
WHAT YOUR FAVORITE MAP PROJECTION SAYS ABOUT YOU
MERCATOR
YOU'RE NOT REALLY INTO MAPS.
VAN DER GRINTEN
YOU'RE NOT A COMPLICATED PERSON. YOU LOVE THE MERCATOR PROJECTION; YOU JUST WISH IT WEREN'T SQUARE. THE EARTH'S NOT A SQUARE, IT'S A CIRCLE. YOU LIKE CIRCLES. TODAY IS GONNA BE A GOOD DAY!
ROBINSON
YOU HAVE A COMFORTABLE PAIR OF RUNNING SHOES THAT YOU WEAR EVERYWHERE. YOU LIKE COFFEE AND ENJOY THE BEATLES. YOU THINK THE ROBINSON IS THE BEST-LOOKING PROJECTION, HANDS DOWN.
DYMAXION
YOU LIKE ISAAC ASIMOV, XML, AND SHOES WITH TOES. YOU THINK THE SEGWAY GOT A BAD RAP. YOU OWN 3D GOGGLES, WHICH YOU USE TO VIEW ROTATING MODELS OF BETTER 3D GOGGLES. YOU TYPE IN DVORAK.
WINKEL-TRIPEL
NATIONAL GEOGRAPHIC ADOPTED THE WINKEL-TRIPEL IN 1998, BUT YOU'VE BEEN A W-T FAN SINCE *LONG* BEFORE "NAT GEO" SHOWED UP. YOU'RE WORRIED IT'S GETTING PLAYED OUT, AND ARE THINKING OF SWITCHING TO THE KAVRAYSKIY. YOU ONCE LEFT A PARTY IN DISGUST WHEN A GUEST SHOWED UP WEARING SHOES WITH TOES. YOUR FAVORITE MUSICAL GENRE IS "POST-".
HOBO-DYER
YOU WANT TO AVOID CULTURAL IMPERIALISM, BUT YOU'VE HEARD BAD THINGS ABOUT GALL-PETERS. YOU'RE CONFLICT-AVERSE AND BUY ORGANIC. YOU USE A RECENTLY-INVENTED SET OF GENDER-NEUTRAL PRONOUNS AND THINK THAT WHAT THE WORLD NEEDS IS A REVOLUTION IN CONSCIOUSNESS.
GOODE HOMOLOSINE
THEY SAY MAPPING THE EARTH ON A 2D SURFACE IS LIKE FLATTENING AN ORANGE PEEL, WHICH SEEMS EASY ENOUGH TO YOU. YOU LIKE EASY SOLUTIONS. YOU THINK WE WOULDN'T HAVE SO MANY PROBLEMS IF WE'D JUST ELECT *NORMAL* PEOPLE TO CONGRESS INSTEAD OF POLITICIANS. YOU THINK AIRLINES SHOULD JUST BUY FOOD FROM THE RESTAURANTS NEAR THE GATES AND SERVE *THAT* ON BOARD. YOU CHANGE YOUR CAR'S OIL, BUT SECRETLY WONDER IF YOU REALLY *NEED* TO.
PLATE CARRÉE
(EQUIRECTANGULAR)
YOU THINK THIS ONE IS FINE. YOU LIKE HOW X AND Y MAP TO LATITUDE AND LONGITUDE. THE OTHER PROJECTIONS OVERCOMPLICATE THINGS. YOU WANT ME TO STOP ASKING ABOUT MAPS SO YOU CAN ENJOY DINNER.
A GLOBE!
YES, YOU'RE VERY CLEVER.
PEIRCE QUINCUNCIAL
YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.
WATERMAN BUTTERFLY
REALLY? YOU KNOW THE WATERMAN? HAVE YOU SEEN THE 1909 CAHILL MAP IT'S BASED— ...YOU HAVE A FRAMED REPRODUCTION AT HOME?! WHOA. ...LISTEN, FORGET THESE QUESTIONS. ARE YOU DOING ANYTHING TONIGHT?
GALL-PETERS
I *HATE* YOU.

Questions from session 1

Q1.1 (Polina)

The replication crisis in psychology raised questions about whether many "established" findings are real. What mechanistic role, if any, could computational modelling play in addressing this crisis?

Q1.2 (Juan)

We have presented models as tools for understanding. However, models are increasingly also tools for prediction and control, specially in AI. When does a model's usefulness for control become ethically problematic, even if it aids understanding? Should neuroscientists consider how their models might be used?

Q1.3 (Shiru)

Foucault argued that scientific categories do not merely describe reality but actively shape it through institutional power. If this is true, what responsibility do scientists bear for the categories they create and propagate? Can a model be simultaneously useful, socially constructed, and in some sense true?

Q1.4 (Miguel)

For Judith Butler, gender is not discovered but performed into existence: a model that consolidates itself through use. Do you agree with Butler? Consider Box's aphorism. In what sense is gender a “wrong" model? In what sense is it a “useful" model? And useful for whom? Apply the same reasoning to sexuality.

Q1.6 (Izei)

The same data often support multiple, incompatible interpretations. This is the underdetermination problem in philosophy of science. If data can't uniquely determine theory, what does? Aesthetics? Social consensus? Pragmatic success? What implications does this have for neuroscience?

Q1.9 (Jacy)

Consider Chomsky's generative grammar. Where does it fit within Marr's three levels? Where does it not? Has the separation of levels been productive for linguistics? What are the costs and benefits of developing theory largely independently of neural data?

Q1.11 (Francesca)

V1 neurons respond to oriented edges. How do we get from this to recognising your grandmother's face? Sketch out what you think the computational problem is at each subsequent stage. Where do you think the biggest gaps in our understanding are?

Representation of information

Computational Neuroscience - Lecture 2

Alejandro Tabas

Computational models in Neuroscience research

1. What is a representation?
2. Single-unit codes and receptive fields
3. Measuring receptive fields
4. Population codes
5. Transformation of information
6. Conclusions
7. Mind reading

Computational models in Neuroscience research

1. **What is a representation?**
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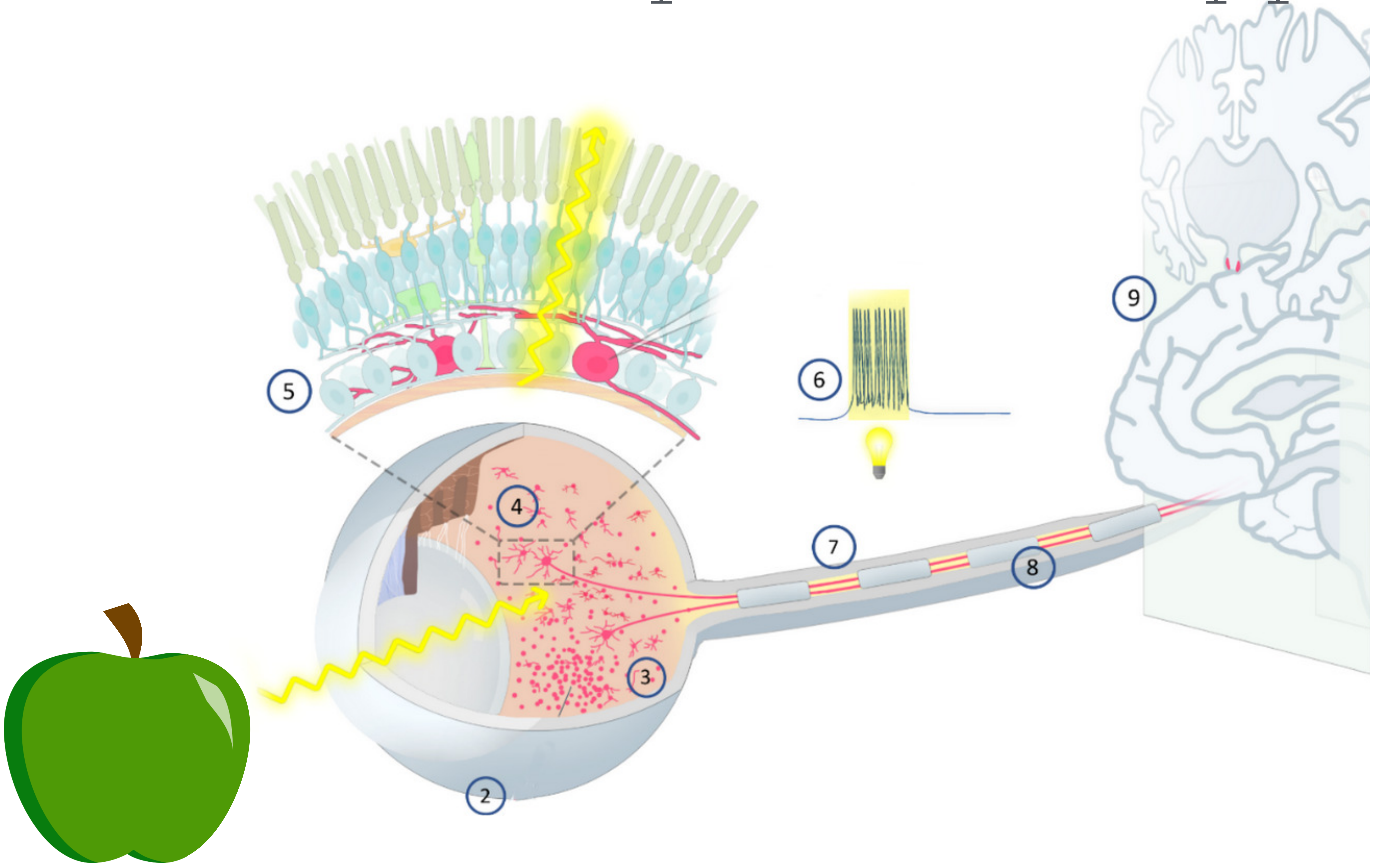
What is a representation?

Lets forget about the brain for a minute…

- What does it mean to represent something? What is a representation?
- Can you think of any example of a representation?
- What makes a good/bad representation?

How does the brain represent an apple?



How does the brain represent information?

Think of some examples of information that you are sure the brain represents

- Does everything we know and think have to be represented in the brain?

What specific resources does the brain have to represent information?

- Do all neuronal spikes encode a representation of information?
- Do all synaptic connections encode a representation of information?

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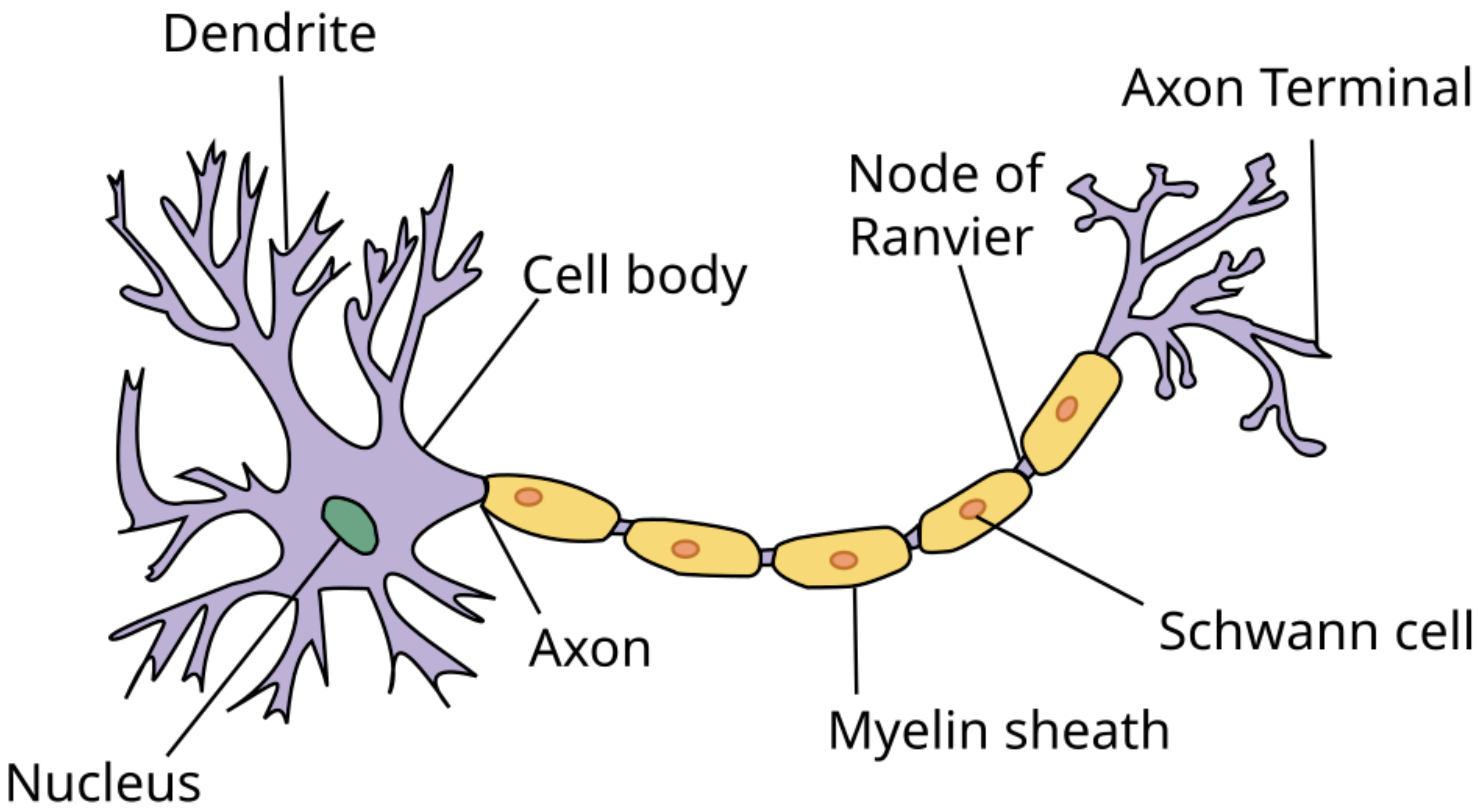
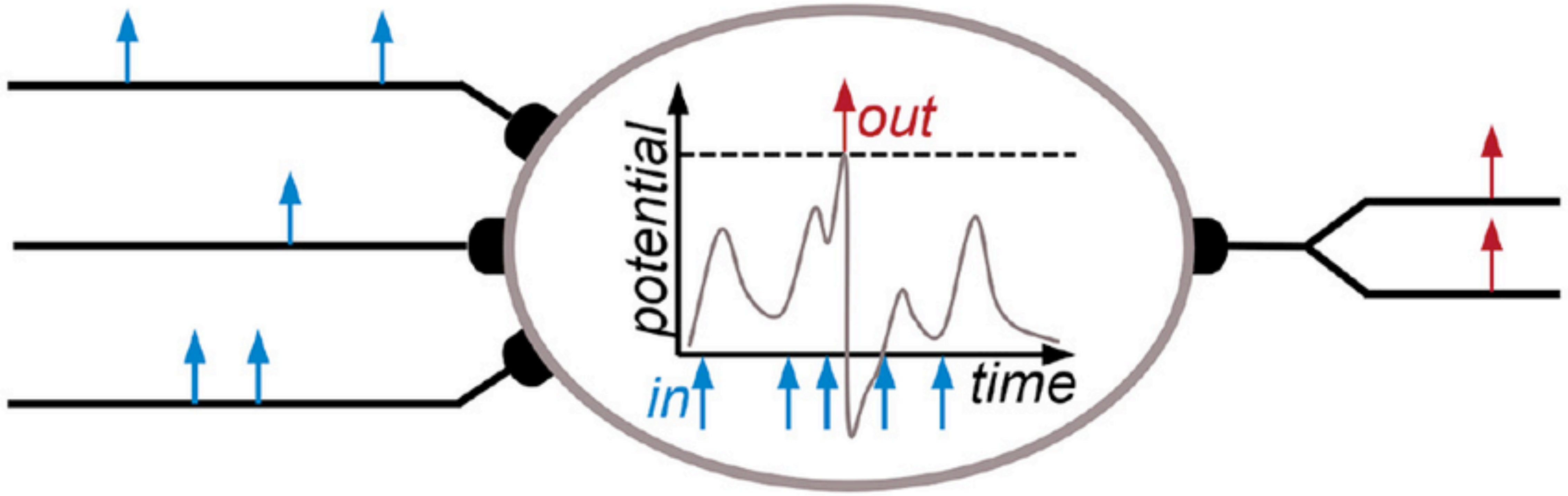
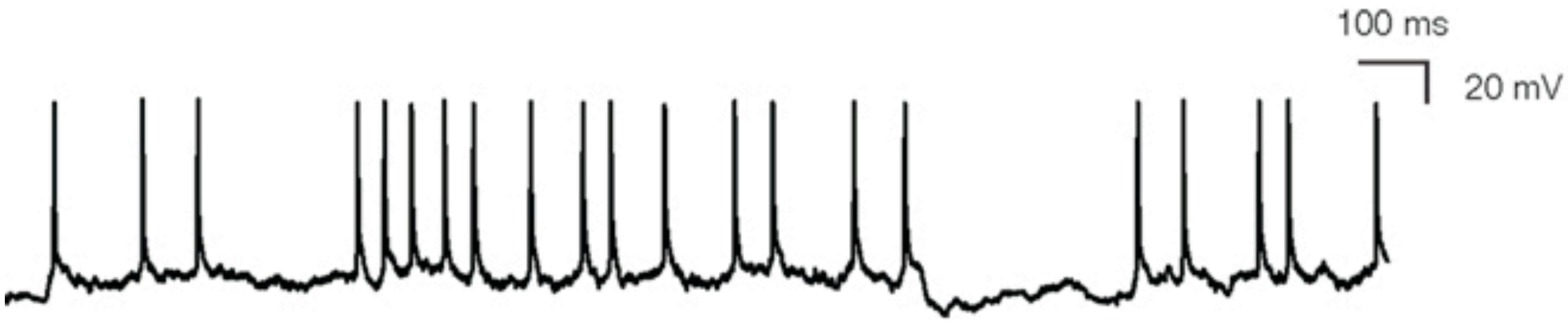
Neuronal spikes

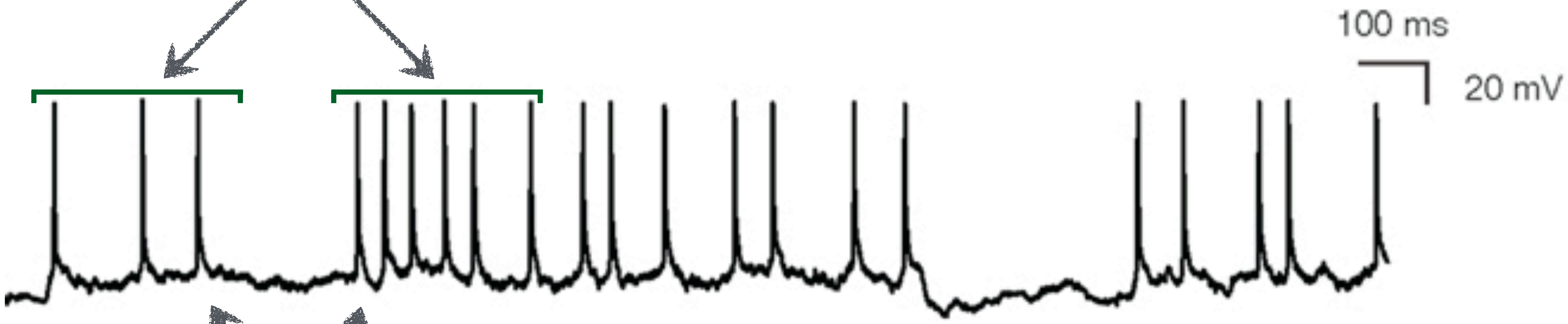






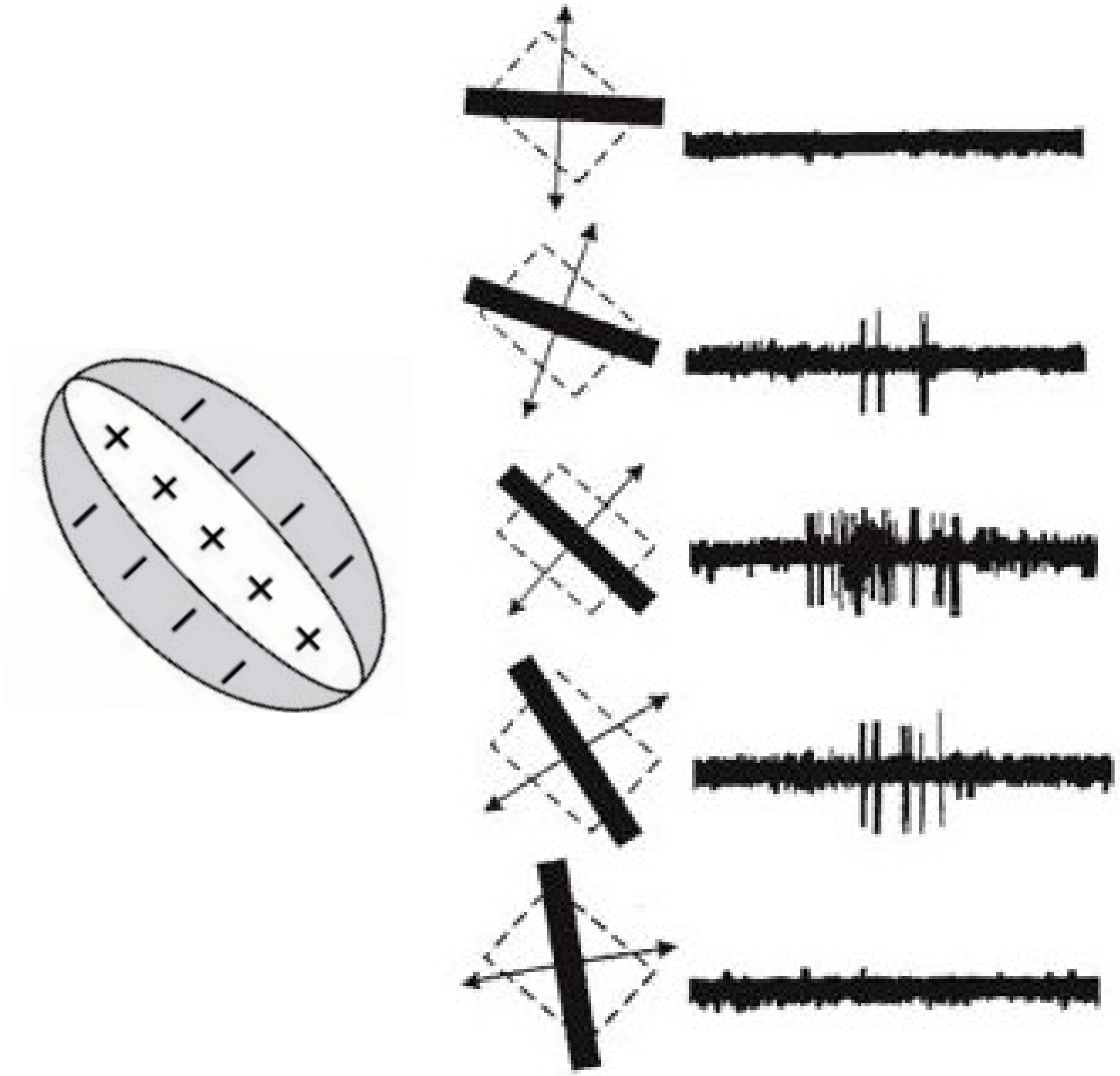
How can single neurons encode information?

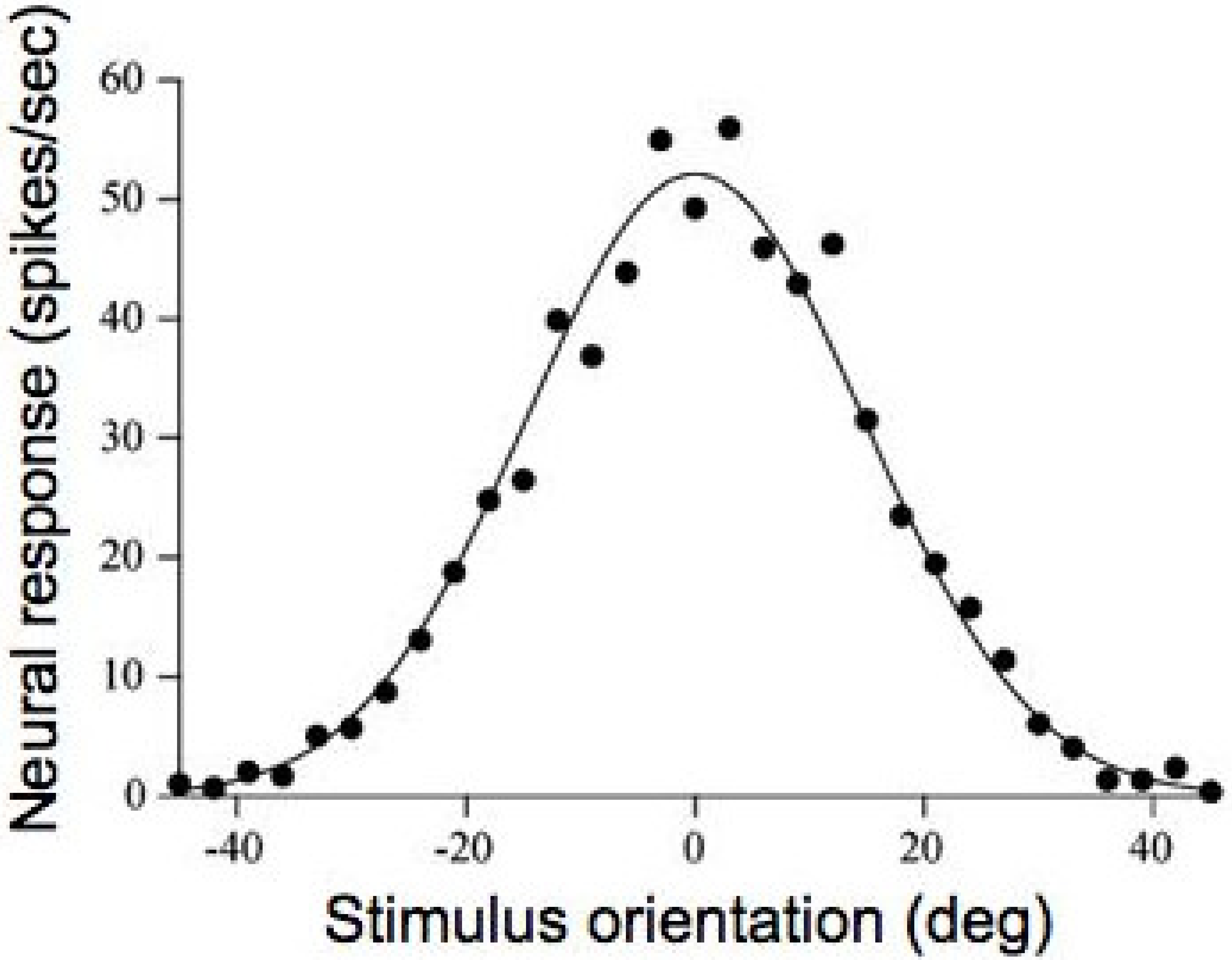
Amount of spikes
per unit of time
(activity, firing rate)



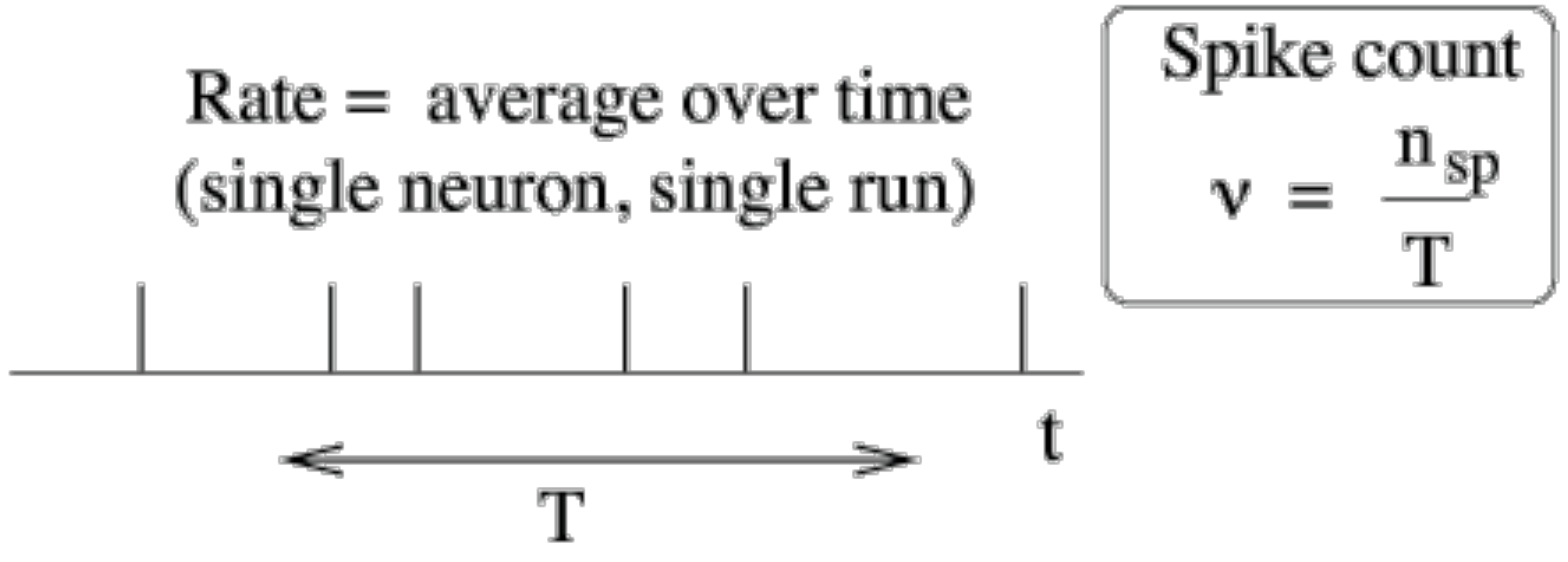
Spike timing

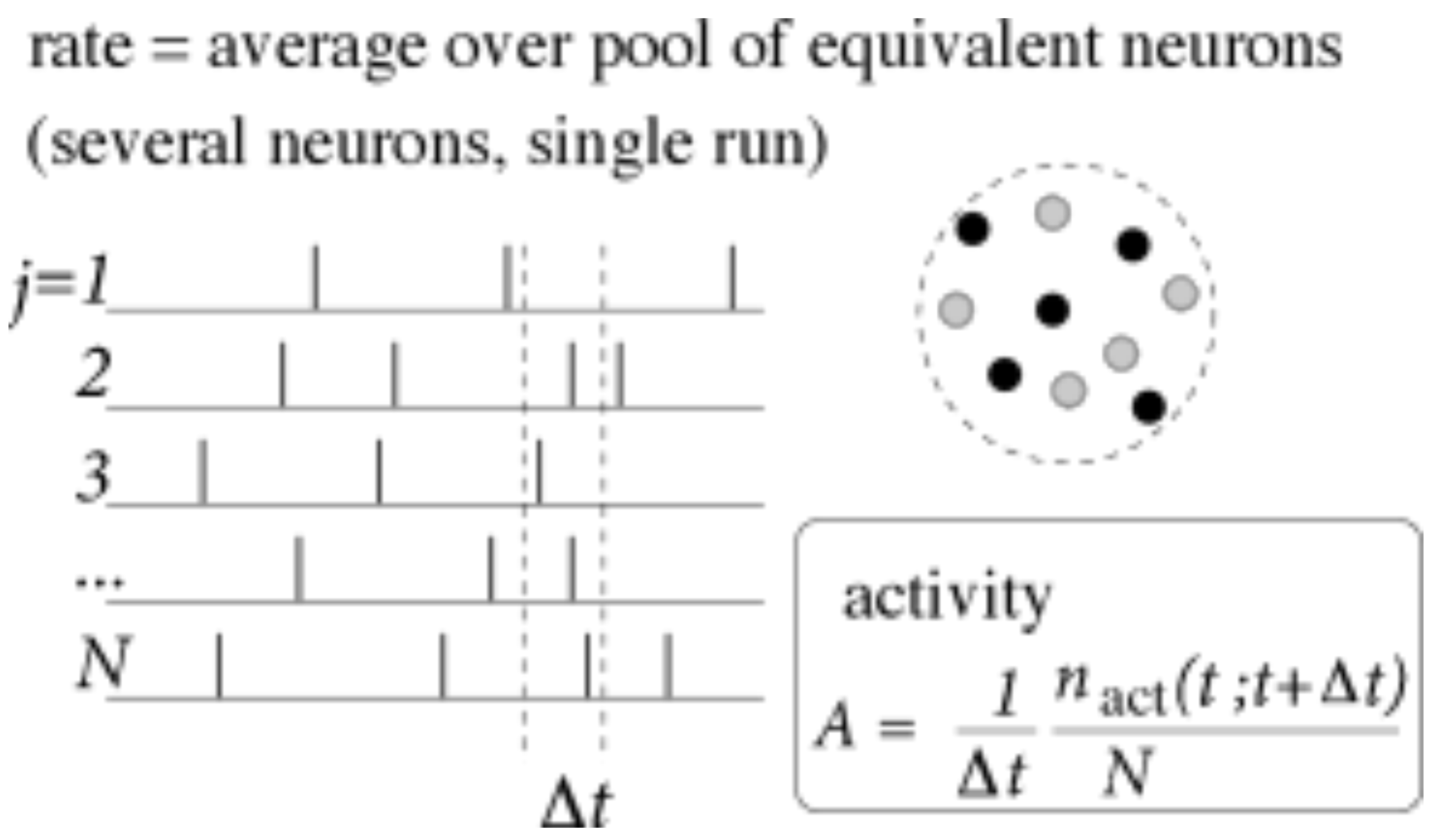
Example: V1 receptive fields

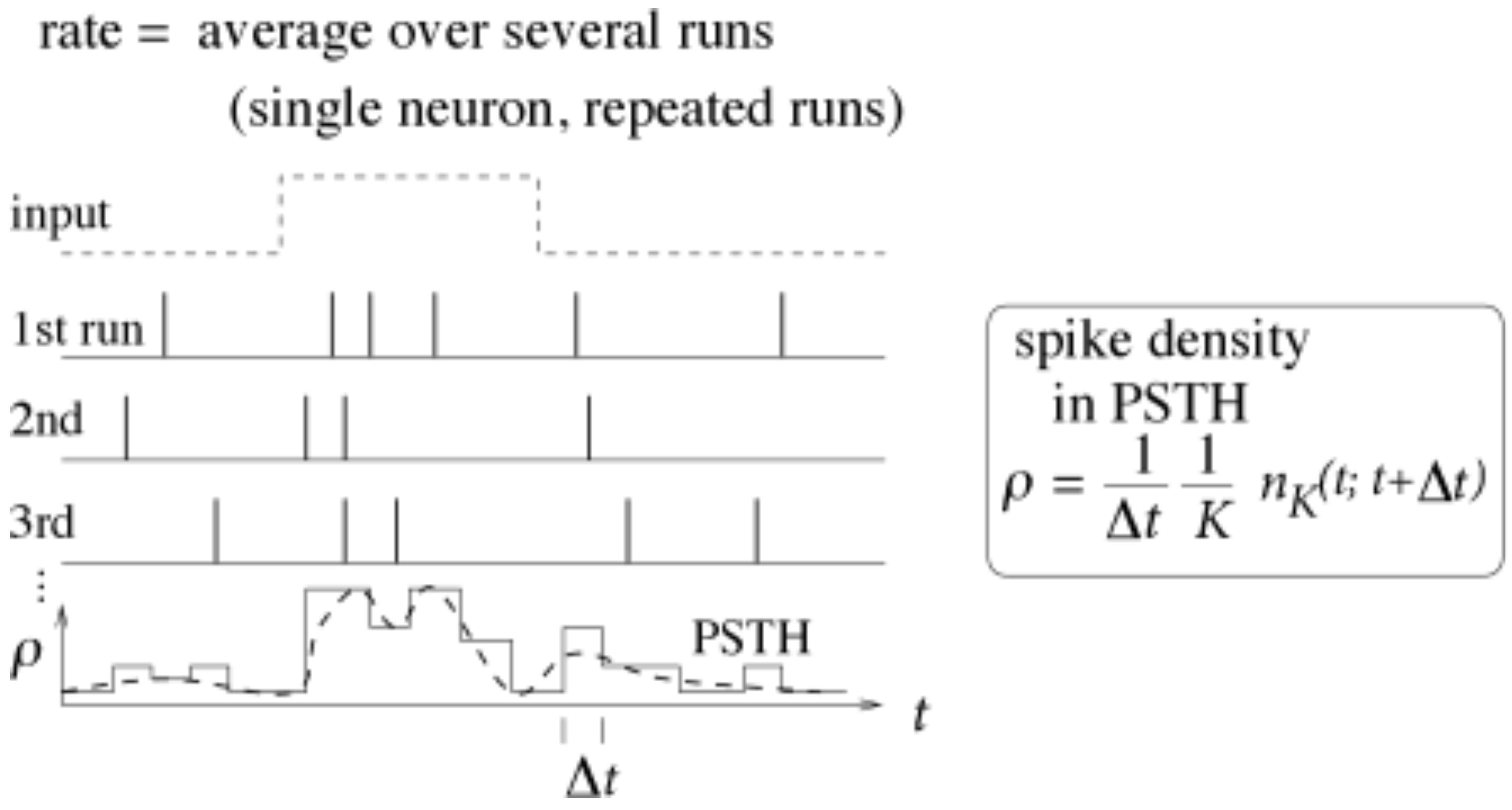




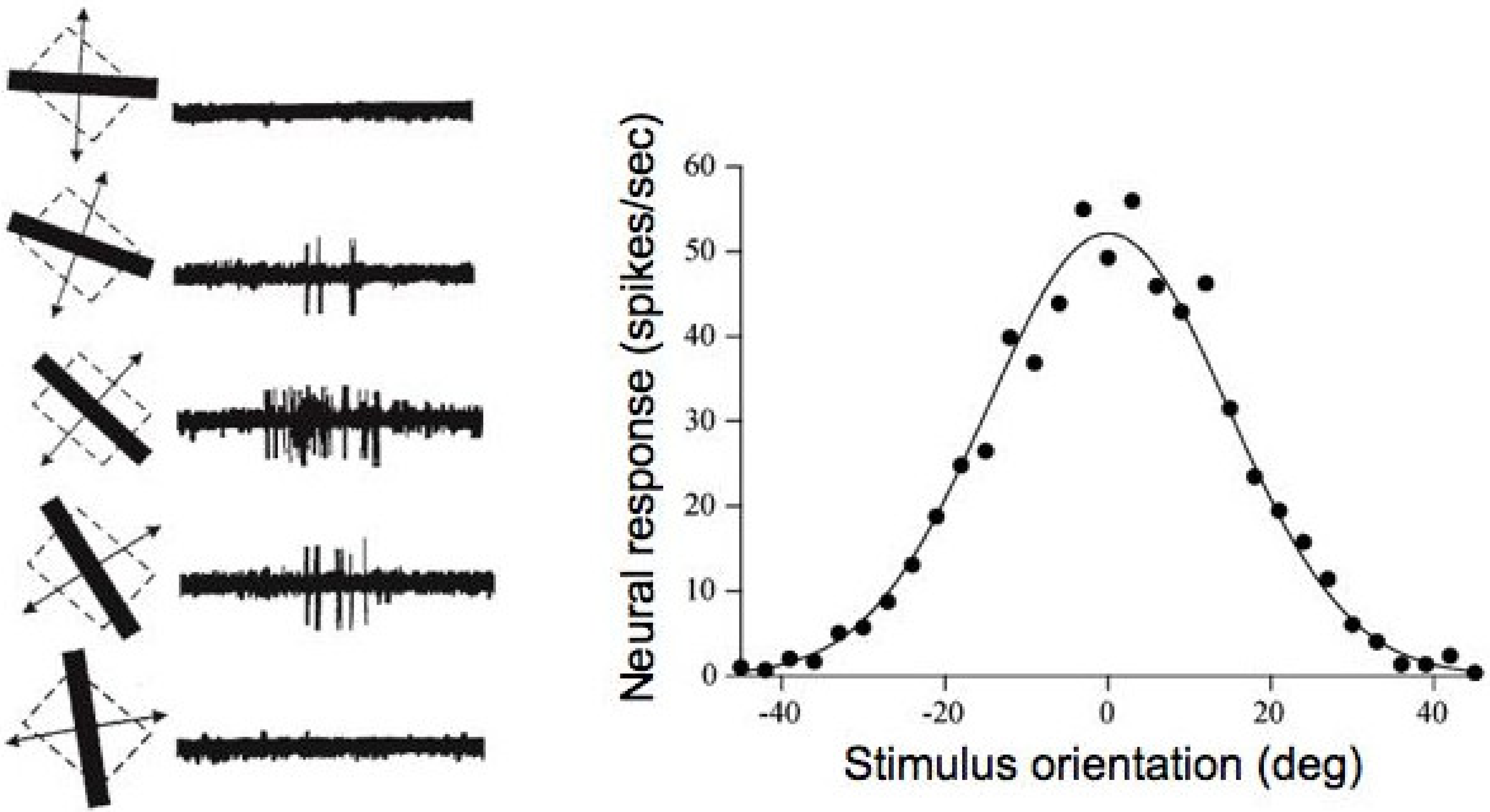
Three ways to define firing rate



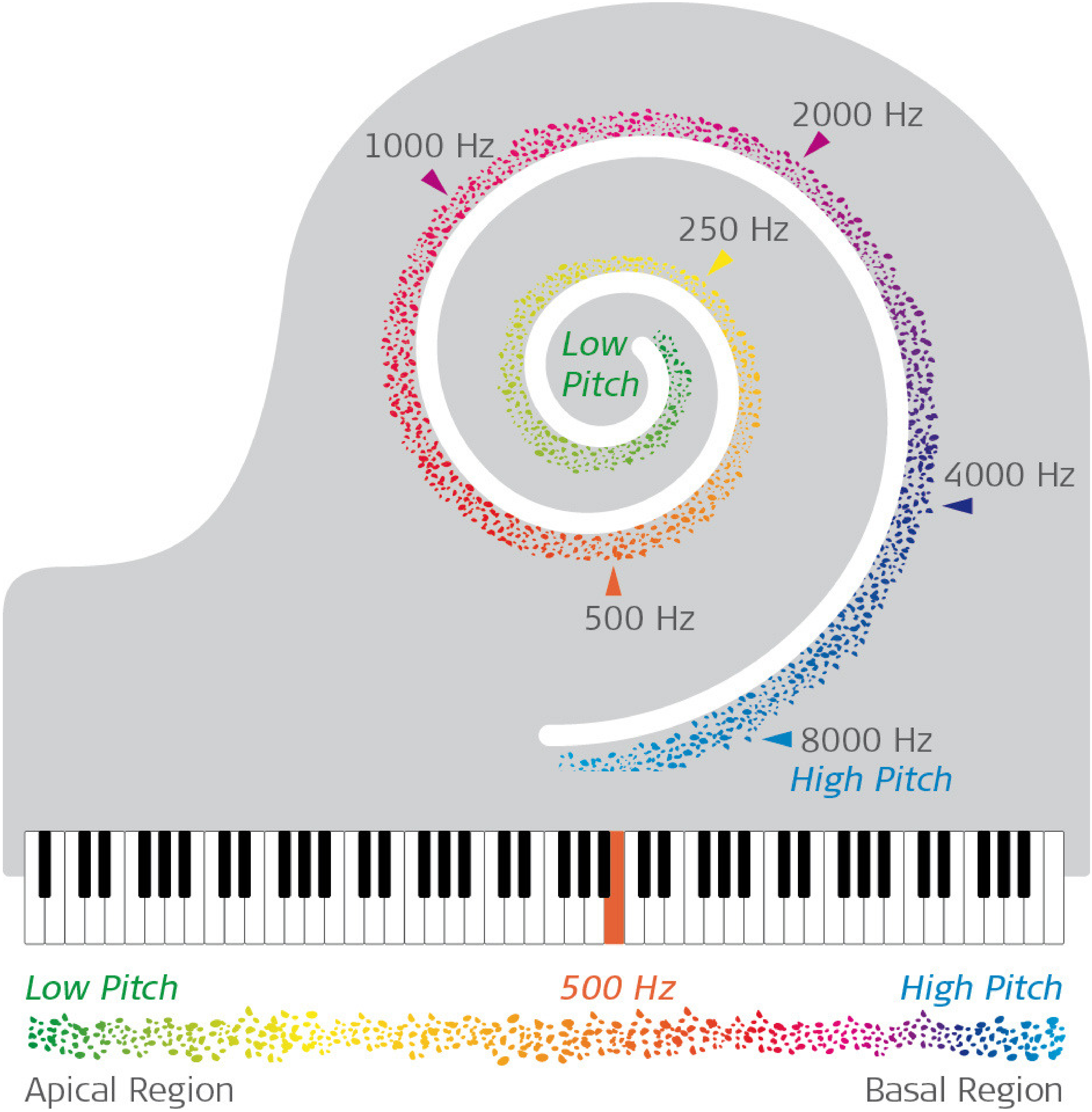


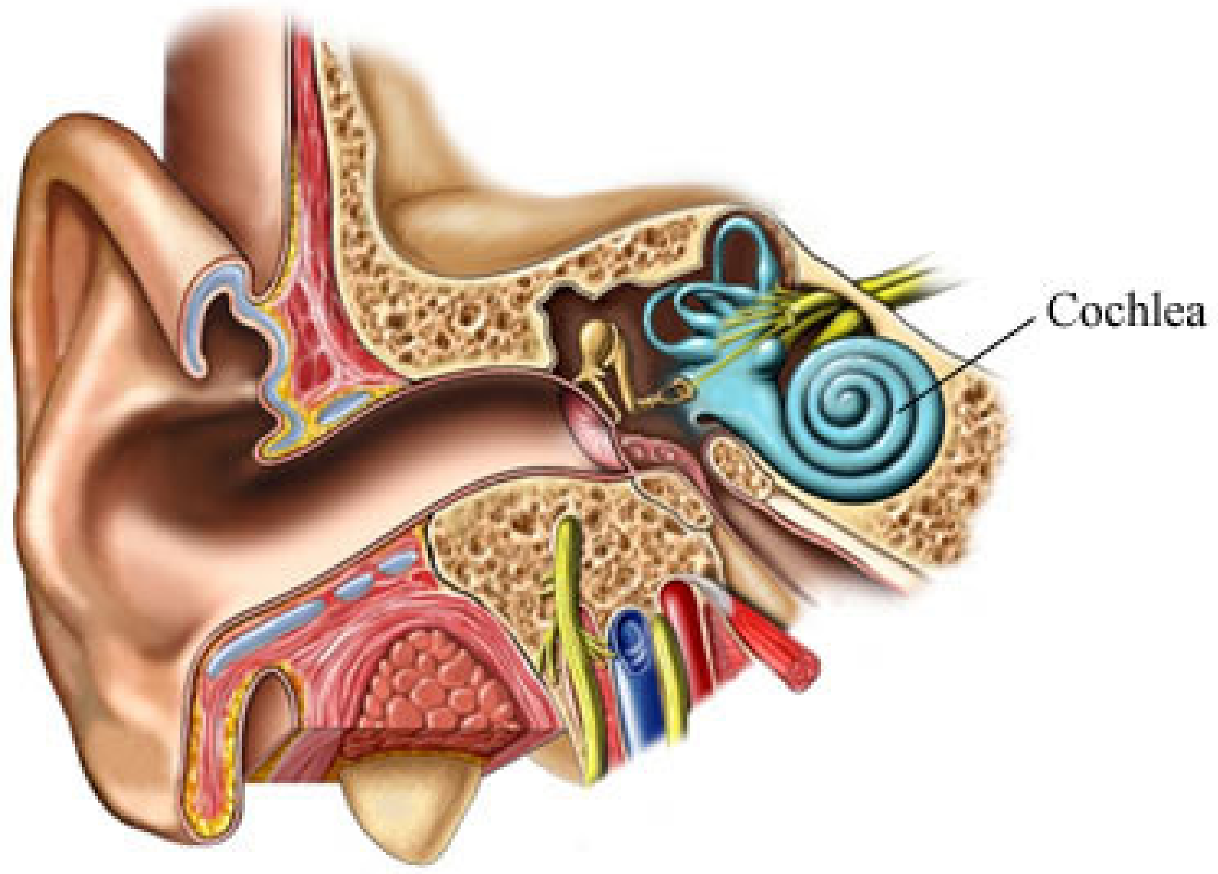


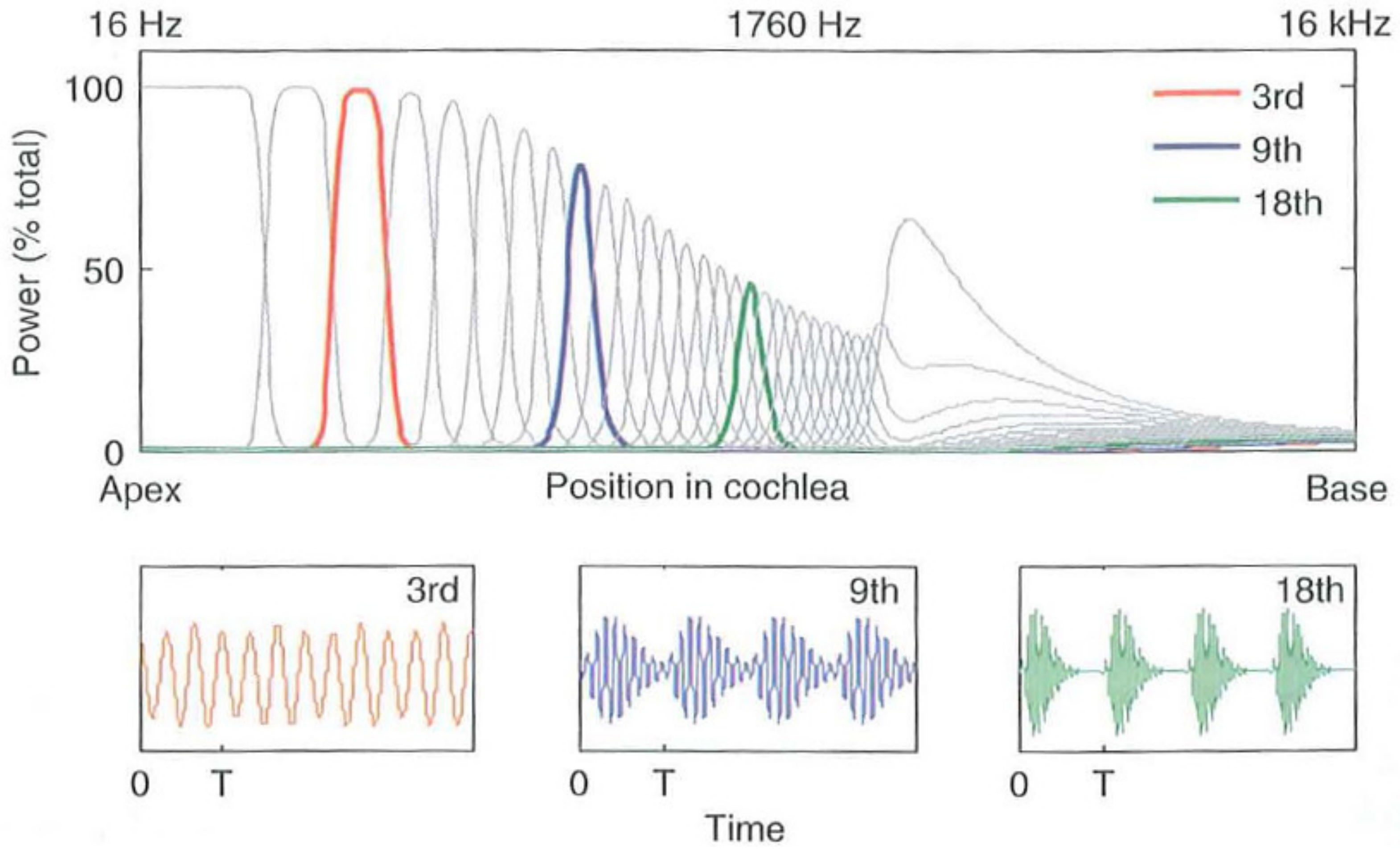
Example: V1 receptive fields



Example: auditory receptive fields

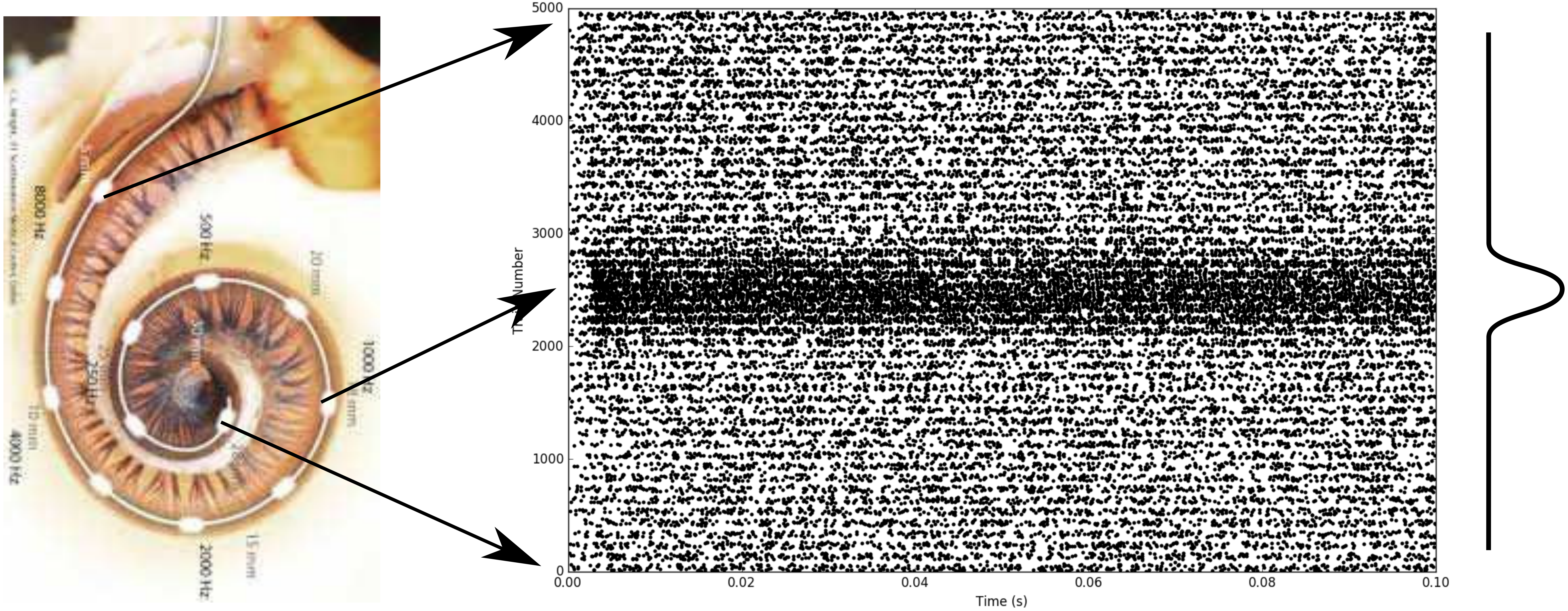






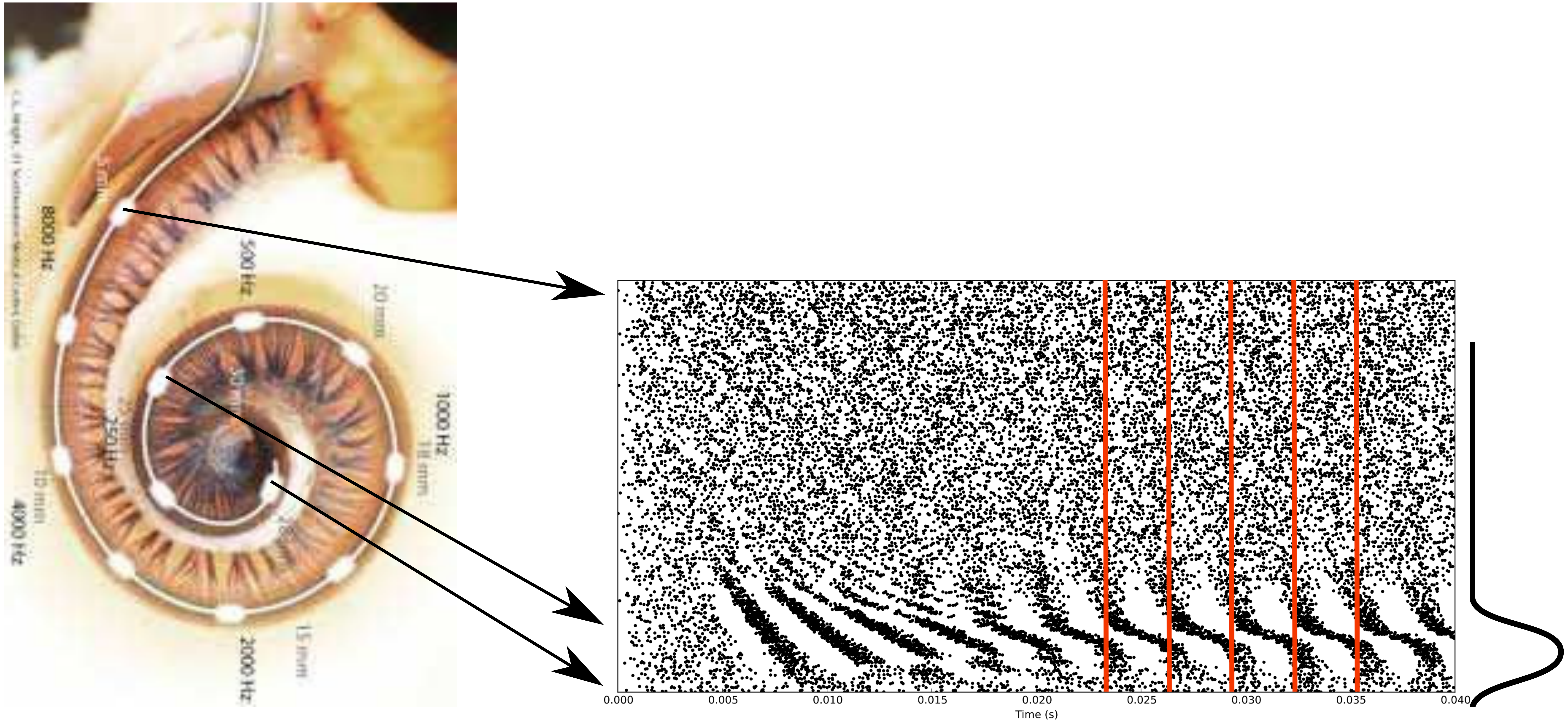
Example: auditory receptive fields

raster plot for an iterated rippled noise with $f_0 = 1000$ Hz

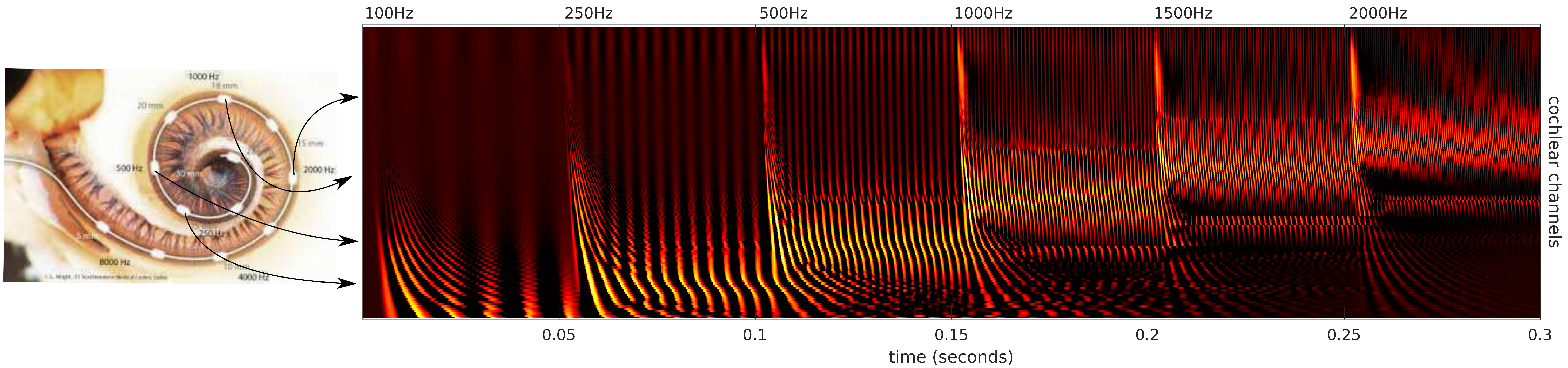


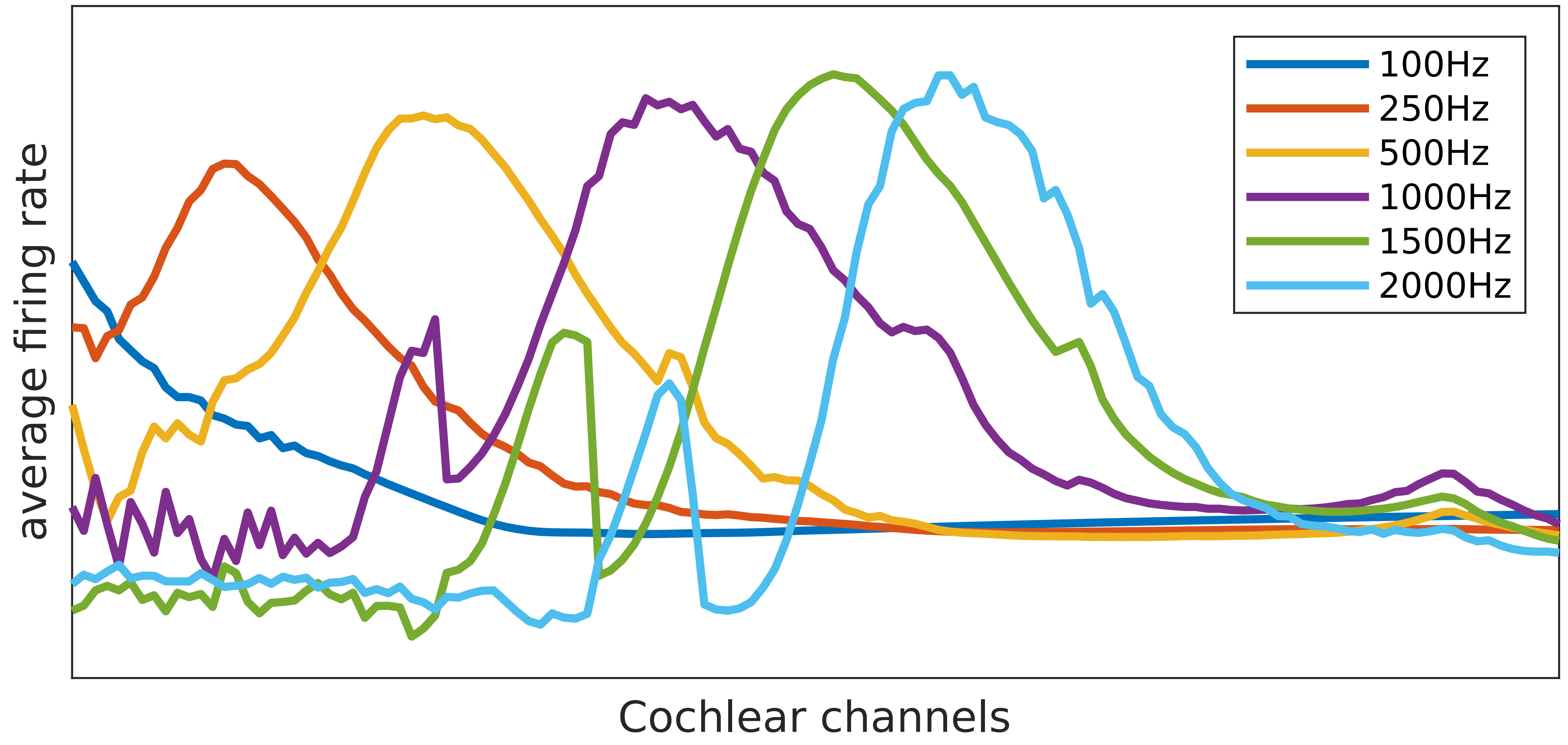
Example of a time code: phase locking

raster plot for a pure tone with $f = 200$ Hz

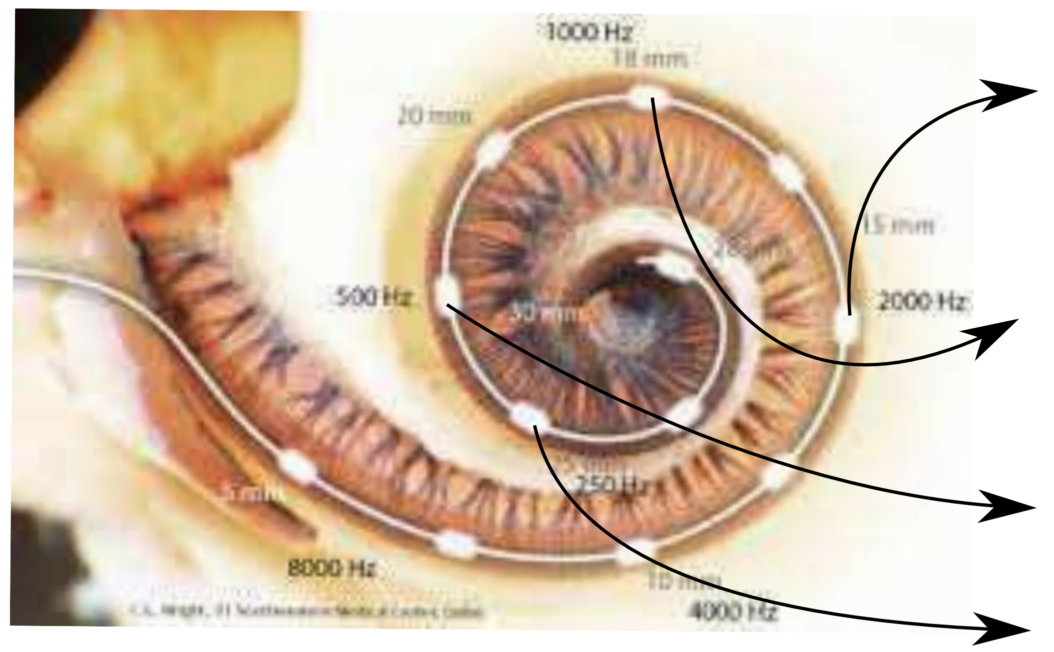


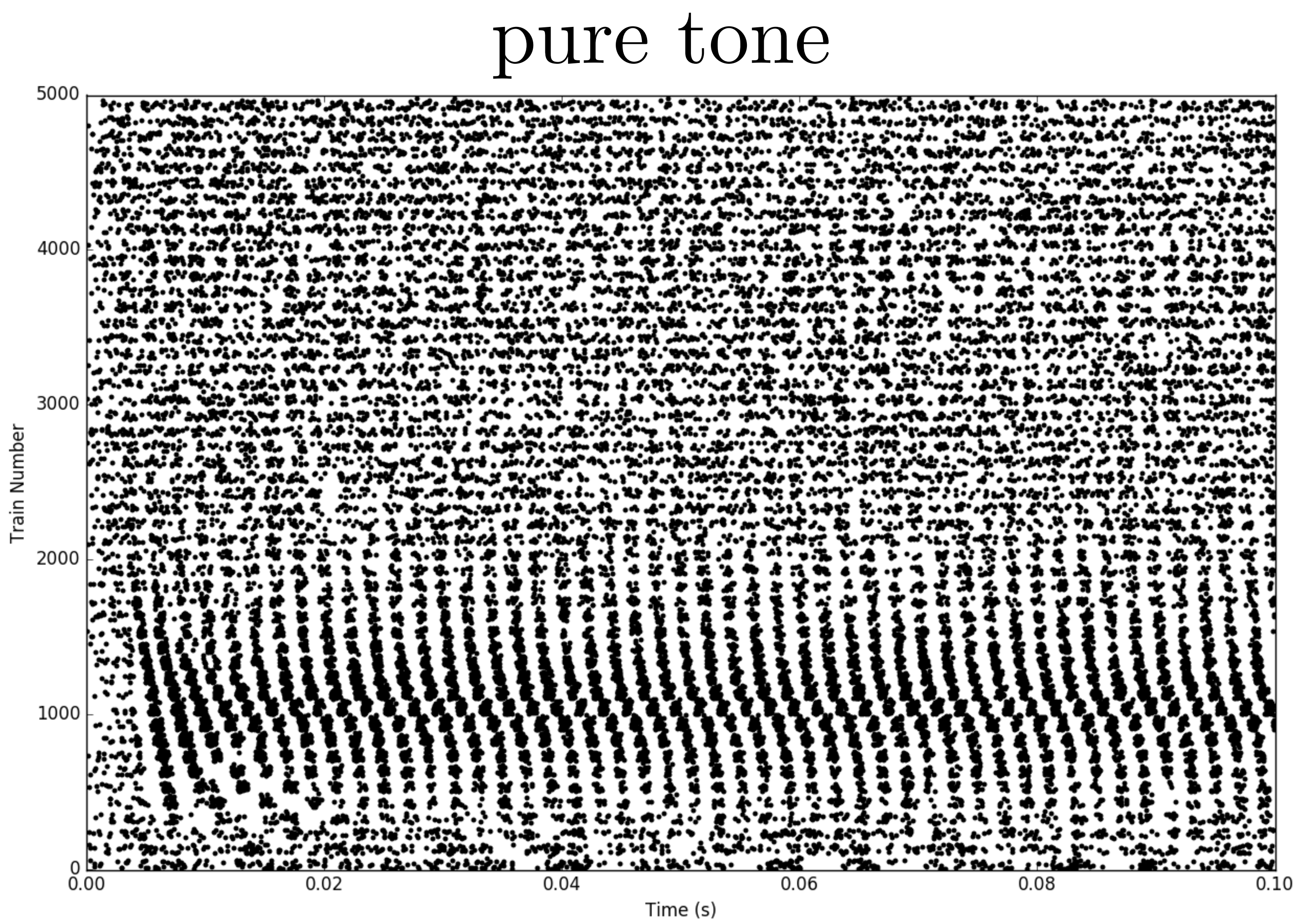
Auditory receptive fields: rate and time codes

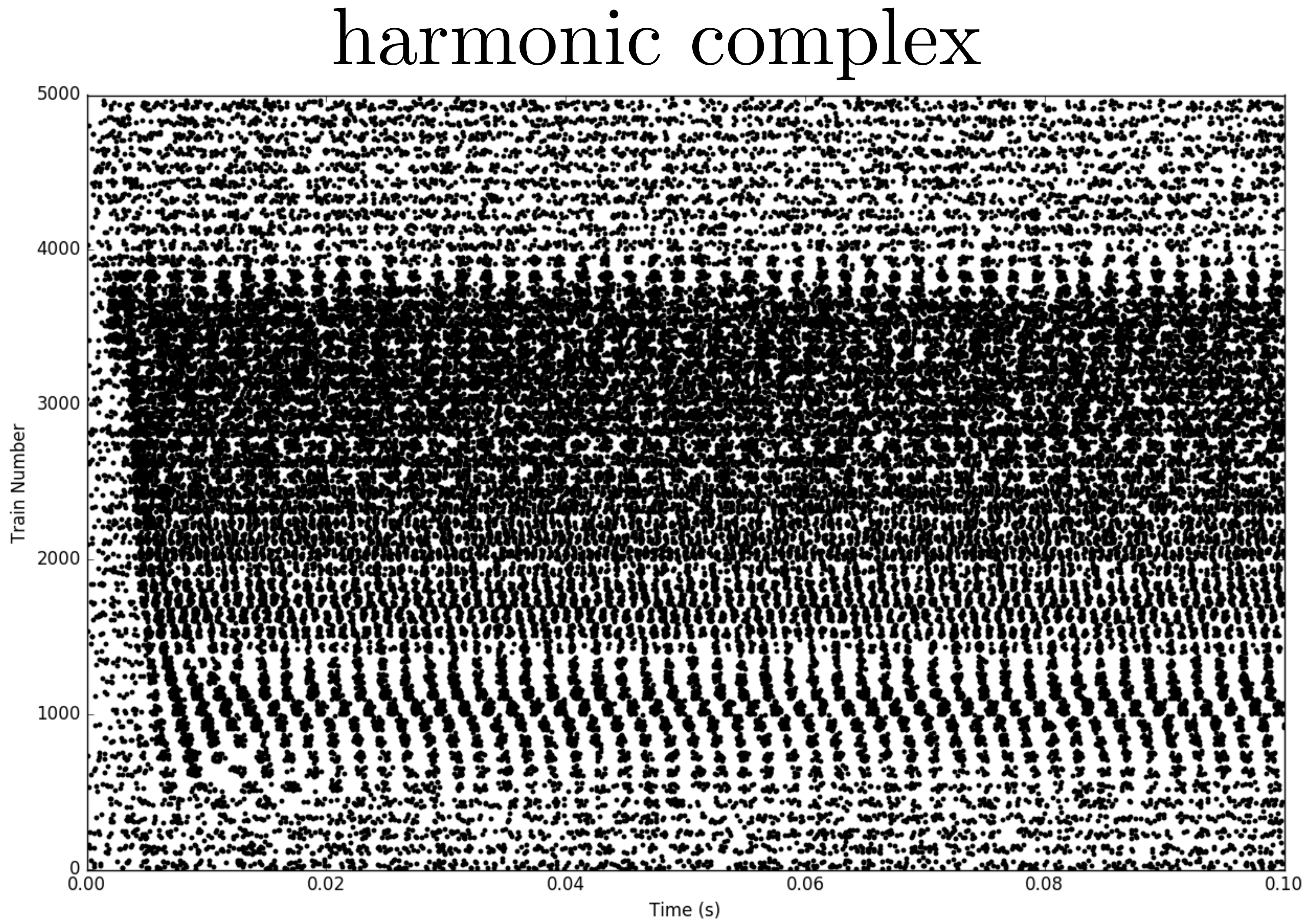


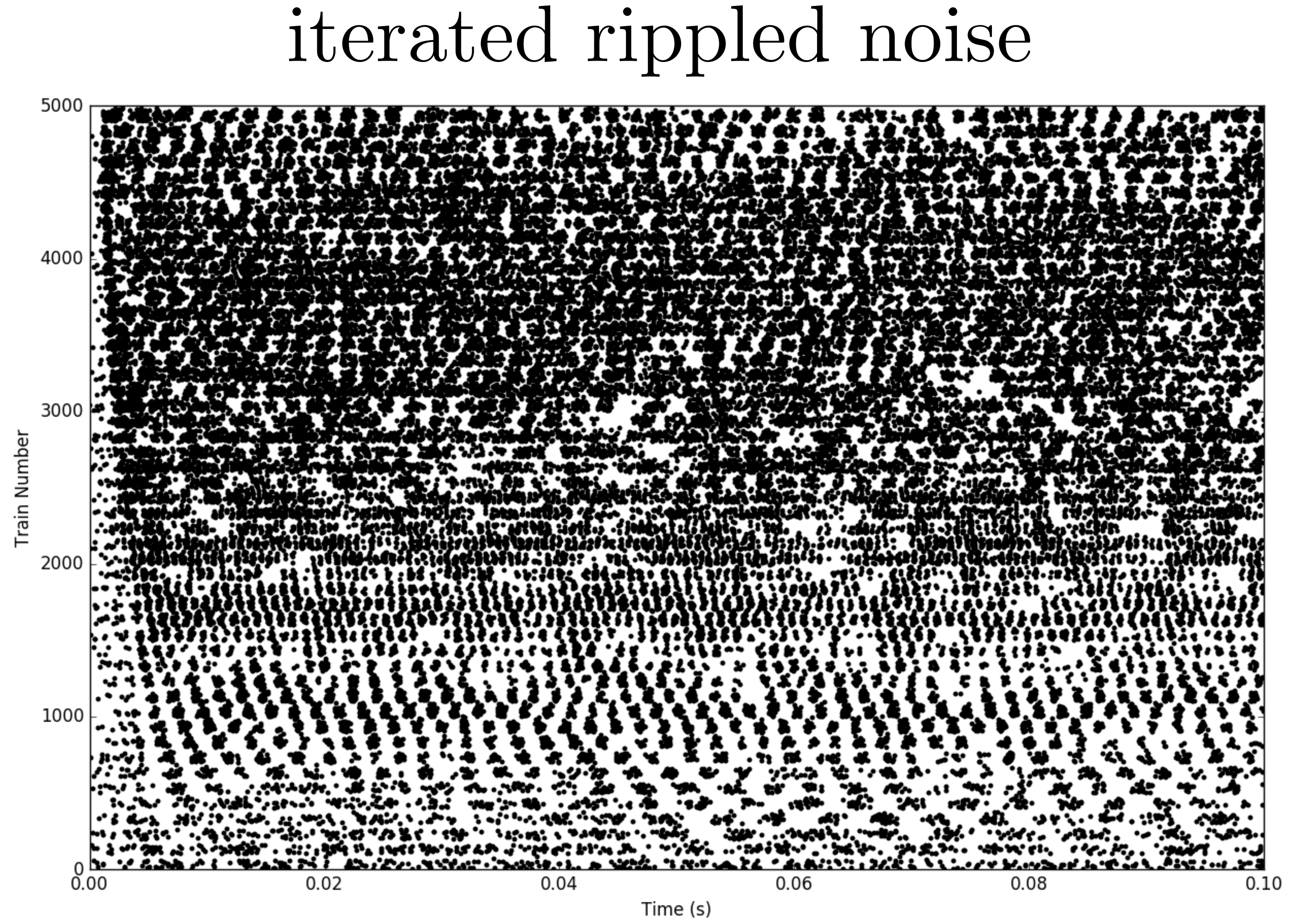


Auditory receptive fields: rate and time codes

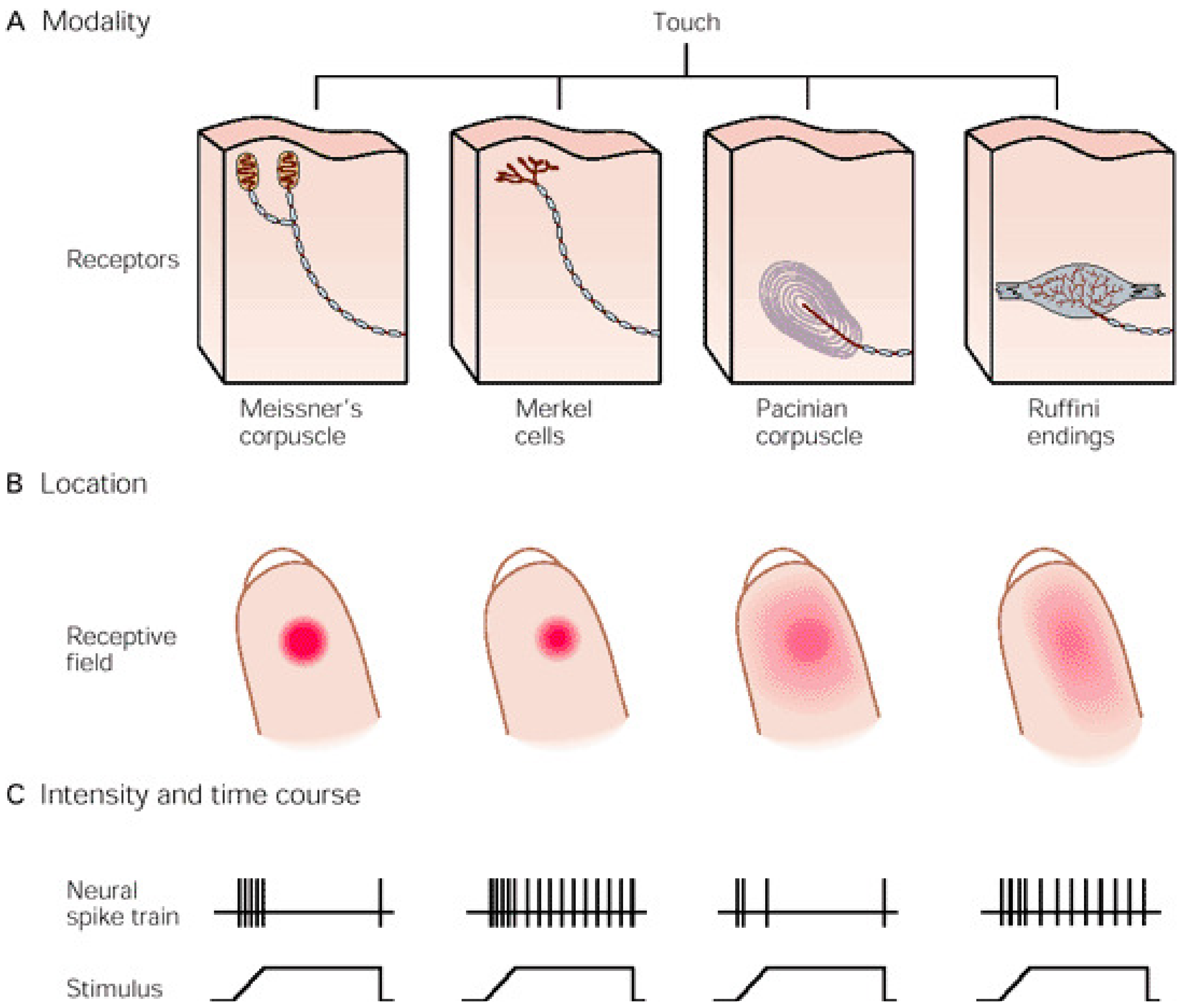




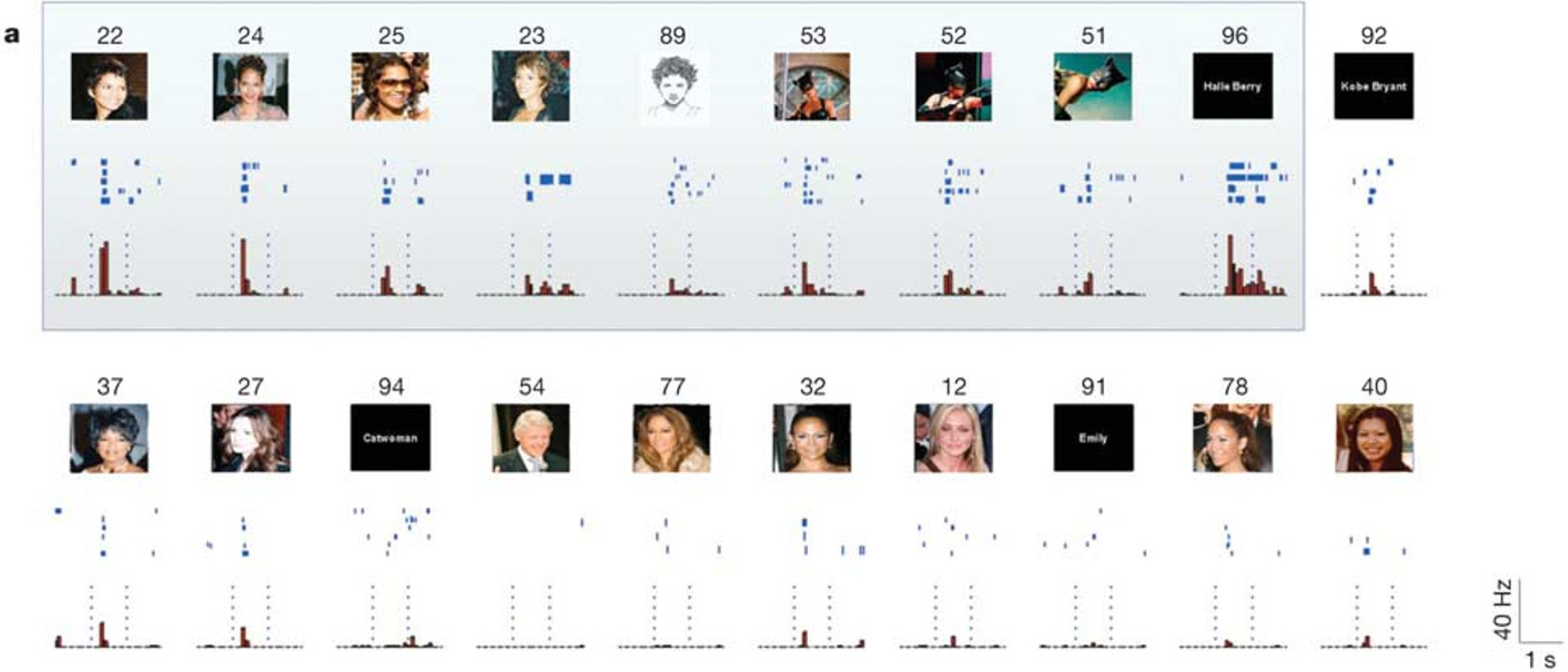




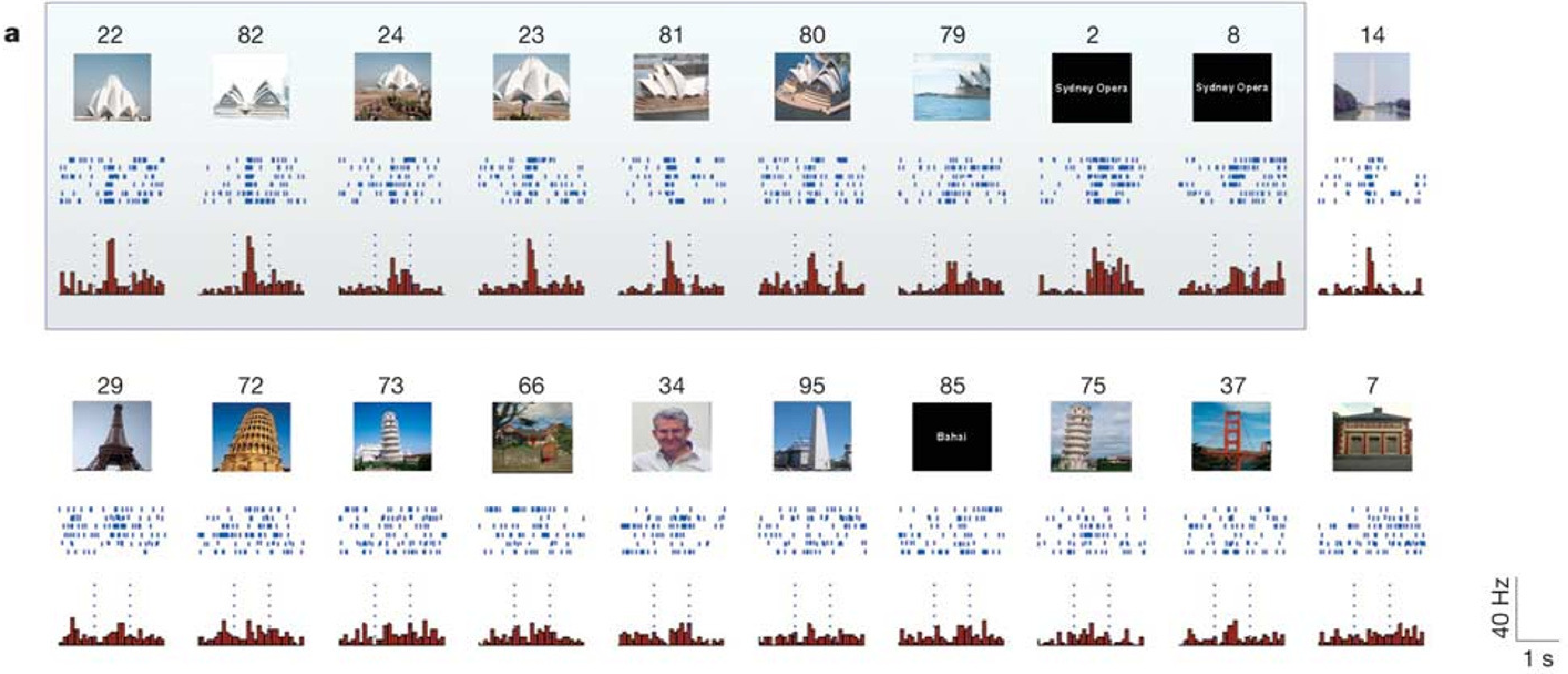
Example: Somatosensory receptive fields



Example: Abstract receptive fields



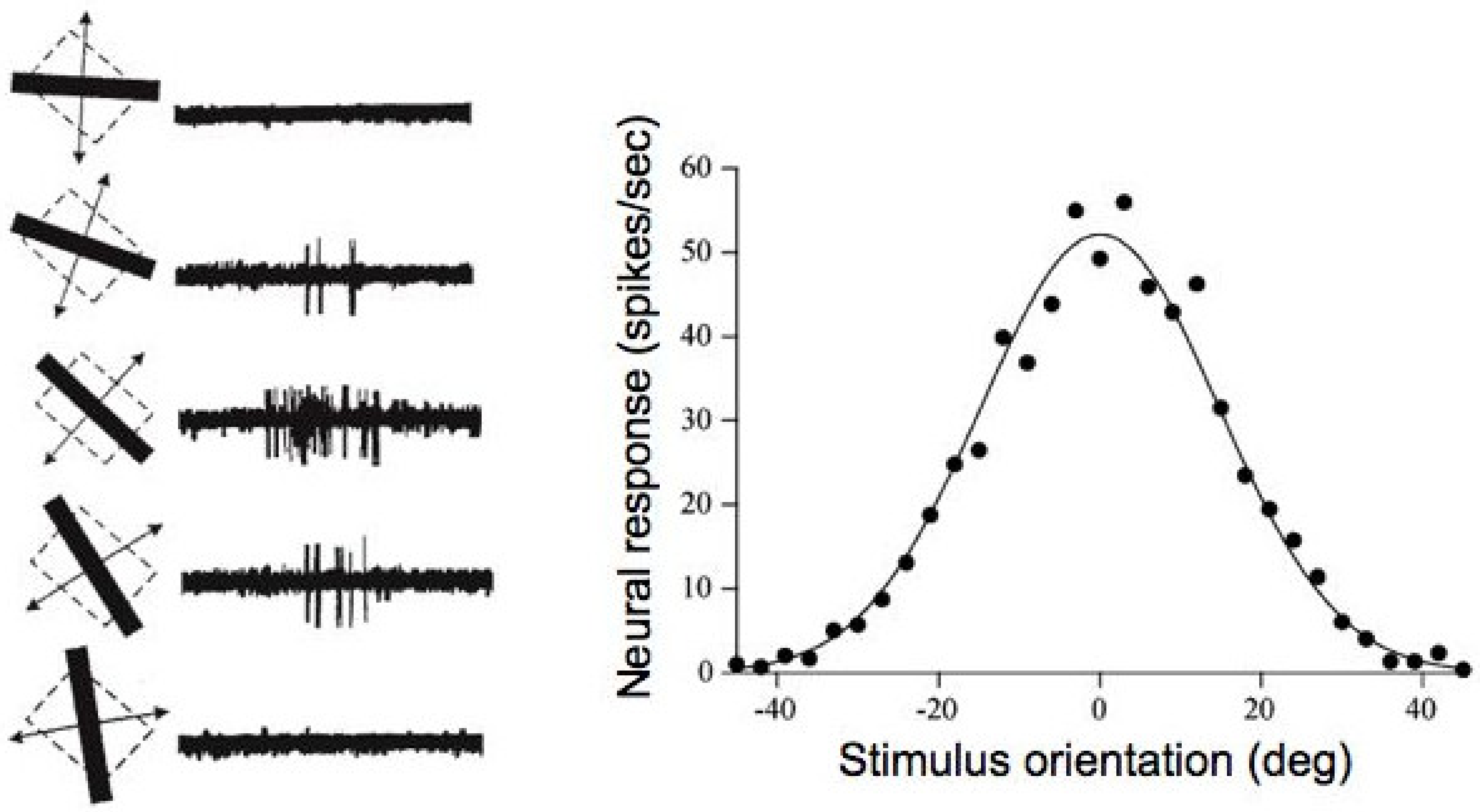
Example: Abstract receptive fields

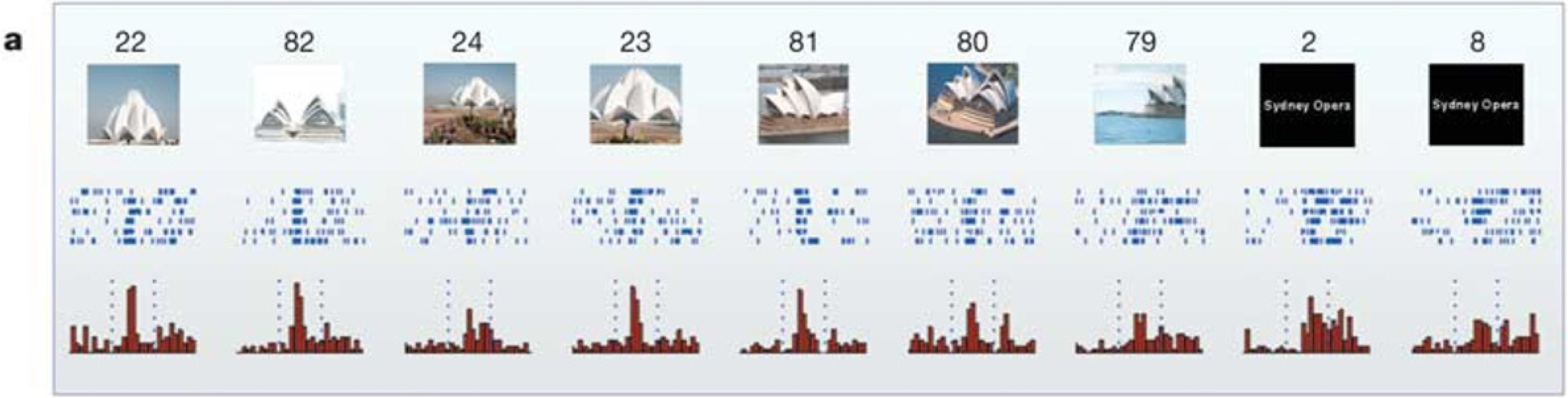


Invariance

Consider these two neural codes

- What advantages does each of them have?
- Which one is more efficient?
- Where in the brain would you expect to find each of them?





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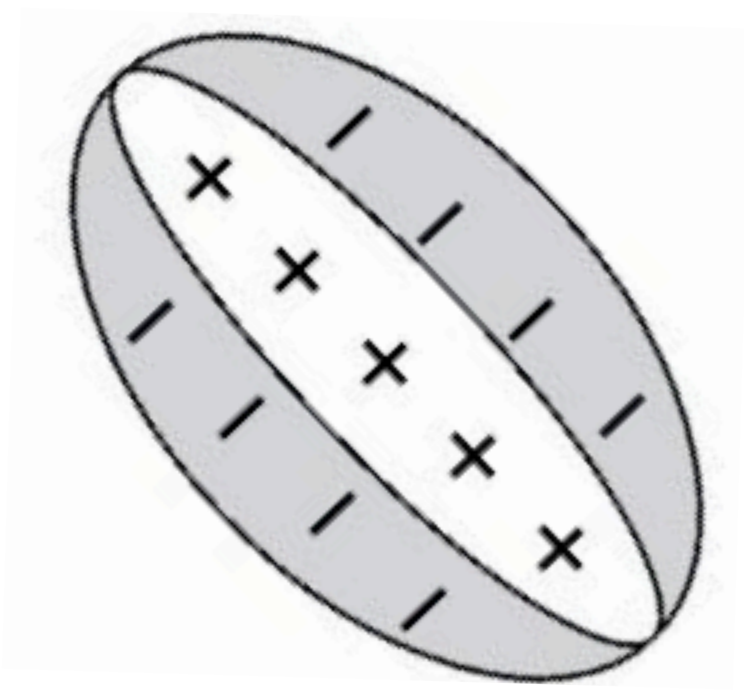
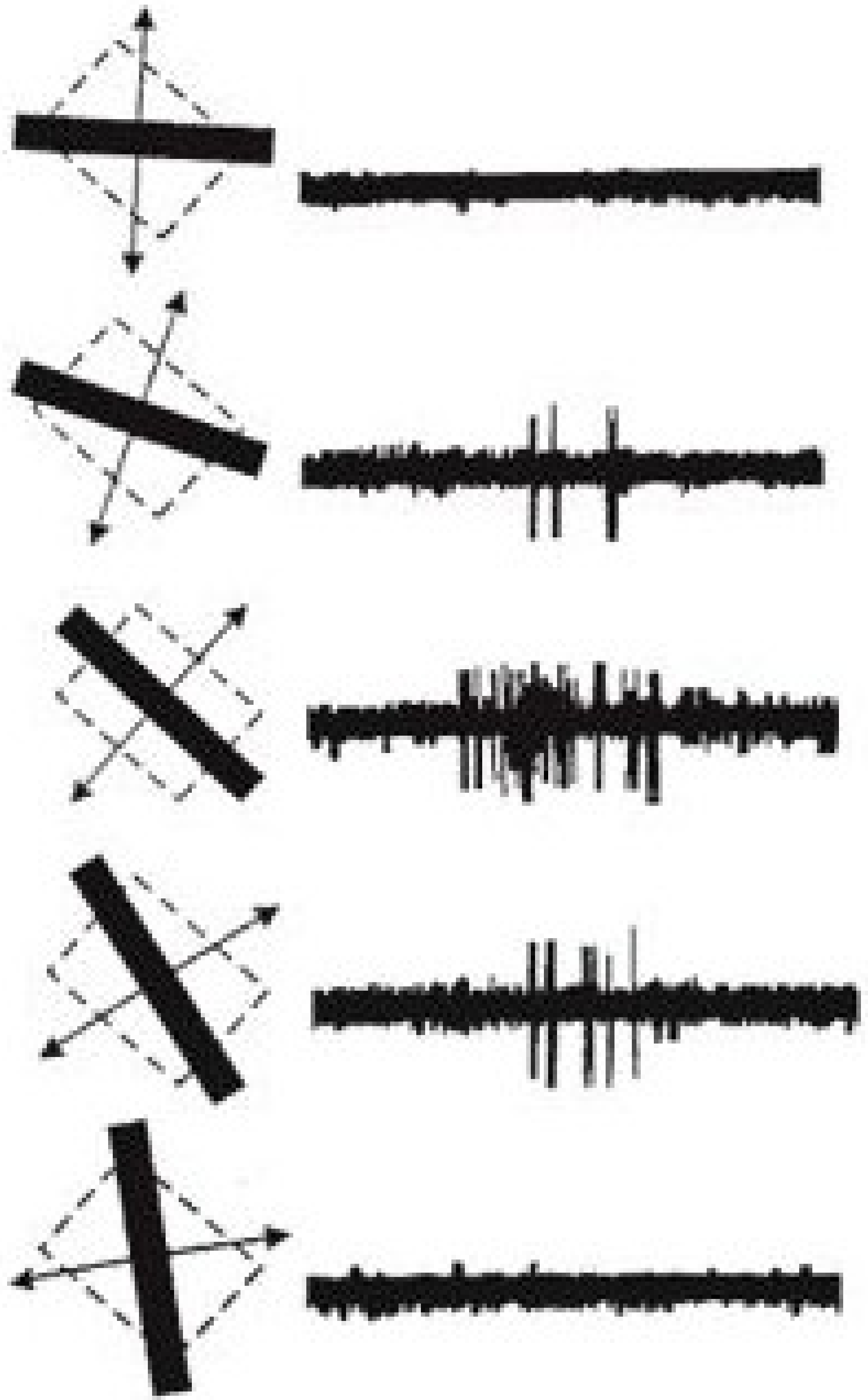
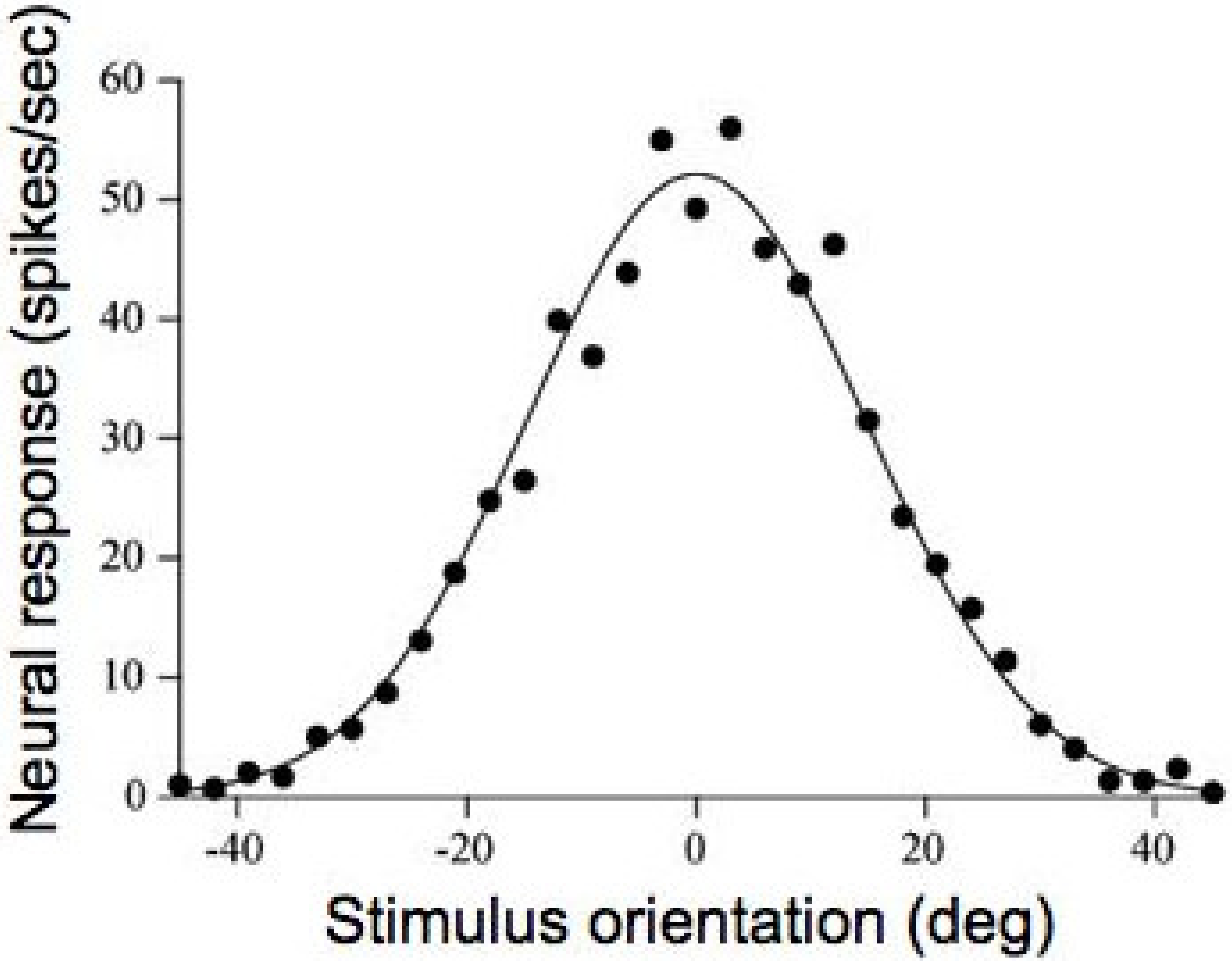
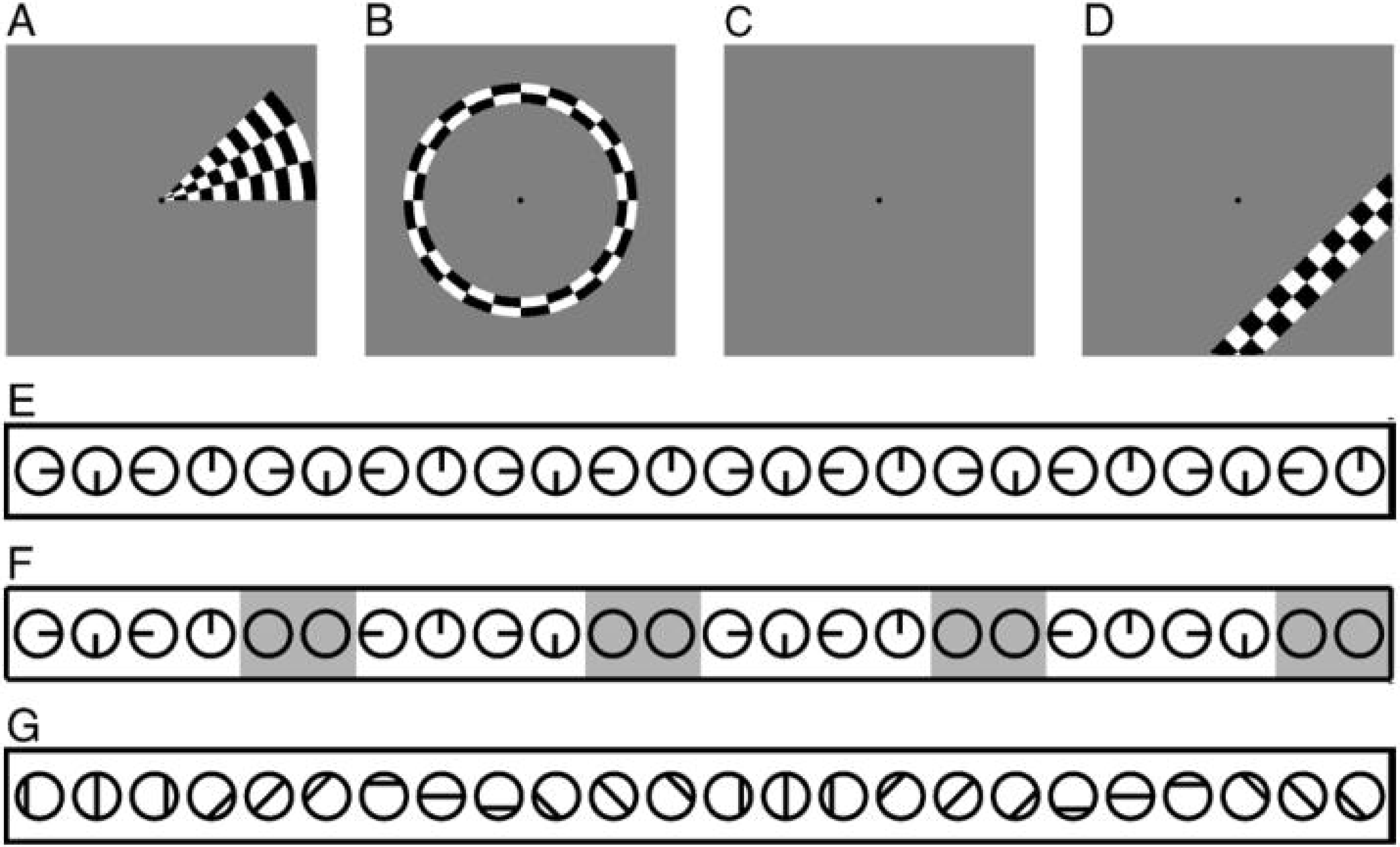
V1 receptive fields







Measuring V1 RFs with fMRI



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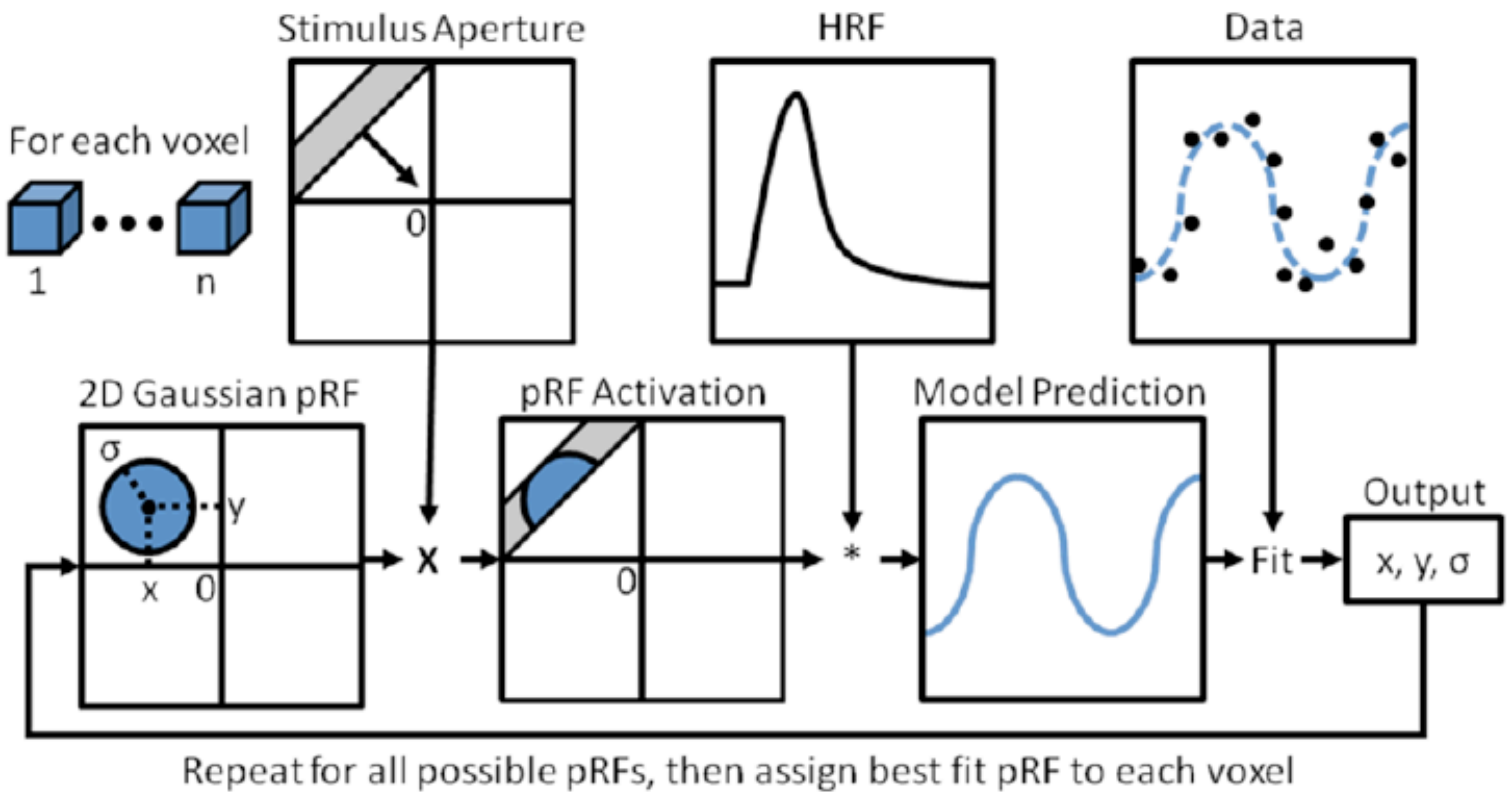
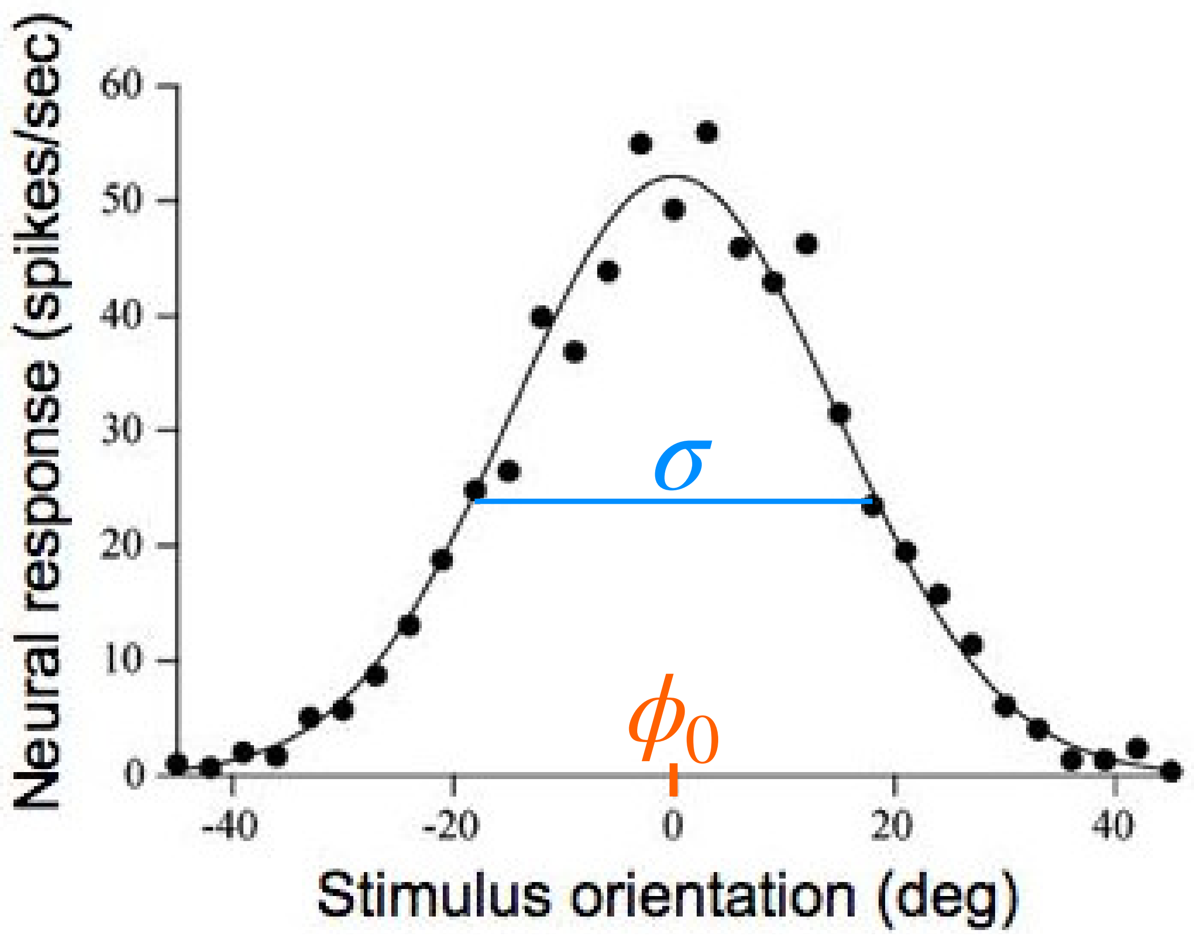
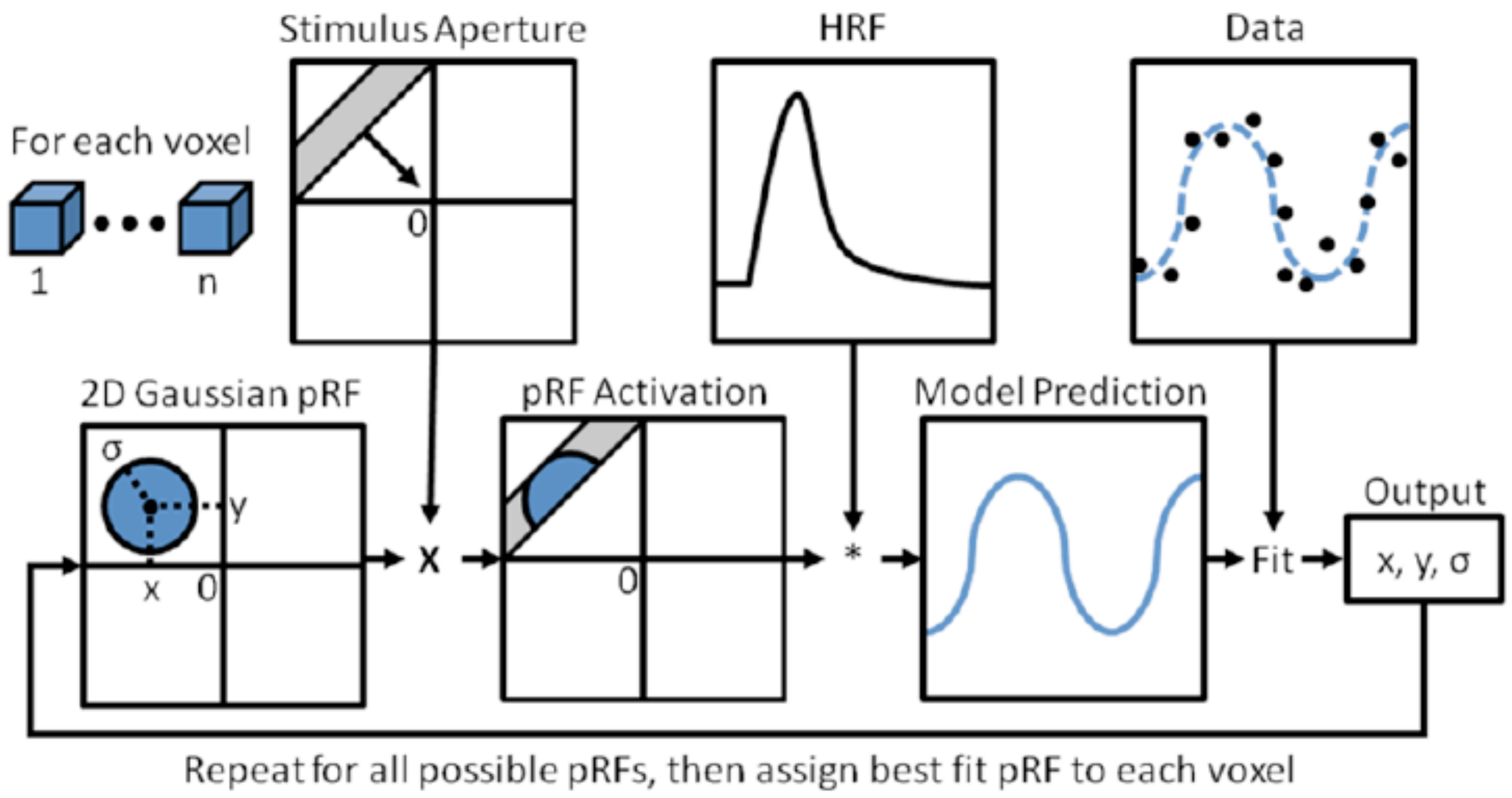


Parametrising orientation in V1 RFs

$$g_{\sigma,\phi_0}(\phi) = e^{-\frac{(\phi - \phi_0)^2}{2\sigma^2}}$$





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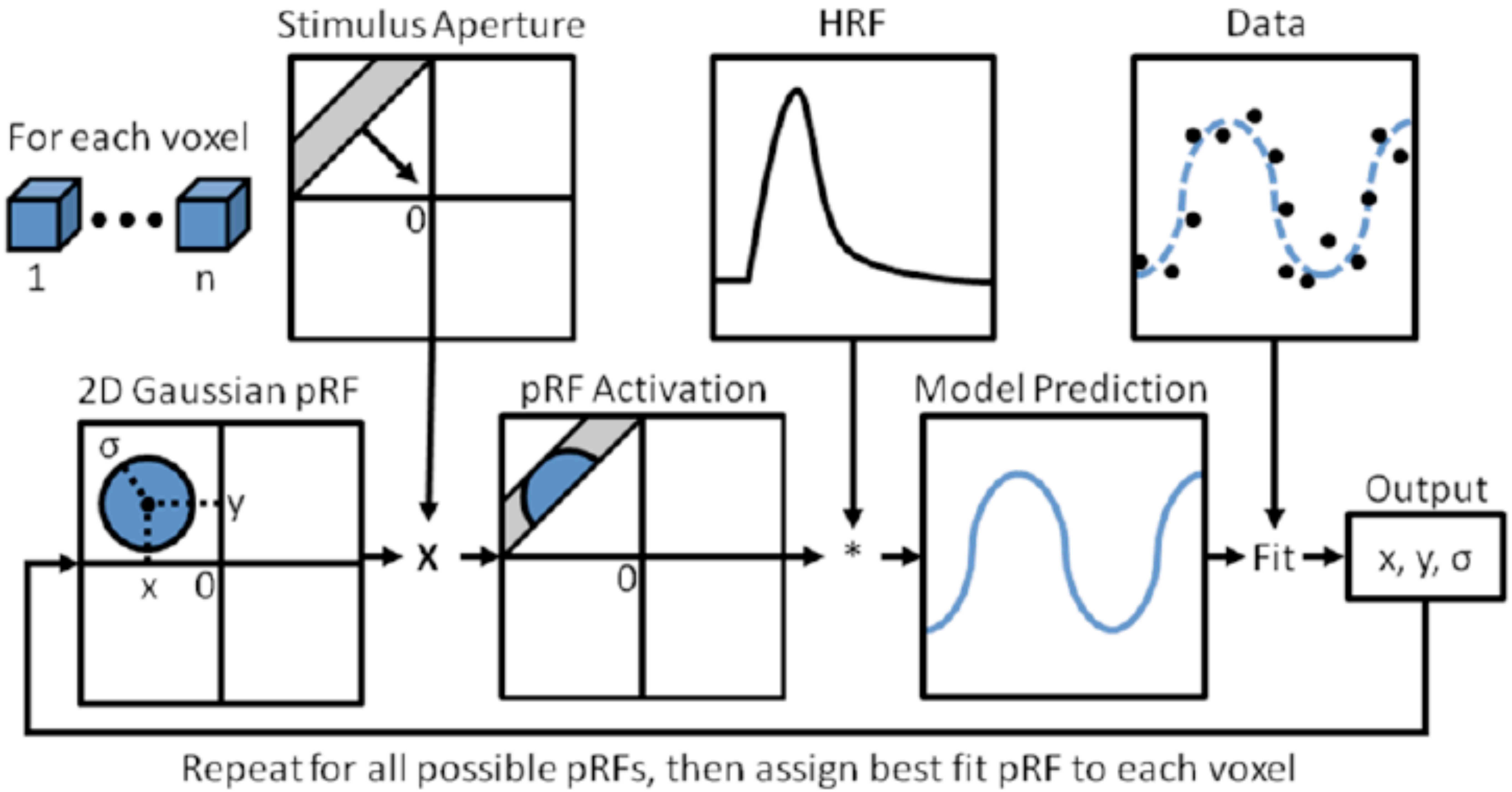
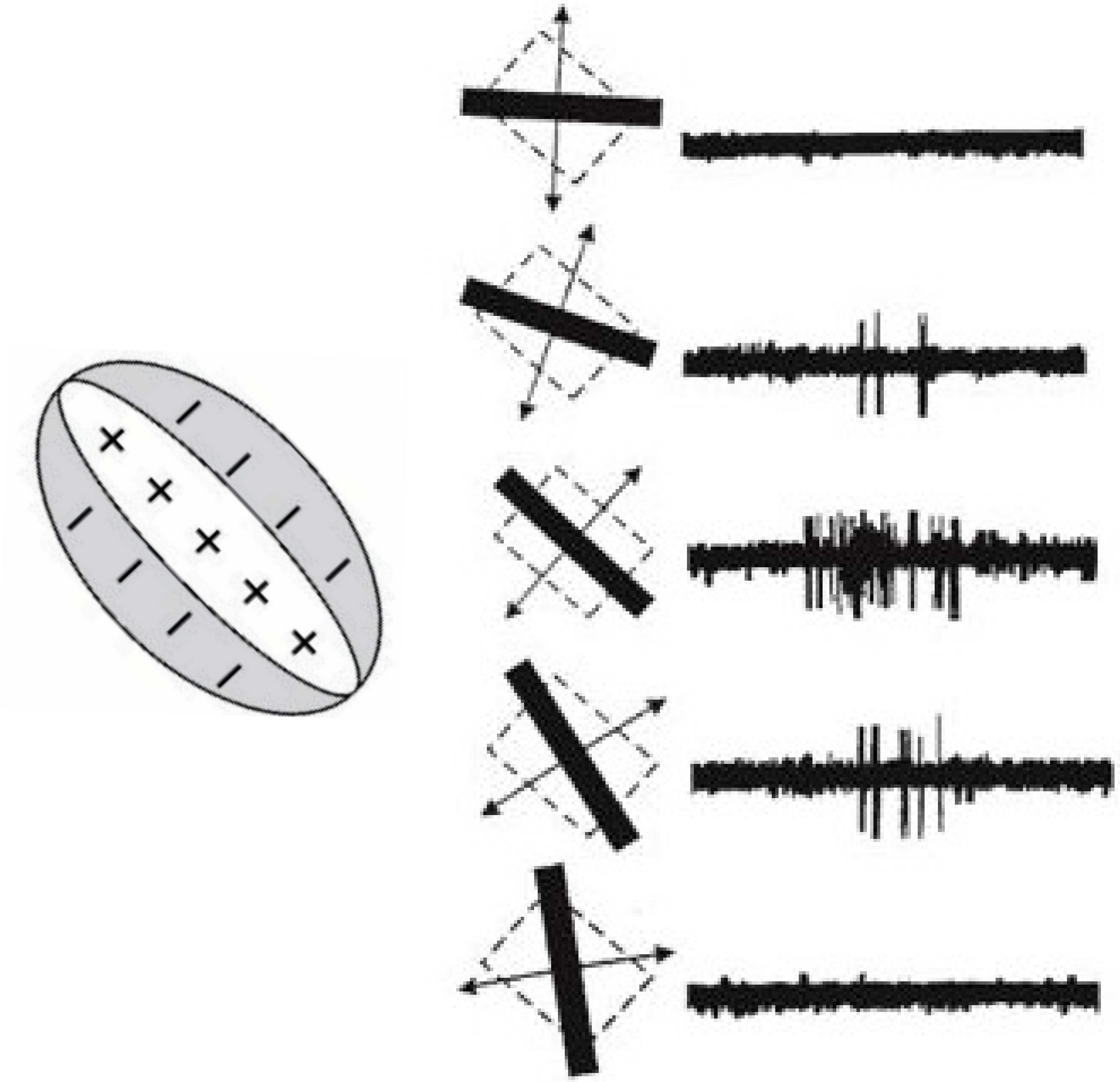
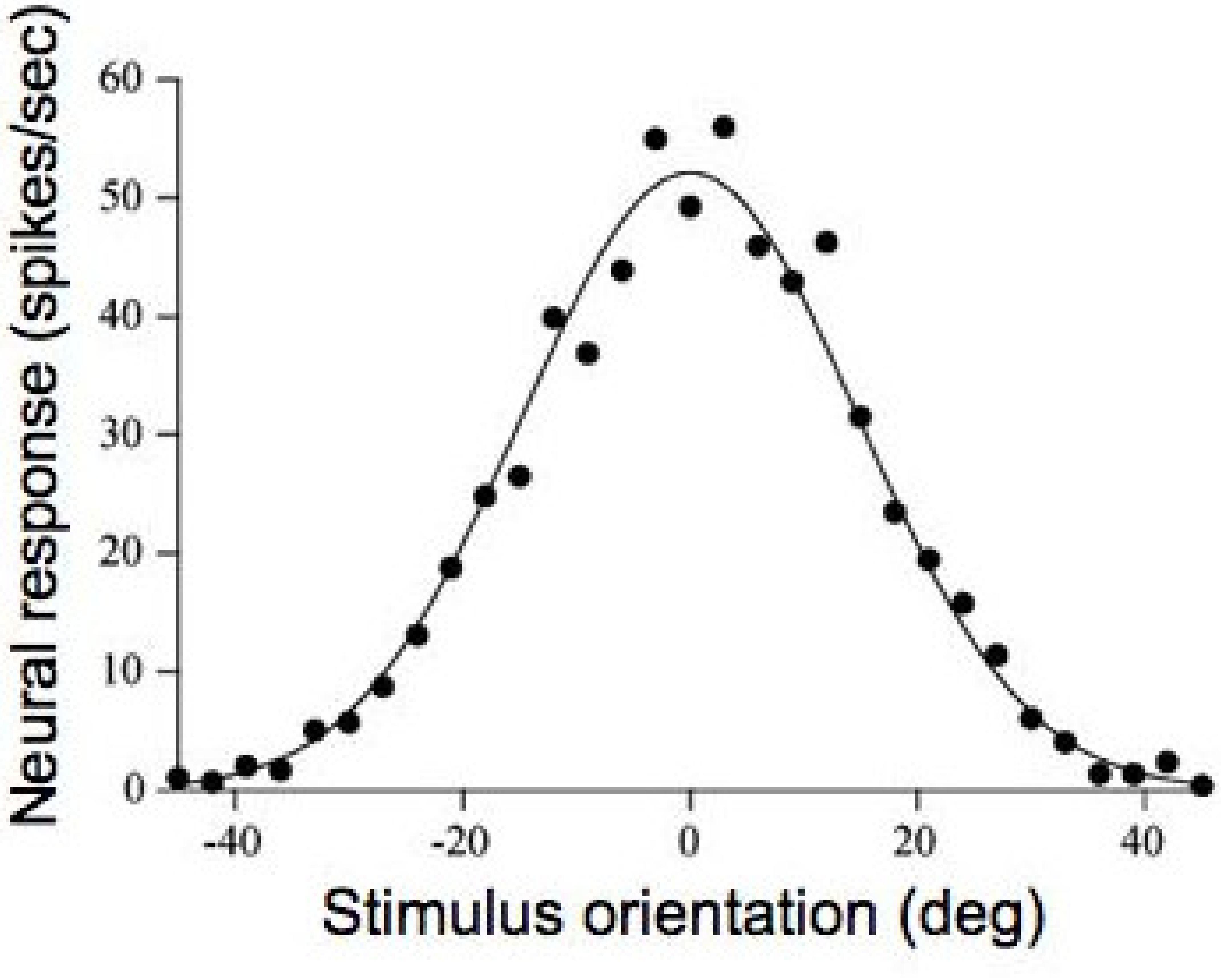


Parametrising position in V1 RFs





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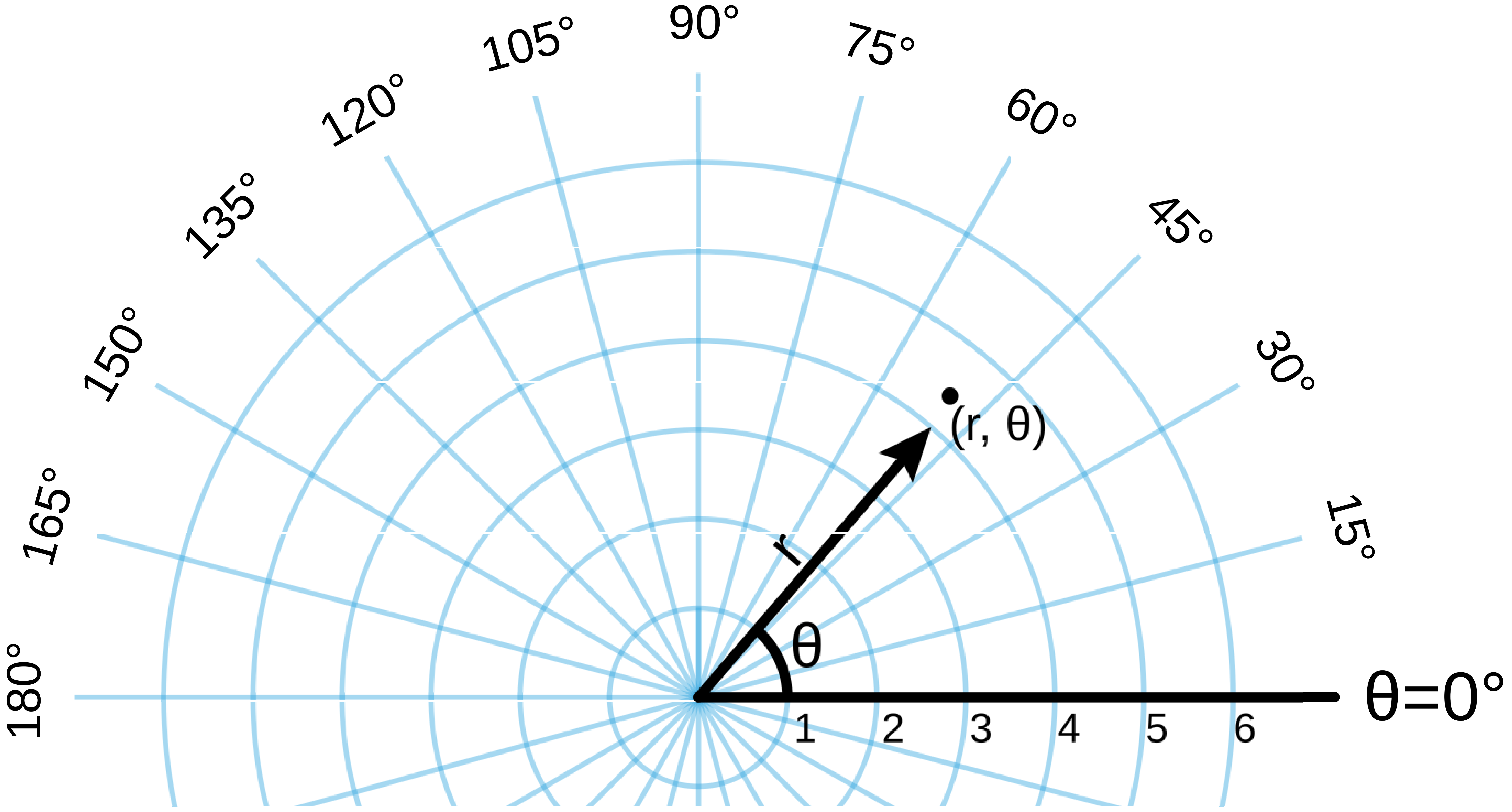

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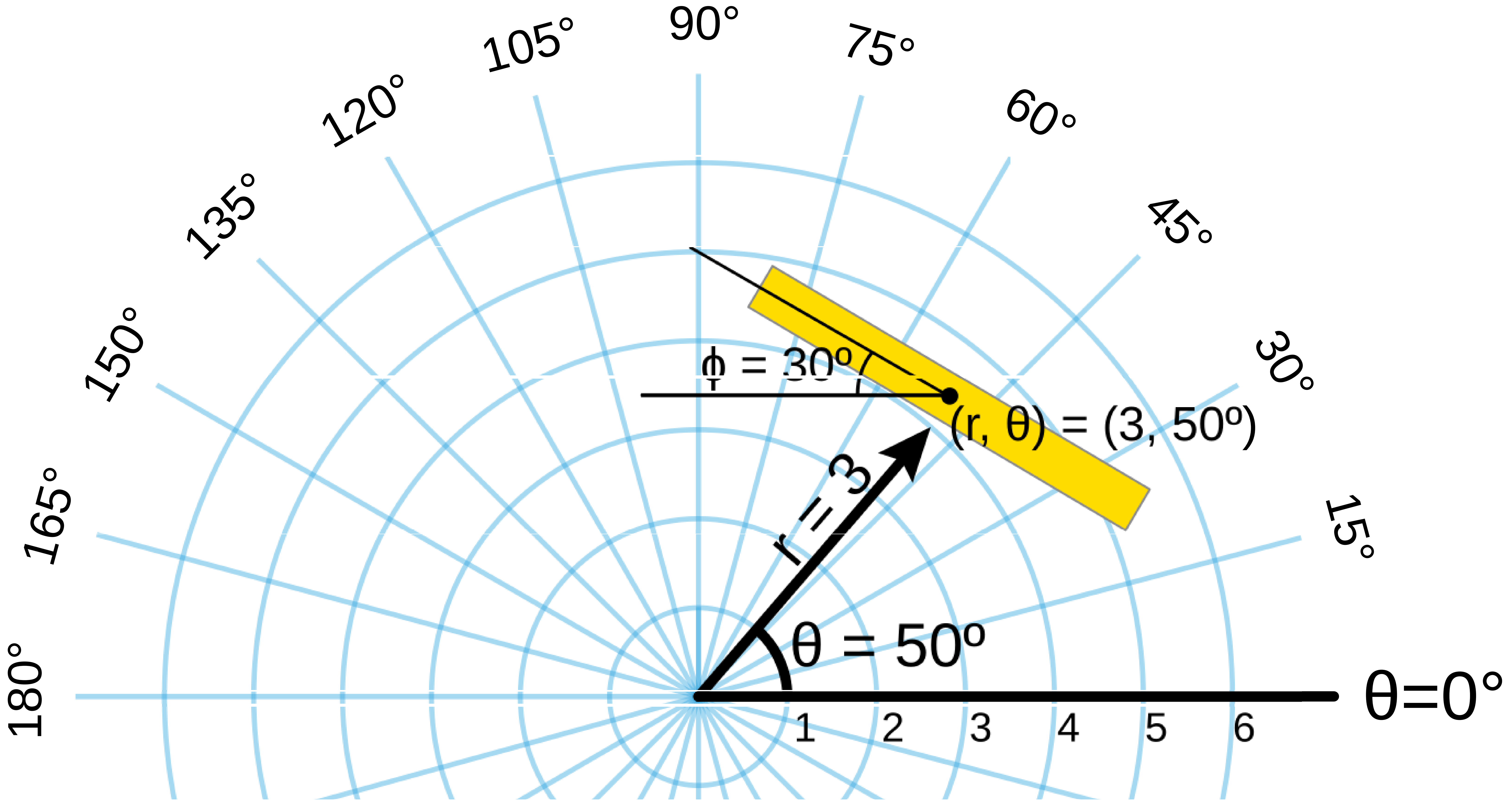

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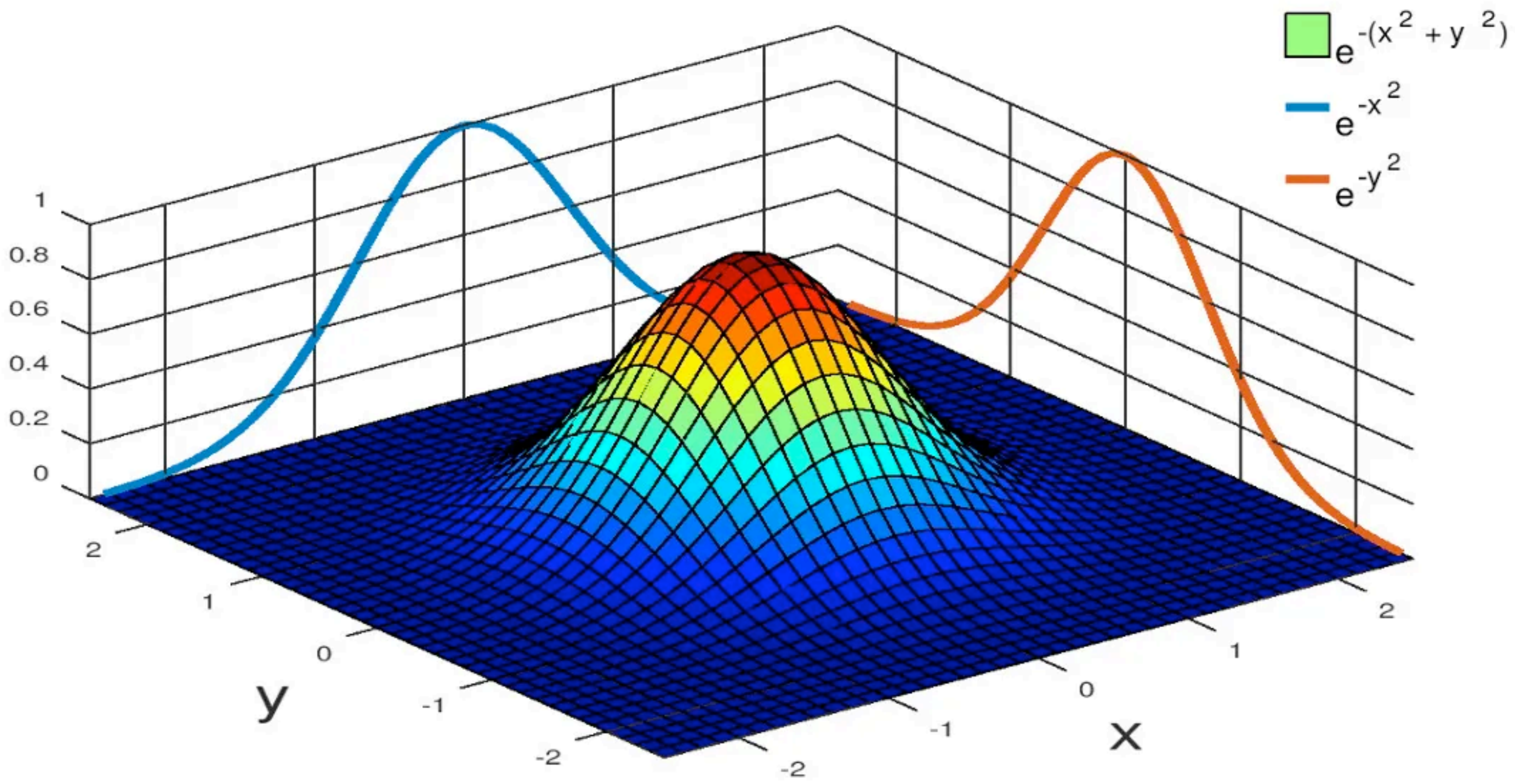
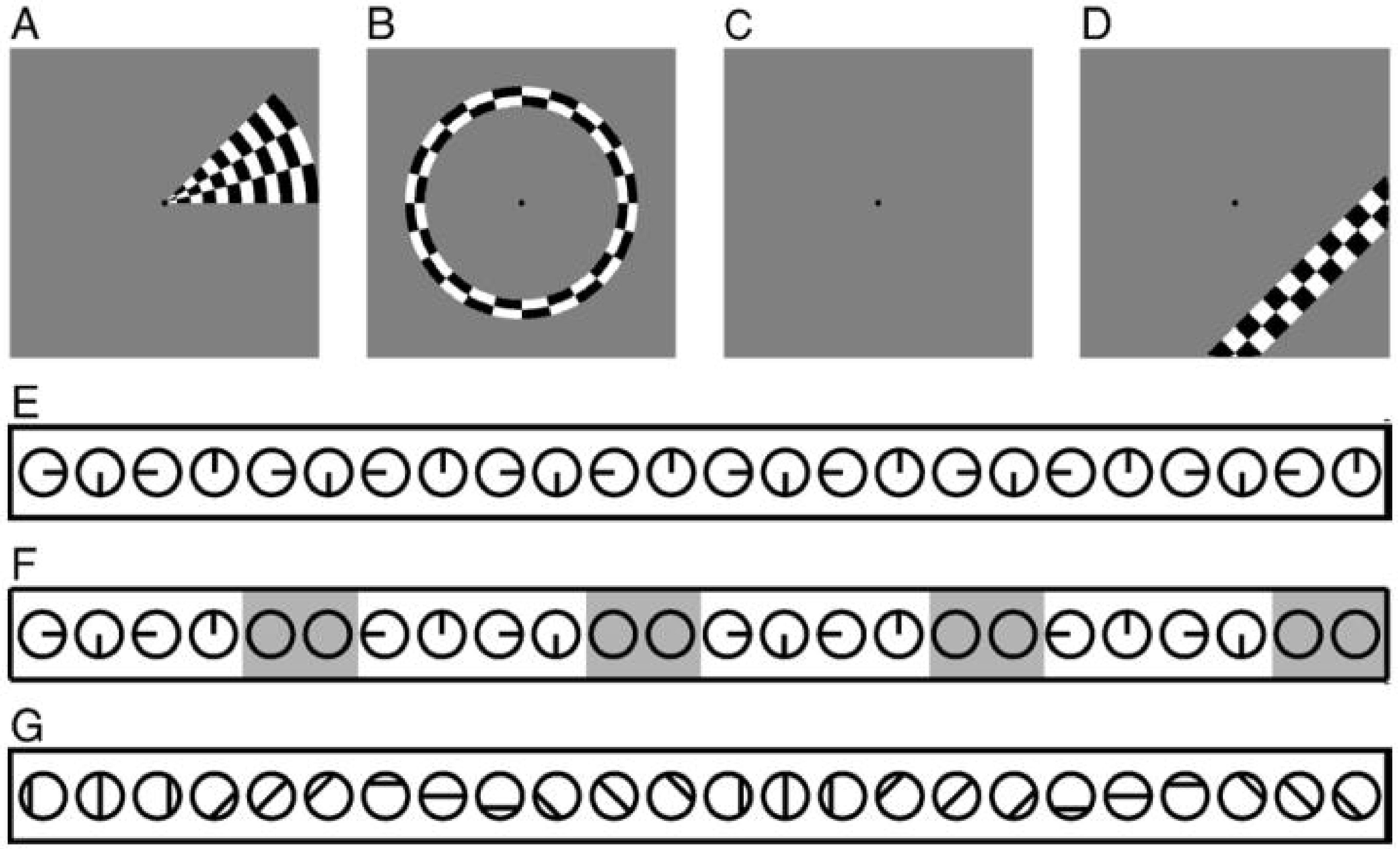
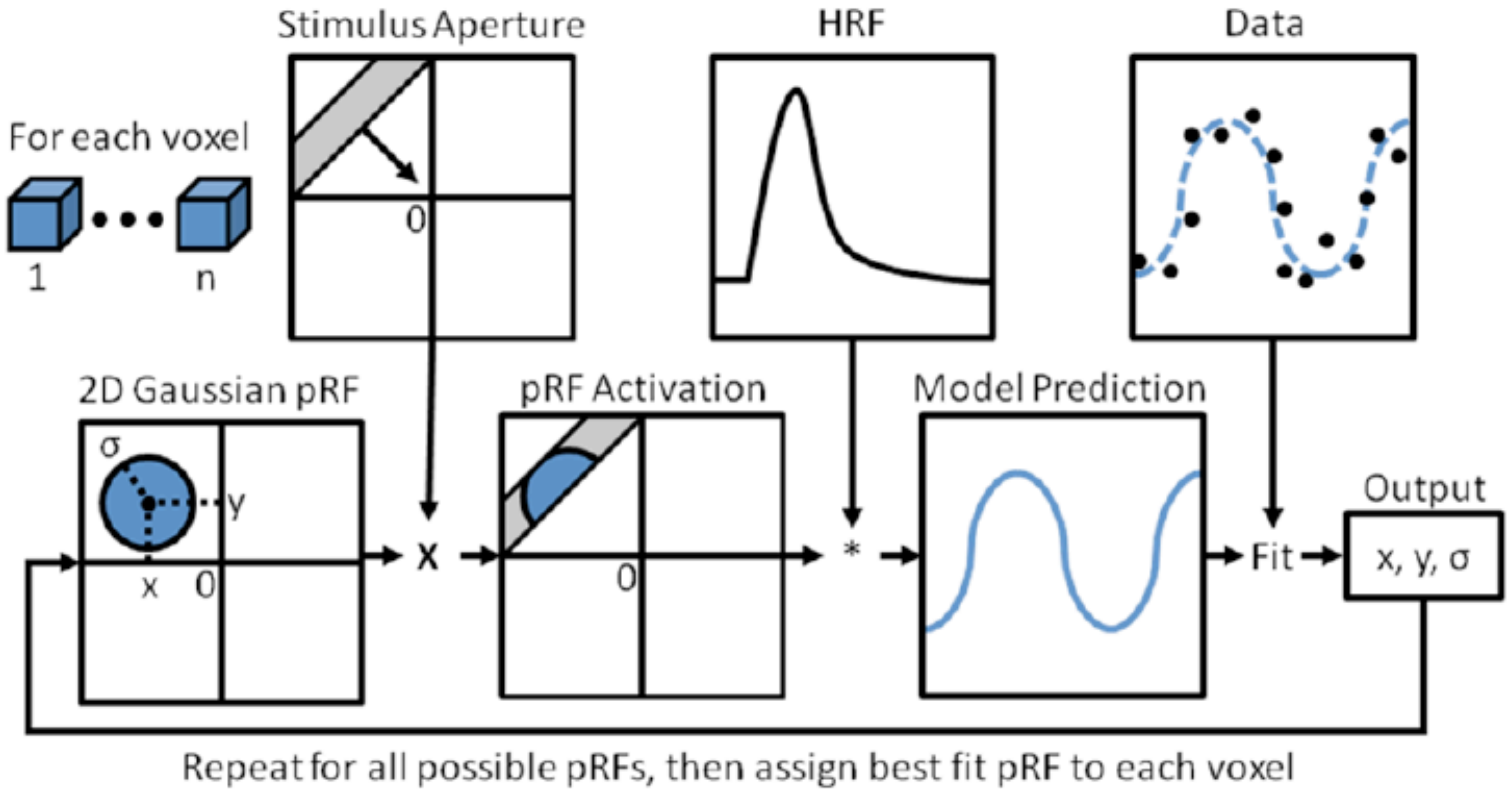


$$g_{r_0,\sigma_r,\theta_0,\sigma_\theta}(r,\theta) = e^{-\frac{(r-r_0)^2}{2\sigma_r^2}-\frac{(\theta-\theta_0)^2}{2\sigma_\theta^2}}$$

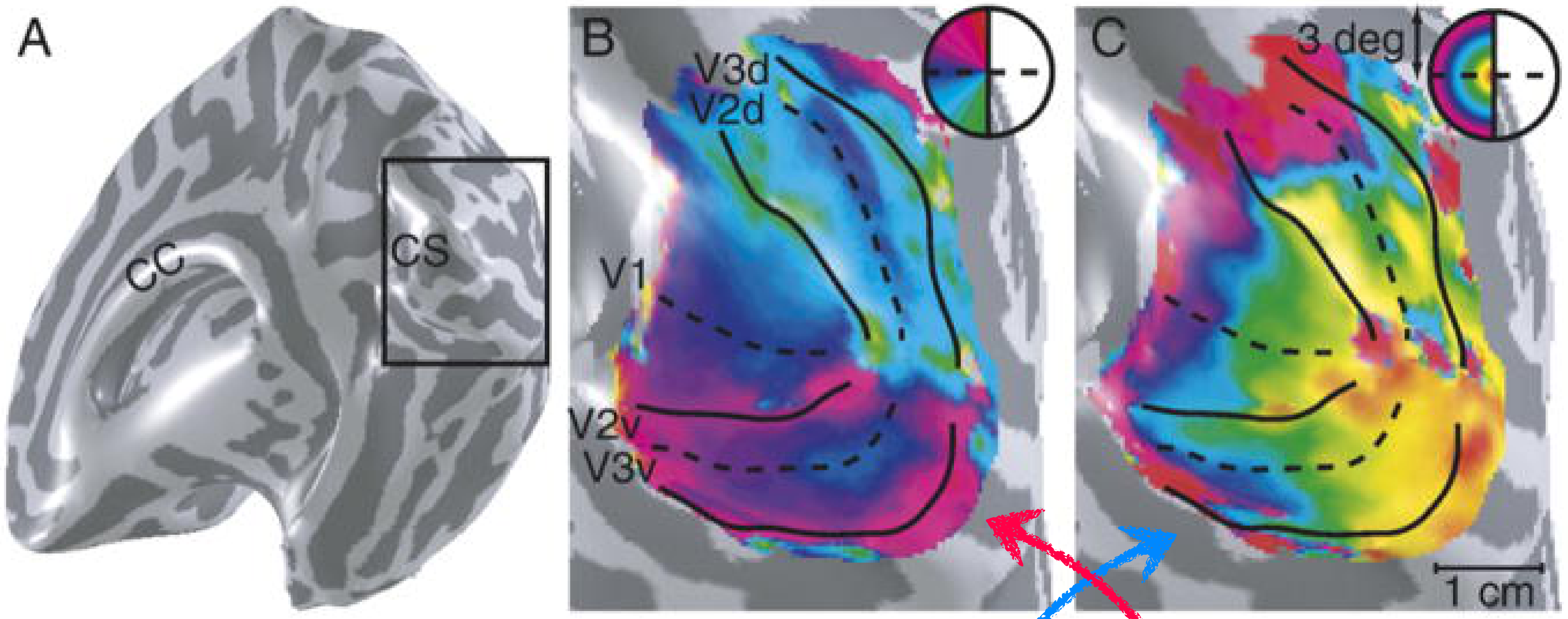
Parametrising orientation in V1 RFs



$$g_{r_0,\sigma_r,\theta_0,\sigma_\theta,\phi_0,\sigma_{phi}}(r,\theta,\phi) = e^{-\frac{(r-r_0)^2}{2\sigma_r^2}-\frac{(\theta-\theta_0)^2}{2\sigma_\theta^2}-\frac{(\phi-\phi_0)^2}{2\sigma_\phi^2}}$$



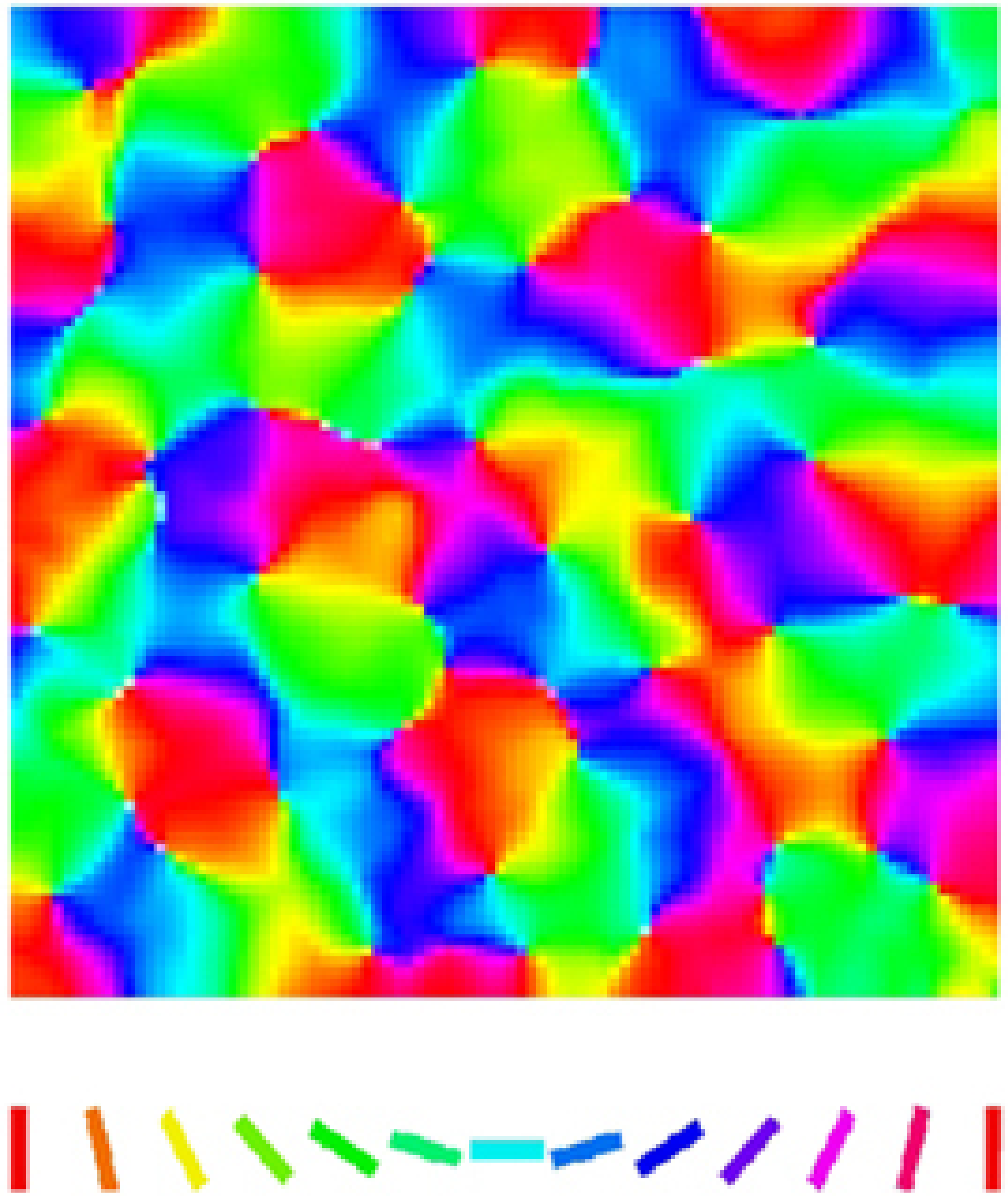
Measuring V1 RFs with fMRI



Layer 4C orientation selectivity&preference

Layer 4C phase preference

Layer 2/3 orientation selectivity&preference



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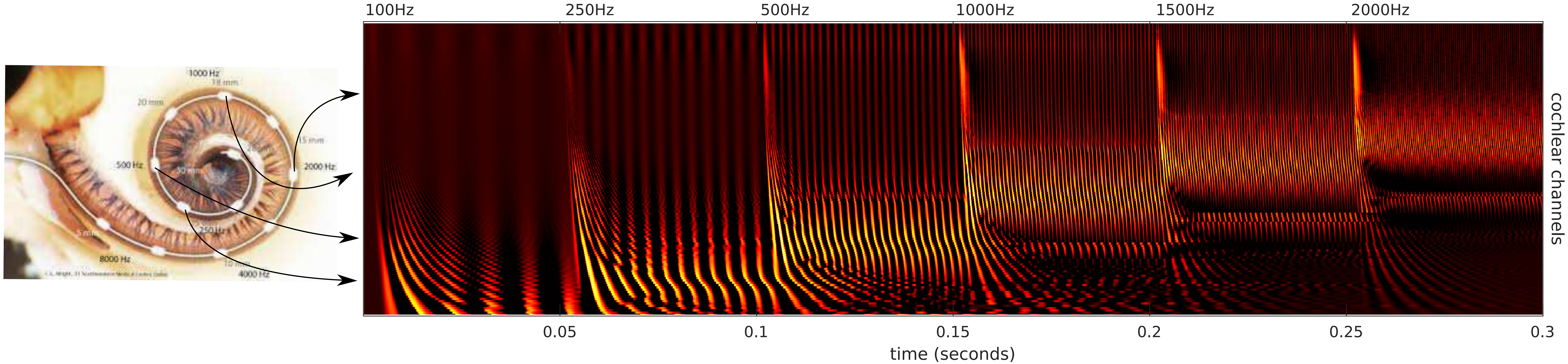
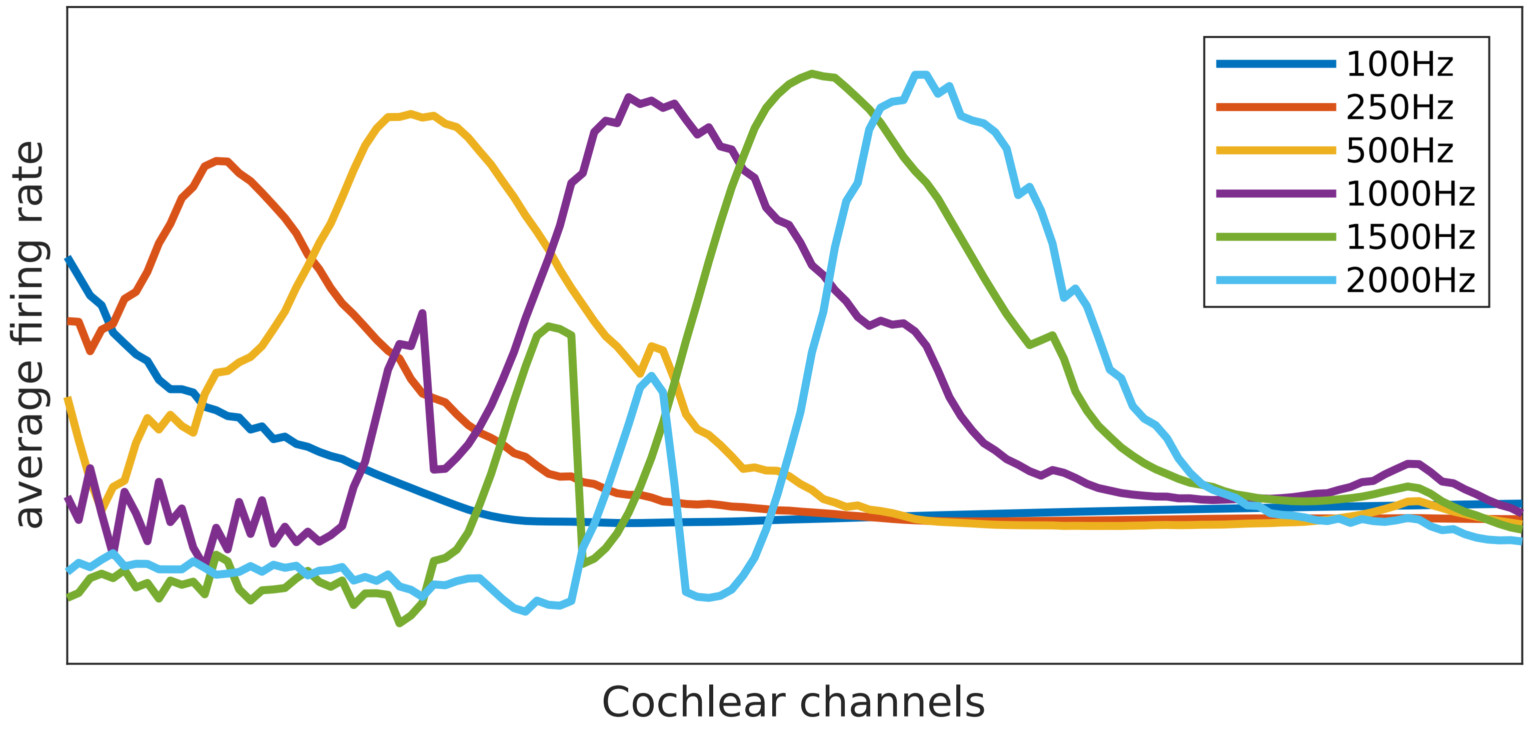
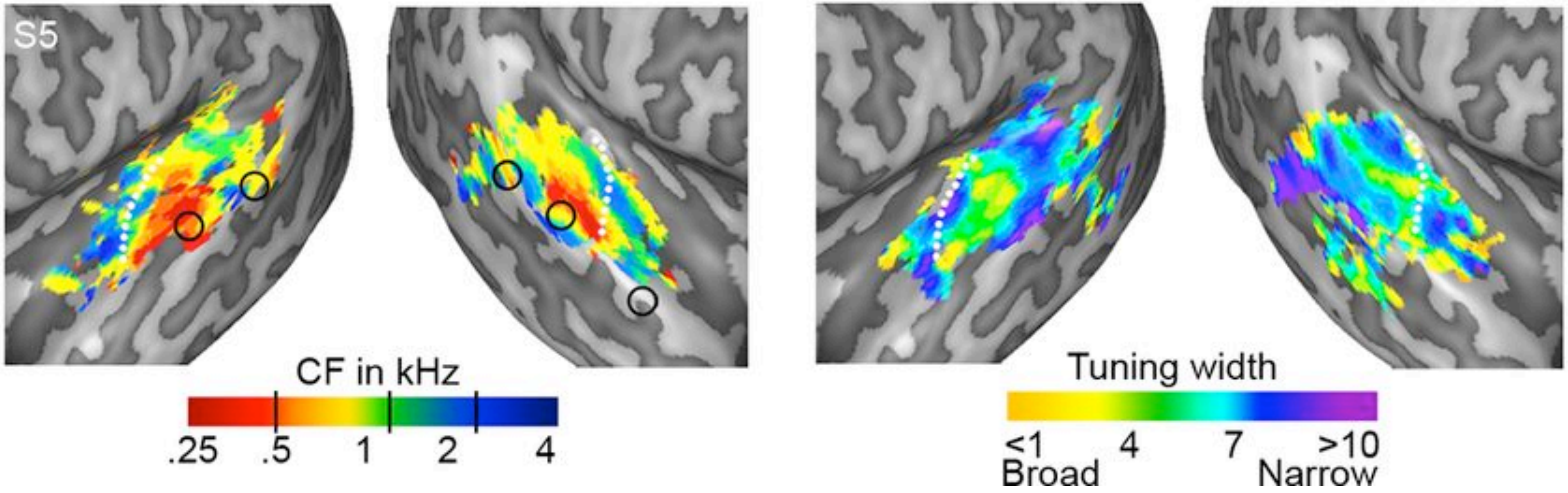
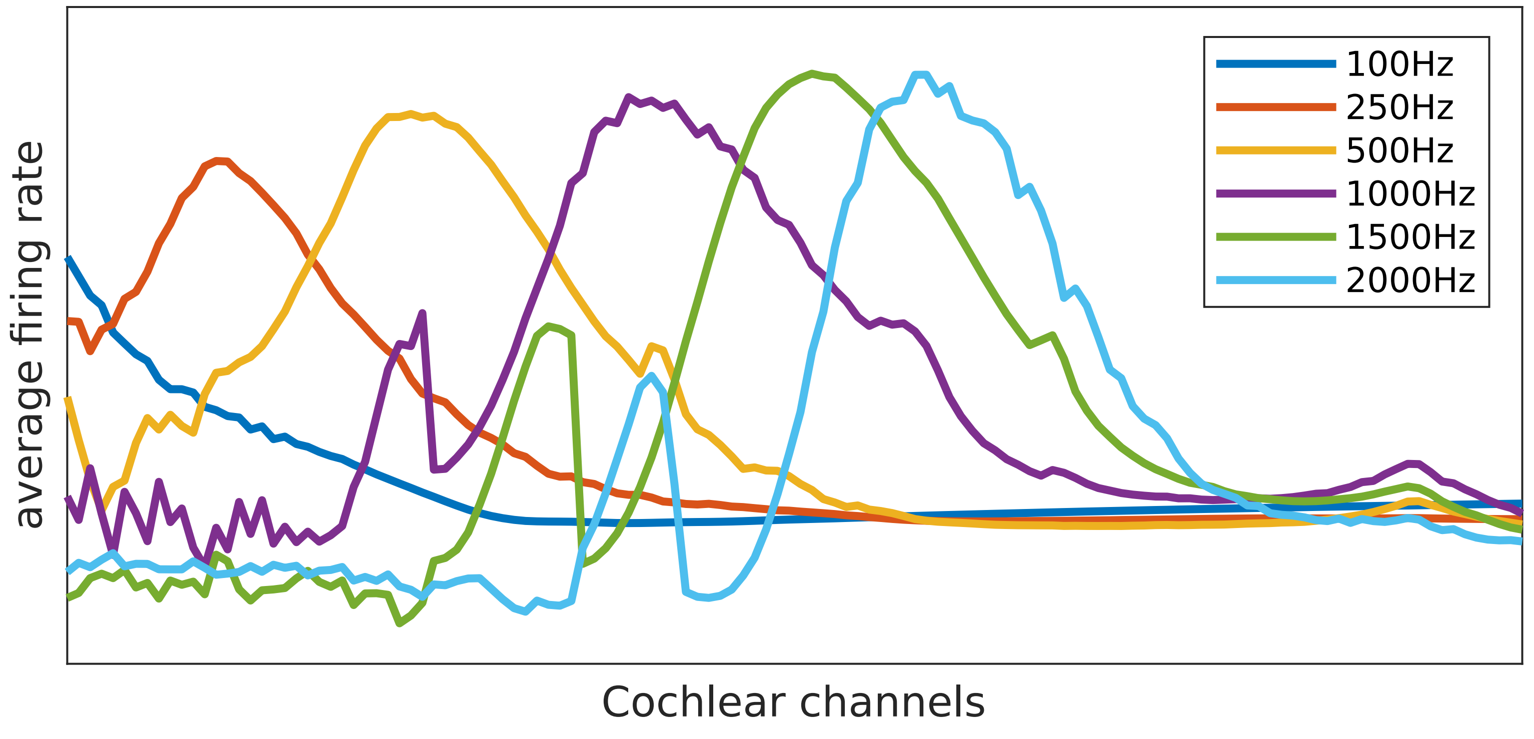
Measuring auditory RFs with fMRI





Measuring auditory RFs with fMRI





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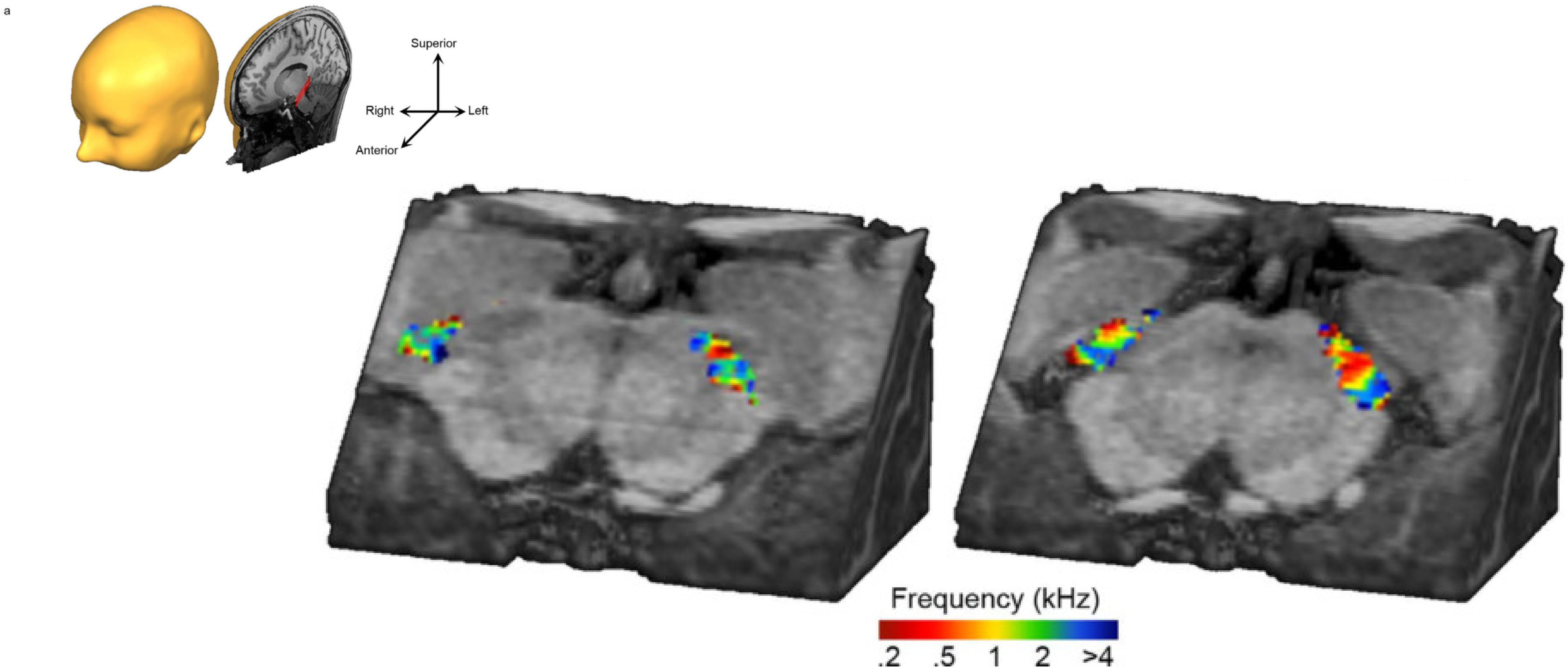

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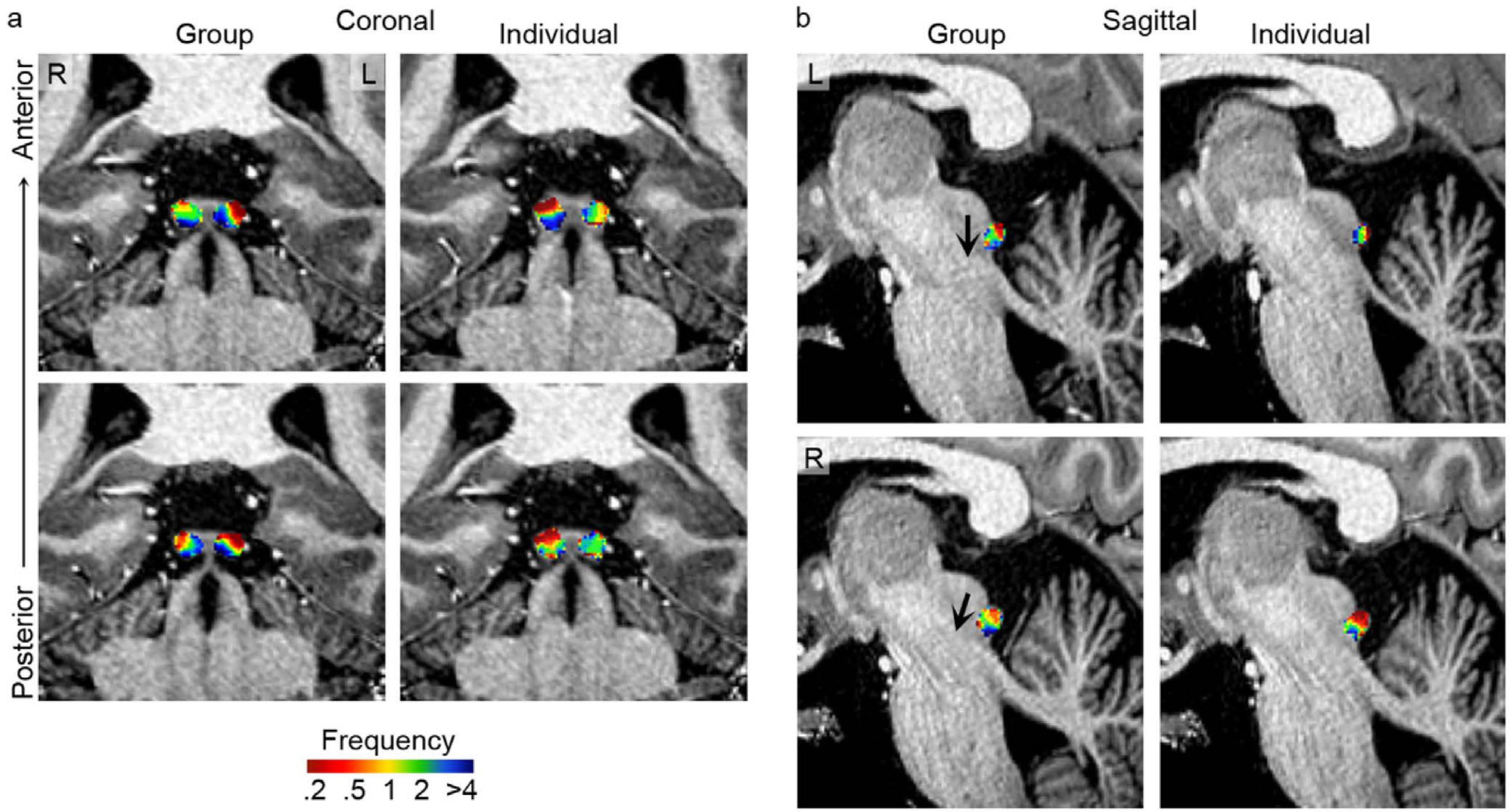

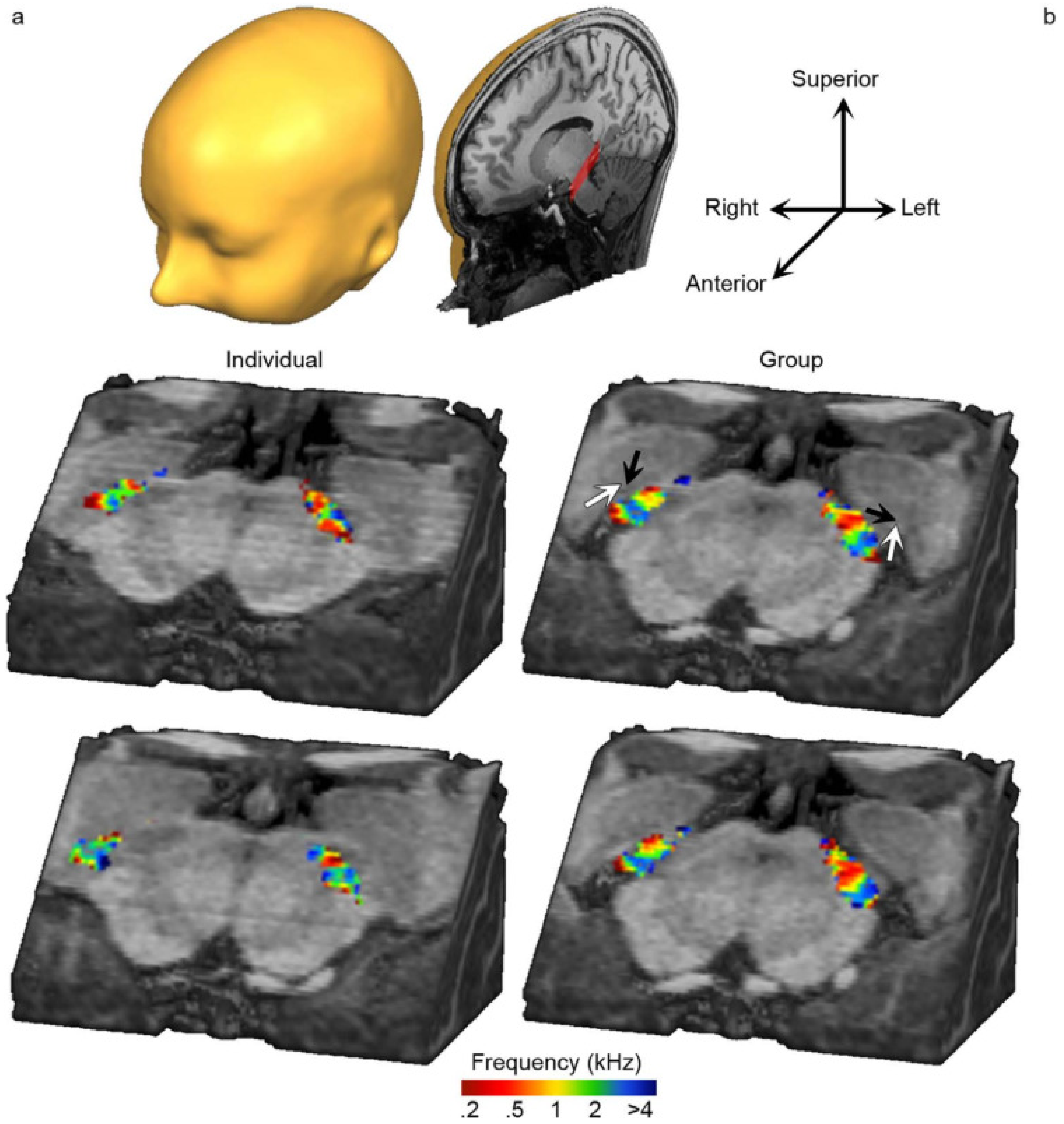

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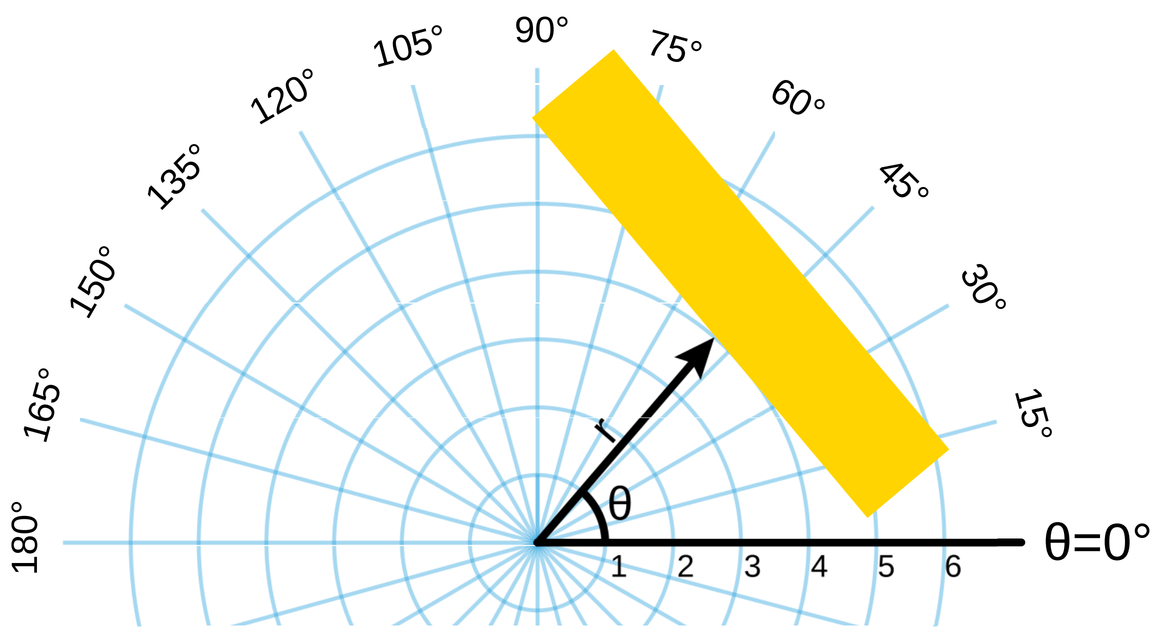
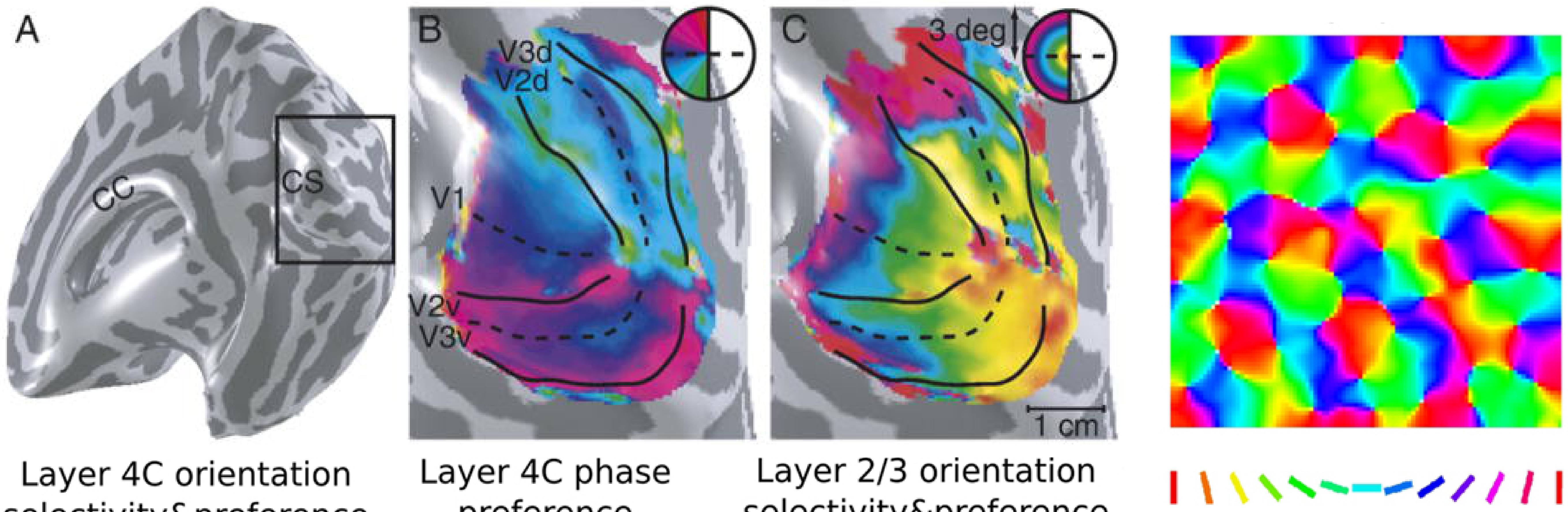
Multi-dimensional codes

So far we have showed how single units selectively encode a stimulus feature

- How would this code be used to encode this bar of light?



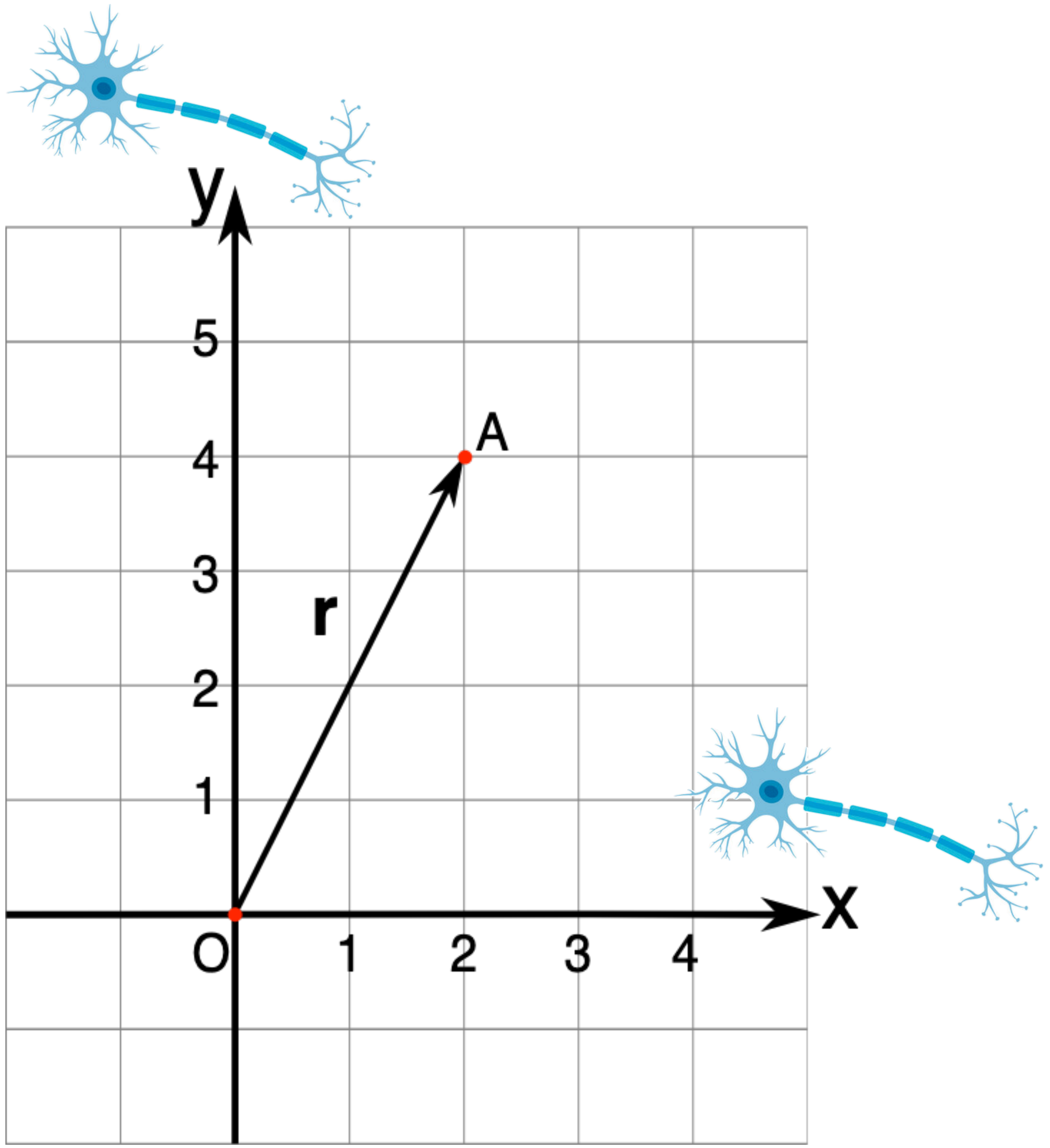


Layer 4C orientation selectivity&preference

Layer 4C phase preference

Layer 2/3 orientation selectivity&preference

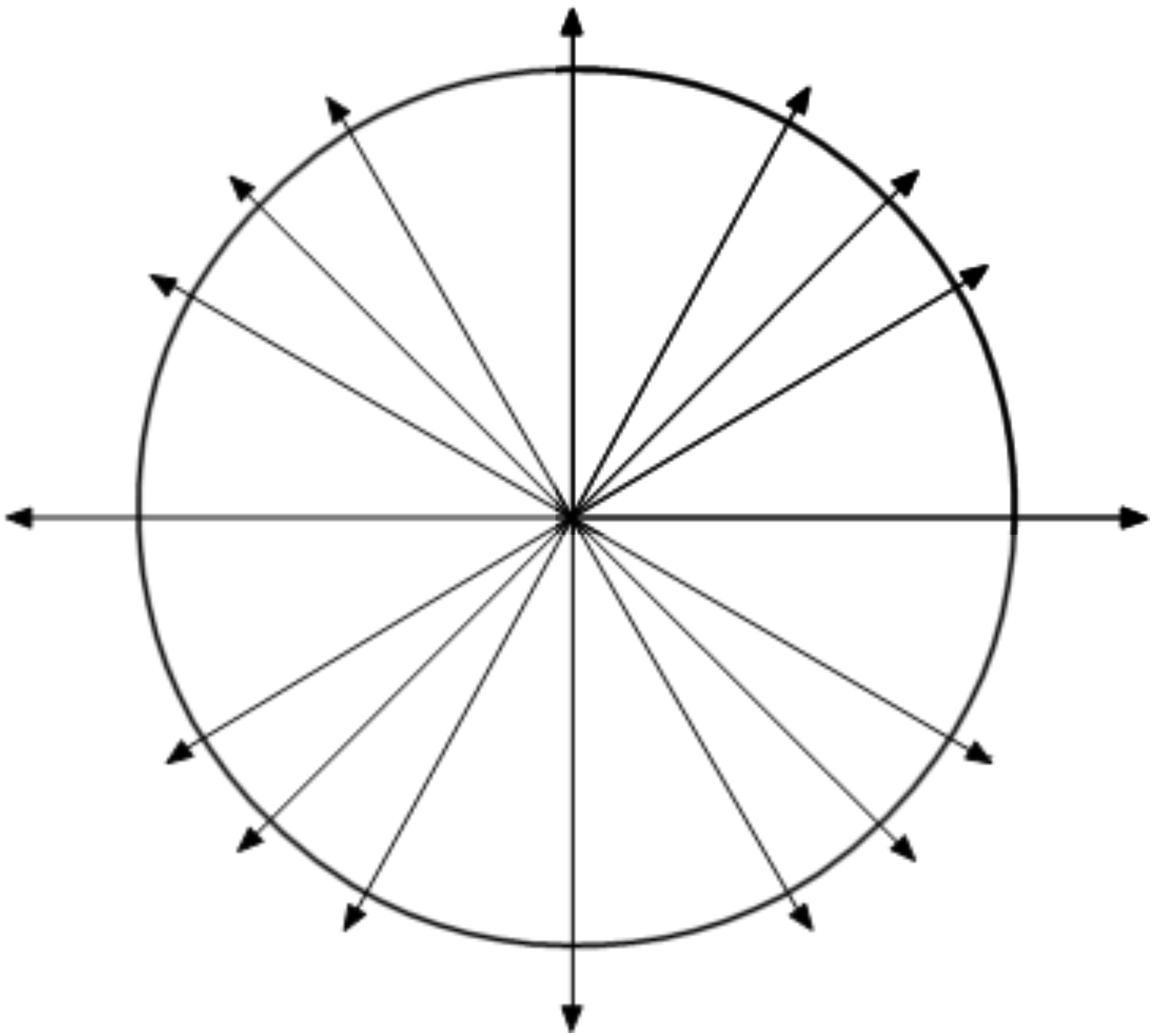
Vectors and bases



$$\{\ \uparrow\ ,\ \rightarrow\ \}$$

$$\nearrow\ = 1 \times \uparrow\ + \frac{1}{2} \times \rightarrow$$

Vector spaces



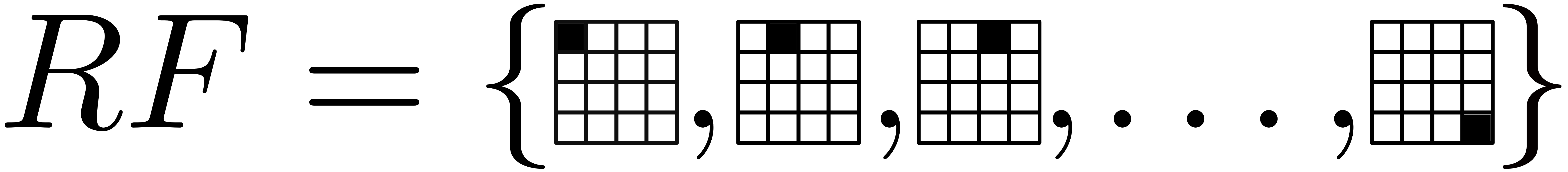
{ ↑ ,{ ↑→ ,, ↓→ ,}← }

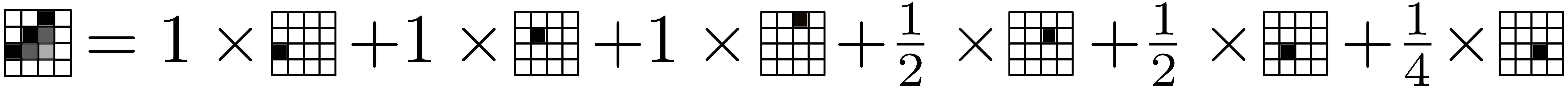
A vector space for colour

$$RF = \{\textcolor{red}{\bullet}, \textcolor{green}{\bullet}, \textcolor{blue}{\bullet}\}$$

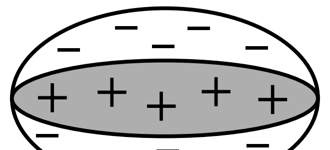
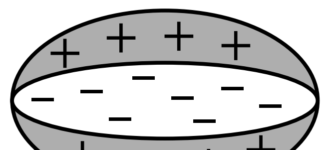
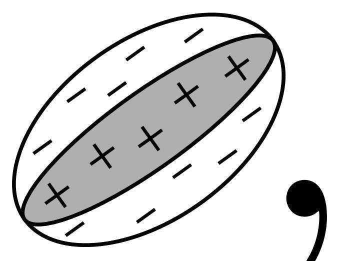
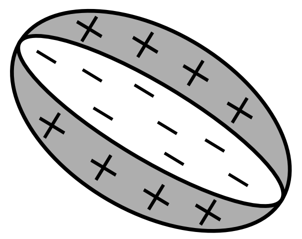
$$\textcolor{teal}{\bullet} = \frac{1}{2} \times \textcolor{red}{\bullet} + \frac{3}{4} \times \textcolor{green}{\bullet} + \frac{3}{4} \times \textcolor{blue}{\bullet}$$

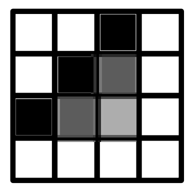
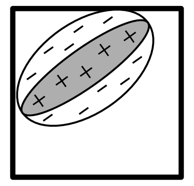
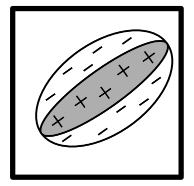
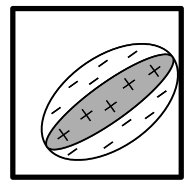
A vector space for retinal activation



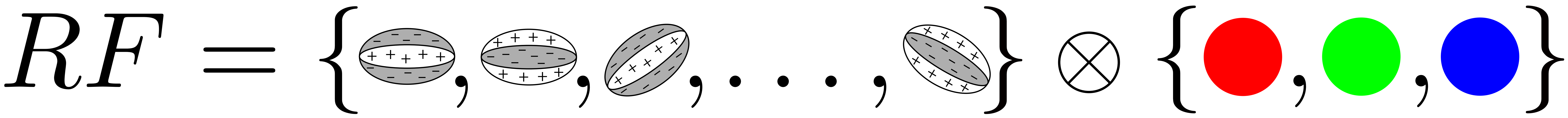


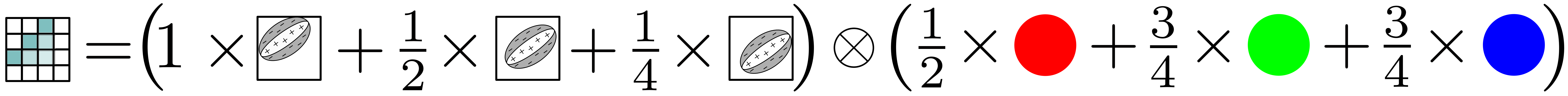
Another vector space for retinal activation

$RF = \{$ , , , $\ldots,$  $\}$

 $= 1 \times$  $+ \frac{1}{2} \times$  $+ \frac{1}{4} \times$ 

Composition of vector spaces

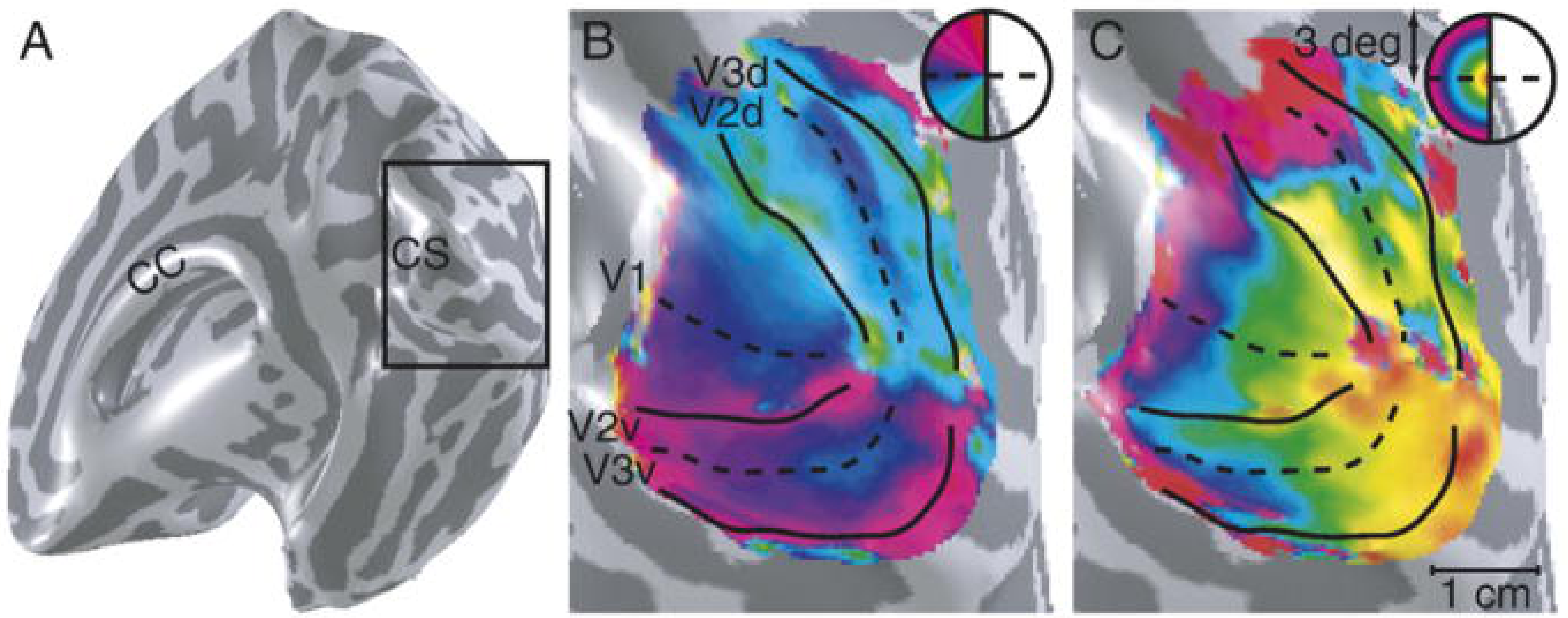




Multi-dimensional codes

So far we have showed how single units selectively encode a stimulus feature

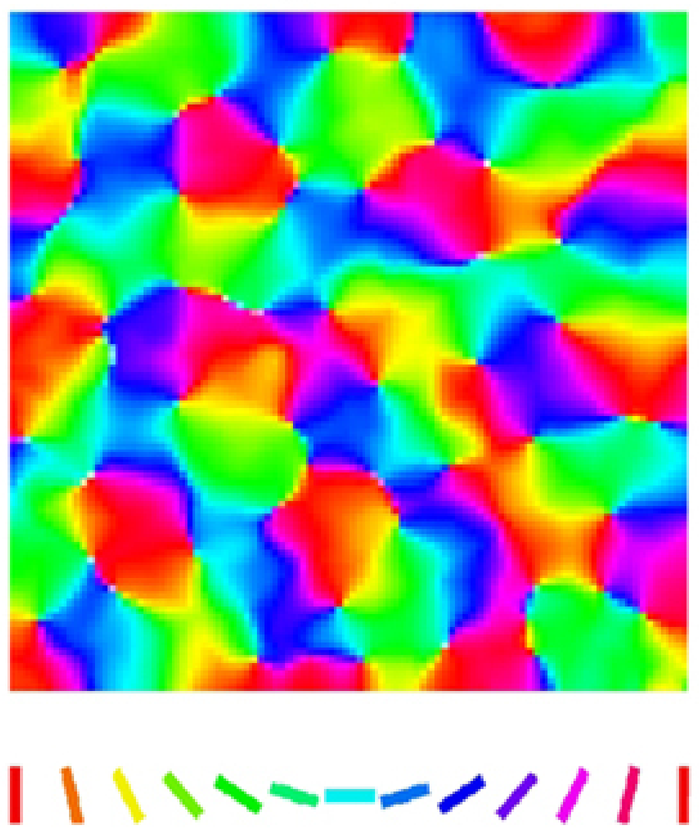
- How would this code be used to encode this bar of light?

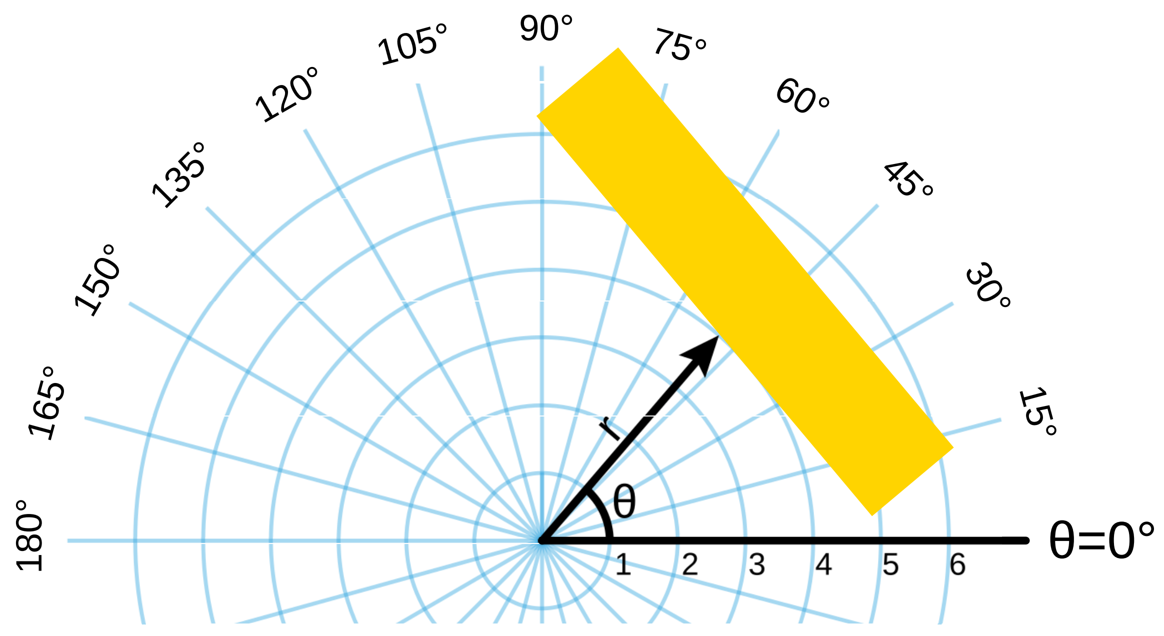


Layer 4C orientation selectivity&preference

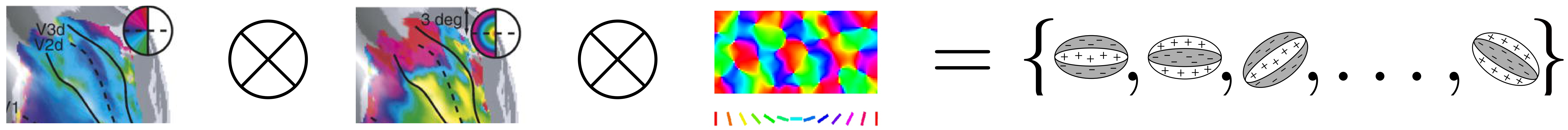
Layer 4C phase preference

Layer 2/3 orientation selectivity&preference





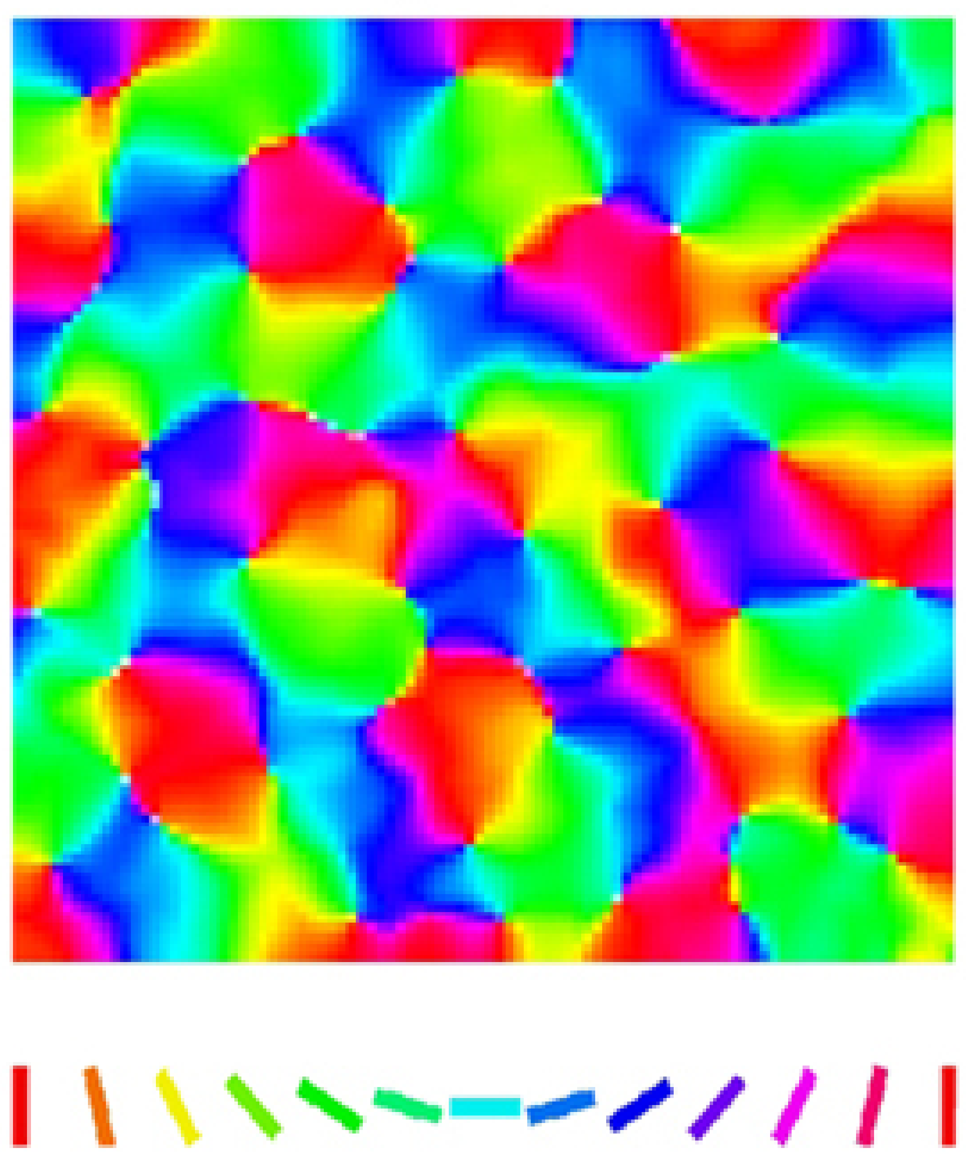
The bar or light can be encoded in the space spanned by the basis vectors:

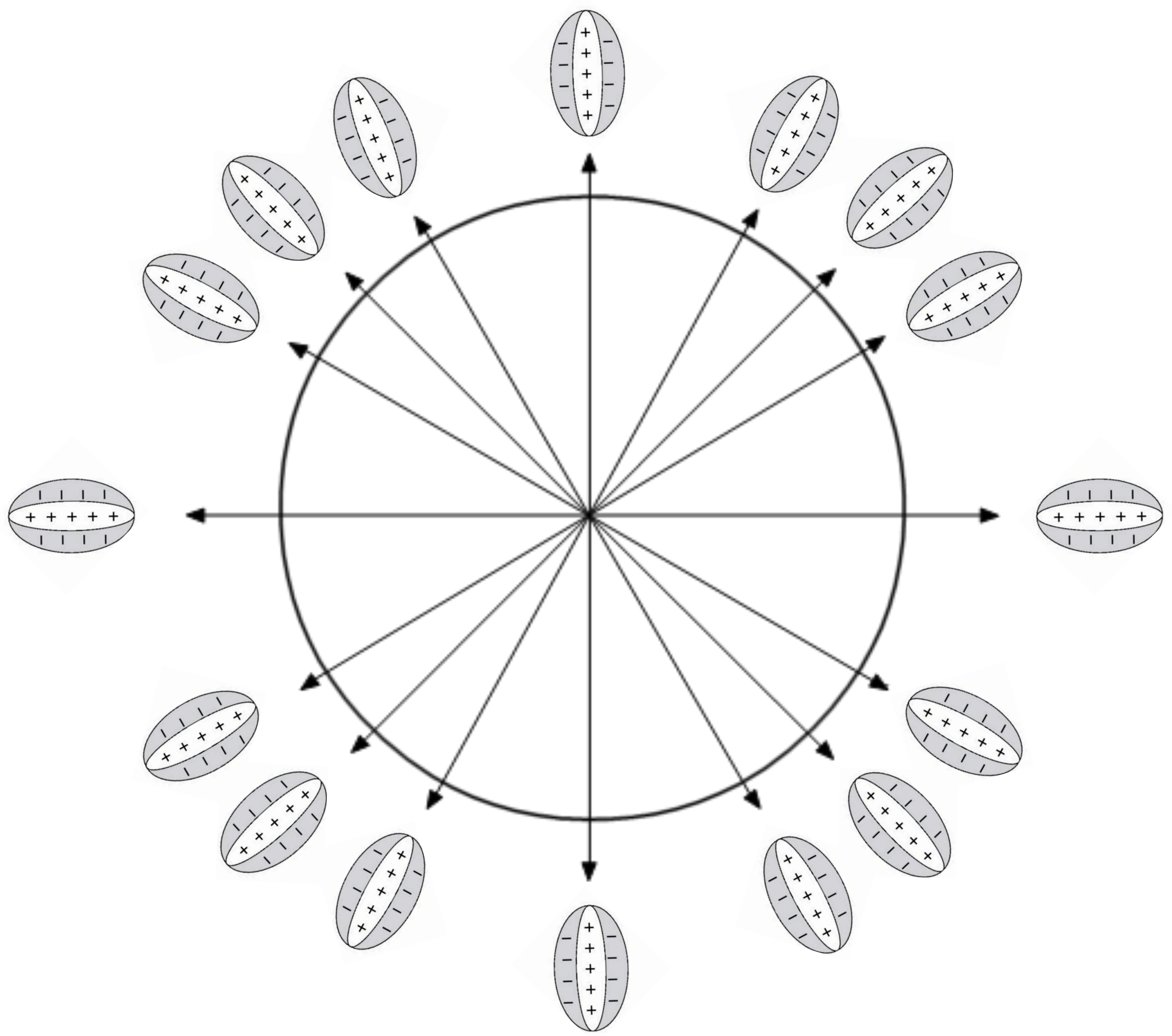


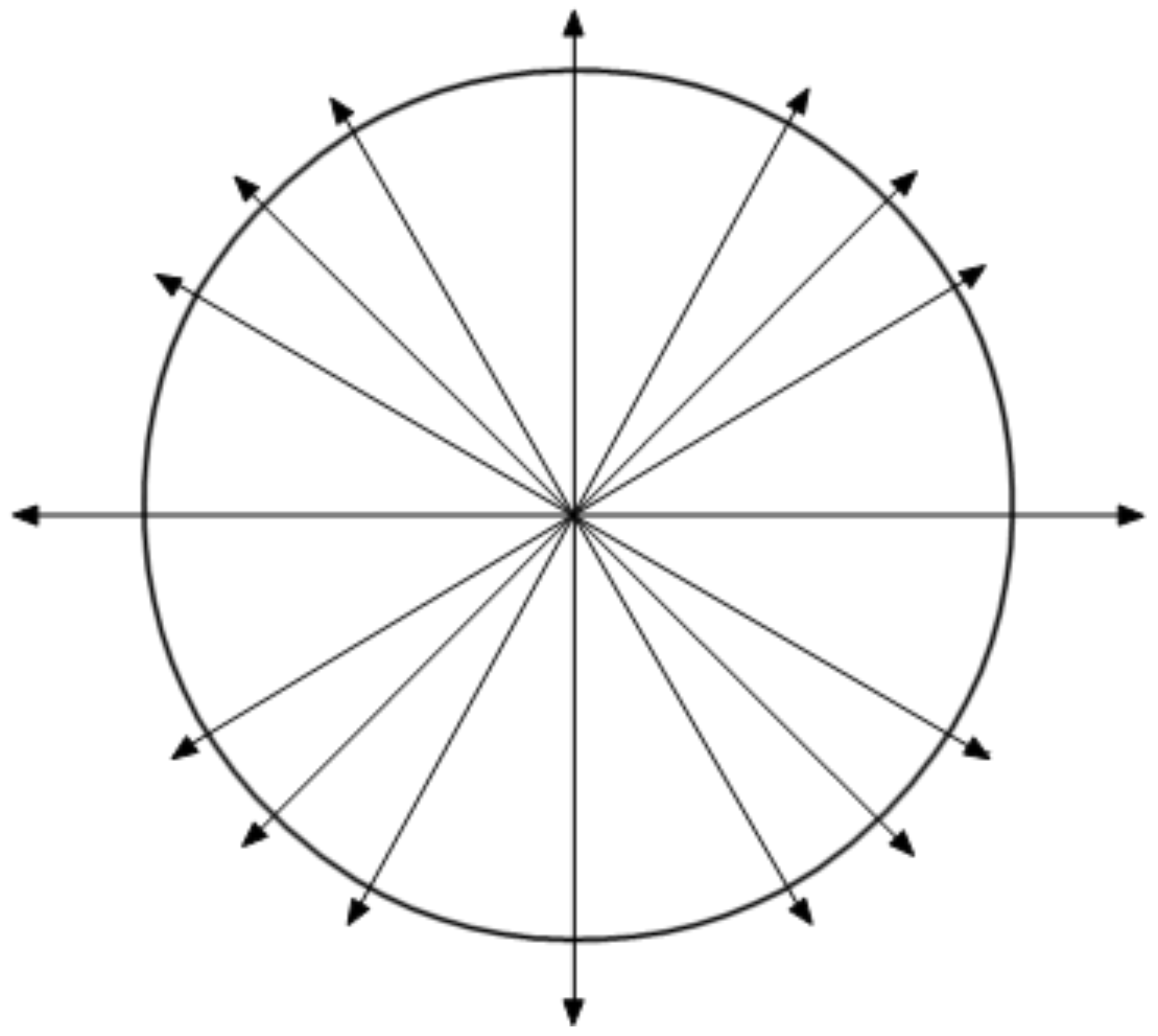
Beyond single-unit codes

So far we have showed how single units selectively encode a stimulus feature

- In which other ways could neural activity encode information?





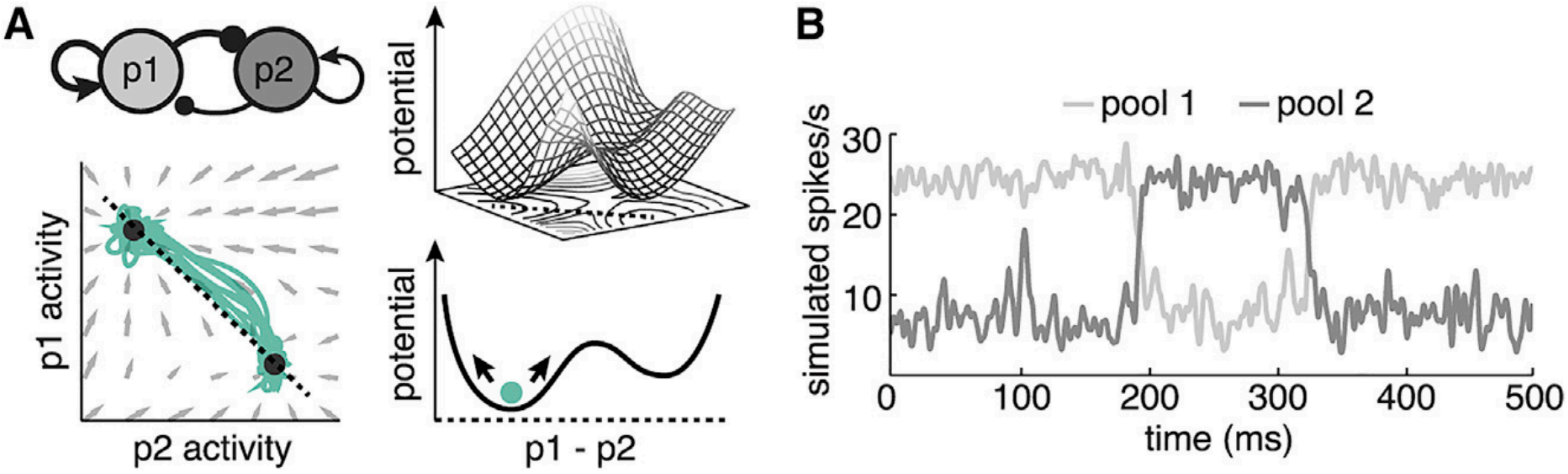


$\{ \uparrow , \rightarrow , \downarrow , \leftarrow \}$

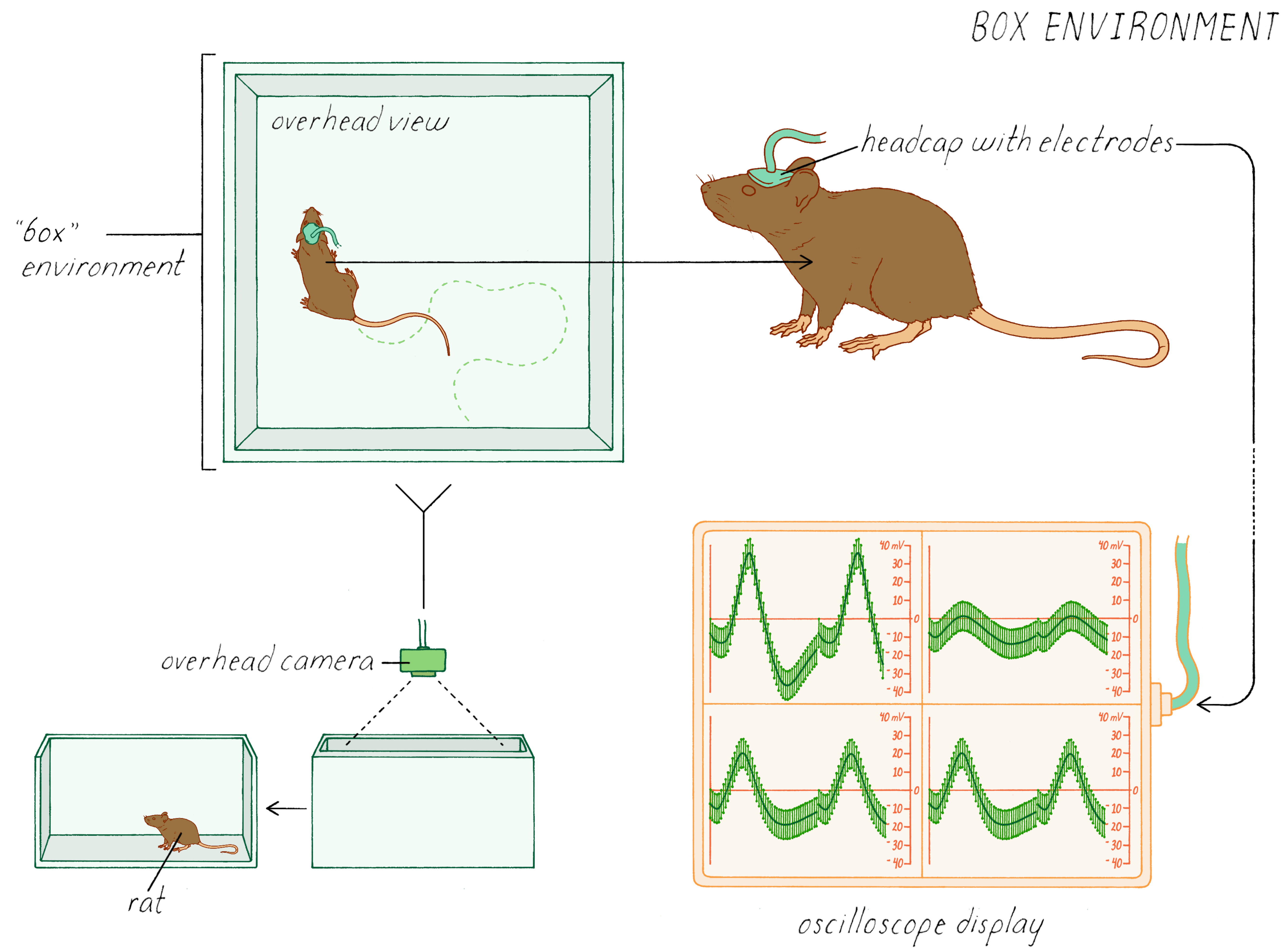
Population encoding

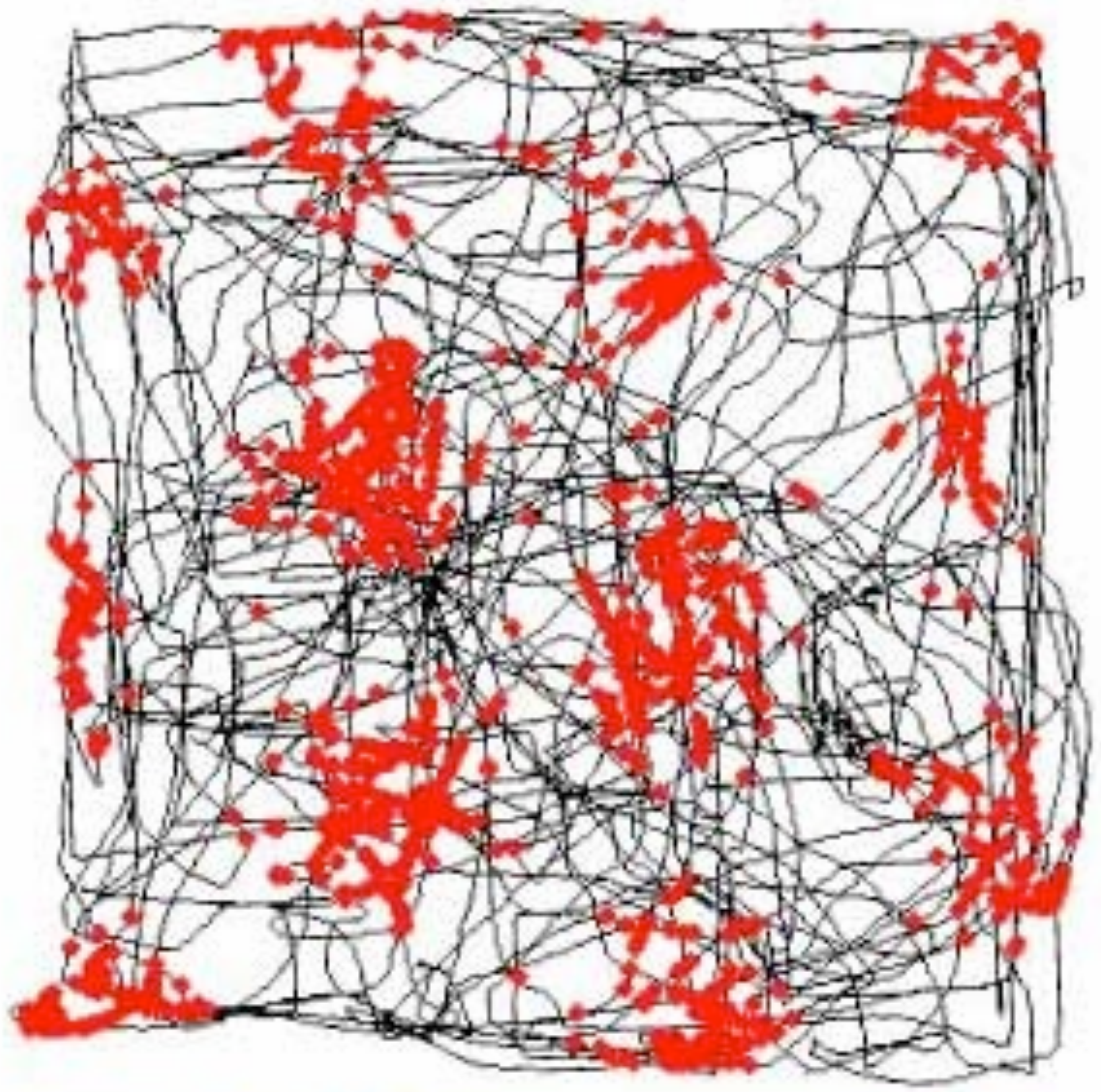
Neurons are not generally selective to a single stimuli:

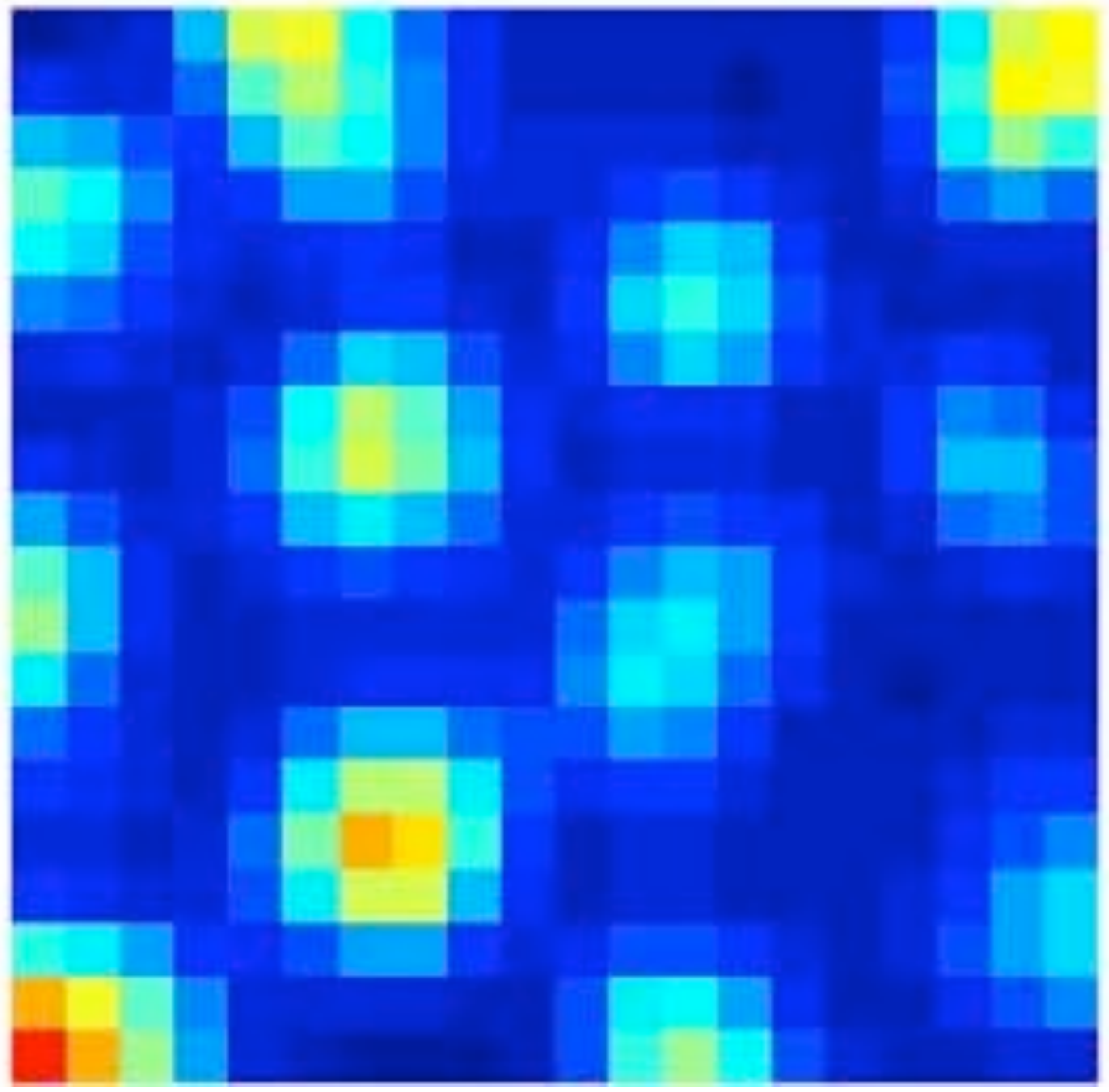
- neurons span a vector space that multiplexes information (RFs are the exception, not the rule)



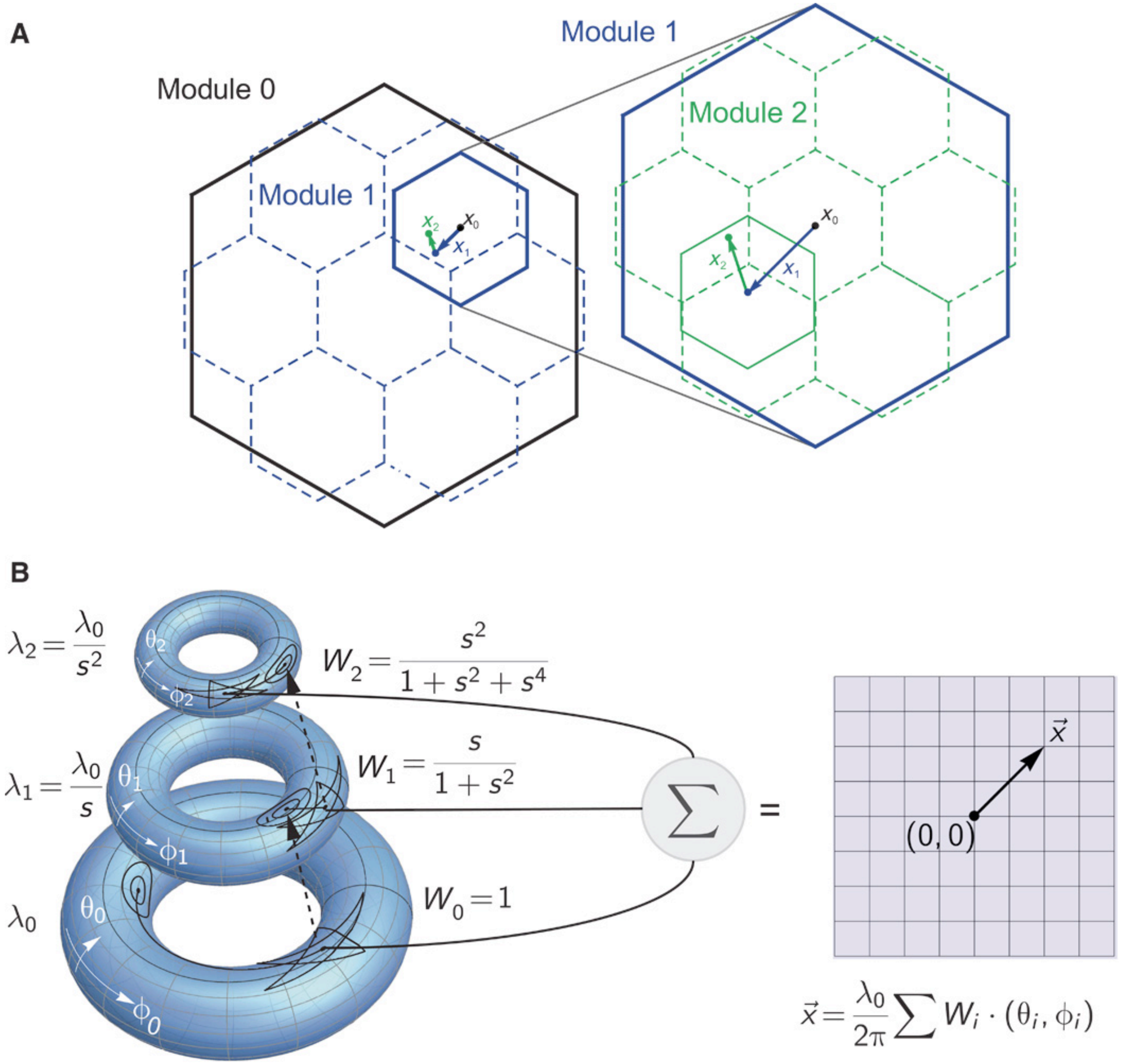
Example: Grid cells

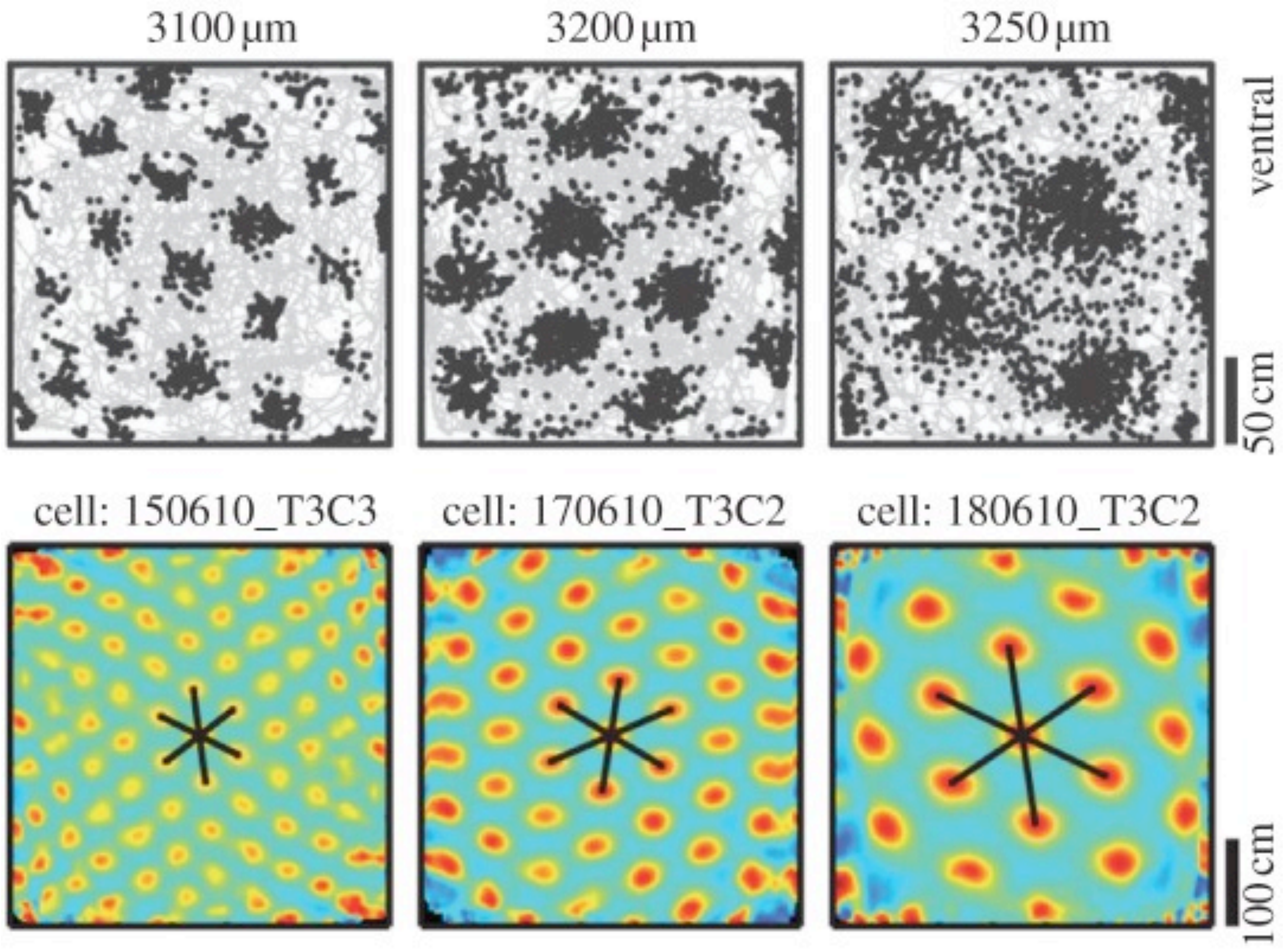






Example: Grid cells





Computational models in Neuroscience research

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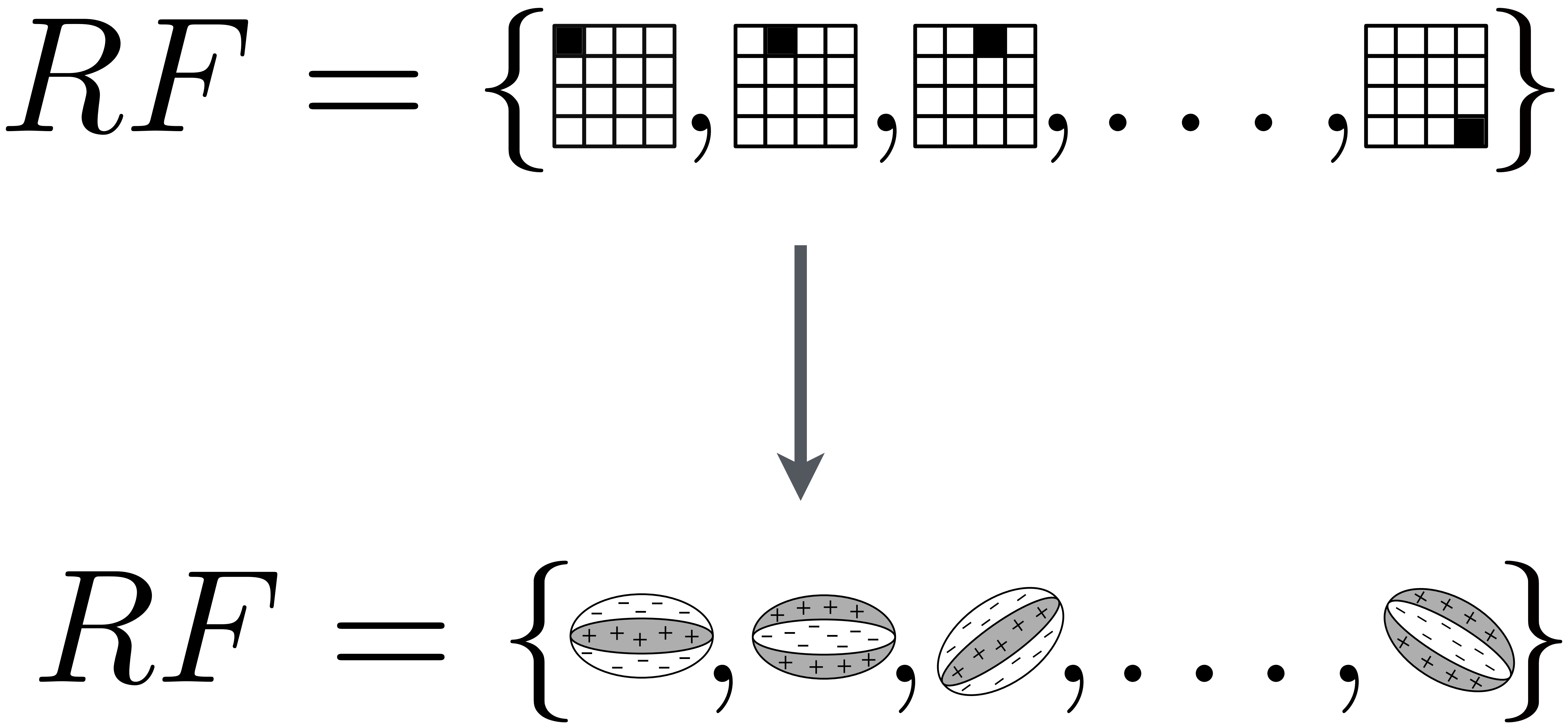
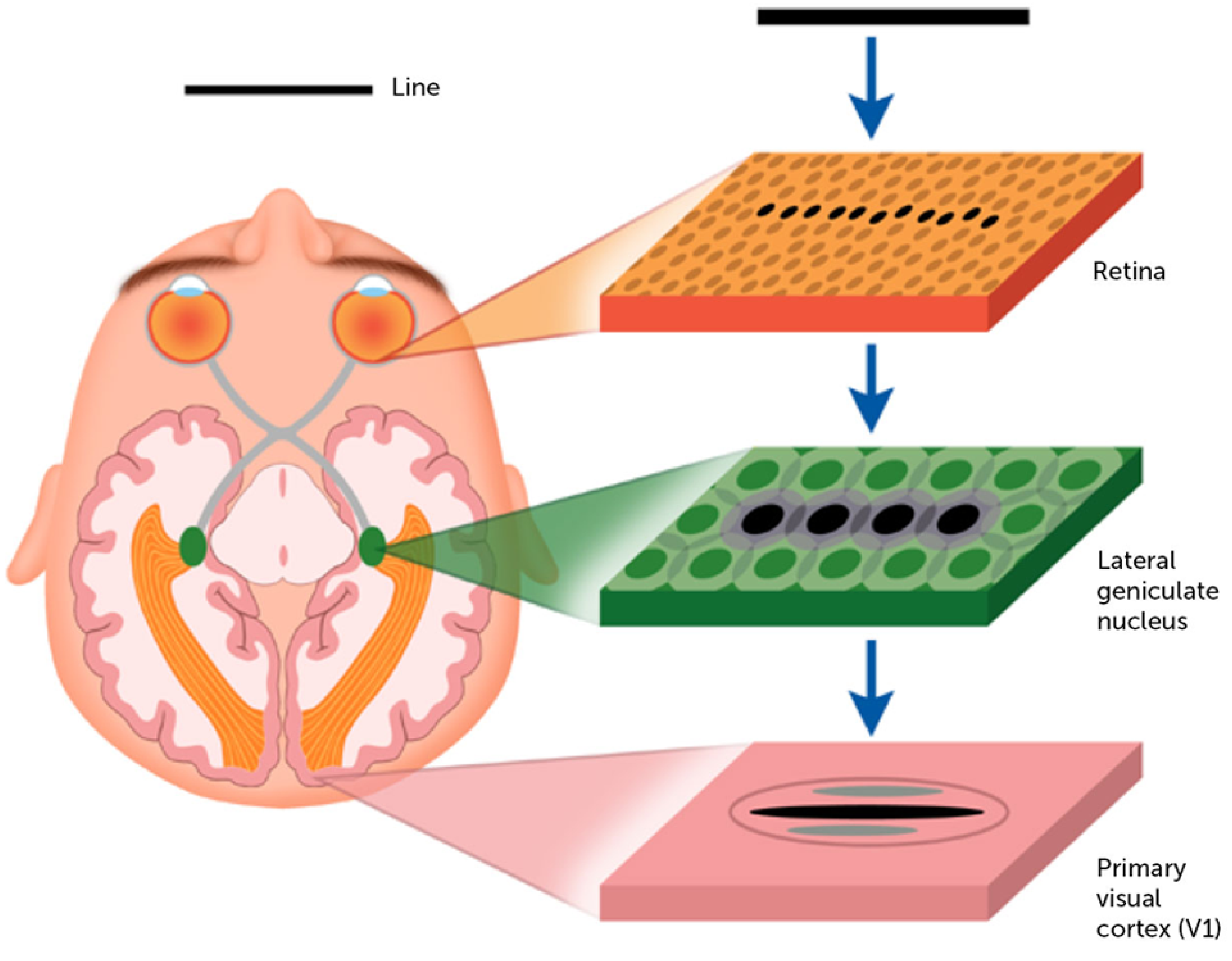
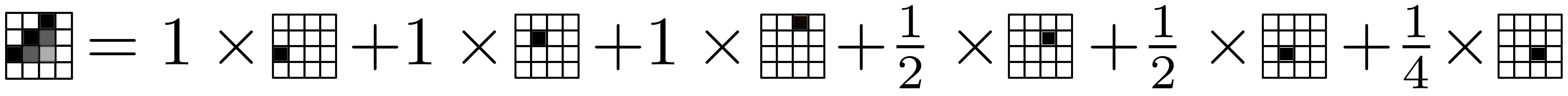
4. Population codes
5. **Transformation of information**
6. Conclusions
7. Mind reading

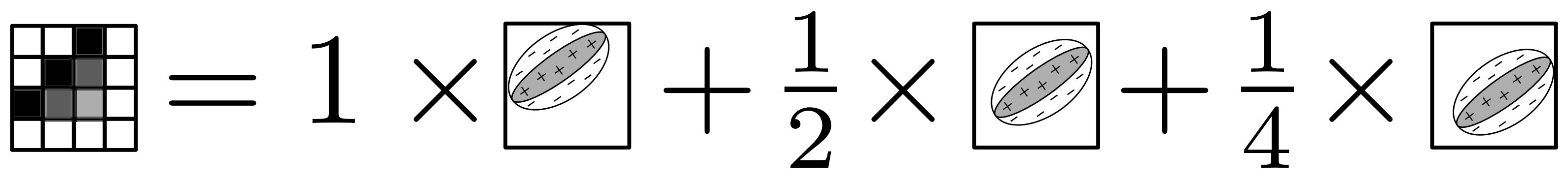
Transformations between RFs

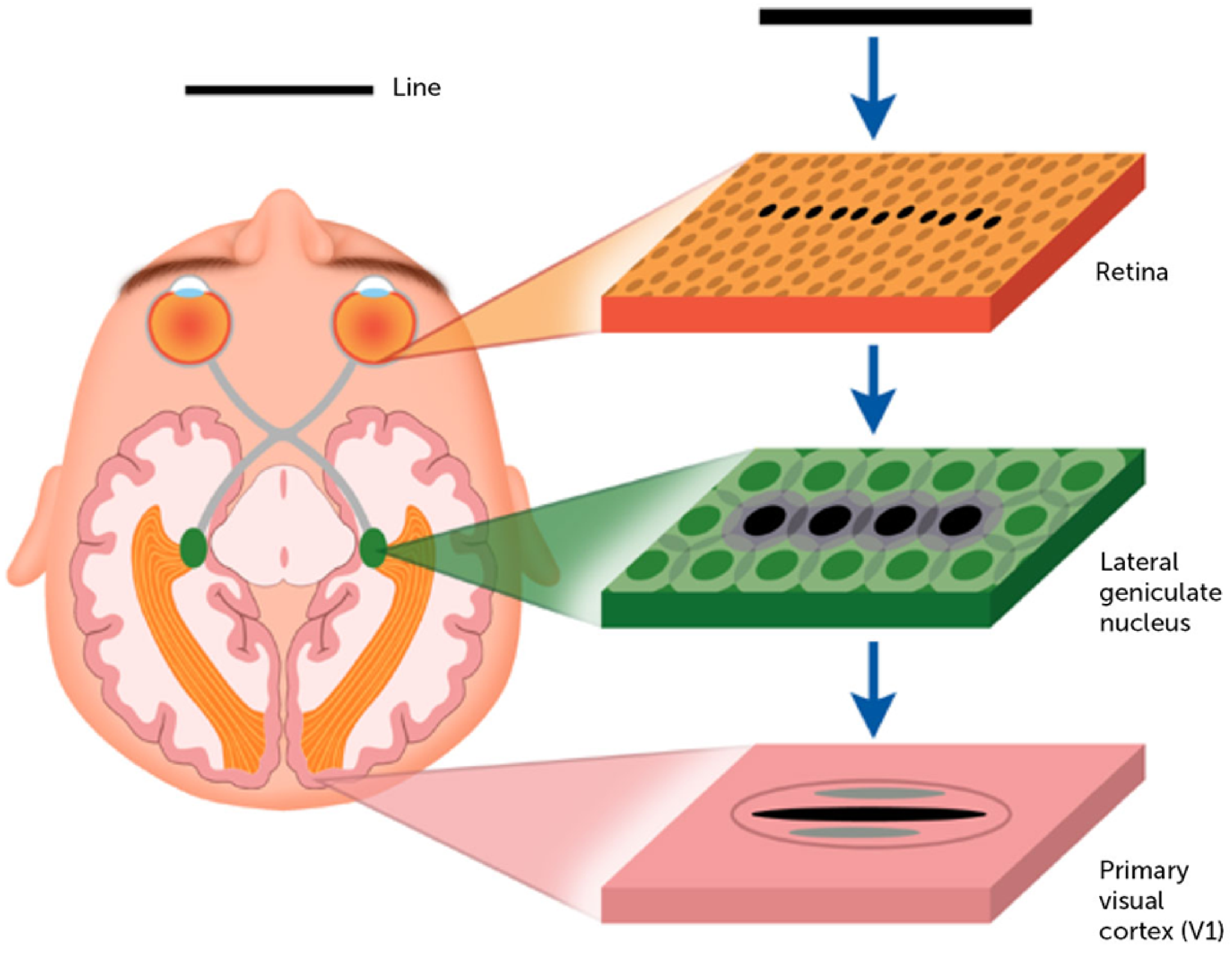




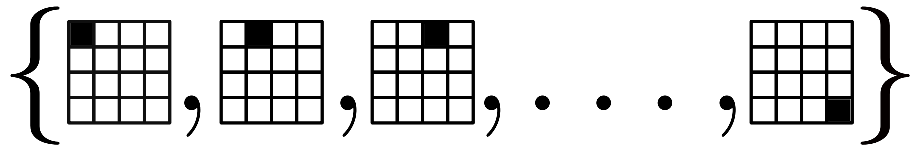
Transformations between RFs

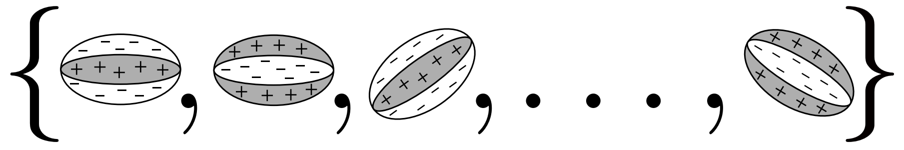






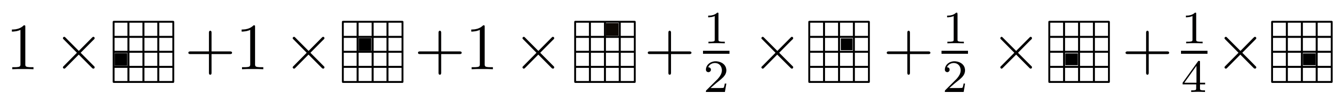
Transfer = Mapping between vector spaces

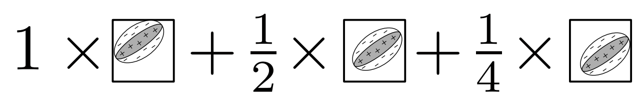


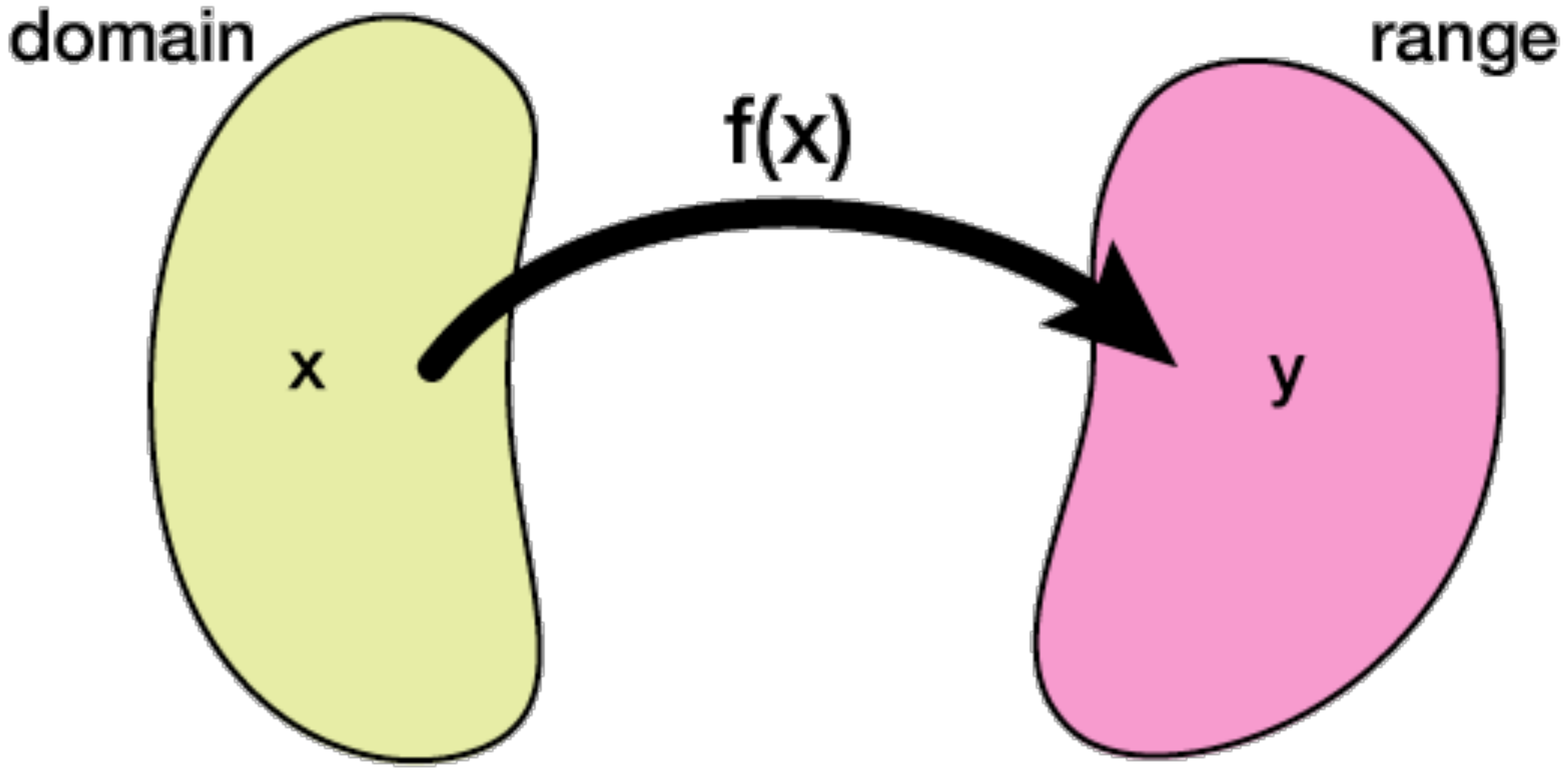


$$f : \mathcal{S}_1 \to \mathcal{S}_2$$

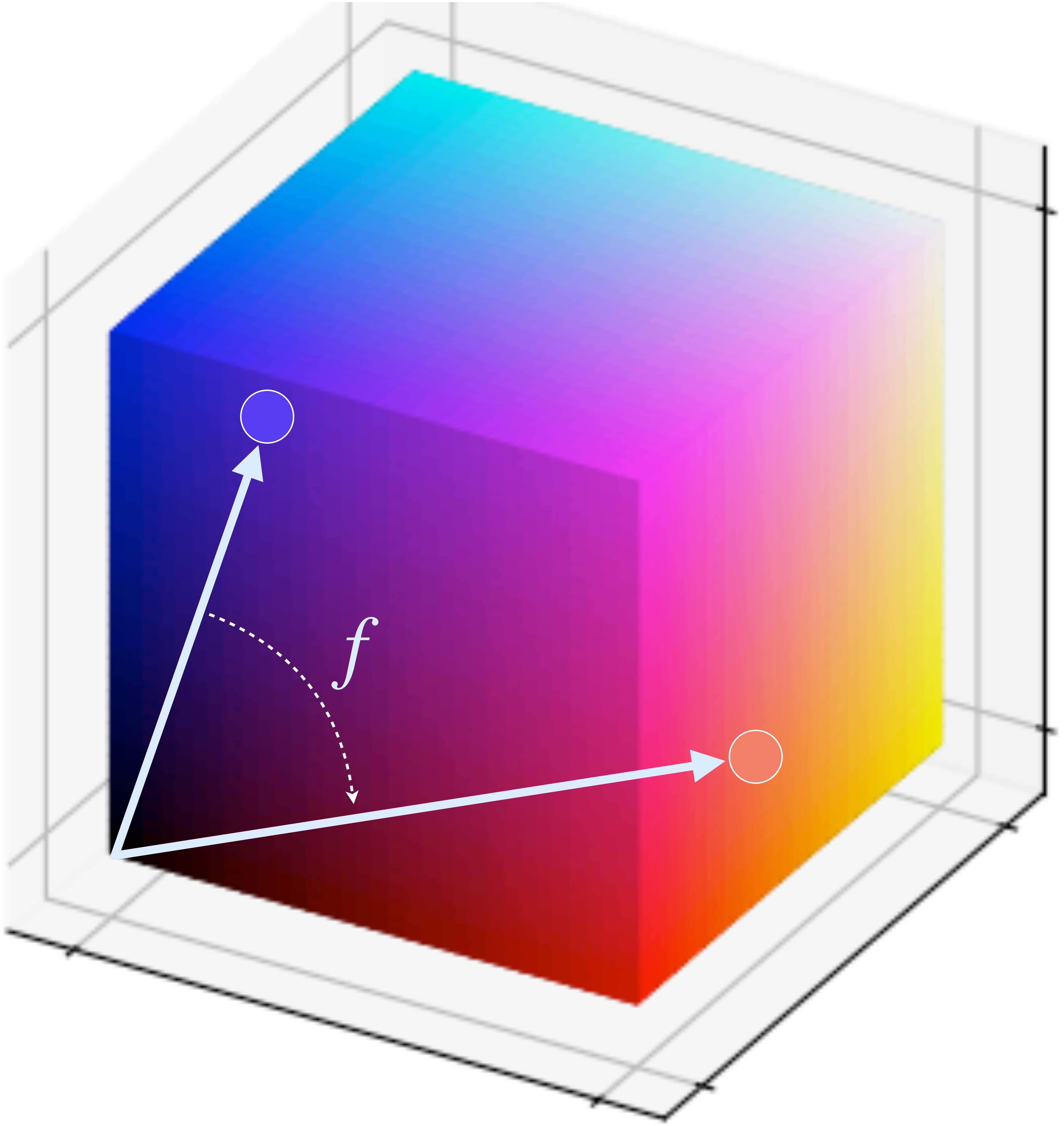
$$\vec{x} \to \vec{y} = f(\vec{x})$$

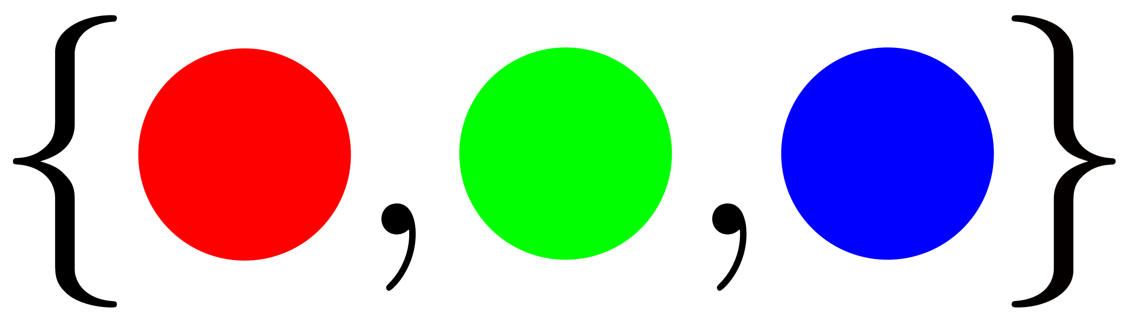






Transformations = mappings between vector spaces





Transformations in multi-dimensional codes

- Rotations in the code vector space modify information
- Pieces of information can be added within the same space (blue + yellow = green)

Computational models in Neuroscience research

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7. Mind reading

Conclusions

The brain can represent information through:

- Single neuron spikes
  - Spike timing
  - Firing rate
- Population codes
  - Single-unit coding (one-dimensional firing rate)
  - Multi-unit coding (multi-dimensional firing rate)
- ...

Conclusions

Information representation can be modelled using:

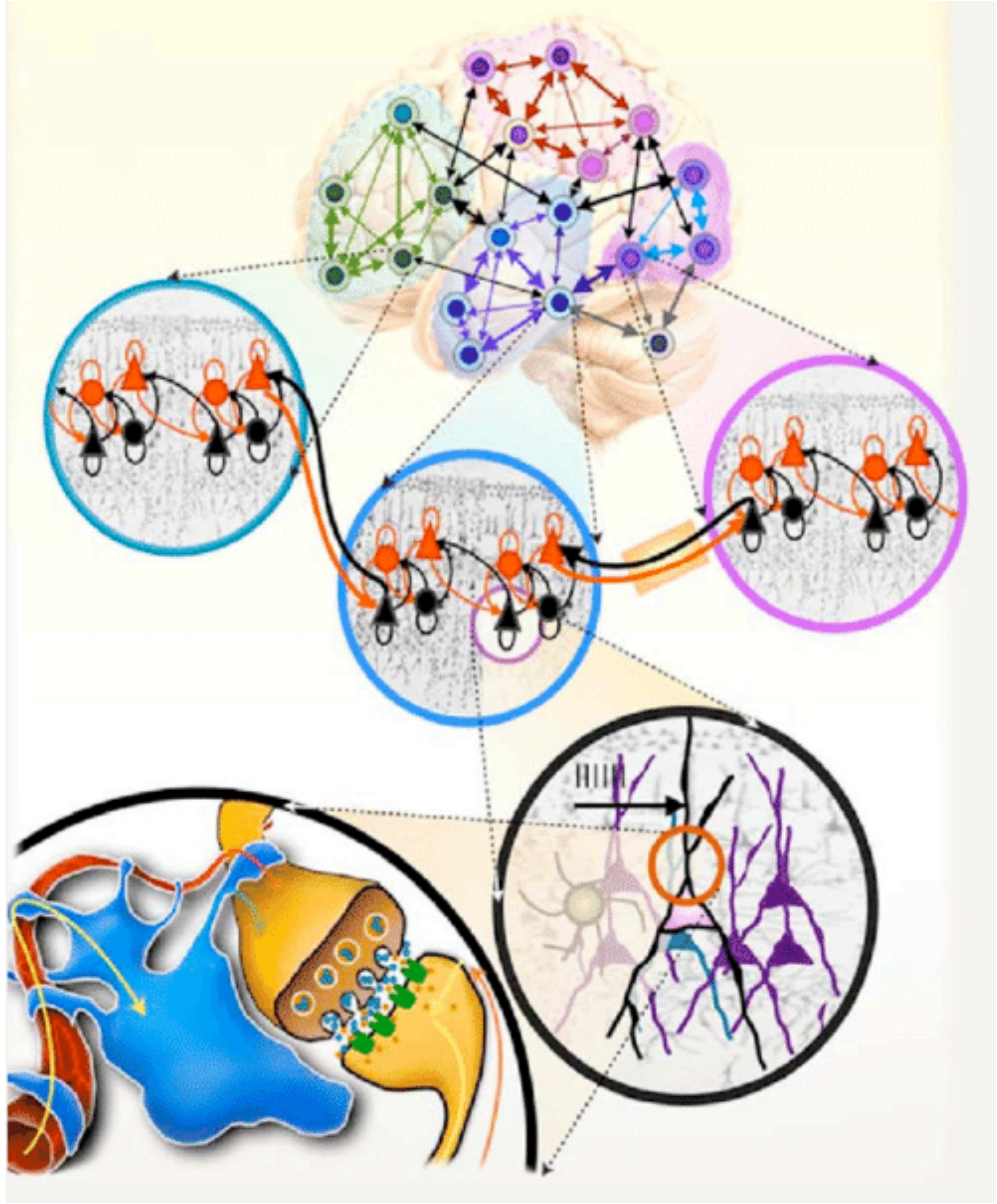
- Parametric receptive fields
- Vector spaces
- ...

Information transfer can be modelled as:

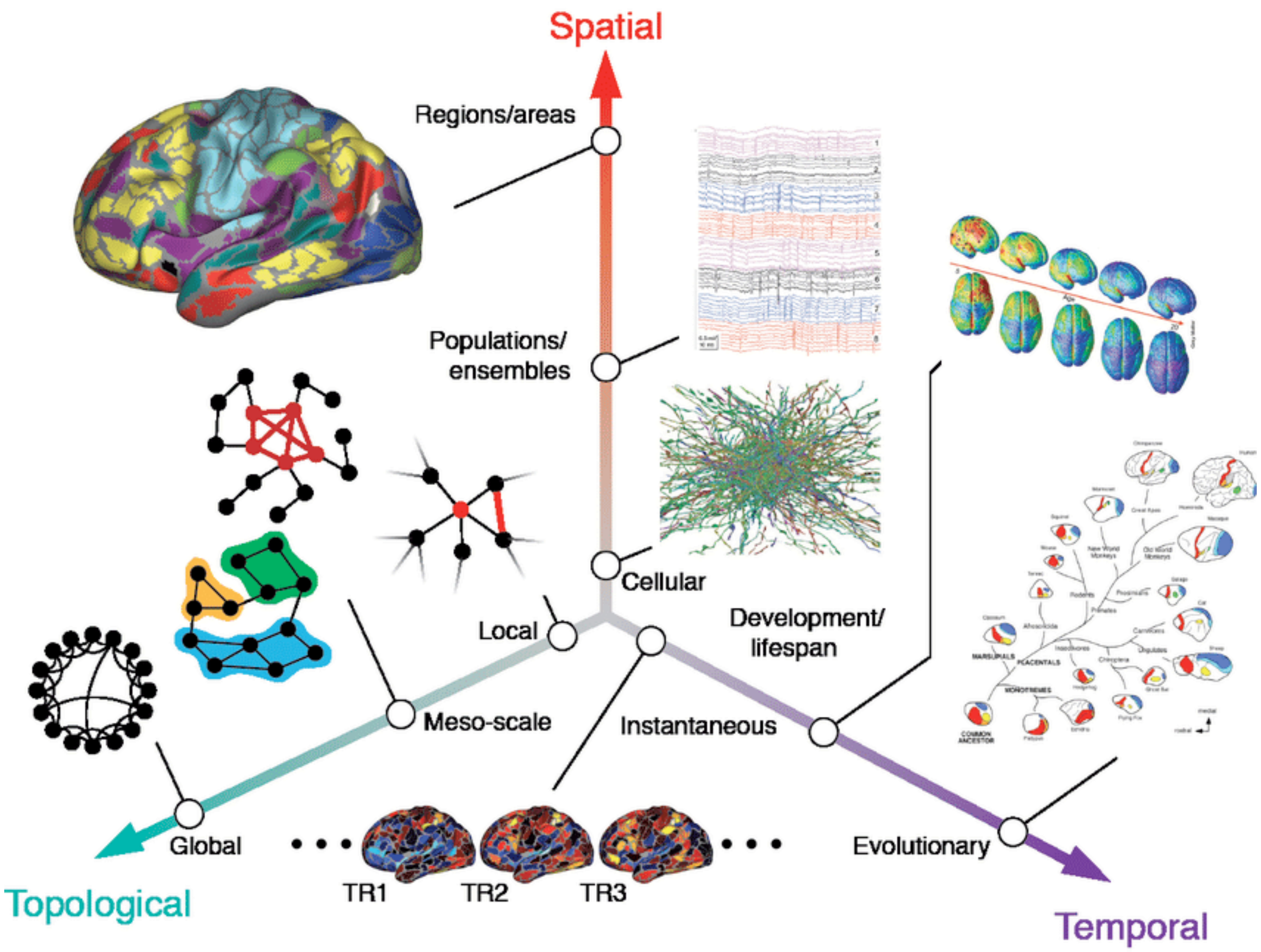
- Mappings between vector spaces (transfer)
- Rotations and other operations within the same vector space (transformation)
- ...

A note for caution: even more levels of analysis

macroscopic



microscopic



Computational models in Neuroscience research

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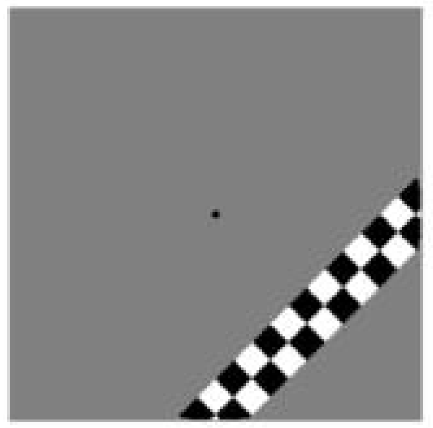
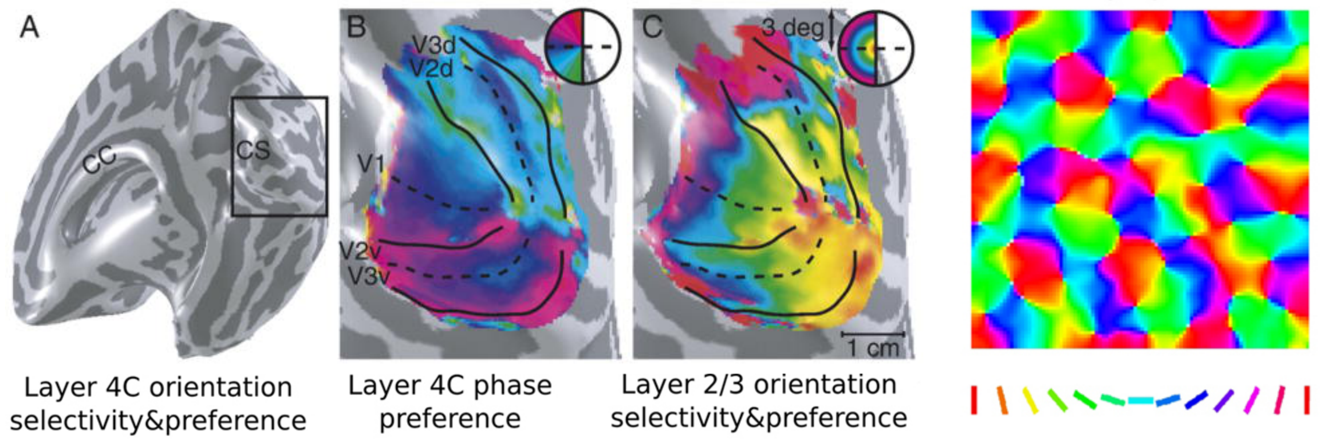
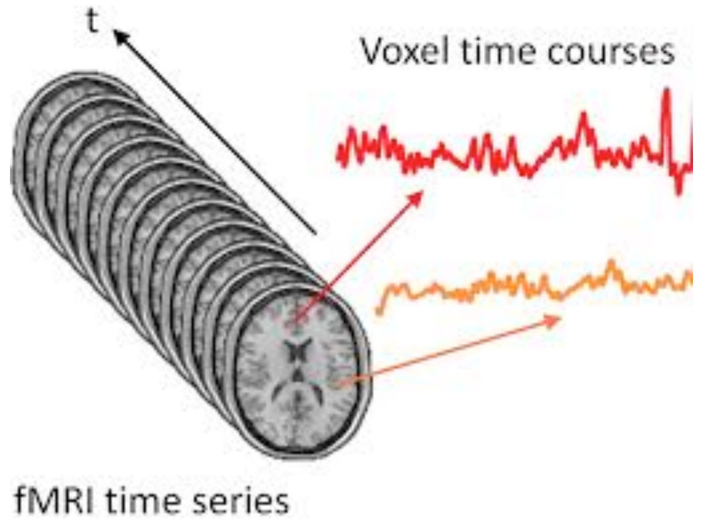
Encoding and decoding

Encoding: finding where and how stimulus features are represented in the brain

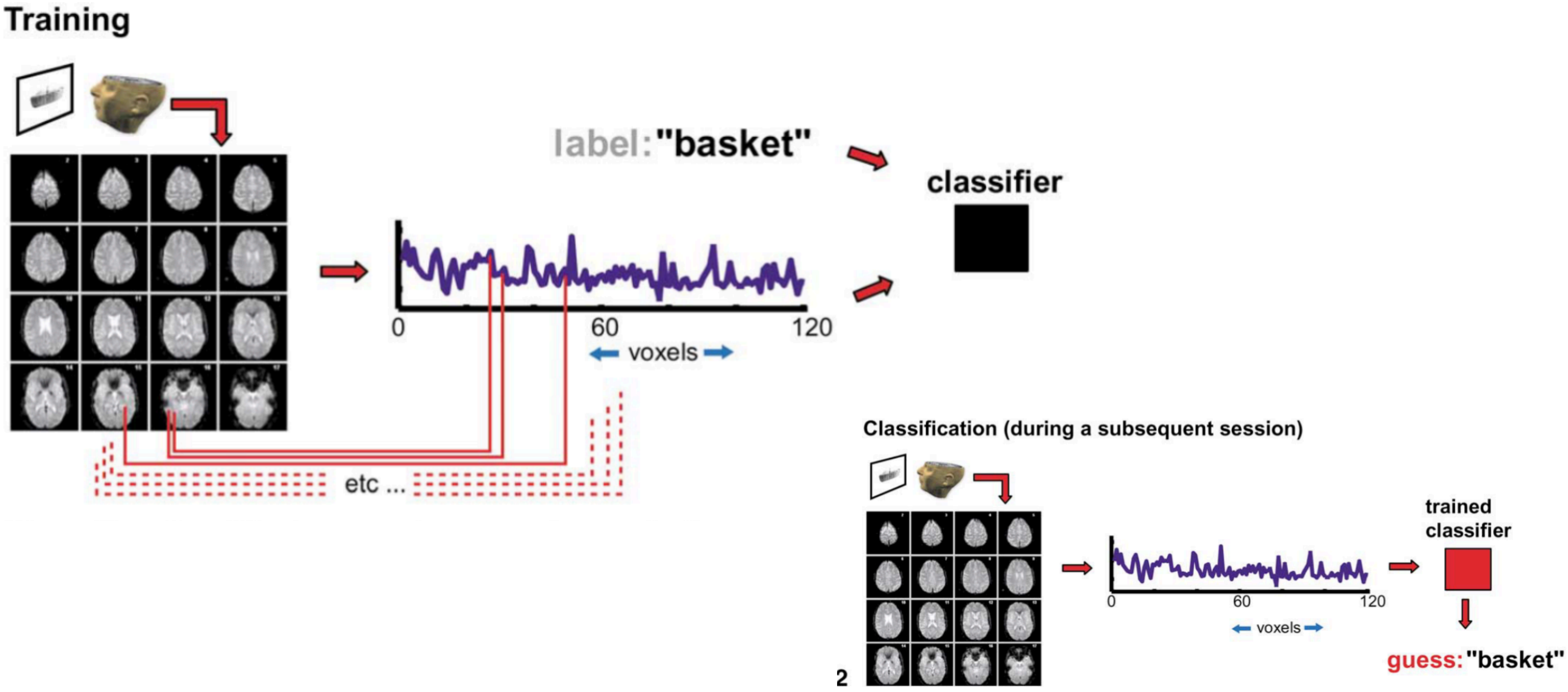




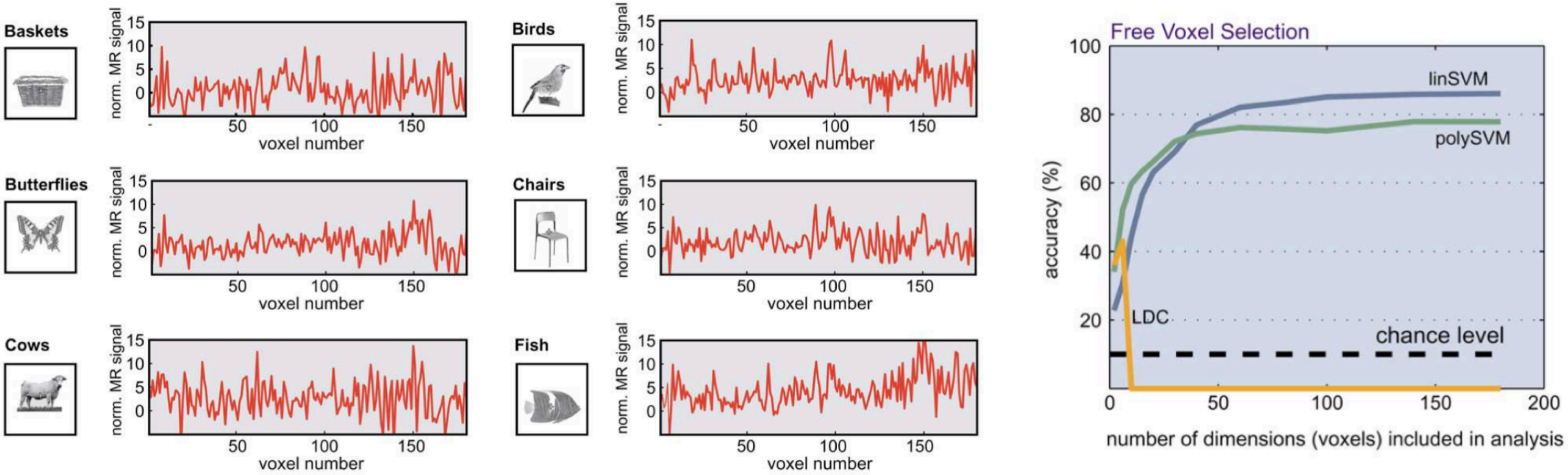
Decoding: infer the information represented in the brain from a measure of its activation



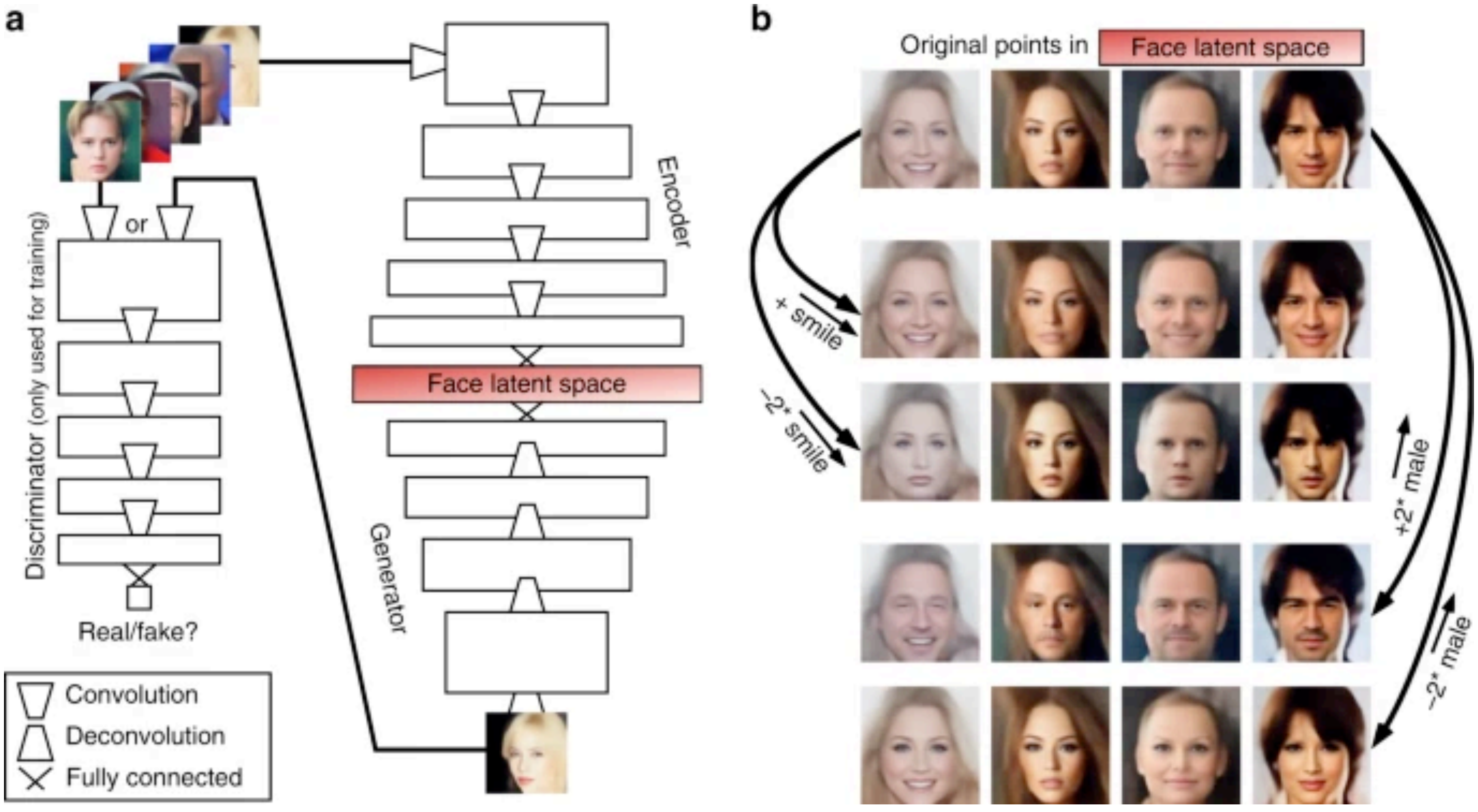
The essentials of decoding



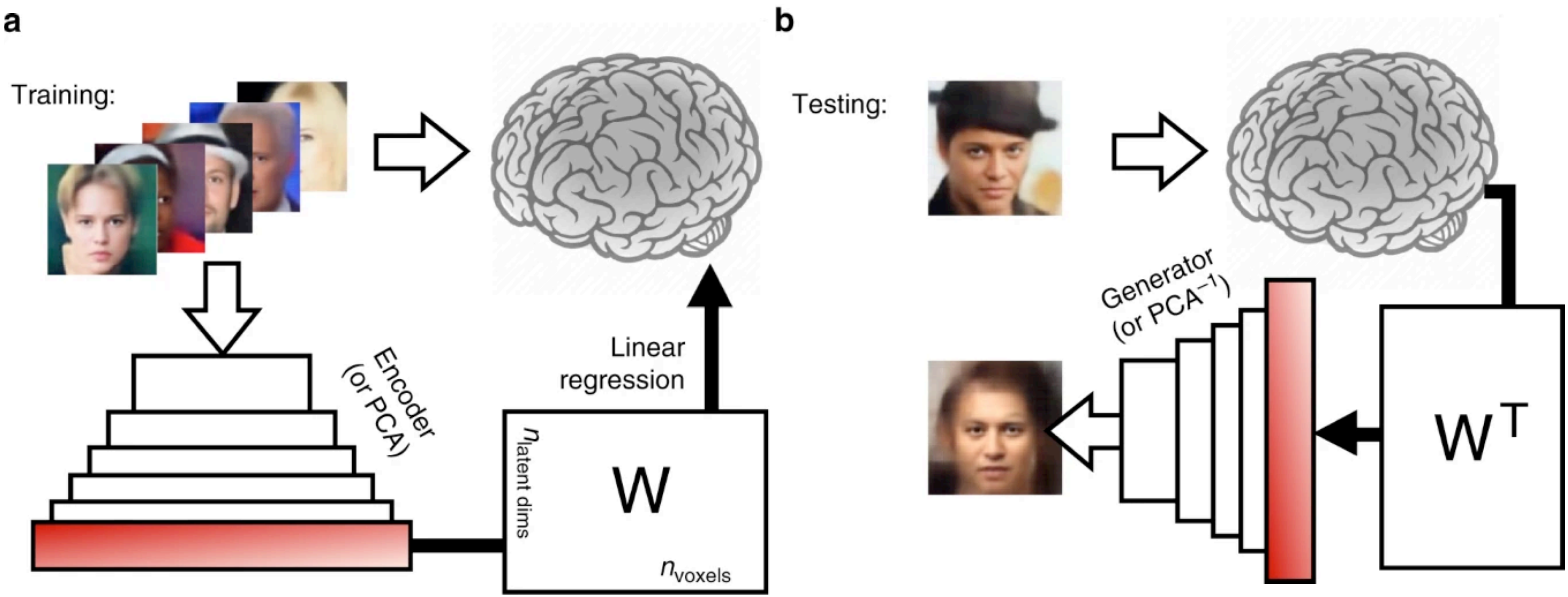
Decoding in 2003



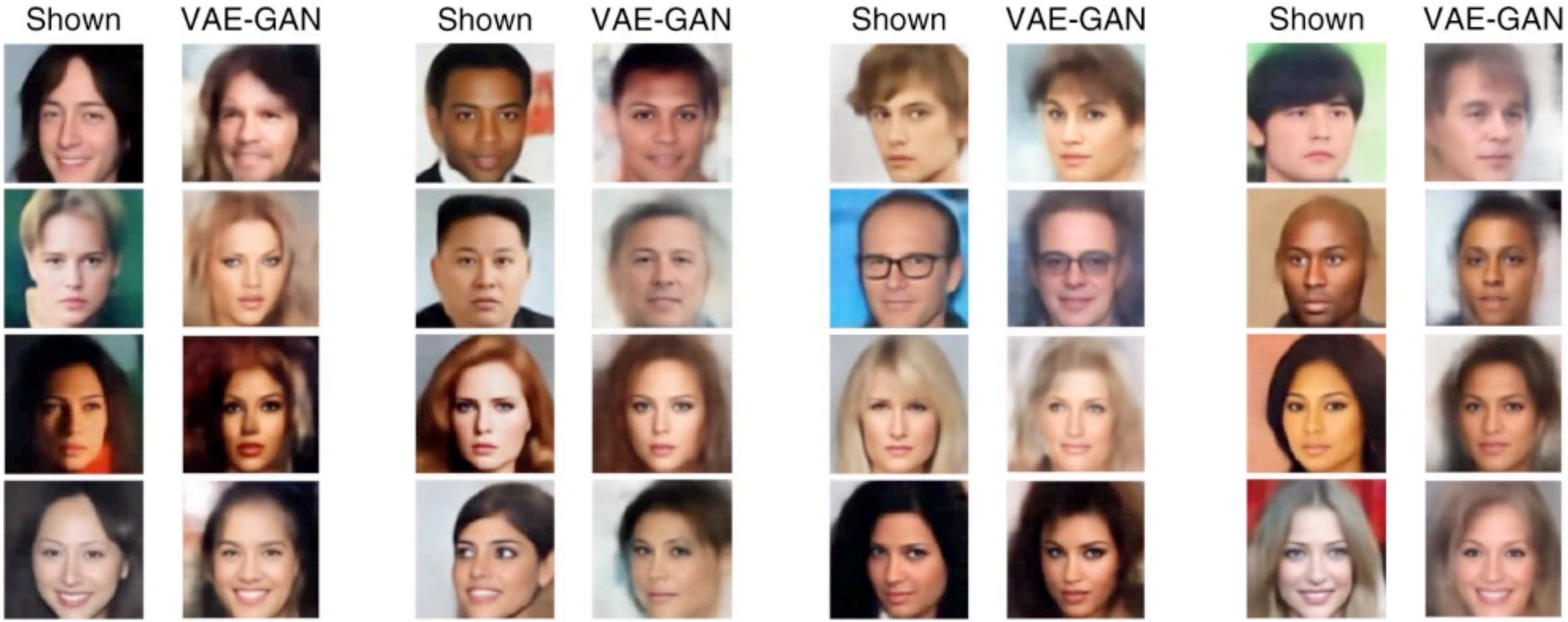
Decoding in 2019



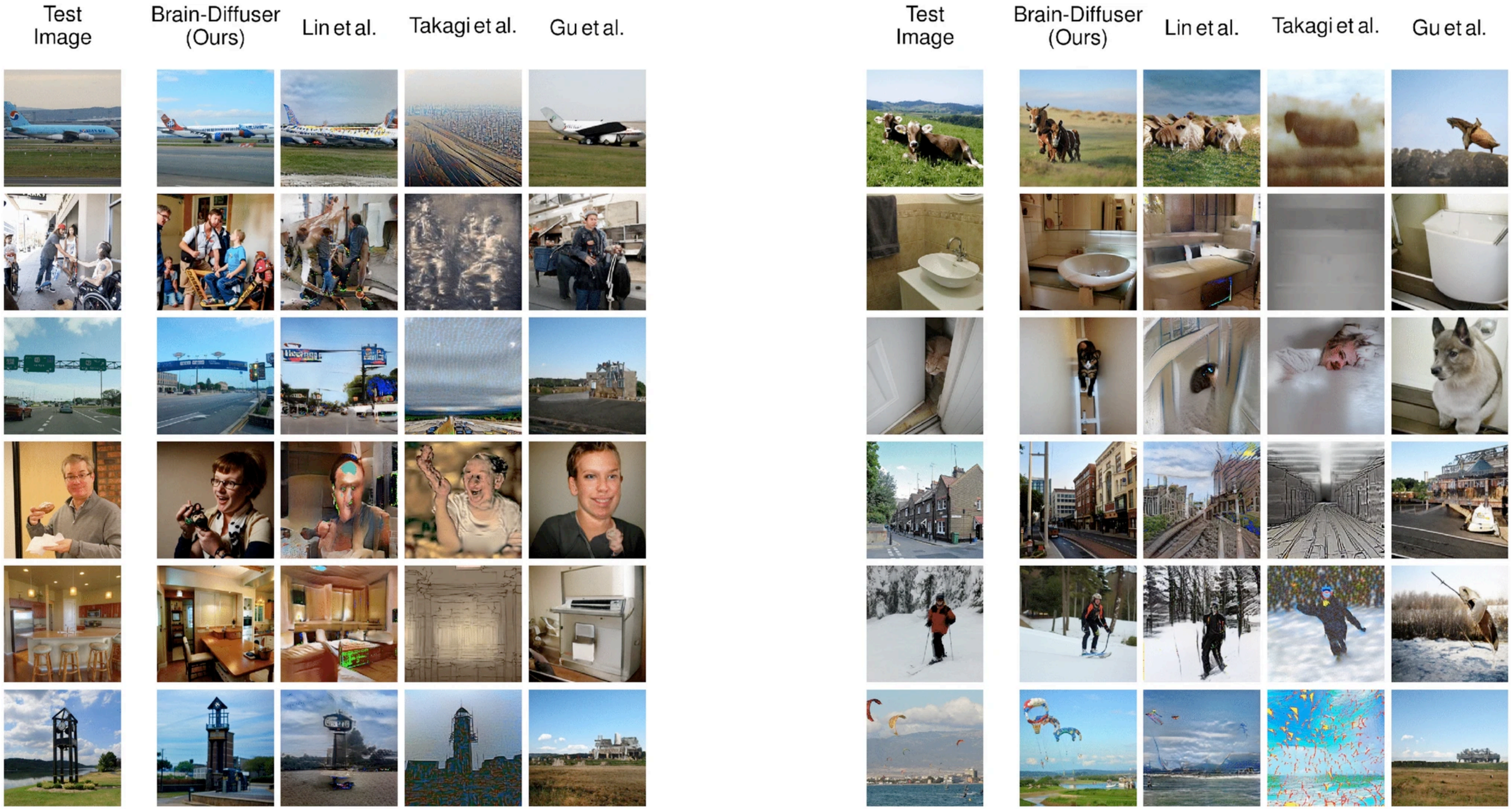
Decoding in 2019



Decoding in 2019



Decoding in 2023



Questions for next session

Questions for next session: Q2.1

A neuron's receptive field describes how it responds to the world. Is this an objective property of the stimulus or a subjective model constructed by the brain? If different organisms have different RFs for the same sensory input, whose model is correct? What does this tell us about the nature of representation?

Questions for next session: Q2.2

Why do some receptive fields, like the orientation selectivity of V1, have finite width? Why don't they, instead, respond selectively only to a single orientation value? What constraints or principles force the brain to use broader tuning?

Questions for next session: Q2.3

Receptive fields in the epidermis show considerable variability in size and overlap. What might be the normative principles underlying this variability?

Questions for next session: Q2.4

Imagine you're designing a brain from scratch with no evolutionary constraints. Which properties would be desirable in the brain's internal representations of the visual input? For a few of the properties you list, try to formulate specific normative or phenomenological hypotheses on the kind of receptive fields we would expect in the visual pathways. How would you test such hypotheses?

Questions for next session: Q2.5

Take a close look at the beginning of the responses across cochlear frequency channels at the beginning of each tone. What are the first valleys in the response pattern encoding? Why do lower frequencies show longer delays and extended responses compared to higher frequencies?

Questions for next session: Q2.6

Imagine a neural population represents a stimulus feature (e.g., on-off RF responses in the visual thalamus) in its activity pattern but this information is not transmitted to any downstream area. What can you say about whether this information is represented in the brain?

Questions for next session: Q2.7

Different measurement techniques (single-unit recordings, fMRI, EEG) reveal different aspects of neural representation. How does our choice of measurement tool shape our theories about how the brain represents information? What biases might this introduce?

Questions for next session: Q2.8

Modern techniques can reconstruct faces or images from brain activity. What does successful decoding prove or help us understanding about the representation?

All course materials:

github.com/qtabs/compneuro4cogneuros