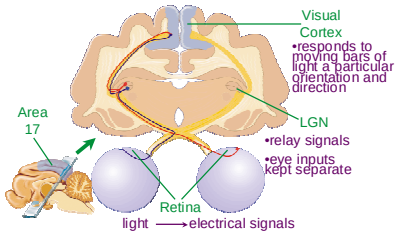
Visual System Development and Organization:
Using Direction and Orientation Maps to Compare Theory and Experiment

Brian Blais
Christian Latino
Bryant College

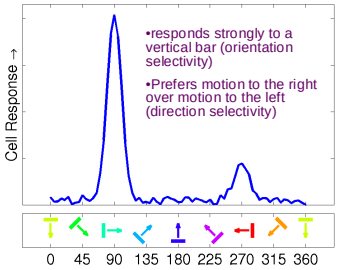
Plasticity
A Synaptic Modification Simulation Environment
web.bryant.edu/~bblais/plasticity

The project described was supported by NIH Grant Number P20 RR16457-01 from the BRIN Program of the National Center for Research Resources.

Visual System

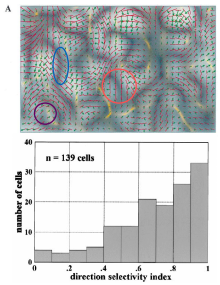


Orientation and Direction Selectivity



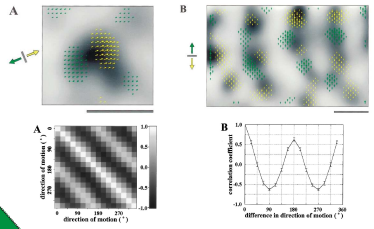
Experimental Measurements

(Shmuel and Grinvald,1996)



- Regions of similar orientation but opposite direction preference
- Line-like regions of low direction selectivity
- Point-like regions of strong changes in orientation near endpoints of low direction selectivity lines
- Approximately 525,000 neurons each with 6000 synapses

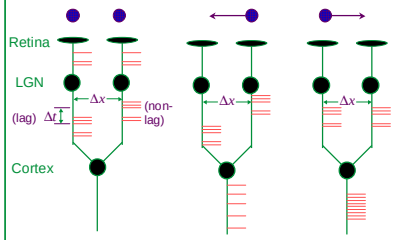
Correlations Between Direction Maps



- Maps of response to direction of motion are correlated with maps of both similar orientation, and opposite direction

How Does Direction Selectivity Arise?

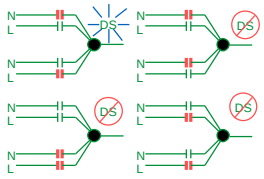
Both Spatial and Temporal Separation Needed for DS



- lagged and non-lagged LGN cells → temporal processing
- "lag" can be:
  - simple delay [not consistent with low-frequency DS]
  - phase delay
  - general temporal filter

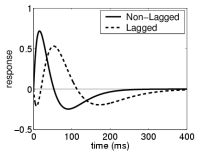
Proper Spatial and Temporal Separation Needed for DS

- Spatial separation of strong synapses from lagged and non-lagged inputs

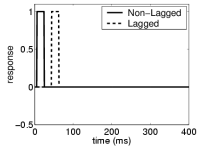


Temporal Properties of LGN Cells

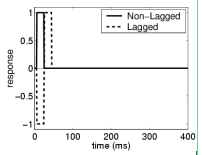
Experimentally Measured



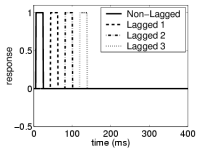
2-channel Time Delay



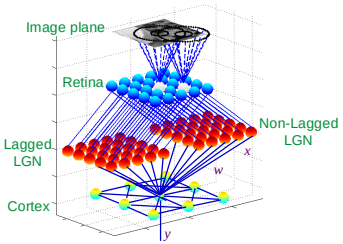
2-channel Phase Delay



4-channel Time Delay



Model

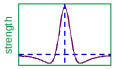


Cell Activity

Feedforward Connectivity $y_k^0 = \sum_j w_{kj} x_j$

Lateral Connectivity $y_i = \sum_k L_{ik} \sigma(y_k^0)$

- Short-range excitation
- Long-range inhibition
- Difference of Gaussians form



Total Activity $y_i = \sigma\left(\sum_j w_{ij} x_j + \sum_k L_{ik} \sigma\left(\sum_l w_{kl} x_l\right)\right)$

Synaptic Modification

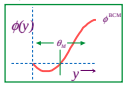
Competitive Hebbian:
(Oja, 1982, MacKay and Miller, 1994)

$\Delta w_{ij} = y_i x_j - y_i^2 w_{ij}$

BCM:
Sliding Threshold
(Bienenstock, et.al., 1982, Law and Cooper 1992)

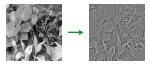
$\Delta w_{ij} = y_i (y_i - \theta_i) x_j$

$\Delta \theta_i = \frac{1}{\tau}(\theta_i - y_i^2)$

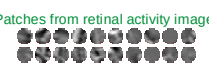


Motion Environment

Image → Retinal activity



- Patches from retinal activity image



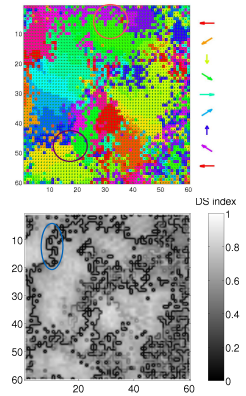
- Patches from noise

drifts and saccades

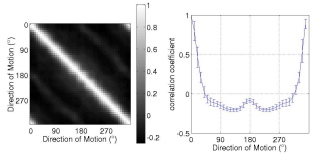
Results

- Regions of similar orientation but opposite direction preference
- Line-like regions of low direction selectivity
- Point-like regions of strong changes in orientation near endpoints of low direction selectivity lines

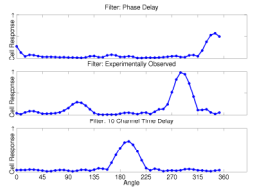
- BCM Learning Rule
- 60x60 Network (3600 Neurons, 338 synapses per neuron)
- Lateral Connectivity: Center 3, Surround 9
- Motion in Environment: 2 pixels per iteration



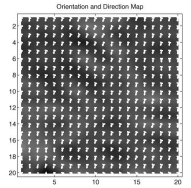
Correlations Between Direction Maps



Temporal Filters



Competitive Hebbian Learning Rule



- Motion down more often than motion up
- All orientations identical → no structure in map

Conclusions

- BCM synaptic learning rule, with a simple motion environment, and some lateral connectivity, can lead to the formation of DS maps
- Competitive Hebbian cannot achieve realistic OR and DS maps
- The temporal filtering seems to have little effect on the development of direction selectivity, but may influence the maps, or other selective properties (e.g. temporal frequency tuning)

To Do

- Better quantification of the comparison between experiment and theory
- Use a more realistic motion environment (natural image movies)
- Explore the differences between learning rules, and the temporal filters