Introduction of a Biologically Plausible Color Descriptor to a Neurodynamical Model of the Primary Visual Cortex

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Master Thesis Defense
September 2014

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how can color
be represented
as **data**?

how does the **brain** represent color?

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how can color be represented as **data**?

how does the brain **process** color?

how does the **brain** represent color?

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how can color be represented as **data**?

…at a very **early** stage of visual processing.

how does the brain **process** color?

Overview

- What is color?
- Color in biology
- Color descriptor(s)
- Neurodynamical model
- Results
- Conclusions
- Discussion

Color.

Color
Does Not
Exist*

*physically

Light has wavelength.

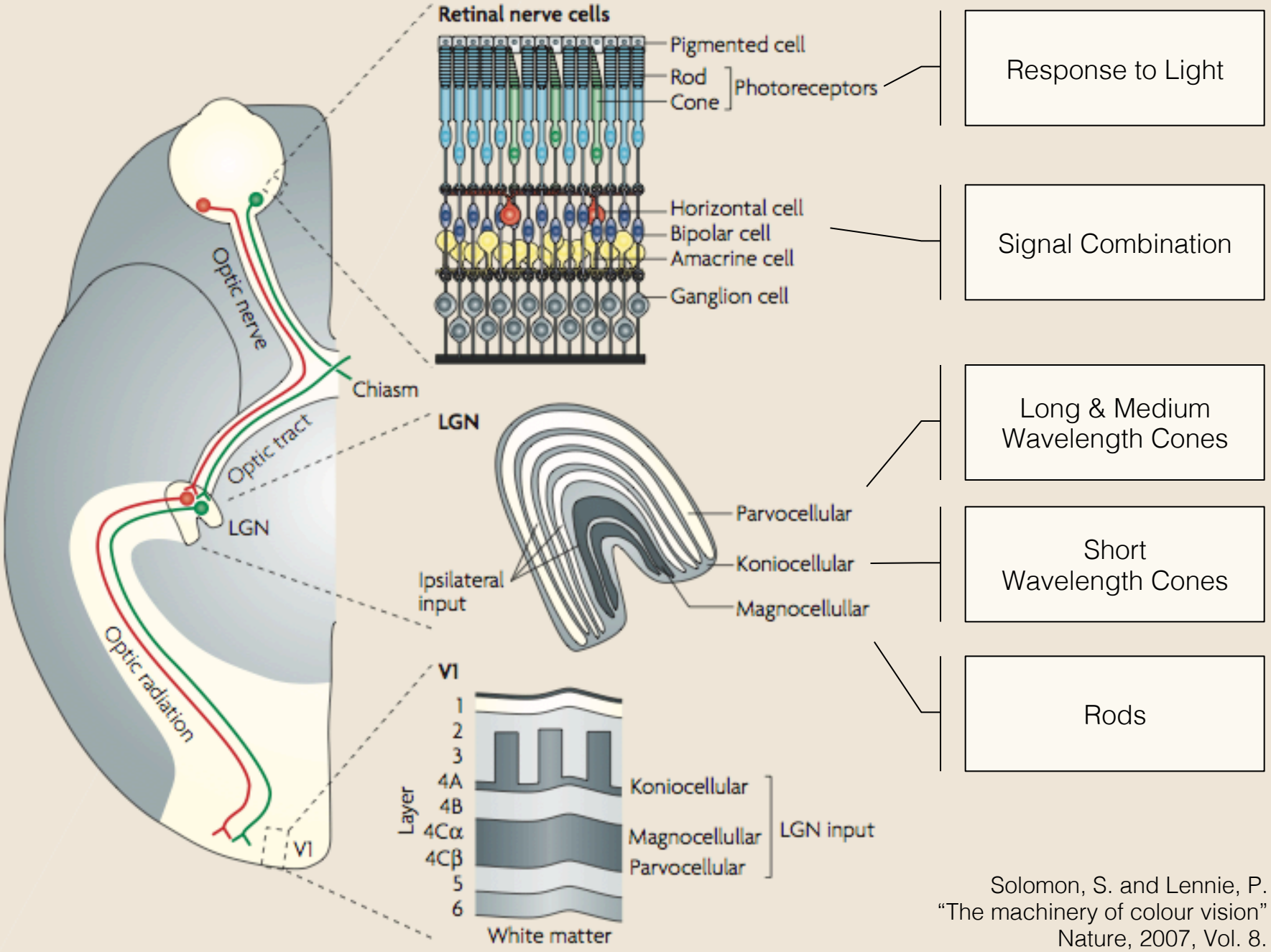
Light sources have spectral power distributions.

Objects have spectral reflectance properties.

Organisms perceive color.

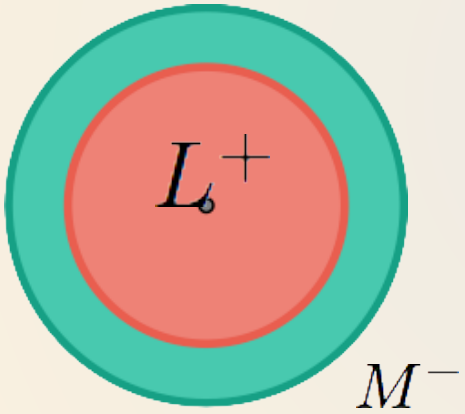
The perceived color of an object
is defined by the **illuminant**,
the object's **physical properties**,
and its **context**

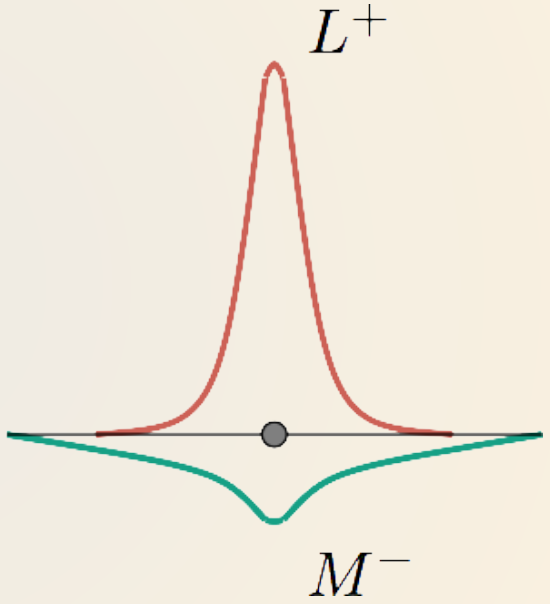
. . . let's see how.



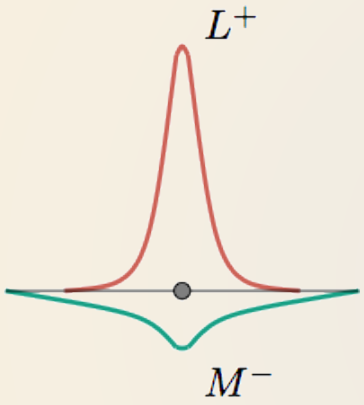
Solomon, S. and Lennie, P.
"The machinery of colour vision"
Nature, 2007, Vol. 8.

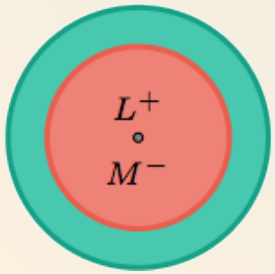
Receptive Fields



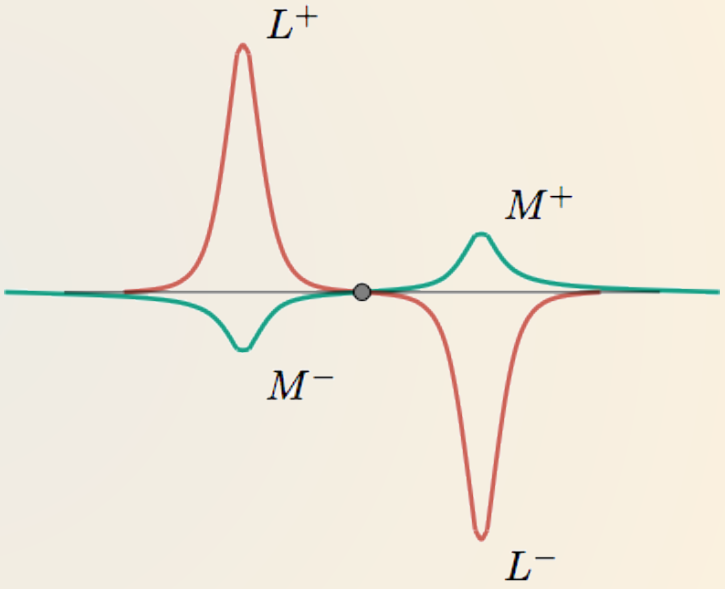


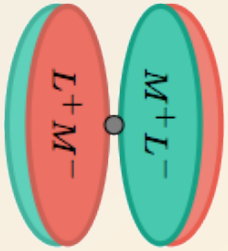
Single-Opponent Neurons





Double-Opponent Neurons





Single-Opponent & Double-Opponent

Stimulus Response Patterns

Single-Opponent & Double-Opponent Characteristics

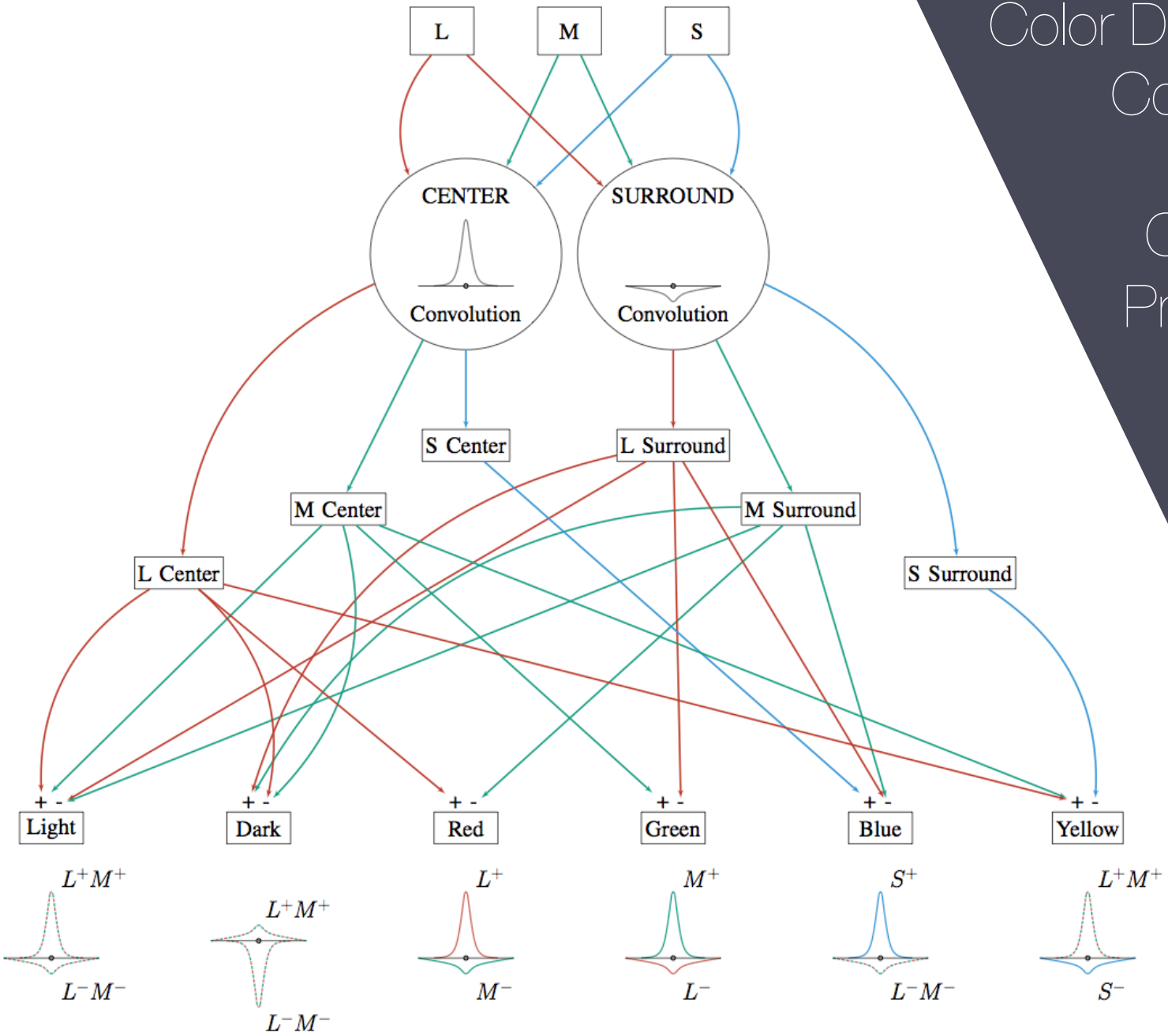
	Single-Opponent Cells	Double-Opponent Cells
Cone Opponency:	Yes	Yes
Spatial Opponency:	**No**	Yes
Achromatic Selectivity:	Yes	Yes
Chromatic Selectivity:	Yes	Yes
Orientation Selectivity:	**No***	Yes
Spatial Frequency Selectivity:	Yes	Yes

Single-opponent neurons respond best to regions of color.

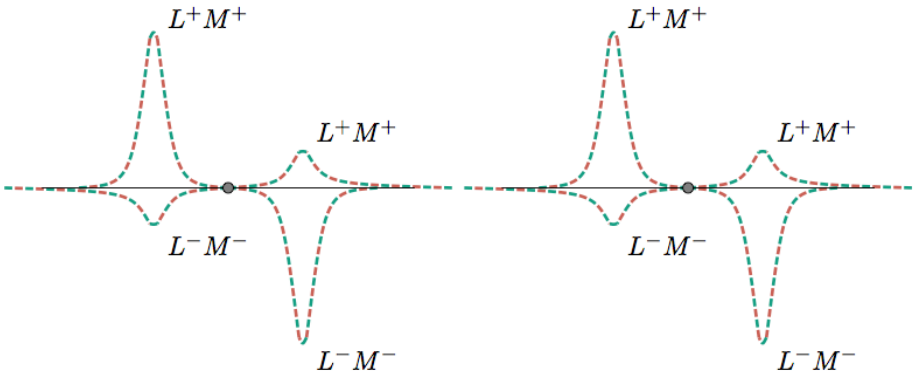
Double-opponent neurons respond best to the boundaries between.

Opponent processing
of single and double-opponent receptive fields
will describe color, in it's context,
in a biologically plausible manner.

Color Descriptor: Convolution & Opponent Processing

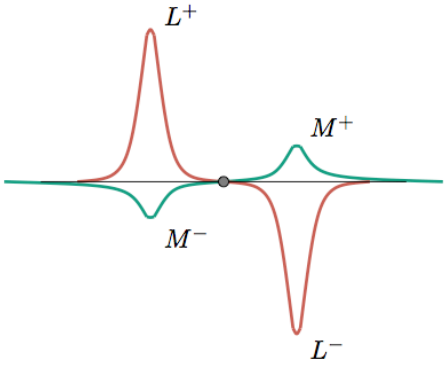


Double-opponent receptive fields modeled with off-center Gaussians.

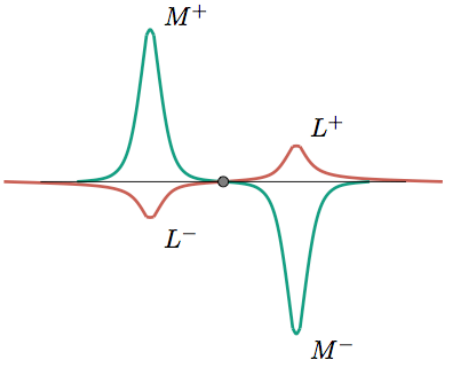


(a) Light DO Receptive Field

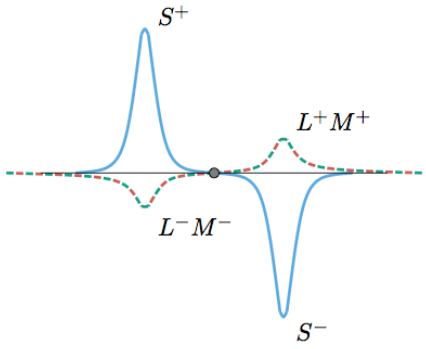
(b) Dark DO Receptive Field



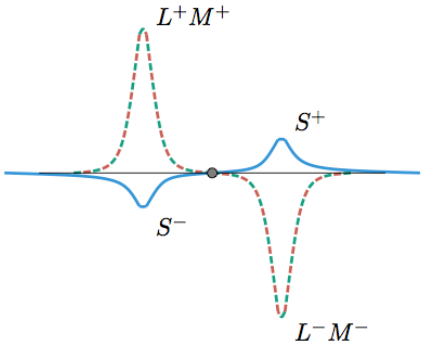
(c) Red DO Receptive Field



(d) Green DO Receptive Field



(e) Blue DO Receptive Field



(f) Yellow DO Receptive Field

Opponent color processing…

$$Light(c,s,\sigma) = max(0, \frac{L(c,\sigma)+M(c,\sigma)}{2} - \frac{L(s,\sigma)+M(s,\sigma)}{2} - 0.5)$$
$$Dark(c,s,\sigma) = max(0, \frac{L(s,\sigma)+M(s,\sigma)}{2} - \frac{L(c,\sigma)+M(c,\sigma)}{2} + 0.5)$$
$$Red(c,s,\sigma) = max(0, L(c,\sigma) - M(s,\sigma))$$
$$Green(c,s,\sigma) = max(0, M(c,\sigma) - L(s,\sigma))$$
$$Blue(c,s,\sigma) = max(0, S(c,\sigma) - \frac{L(s,\sigma)+M(s,\sigma)}{2})$$
$$Yellow(c,s,\sigma) = max(0, \frac{L(c,\sigma)+M(c,\sigma)}{2} - S(s,\sigma))$$

Neurodynamical Model

Penacchio *et al.* 2013
(based on work by Z Li 1998)

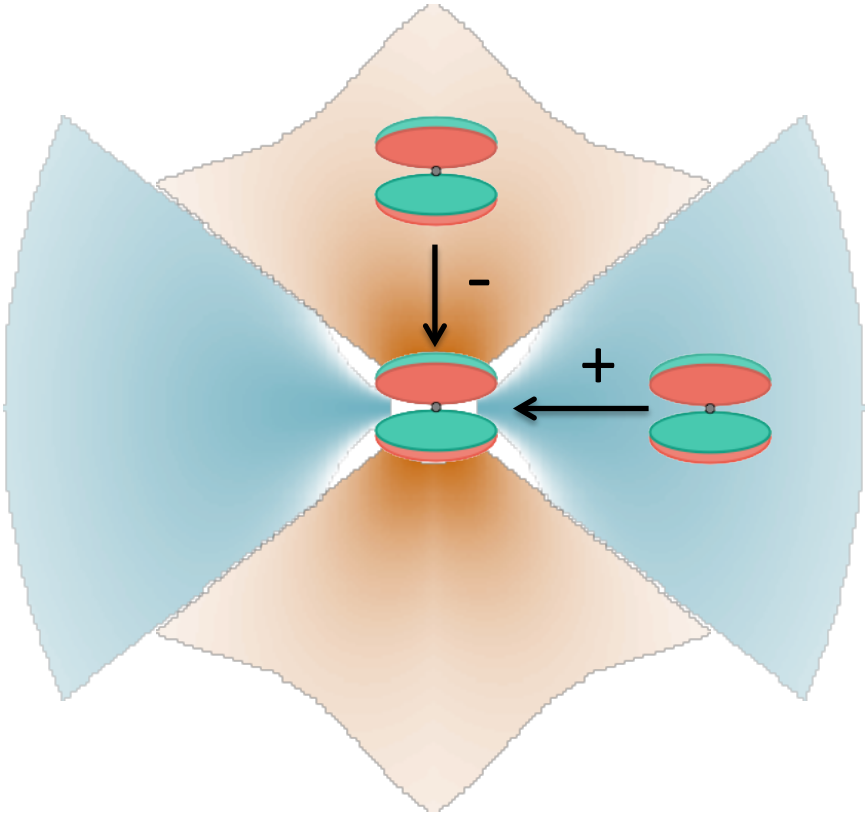
Model of the
dynamic interactions
between neurons
over time.

Neurodynamical Model

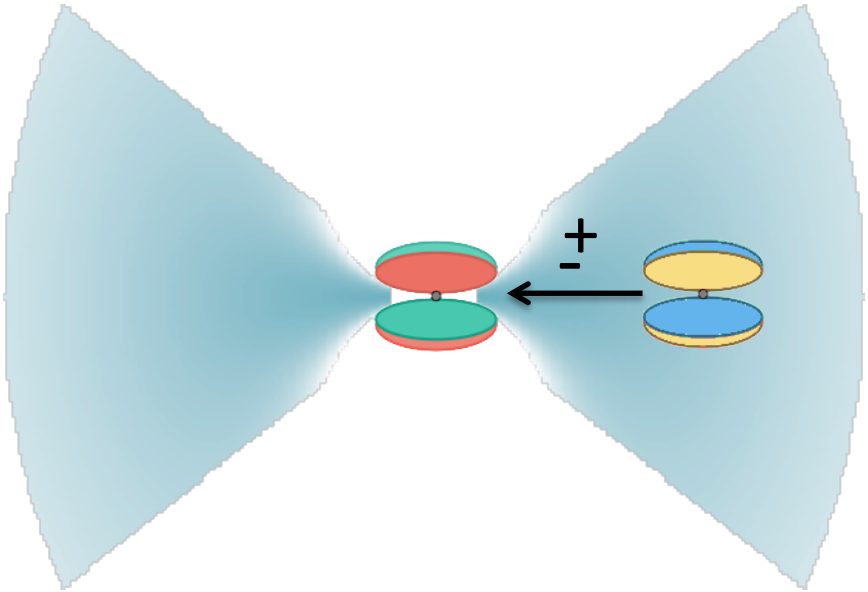
Penacchio *et al.* 2013
(based on work by Z Li 1998)

..of a 5-dimensional matrix:
positions x & y, decomposed
Into 6 color channels
at s scales
and 4 orientations.

Receptive fields specific to cells' orientation selectivities.



Receptive fields specific to cells' (a)chromatic selectivities.



Receptive fields specific to cells' (a)chromatic selectivities.

to \ from	Light	Dark	Red	Green	Blue	Yellow
Light	+	-	+	+	+	+
Dark	-	+	+	+	+	+
Red	+	+	+	-	+	+
Green	+	+	-	+	+	+
Blue	+	+	+	+	+	-
Yellow	+	+	+	+	-	+

Results.

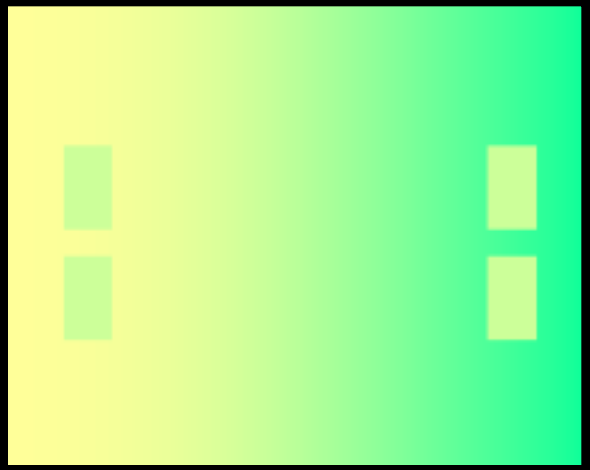
Input images were scaled to ~150px wide.

3 scales (spatial frequencies) were used.

Each experiment was run for 20 time steps,
with 10 iterations of neural interaction at each step.

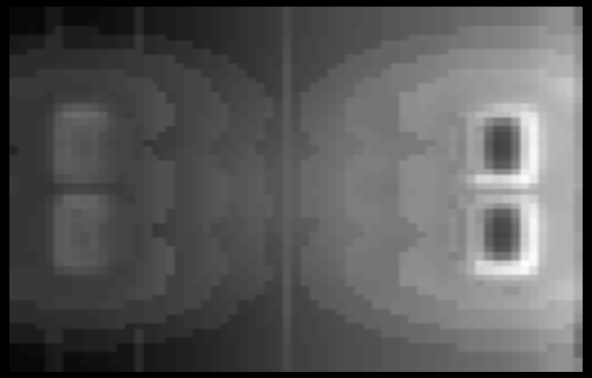
We averaged neural activity at each time step.

Subtracted opponent color channels from each other.

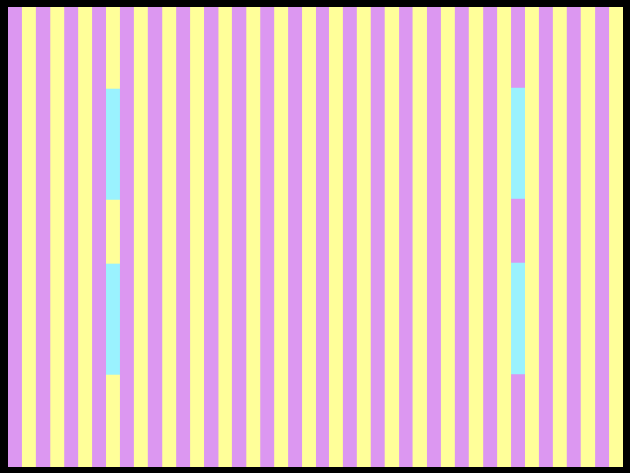


Light^{+}
Dark^{-}

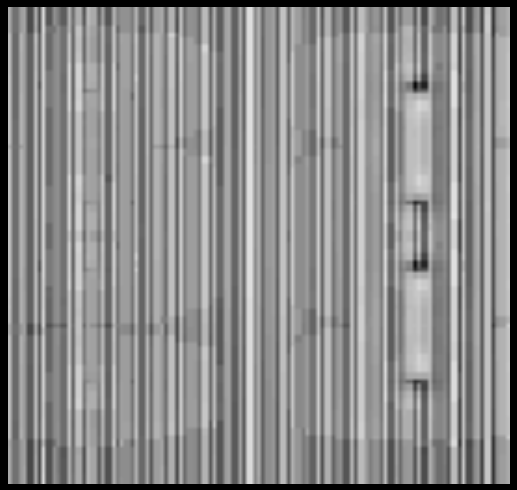
Red^{+}
Green^{-}



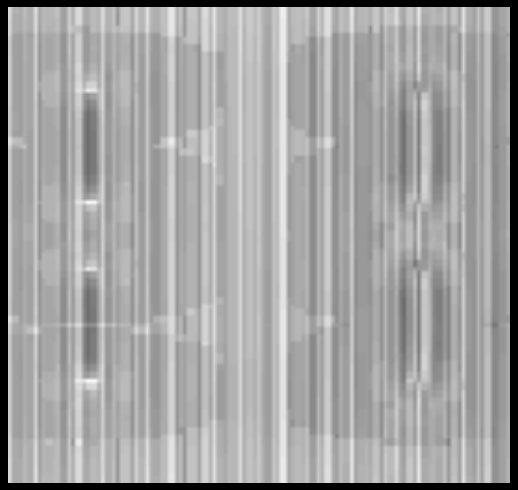
Blue^{+}
Yellow^{-}



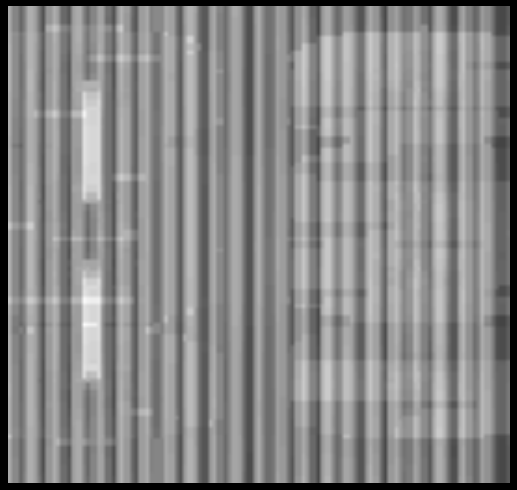
Light^{+}
Dark^{-}



Red^{+}
Green^{-}



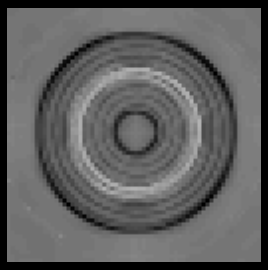
Blue^{+}
Yellow^{-}

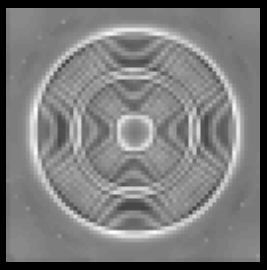


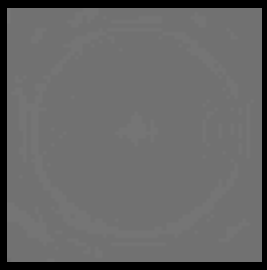
Blue^{+}
Yellow^{-}

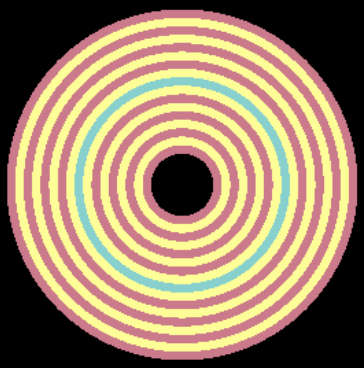
Red^{+}
Green^{-}

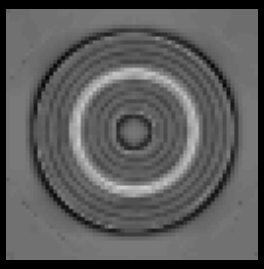
Light^{+}
Dark^{-}

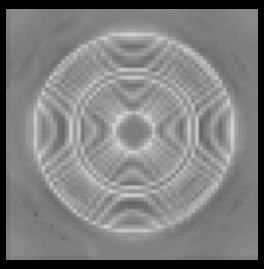


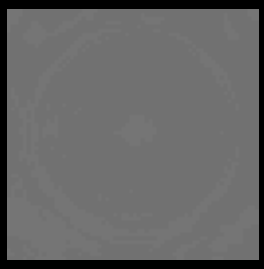


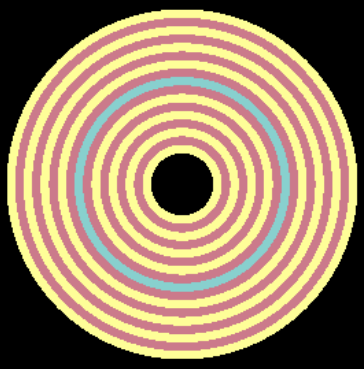








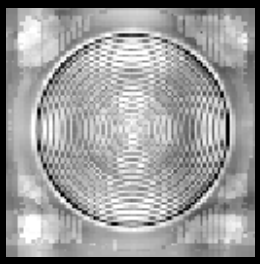


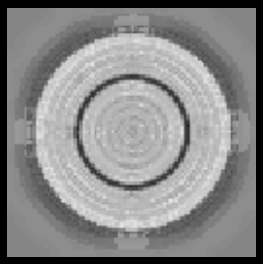


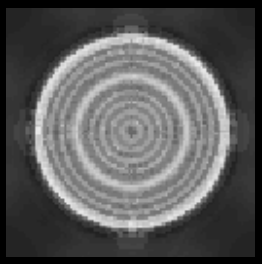
Blue^{+}
Yellow^{-}

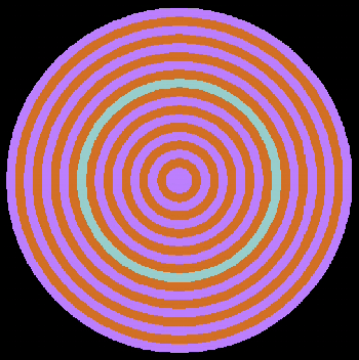
Red^{+}
Green^{-}

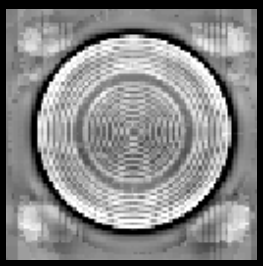
Light^{+}
Dark^{-}

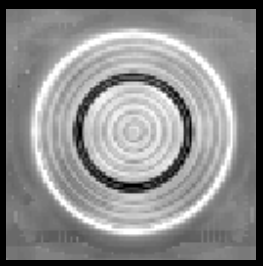


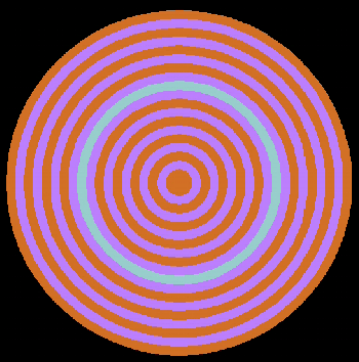












Conclusions

- Color Description
  - ✓ Biologically plausible representation of color in V1.
  - – Better understanding of light & dark receptive fields needed.
  - – Tweaking of receptive field dimensions suggested.

- Neurodynamical Model
  - ✓ Biologically plausible model of feature processing in V1.
  - – Analysis of inter-color connections/weights needed.

- Way forward..

  Systematic analysis of behavior:

  1. Analysis of evolution of neurodynamical model.
  2. Analysis of effects of parameters.
  3. Comparison with psychophysical metrics.

Discussion