Adaptive Coding of Motion in Macaque Visual Cortex

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Adaptation in Sensory Systems - an Example:
Cortical Contrast Gain Control

Ohzawa et al., 1985

[Recording from: V1 simple cell, anaesthetized cat]
“Labeled-line” models based fixed tuning curves

Are fixed tuning curves an appropriate representation of the motion sensitivity of direction selective cells under more variable stimulus conditions?
Direction Selective Cells in Visual Cortex

Motion pathway:
- V5
- V1
- LGN
- Retina

Temporal frequency

Spatial frequency

Preferred

Antipreferred

Velocity = TF / SF

Intensity

Time (ms)
Binary Random Motion Stimulus

[ All data recorded from DS cells in anaesthetized macaques ]

Displacement $\Delta$, every 10ms
8 octaves; max. $\frac{1}{4}$ cycle (25 Hz)
“Equivalent Temporal Frequency” (ETF)

Faster speed (larger $\Delta$)

Slower speed (smaller $\Delta$)
Input-Output Relationship

Estimated separately for each stimulus condition (ETF)
Provides a good fit of the data
Gain & Range Changes Across the Population

**Response range**

![Graph showing response range and gain changes across the population for different ETF values.](image)

**Gain**

-Slope (relative)

-Scale: 0.1 to 100

ETF (Hz): 0.1 to 10

-V5 and V1 lines represent different ranges of response and gain changes.
Constant “relative sensitivity”

Example cell 1

Example cell 2
Motion gain changes rapidly

There is also a slow component – but it is very weak in comparison
Gain control in models of motion detection

Motion Energy Model with conductance based LIF spike generation...

...explains only a portion of the change in gain

...see also: Borst et al. (2005)
Tuning curves revisited...
Summary & Conclusions

• A random motion stimulus suggests that motion encoding by DS cells is highly context dependent (here: variance)
  – Change in temporal integration (Bair & Movshon, 2004)
  – Change in gain (IO relationship)

⇒ Direction selective cells seem to be poorly characterized by a single input-response (tuning) curve

• Potentially functionally beneficial
  – Allows to encode stimulus values efficiently over a broad range
  – High gain compensates for weak signal (slow stimulus)

• But what about the resulting ambiguity?
  – Seems to be hard to reconcile with the idea of labeled-line models
Summary & Conclusions (contd.)

• Results are surprisingly consistent with studies in other species and other sensory modalities
  
  
  
  See also Ringach & Malone (2007) for related results

• BUT:
  
  – the effect is very different from classical adaptive phenomena (e.g. cortical contrast gain control)
  
  – Perhaps better described as an “adaptive nonlinearity”

• And of course:
  
  - The linear-nonlinear model is still a very limited description of the cells’ response properties

• Open questions:
  
  – Underlying mechanism(s)?
  
  – How would such a representation be read out?