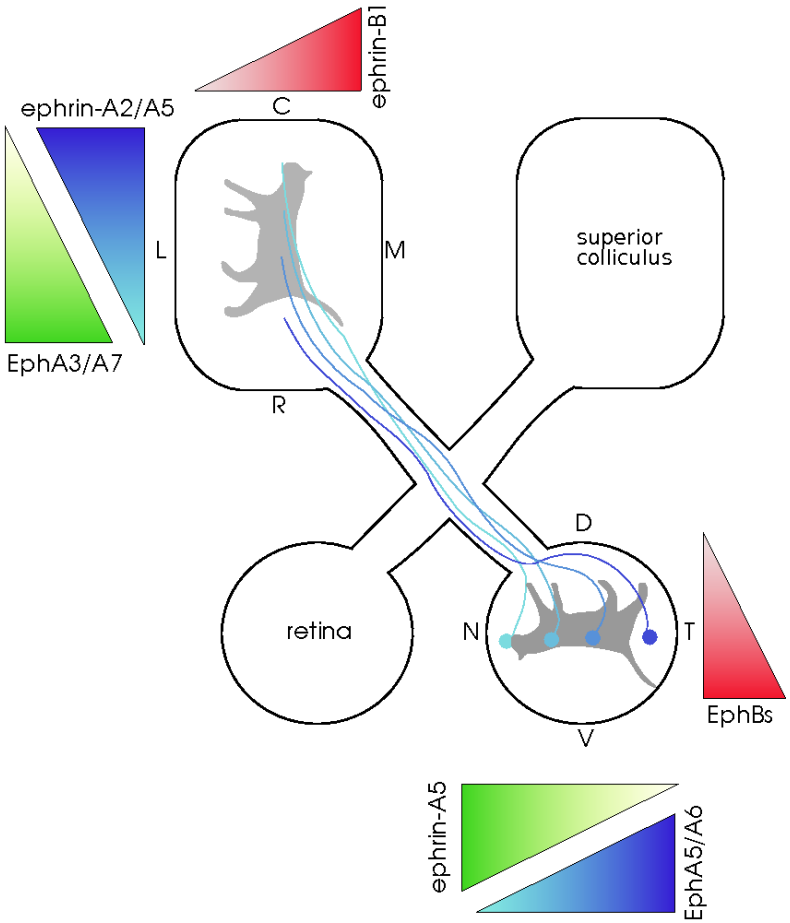
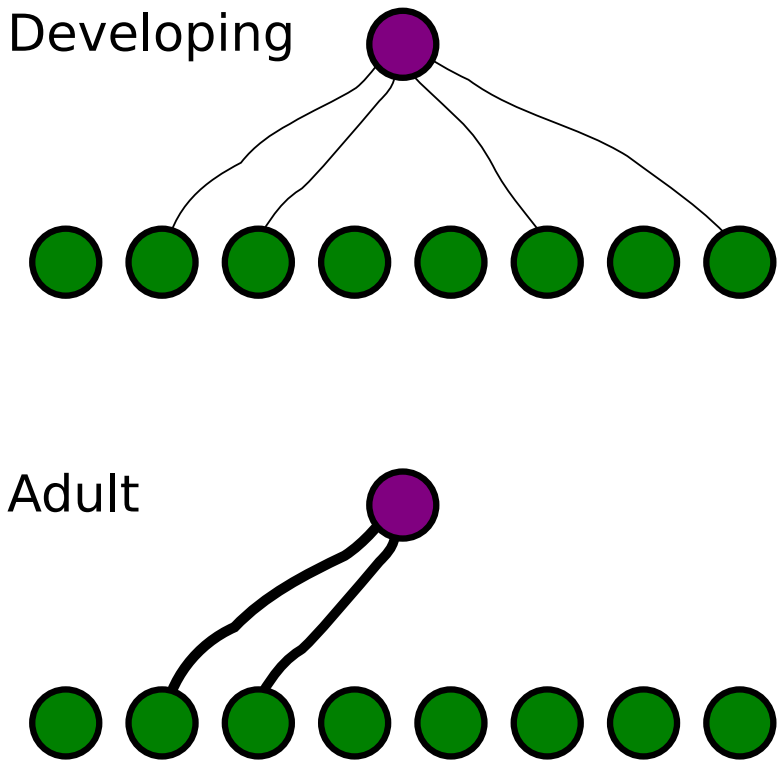
Refinement of visual connections

Two major principles of sensory map formation

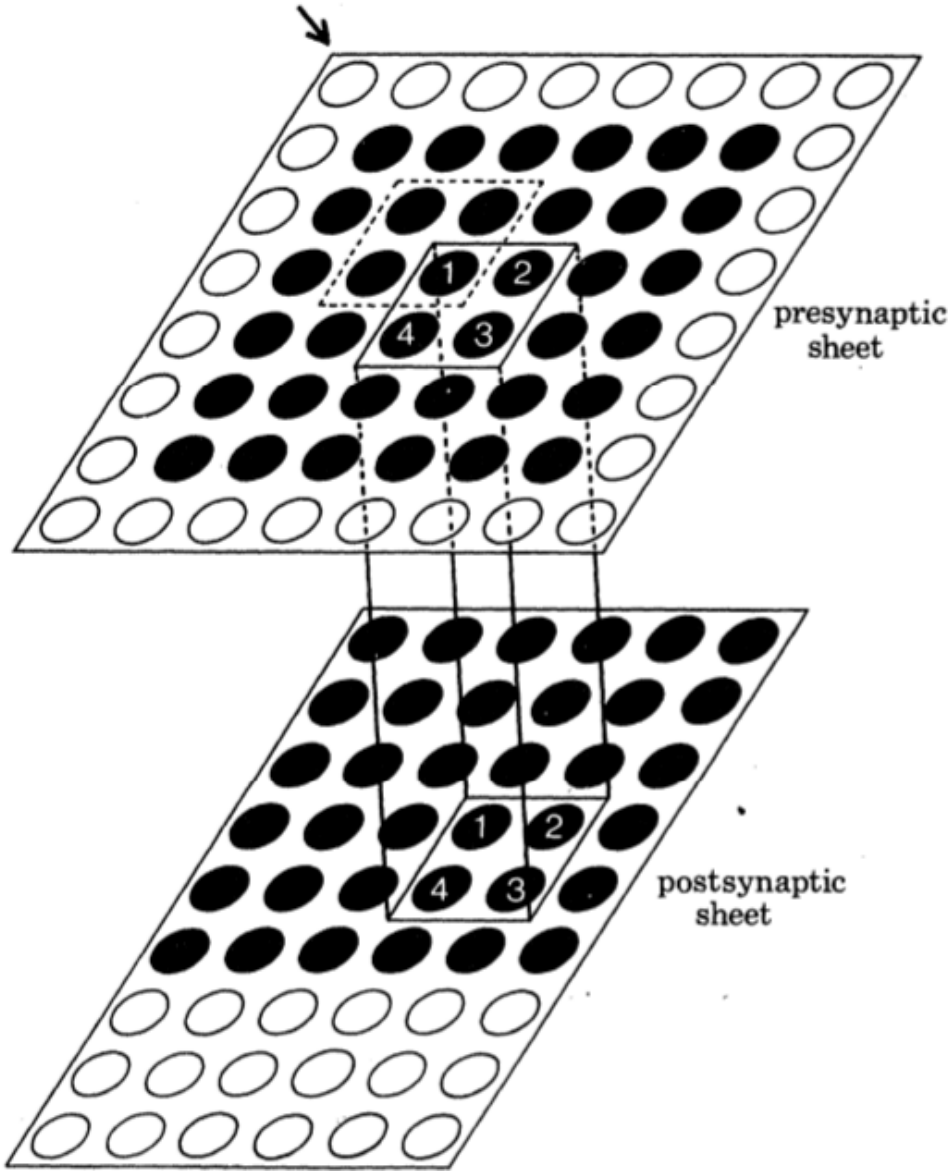
1. Activity-independent processes to establish overall connectivity. Molecular gradients.
2. Activity-dependent processes to refine local connectivity.





Models may help inform relative contributions of each mechanism.

Willshaw and von der Malsburg (1976): architecture



Principles of topographic map formation

Key elements of map formation, demonstrated by Willshaw & von der Malsburg (1976):

1. Neighbouring presynaptic neurons fire in synchrony (retinal waves).
2. Cells that fire together wire together.
3. Neighbouring postsynaptic neurons should develop similar connections.
4. Constraints on synaptic growth (normalisation).
5. Map polarity.

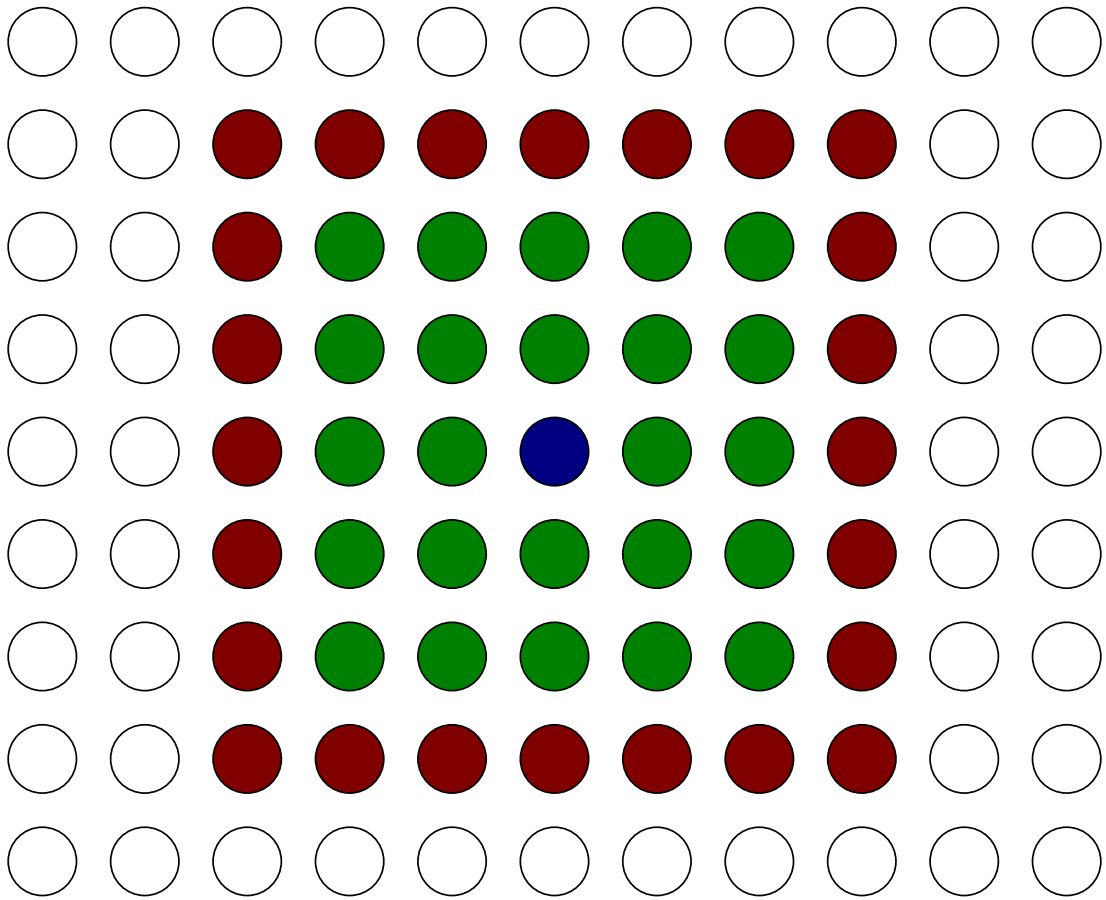
Item 1 proposed before discovery of retinal waves.

2. Cells that fire together wire together

Output is a weighted function of input activity.

3. Correlated output

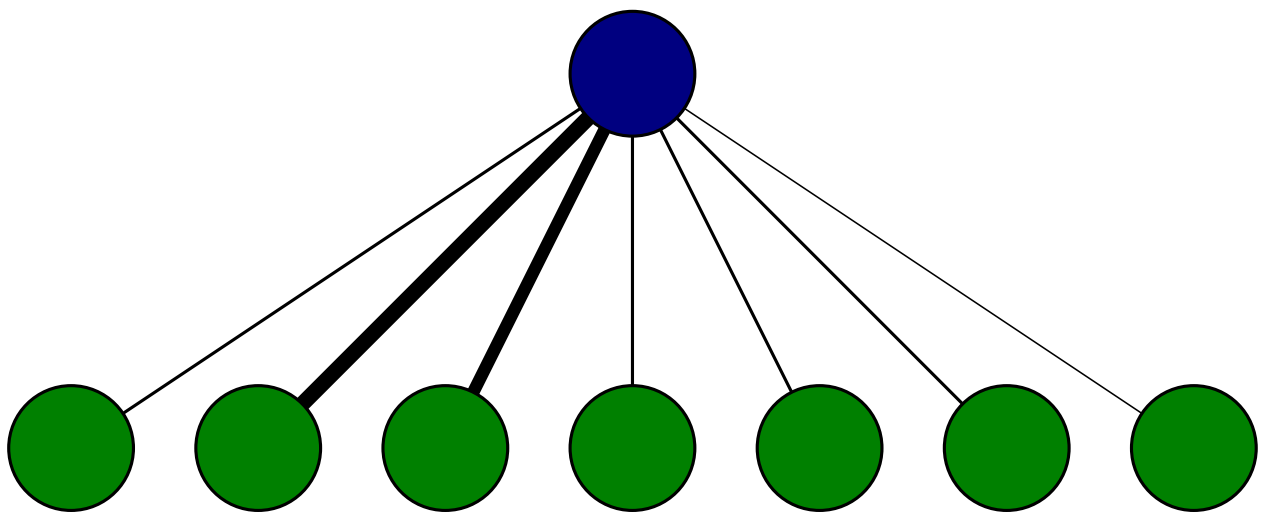
Short-range excitatory (green); longer-range inhibitory (red). Additional growth rules.



4. Normalisation

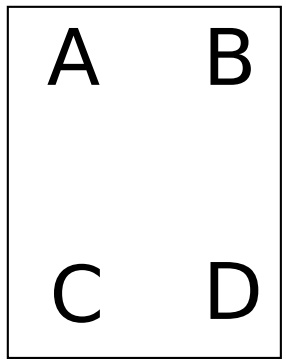
Sum of weights synapsing onto one target neuron (j, blue) is constant.

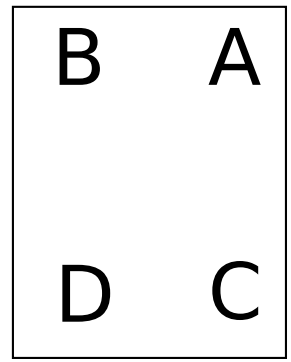
$$\sum_i w_{ij} = K$$

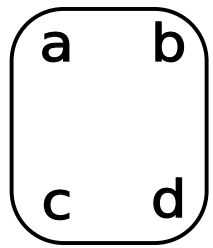


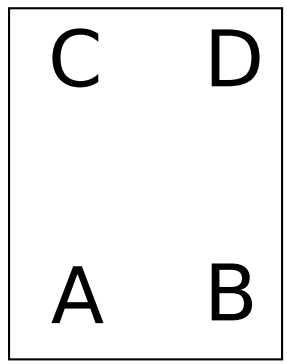
5. The problem of map polarity

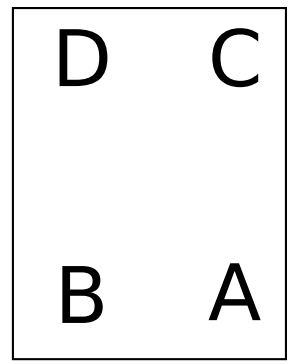
How many ways are there to map one rectangle onto another?



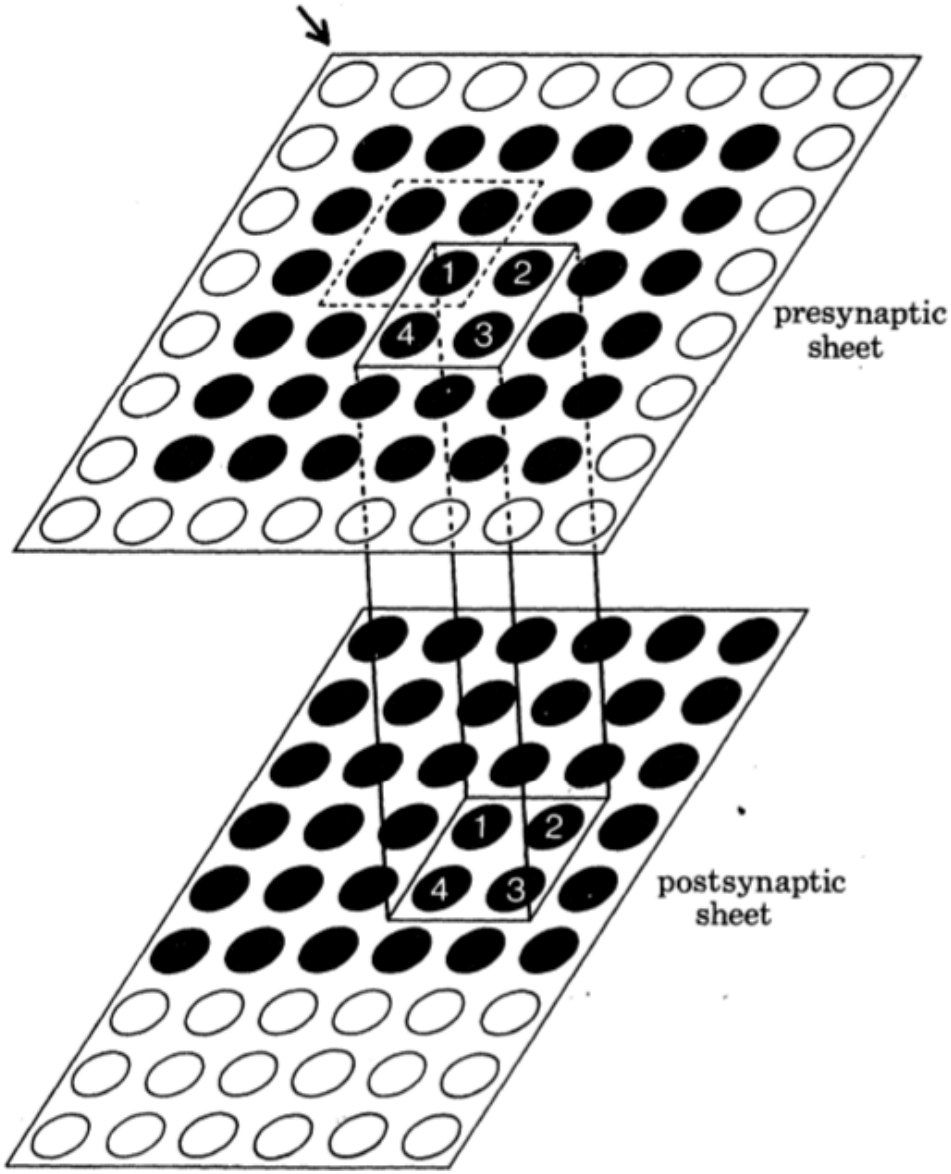




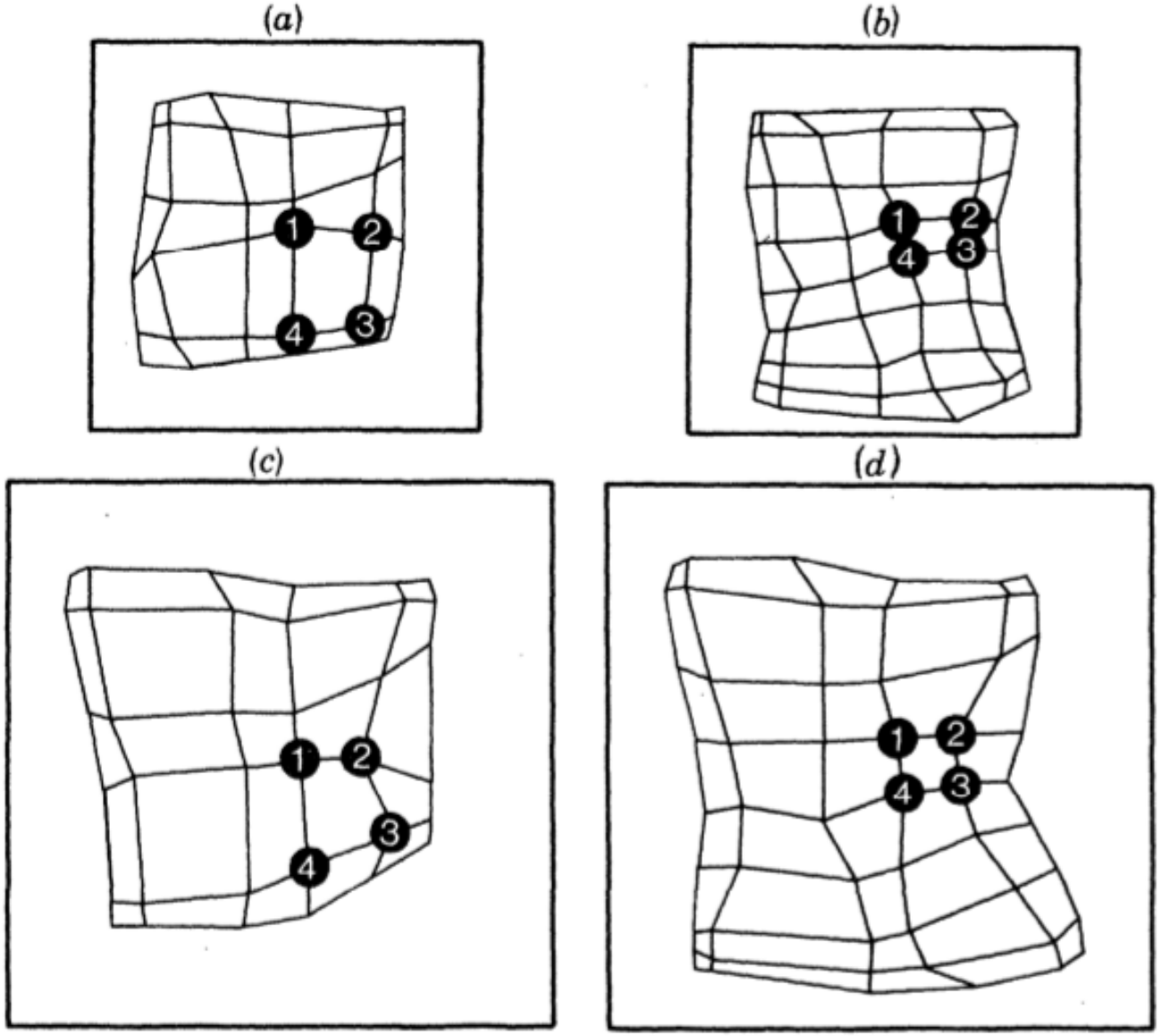




5. Polarity markers in the model



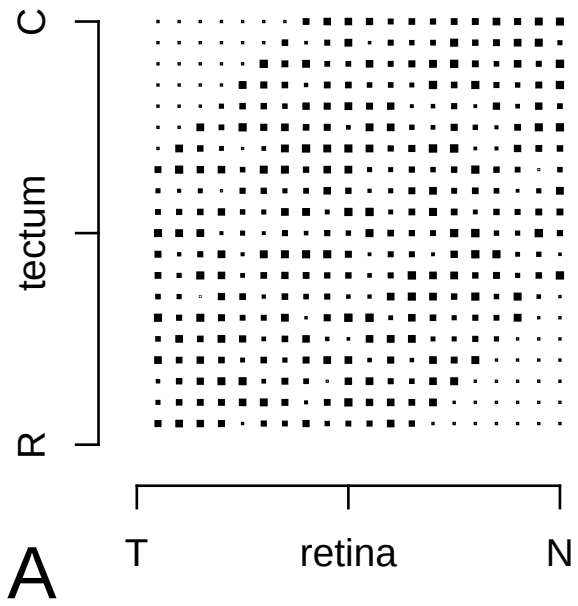
Results: systems matching

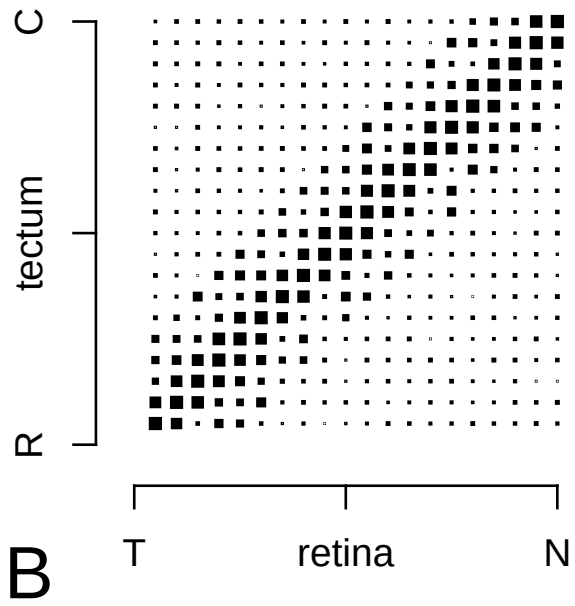


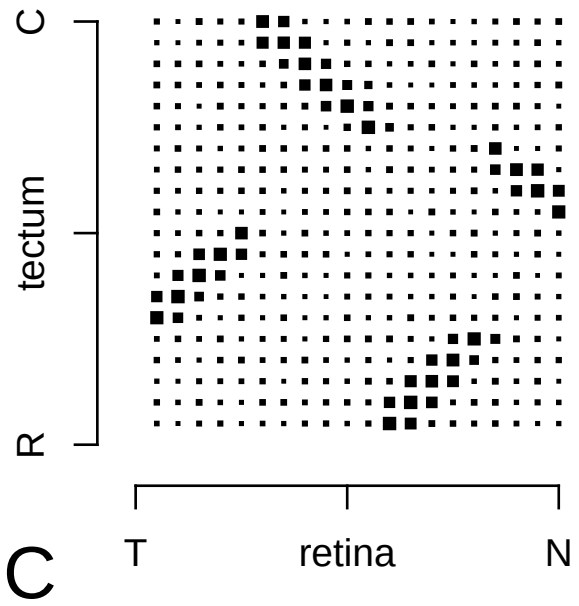
(a) $6 \times 6 \Rightarrow 6 \times 6$. (b) $6 \times 6 \Rightarrow 9 \times 6$.

(c) $8 \times 8 \Rightarrow 6 \times 6$. (d) $8 \times 8 \Rightarrow 9 \times 6$.

Role of polarity information

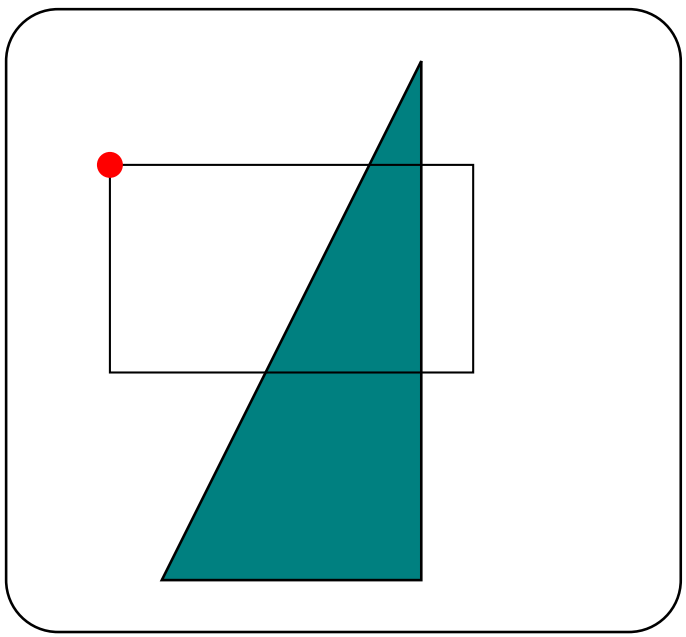


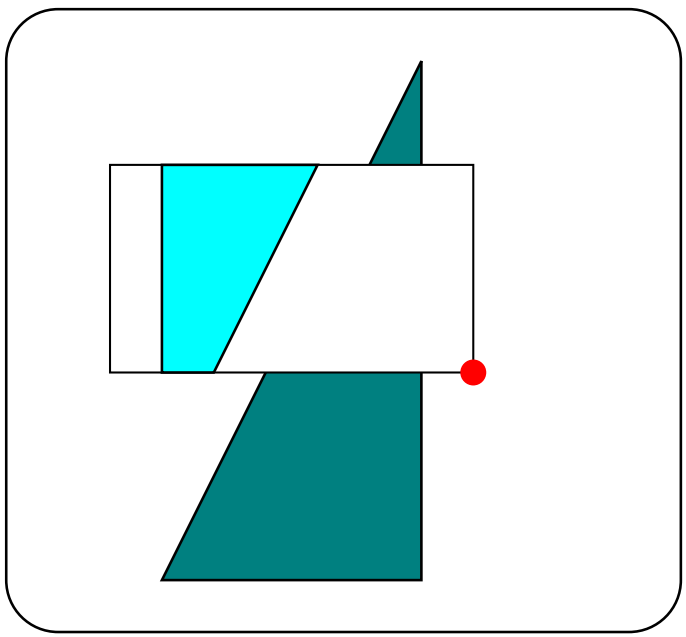




Limitation of activity model

Cannot account for tectal rotation experiments, as model regenerates normal map.



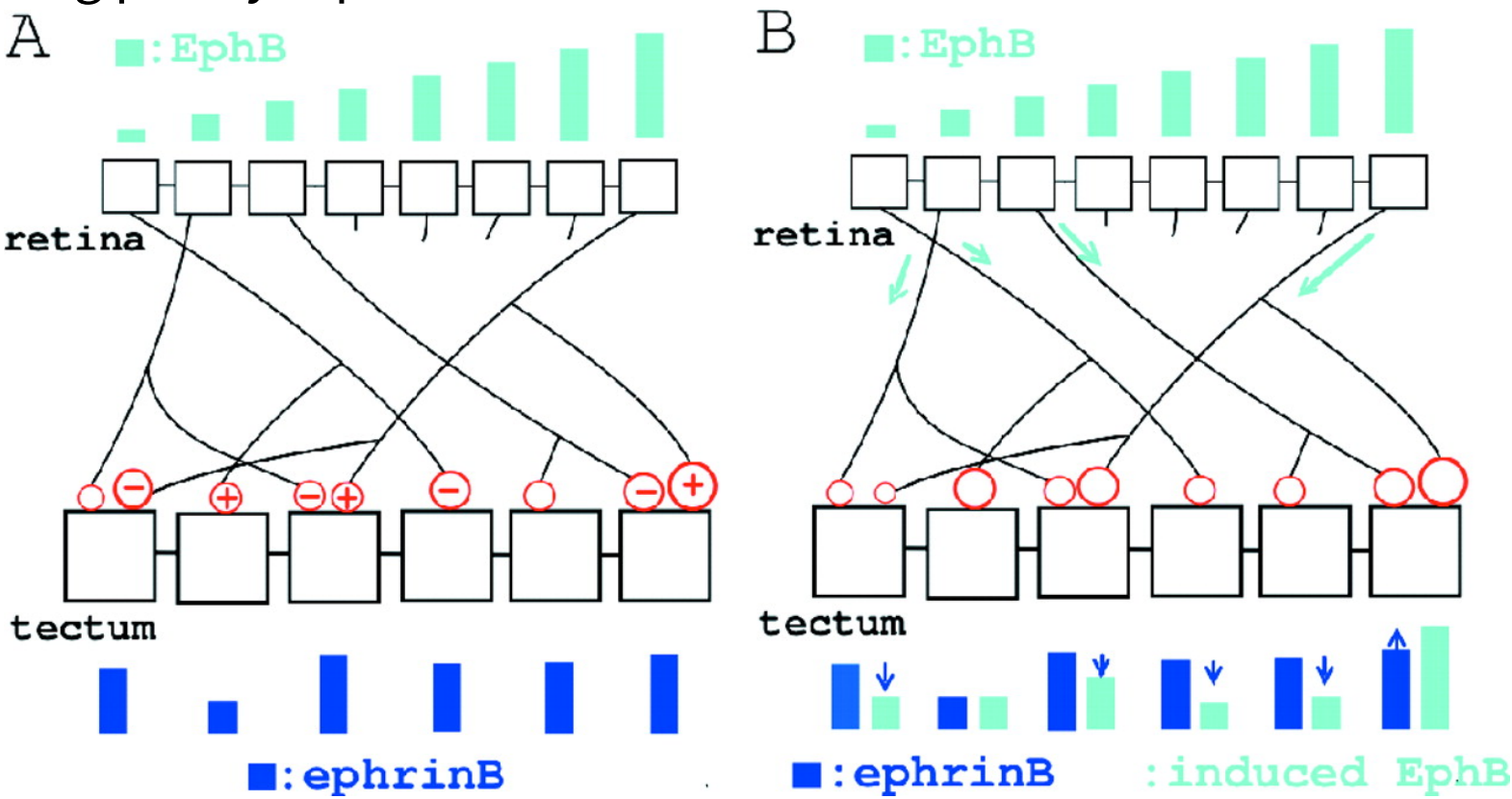


Gradient-based models

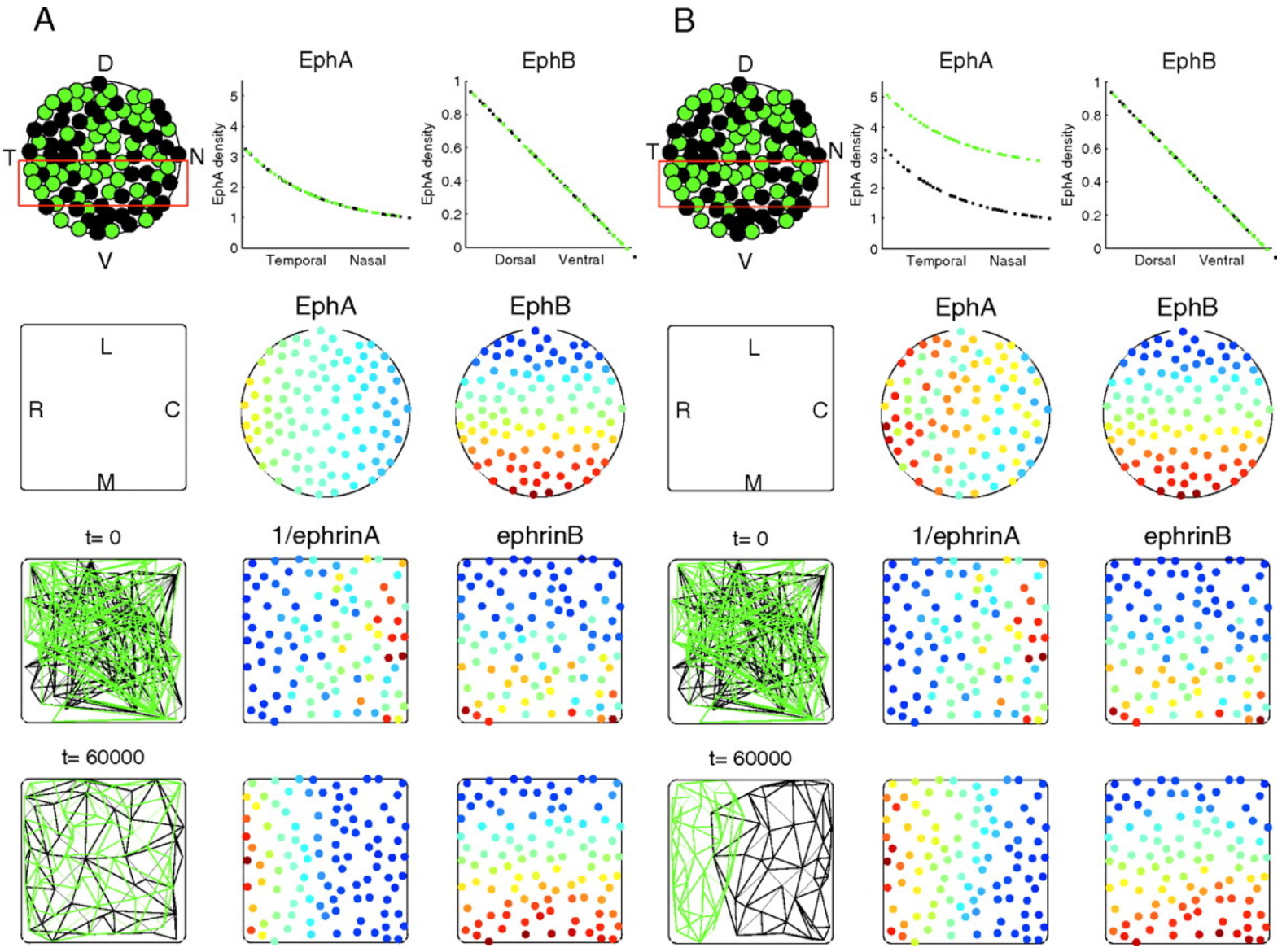
- Marker induction model (Willshaw & von der Malsburg 1979).
- Before discovery of Eph and ephrins.
- Updated to include knowledge of Ephs (Willshaw 2006).
- How are matching gradients established? Assume that retinal labels are fixed, and target labels are induced.
- Weak polarity information (via synapses or gradients) still required.
- Key results:
  1. Account for Eph KI family (Brown et al 2000; Reber et al 2004).
  2. Growing domains.

Methods

A: updating synaptic connections (Eph B pathway).
B: inducing postsynaptic markers.

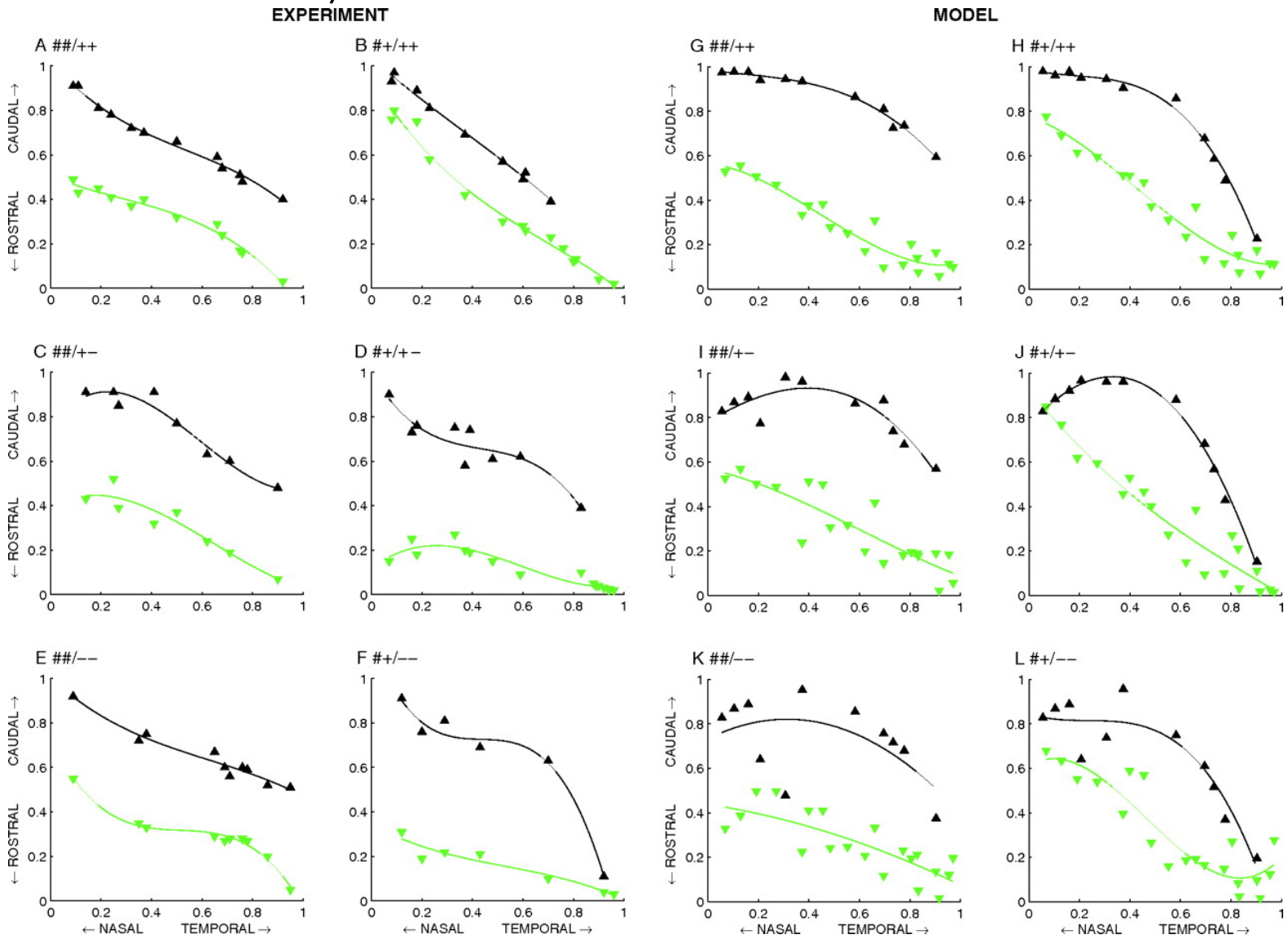


EphA3 simulations

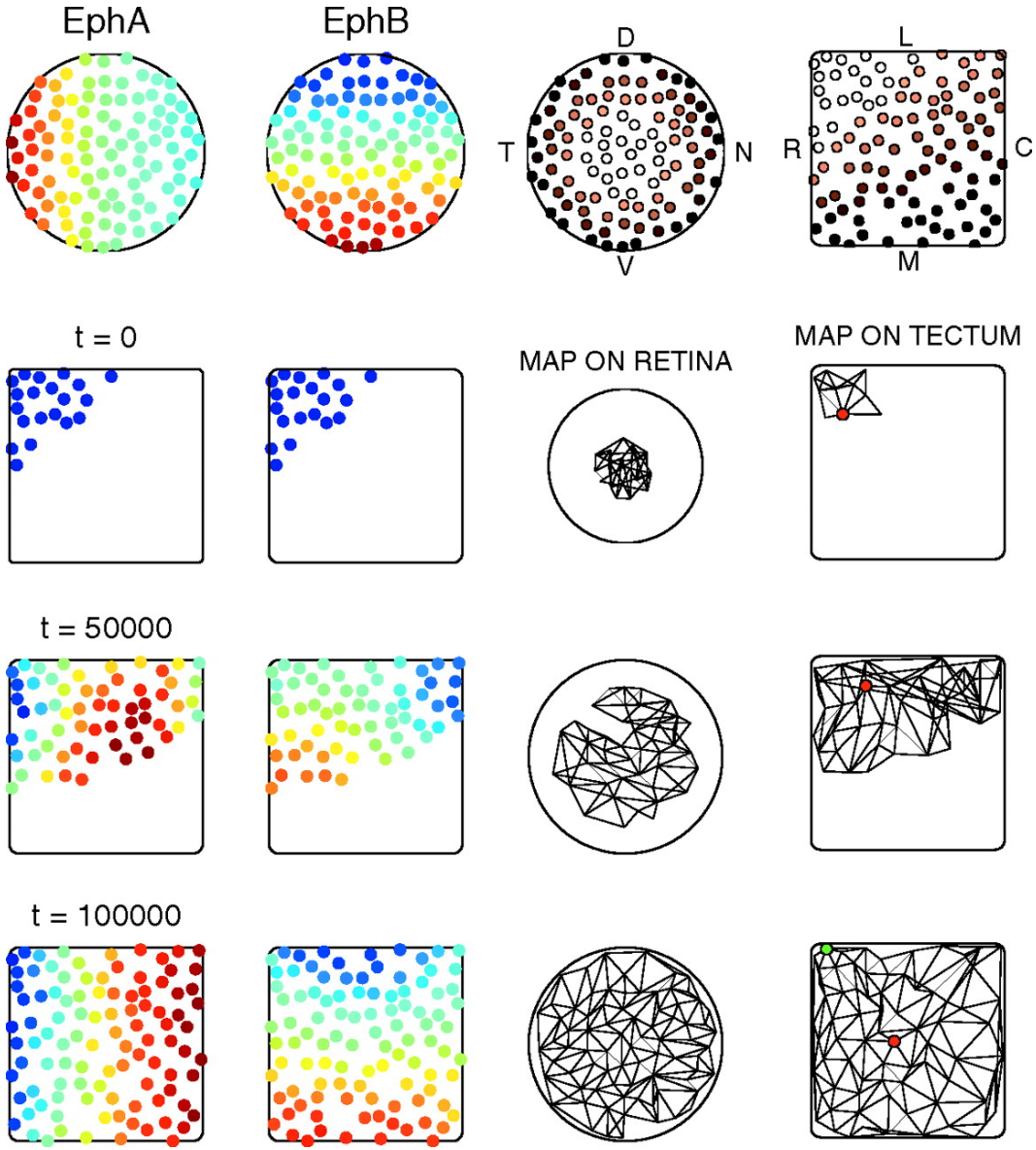


Reber et al (2004): EphA3/EphA4

(Green = Isl-2 +ve RGCs)



Xenopus: continuous retinal and tectal growth



Summary

- Neural activity can make maps, but needs extra polarity information.
- Molecular gradients can equally solve problem and account for surgical manipulations.
- Open questions:
  1. Are gradients inducible?
  2. What is interplay between activity and gradients — do they work on separate temporal scales, or are they mechanistically linked (e.g. Landmesser)?