LISSOM Maps for Multiple Features

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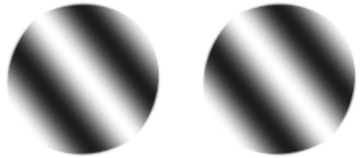
Input feature dimensions

Orientation (OR) is only one of many input features that can be detected in a pair of small circular apertures:



Others:

- Position (X,Y): where is the pattern in the visual field?
- Ocular dominance (OD): which eye has the pattern?
- Motion direction (DR) and speed (SP)
- Spatial frequency (SF)
- Color (CR)
- Disparity (DY): position offset between eyes
- Temporal frequency (TF): rate of flickering

Ocular dominance

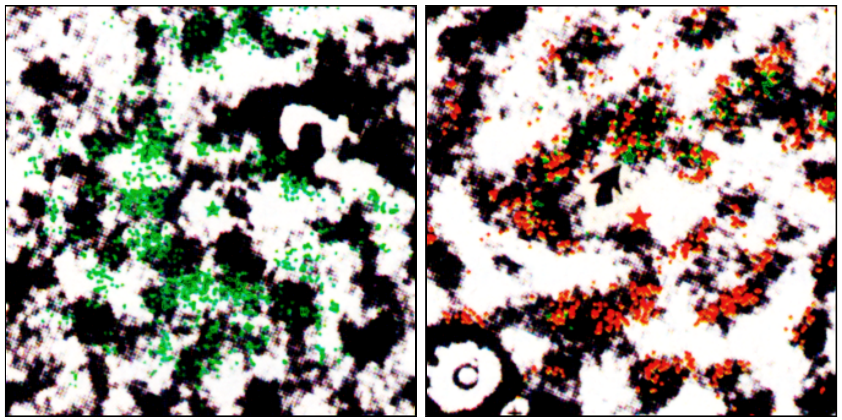
In species with binocular vision (forward-facing eyes), layer 4 typically has an alternating map of eye preference.

In normal, non-strabismic cats, the long-range lateral connections in layer 2/3 do not typically follow this map.

The OD map is aligned with the map for orientation, such that boundaries between OR regions typically intersect OD borders at right angles.

Similarly, regions of large OR gradient typically do not intersect OD borders.

Ocular dominance maps and lateral connections

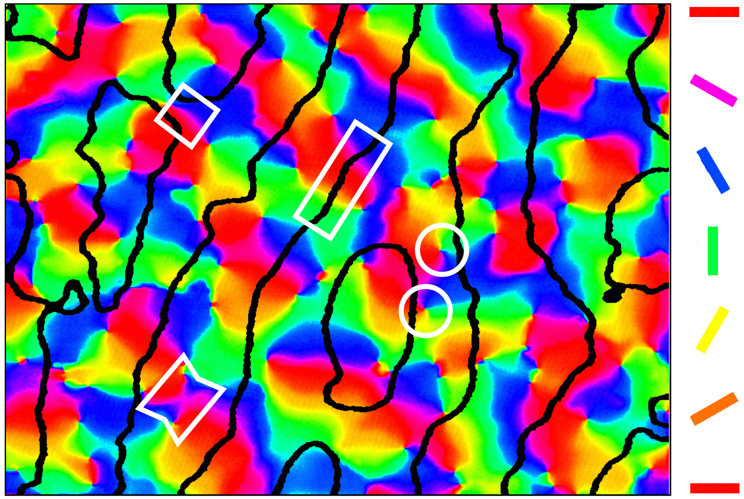


CMVC figure 5.2

Normal cat | Strabismic cat

(Löwel & Singer 1992)

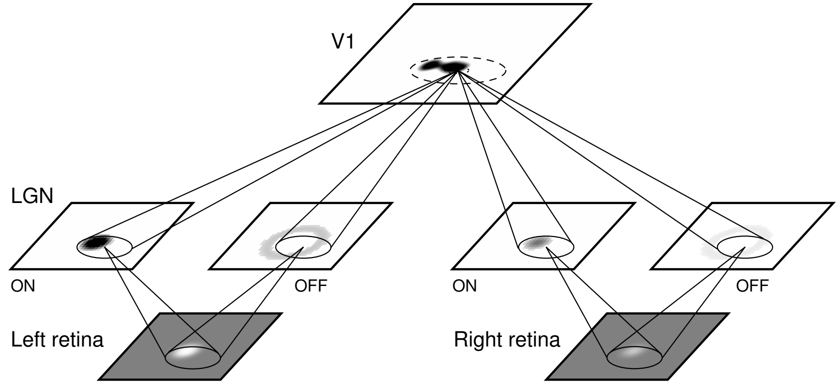
Combined macaque OR/OD map



CMVC figure 5.3

(Macaque; Blasdel 1992)

LISSOM ocular dominance model

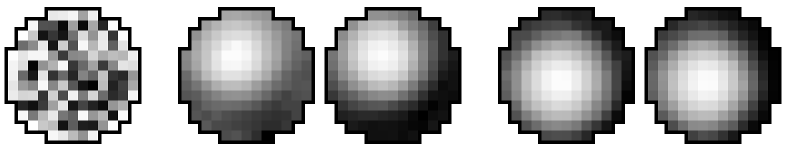


CMVC figure 5.14

Same as orientation map model but with two eyes and circular Gaussians.

Basic simulation: Both eyes identical except for brightness

Self-organization of afferent weights into OD receptive fields



All | Left | Right | Left | Right

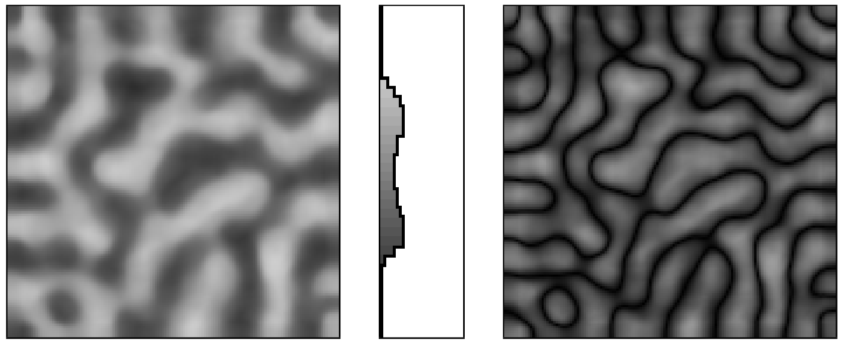
Initial | Final partly monocular (ON—OFF) | Final strongly binocular (ON—OFF)

CMVC figure 5.15

Initially, all CFs were identical.

Some neurons end up binocular, some partly monocular.

Self-organized OD map



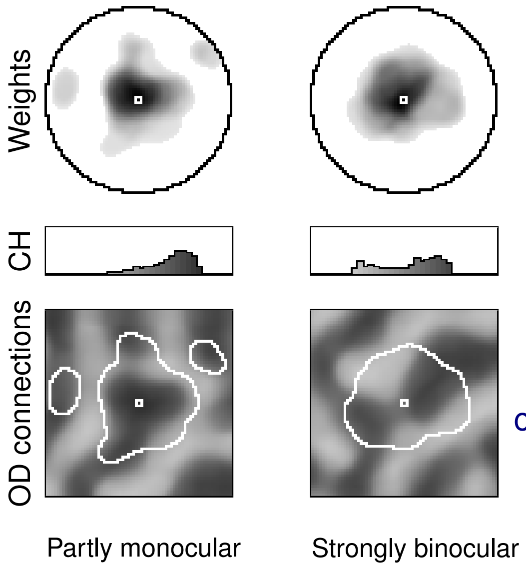
OD preference | OD H | OD selectivity

CMVC figure 5.16

Smoothly varying distribution of OD preferences.

Ranges from partly monocular through strongly binocular.

OD lateral connections

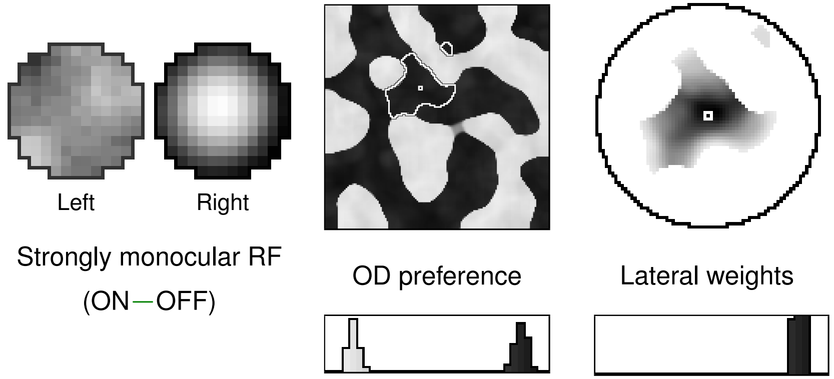


Monocular neurons connect primarily to one eye.

Binocular neurons connect to both eyes.

CMVC figure 5.17

Strabismic map and connections



CMVC figure 5.18

Strabismic case: Positions entirely uncorrelated.

Nearly all neurons become strongly monocular; lateral connections are purely monocular (as in cats).

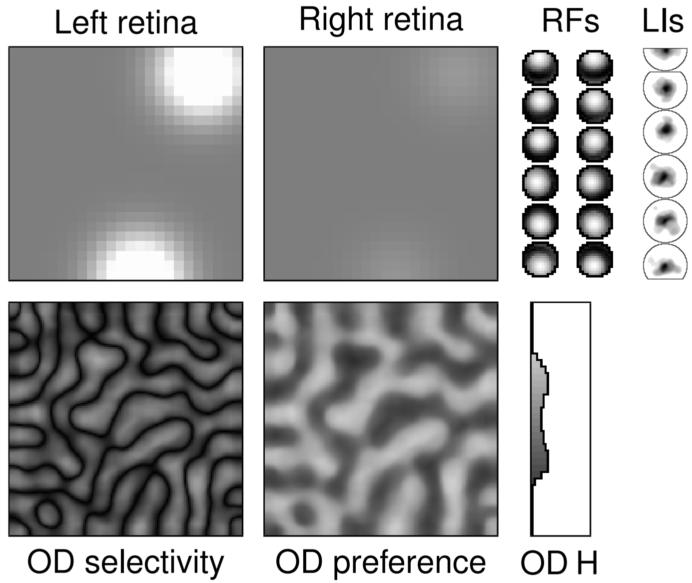
Factors driving OD map development

OD in LISSOM must be driven by differences in input activity.

Previous slides showed results based on brightness differences (which we will call Dimming) and complete position differences (strabismus).

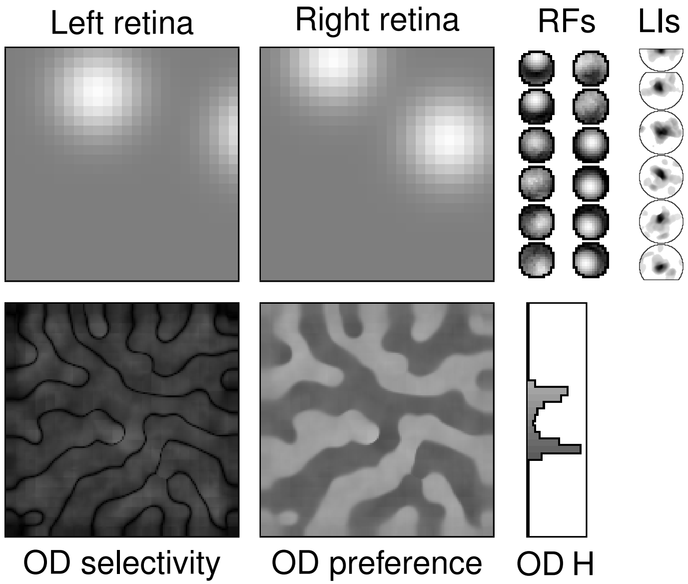
Can mild position differences account for OD also?

OD: Dimming



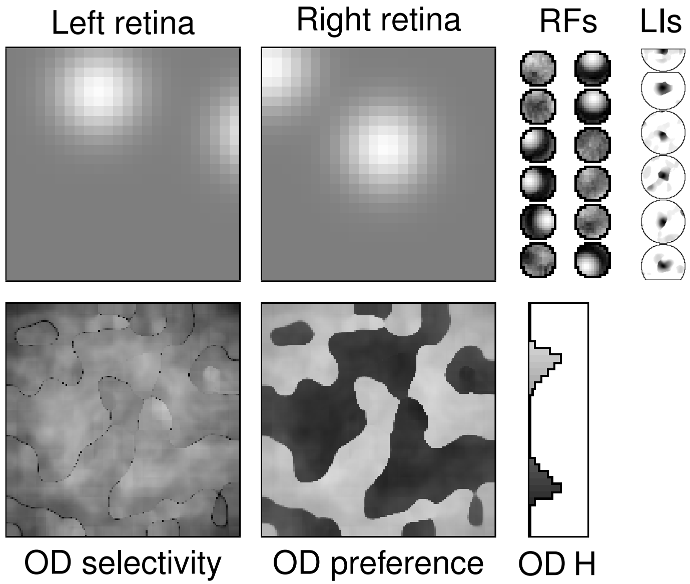
CMVC figure 5.19, Dimming

OD: Mild disparity



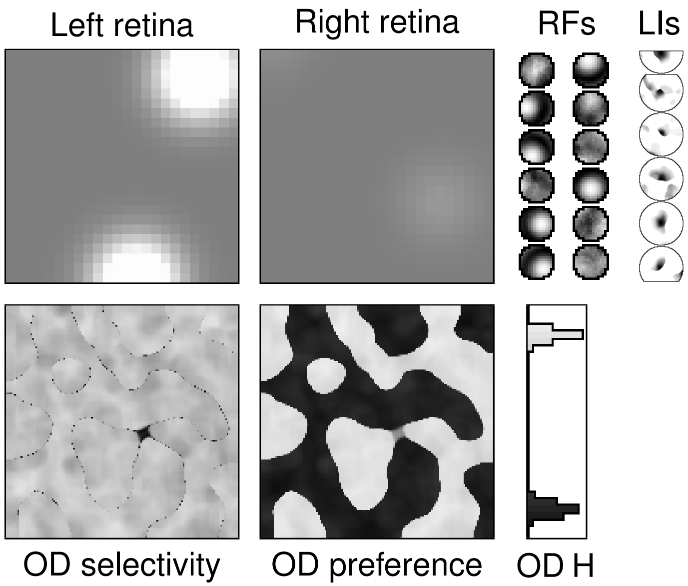
CMVC figure 5.19, Mild

OD: Moderate disparity



CMVC figure 5.19, Moderate

OD: Strabismic disparity



CMVC figure 5.19, Strabismic

OD map conclusions

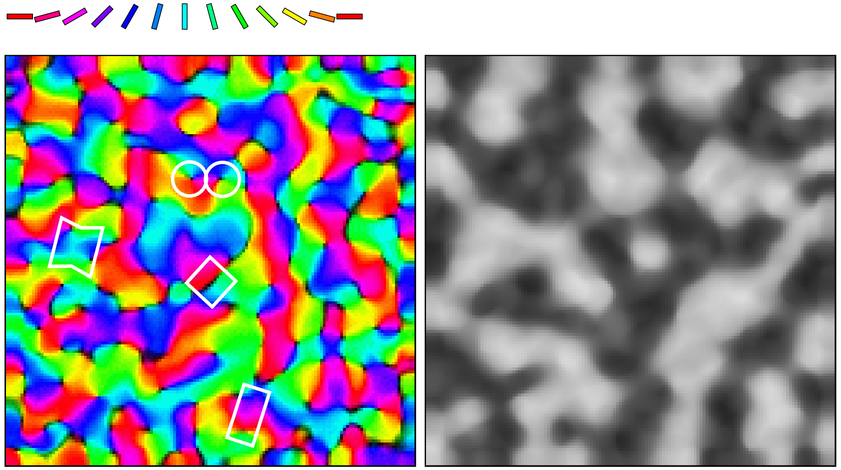
Disparity alone does not appear to be a likely driver for realistic adult OD, where most neurons are expected to be binocular.

Unclear what Dimming condition represents, yet results are more plausible.

Not yet clear in animals how much of OD is activity dependent; probably a combination of many factors.

Next: joint OR/OD map, with same architecture but Dimmed oriented inputs.

Self-organized OR/OD map

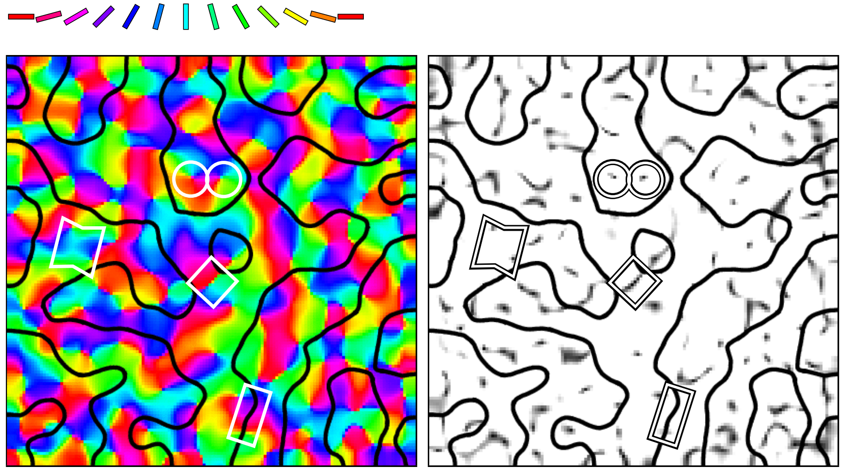


OR preference & selectivity — OD preference

CMVC figure 5.27ab

Each map is a good match to separate maps, animals.

Joint OR/OD map plots



OR preference & OD boundaries — OR selectivity & OD boundaries

CMVC figure 5.27bc

Joint map interactions are similar to animal results.

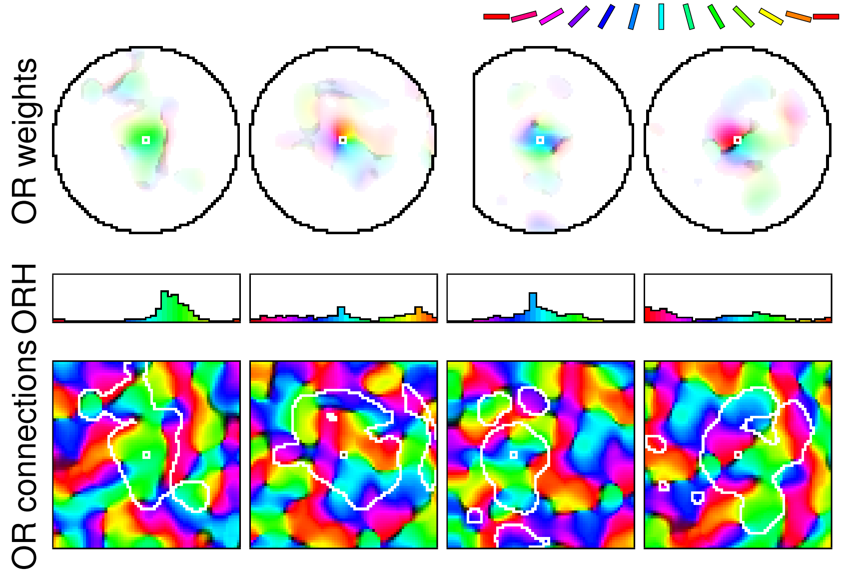
OR/OD: Lateral connections

As we will see next, the lateral connections in the OR/OD map closely match the results from the separate OR and OD simulations.

Long-range lateral connections link neurons with similar orientation preferences, but typically connect to both eyes.

Thus multiple maps can be represented simultaneously in the same set of neurons without disrupting one another.

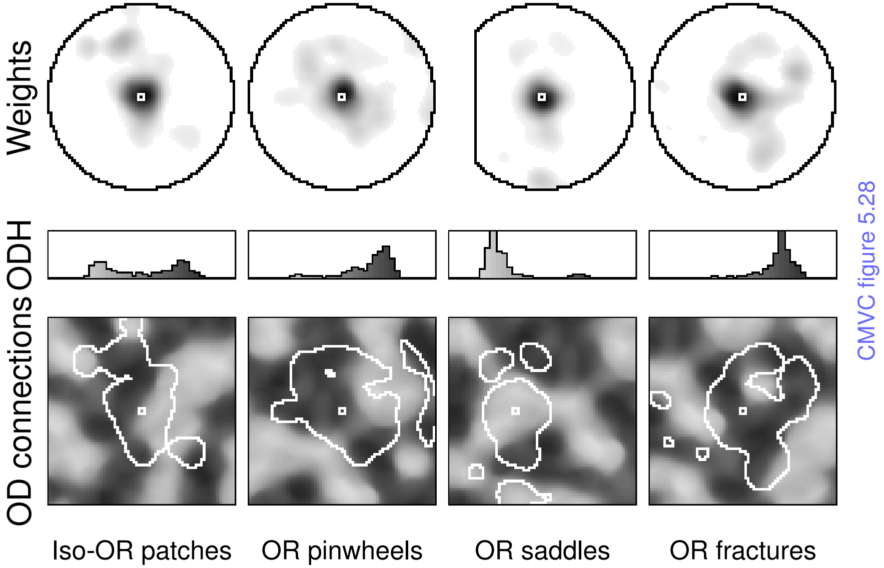
OR/OD: OR lateral connections



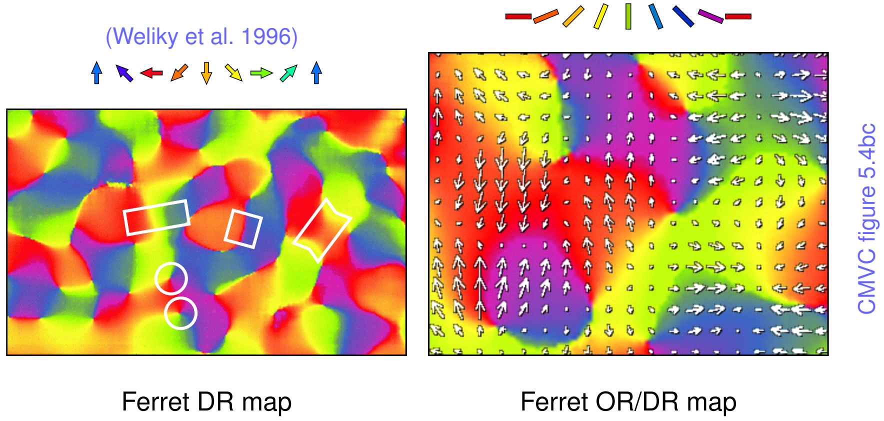
Iso-OR patches — OR pinwheels — OR saddles — OR fractures

CMVC figure 5.28

OR/OD: OD lateral connections



Combined OR/DR maps in animals

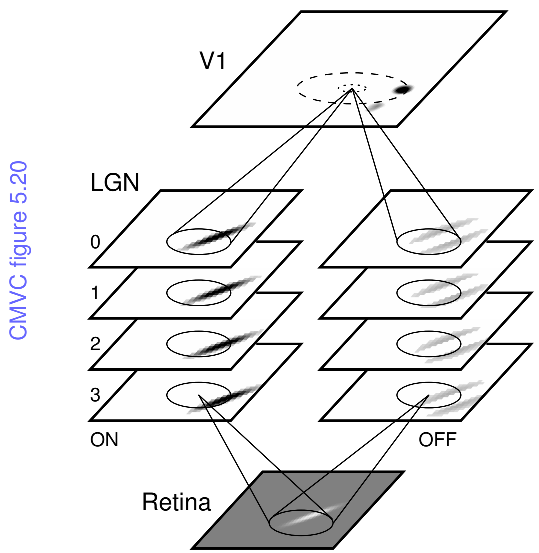


Ferrets and cats have maps for motion direction.

Global organization similar to OR, but 360° periodicity.

Often one OR patch is subdivided into opposite DR prefs.

LISSOM model of OR/DR

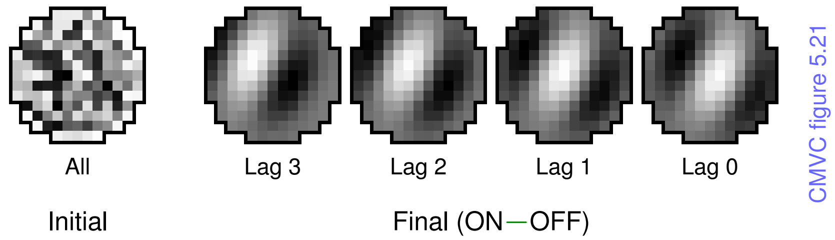


Same as Gaussian orientation map model, but with four different copies of the retina, each with different delays.

Models lagged cells in cat LGN.

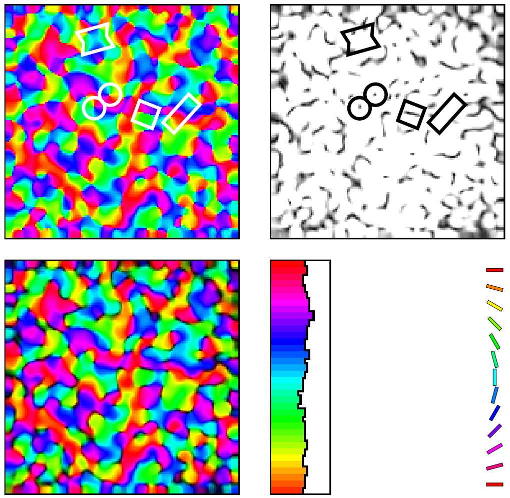
(Mastronarde et al. 1991; Saul & Humphrey 1992)

Self-organization of afferent weights into spatiotemporal RFs



Nearly all neurons develop strong preferences for moving, oriented Gaussians.

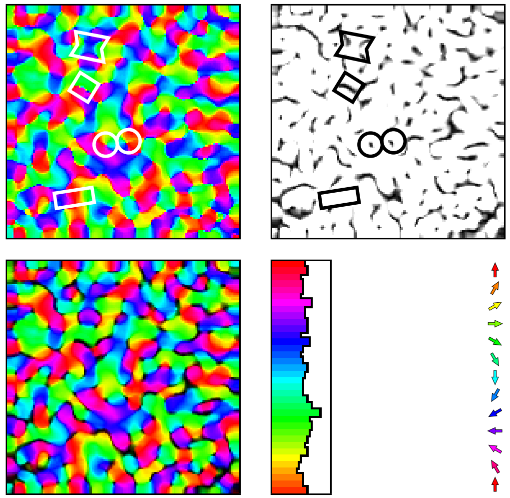
OR/DR: Orientation map



CMVC figure 5.22

Orientation map similar to OR-only map, animals.

OR/DR: Direction map



CMVC figure 5.22

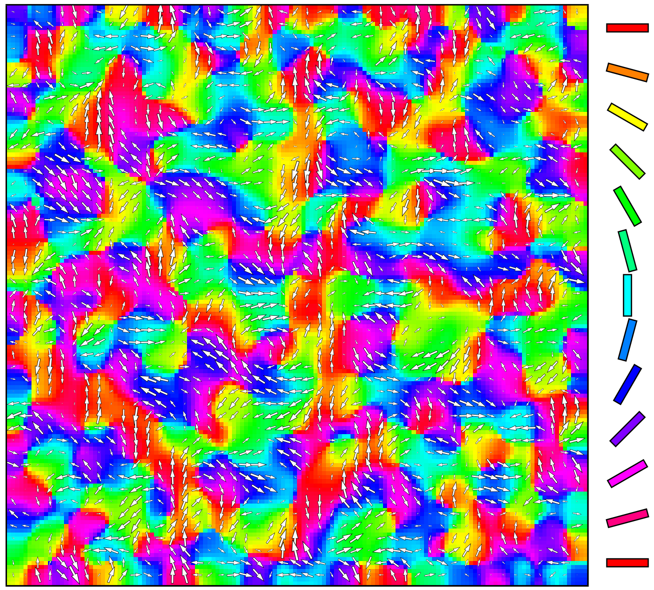
Direction map similar to OR map, animals.

OR/DR: Joint map, connections

As we will see next, the joint OR/DR map often has direction patches meeting at right angles.

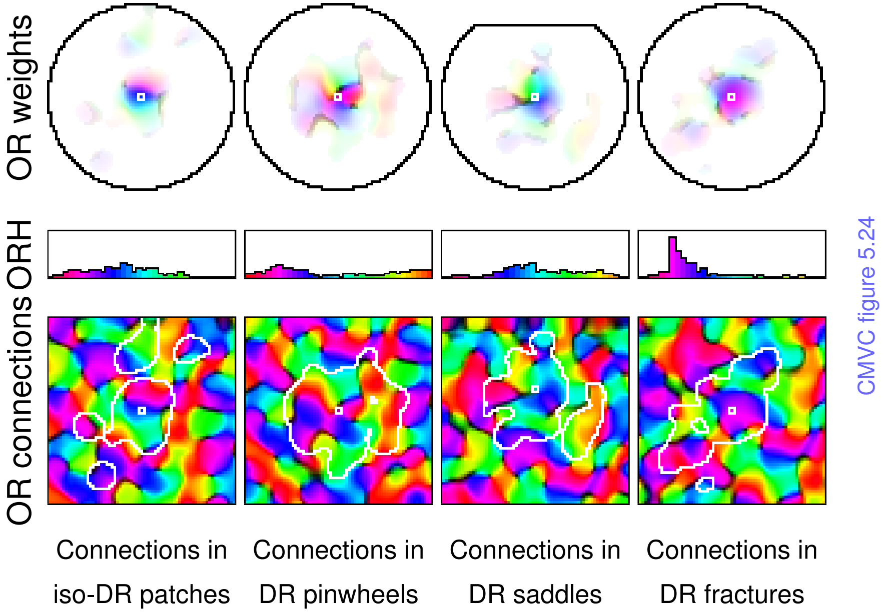
The lateral connections are similar to the OR case, but also respect the DR map, so that long-range connections link neurons with similar OR *and* DR preferences (strong prediction).

Gaussian OR/DR map

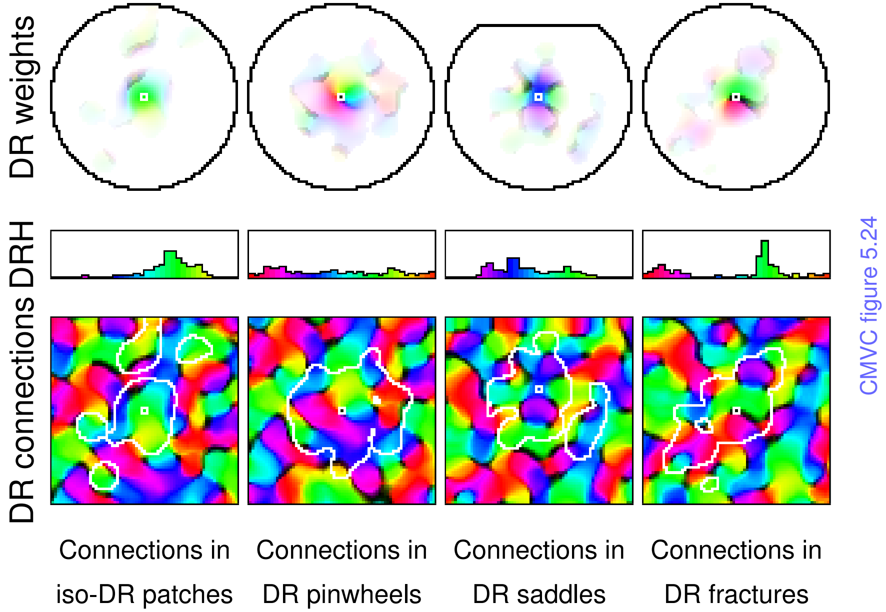


CMVC figure 5.23

OR/DR: OR lateral connections



OR/DR: DR lateral connections



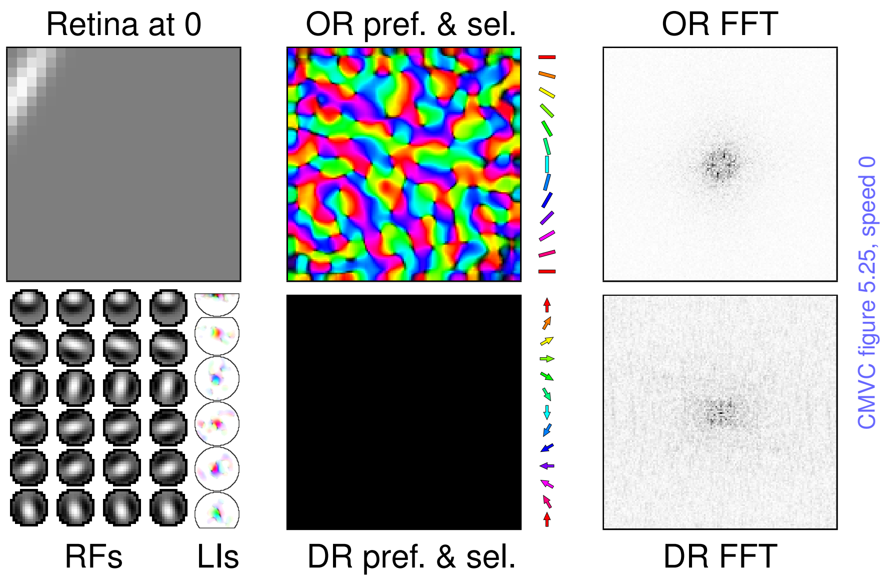
OR/DR: Effect of input speed

Varying the input speed allows us to smoothly trade off between a map dominated by orientation (slow speeds) and one dominated by motion direction (fast speeds).

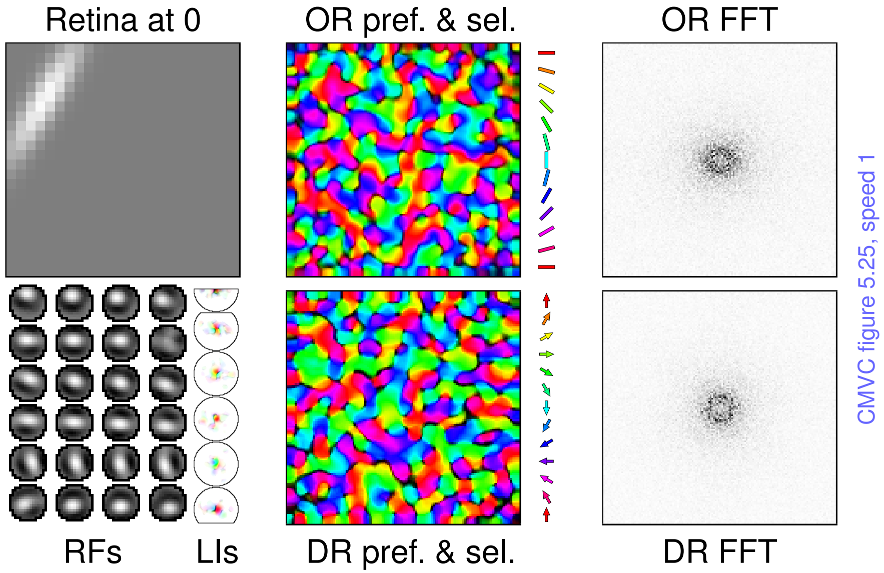
Meaningful top speed is limited by the size of the anatomical CF – if too fast, only one delayed image will match any CF.

Map organization smoothly changes from large-scale OR organization to large-scale DR organization.

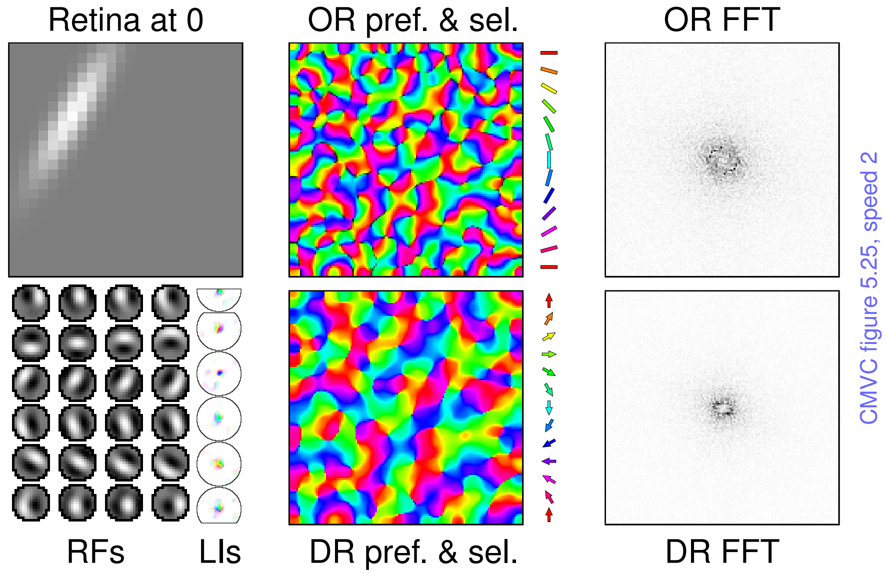
OR/DR map: Speed 0



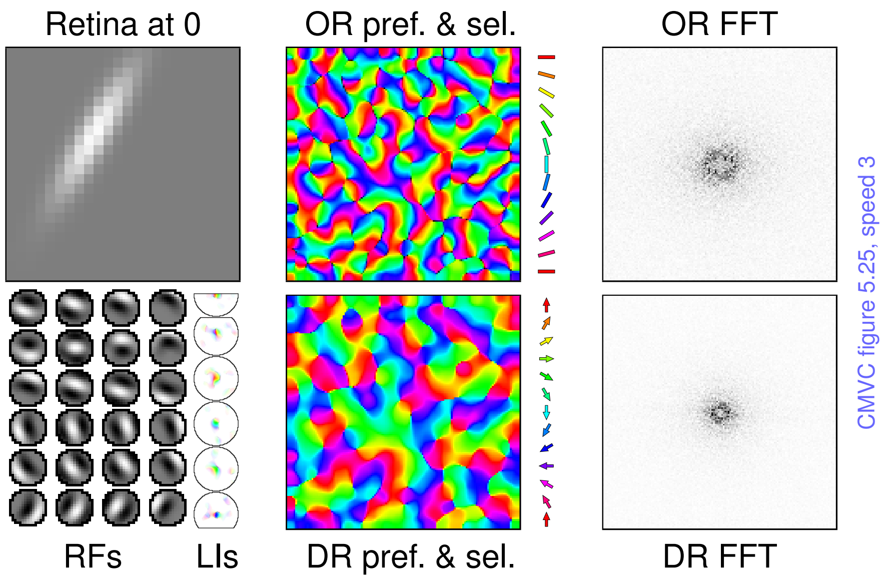
OR/DR map: Speed 1



OR/DR map: Speed 2



OR/DR map: Speed 3



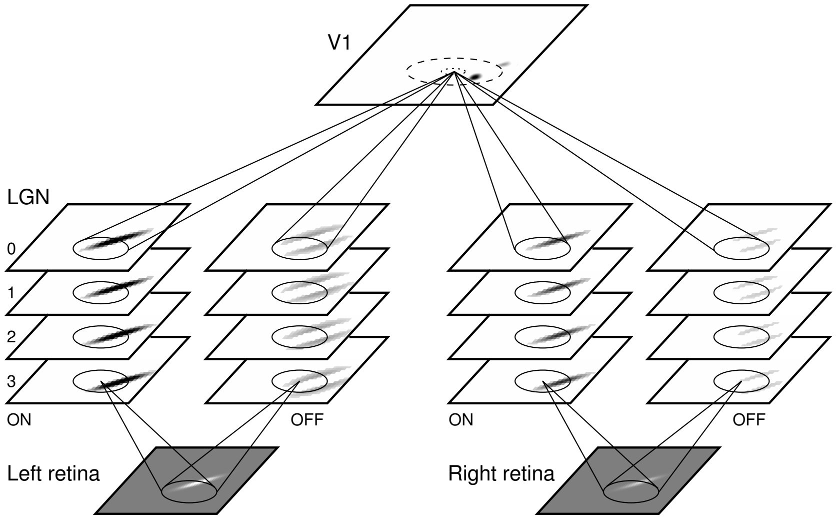
Simulating OR/OD/DR

Joint simulation of orientation, ocular dominance, and direction maps.

Same V1 architecture as all previous cases, but now with even more RGC/LGN sheets.

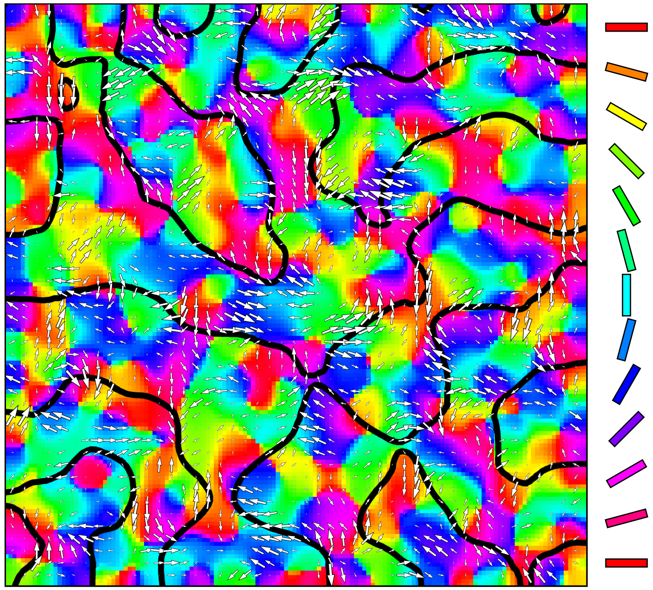
Still not yet approaching true complexity of early visual system – needs color (at least five times as many RGC/LGN sheet types needed), multiple spatial frequencies (at least twice as many LGN sheet types needed), input disparities, and probably other RGC/LGN cell types.

LISSOM model of OR/OD/DR



CMVC figure 5.26

Gaussian OR/OD/DR map



CMVC figure 5.27

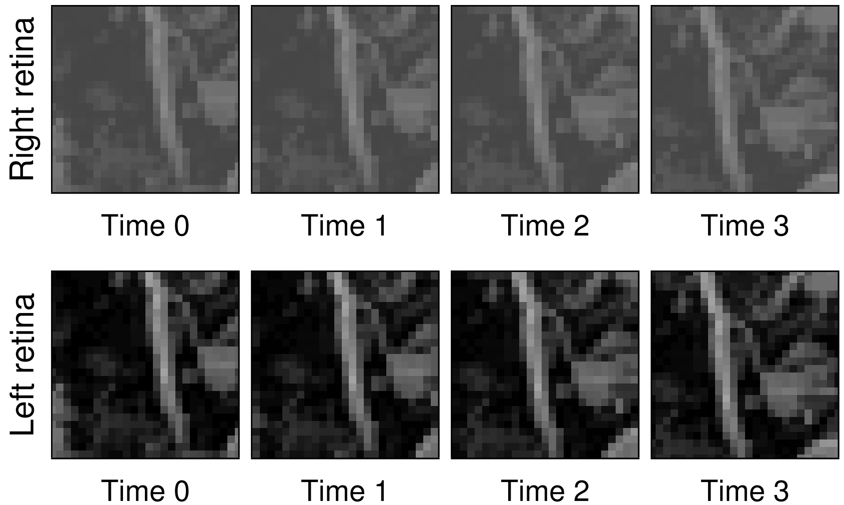
OR/OD/DR: Nature

OR/OD/DR map with natural image input (Shouval et al. 1996, 1997).

Uses same architecture as Gaussian case, with dimming and lagged LGN cells.

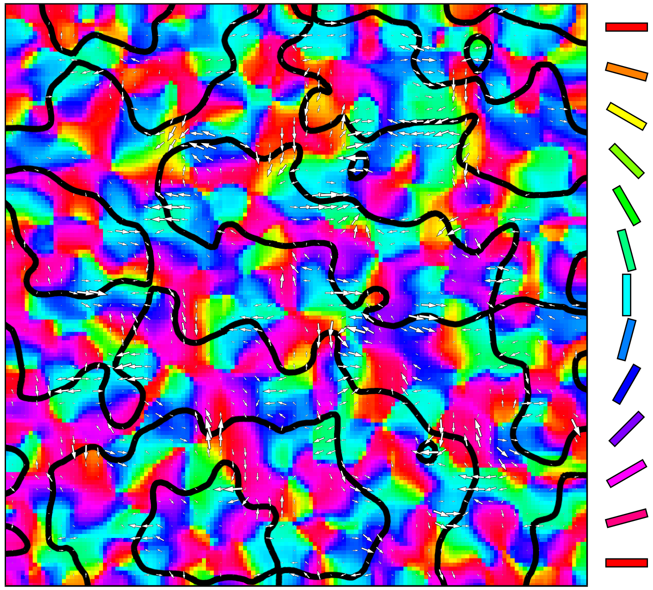
Similar results, but greater variety of RFs and less selectivity overall.

OR/OD/DR training images



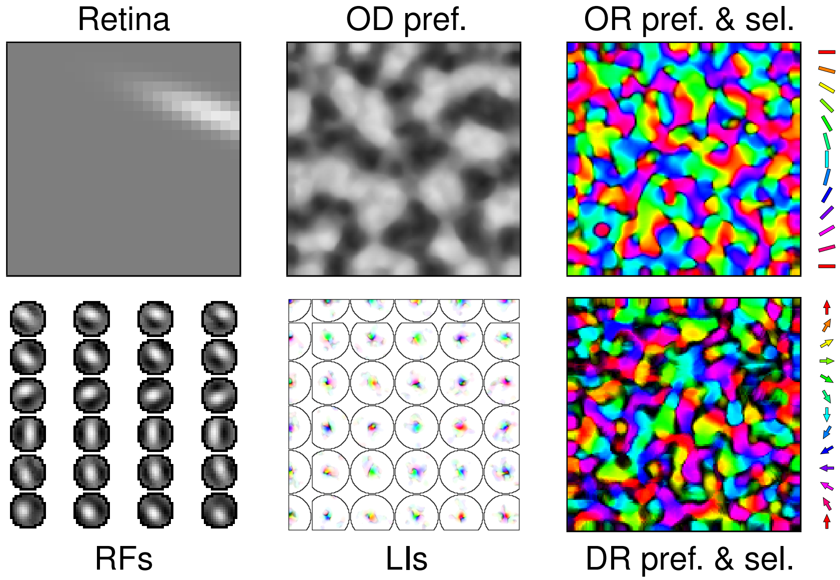
CMVC figure 5.30

Natural image OR/OD/DR map



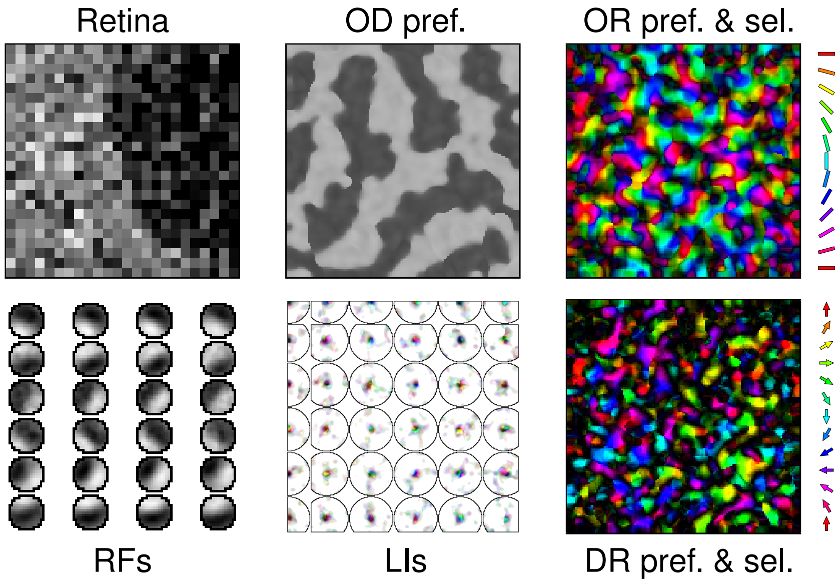
CMVC figure 5.31

OR/OD/DR: Gaussians



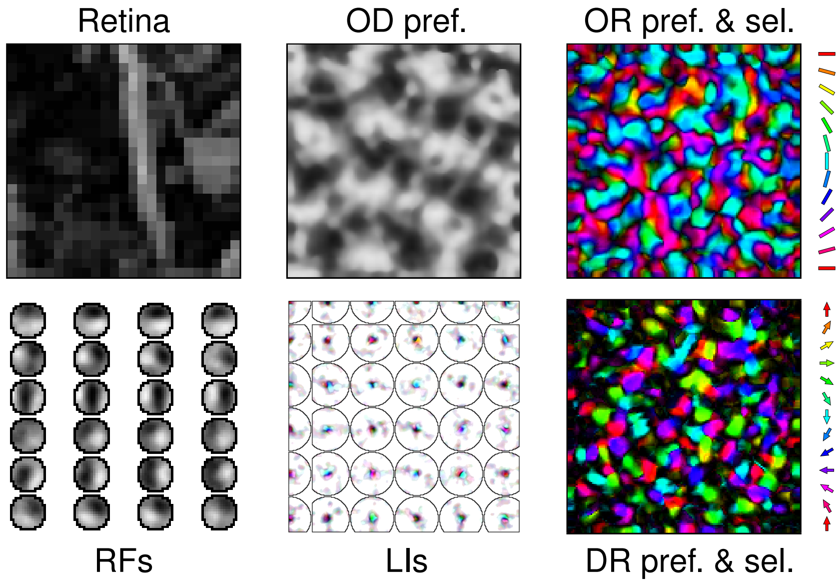
CMVC figure 5.32, Gaussians

OR/OD/DR: Noisy disks



CMVC figure 5.32, Noisy disks

OR/OD/DR: Nature



CMVC figure 5.32, Nature

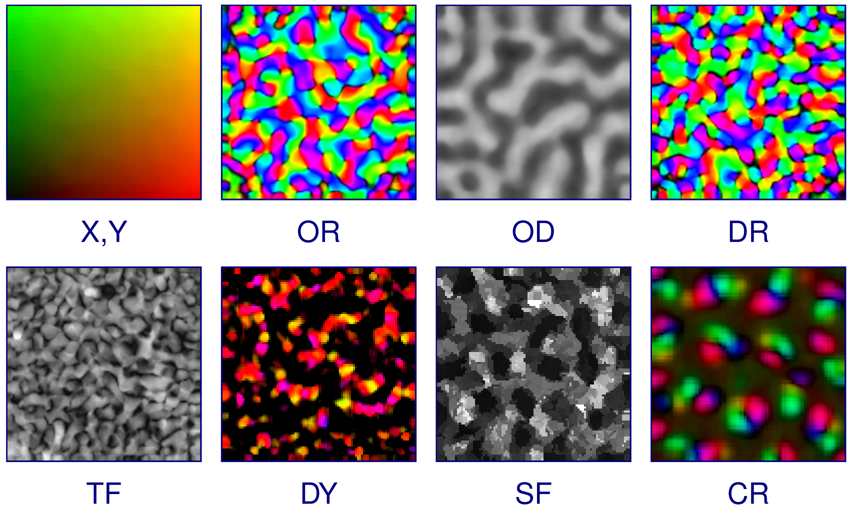
Other dimensions in V1

Since the book was published, all the other spatial dimensions have also been replicated in LISSOM:

- Color (CL): Joint work with Judah De Paula (Bednar et al. 2005) and Chris Ball
- Spatial frequency (SF): Joint work with Christopher Palmer (Palmer & Bednar 2006)
- Disparity (DY): Joint work with Tikesh Ramtohul (Ramtohul 2006)

Preliminary work combines X/Y/OR/OD/DR/TF/CR/SF/DY, using 80 types of RGC/LGN cells (covers all but TF; Gerasymova 2008; Bednar 2012).

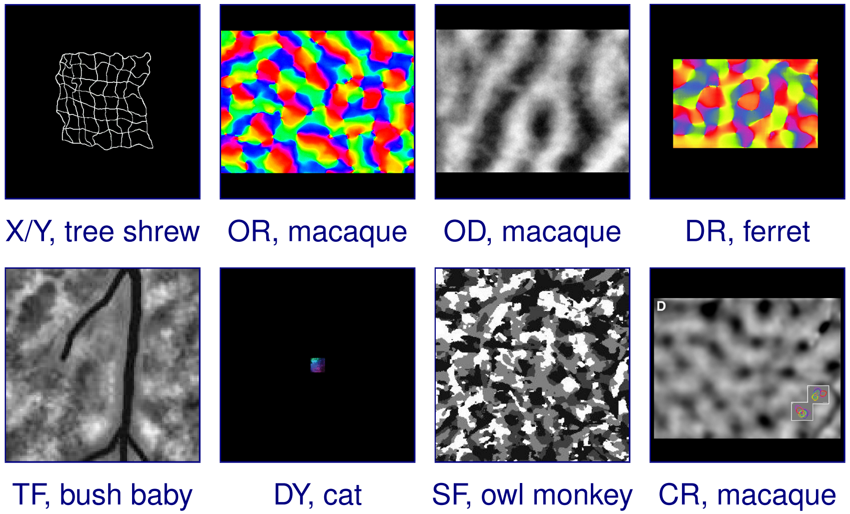
Individual model maps



Subsets of features developed in different models

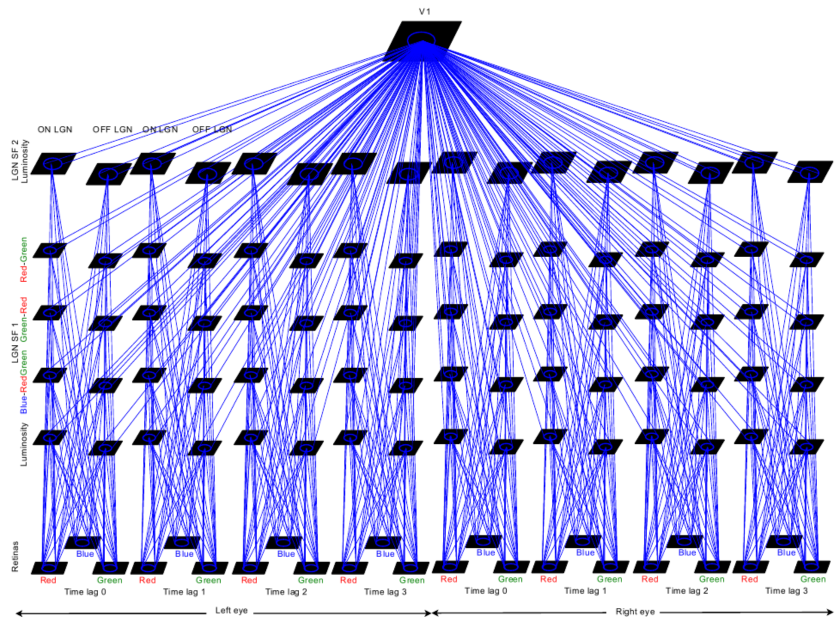
(with C. Ball, T. Ramtohul, C. Palmer, J. De Paula, K. Gerasymova)

Animal Maps in V1



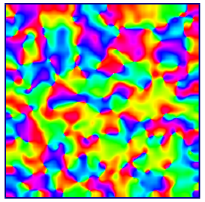
(Each panel shows 4mm$\times$4mm)

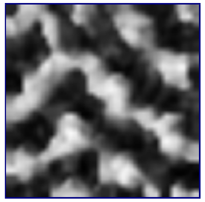
Joint X/Y/OR/OD/DR/TF/CR/SF/DY

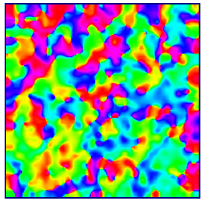


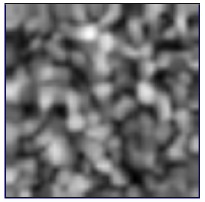
Joint X/Y/OR/OD/DR/TF/CR/SF/DY

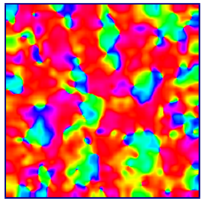

PO (X,Y)

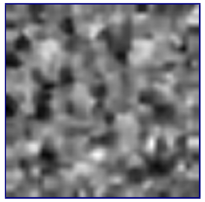

OR

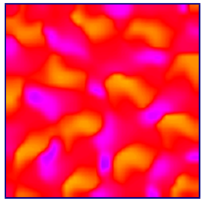

OD


DR


TF


DY


SF


CR

Work in progress, but covers all spatial maps. (Smoothed)

Summary

Same LISSOM V1 can be used to model numerous (all?) feature dimensions, without modification.

Theory: cortical areas are similarly equipotent, and can reorganize to represent or process any dimension that typically varies and that our sensors can detect.

Though the organization is driven entirely by the input, a large class of inputs typically suffices to develop preference for a given feature.

In each case, the lateral connections store the long-range correlations in activity patterns within V1.

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