LISSOM Orientation Maps

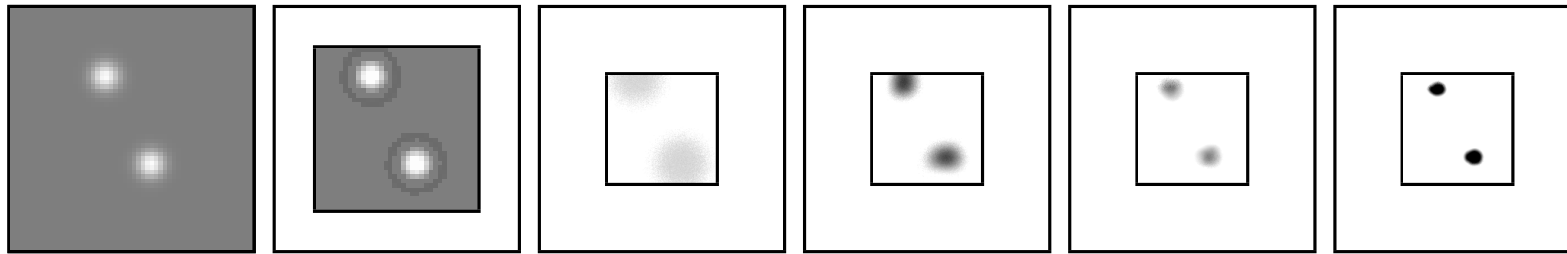## Dr. James A. Bednar

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Modeling Orientation

- Starting point: Retinotopy model

- Same architecture, different input pattern

- Three dimensions of variance: x, y, orientation

- How will that fit into a 2D map?
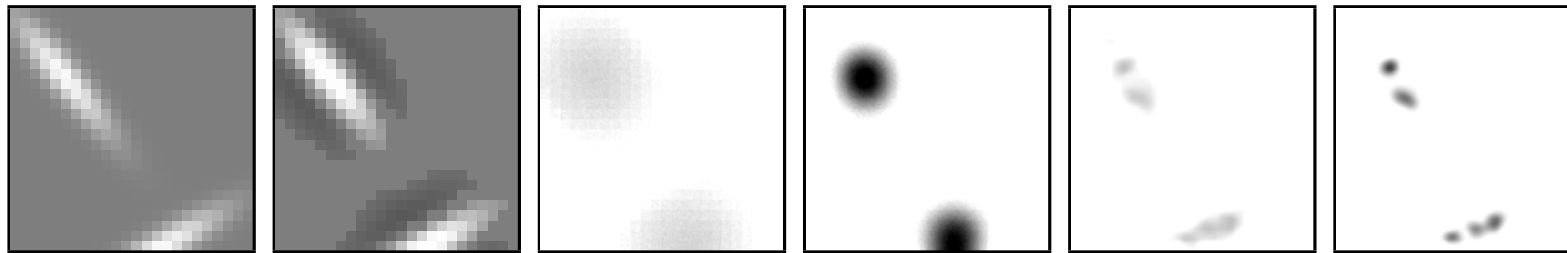
Retinotopy input and response

| Retinal activation | LGN response | Iteration 0: Initial V1 response | Iteration 0: Settled V1 response | 10,000: Initial V1 response | 10,000: Settled V1 response |

(Reminder from last time)

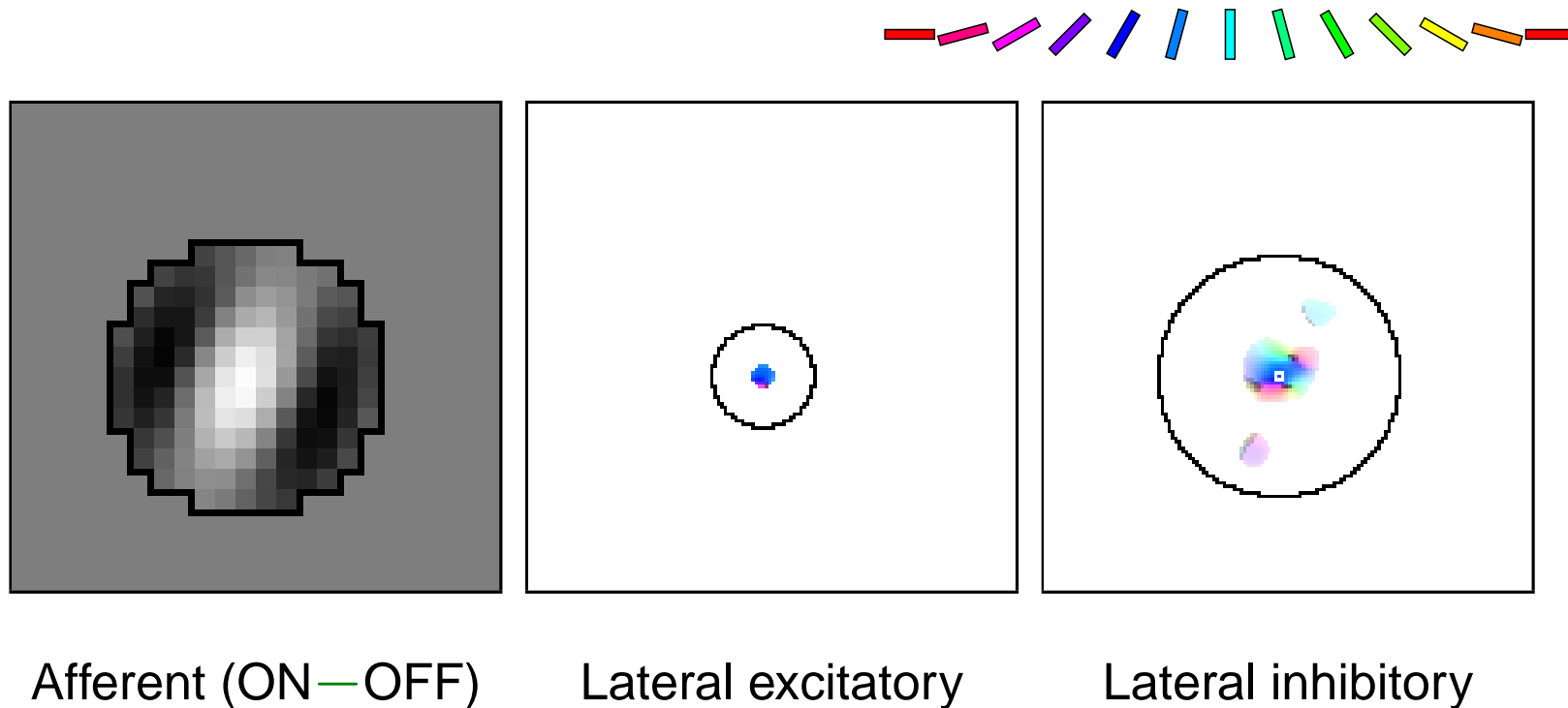# Orientation input and response

| Retinal activation | LGN response | Iteration 0: Initial V1 response | Iteration 0: Settled V1 response | 10,000: Initial V1 response | 10,000: Settled V1 response |

- Multiple activity blobs per input pattern: orientation-specific

Self-organized V1 weights
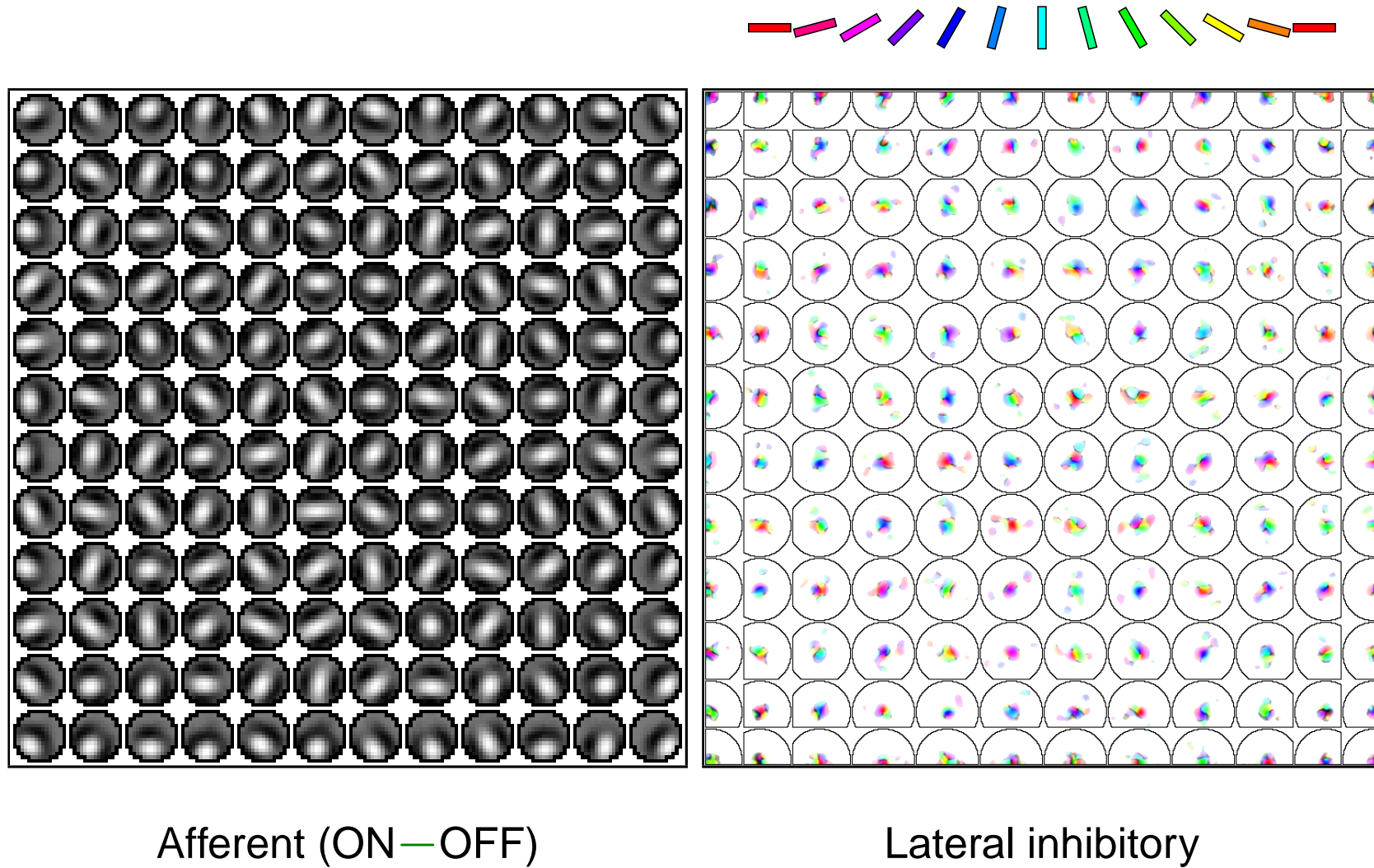

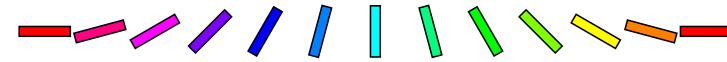Afferent (ON—OFF)   Lateral excitatory   Lateral inhibitory

Typical:
- Gabor-like afferent CF
- Nearly uniform short-range lateral excitatory
- Patchy, orientation-specific long-range lateral inhibitory
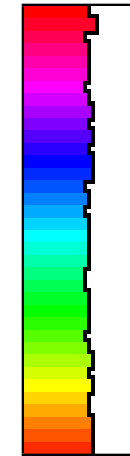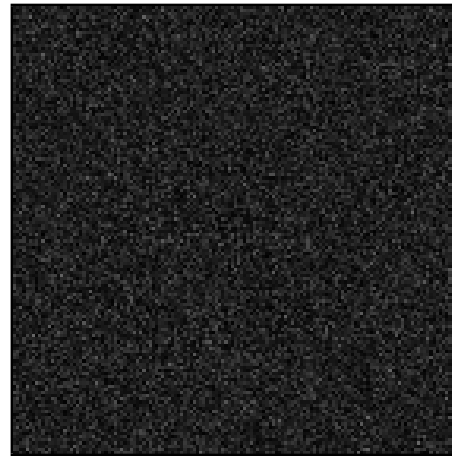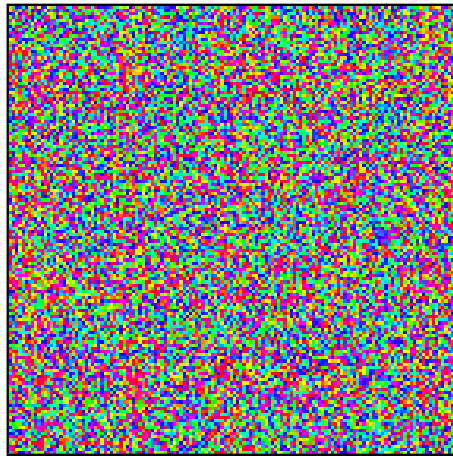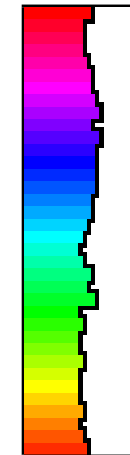
Self-organized weights across V1

Afferent (ON—OFF)

Lateral inhibitory

OR map self-organization
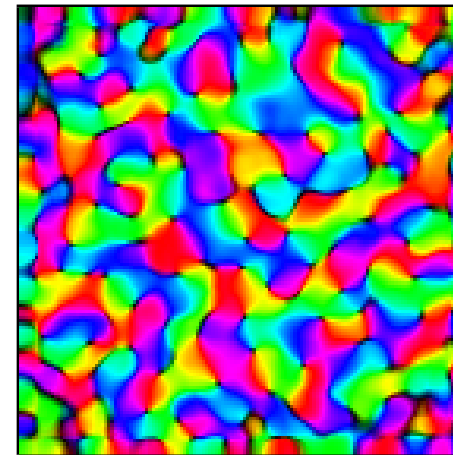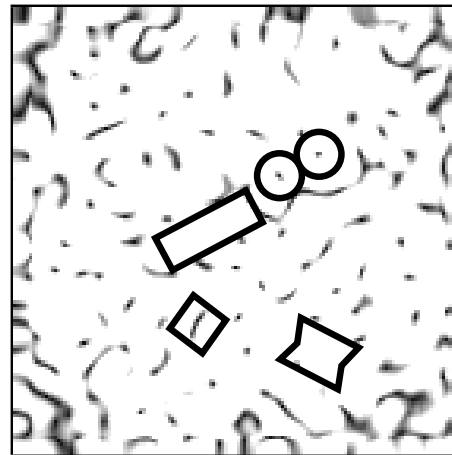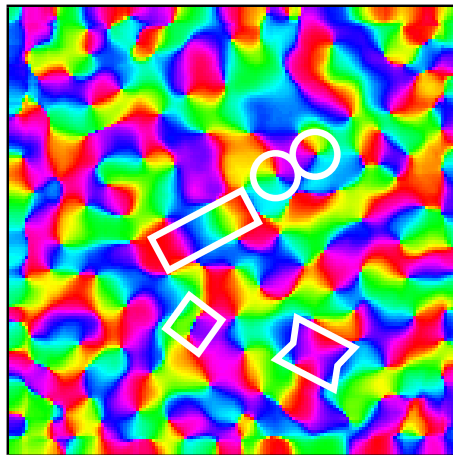
OR preference   OR selectivity   OR preference & selectivity   OR H

Iteration 0

Iteration

CMVC figure 5.9

Macaque ORmap: Fourier,gradient
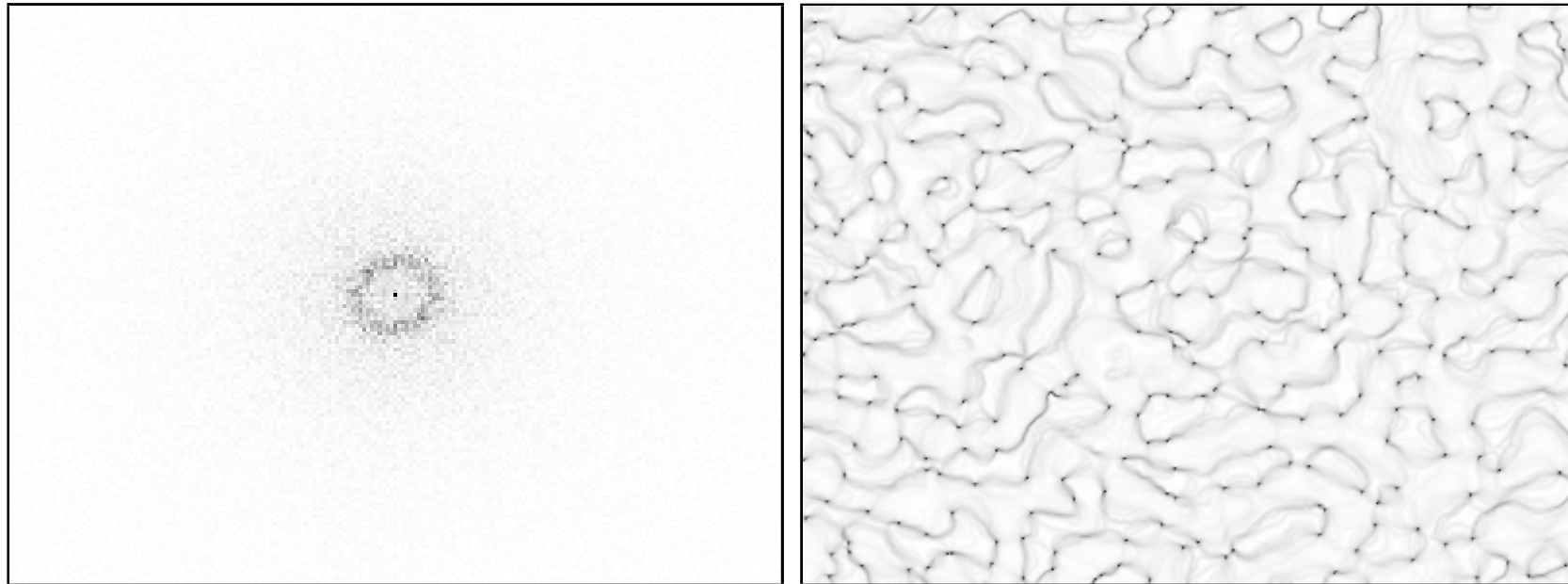
CMVC figure 5.1

Fourier spectrum   Gradient
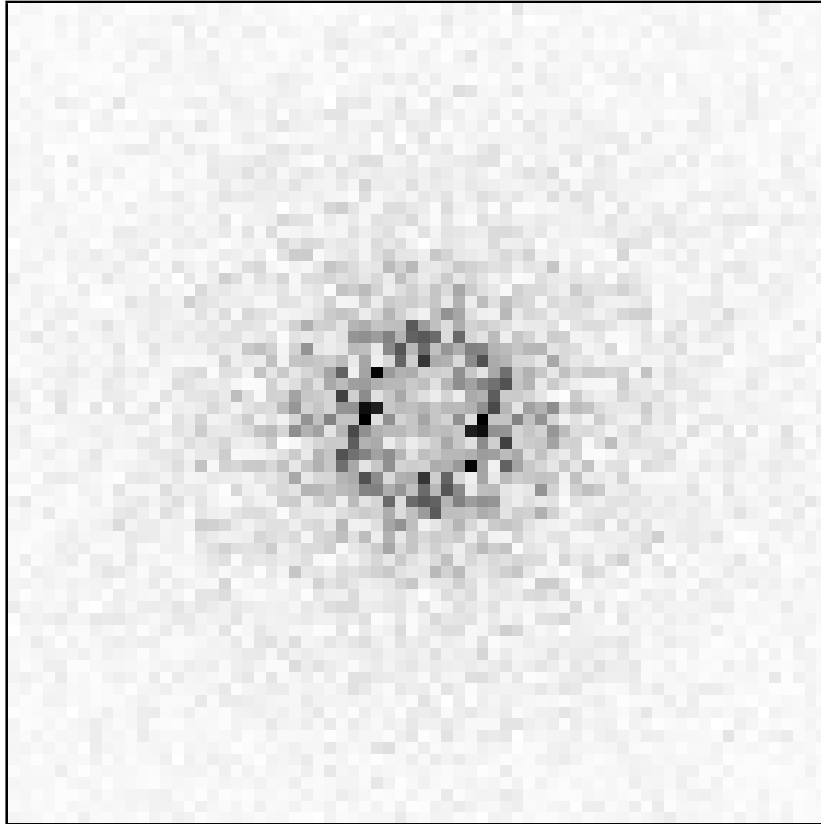
In monkeys:

- Ring-shaped spectrum: repeats regularly in all directions
- High gradient at fractures, pinwheels.

OR Map: Fourier, gradient

CMVC figure 5.10
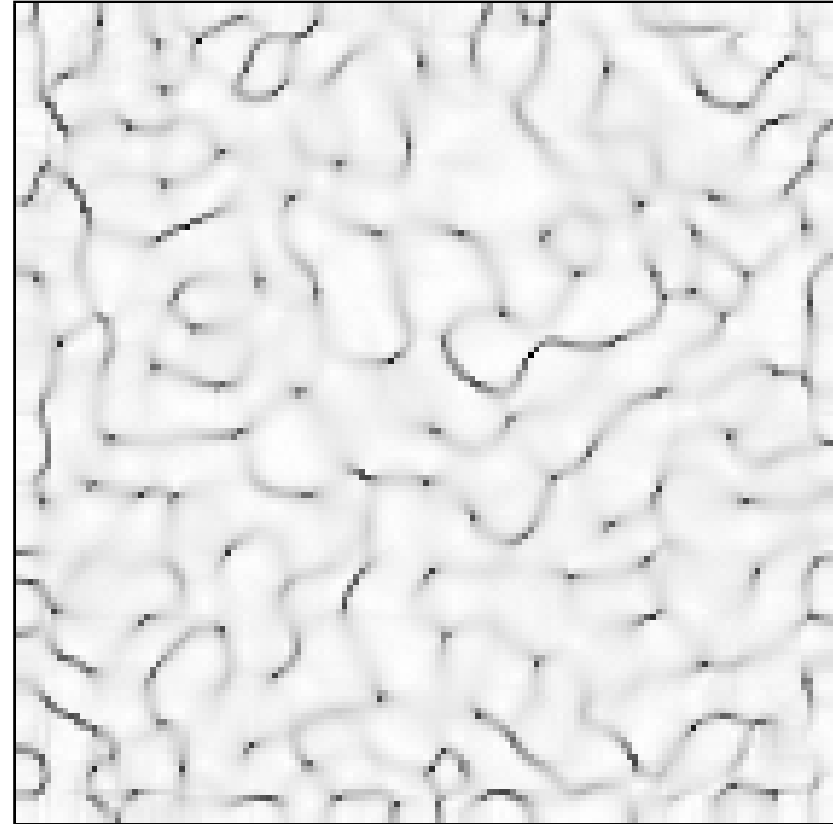
Fourier spectrum   Gradient

LISSOM model has similar spectrum, gradient

OR Map: Retinotopic organization
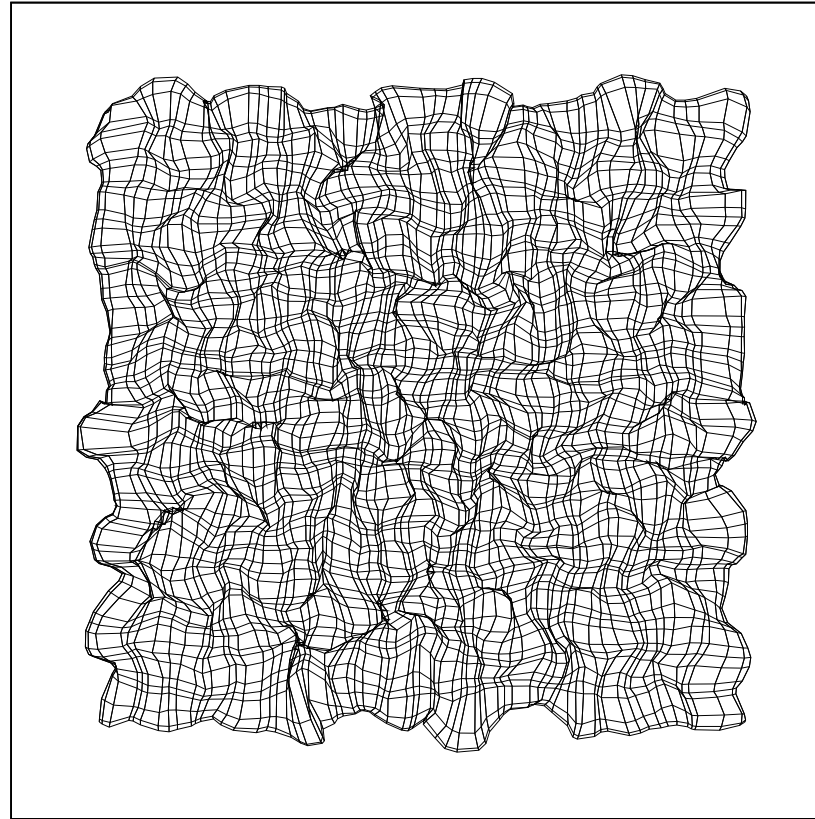
- Retinotopy is distorted locally by orientation prefs

- Matches distortions found in animal maps?

OR Map: Lateral connections

Connections in iso-OR patches

Connections in OR pinwheels

Connections in OR saddles

Connections in OR fractures
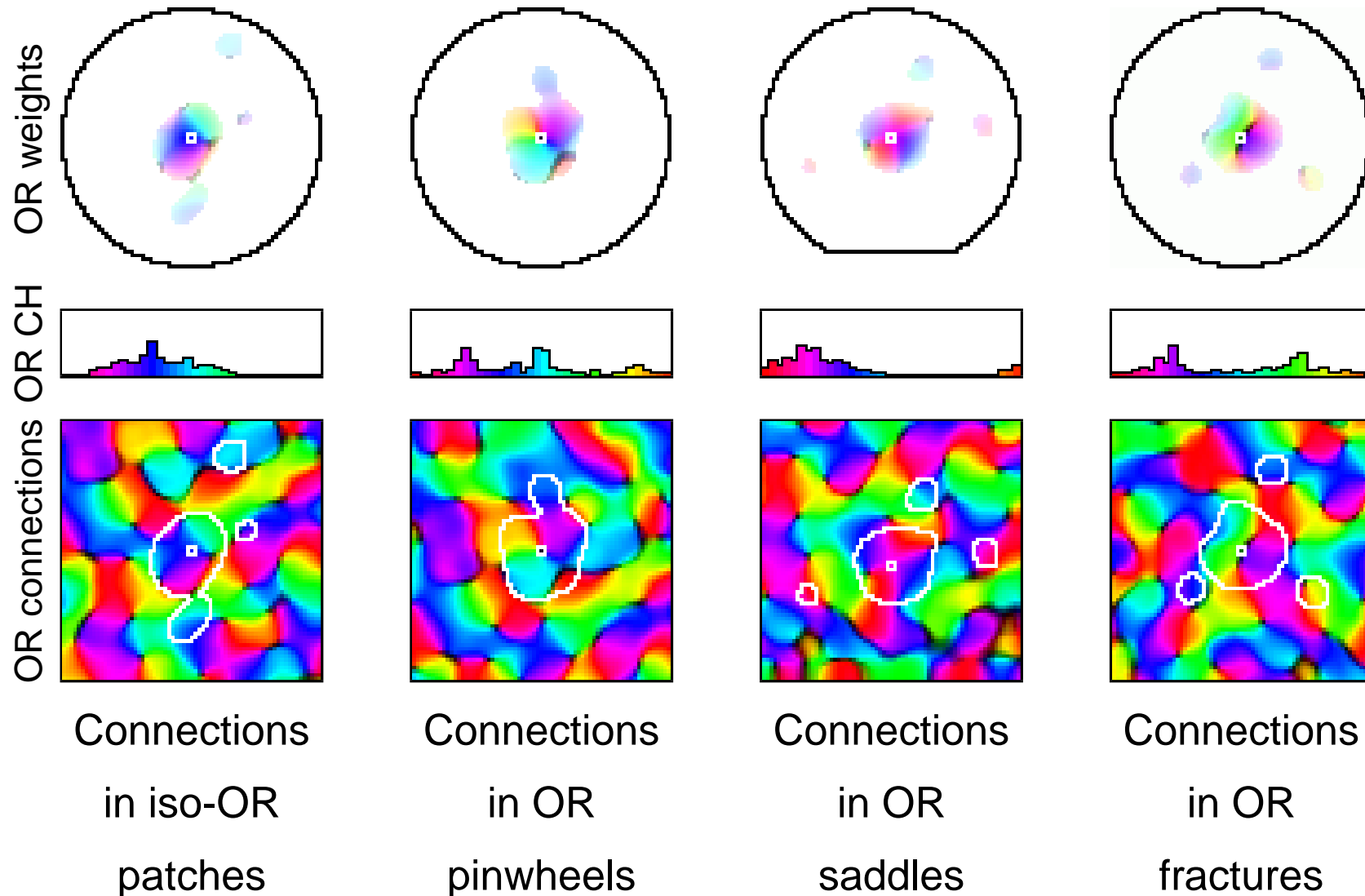
CMVC figure 5.12

Effect of initial weights

(a) Iteration 0 (b) Iteration 50 (c) Iteration 10,000
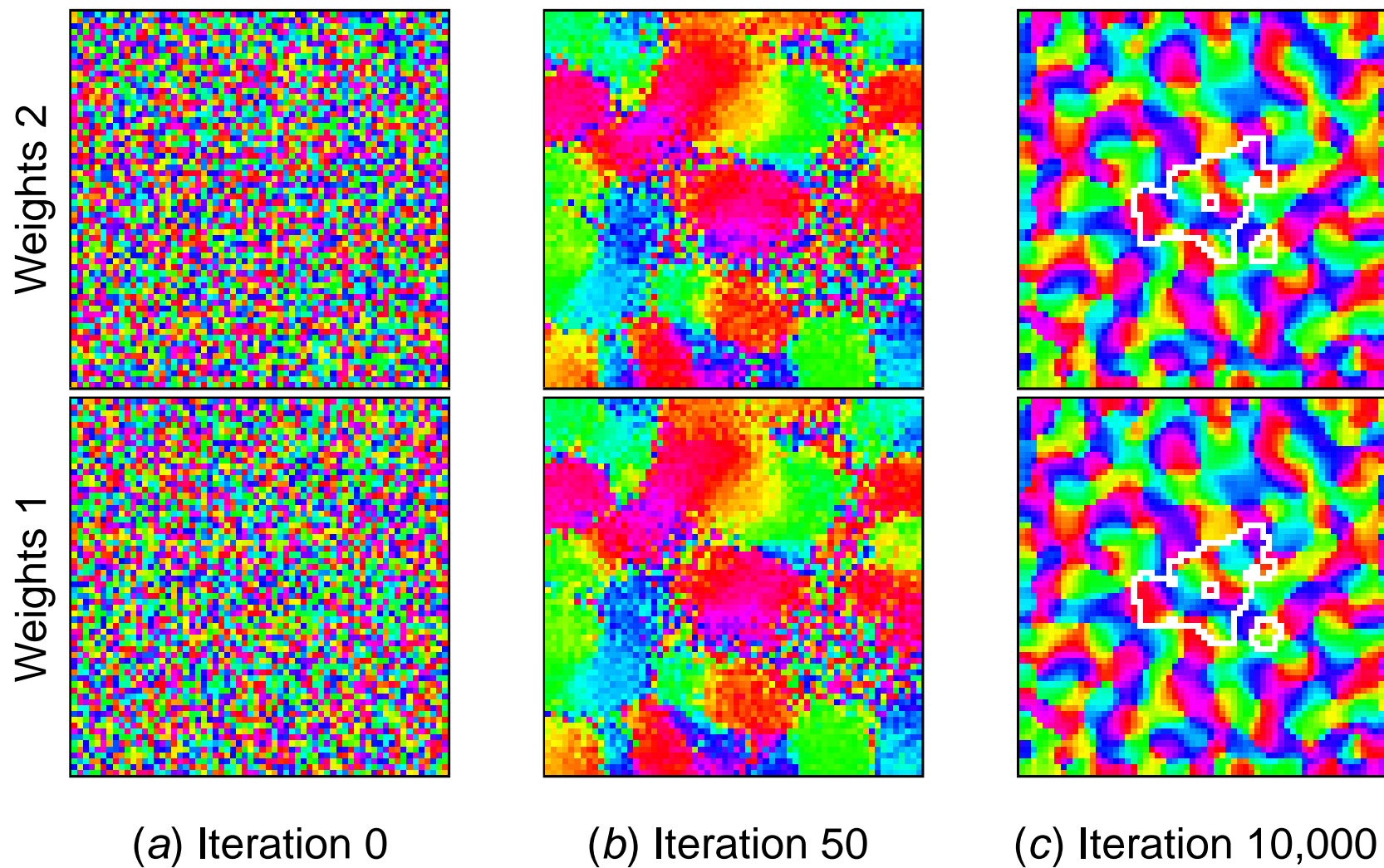
Changing weights doesn't change map folding pattern.

CMVC figure 8.5

Effect of input streams

(*a*) Iteration 0   (*b*) Iteration 50   (*c*) Iteration 10,000
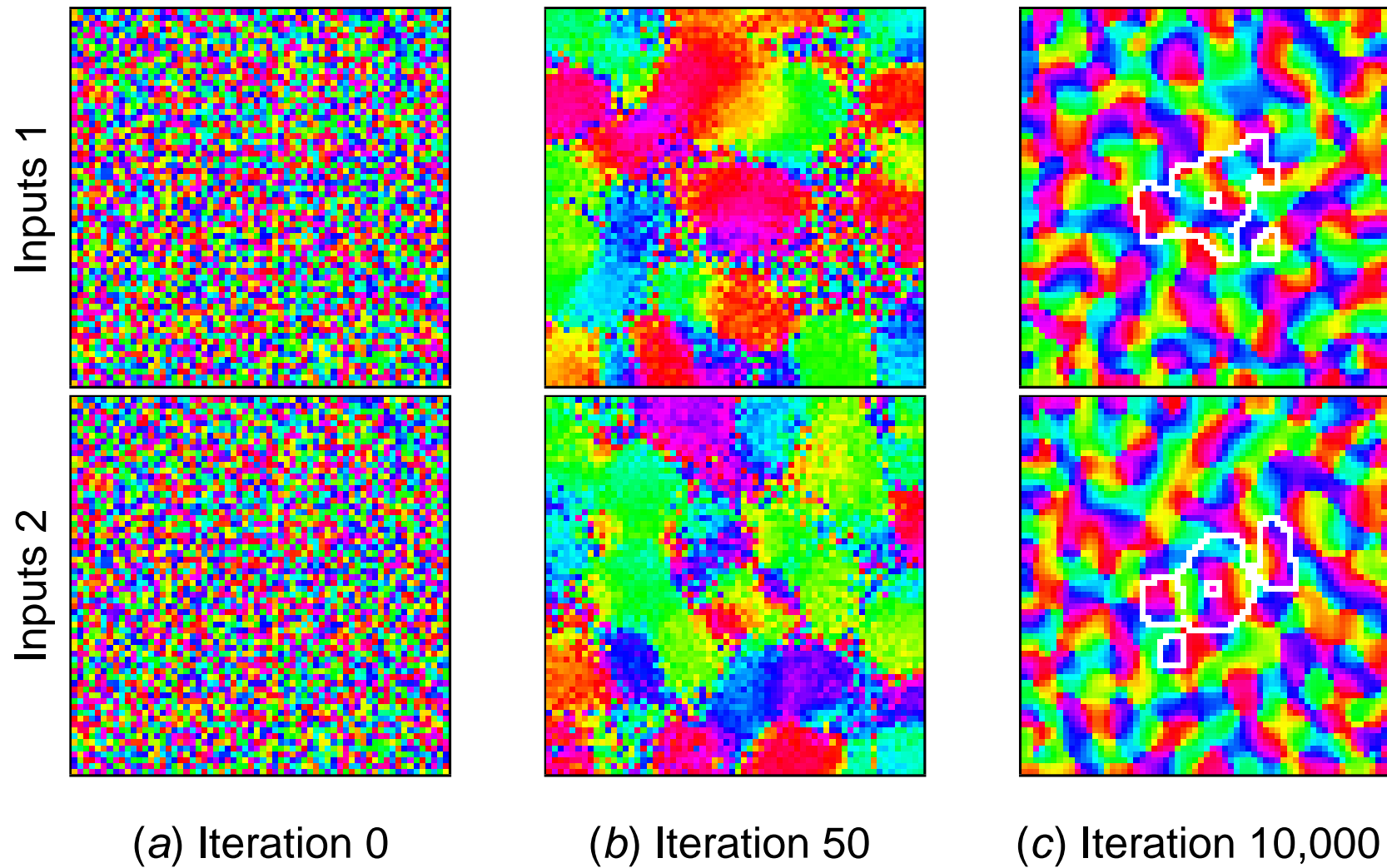
Changing inputs changes entire pattern.

Scaling retinal and cortical area
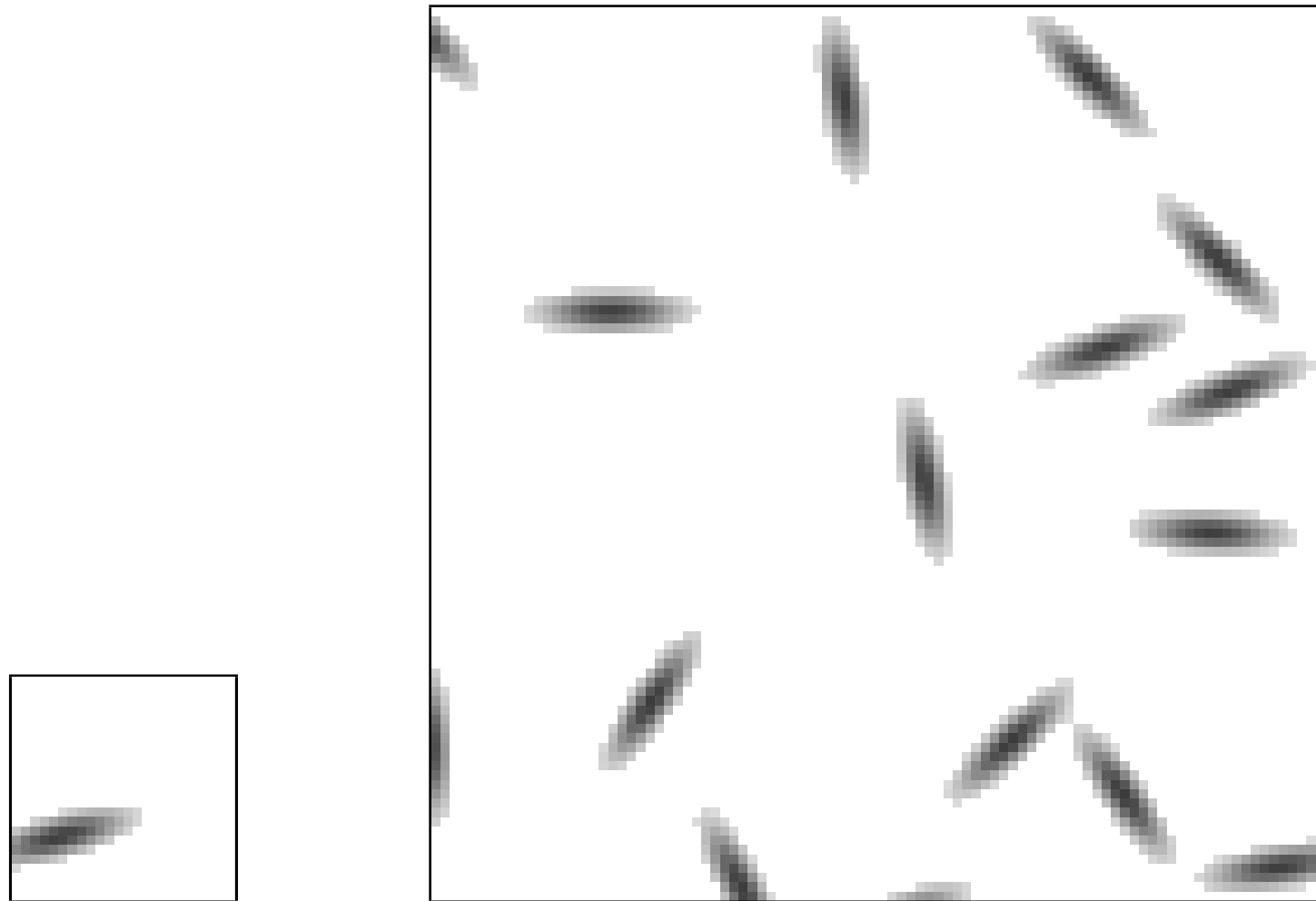
(*a*) Original retina: $R = 24$ (*b*) Retinal area scaled by 4.0:
$R = 96$

CMVC figure 15.1a,b

Scaling retinal and cortical area
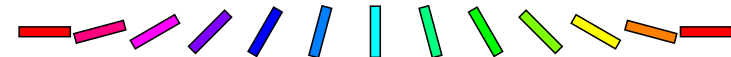
(*c*) Original V1:
$N = 54$, 0.4 hours, 8 MB
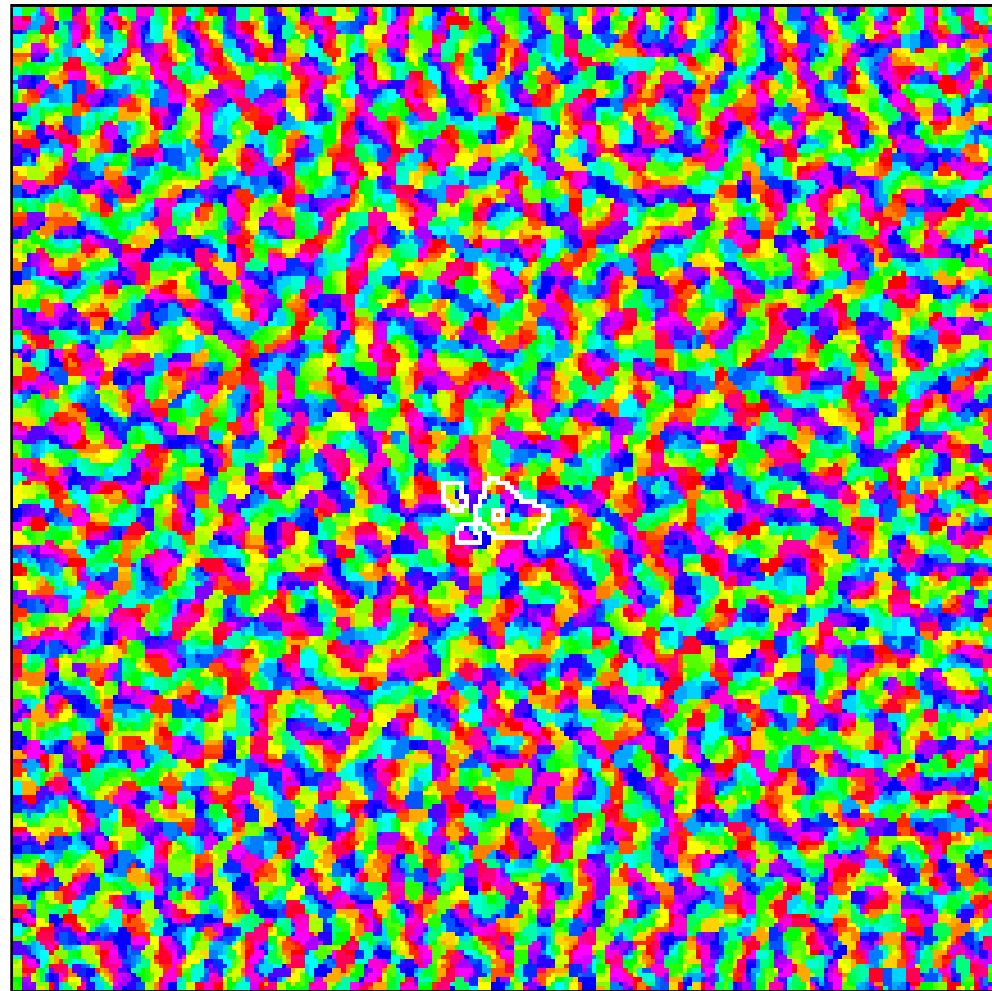
(*d*) V1 area scaled by 4.0:
$N = 216$, 9 hours, 148 MB

Scaling retinal density

Retina

V1

Original retina   Retina scaled by 2   Retina scaled by 3

CMVC figure 15.2

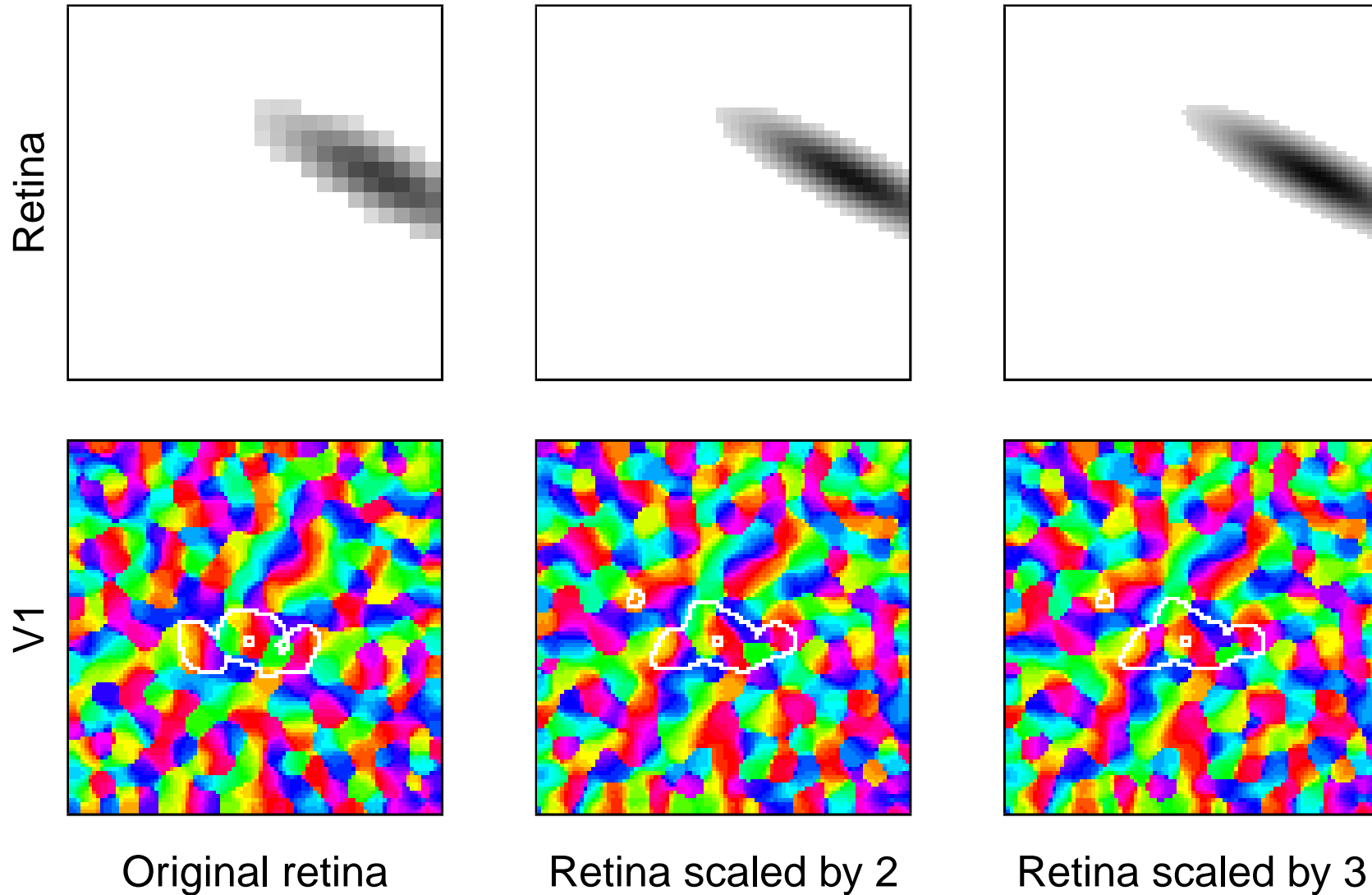# Scaling cortical density
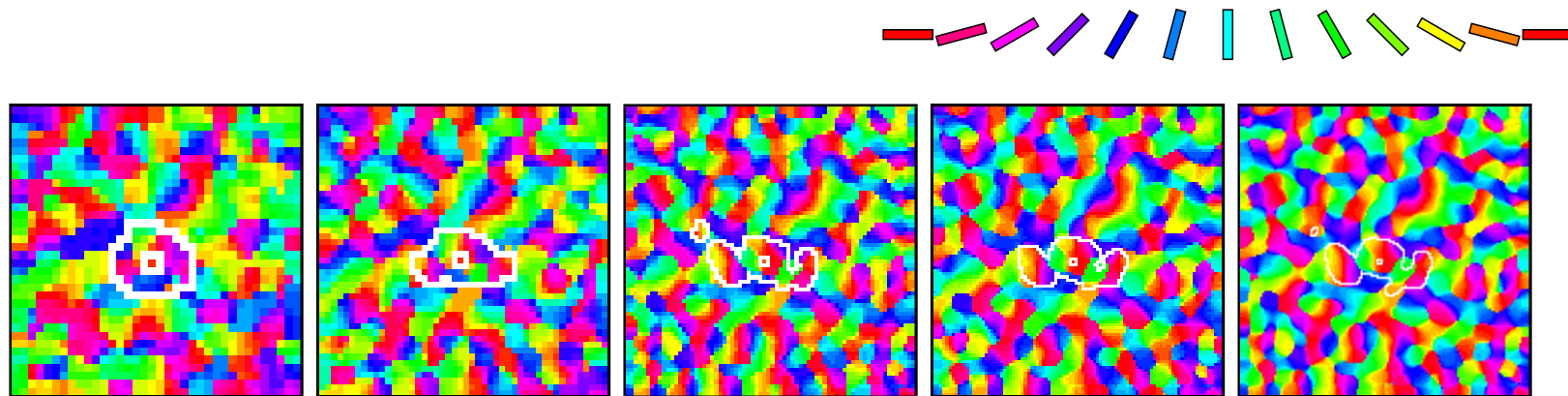
(a)	(b)	(c)	(d)	(e)
36×36:	48×48:	72×72:	96×96:	144×144:
0.17 hours,	0.32 hours,	0.77 hours,	1.73 hours,	5.13 hours,
2.0 MB	5.2 MB	22 MB	65 MB	317 MB

Above minimum density (due to lateral radii),

density not crucial for organization

CMVC figure 15.3

Full-size V1 Map
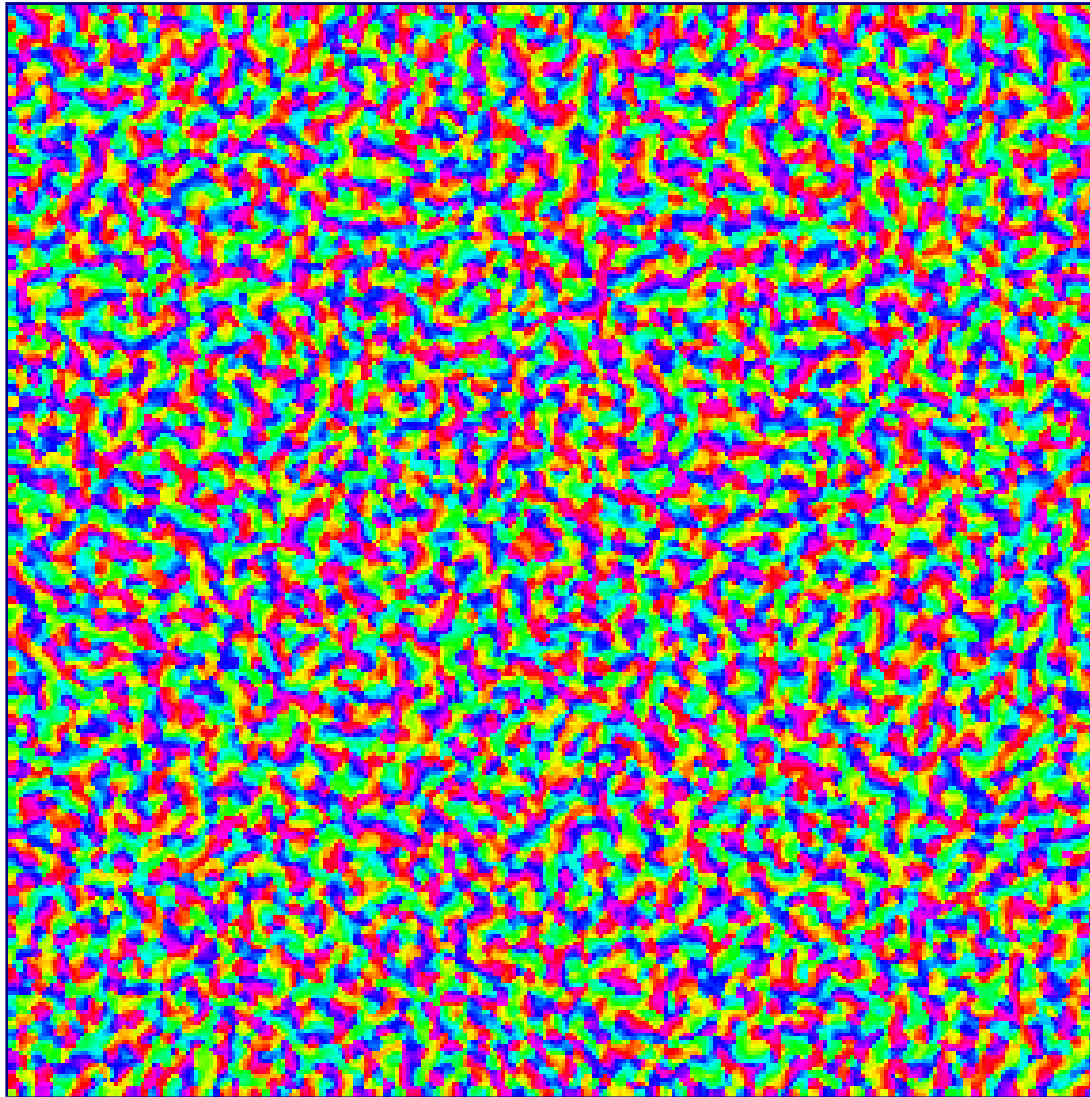
- Map scaled to cover most of visual field

- Allows testing with full-size images

- 30 million connections

Sample Image

LGN Response

V1 Response with γ_n

V1 Orientation Map
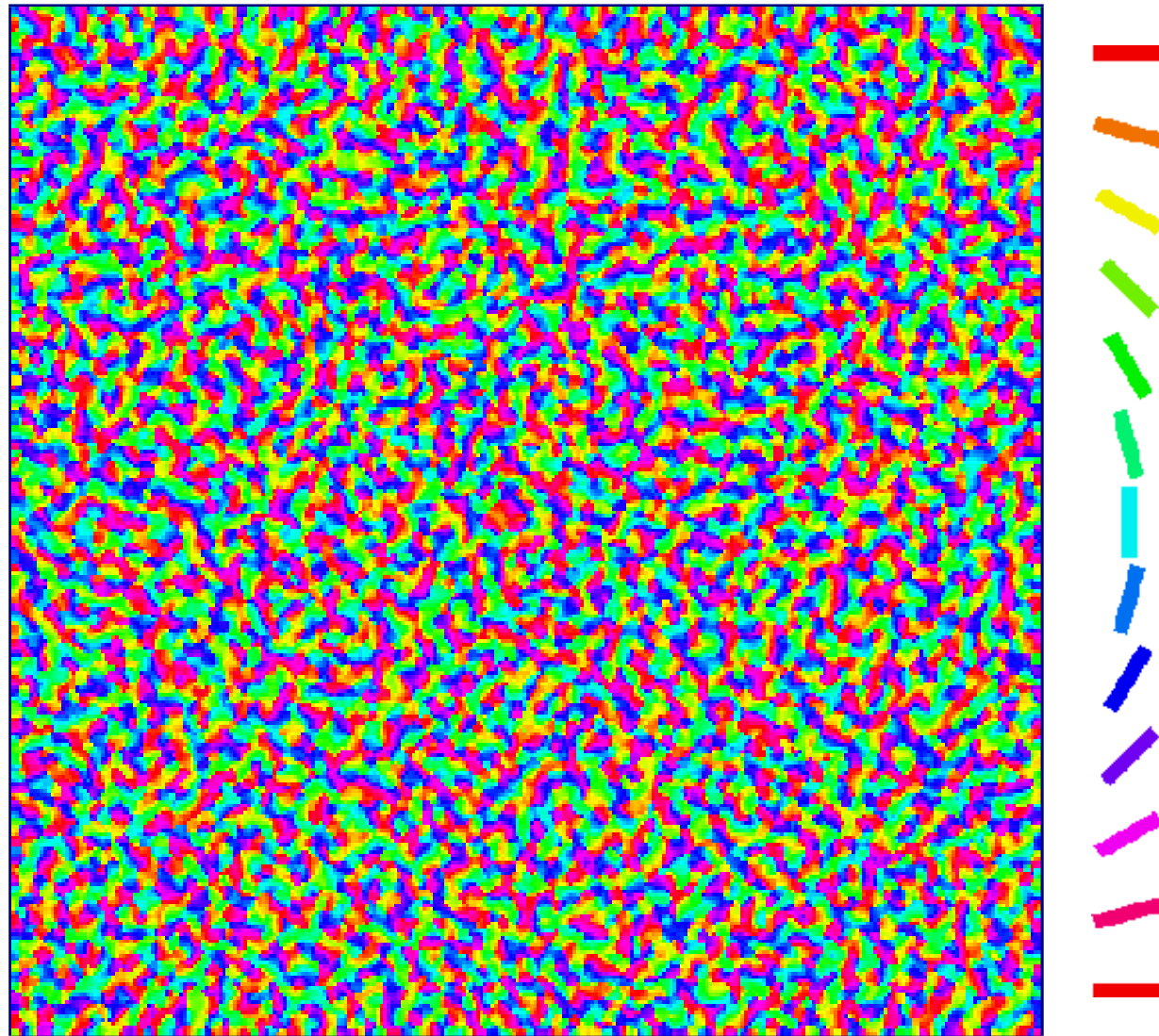
Afferent normalization

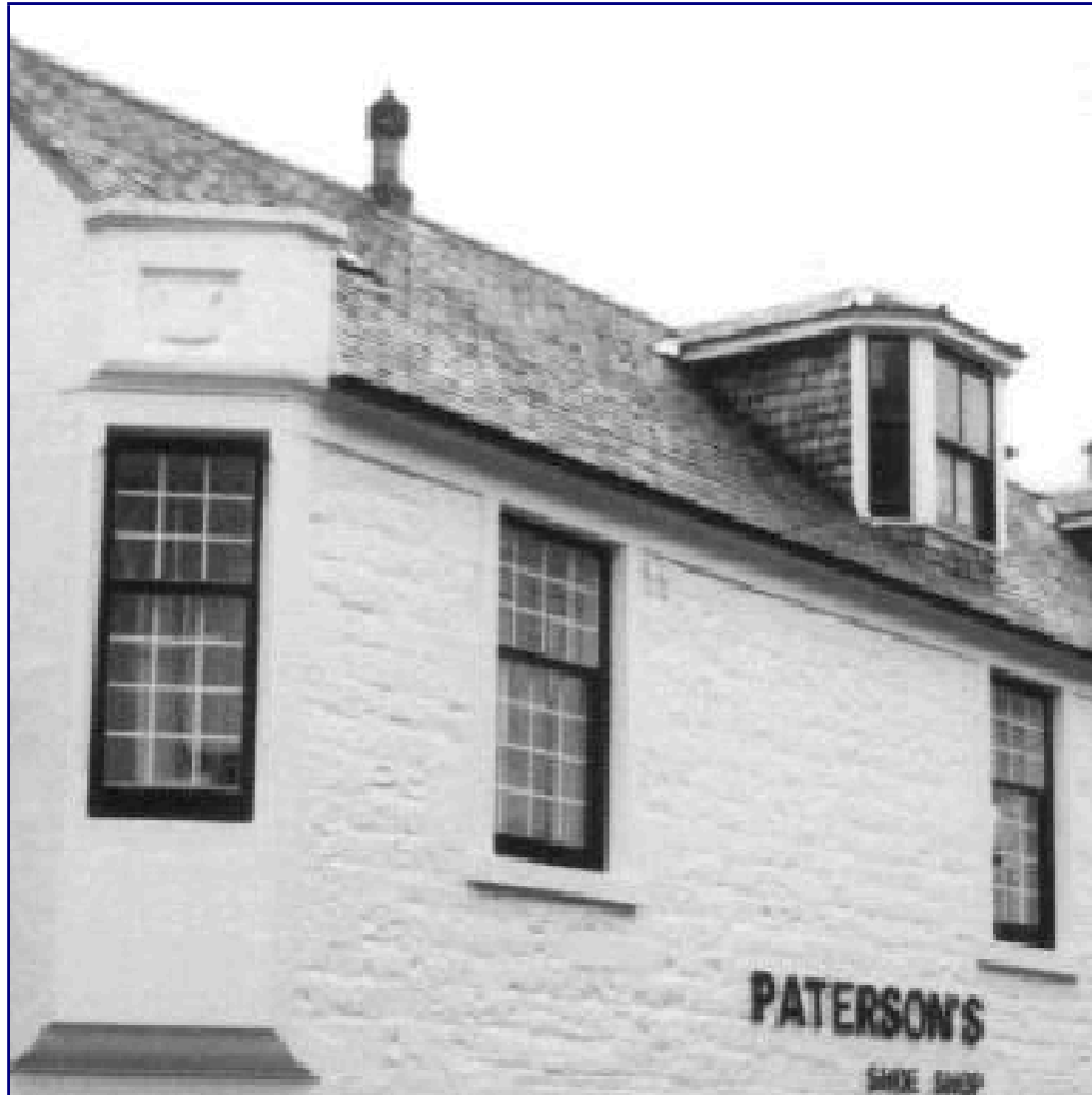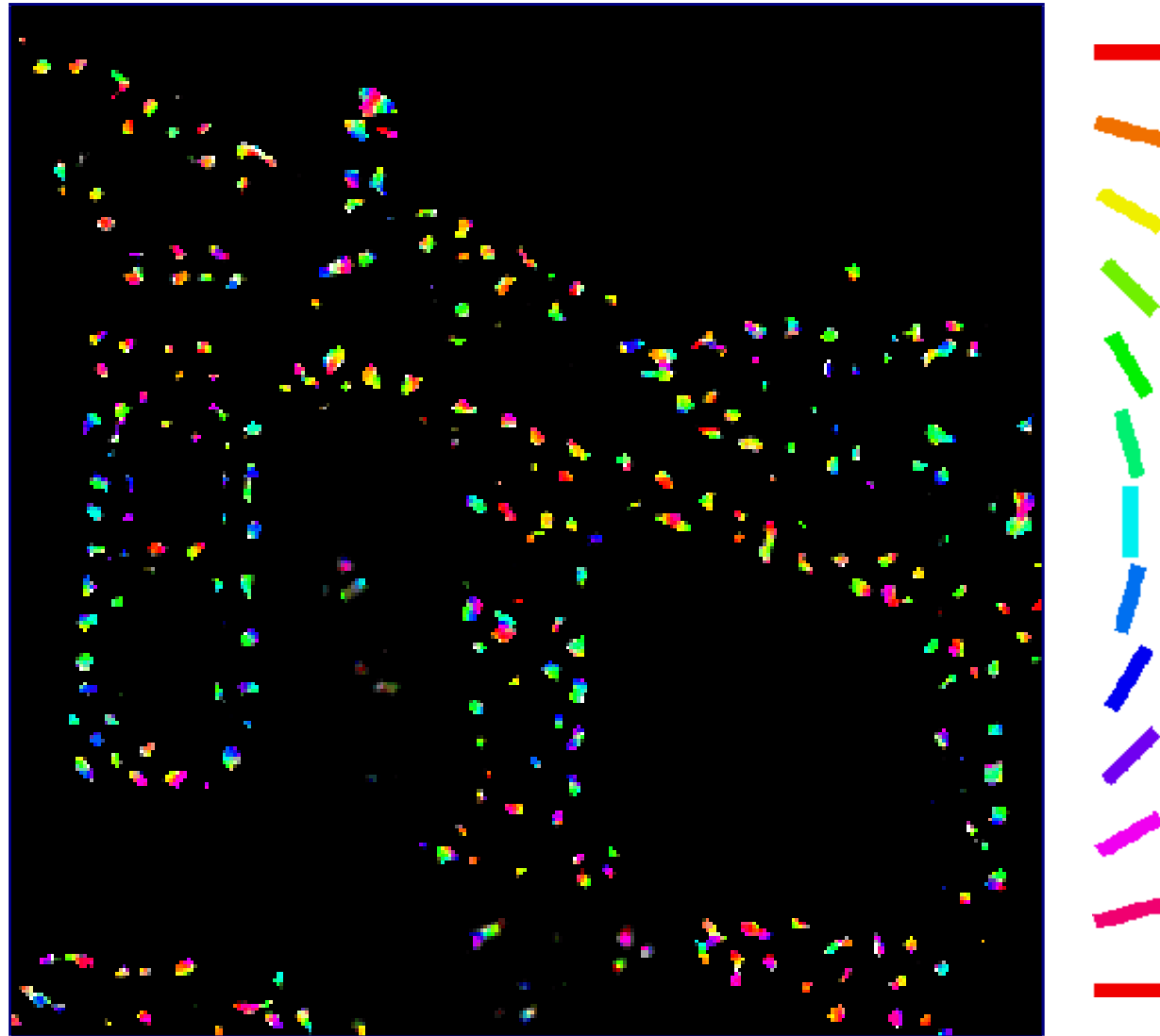Mechanism for contrast invariant tuning:

$$s_{ij} = \frac{\gamma_{\mathrm{A}} \left(\sum_{\rho ab} \xi_{\rho ab} A_{\rho ab,ij} \right)}{1 + \gamma_{\mathrm{n}} \left(\sum_{\rho ab} \xi_{\rho ab} \right)}, \qquad (1)$$

$\xi_{\rho ab}$: activation of unit (a, b) in afferent RF ρ of neuron (i, j)

$A_{ab,ij}$ is the corresponding afferent weight

$\gamma_{\mathrm{A}}, \gamma_{\mathrm{n}}$ are constant scaling factors

LGN response to large image

Retinal activation   LGN response
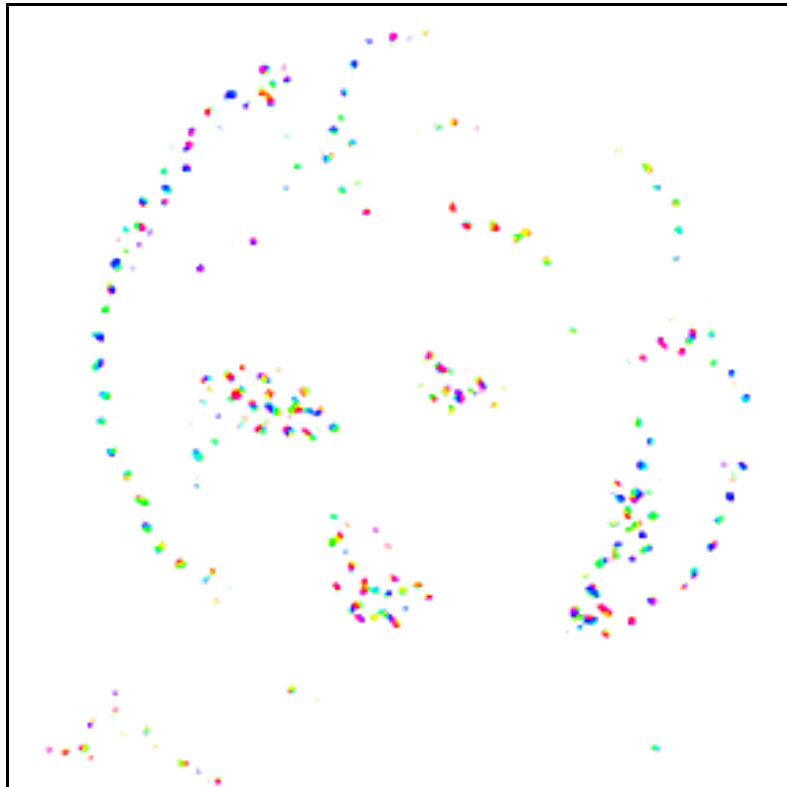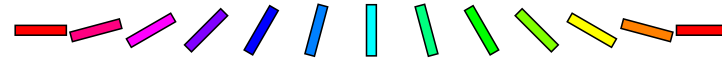
LGN responds to most of the visible contours

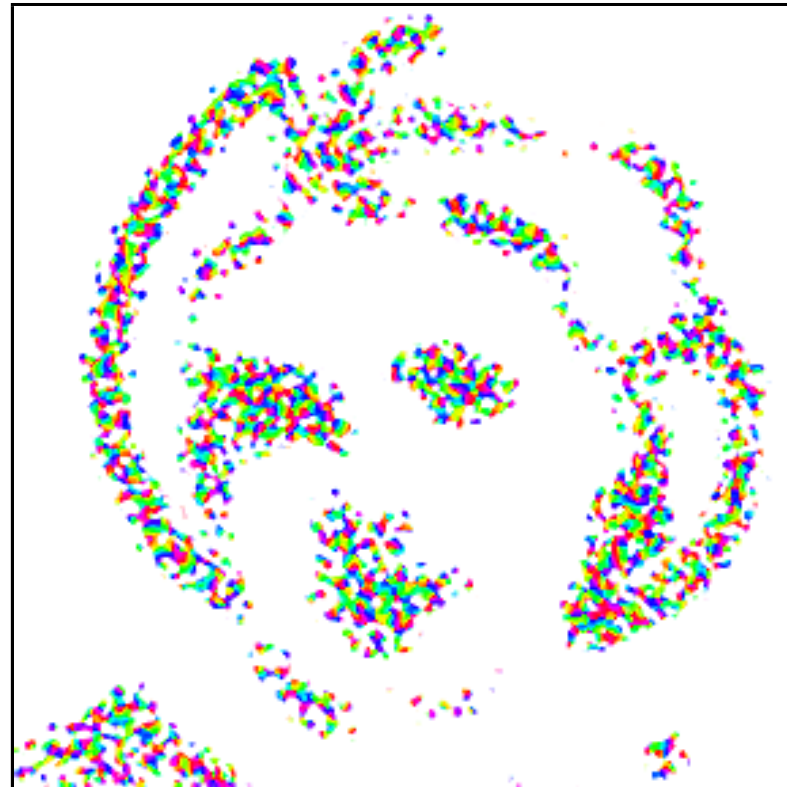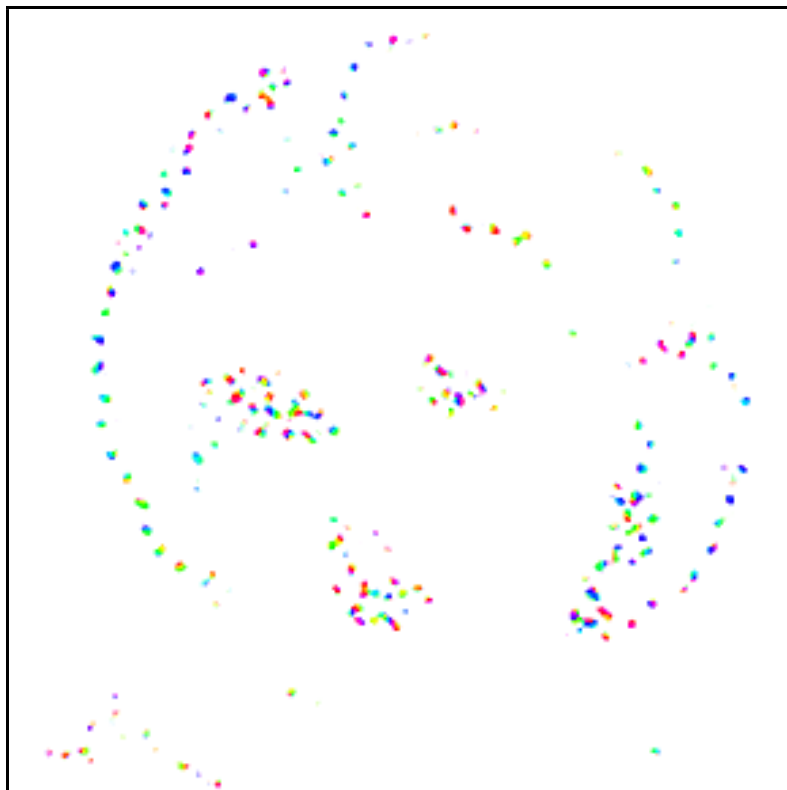# V1 without afferent normalization

V1 response:

$$\gamma_n = 0, \gamma_A = 3.25$$

V1 response:

$$\gamma_n = 0, \gamma_A = 7.5$$

Cannot get selective response to all contours

V1 with afferent normalization
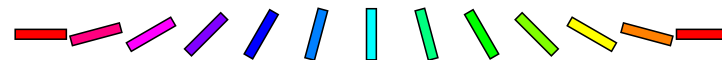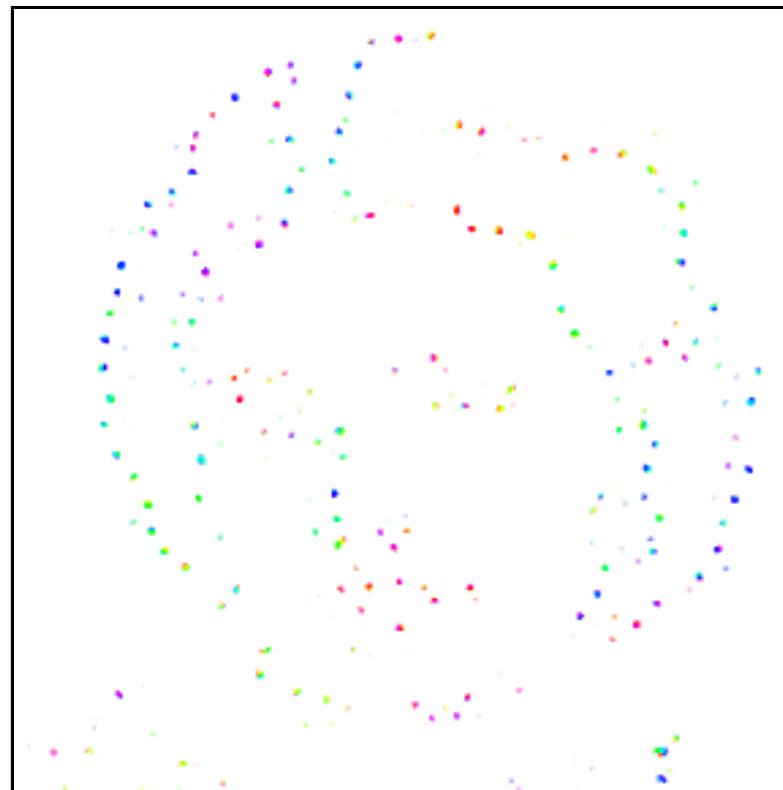
V1 response:

$\gamma_\mathrm{n} = 0, \gamma_\mathrm{A} = 3.25$

V1 response:

$\gamma_\mathrm{n} = 80, \gamma_\mathrm{A} = 30$

Responds based on contour, not contrast

CMVC figure 8.2c-e

Tuning with afferent normalization
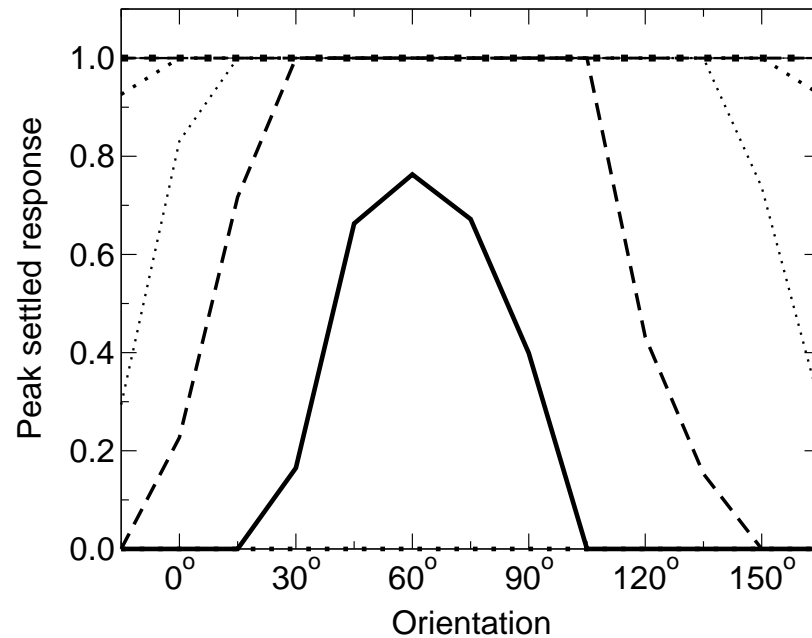
$\gamma_n = 0, \gamma_A = 3.25$
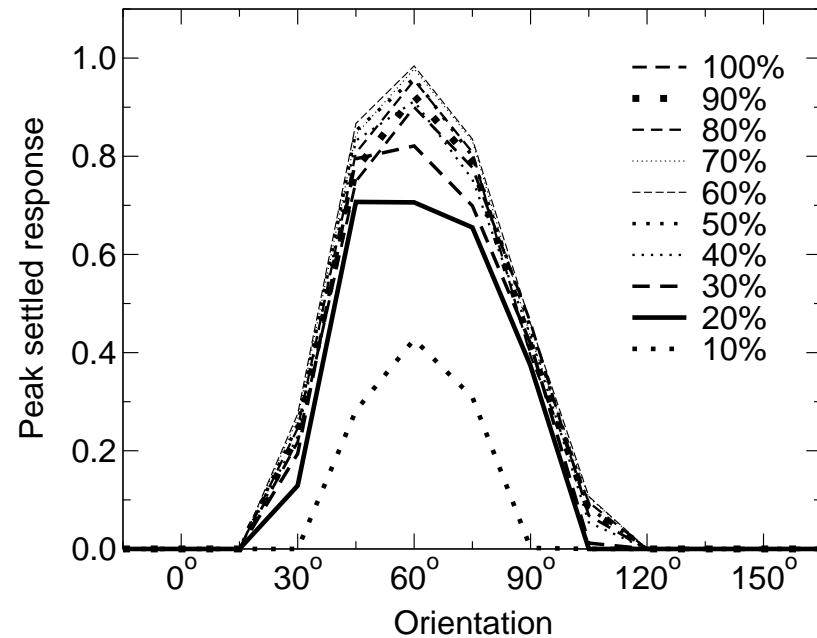
$\gamma_n = 80, \gamma_A = 30$

CMVC figure 8.3

Sine grating tuning curve:

- Without γ_n: selectivity lost as contrast increases

- With γ_n: always orientation-specific

OR Map: Gaussian

Retina LGN RFs LIs White line RFs only

ORpref.&sel. OR H OR FFT

CMVC figure 5.13

OR Map: +/- Gaussian

Retina   LGN   RFs   LIs
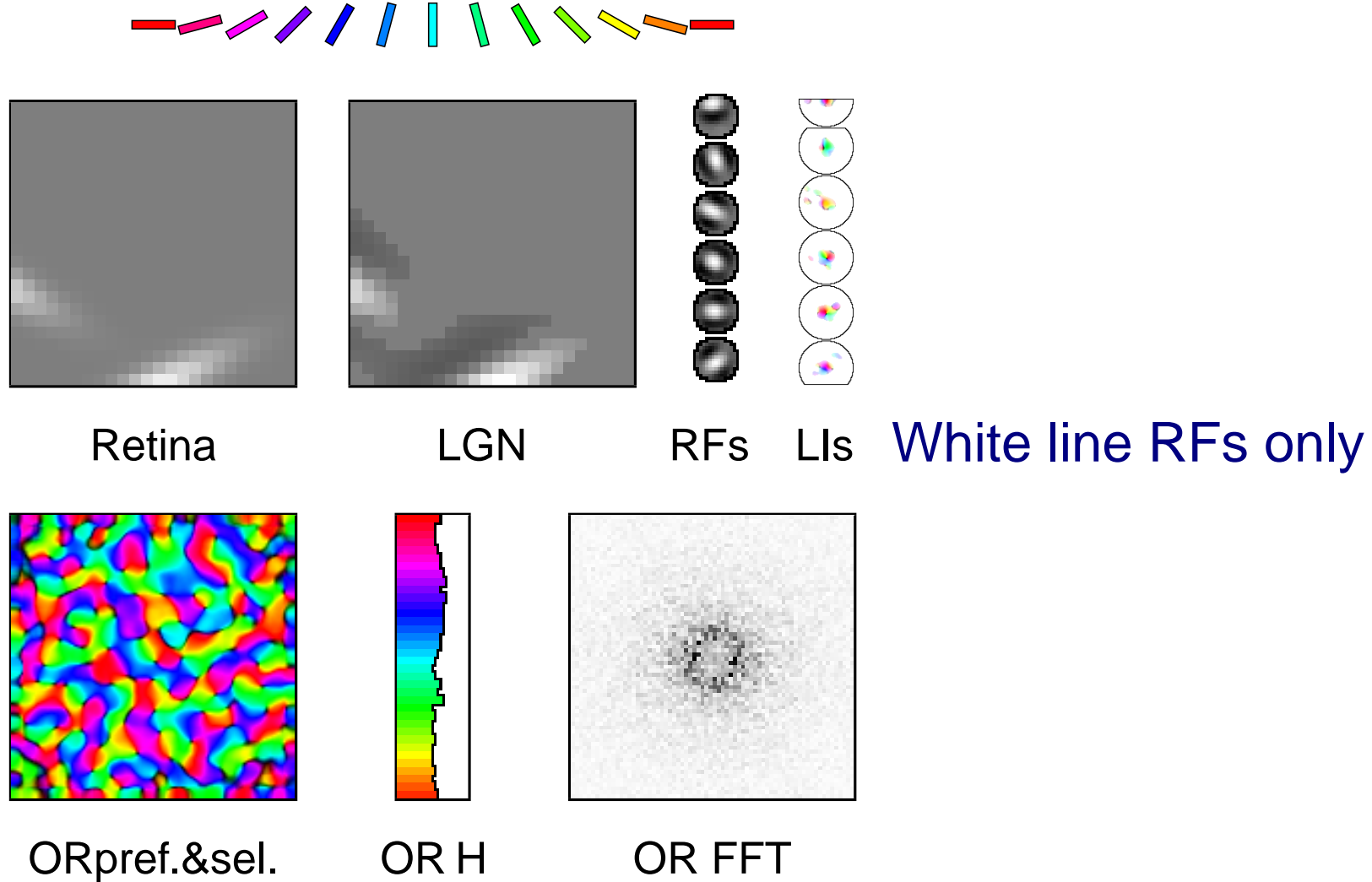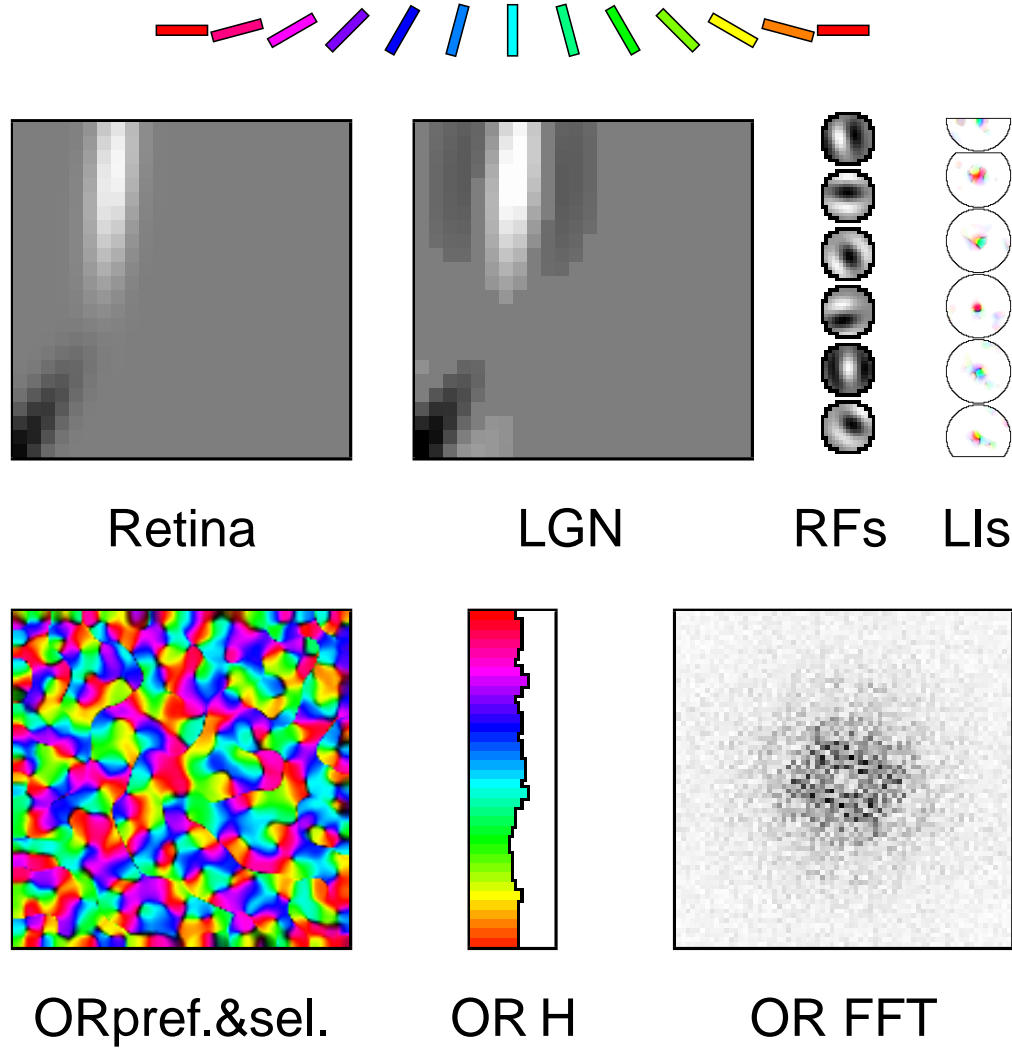
White or black line
RFs

ORpref.&sel.   OR H   OR FFT

OR Map: Retinal wave model

CMVC figure 5.13

Retina   LGN   RFs   LIs

ORpref.&sel.   OR H   OR FFT
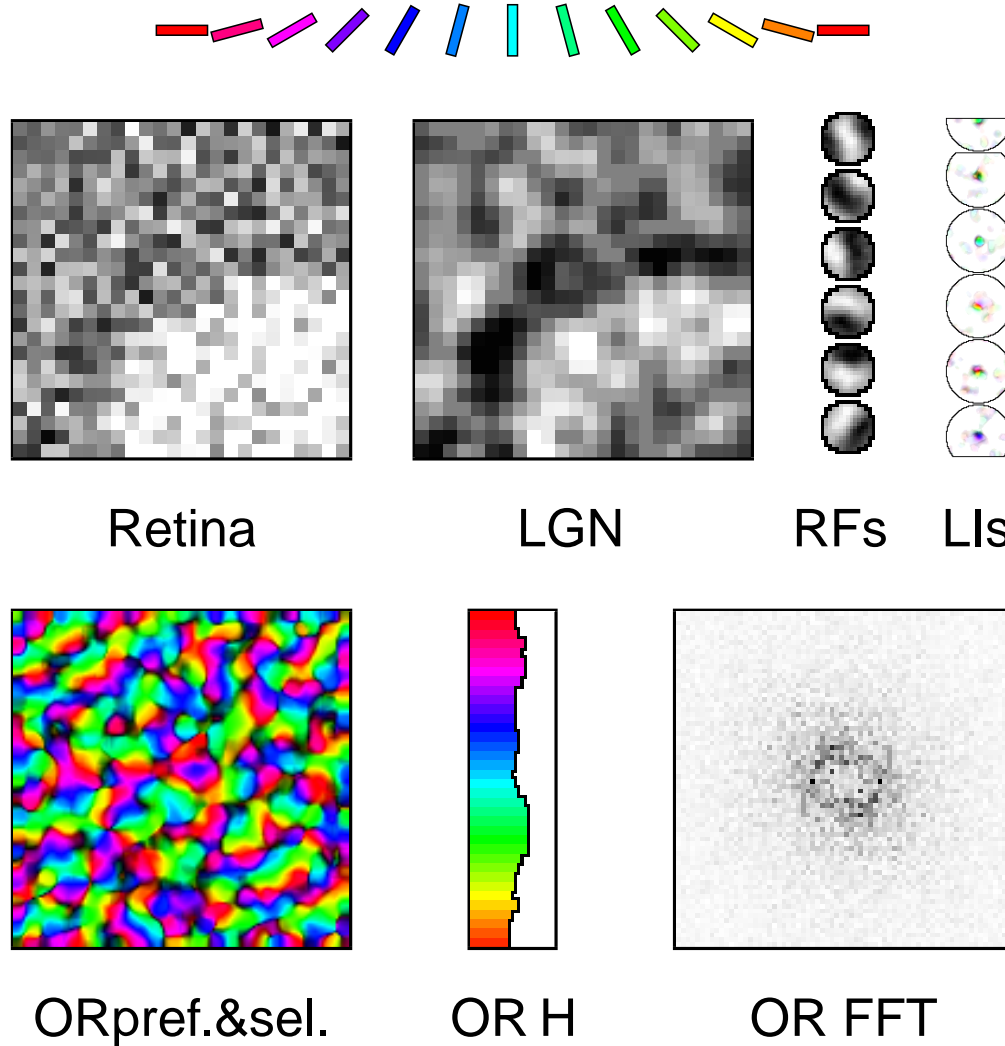
Some line, mostly edge RFs

OR Map: Smooth disks

CMVC figure 5.13
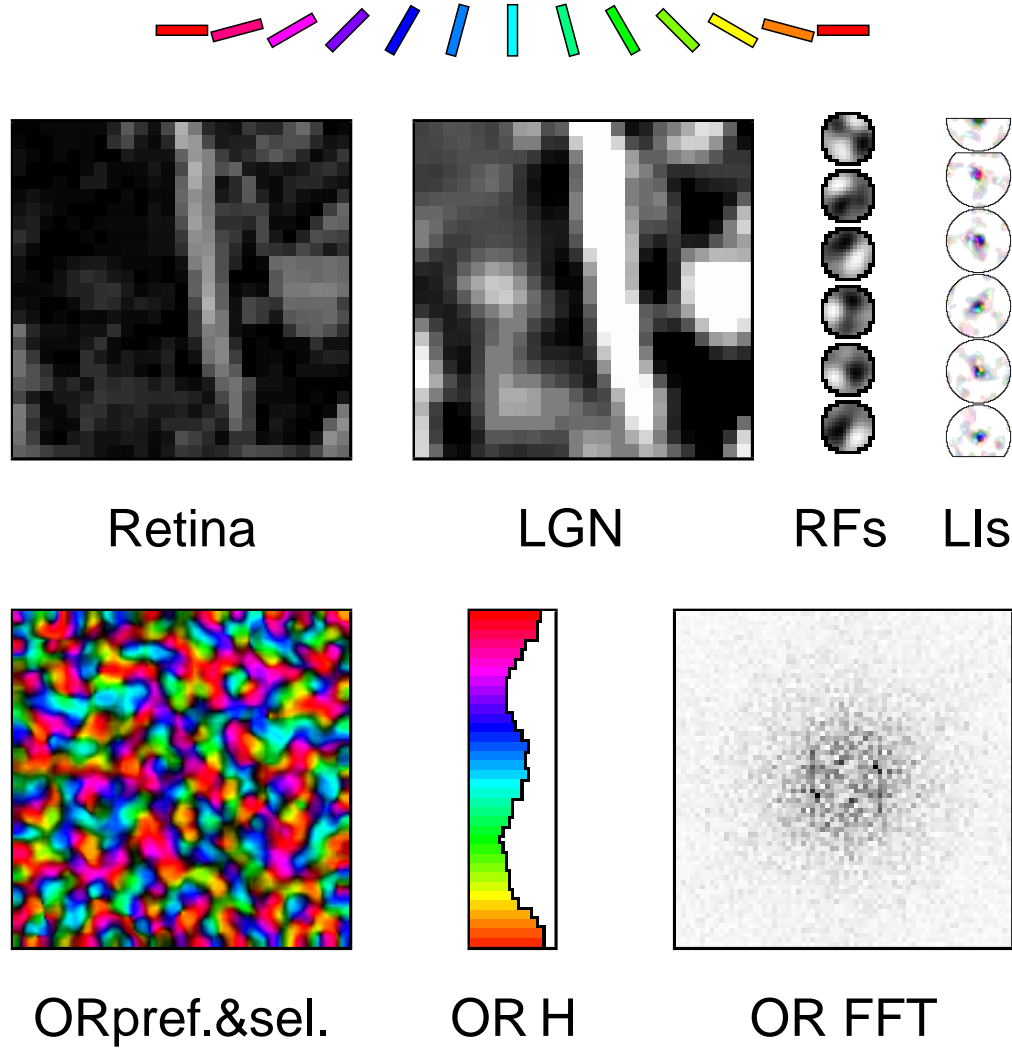
Retina   LGN   RFs   LIs   All edge RFs

ORpref.&sel.   OR H   OR FFT

OR Map: Natural images

OR Map: Uniform noise

Retina   LGN   RFs   LIs

ORpref.&sel.   OR H   OR FFT
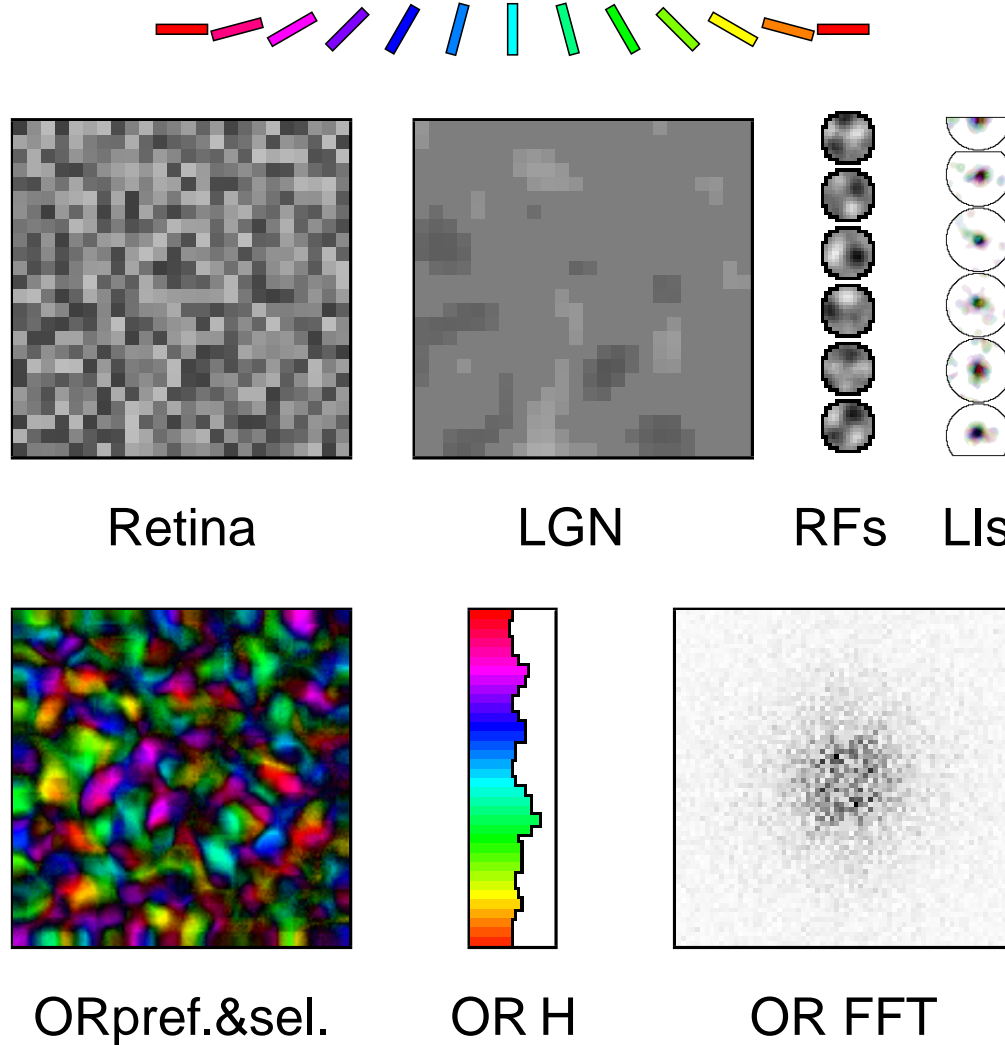
CMVC figure 5.13

Relatively

unselective RFs

Modeling pre/post-natal phases

Input patterns

0   1000   5000   10000
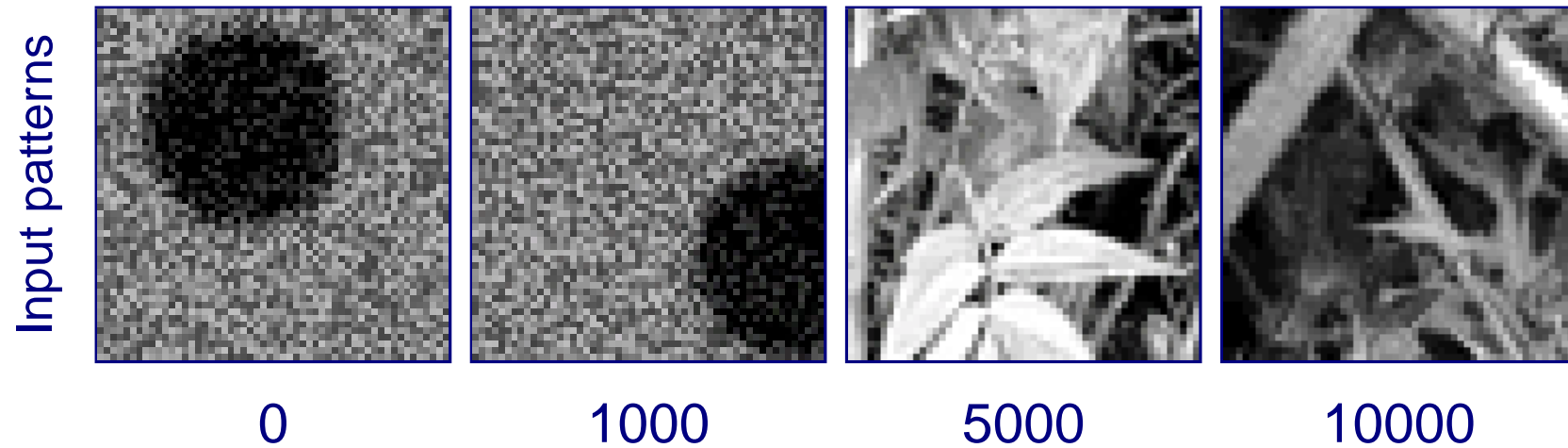
- **Prenatal:** internal activity

- **Postnatal:** natural images (Shouval et al. 1996)

Pre/post-natal V1 development

Input patterns

Orientation maps

0   1000   5000   10000
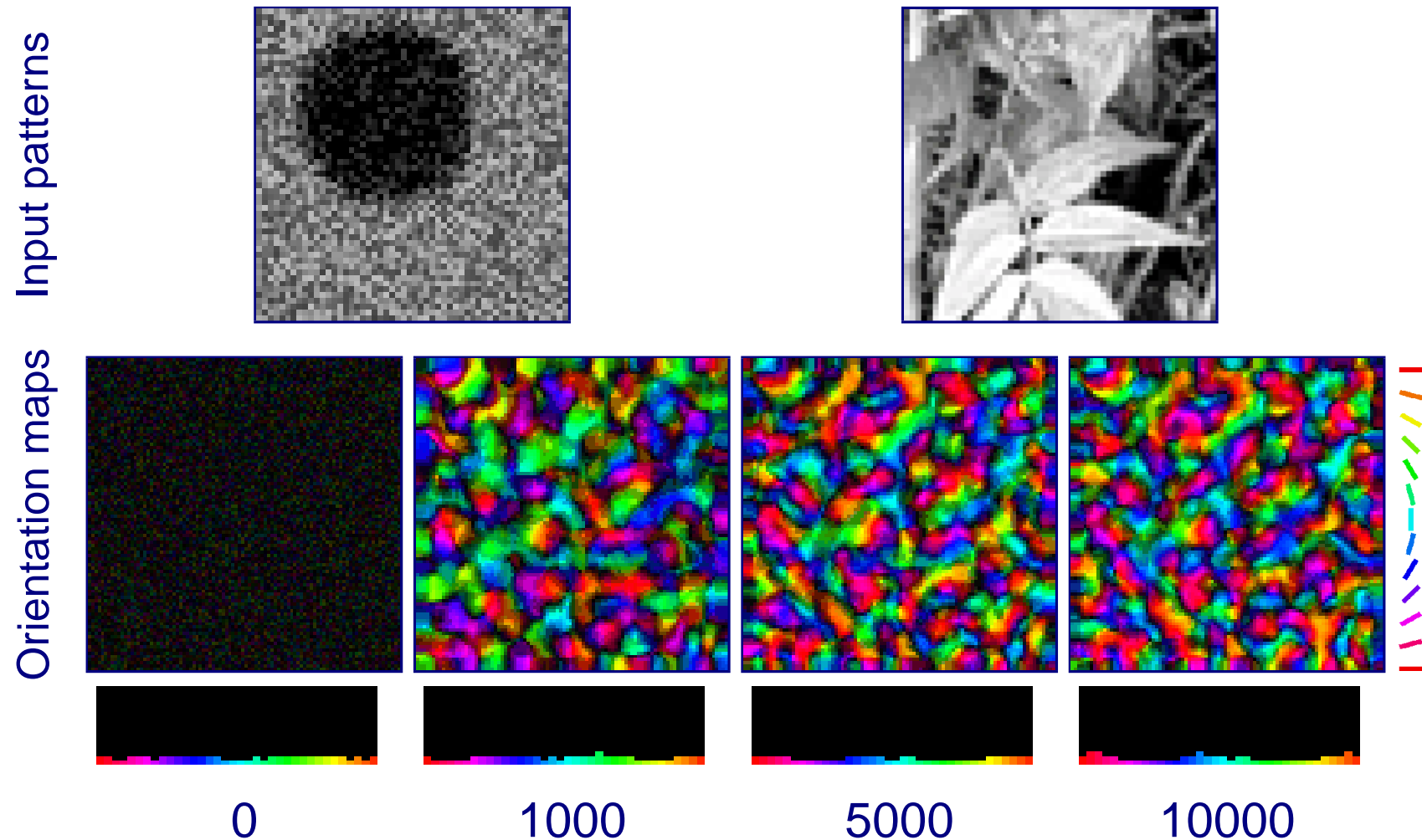
- Neonatal map smoothly becomes more selective

Statistics drive development

Input patterns

Orientation maps

0	1000	5000	10000
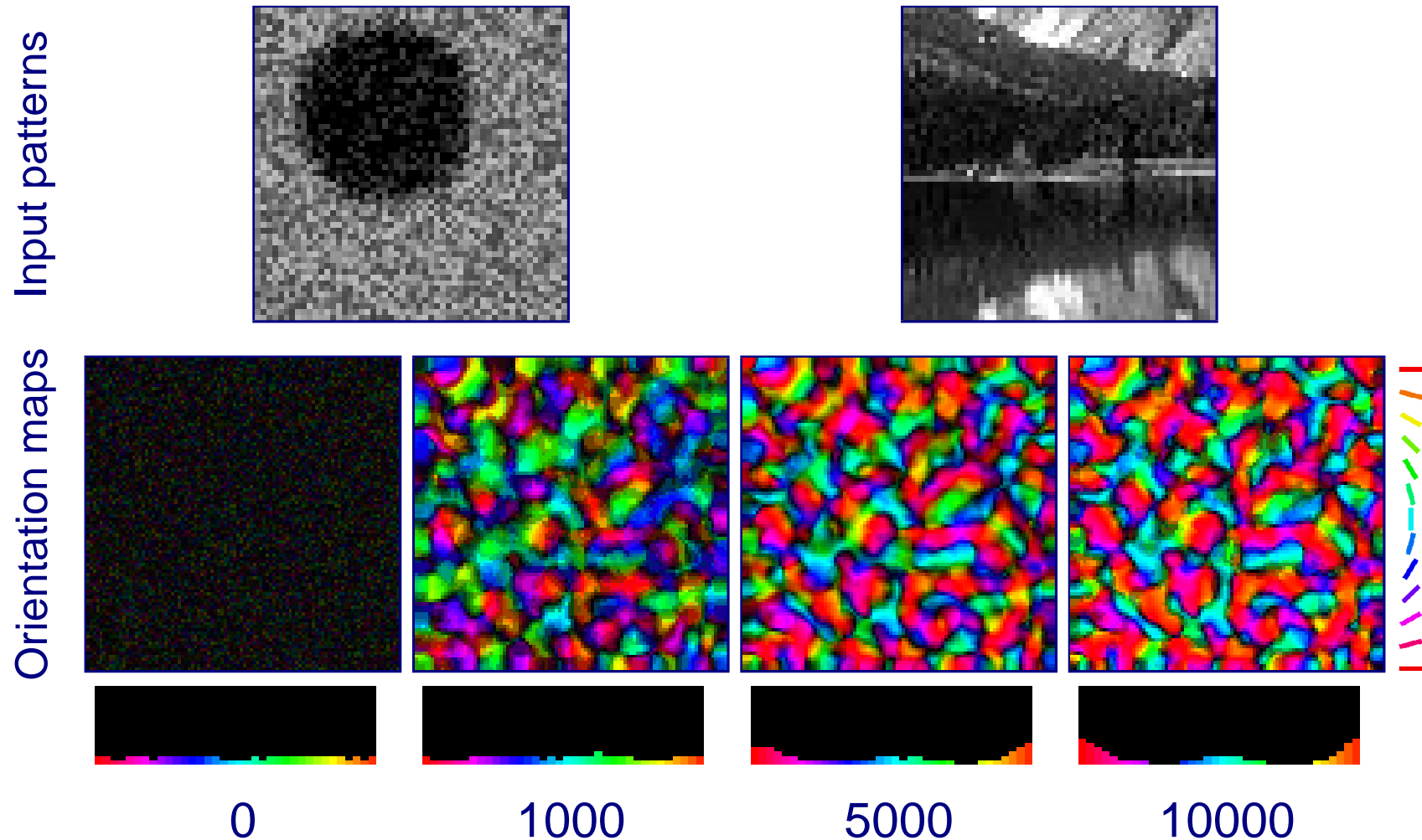
- Biased image dataset: mostly landscapes
- Smoothly changes into horizontal-dominated map

OR Histograms

0°   90°   180°   0°   90°   180°
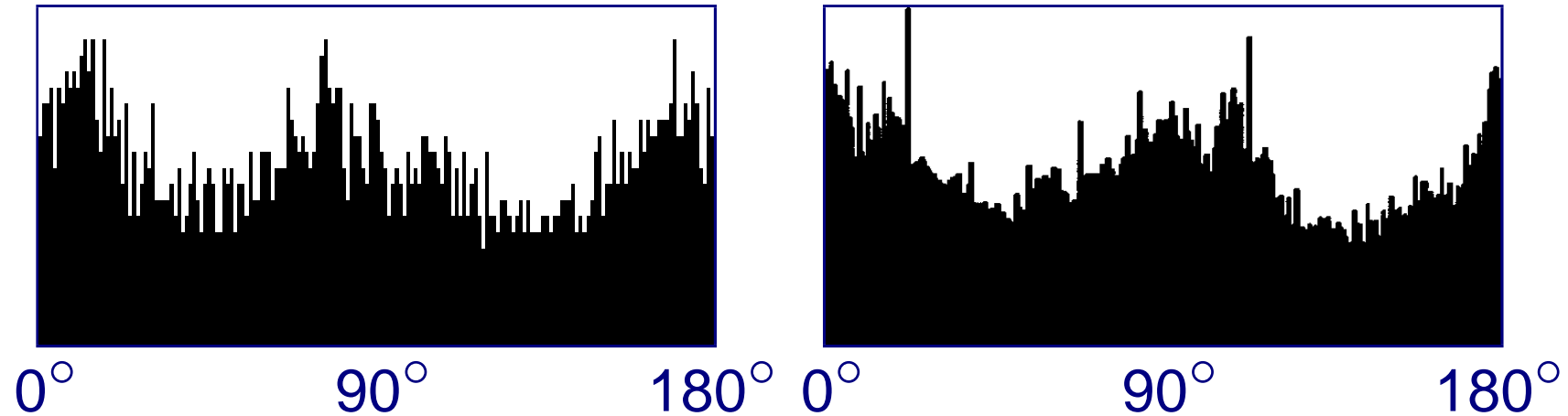
HLISSOM model   Adult ferret V1

(Coppola et al. 1998)

- After postnatal training on Shouval natural images, orientation histogram matches results from ferrets

- Model adapts to statistical structure of images

Summary

- Development depends on the features of the input pattern

- Orientation maps develop with many different input patterns

- Develops Gabor-type RFs with most inputs

- Breaks up image into oriented patches

- Response must be scaled by local contrast to work well for large images

- Matching biology requires prenatal, postnatal phases

References

Coppola, D. M., White, L. E., Fitzpatrick, D., & Purves, D. (1998). Unequal representation of cardinal and oblique contours in ferret visual cortex. *Proceedings of the National Academy of Sciences, USA, 95* (5), 2621–2623.

Miikkulainen, R., Bednar, J. A., Choe, Y., & Sirosh, J. (2005). *Computational Maps in the Visual Cortex*. Berlin: Springer.

Shouval, H. Z., Intrator, N., Law, C. C., & Cooper, L. N. (1996). Effect of binocular cortical misalignment on ocular dominance and orientation selectivity. *Neural Computation, 8* (5), 1021–1040.