LISSOM Orientation Maps

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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

Orientation input and response

(Reminder from last time)

- Response before training similar to retinotopy case
- Response after training has multiple activity blobs per input pattern
- Blobs are orientation-specific
Self-organized V1 weights

Typical:
- Gabor-like afferent CF
- Nearly uniform short-range lateral excitatory
- Patchy, orientation-specific long-range lateral inhibitory

Self-organized weights across V1

Macaque OR map: Fourier, gradient

In monkeys:
- Ring-shaped spectrum: repeats regularly in all directions
- High gradient at fractures, pinwheels.
**OR Map: Fourier, gradient**

- 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

**Effect of initial weights**

- Changing weights doesn’t change map folding pattern.
Effect of input streams

Inputs 1

(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: $R = 96$

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

Original retina
Retina scaled by 2
Retina scaled by 3
Scaling cortical density

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

Above minimum density (due to lateral radii), density not crucial for organization

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
Afferent normalization

Mechanism for contrast invariant tuning:

\[
    s_{ij} = \frac{\gamma_A \left( \sum_{\rho_{ab}} \xi_{\rho_{ab}} A_{\rho_{ab},ij} \right)}{1 + \gamma_n \left( \sum_{\rho_{ab}} \xi_{\rho_{ab}} \right)},
\]

(1)

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

\(A_{\rho_{ab},ij}\) is the corresponding afferent weight

\(\gamma_A, \gamma_n\) are constant scaling factors

LGN response to large image

LGN responds to most of the visible contours
**V1 without afferent normalization**

V1 response:

\[ \gamma_n = 0, \gamma_A = 3.25 \]

Cannot get selective response to all contours

**V1 with afferent normalization**

V1 response:

\[ \gamma_n = 0, \gamma_A = 7.5 \]

Responds based on contour, not contrast

Sine grating tuning curve:

- Without \( \gamma_n \): selectivity lost as contrast increases
- With \( \gamma_n \): always orientation-specific

**Tuning with afferent normalization**

\[ \gamma_n = 0, \gamma_A = 3.25 \]

\[ \gamma_n = 80, \gamma_A = 30 \]

**OR Map: Gaussian**

- ORpref.&sel.
- OR H
- OR FFT
- Retina
- LGN
- RFs
- Ls
- White line RFs only
OR Map: +/- Gaussian

- White or black line
- Some edge RFs

OR Map: Retinal wave model

- Some line, mostly edge RFs

OR Map: Smooth disks

- All edge RFs

OR Map: Natural images

- All types of RFs
- Longer range lateral weights
- Histogram: horizontal, vertical bias
**OR Map: Uniform noise**

- Retina
- LGN
- RFs
- LIs

Relatively unselective RFs

**Pre/post-natal V1 development**

- Input patterns
- Orientation maps

- Neonatal map smoothly becomes more selective

**Modeling pre/post-natal phases**

- Input patterns

- Prenatal: internal activity
- Postnatal: natural images (Shouval et al. 1996)

**Statistics drive development**

- Biased image dataset: mostly landscapes
- Smoothly changes into horizontal-dominated map
OR Histograms

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

