





A Computational Approach to the control of voluntary saccadic eye movements

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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 migth 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)]. A Computational Approach to the control of voluntary saccadic eye movements

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Different eye movements

- Vergence, optokinetic reflex, vestibulo-ocular reflex
- Smooth pursuit
 - keep foveated a small moving stimulus
 - slow and continuous movements : from 80 to 160 deg/sec
 - small amplitude
- Sacades, microsaccades
 - bring an object of interest on the fovea
 - ▶ fast movements : up to 1000 deg/sec
 - large range of amplitudes: less than 1 degree, up to 100 degrees

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Fixation

Movements of the eyes - 2nd Edition - Pion London - R. Carpenter 1988

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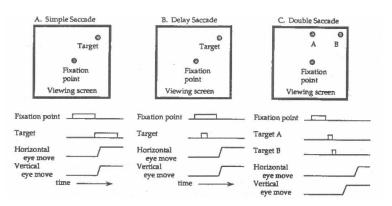


FIG.: Adapted from [Dominey et al.(1992)]

- 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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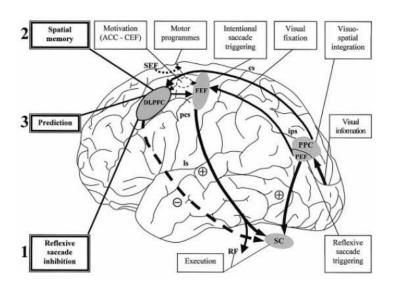


FIG.: Cortical areas involved in the control of saccades [Pierrot-Deseilligny(2003)]

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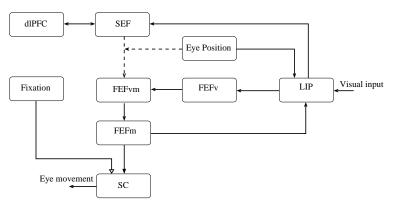


FIG.: Schematic illustration of the model's architecture

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The Lateral Intraparietal area (LIP)

Afferents:

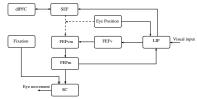
- feeds by the visual input
- projects both to
 - FEFV for a visual selection
 - SEF to memorize the presented locations

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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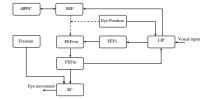
The Frontal Eye Field(FEF)

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



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

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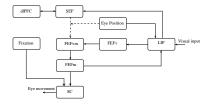




The memory circuit

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), Shlag(1987), Tehovnik(1998), Goldman-Rakic(1987), Pierrot-Deseilligny(2003)] A Computational Approach to the control of voluntary saccadic eye movements

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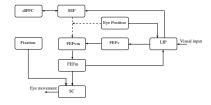
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The Superior Colliculus

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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Computational constraints (1/2)

- Distributed, local, asynchronous and numerical computations
- ► Set of 2-dimensional maps of units of size NxN (N=30 for the simulations)
- Dynamic Neural Fields

$$\Delta u(x,t) = -\alpha.u(x,t) + \sum_{y} w(x,y).u(y,t) + I(x,t)$$

$$I(x,t) = \sum_{y} w(x,y).v(y,t) \text{ for classical cells}$$

$$I(x,t) = \sum_{i} w_{i}.\prod_{v \in E_{i}} v(y,t) \text{ for sigmapi cells}$$

[Amari(1977), Taylor(1999)]

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Dynamic Neural Fields

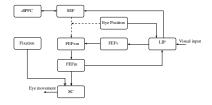
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Computational constraints (2/2)

 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

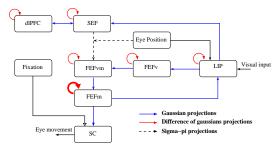


Fig.: Schematic illustration of the model's architecture

- 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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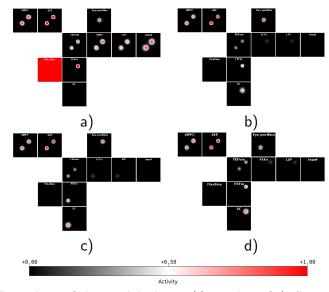
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Illustration of the model



For videos of the model : http ://www.loria.fr/ \sim fix

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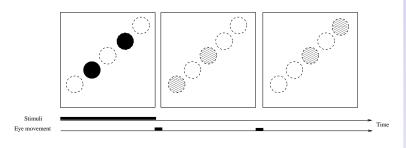
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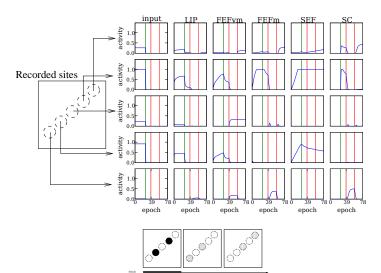
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Properties of the model

- ► The memory is a property of the circuit SEF, dIPFC not a parietal intrinsic property
- Single shot remapping from a head-centered memory (versus moving hill)
- Selection of a target in FEFm from :
 - ▶ visual targets : LIP \rightarrow FEFv \rightarrow FEFvm
 - ▶ remembered targets : $SEF \rightarrow FEFvm$
- ▶ The selection of a motor target is sent back to LIP

Applicable to :

 simple saccade, memory-guided saccades, n-step saccades without order

Functional point of view instead of detailed description of each area

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- Add a mechanism to learn the sequences of saccades :
 - ► Mitchel&Zipser(2003) : N layers for N-step task
 - ► Dominey&Arbib(1995) : Learned by reinforcement
- ► Study the role of the basal ganglia loop in the selection of a target
- Consider other paradigms such as antisaccade task (supposed to involve the SEF)
- Analyse how to define a semantic for the stimuli (e.g. fixation stimulus)
- Study the influence of other areas (e.g. ventral pathway)

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Thank you for your attention. Any questions?

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Testing quasi visual neurons in the monkey's frontal eye field with the triple step paradigm Tian, J., Shlag, J., Shlag-Rey, M.(2000) Experimental Brain Research; 130; 433–440 SEF:

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The Lateral Intraparietal area (LIP)

- visual responses
- gain fields properties: retinotopic receptive fields, modulated by the position of the eyes [Andersen et al.(1985)]
 - provides the substrate to decode eye- and headcentered representation [Pouget et al.(2002)]
- ▶ modulated by behavioral relevance, attention [Colby et al.(1996),Gottlieb et al.(1998)]
- sustained activity during delay task [Gnadt(1988),Barash(1991)]
- remapped responses [Merriam et al.(2005)]
- ▶ doesn't seem to encode a saccadic target (e.g. in antisaccade task [Gottlieb(1999))

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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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Some properties of SEF:

- learning and initiating motor programms such as saccadic sequences [Lu(2002)]
- multiple frames of reference in SEF ([Shlag(1987)],head-centered [Tehovnik(1998)])

Some properties of dIPFC [Goldman-Rakic(1987)] :

- spatial short term memory
- regulation of motor outputs : initiating, facilitating, canceling

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The Superior Colliculus

Superior Colliculus [Mays(1980)] :

- encodes spatially (amplitude, direction) the target of an eye movement
- visual responses in the superficial layers, motor responses in the deepest layers

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- ▶ inhibited by SNr in the basal ganglia (when)
- afferents from FEF and LIP (where)

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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 recurent 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)]

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- ▶ or of FEF :
 - N layers for N-step task [Mitchel, Zipser(2003)]

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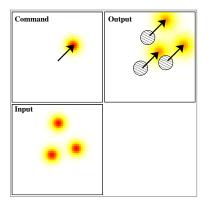
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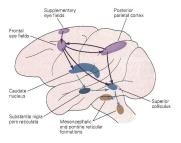


$$I_{output}(\vec{y},t) = norm* \sum_{\vec{x} \in [0:N]^2} Input(\vec{x},t).Command(\vec{y} - \vec{x} + \vec{c},t)^{Shape of the weights}$$
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[Fix et al(2006), Weber and Wermeter(2007)]

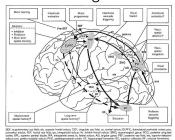
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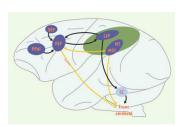
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Goldberg 2000



Pierrot Deseilligny 2004





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