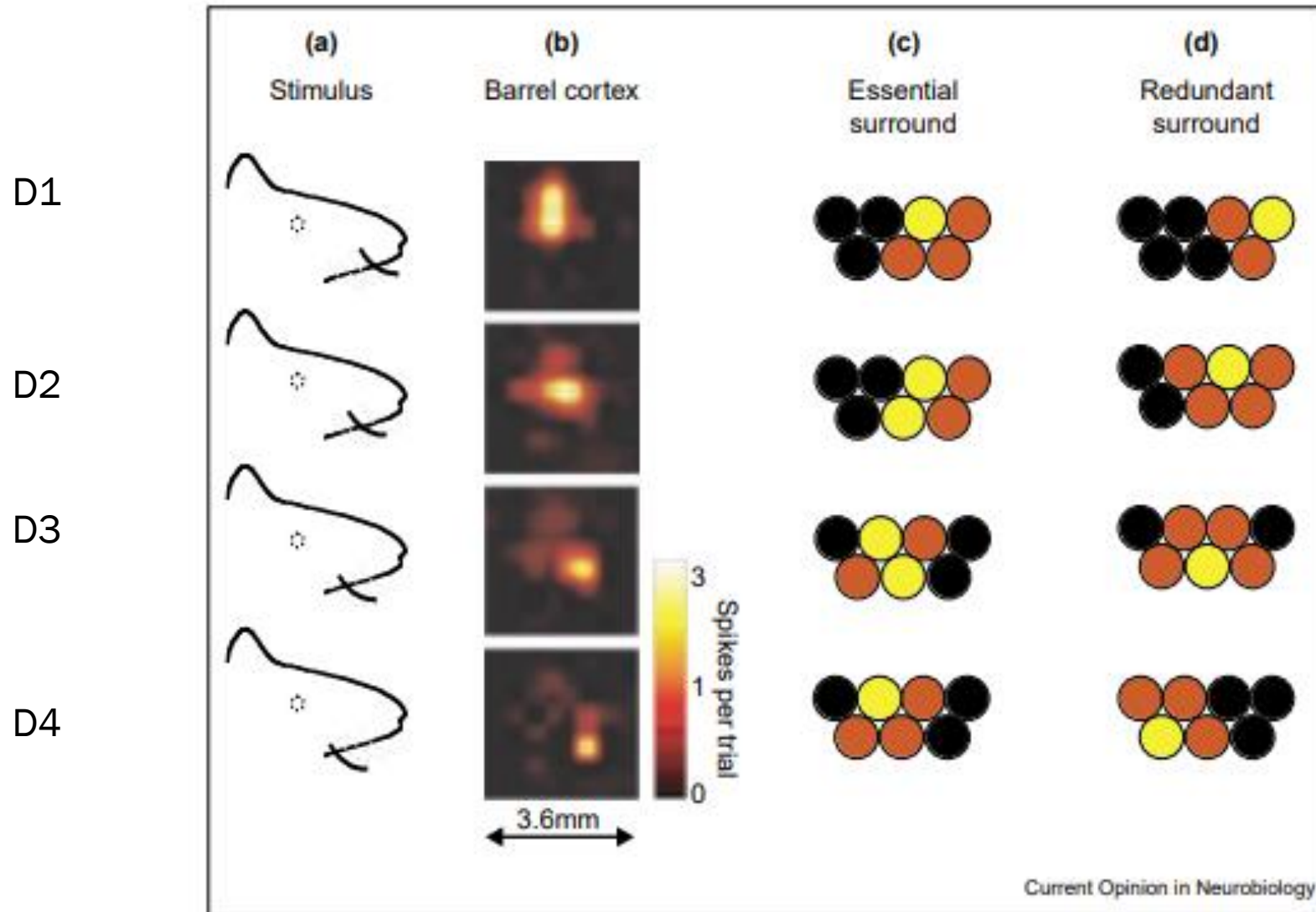


# **SPATIAL ORGANIZATION OF NEURAL CODING:**

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Anatomical relationships and stimulus locations

# Role of spatial organization



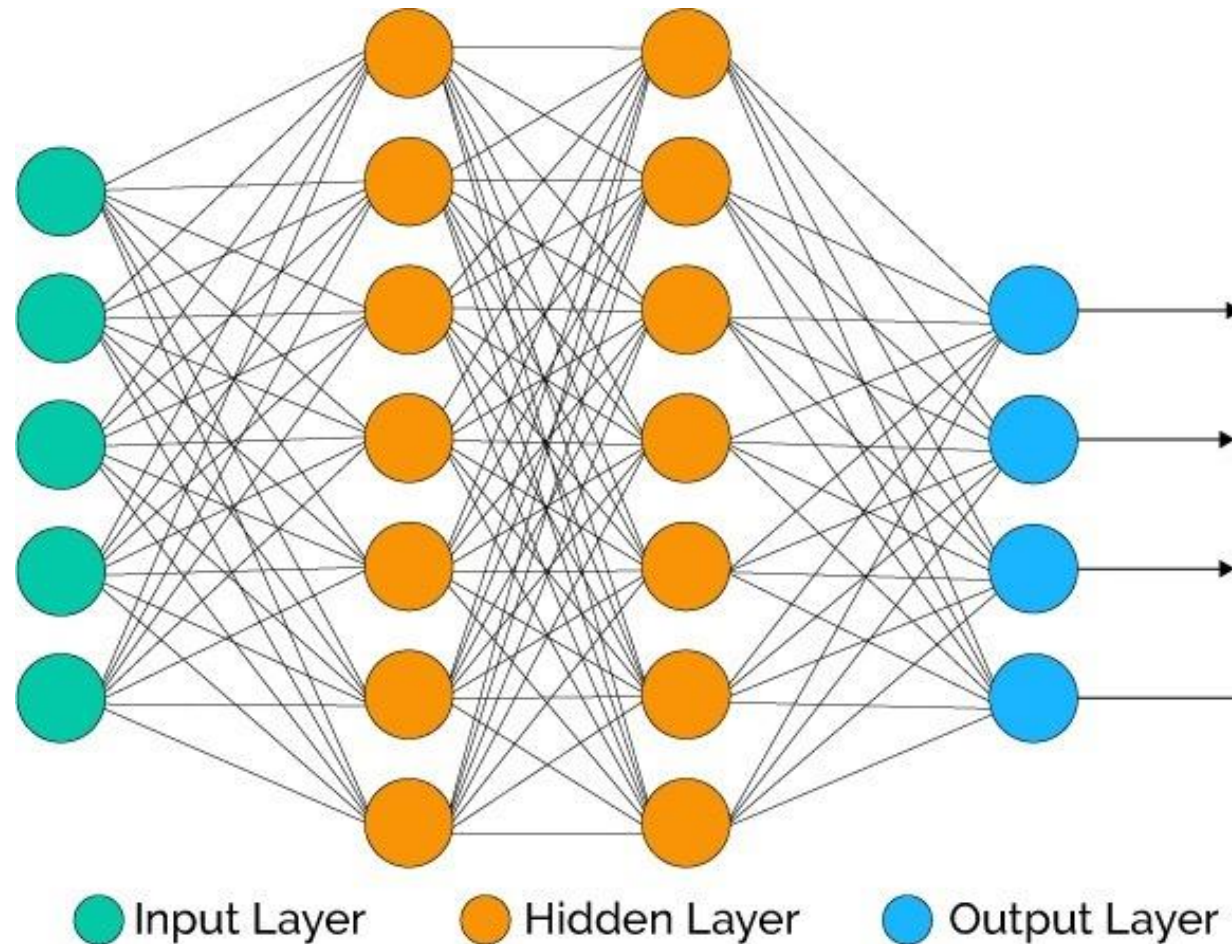
# ANN decoder... simplified

# ANN decoder

- Activation of neurons on an arbitrary scale of 0 to 1 (electrode data)

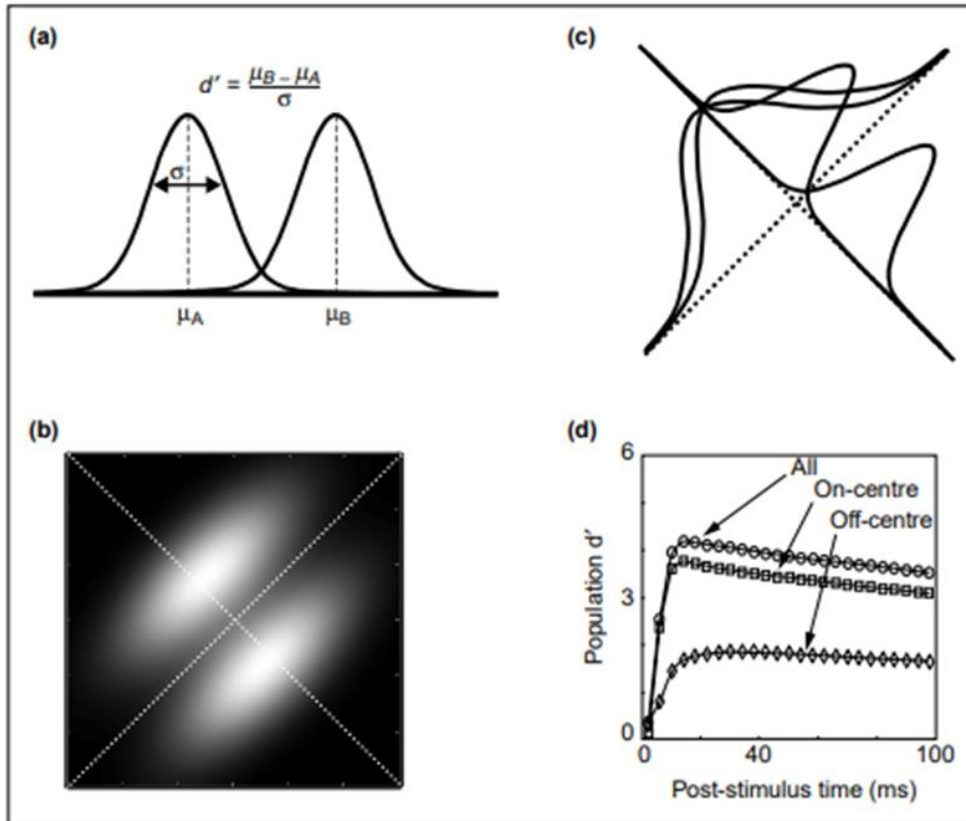
## Results:

- ANN determines the stimulus type for 30 neurons more easily than for 1 neuron



Can an ideal decoder identify the stimulus, based on its neural representation?

# Is the combination of neurons firing important or do surrounding neurons “support” the homotopic activation?



Petersen et al., 2002

- Population  $d'$ : “the difference in the mean number of spikes evoked by two stimuli normalized by the spike count variability.”
- Results:  $d'$  for off-center columns is high enough to discriminate the stimuli → multicolumnar coding?
  - But, 90% of discriminability due to the on-center → spatially localized coding

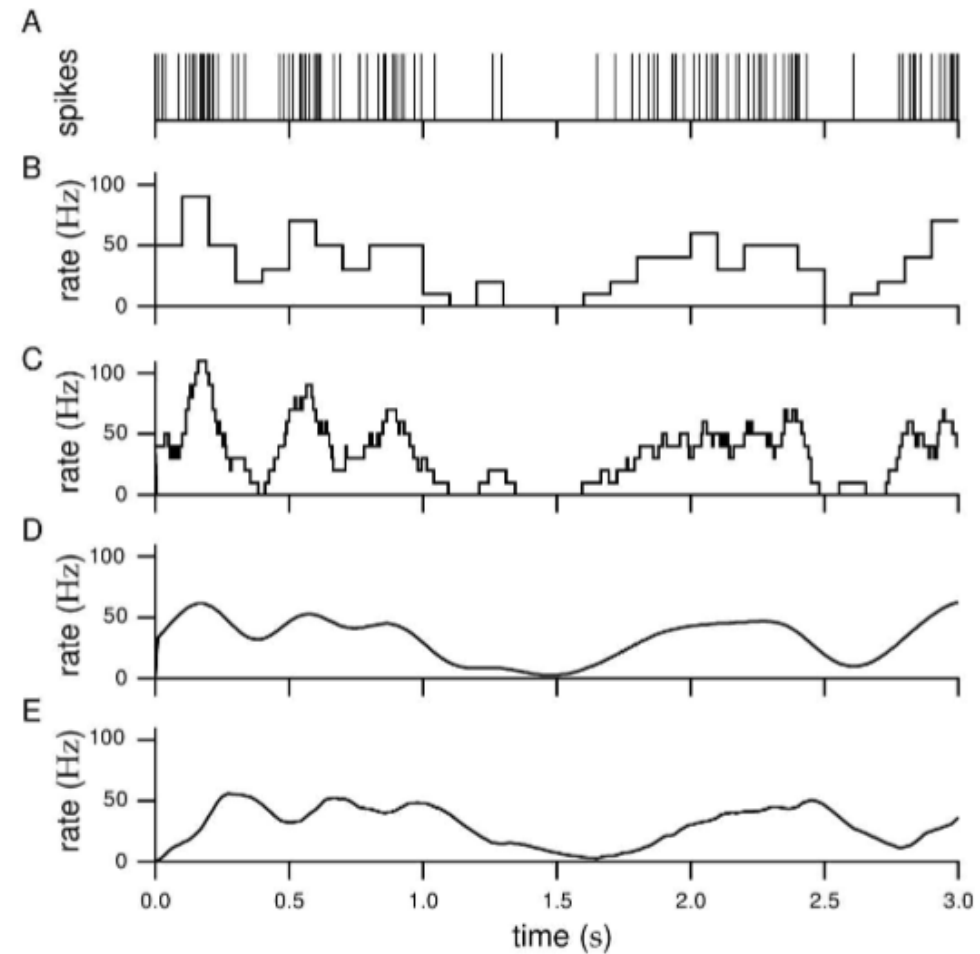


# **ROLE OF SPIKE TIMING**

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For population coding

# Recall spike timing





# Role of spike timing

Count all spikes in the given time window

Number of spikes per period of time  $t$  after stimulation

$T = 40\text{ms}$  in the experiment

Divide the time period into the “bins”, and count the number of spikes within each bin

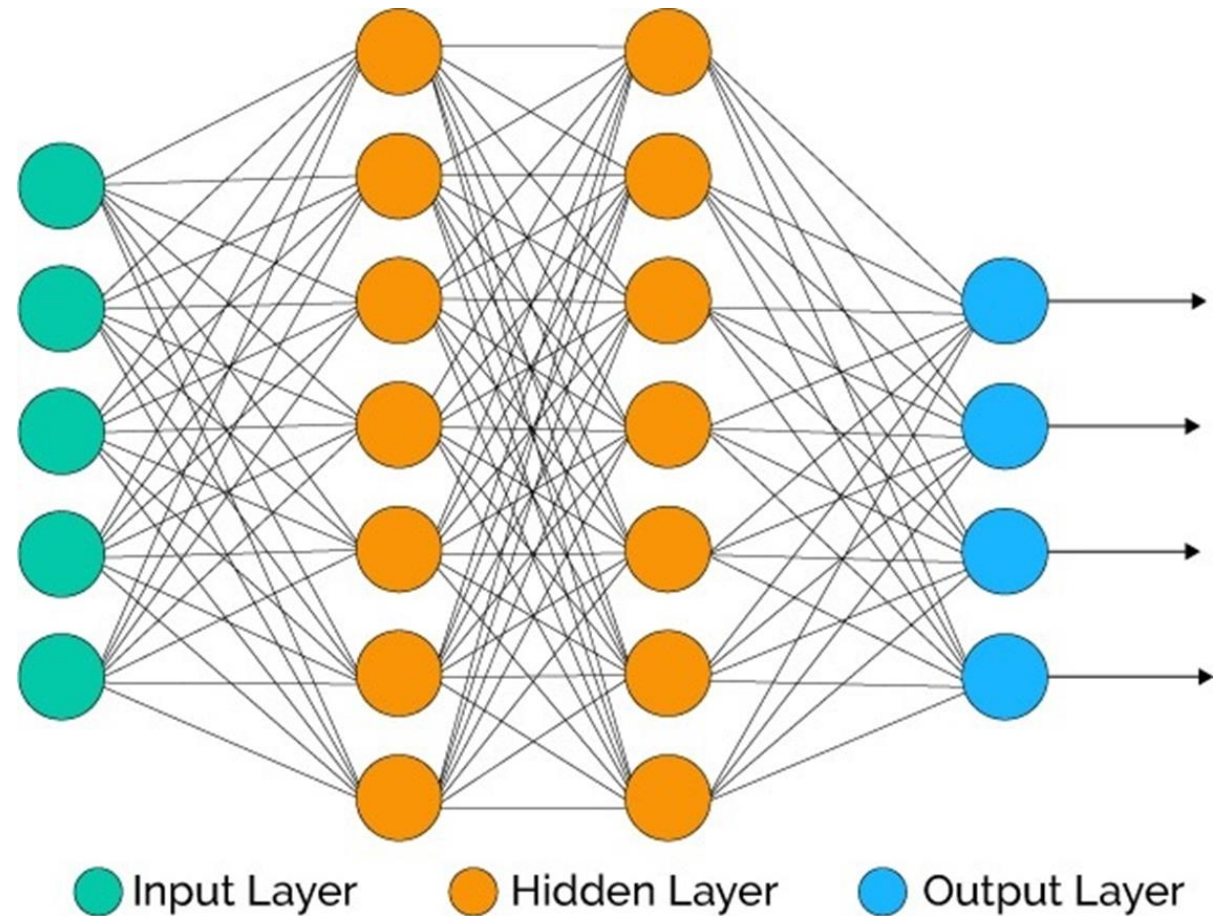
Precision of the spike timing

# ANN approach

- Only 1 bin (40ms long)
- Increase the resolution (6ms-  
each bin)

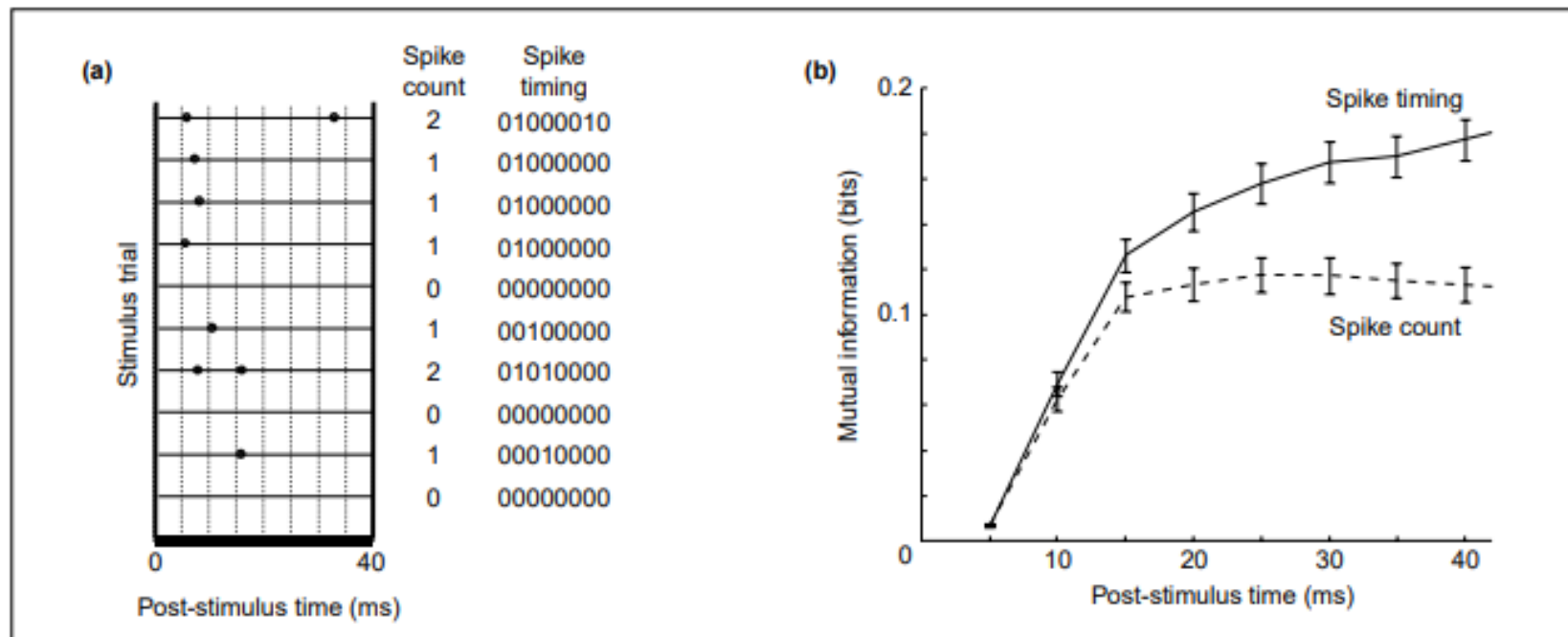
## Results:

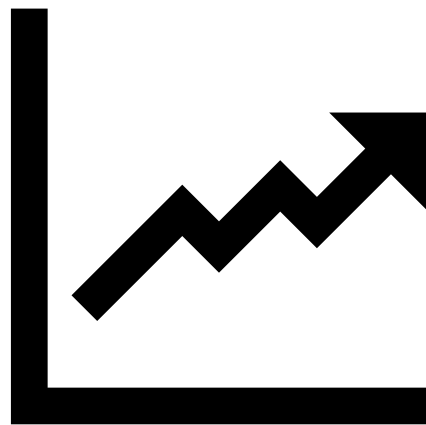
Stimulus discriminability  
improves with higher temporal  
resolution



# Information theory approach

- Information theory: “how well an ideal observer of neuronal responses can, on average, discriminate which stimulus occurred, based on a response observed on a single trial.”
- Results: 90% of information transmitted by the train could be accounted for by just the first spike in sequence timing. Later spikes were redundant, but informative.





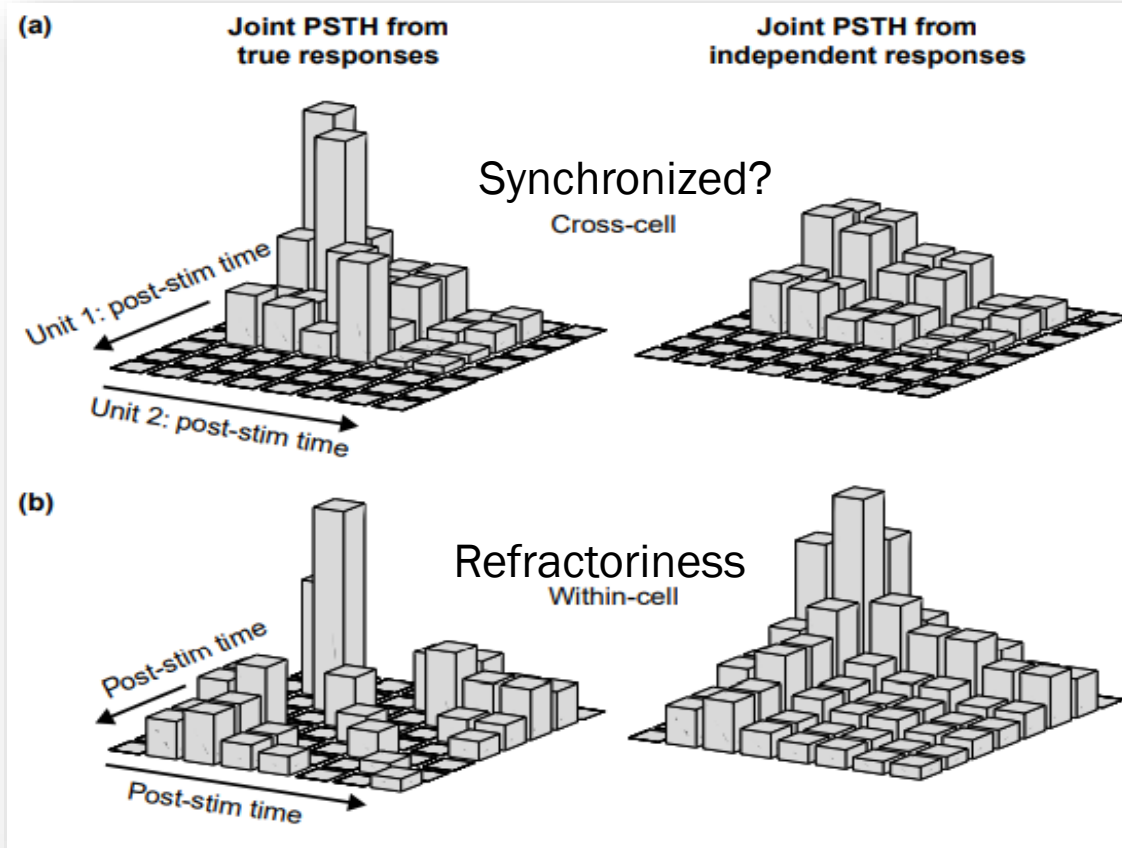
# **ROLE OF CORRELATED SPIKE PATTERNS**

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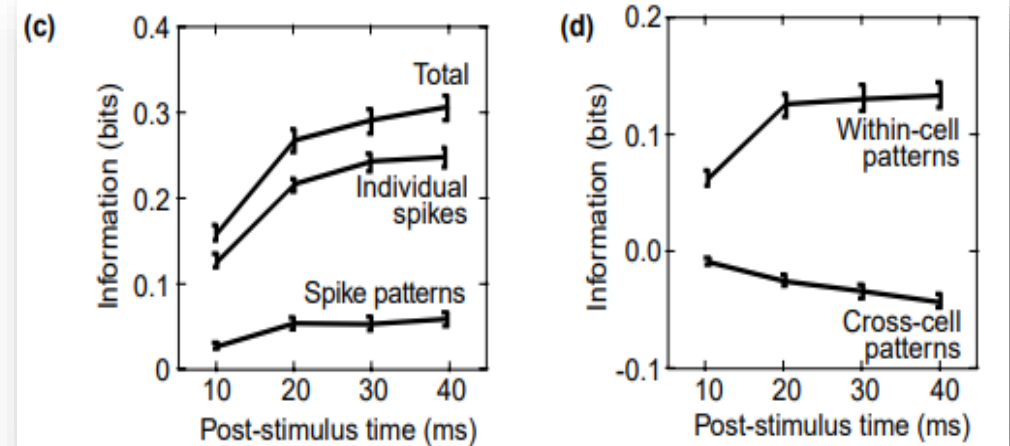
For population coding

# Role of correlated spike patterns

- Do correlations provide an ideal decoder with more precise information?



Petersen et al., 2002



Petersen et al., 2002

Results (52 pairs analyzed): cross-cell patterns are likely not synergistic

# Significance and Limitations



## Significance:

- A computer can be used to decode neuronal activity
- Implications for brain decoding technologies



## Limitations:

- Current statistical models may contradict one another: correlation vs redundancy
- An “ideal decoder” and its applicability

# Discussion points

Code  
features

Spatial  
organization

Widespread network vs  
restricted subset of neurons

Spike timing

Number of spikes over long  
time interval vs **precise**  
position of spike in time

Spike  
correlation

Are the **spikes independent**  
or is their correlation  
important?

# Conclusions



Neurons beyond the principal column of stimulation fire redundantly



Precise timing of individual spikes (especially the first one) are key for perceptual decision



Neuronal activation correlation account for a small amount of all available information during network activation



# Future Directions

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Cross-cell correlation: how can we use it better?

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Can we identify individual spikes for every single type of perceptual decision?

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How can ANN models reflect neural plasticity?

# References

1. Dayan & Abbott: Theoretical Neuroscience. MIT Press 2001
2. Petersen, R. S., Panzeri, S. & Diamond, M. E. Population coding in somatosensory cortex. *Curr. Opin. Neurobiol.* **12**, 441-447 (2002).

# References: Images and Videos

- <http://matlab.izmiran.ru/help/toolbox/nnet/selfor11.html>
- [https://www.researchgate.net/figure/fMRI-response-to-rat-whisker-barrel-cortex-stimulation-A-Group-statistical-activation\\_fig4\\_267272836](https://www.researchgate.net/figure/fMRI-response-to-rat-whisker-barrel-cortex-stimulation-A-Group-statistical-activation_fig4_267272836)
- <http://i.imgur.com/PUXBQ2W.jpg>
- <https://www.xenonstack.com/blog/data-science/artificial-neural-networks-applications-algorithms/>
- <https://www.youtube.com/watch?v=aircAruvnKk>