Trichromatic reconstruction from the interleaved cone mosaic: Bayesian model and the color appearance of small spots

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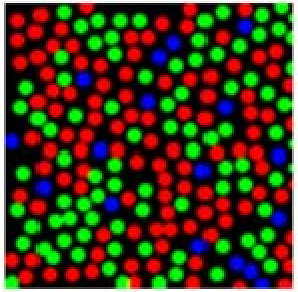
The Problem at Hand

Human colour vision is mediated by **3 classes of retinal cones**: L, M and S



At each cone location the isomerisation rate of a **single cone class** is available

The visual system needs to **reconstruct the isomerisation of the two missing cone classes** at each location to represent the trichromatic signal

Aim of the work

1. Proposing a Bayesian model to **reconstruct the trichromatic signal** at each cone location

2. Evaluating the model predictions with respect to data obtained through a **psychophysical experiment**

The Psychophysical Experiment

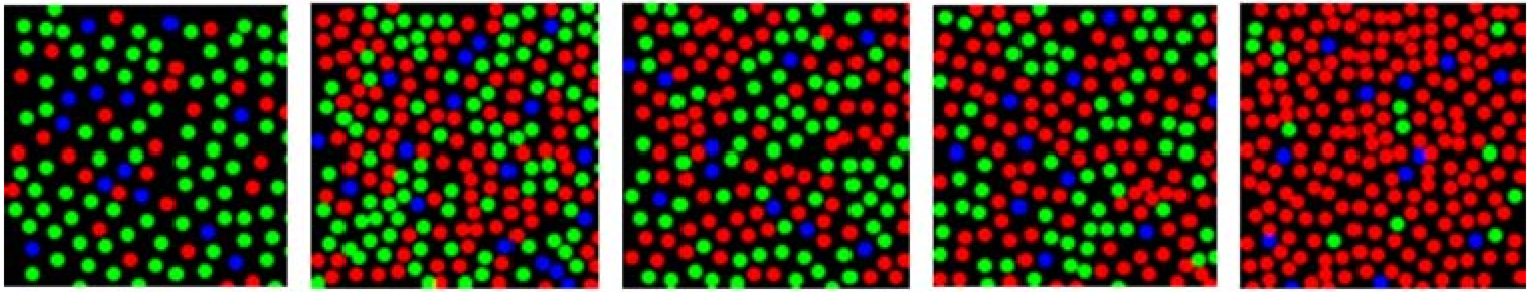
Experiment reported in

Hofer et al. “Different sensations from cones with the same photopigment”

1. Observers named the colour of small flashed retinal spots

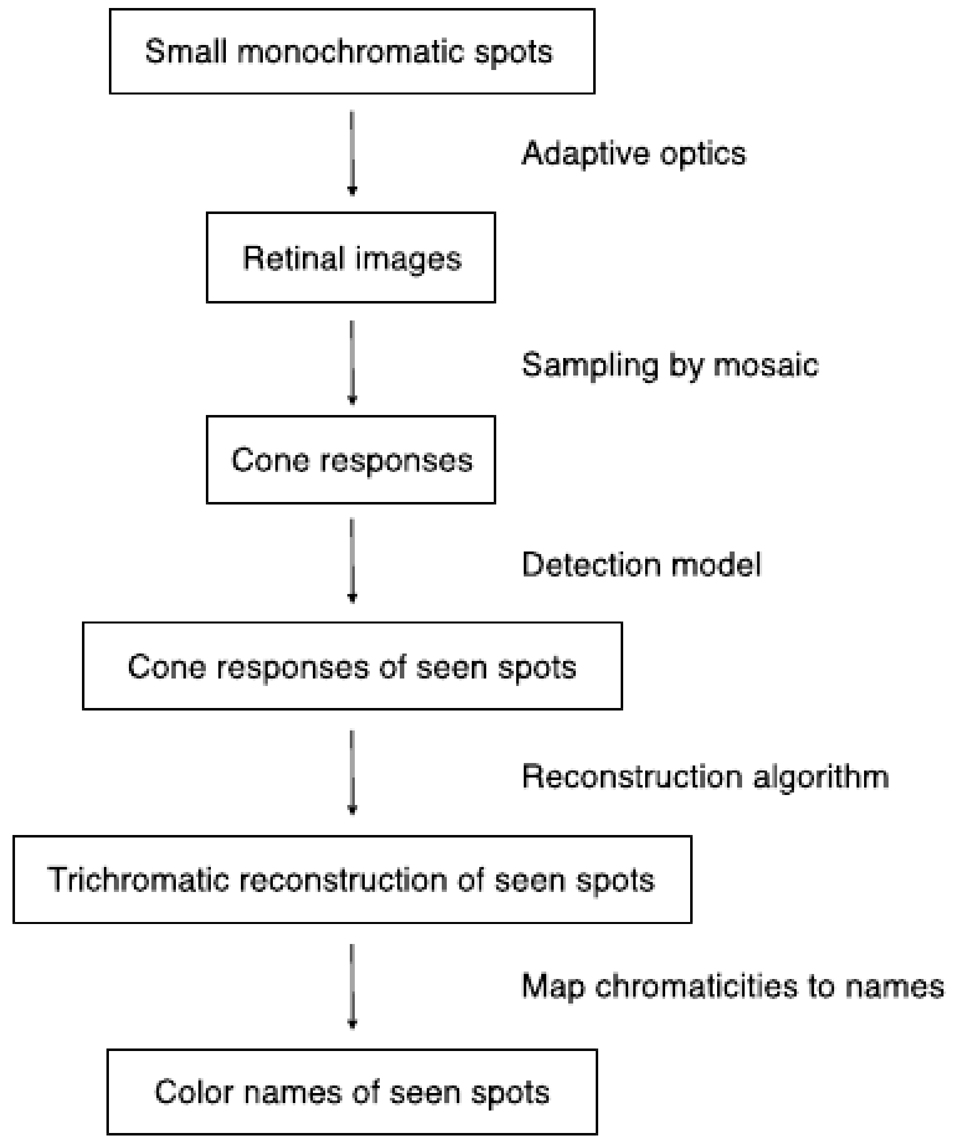
2. Spots had retinal size similar to the acceptance aperture of single cones

3. Measurements of the spatial arrangement and classes of the cones were obtained for each observer

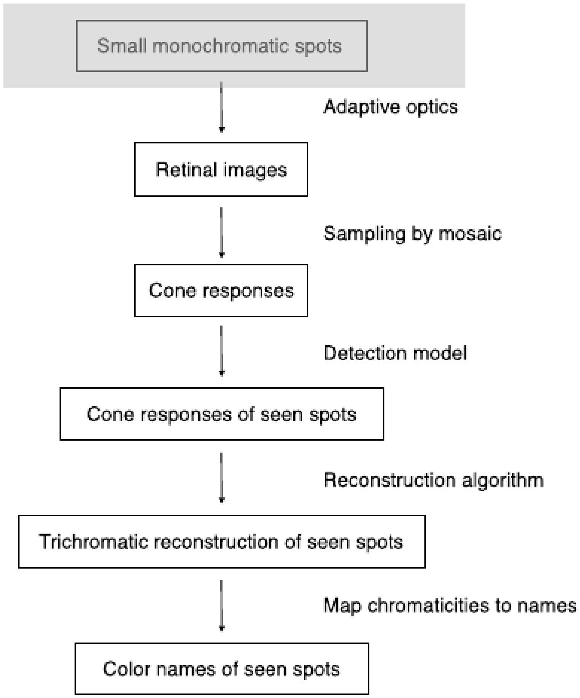


One cone was stimulated and **the colour reported was the result of the reconstruction algorithm**

Model Structure



Model Structure – Stimulus Representation

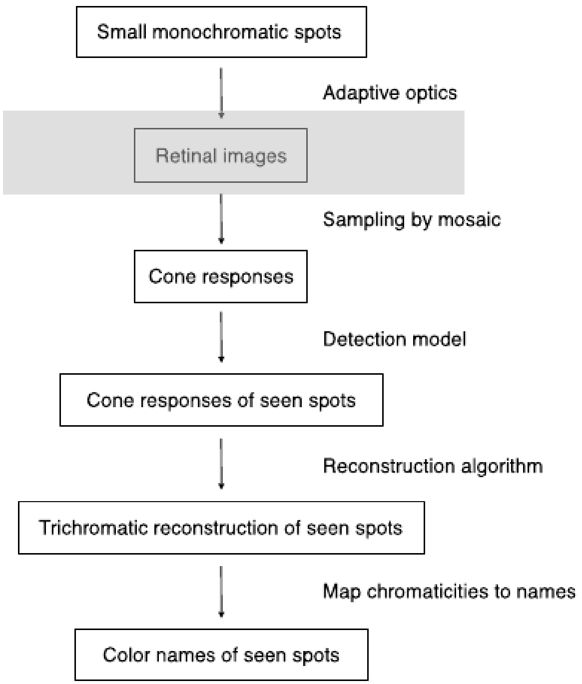


1. Spots where represented as images with size comparable to the physical stimulus

2. Spot location was chosen at random (avoiding edges)

3. The wavelength of the spots matched those presented in the experiments

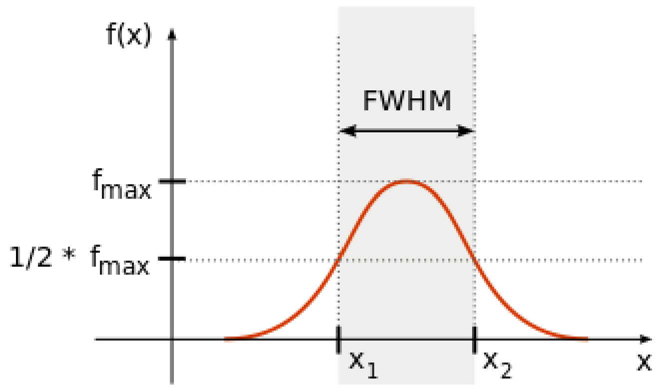
Model Structure – Calculation of Retinal Image



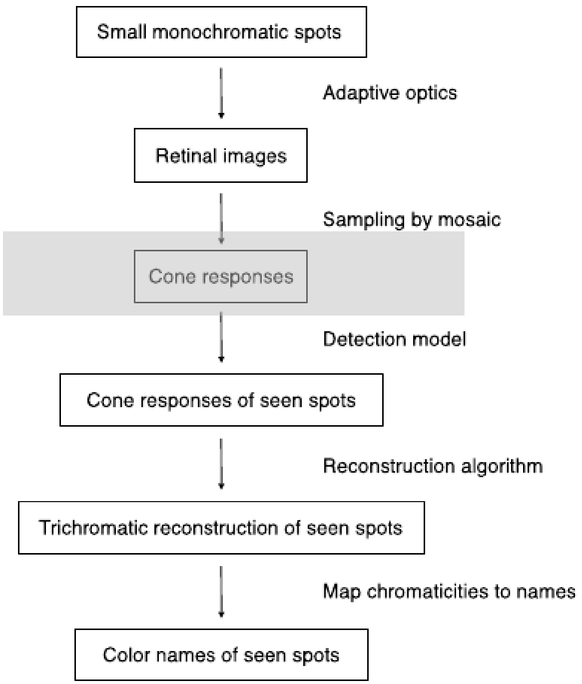
1. The point spread functions calculated for each individual observer were used to compute the retinal images

2. Blurring by the cone aperture was introduced at this stage

3. Gaussian aperture with full-width at half-maximum of 61.5% of the nominal cone diameter

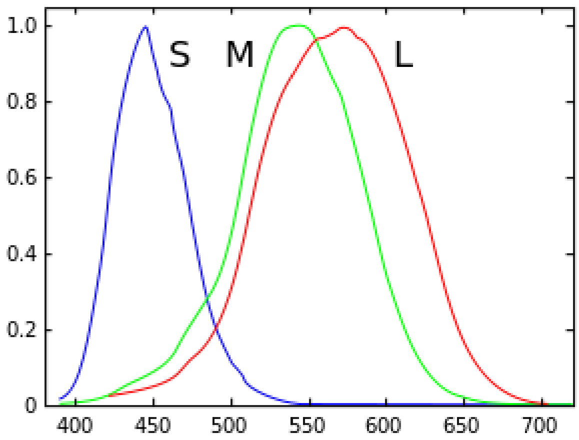


Model Structure – Calculation of Cone Responses



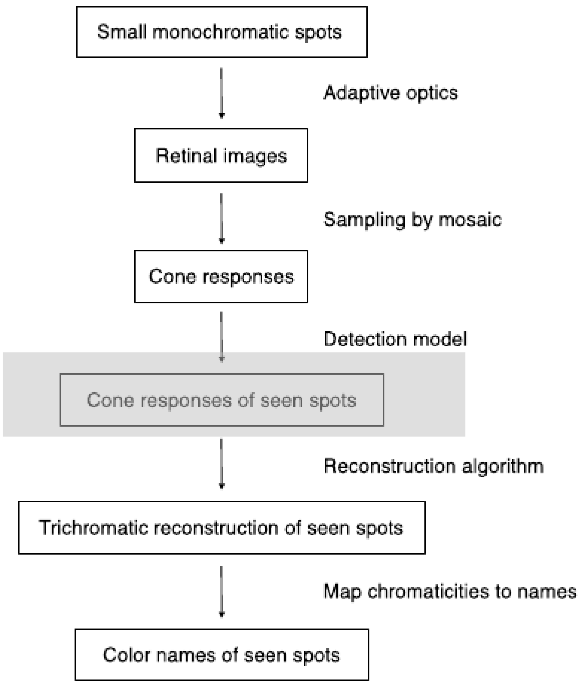
1. Cone maps from the experiments were used to determine which cone class was at each location

2. Smith-Pokorny estimates of cone spectral sensitivities were used to compute the mean isomerisation **m**



Cone responses ~ Poisson(**m**)

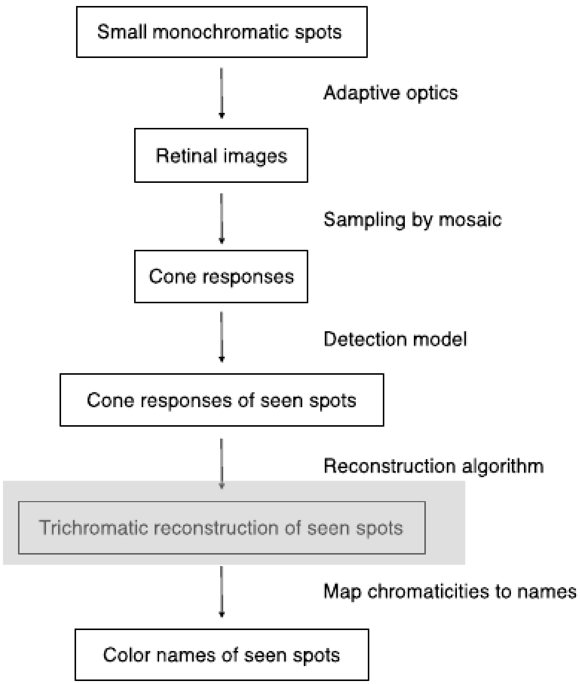
Model Structure – Detection Model



1. Cone responses are pooled over a small neighbourhood

2. Spots causing low pooled response are classified as “unseen” and discarded

Model Structure – Bayesian Model for Trichromatic Reconstruction



Likelihood

Derived from the model of the image formation process

$$cr_{mean} = f(\theta)$$

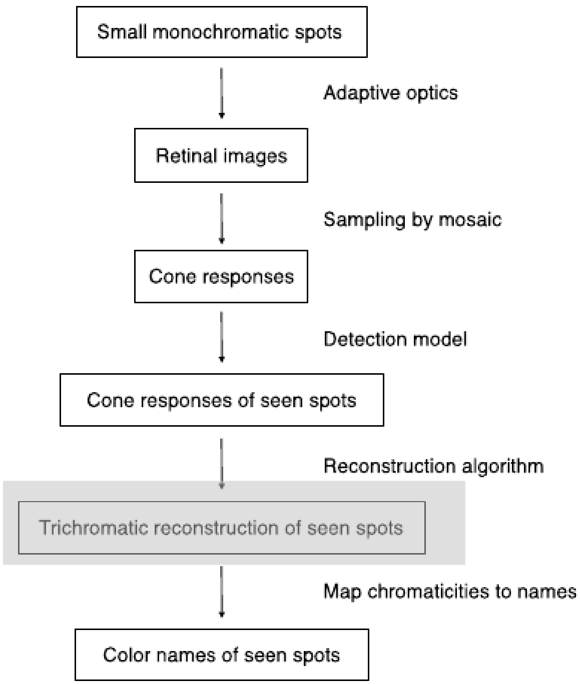
$$cr_{noise} = cr_{mean} + \varepsilon_{noise}$$

$$\varepsilon_{noise} \sim Gaussian(0, K_{noise})$$

K_{noise} diagonal with elements equal to cr_{mean}

cr_{noise} is a Gaussian Approximation to the Poisson model

Model Structure – Bayesian Model for Trichromatic Reconstruction



Prior over retinal images

$$p(x) \sim Gaussian(u_x, K_x)$$

K_x typically 30.000 x 30.000

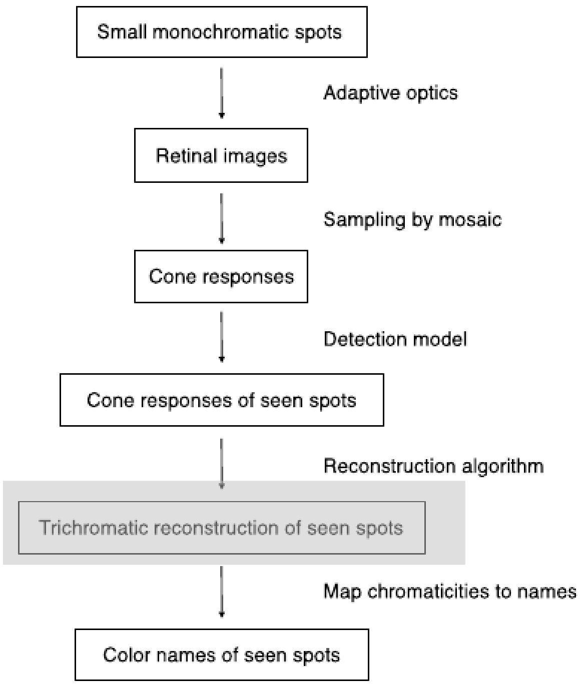
Assumption 1: prior separable in space and colour

Assumption 2: spatial component is separable in the vertical and horizontal dimensions (assumed to be the same)

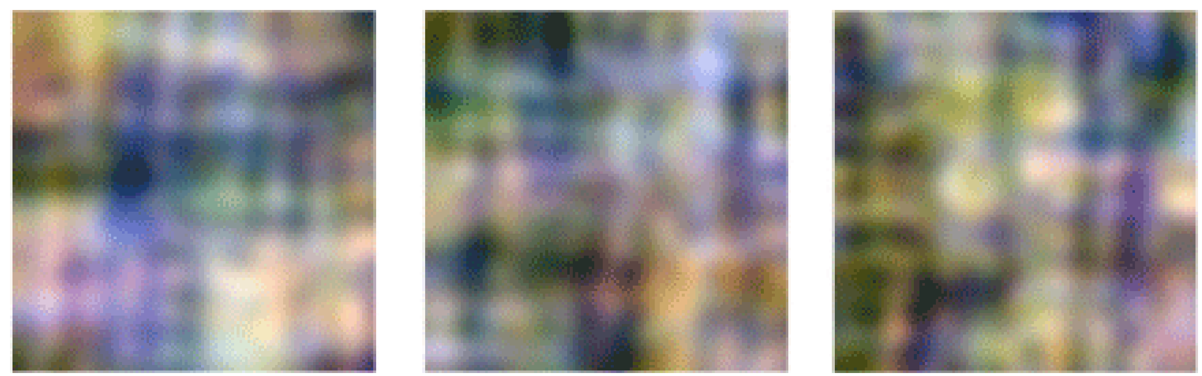
$$p(x_{space}) \sim Gaussian$$

$$p(x_{colour}) \sim Gaussian$$

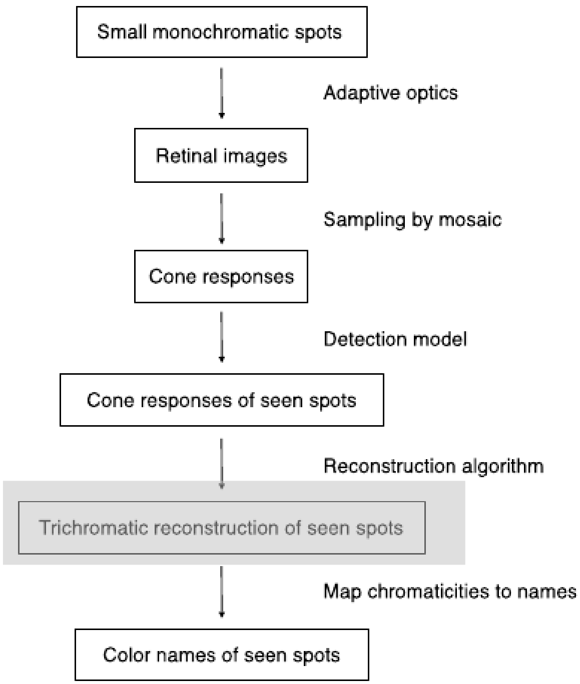
Model Structure – Bayesian Model for Trichromatic Reconstruction



Samples from the prior



Model Structure – Bayesian Model for Trichromatic Reconstruction

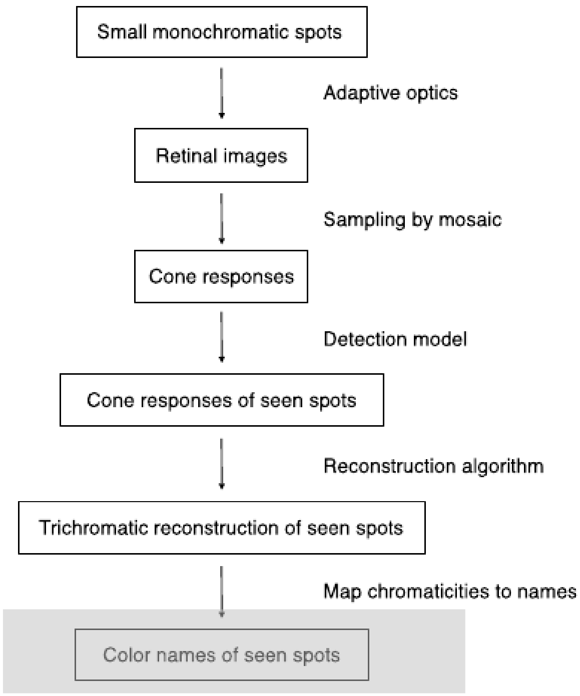


Posterior

The model includes only Gaussian components and linear transformations so the posterior is Gaussian.

The **posterior mean** can be **computed analytically**

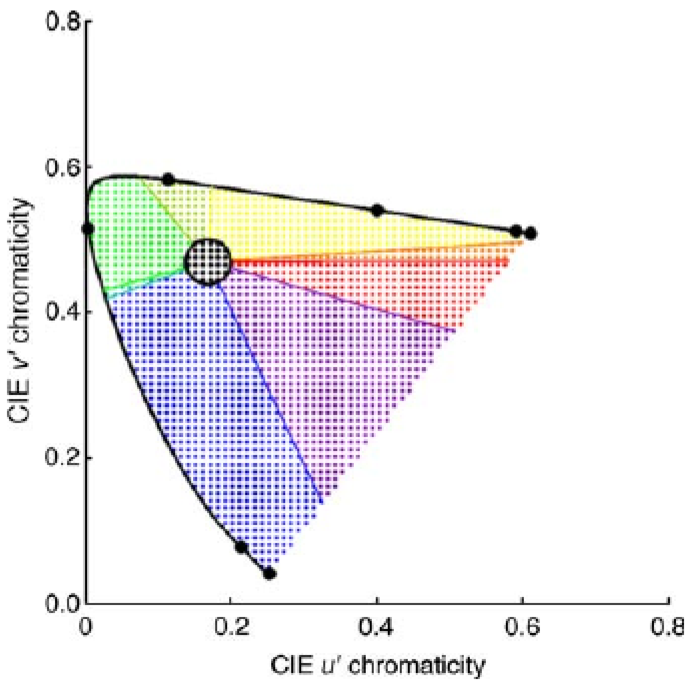
Model Structure



Average L, M, S responses over the reconstructed image are computed

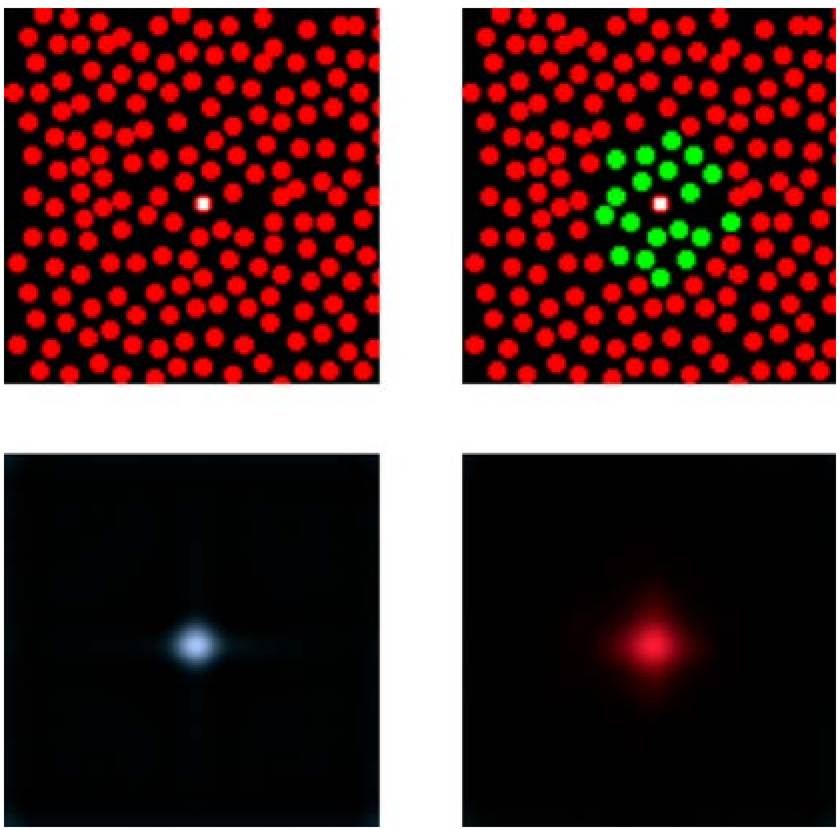
CIE u'v' chromaticity values corresponding to the LMS triplet are computed

Colour name is assigned from CIE u'v' values



Reconstruction Results – Single Cone Stimulation

A single L cone is stimulated in two different mosaic configurations



Left Example:

The absence of M/S receptors gives no information about the relative spectrum of the stimulus

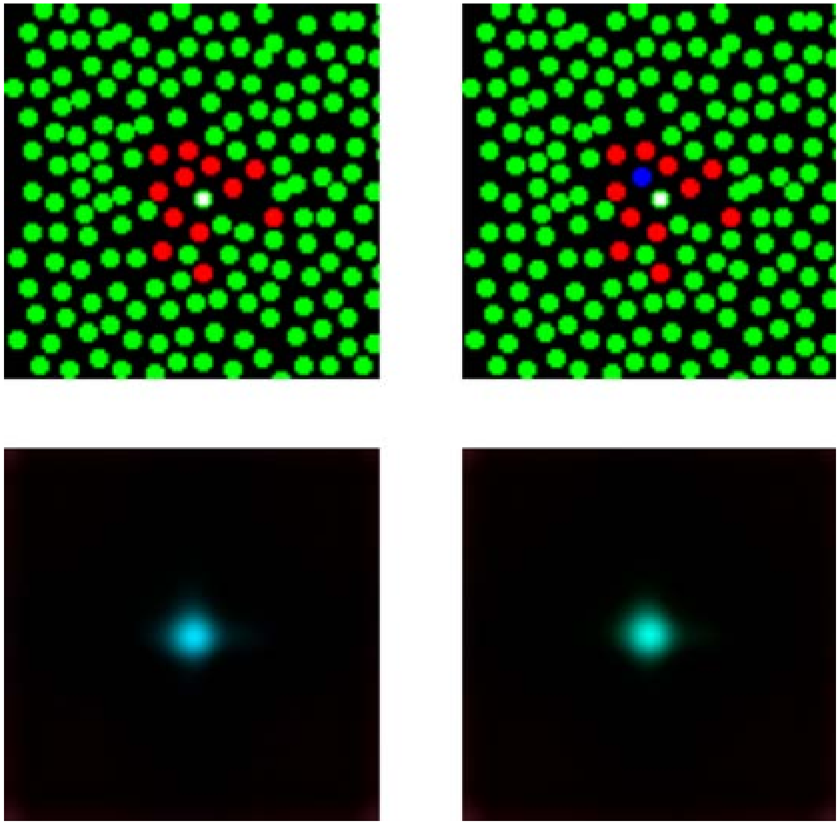
Result : mean of the prior (CIE daylight D65)

Right Example:

The presence of M cones with no response around the L cone move the posterior estimate towards red

Reconstruction Results – Single Cone Stimulation

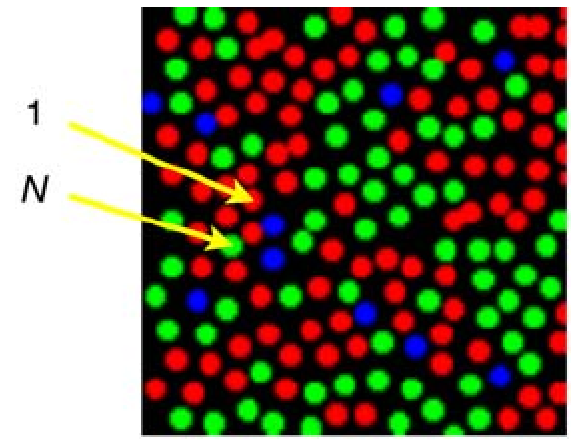
A single M cone is stimulated in two different mosaic configurations

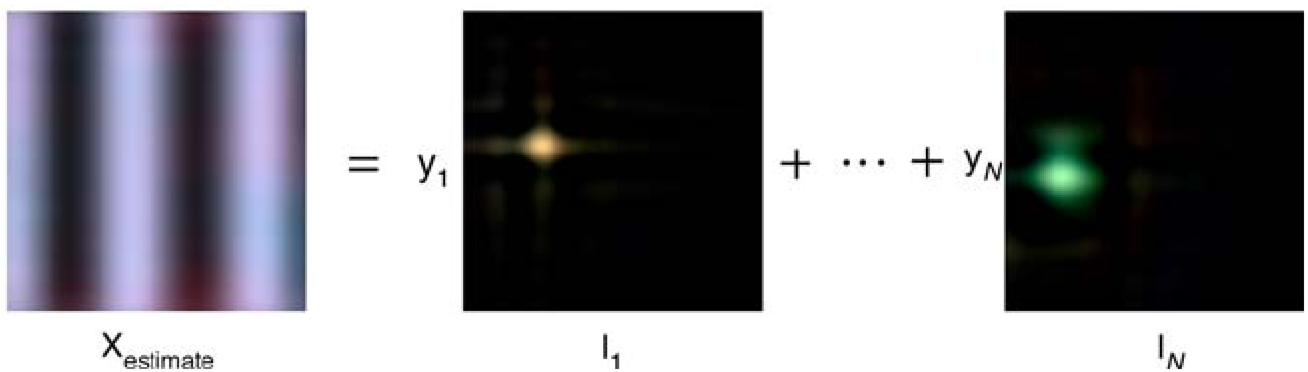


Adding a “silent” S cone to the mosaic moves the estimate towards green

Reconstruction Results – Extended Stimulus

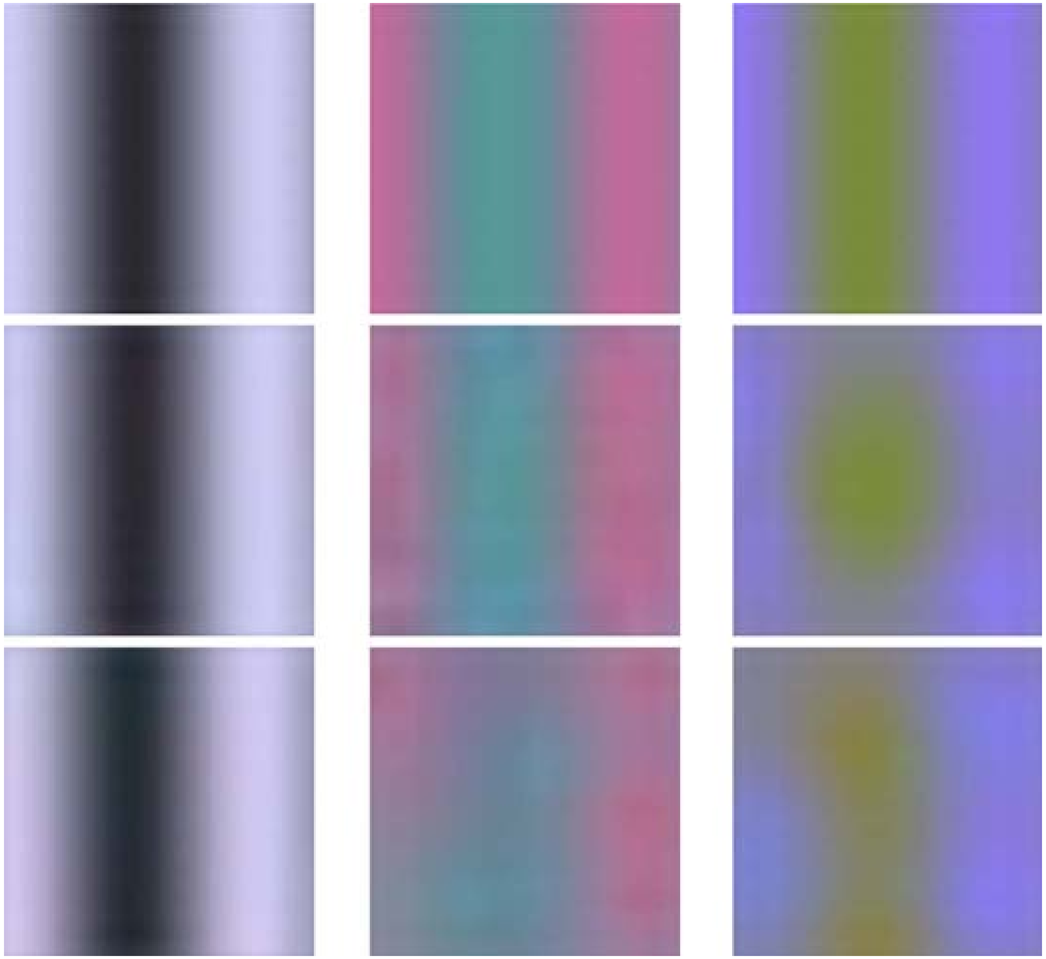
$$\begin{bmatrix} | \\ X_{estimate} \\ | \end{bmatrix} = \begin{bmatrix} | & & | \\ I_1 & \cdots & I_N \\ | & & | \end{bmatrix} \begin{bmatrix} y_1 \\ \vdots \\ y_N \end{bmatrix}$$





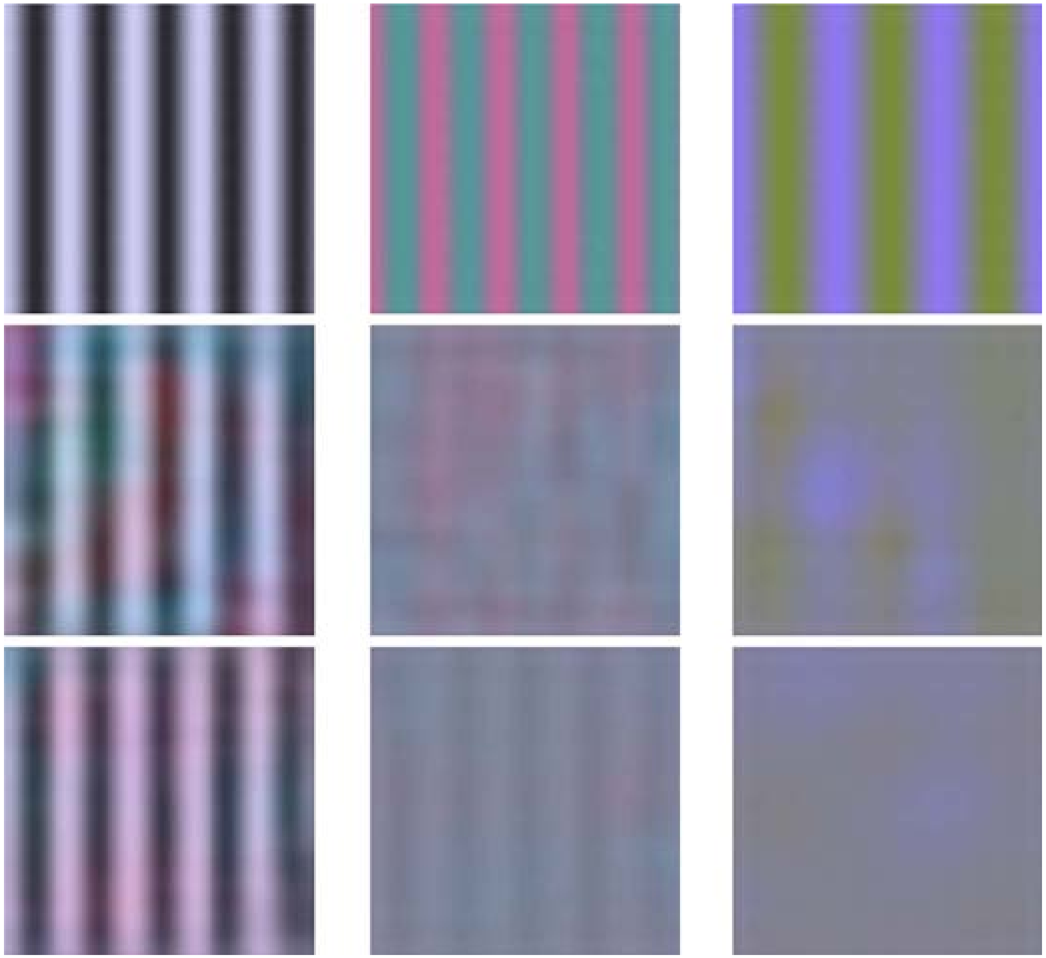
Single responses can be combined together to compute a reconstruction of extended stimuli

Reconstruction Results – Low Spatial Frequency Gratings



Simulated Stimulus (top row) followed by two reconstructions

Reconstruction Results – High Spatial Frequency Gratings



Simulated Stimulus (top row) followed by two reconstructions