Population Vectors

Population Vectors

Network Computations

Evidence for Network Computations

- Number of neurons (cortex). Number of synapses.

- Multiple levels of organizations: Areas. Layers. Microcircuits.

- Presence of Correlations (common inputs Vs interconnections) → Cooperation between neurons.

- Synapses (cortex).
  - Excitatory, inhibitory, modulatory.
  - Short-term dynamics (facilitation, depression).
  - Long term dynamics (LTP, LTD).

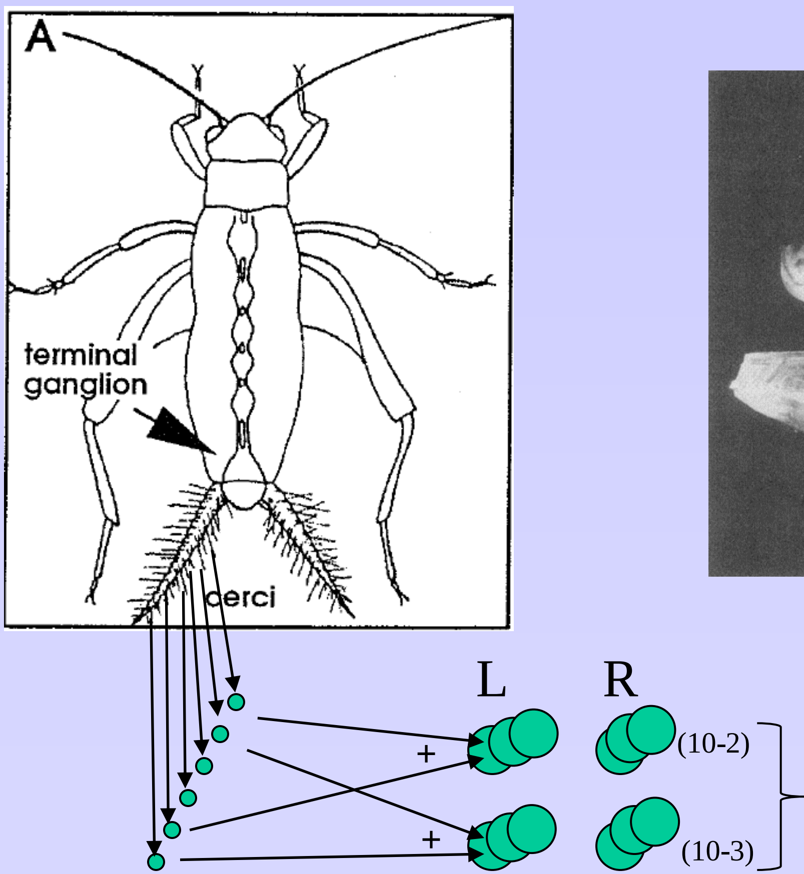
  } Potential for rich 'computations'

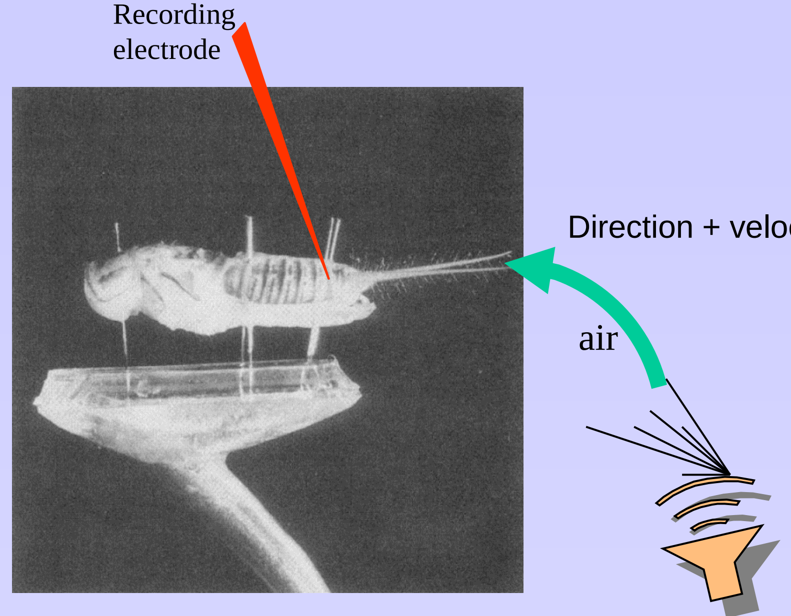
- Tuning curves. Continuous/smooth with exceptions (face/place cells?).

⇒ Information processing relies on **populations of neurons**.

Quantifying populations: Population Vectors

- Cricket: Small nervous system. *Identified* neurons.
- Cercal system: sense the direction/velocity of incoming air (predators)





(Miller et al. 1991)

10-2, 10-3: single cells coding

FR = α.log(Air_velocity)

~1000s
Terminal ganglion

4!
Cercal glomeruli

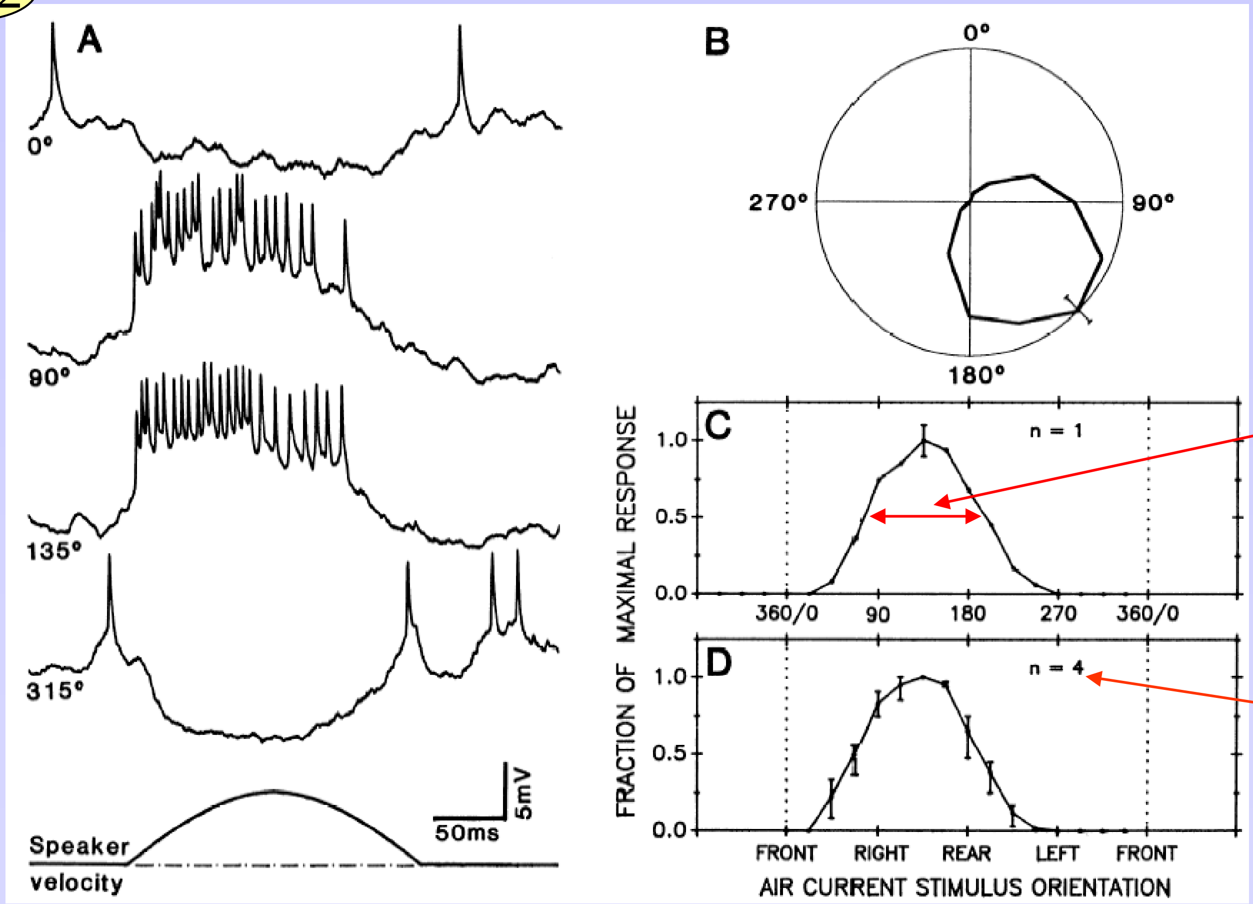
→ What about Air_direction?

Population Vectors

- Building the tuning curve (at 50-75% max response)

10-2

Air direction



Coding accuracy (single cell)

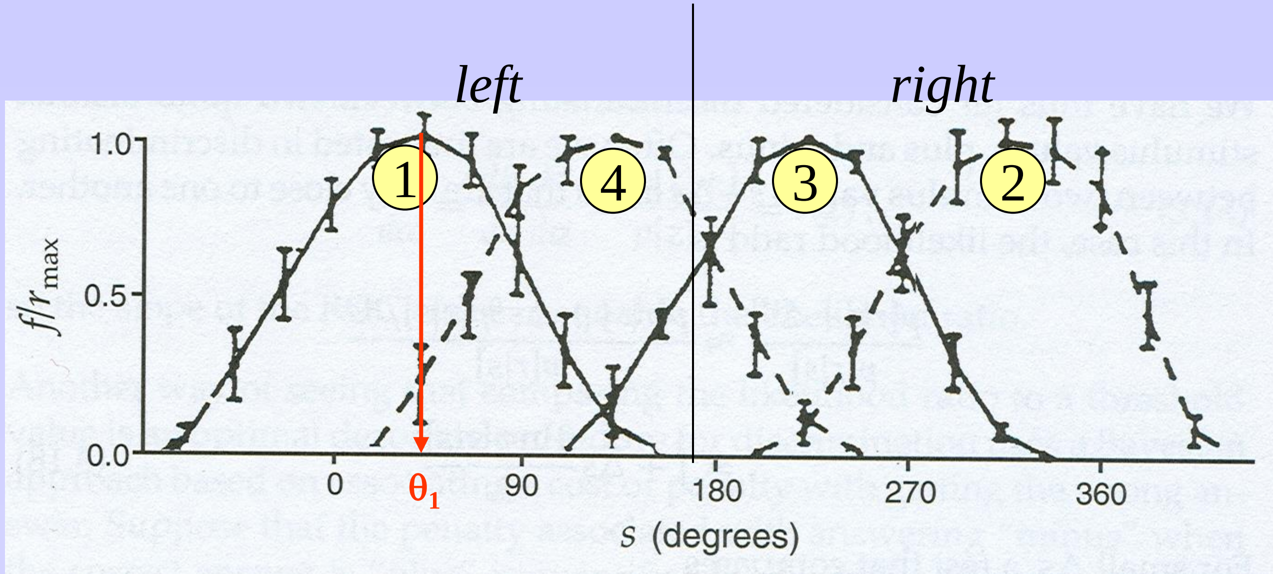
Same neuron
4 different animals

(Miller et al. 1991)

In general, behavioral accuracy of the animal is greater that the accuracy of individual neuron's tuning curves.

Population Vectors

➔ The 4 cells types have evolved to optimally cover the entire stimulus space!



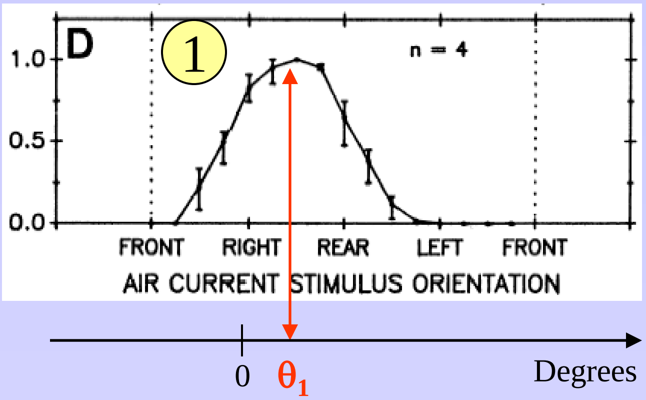
(Miller et al. 1991)

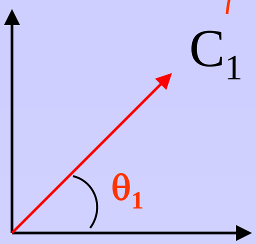
- Fitting the tuning curves, across the population: Half-rectified cosine tuning curves

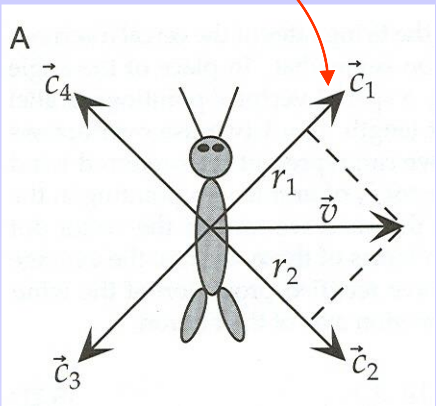
$$r_1(s) = r_1^{\max}\left[\cos(s-\theta_1)\right]_+$$

Population Vectors

- Move to a vectorial space







$$s, F(s) \Leftrightarrow \vec{v} \qquad \cos(s-\theta_1) = \vec{v}.\vec{C}_1 \qquad r_1(s) = r_1^{\max}\left[\vec{v}.\vec{C}_1\right]_+$$

➔ Orthogonal, unidirectional vectors

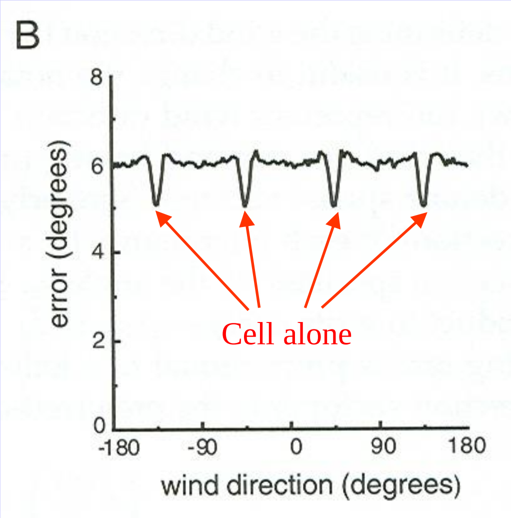
➔ The cricket nervous system uses the Cartesian Coordinate system …!!!

Population Vectors

- Population Vector: Full representation of the stimulus space. At what cost?

$$v \longrightarrow \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix} \longrightarrow \textbf{Noise (from data)} \xrightarrow{\textit{reconstruction}} v?$$

Population vector



$$\overrightarrow{V}_{pop} = \sum_{i<N} r_i \overrightarrow{C}_i \Longrightarrow \overrightarrow{V}_{pop} \Leftrightarrow \tilde{s}, F(\tilde{s})$$

Population N neurons

Estimate of the stimulus

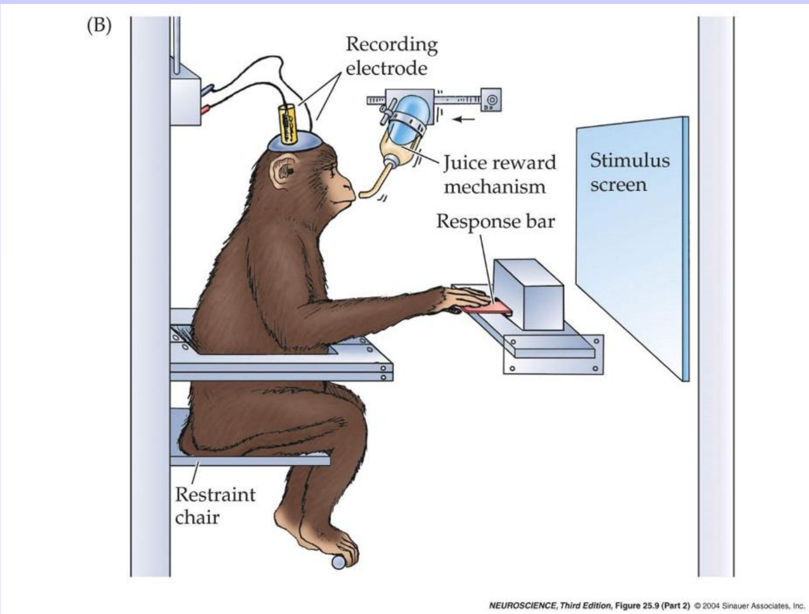
➔ Population coding error ~= 6 Deg.

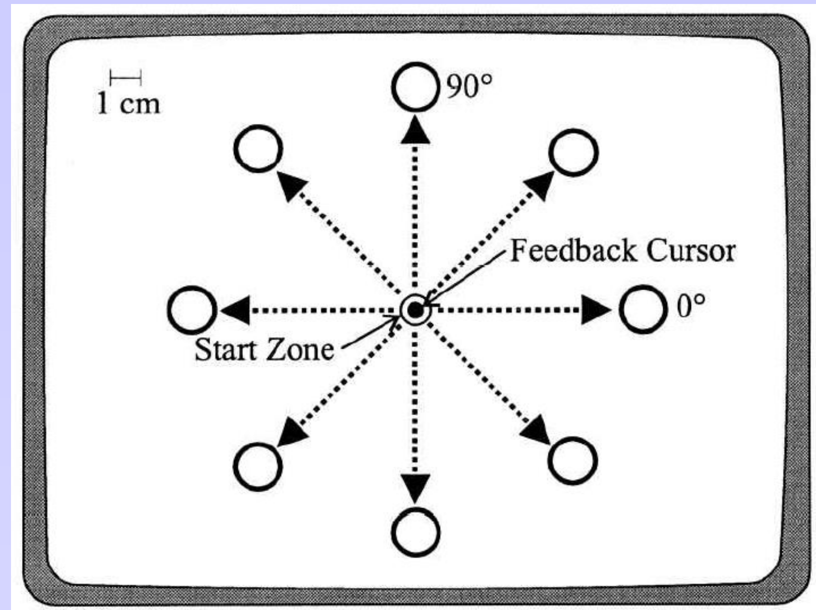
➔ Single cell coding error at pref orientation ~= 5 Deg.

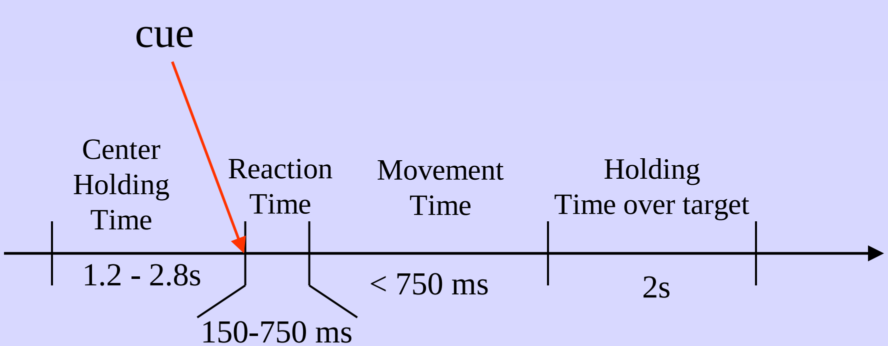
➔ ‘Price to pay’ for population coding at all orientations ~= 1Deg!

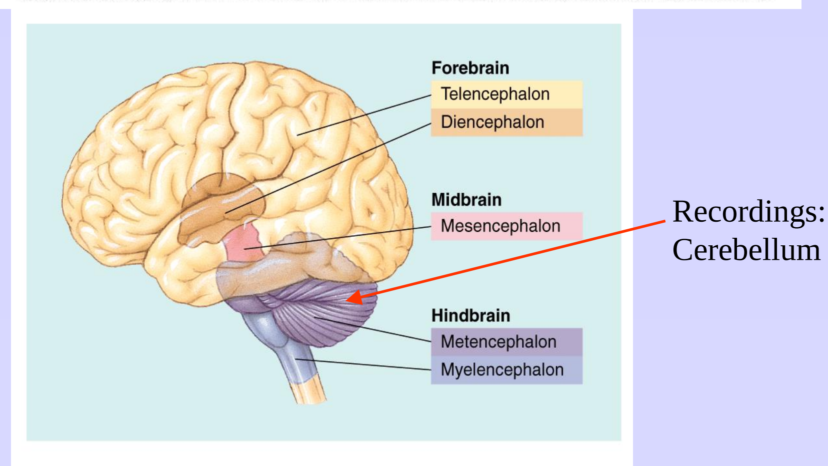
Population Vectors

- Computing a population vector for large populations: Arm movements



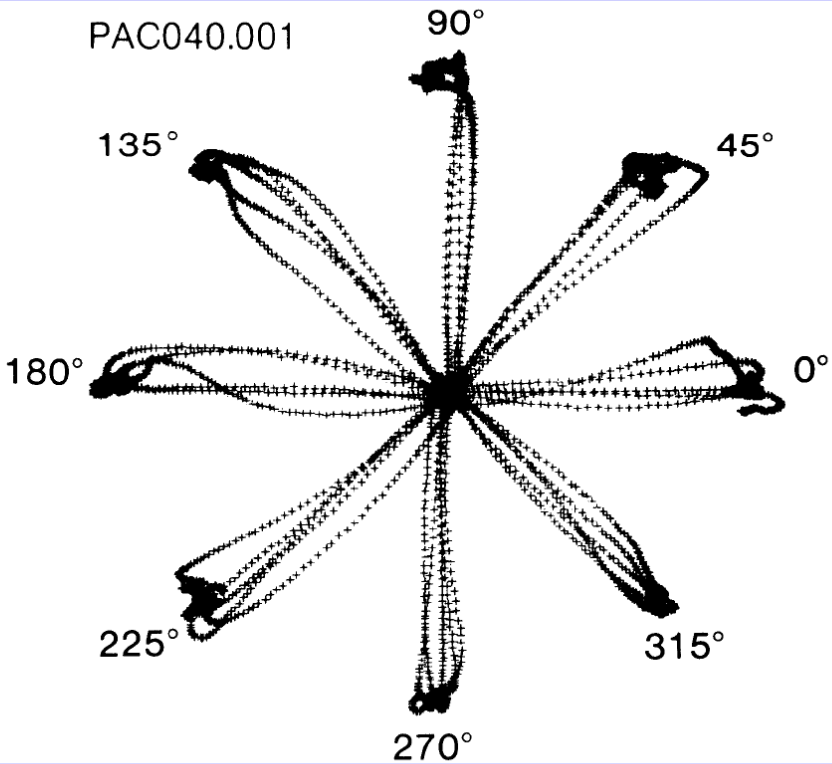




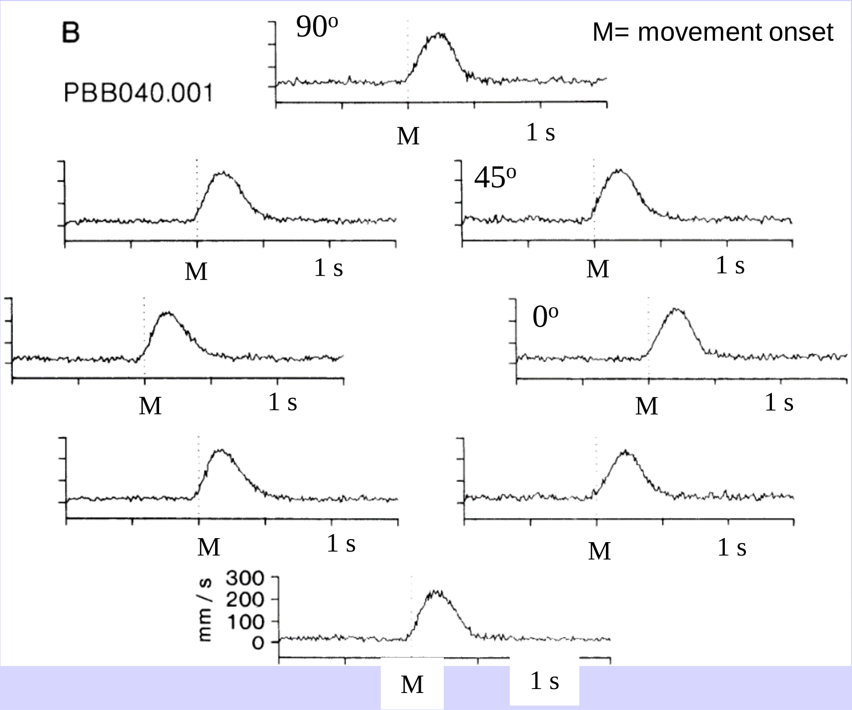


Population Vectors

- Movement trajectories. 1 block = 5x8 movements



Reliable movements

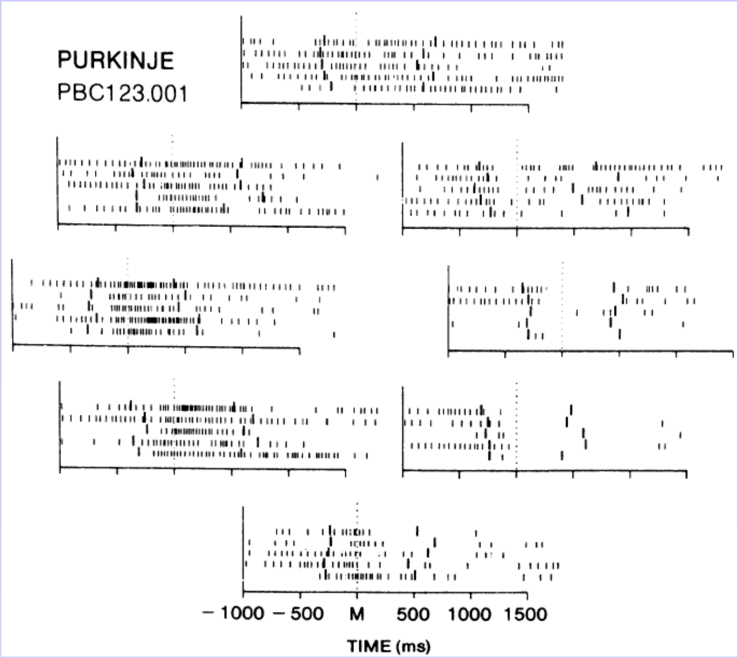


Isotropic speeds

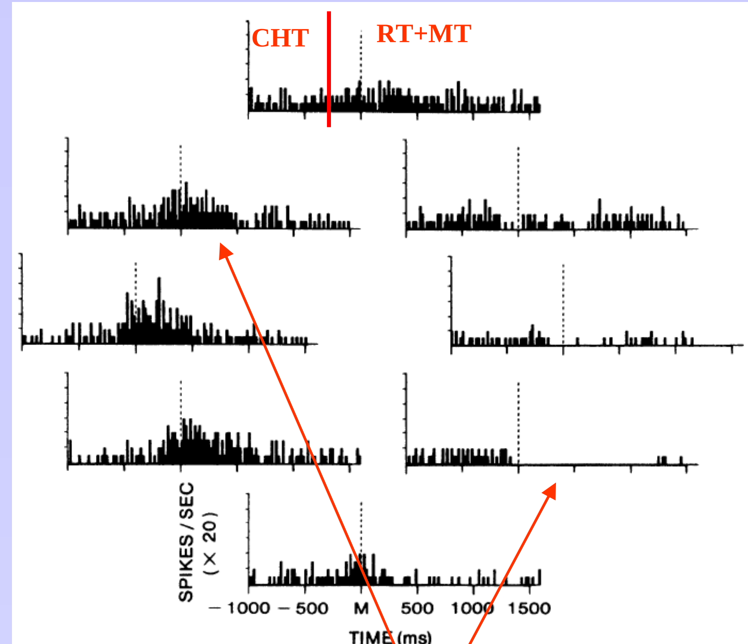
→ No reason to think that direction coding depends on speed.

(Fortier et al, 1989)

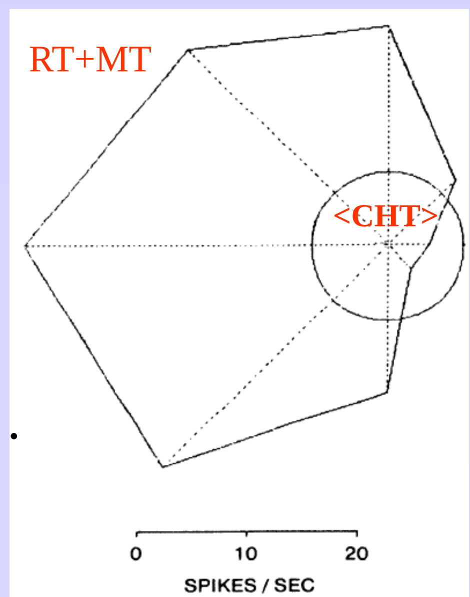
Population Vectors



PSTH



CHT: center holding time
RT: reaction time
MT: movement time



Directional cell:
opponent processes

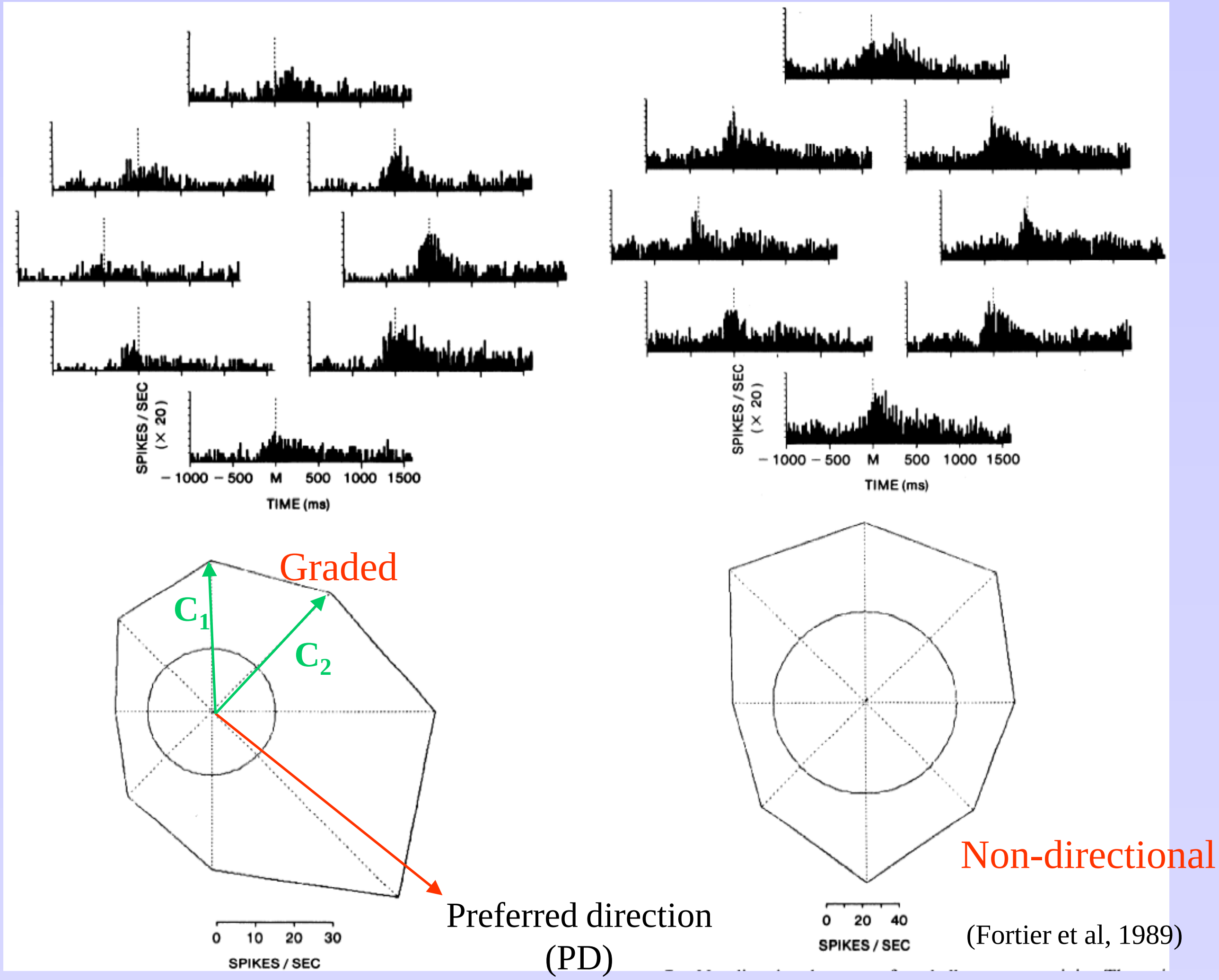
From raw data to
quantification of the phenomenon…

(Fortier et al, 1989)

Population Vectors

- Summary of the phenomenon for each cell: Preferred Direction vector

$$\overrightarrow{PD} = \sum_i \overrightarrow{C_i}$$

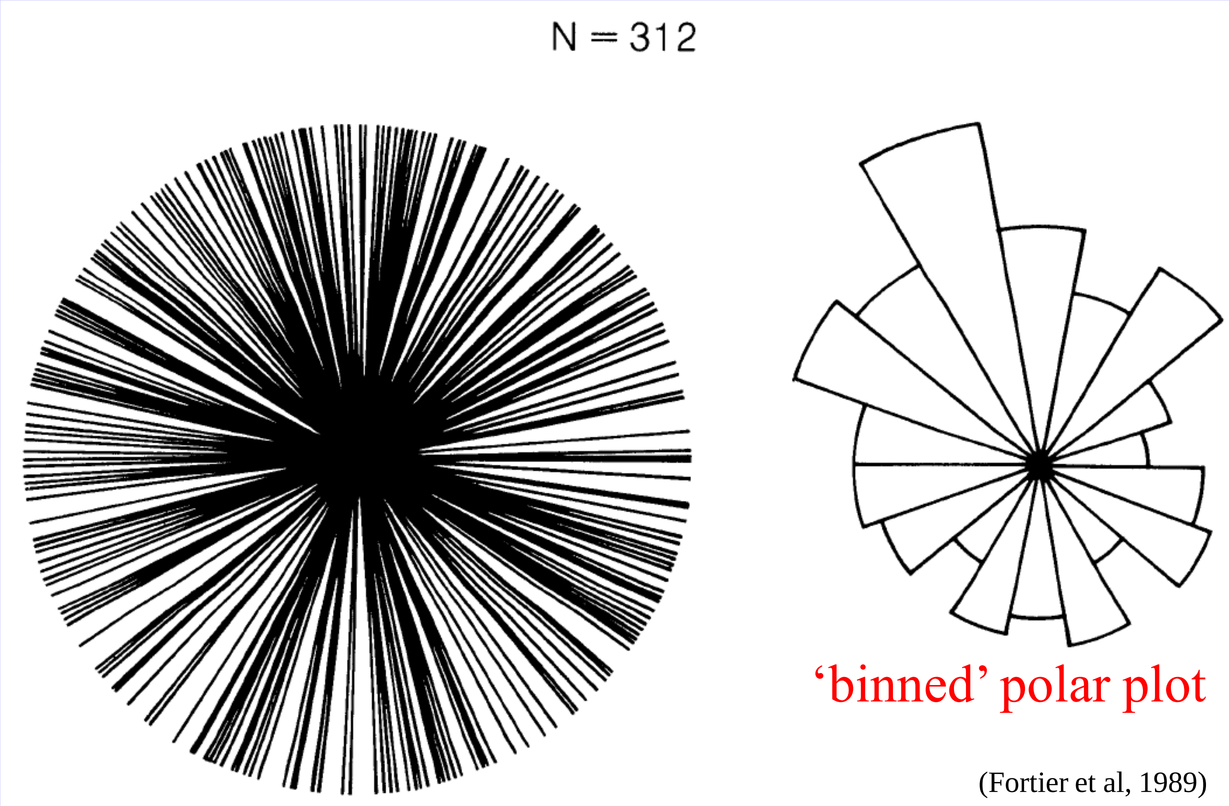


Significance of PD?

Distribution of PDs?

Population Vectors

- Nearly uniform distribution of preferred direction
  → nearly uniform coverage/tesselation of stimulus space (*orientation*)

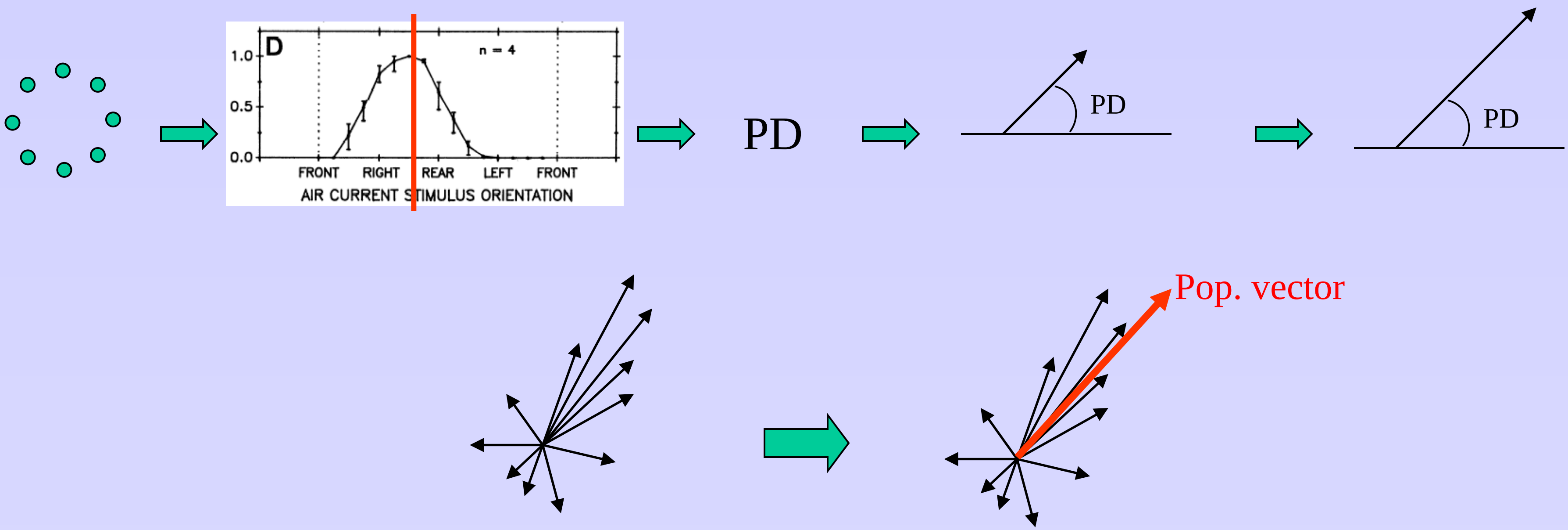


Can a population of neuron 'predict' the direction of movement?

Population Vectors (discretely sampled continuous space)

Method:

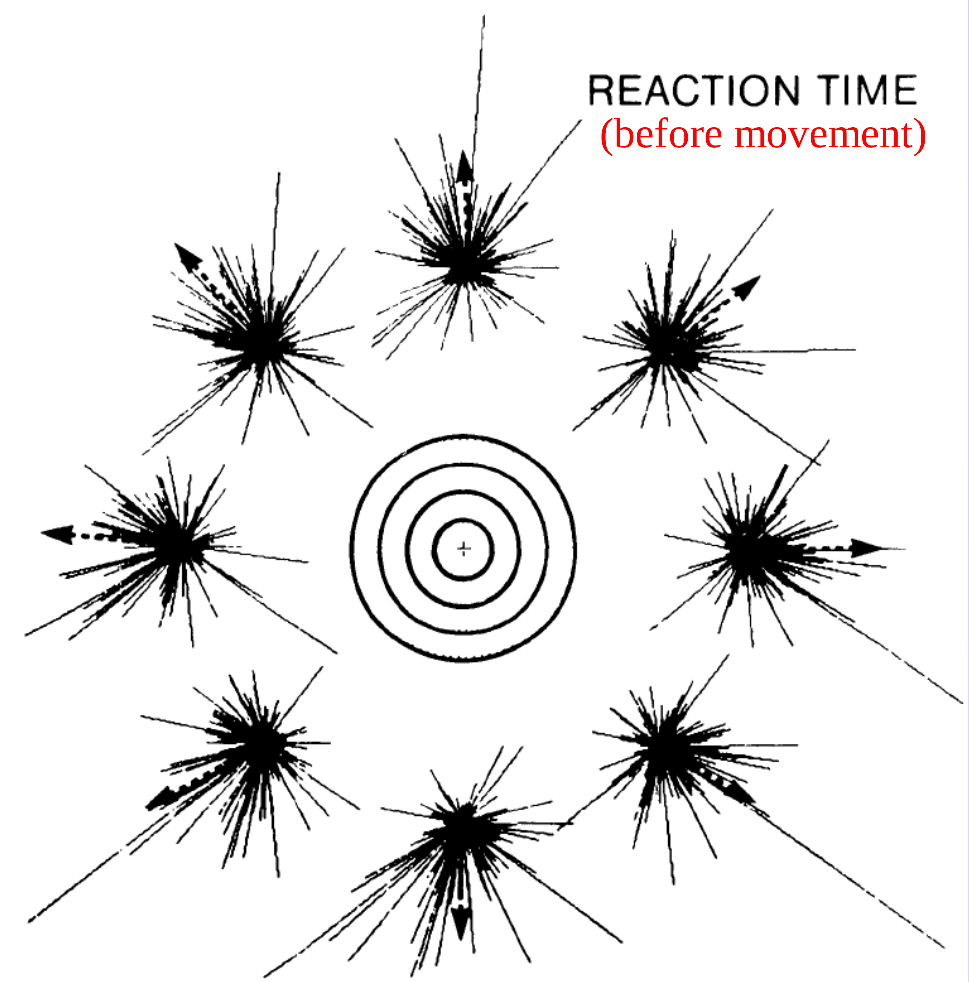
- Compute and fit the tuning curve of a cell
- Find the preferred direction (PD)
- For a given experimental condition, draw a vector of direction PD, and length equal to the measured firing rate of the cell.
- The sum of all vectors computed as above is the **Population Vector**.



Population Vectors

- 8 conditions: 8 directions during RT.

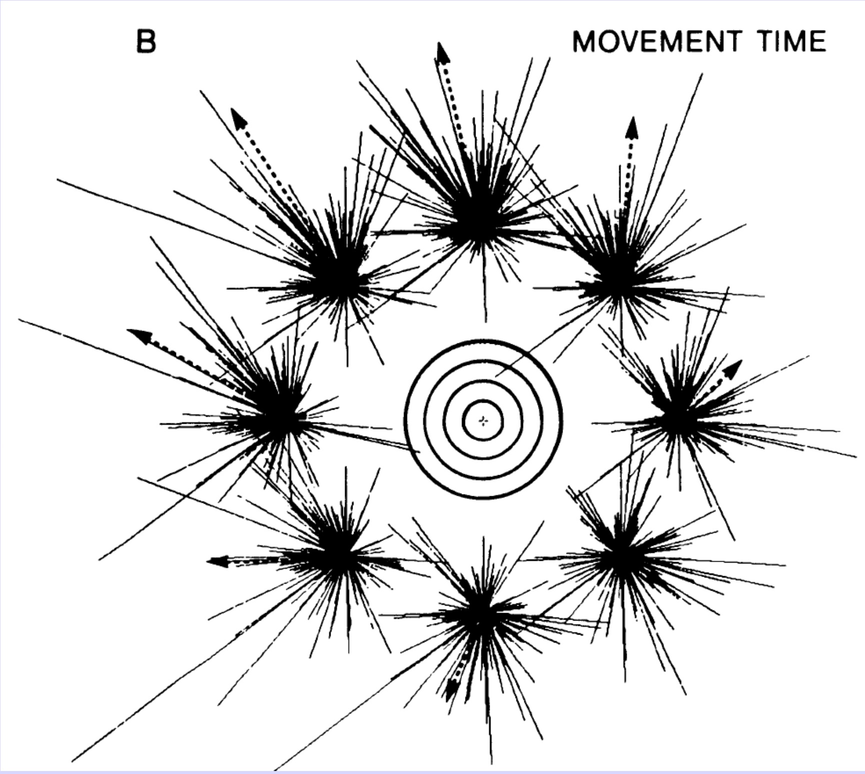
➔ As a population, cerebellar cells encode the <u>intended</u> direction of movement.

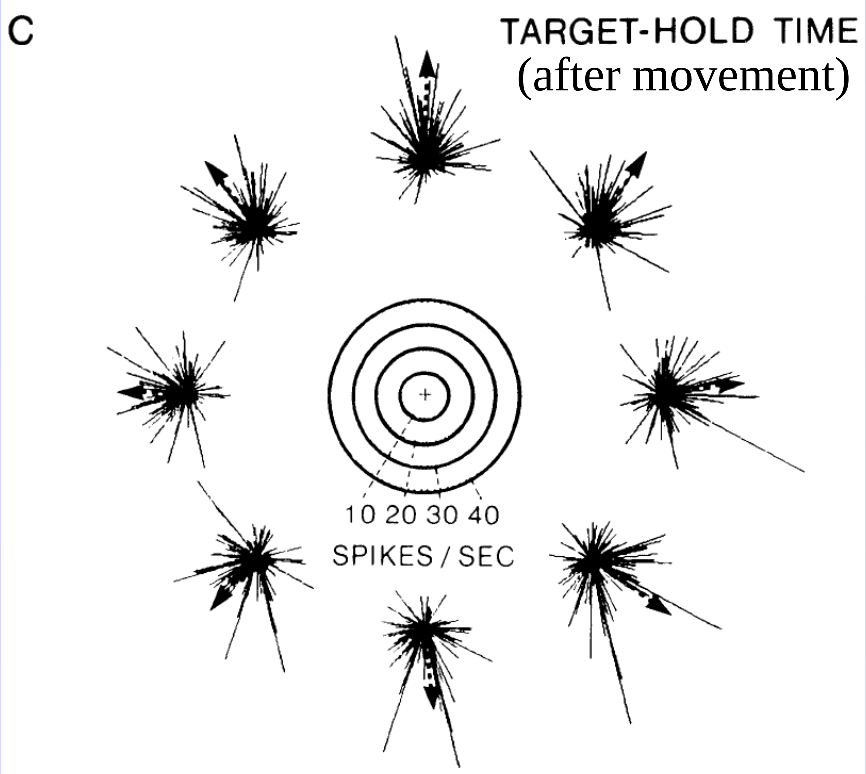


(Fortier et al, 1989)

Population Vectors

- ➔ The strongest population behavior is <u>during</u> movement
- ➔ The population firing also indicates what movement direction just <u>occurred</u>



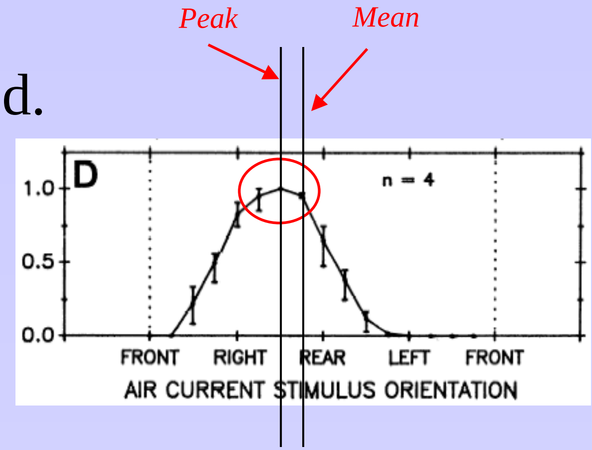


(Fortier et al, 1989)

Population Vectors

Problems:

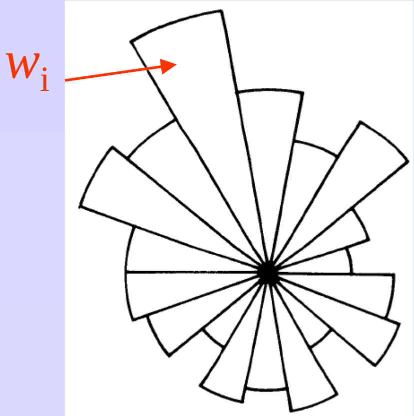
- Tuning not always ‘cosine’.
- Preferred directions not always uniformly distributed.
- Variance in the tuning curve is not always constant.
- Not enough neurons (?).
- Tuning may not be stationary.



Some Possible (simple) Solutions:

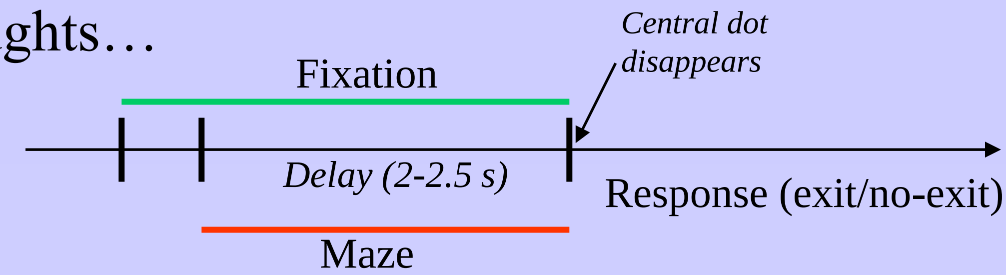
- PD: Use mean, rather than peak (correction for tuning curve asymmetry).
- Population vector: Weigh with population Preferred Direction density.

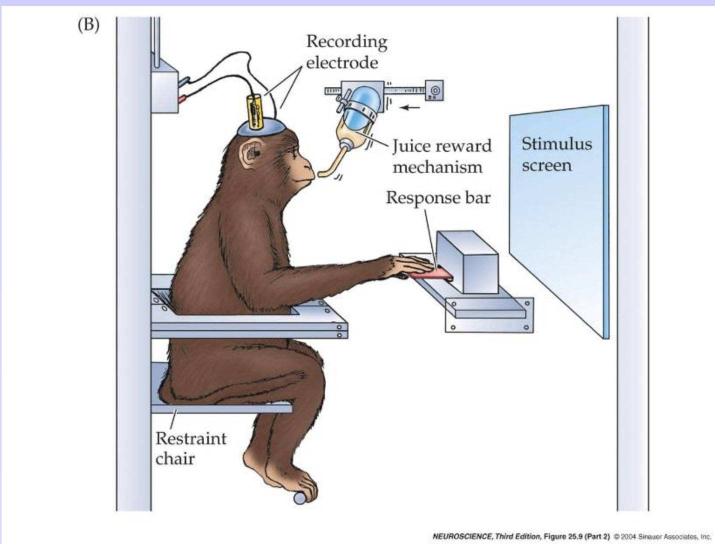
$$\overrightarrow{PD} = \sum_i \overrightarrow{C_i} \quad \Rightarrow \quad \overrightarrow{PD} = \sum_i w_i \overrightarrow{C_i}$$



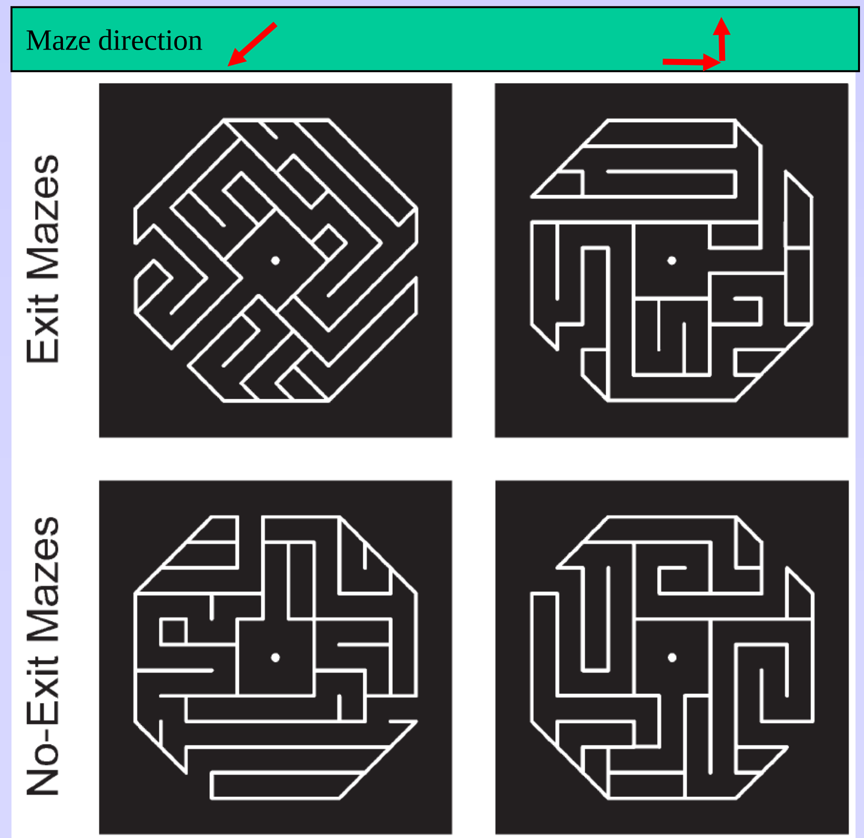
Population Vectors (no overt behavior)

- Reading Monkey Thoughts…





Stimuli

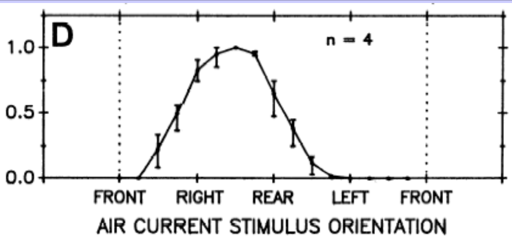


Parietal cortex (area 7a)
(→ premotor → motor → spinal cord)

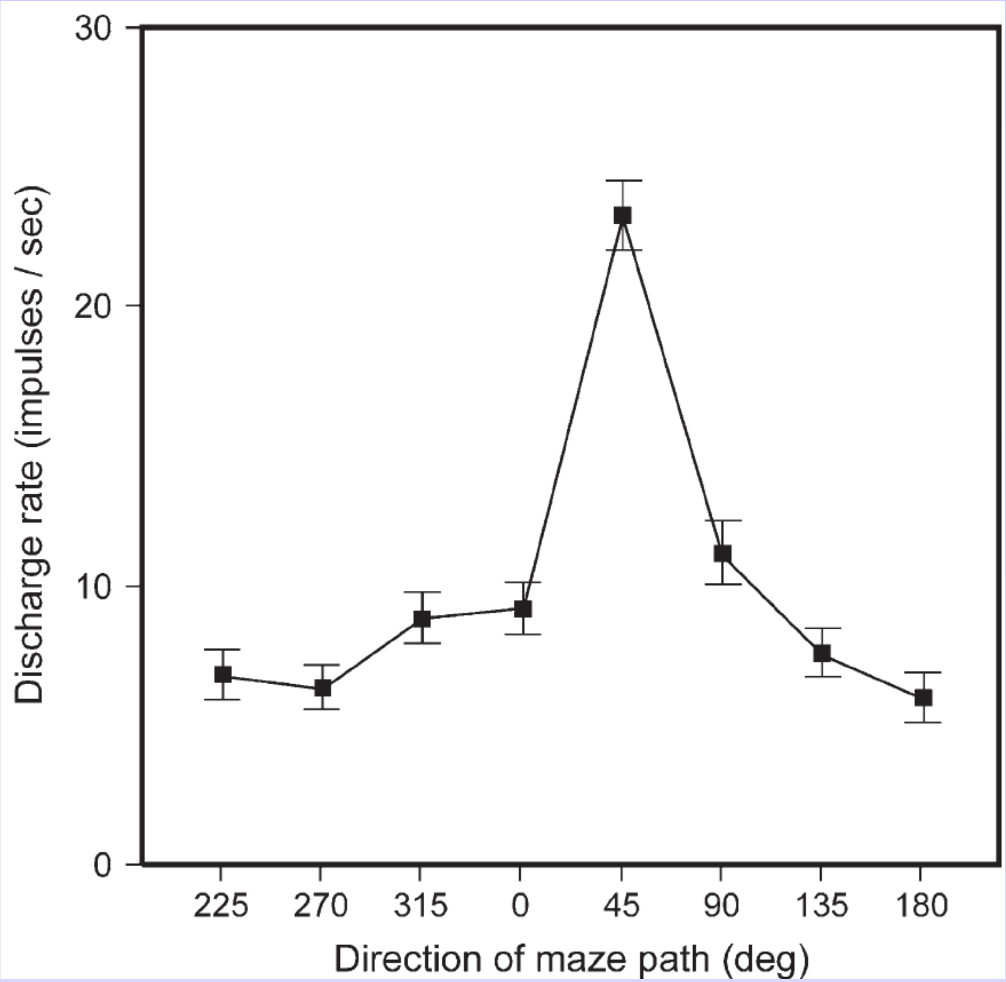
(Crowe et al. 2005)

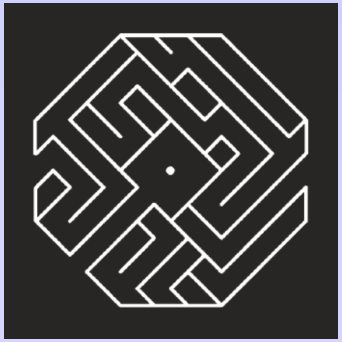
Population Vectors

- Single cell tuning curve. Note: <u>not</u> cosine



(Miller et al. 1991)



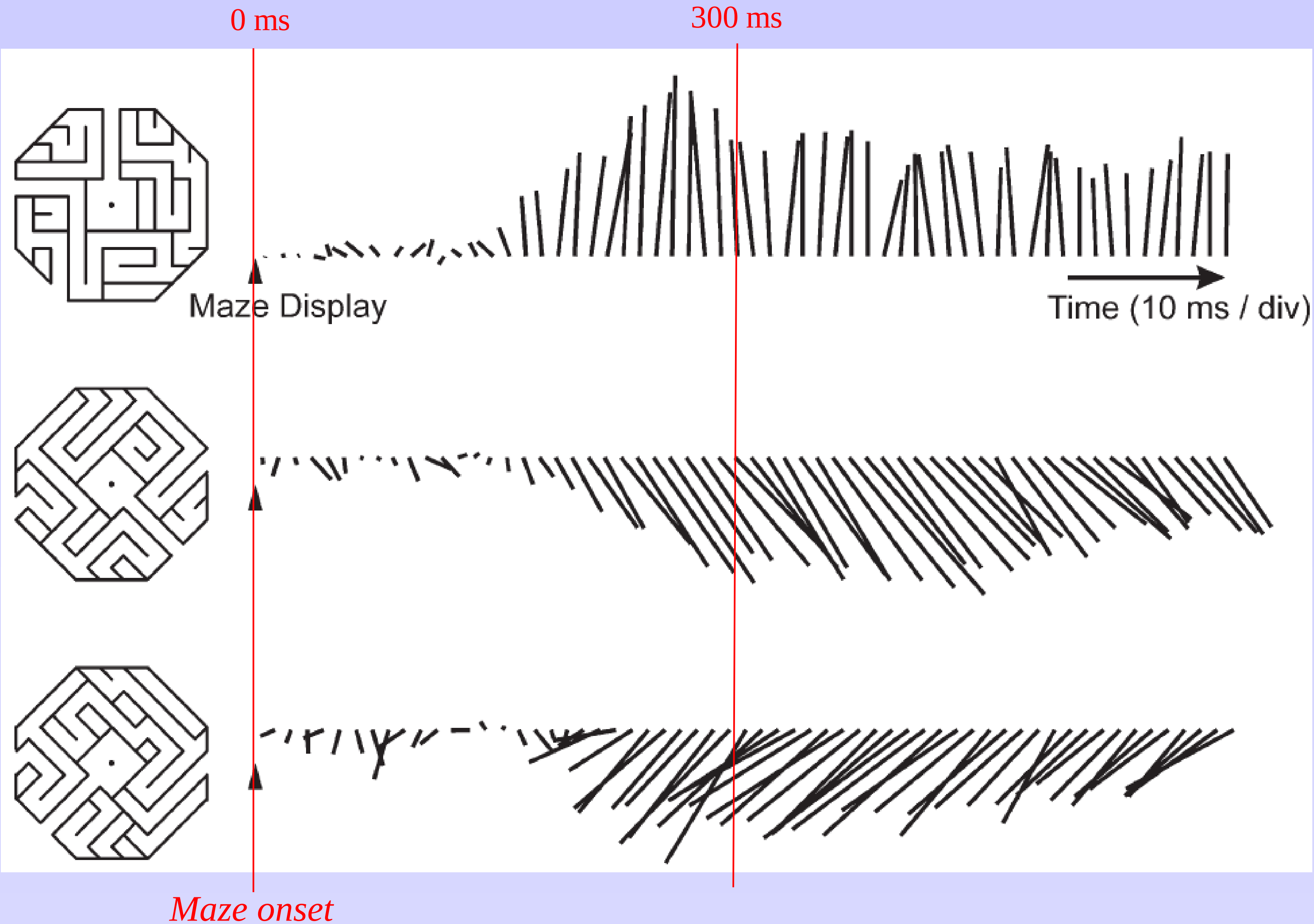


No turn mazes, during delay period

(Crowe et al. 2005)

Population Vectors

- Population vector dynamics after maze onset: computed every 10 ms.

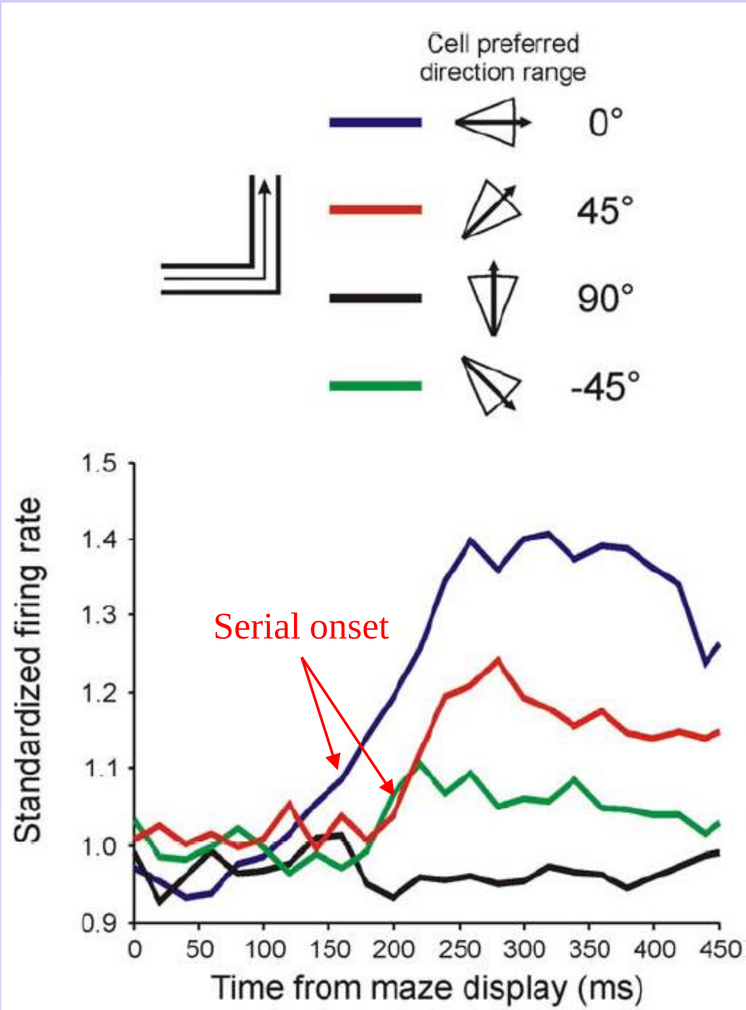


(Crowe et al. 2005)

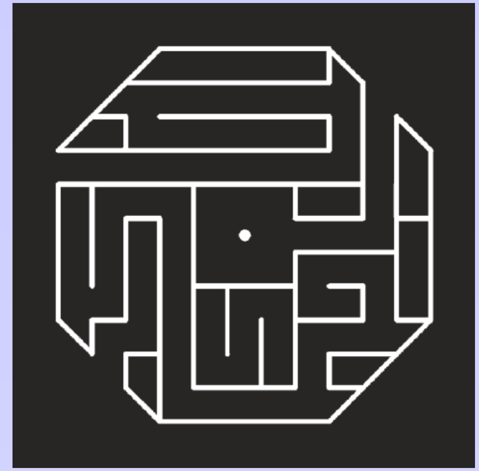
➔ Population predicts the correct response

Population Vectors

- 2-step thinking…One-turn mazes



(Crowe et al. 2005)



Parallel maintenance

➔ 0 Deg then 45 Deg

➔ Serial Onset (internal simulation)