Computation in the Retina

Computational Models of Neural Systems
Lecture 8.1

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Spatiotemporal Ganglion Cell Model

From Meister & Berry, 1999:

\[ A(t) = \delta(t) - h \cdot e^{-t/\tau} \quad \text{temporal response} \]

\[ B(x) = k_c \cdot \exp\left(\frac{-x^2}{2r_c^2}\right) - k_s \cdot \exp\left(\frac{-x^2}{2r_s^2}\right) \quad \text{spatial response (DoG)} \]

\[ R(t) = R_0 + \int \int I(x, t') \cdot B(x) \cdot A(t - t') \, dx \, dt' \]
Response to Moving Bar

(A) Simple ganglion cell model.

(B) Responses of cat ON-type ganglion cell, and model.

(C) Separate pathways for center and surround allows for different response parameters.
Contrast Gain Control

Cat ON-type X cell (jagged) and model response (smooth)
Cat Y Cell Model

- Larger receptive field than X cell.
- Up to 100 nonlinear subunits.
- Burst of spikes at spot onset and offset.
- Poor spatial resolution, but very sensitive to moving textures.
- What are the subunits? RFs are similar to X cells.
Analog Implementation of Neural Circuits

- Pioneered by Carver Mead at Caltech
- VLSI = Very Large Scale Integration
- CMOS = Complementary Metal Oxide Semiconductor
- CMOS is a low power implementation technology for fabricating VLSI chips
Analog vs. Digital VLSI

- Analog: direct analogy between circuit mechanisms and the computation being emulated.
- Digital: symbolic encoding of information and the rules for manipulating it.

Slower than analog, but good for multiplexing.
Early Silicon Retina Models: Mahowald and Mead

- P: photoreceptor
- B: bipolar cell
- ●: horizontal cell

- Horizontal cells are connected to form a hexagonal resistive network, modeling the effect of gap junctions.
Response to Flashing Light Stimulus of Varying Width


- Hexagonal array: each photoreceptor has six neighbors.

- Transient ganglion cells receive input from central photoreceptors and six neighboring sustained ganglion cells.
Pixel Layout

P: photoreceptor
OR: outer retina circuitry
B: bipolar cells
IR: inner retina circuitry
GC: ganglion cells
Outer Retina Model

CO = cone; CT = cone terminal; HC = horizontal cell
Outer Retina Circuit

Phototransistors
Four Ganglion Cell Types

Sustained  Transient
Inner Retina

NA = narrow field amacrine cell
WA = wide field amacrine cell
BC = bipolar cell
OnS = “on” sustained ganglion cell; OnT = transient
Inner Retina Model
Inner Retina Circuit
Distribution of Firing Rates

- Histogram of firing rates for the four types of ganglion cells.
- Spread shows variability in the pixels due to circuit properties and noise.
Response to Sinusoidal Grating

- 3 Hz 50% contrast sinusoidal grating stimulus.

- Four ganglion cell types:
  - on vs. off center
  - sustained vs. transient response
Response to Natural Images

- Top: response of four cell types to a face image.
- Bottom: image reconstructed from the ganglion cell responses.
Spike Generation

CMOS circuit to generate ganglion cell spikes.

Spike rate is a function of input current.
Address Event Representation

- How to get spikes off the chip? Not enough wires.

- Solution: go digital. Each time a cell spikes, put its address on the AER bus.

- Arbitration handles collisions.