Filtering and normalization in the visual system (and in a few other systems)

Matteo Carandini
UCL Institute of Ophthalmology
circuits how is it computed?

computations what is computed?

behavior why is it computed?

neuronal population activity

A model of the ganglion cell receptive field

ON-center receptive field

“Difference of gaussians” model
Predictions of the “difference of gaussians” model

Enroth-Cugell and Robson (1984)
Fitting the model to the data

Enroth-Cugell et al. (1983)
Responses are weighted sums: linear filtering

\[ R_{i,j} = \sum_{u,v} F_{u,v} I_{i+u,j+v} \]
Center-surround receptive fields enhance edges
Receptive field explains LGN responses to gratings
Tarzan
Predictions based on the receptive field

Mante, Bonin & Carandini (2007)
See also: Dan, Atick & Reid, J Neurosci, 1996
Dowling, 1987 (Fig 1.2)
Selectivity for stimulus orientation and direction

Receptive field of a simple cell

Schematic of the receptive field

Responses to white dots - responses to black dots

DeAngelis, Ohzawa & Freeman (1995)
Dependence of responses on orientation
Dependence of responses on spatial frequency
Selectivity in V1 is extremely sharp
Receptive field predicts spatial selectivity

DeAngelis, Ohzawa & Freeman, 1995

Albrecht (1978); Movshon, Thompson & Tolhurst (1978)
V1 receptive fields enhance oriented edges
receptive fields in space-time
Stimuli and receptive fields in space-time

[Diagrams showing space-time relationships]
V1 simple cell, separable
V1 simple cell, inseparable

Ohzawa, DeAngelis & Freeman, 1996
Space-time receptive fields

DeAngelis, Ohzawa & Freeman, 1995
Receptive field in somatosensory cortex

DiCarlo, Johnson & Hsiao (1998)
A linear model predicts responses
Unrolling the cochlea

Characteristic frequency (kHz)
Receptive fields in frequency space
Measuring a spectro-temporal receptive field
Spectro-temporal receptive field in auditory nerve

Kim & Young (1994)
Spectro-temporal receptive field in auditory cortex

deCharms, Blake & Merzenich (1998)
Responses to noise in auditory nerve

Linear model predictions are good. But only if characteristic frequency is low.

de Boer & de Jongh (1978)
Light adaptation in photoreceptors

Norman & Perlmann (1979)
Cross-orientation suppression

Freeman, Durand, Kiper & Carandini (2002)
Nonlinearities in V1 responses

\[ R = \frac{Lc}{C_{50} + C_{local}} \]

Albrecht & Geisler (1991)
Heeger (1991)
Surround suppression

Blakemore & Tobin (1972)

Cavanaugh, Blair & Movshon (1997)
A possible role for normalization
Three orientations in one location
Contours with different orientations overlap often

Conditional probability

Output of

Output of

Simoncelli and Schwartz, 1997
Normalization enhances V1 neuron independence

Conditional probability

Output of