Exchange with the environment

Sensation

$$s = \mathbf{g}(\boldsymbol{\psi}, a) + \omega$$

Sensory delays

Hidden states

$$\dot{\boldsymbol{\psi}} = \mathbf{f}(\boldsymbol{\psi}, \mathbf{a}) + \omega$$

$$\tilde{m} = \arg\min_{\tilde{m}} F(\tilde{s}, \tilde{m})$$

Internal states

$$a = \arg\min_{a} F(\tilde{s}, \tilde{m})$$

Motor delays

environment

Action

agent

Separated by a Markov blanket

1
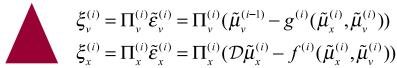
$\mathbf{X}_o^{(1)}$ *Angular direction of gaze in extrinsic coordinates*

Angular direction of target in extrinsic coordinates $\mathbf{X}_t^{(1)}$ $\qquad$ $\mathbf{X}_t^{(1)} - \mathbf{X}_o^{(1)}$ *Angular position of target in intrinsic coordinates*

oculomotor
signals

*reflex
arc*

proprioceptive input $\quad s_o = \mathbf{X}_o^{(1)}$

Sensory inputs

pons

retinal input $\quad s_t = \mathbf{X}_t^{(1)} - \mathbf{X}_o^{(1)}$

frontal eye fields

geniculate

Top-down or backward
predictions

Bottom-up or forward
prediction error

visual cortex

Prediction error (superficial pyramidal cells)

$$\xi_v^{(i)} = \Pi_v^{(i)} \tilde{\varepsilon}_v^{(i)} = \Pi_v^{(i)} (\tilde{\mu}_v^{(i-1)} - g^{(i)}(\tilde{\mu}_x^{(i)}, \tilde{\mu}_v^{(i)}))$$

$$\xi_x^{(i)} = \Pi_x^{(i)} \tilde{\varepsilon}_x^{(i)} = \Pi_x^{(i)} (\mathcal{D}\tilde{\mu}_x^{(i)} - f^{(i)}(\tilde{\mu}_x^{(i)}, \tilde{\mu}_v^{(i)}))$$

Conditional predictions (deep pyramidal cells)

$$\dot{\tilde{\mu}}^{(i)} = \mathcal{D}\tilde{\mu}^{(i)} - \frac{\partial \tilde{\varepsilon}^{(i)}}{\partial \tilde{\mu}^{(i)}} \cdot \xi^{(i)}$$

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Pursuit initiation:
prediction and error

$g(\tilde{m})$

$x_t^{(1)} - x_o^{(1)}$

Ramp motion:
hidden states

$\mu_x^{(i)}$

hidden causes

$\mu_v^{(1)}$

perturbation and action

$\mathbf{v}$

a

time (ms)

time (ms)

Position

Position

3

4

Distance from target

$$|\mathbf{x}_t^{(1)} - \mathbf{x}_o^{(1)}|$$

Peak lag

Pursuit initiation:
prediction and error

Periodic motion:
hidden states

hidden causes

perturbation and action

Smooth pursuit:
prediction and error

Half-cycle motion:
hidden states

hidden causes

perturbation and action

Anticipatory model: prediction and error

Aperiodic motion: hidden states

hidden causes

hidden states

hidden causes

perturbation and action

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