Computational theory of the velocity selectivity in MT neurons

Space-time receptive field

Constructing space-time RF
Complex cells: motion energy

Motion energy & position invariance

Moving stimulus as seen by both subunits at two different moments in time:

Motion energy responses to moving grating
The “aperture problem”

These three motions are different but look the same when viewed through a small aperture (i.e., that of a direction-selective receptive field).

Intersection of constraints

With two different motion components within the aperture, there is a unique solution:

Component vs. pattern motion (perception)

strong pattern-motion percept

weak pattern-motion percept
**Component vs. pattern motion (perception)**

\[ \text{strong pattern-motion percept} = \text{component-motion} + \text{pattern-motion} \]

\[ \text{weak pattern-motion percept} = \text{component-motion} + \text{pattern-motion} \]

**Component vs. pattern motion selectivity**

- **Component-motion cell**
  - Grating component moving up-right \(\Rightarrow\) strong response

- **Pattern-motion cell**
  - Pattern moving up-right \(\Rightarrow\) strong response

**Component vs. pattern motion: single neurons**

Movshon et al., 1983

\[
\begin{align*}
\text{Movshon et al., 1983} & \quad \text{Model} \\
A & = C \\
B & = D \\
E & = G \\
F & = H
\end{align*}
\]

Gratings Plaids Gratings Plaids
Component vs. pattern motion: fMRI adaptation

Pattern motion selectivity across visual areas

Pattern motion selectivity across visual areas

V1 receptive fields  MT receptive field
Intersection of constraints (two components)

Each component activates a different V1 neuron, selective for a different orientation and speed.

Intersection of constraints (many components)

Each component activates a different V1 neuron, selective for a different orientation and speed.

How do you get selectivity for the moving pattern as a whole, not the individual components?

Neural implementation of IOC

Answer: For each possible 2D velocity, add up the responses of those V1 neurons whose preferred orientation and speed is consistent with that 2D velocity.
Pattern motion selectivity theory

Distributed representation of 2D velocity

Testing the theory

Brightness at each location represents the firing rate of a single MT neuron with a different preferred velocity. Location of peak corresponds to perceived velocity.
**Pattern cell**

Kuman & Uka (2013)

**Component cell**

Kumano & Uka (2013)

**Motion summary**

- Functional specialization and computational theory (two balancing principles in the field).
- Defining visual cortical areas (physiology, architecture, connections, topography).
- Parallel pathways: hierarchy of processing with increasingly complex selectivity, increasing invariance, and increasing RF size.
- Canonical computation (linear sum, threshold or sigmoid nonlinearity, normalization, adaptation).
What distinguishes neural activity that underlies conscious visual appearance?

- Neural activity in certain brain areas.
- Activity of specific subtypes of neurons.
- Particular temporal patterns of neural activity (e.g., oscillations).
- Synchronous activity across groups of neurons in different brain areas.
- Neural activity that is driven by a coherent combination of bottom-up sensory information and top-down recurrent processing (e.g., linked to attention).
- Nothing. Once you know the computations, you're done!

A computational theory of color appearance

A computational theory of motion appearance