



A Computational Approach to the control of voluntary saccadic eye movements

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Different eye movements
Experimental paradigms

Biological constraints

The cortical and subcortical areas involved
Architecture of the model

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Shape of the weights

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Visual attention :

- ▶ Feature selective (MT [Treue et al.(1999)], V4 [Desimone et al.(1995)])
- ▶ Spatial selective (V2,V4 [Reynolds(2000)])

Visual attention and oculomotor control might share the same neural substrates :

- ▶ Premotor theory of attention [Rizzolatti(1987)]
- ▶ Visual and oculomotor selection [Awh et al.(2006)]
- ▶ Control of eye movements and spatial attention [Moore et al. (2001)]
- ▶ A common network of functional areas for attention and eye movements [Corbetta et al (1998)]

These experiments reveal a causal relationship between the neural circuits controlling saccadic eye movements and shifts of covert spatial attention[Awh et al.(2006)].

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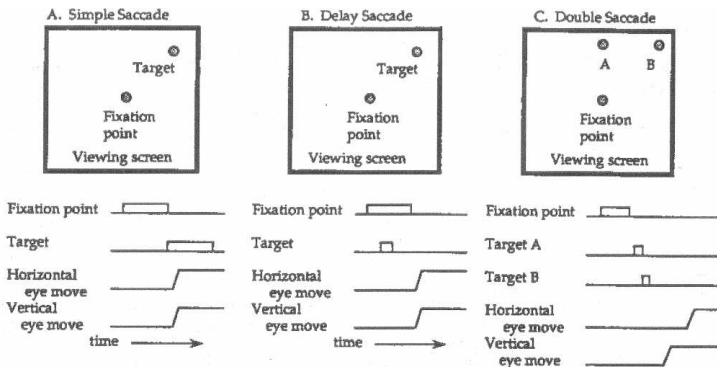


FIG.: Adapted from [Dominey et al.(1992)]

- ▶ simple saccade task
- ▶ delayed saccade task
- ▶ sequences : double, triple step task

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Cortical and subcortical areas involved in the control of voluntary eye movements

- ▶ Retina, Visual cortex
- ▶ Thalamus : LGN
- ▶ Posterior parietal cortex : LIP
- ▶ Frontal cortex : FEF, SEF, dIPFC
- ▶ Anterior Cingulate Cortex
- ▶ Basal ganglia
- ▶ Cerebellum
- ▶ Superior Colliculus
- ▶ Brain stem : Saccadic Burst generator (Spatial to temporal transformation)

[Pierrot-Deseilligny et al. (2004); Krauzlis et al. (2005); Goldberg (2000)]

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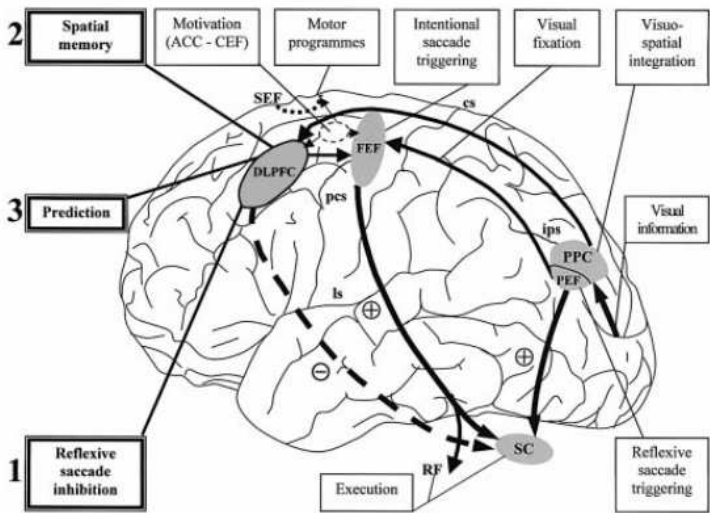


FIG.: Cortical areas involved in the control of saccades [Pierrot-Deseilligny(2003)]

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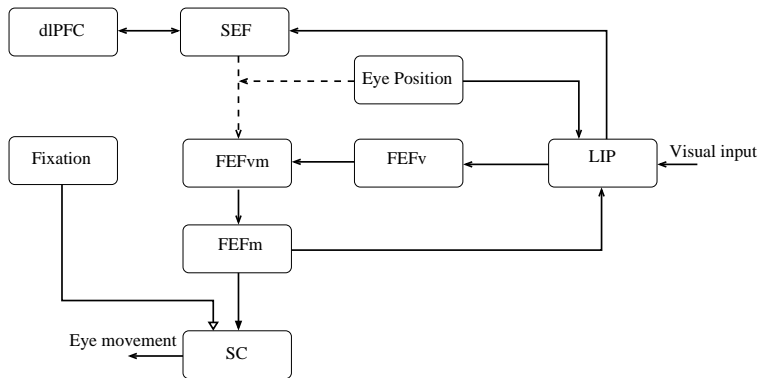


FIG.: Schematic illustration of the model's architecture

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The Lateral Intraparietal area (LIP)

Afferents :

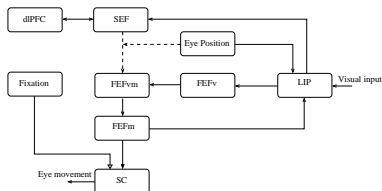
- ▶ feeds by the visual input
- ▶ projects both to
 - ▶ FEFV for a visual selection
 - ▶ SEF to memorize the presented locations

Frame of reference [Andersen(1985), Pouget(2002)] :

- ▶ we can decode from LIP (gain field property) :
 - ▶ an eye-centered representation (FEFV)
 - ▶ a head-centered representation (SEF)

Attentional modulation [Colby(1996),Gottlieb(1998)] :

- ▶ a selected target in FEFM is projected back to LIP



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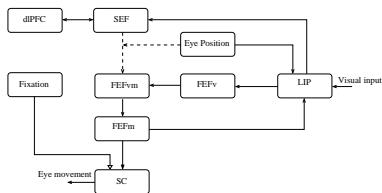
The Frontal Eye Field(FEF)

Different type of responses :

- ▶ Visual responses in FEFV
- ▶ Visual and memory responses in FEFVM
- ▶ Motor selection in FEFM
- ▶ FIXATION cells fire when the eyes must keep still

Afferents

- ▶ FIXATION inhibits SC
- ▶ FEFM excites SC

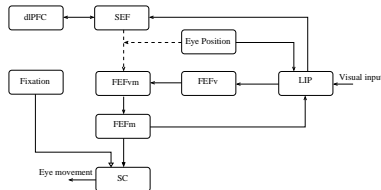


[Bruce et al.(1990) ; Umeno et al.(1997)]

The memory circuit

Specificities in the model :

- ▶ The working memory consists of the recurrent circuit SEF - dIPFC
- ▶ Memory in a head-centered frame of reference
- ▶ Excited by LIP
- ▶ Projecting memorized locations to FEFVM (head- to eye-centered projection)

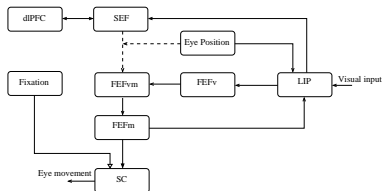


[Lu(2002), Schlag(1987), Tehovnik(1998), Goldman-Rakic(1987), Pierrot-Deseilligny(2003)]

The Superior Colliculus

Specificities in the model :

- ▶ Only a motor layer
- ▶ When : Inhibited by FIXATION
- ▶ Where : projections from FEFm to SC



[Mays et al.(1980), Lee et al.(1988)]

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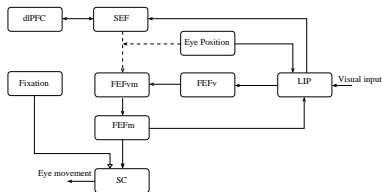
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Computational constraints (2/2)

- ▶ Remapping from Head- to eye-centered representations performed by a spatial convolution with sigmapi cells.



[Fix et al(2006) ; Weber,Wermter(2006)]

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Shapes of the fixed weights

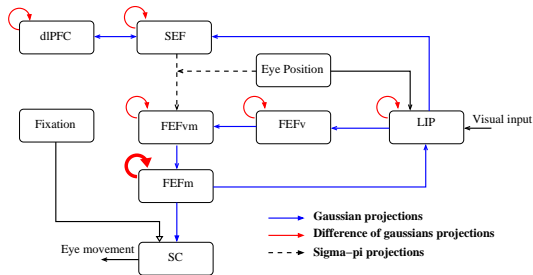


FIG.: Schematic illustration of the model's architecture

- ▶ Gaussian receptive fields for afferent connections
- ▶ Difference of Gaussians for lateral connections
- ▶ Fixed weights : no learning
- ▶ Specificity for FEFm : local excitatory, large inhibitory to implement a WTA-like competition

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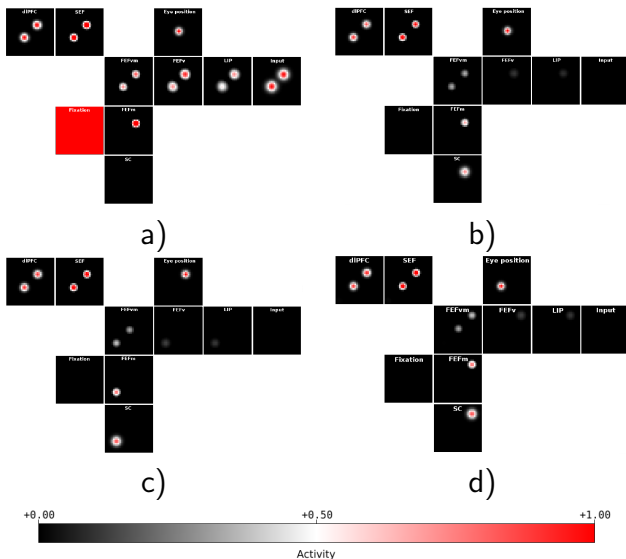
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Illustration of the model



For videos of the model : <http://www.loria.fr/~fix>

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Recordings of cells' activity in the model

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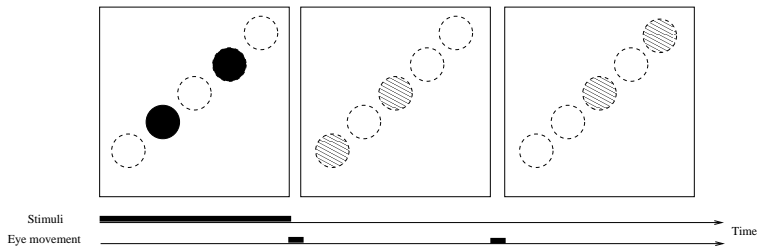
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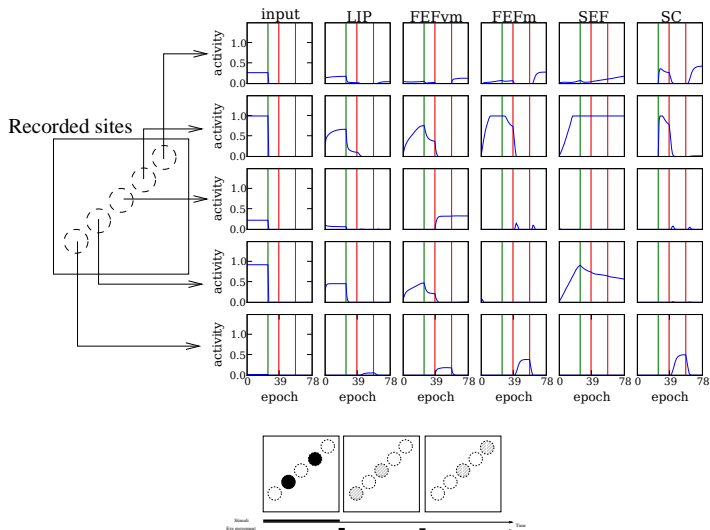
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Thank you for your attention.
Any questions ?

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The Frontal Eye Field (FEF)

Anatomical properties

- ▶ strong topographically organised projections with posterior parietal areas
- ▶ direct projection to SC and the brainstem (where)
- ▶ indirect projection to SC through the basal ganglia (when)

Physiological properties [Bruce et al.(1990) ; Umeno et al.(1997)]

- ▶ eye-centered frame of reference
- ▶ visual cells : Respond to visual stimuli onset
- ▶ movement cells : Response related to saccade onset
- ▶ visiomovement cells : Both visual and motor response
- ▶ Fixation cells : fire when a saccade must be inhibited

Crucial when a choice must be made between two targets

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State of the art

Local models

- ▶ brain stem : Robinson(1975), Scudder(1988), ...
- ▶ SC : van Opstal(1989), Optican(1994) , ...
- ▶ cerebellum : Dean(1994), Gancarz(1999), ...
- ▶ Basal ganglia : Dominey et al.(1992,1995), Brown(2004)
- ▶ FEF : Brown et al.(2004)
- ▶ LIP : Andersen et al.(1975); Pouget et al.(2001)

Global models

- ▶ LIP,FEF,PFC,SC,BG : Dominey et al. (1992, 1995)
- ▶ LIP,FEF : Mitchell et al. (2001, 2003)
- ▶ V4,LIP,IT,FEF,PFC,BG : Brown et al.(2004)

[Girard, Berthoz (2005)]

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Some of the hypotheses of [Dominey et al] and [Mitchell et al]

The memory is a property of

- ▶ LIP cells with recurrent connections
 - ▶ property of LIP [Dominey,Arbib(1992,1995) ; Mitchel,Zipser(2001)]
 - ▶ remapped by a moving-hill property [Dominey,Arbib(1992,1995)]
 - ▶ eye- and head-centered cells in LIP [Mitchel,Zipser(2001)]
 - ▶ **but** no moving hill in FEF [Sommer,Wurtz(2006)]
- ▶ or of FEF :
 - ▶ N layers for N-step task [Mitchel,Zipser(2003)]

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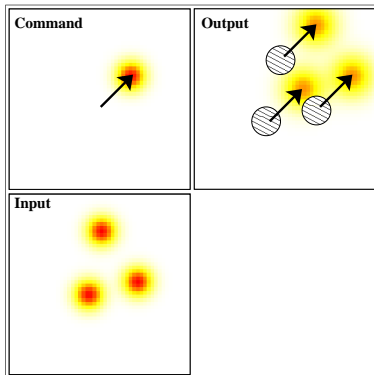
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Using sigma pi cells to remapp activities



$$I_{output}(\vec{y}, t) = norm * \sum_{\vec{x} \in [0; N]^2} Input(\vec{x}, t) \cdot Command(\vec{y} - \vec{x} + \vec{c}, t)$$

[Fix et al(2006), Weber and Wermeter(2007)]

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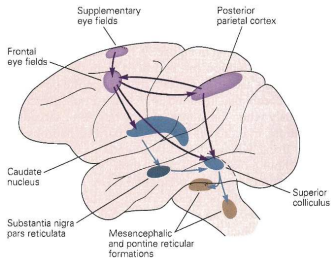
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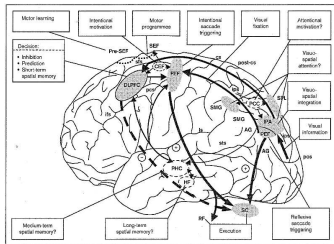
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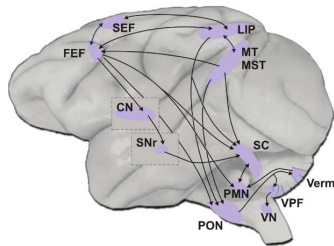


Goldberg 2000

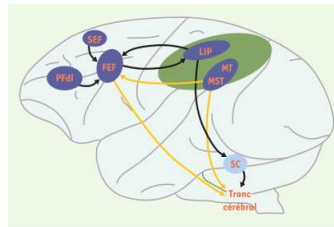


Pierrot Deseilligny 2004

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Krauzlis 2005



Wardak 2004

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