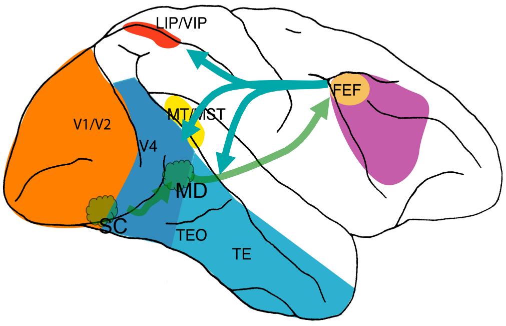
Space Perception

Basis-Function Networks

Suggested reading:

- Pouget, A., and Snyder, L. (2000) Computational approaches to sensorimotor transformations. Nature Neuroscience. 3:1192-1198.
- Deneve S, Latham PE, Pouget A. (2001) Efficient computation and cue integration with noisy population codes. Nat Neurosci., 4:826-31.
- Pouget A, Deneve S, Duhamel JR. (2002) A computational perspective on the neural basis of multisensory spatial representations. Nat Rev Neurosci., 3:741-7.

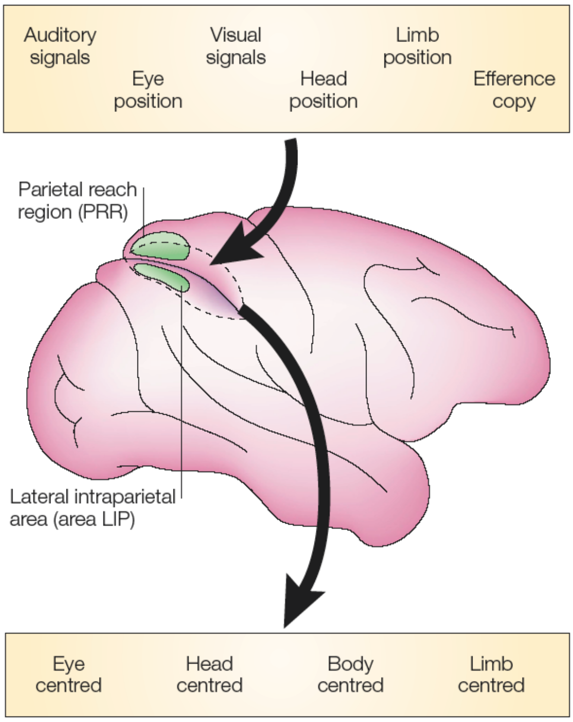
Space Perception



Contents:

- The function of the parietal cortex
- Eye centered neuron
- Head centered neuron
- Reference frames
- Gain fields
- Coordinate transformation with basis function maps
- Cue integration
- Visual stability
- Mislocalisation of flashed stimuli

Multi-modal Representation

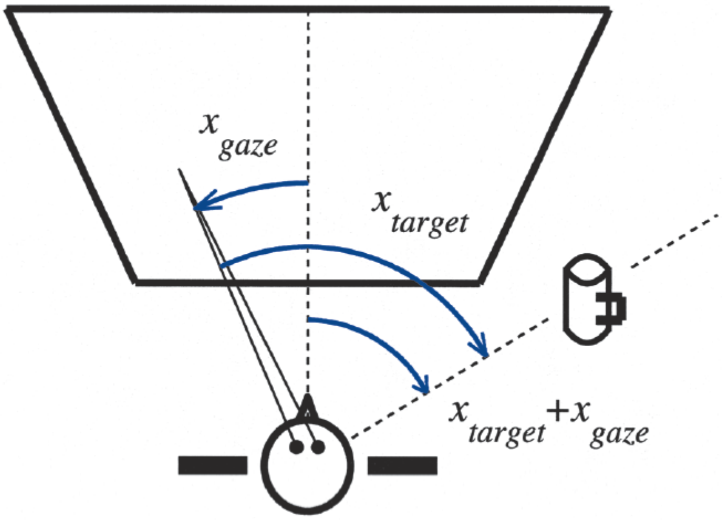


From: Cohen & Andersen (2002). Nature Rev Neurosci 3:553-562.

The posterior parietal cortex (PPC) is devoted to compute visual information for action preparation. Higher areas in the PPC are multimodal and integrate several sources of information for action.

It is likely that such integration is obtained in different stages of specialized action systems. However, they might obtain their information from a more general, multimodal representation.

Localization

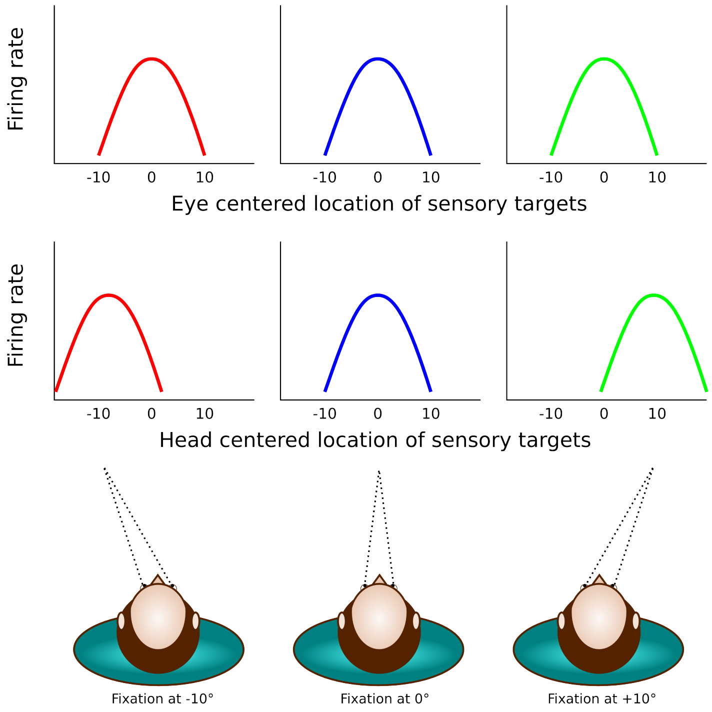


From: Salinas & Sejnowski (2001) The Neuroscientist 7:430-440.

The position of a stimulus x_{target} is initially given in an eye centered (retinal) reference system. If the eye position x_{gaze} with reference to the head position is known, then the position of a stimulus in a head-centered reference system can by easily computed.

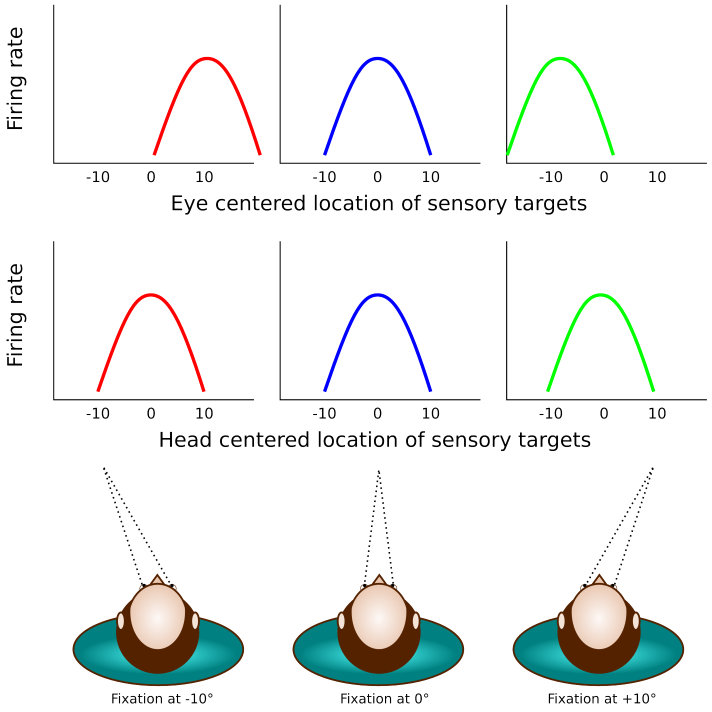
Eye centered neuron

Has the same response in **eye** centered coordinates, irrespectible of gaze direction.

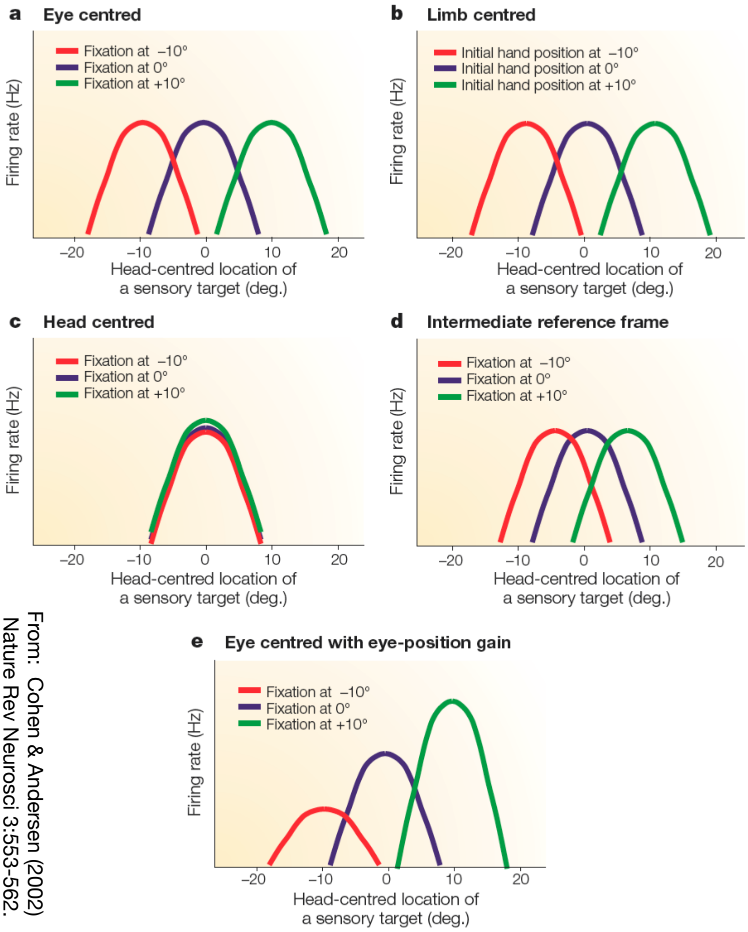


Head centered neuron

Has the same response in **head** centered coordinates, irrespectible of gaze direction.



Reference Frames



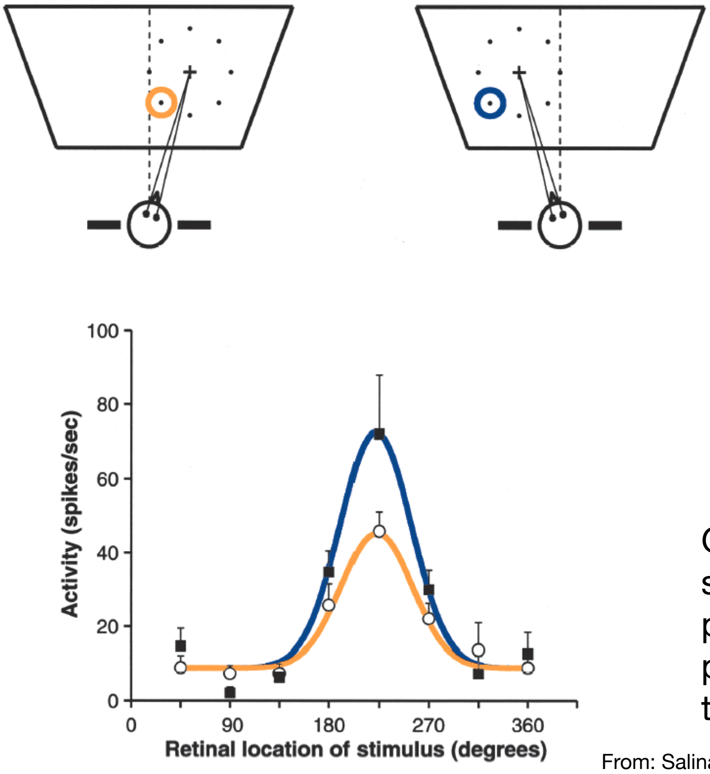
From: Cohen & Andersen (2002) Nature Rev Neurosci 3:553-562.

The posterior parietal cortex represents stimuli in different reference frames such as eye-centered, hand-centered, body-centered or head-centered.

Some neurons, however, show receptive fields which cannot be assigned to a specific reference frame (d).

In other neurons the firing rate depends on the eye position (e).

Gain-Fields



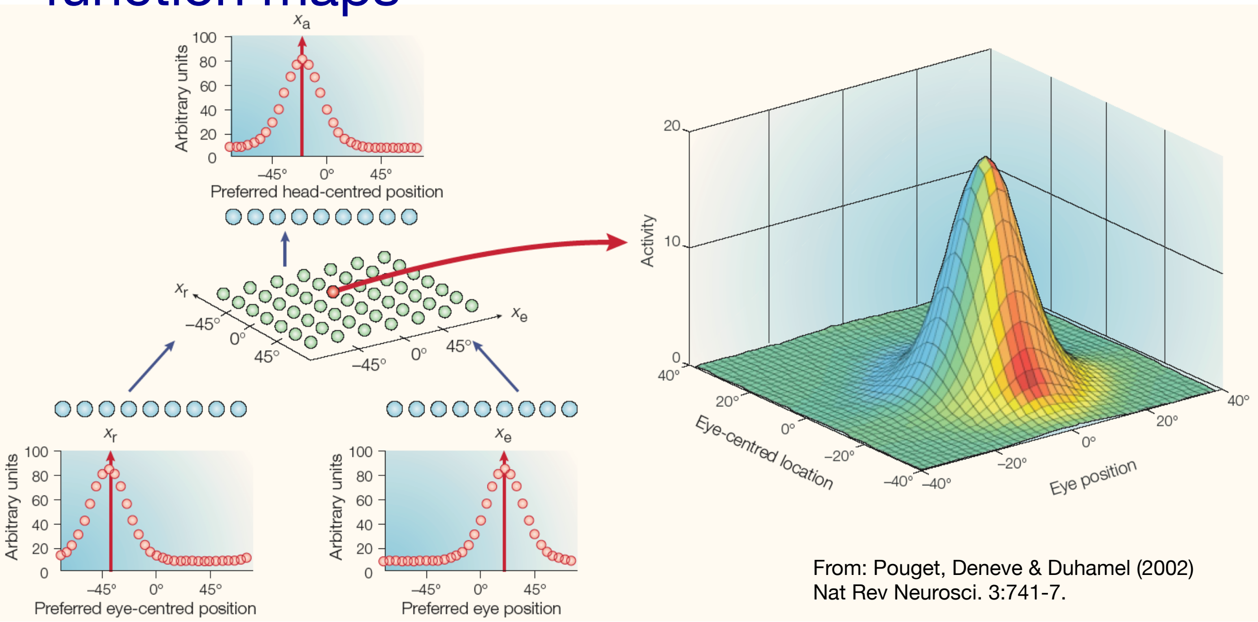
In analogy to the RF a gain field describes the change of the response of a neuron in response to another variable. For example, the position of a stimulus is x_{target} and the eye position is x_{gaze} , then the neural response of a gain-field is:

$$r = f(x_{target})g(x_{gaze})$$

Gain-fields have been found in several types in the posterior parietal cortex. They have useful properties for coordinate transformations.

From: Salinas & Sejnowski (2001) The Neuroscientist 7:430-440.

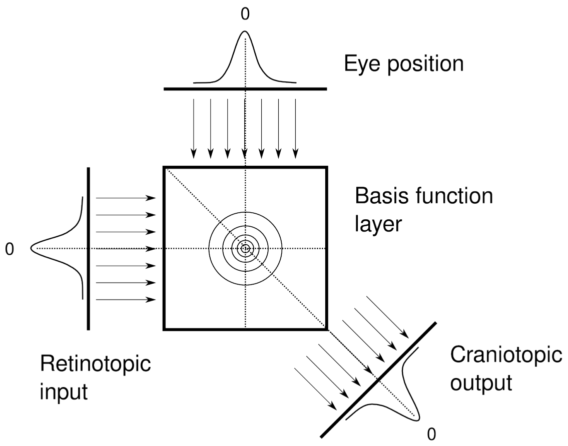
Coordinate-transformation with basis function maps

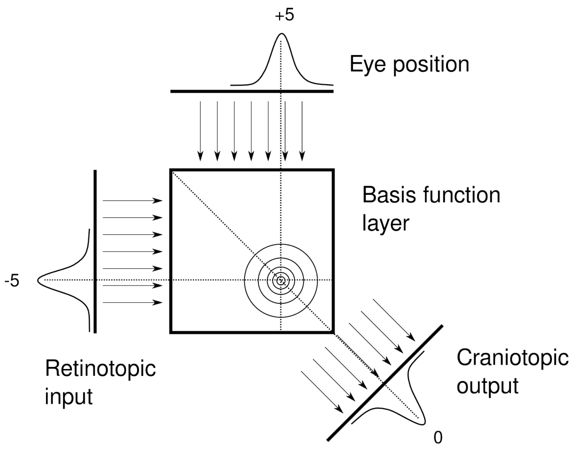


From: Pouget, Deneve & Duhamel (2002)
Nat Rev Neurosci. 3:741-7.

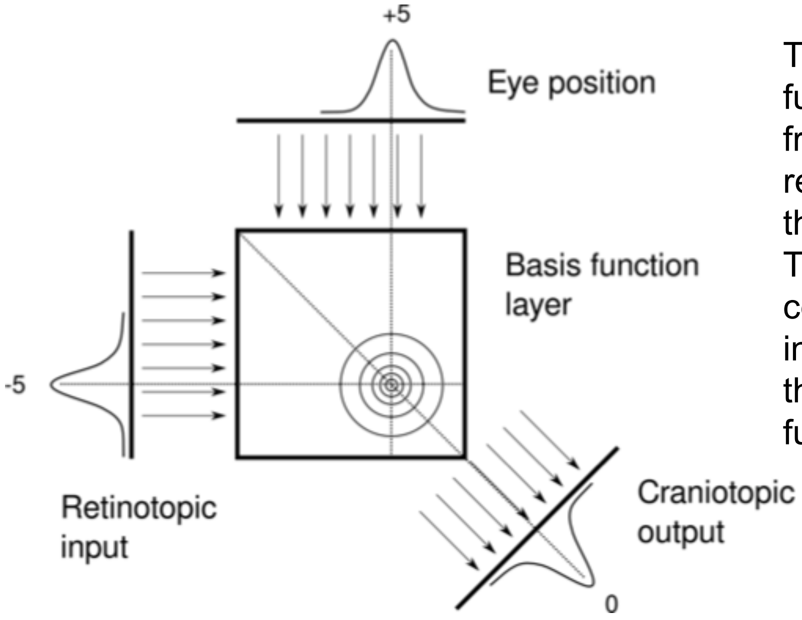
Basis function maps build a population code.The activation of the basis function units is obtained by combining the input populations with gain-fields. The output population is computed by a simple linear combination of the basis function units.

Coordinate-transformation with basis function maps





Coordinate-transformation with basis function maps



The neuron $b_{i,j}$ in the basis function layer receives input from neuron r_i from the retinotopic map and e_j from the eye position map.
The neuron h_k in the head-centered map receives input from all neurons from the basis function layer that fulfill $i+j=k$.

$$b_{i,j}=r_j \cdot e_i$$

$$h_k = \sum_{i+j=k} b_{i,j}$$

Basis function map

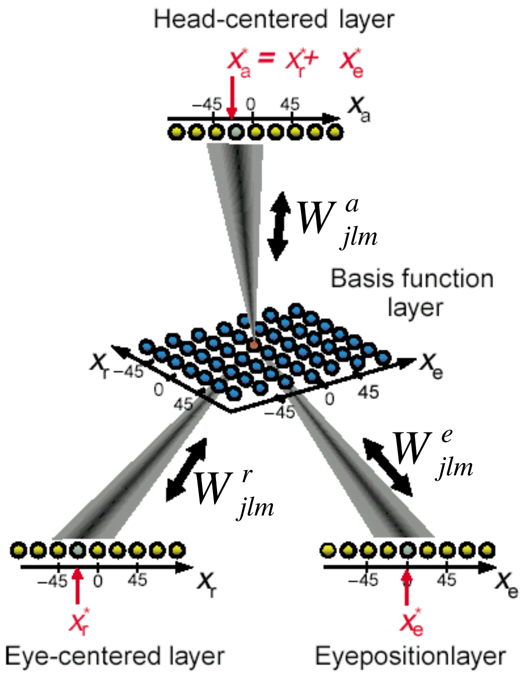


Illustration of the connections from a representative cell of the basis function map (red). The connections are bi-directional and weighted such that the cell primarily responds to a specific stimulus position x^*_r, an eye position x^*_e and a head position x^*_a (green).

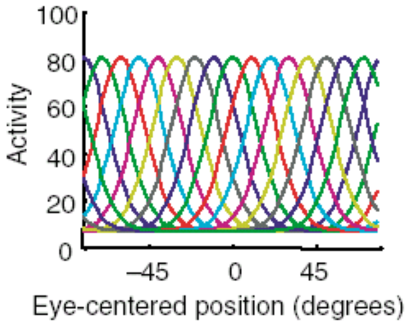
The weights follow the equation

$$x^*_a = x^*_r + x^*_e$$

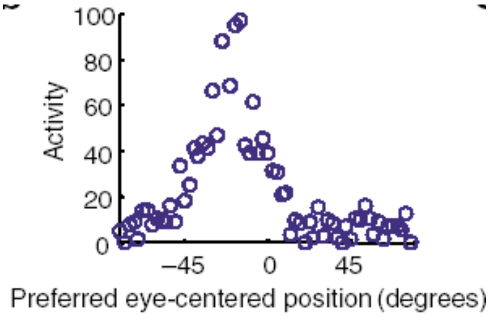
and all its permutations.

Such a basis-function network implements a multi-dimensional attractor.

Tuning-Curve



The neurons of the input layers are tuned towards a specific range of the input, e.g. by a Gaussian tuning curve.



- A stimulus (at –20°) is represented as a noisy population.

Network-details

The three input layers consist of topographically organized layers with *N* neurons. The index of each neuron, *j* = 1. . . *N* refers to the position of the neuron in the layer. The basis-function layer is a 2D map of *N/2*N/2* neurons, whose position is determined by *l,m*, with *l* = 2, 4, . . .,*N* and *m* = 2, 4, . . .,*N*.

The input neurons are bi-directionally connected to the neurons of the basis function map. The connection matrixes are denoted as W^r, W^e and W^a respectively and refer to the retinotopic representation, the eye position and the head-centered position.

$$\begin{aligned}
W^r_{jlm} &= K_w \exp\left[\frac{\cos[(2\pi/N)(j-l)]-1}{\sigma_w^2}\right] \\
W^e_{jlm} &= K_w \exp\left[\frac{\cos[(2\pi/N)(j-m)]-1}{\sigma_w^2}\right] \\
W^a_{jlm} &= K_w \exp\left[\frac{\cos[(2\pi/N)(j-l-m)]-1}{\sigma_w^2}\right]
\end{aligned}$$

Activation of the neurons

The activation function consists of a quadratic non-linearity and a divisive normalization. $A_{lm}(t)$ is the activation of a neuron (l,m) in the basis-function map at the time t, and $R_{rj}(t)$, $R_{ej}(t)$, and $R_{aj}(t)$ the activity of neuron j in each input layer.

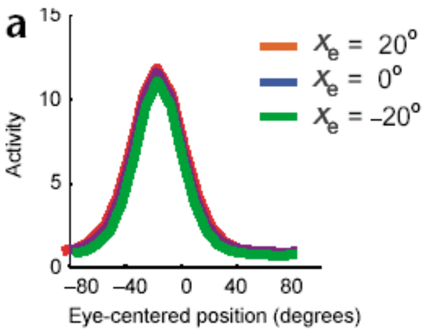
$$\begin{aligned}
A_{lm}(t+1) &= \frac{L_{lm}(t)^2}{S+\mu\sum_{l'm'} L_{l'm'}(t)^2} \\
R_{rj}(t+1) &= \frac{\left[\sum_{lm} W^r_{jlm} A_{lm}(t+1)\right]^2}{S+\mu\sum_j \left[\sum_{lm} W^r_{jlm} A_{lm}(t+1)\right]^2} \\
R_{ej}(t+1) &= \frac{\left[\sum_{lm} W^e_{jlm} A_{lm}(t+1)\right]^2}{S+\mu\sum_j \left[\sum_{lm} W^e_{jlm} A_{lm}(t+1)\right]^2} \\
R_{aj}(t+1) &= \frac{\left[\sum_{lm} W^a_{jlm} A_{lm}(t+1)\right]^2}{S+\mu\sum_j \left[\sum_{lm} W^a_{jlm} A_{lm}(t+1)\right]^2}
\end{aligned}$$

$$L_{lm}(t) = \sum_j W^r_{jlm} R_{rj}(t) + \sum_j W^e_{jlm} R_{ej}(t) + \sum_j W^a_{jlm} R_{aj}(t)$$

Simulation results

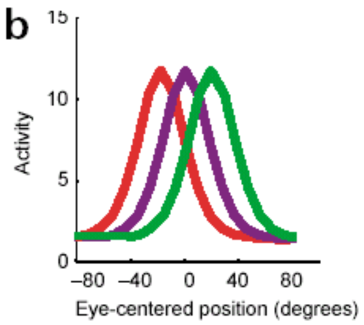
The network will be initialized with three noisy input hills according to a poisson distribution, and the network will be iterated for three cycles, while the input is removed.

eye-centered RF



The RF does not change, regardless of the position of the eye in space.

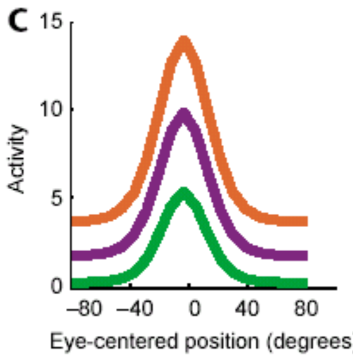
head-centered RF



The head-centered RF moves for the same amount, but in different direction than the eye movement.

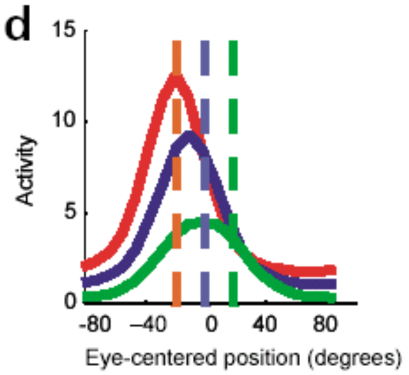
Simulation results

RF of a basis-function unit in the feedforward case



The unit exhibits an eye-centered receptive field with a position that does not vary with eye position. The height of the tuning curve, however, is modulated by eye position. This is known as a gain field.

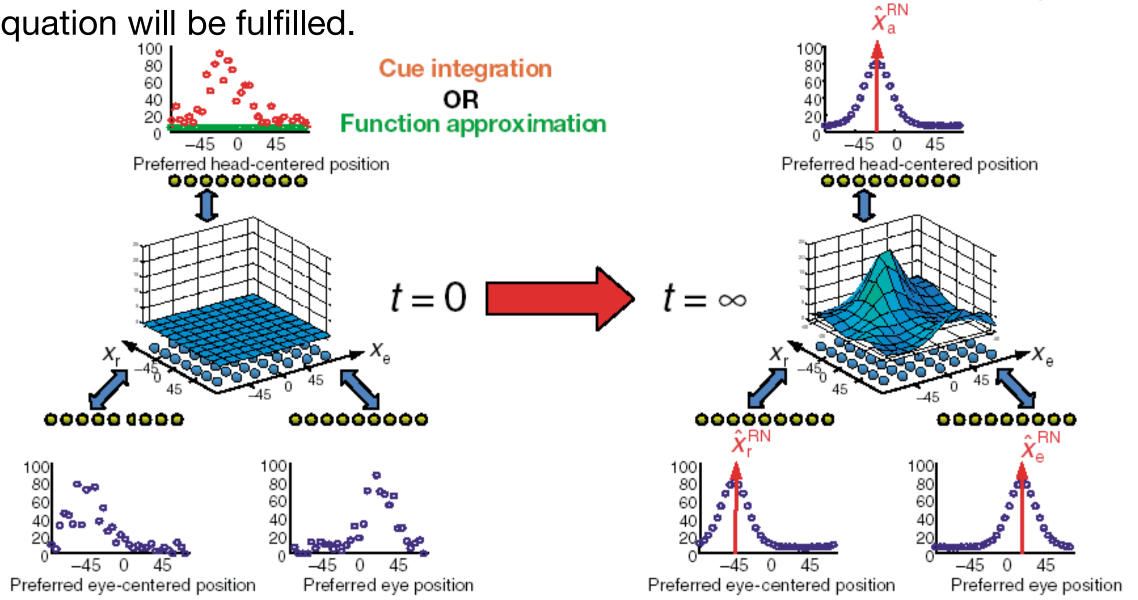
RF of a basis-function unit in the feedforward and feedback case



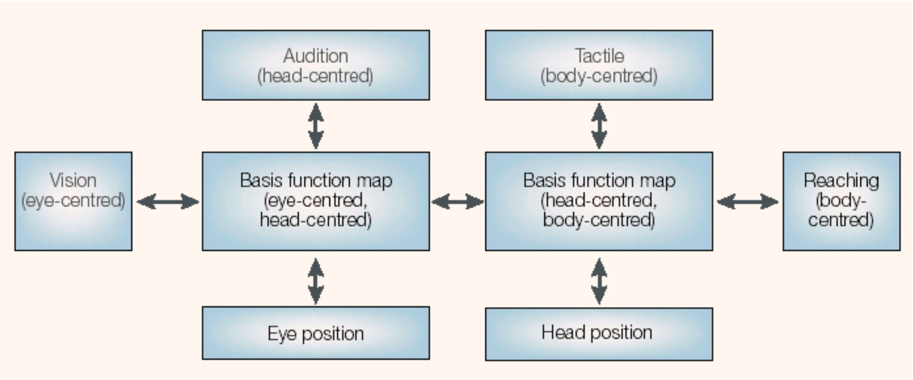
The position and height of the eye-centered RF changes with eye position. The shift is only half of what is predicted for a unit with a head-centered receptive field; it has a partially shifting receptive field.

Cue-Integration

If the network is simulated with three inputs (cue integration), it has to integrate the activation from the respective input layer with those from other layers.
If the network is simulated with only two inputs (function approximation) the activation of the third layer will be determined such that the mapping equation will be fulfilled.



Basis function maps



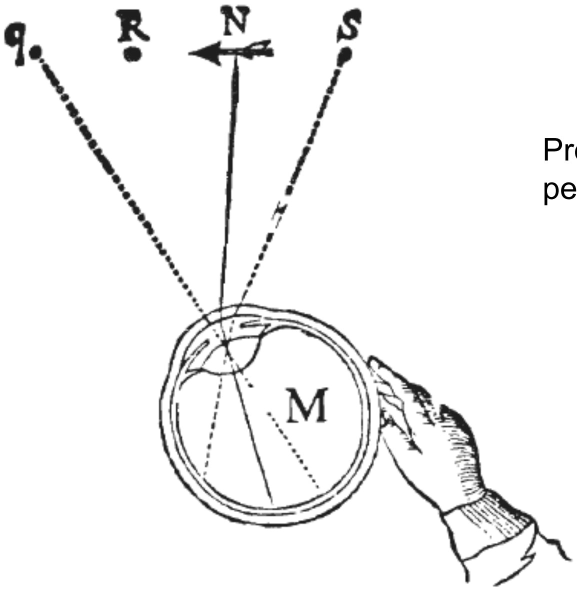
From: Pouget, Deneve & Duhamel (2002)
Nat Rev Neurosci. 3:741-7.

Multiple coordinate systems might rely on basis function maps. The output of basis function maps can be linearly combined to obtain any non-linear function (e. g. fourier transformation: sum of sinus-and cosinus-functions). Basis functions are required to have non-linear receptive fields (e.g. Gaussian) and interactions between the signals must be non-linear as well.

The image on the retina

EyeSeeCam Project Munich

Observations made by Descartes



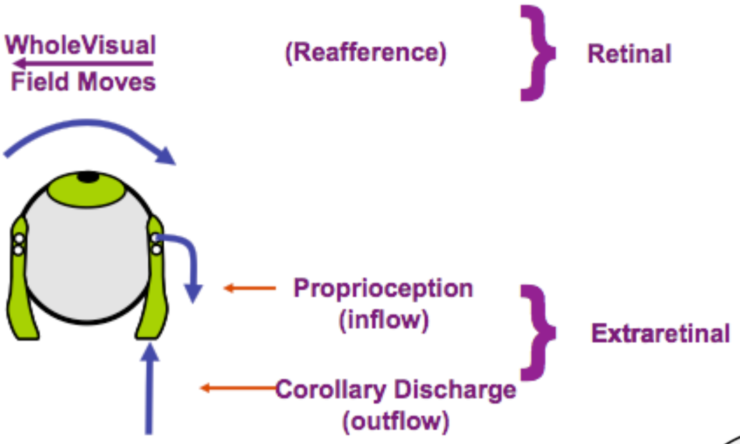
Pressing at the eyeball leads to the perception of motion !

Figure 1. Optical analysis of the passive eyepress (from Descartes, 1664 (1972). N, original fixation point; q, fixation point during eyepress. It is assumed that the finger rotates the eye in the head.

Descartes, R. *Treatise of man* (T. S. Hall, trans. & Ed.). Cambridge, Mass: Harvard University Press, 1972. (Originally published 1664.)

From: Stark, L., Bridgeman, B. (1983) Role of corollary discharge in space constancy. Perception & Psychophysics, 34:371-380.

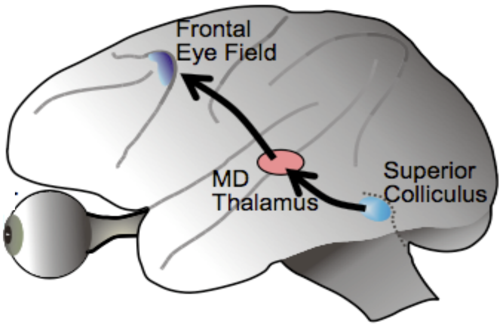
Signals that may be used to establish visual stability



WholeVisual Field Moves — **(Reafference)** } **Retinal**

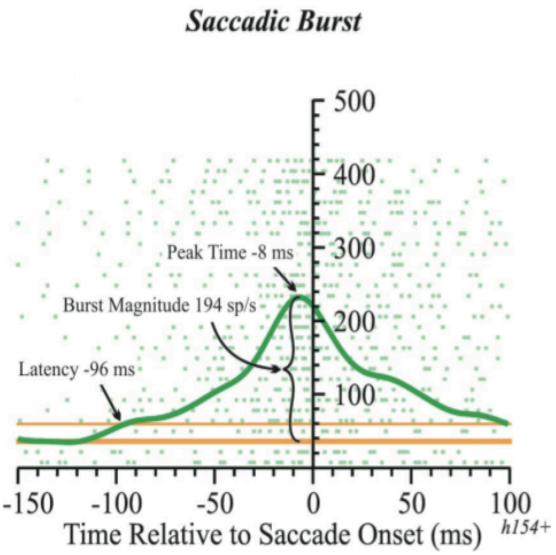
Proprioception (inflow)

Corollary Discharge (outflow) } **Extraretinal**

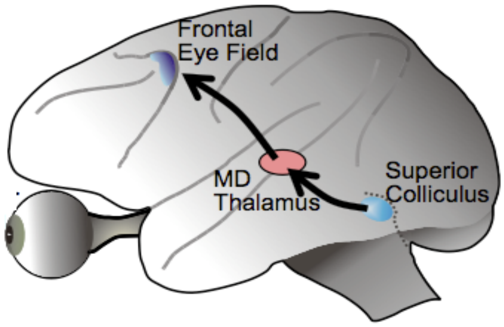


From: Wurtz RH. (2008) Neural Mechanisms of visual stability. Vision Research.

Signals that may be used to establish visual stability

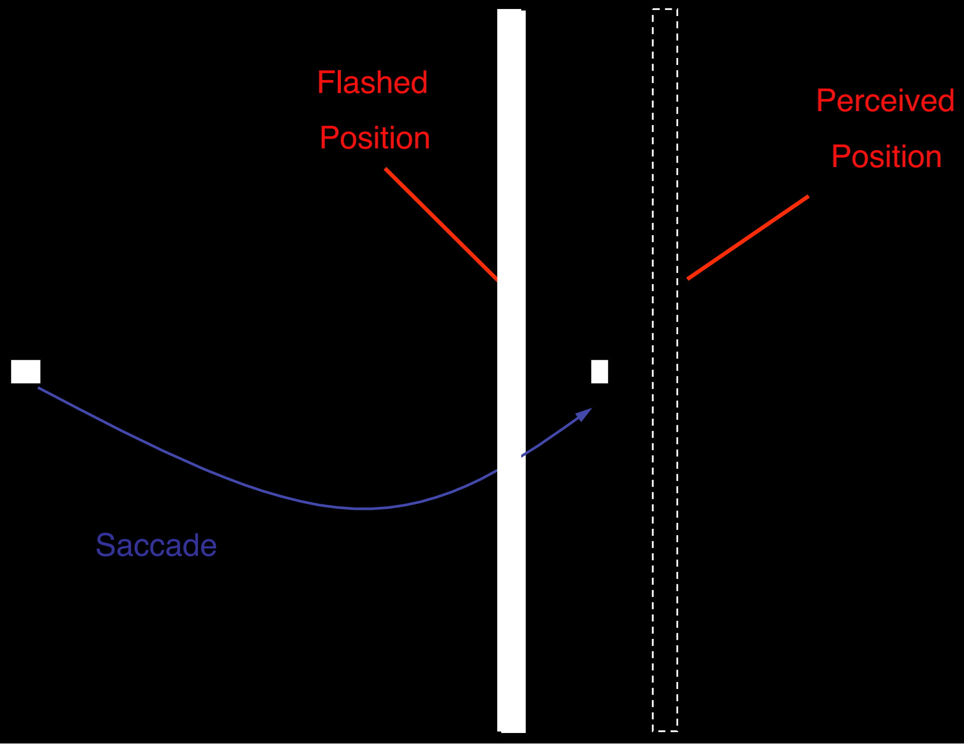


Sommer & Wurtz, J. Neurophysiol, 2004
Sommer & Wurtz, Annu. Rev. Neurosci., 2008



From: Wurtz RH. (2008) Neural Mechanisms of visual stability. Vision Research.

Localization of briefly flashed stimuli around saccade onset

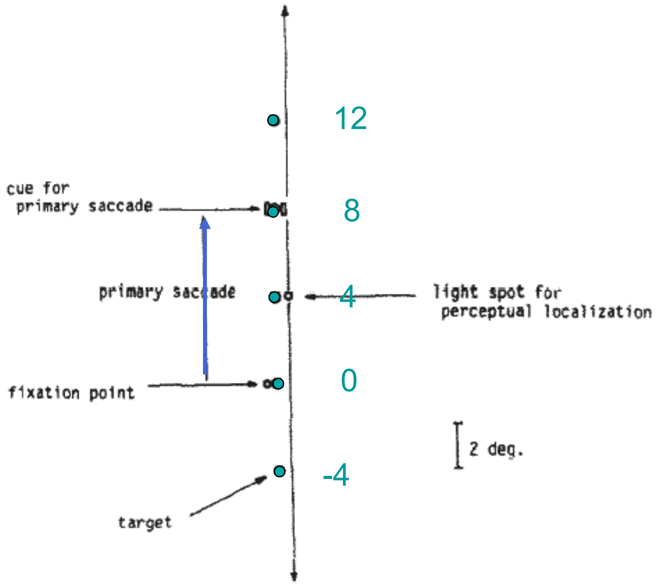


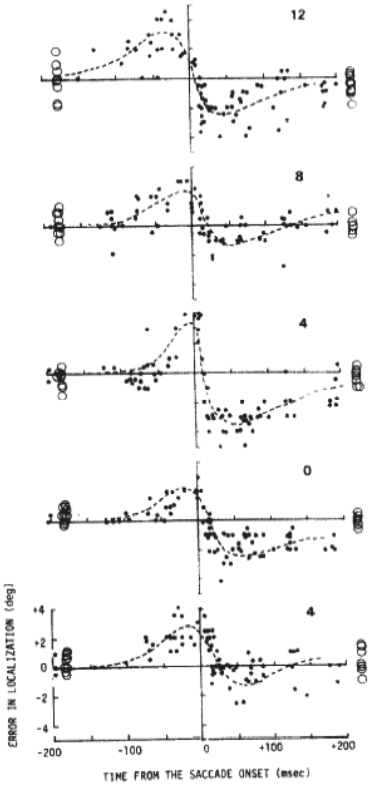
Flashed Position

Perceived Position

Saccade

The localization of briefly flashed stimuli around saccade onset

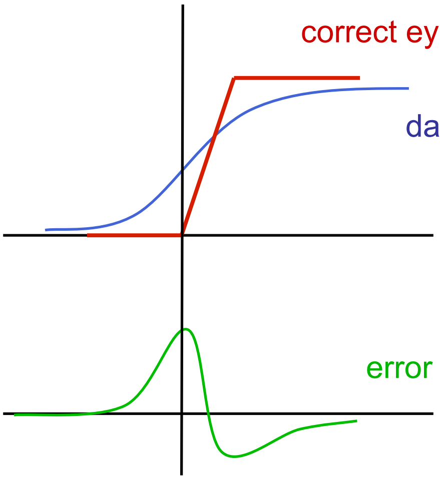




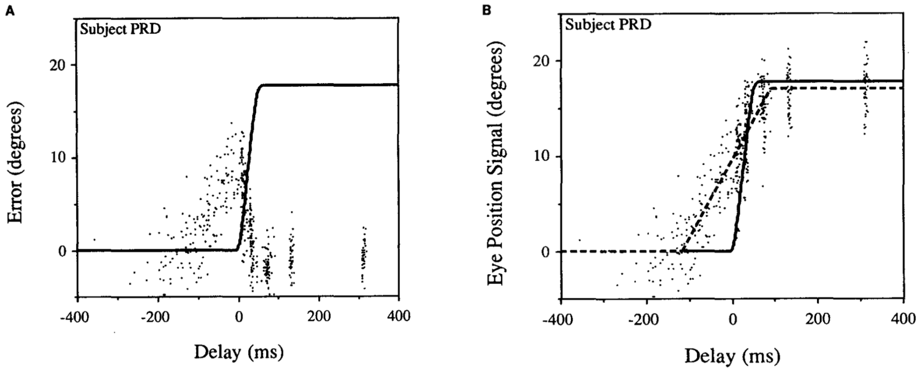
Honda H (1991)
The time course of visual mislocalization and of extraretinal eye position signals at the time of vertical saccades.
Vision Res 31: 1915-1921.
Honda, Vision Res., 1991.

A simple concept to explain the mislocalization of briefly flashed stimuli

Typical explanation:

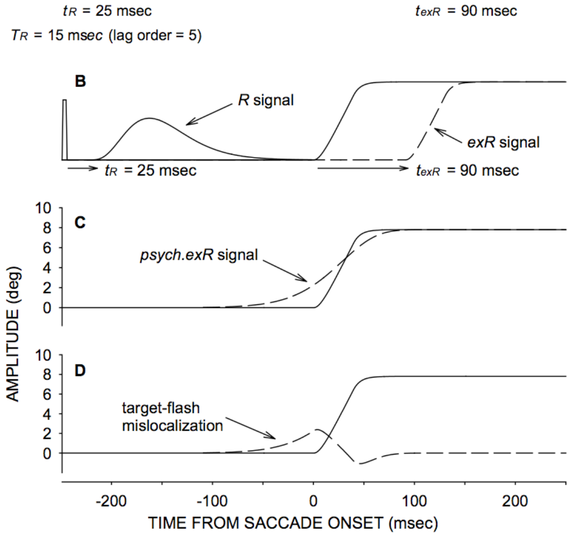


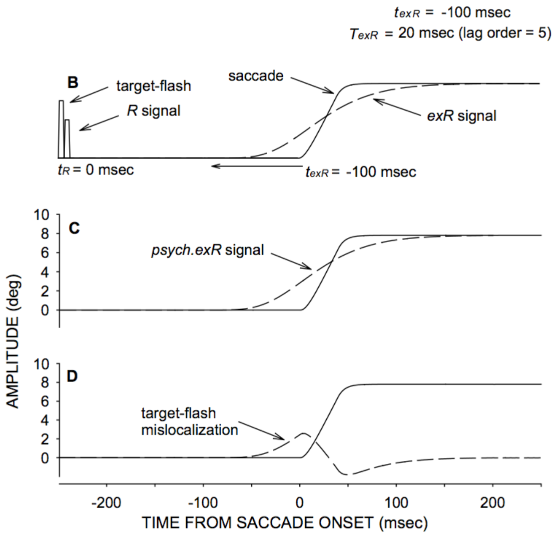
Modeling approaches



Dassonville, Vis Neurosci., 1992

Modeling approaches

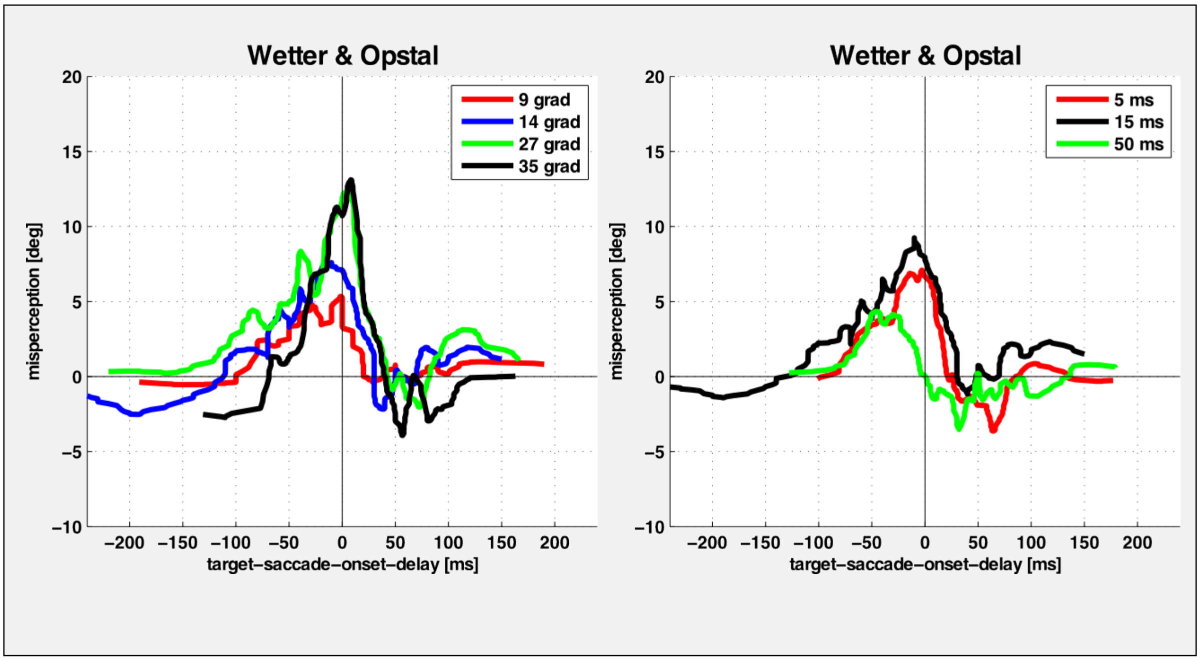




Pola, Vision Res., 2004.

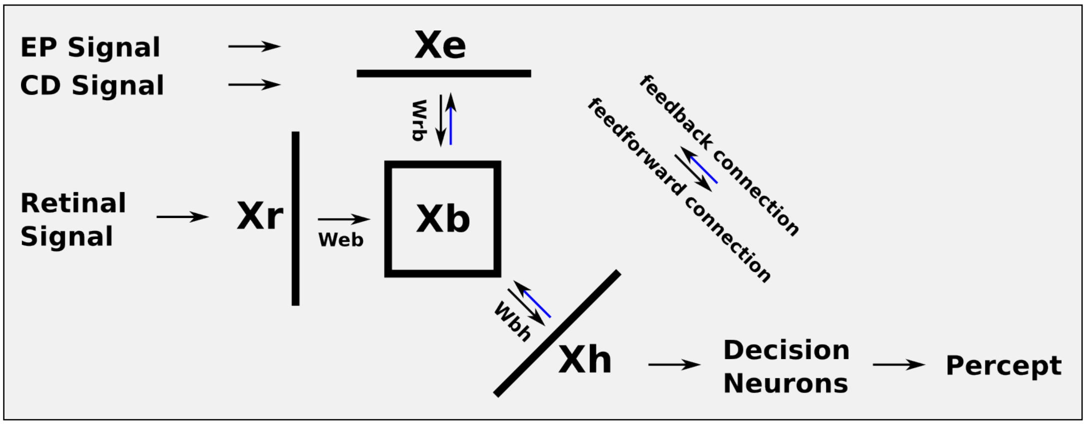
Problems of motor theories for spatial updating

saccade amplitude flash duration



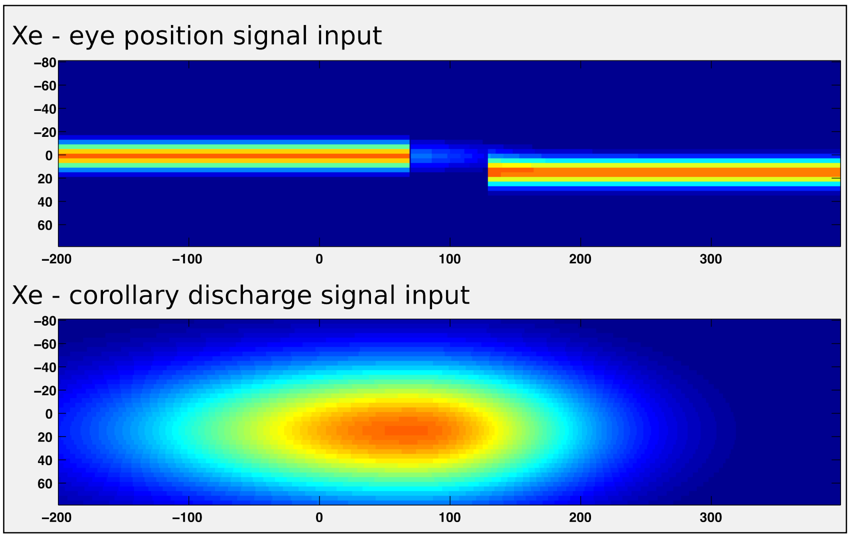
From: Van Wetter & Van Opstall (2008) Journal of Vision

Model for mislocalisation in total darkness



EP Signal →
CD Signal →
Xe
Wrb
feedback connection
feedforward connection
Retinal Signal → Xr → Web Xb
Wbh
Xh → Decision Neurons → Percept

Model: eye position signals



tonic eye
position signal

phasic corollary
discharge signal

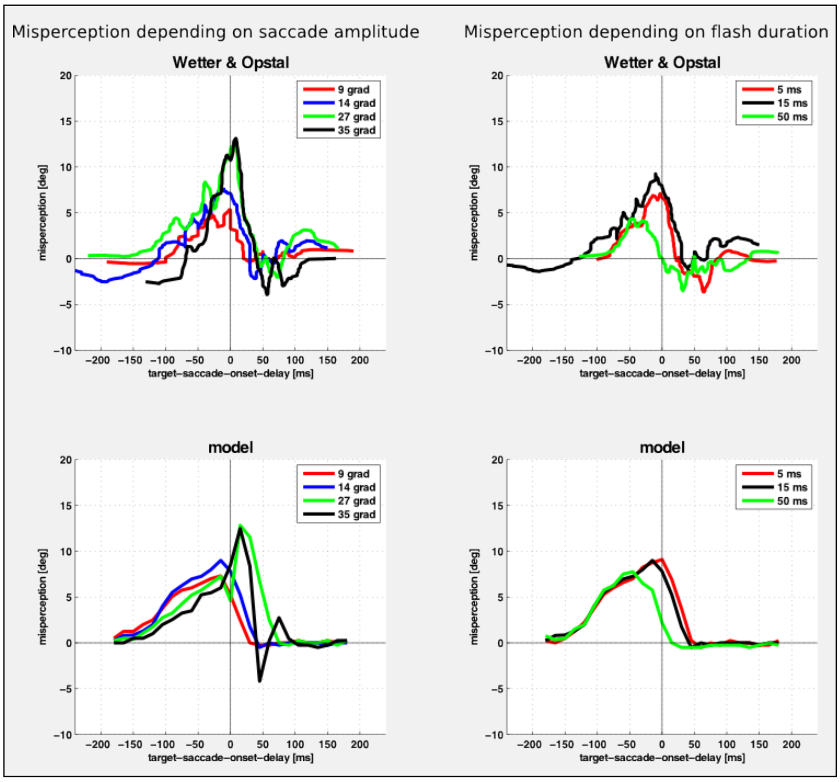
Results

saccade amplitude dependency

flash duration dependency

experimental
data

model
outcomes



Discussion

The function of the parietal cortex can be well described to provide stimulus location within different reference frames appropriate for the planned action.

Basis function networks can serve for cue-integration and coordinate transformation. The cue can be of different modality than the stimulus.

Basis function networks, if slightly modified can also explain psychophysical phenomena such as the mislocalisation of briefly flashed stimuli in total darkness.