

# Temporal pattern recognition in retinal ganglion cells is mediated by dynamical inhibitory synapses

**Simone Ebert**, Thomas Buffet, Semihchan Sermet, Olivier Marre, Bruno Cessac

07.02.2023

**Complex Days 2023**

Nice

*Inria*

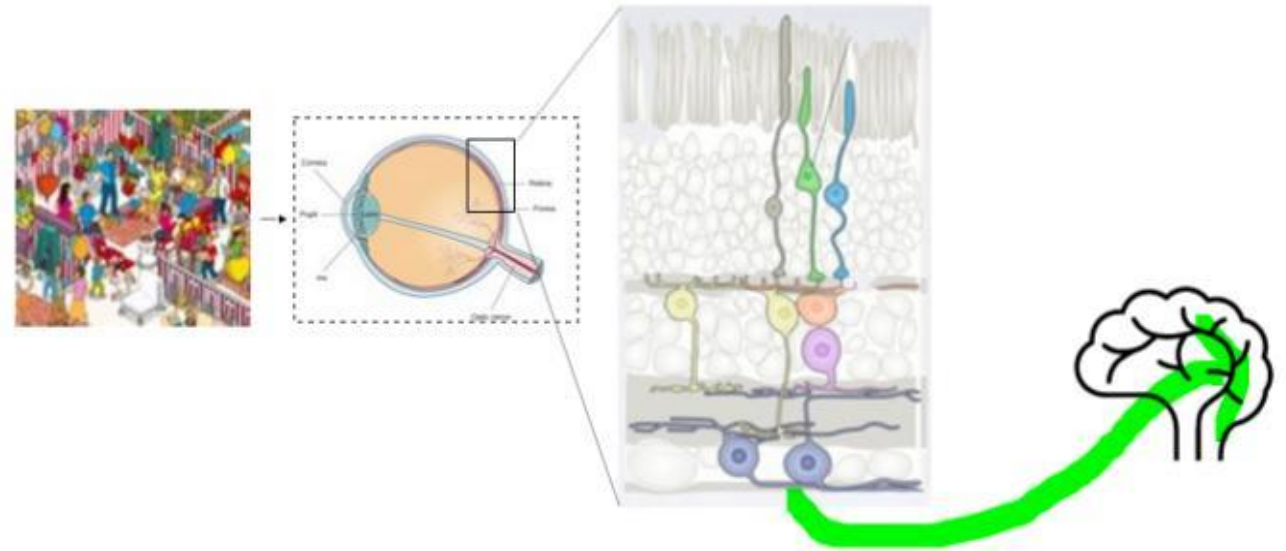


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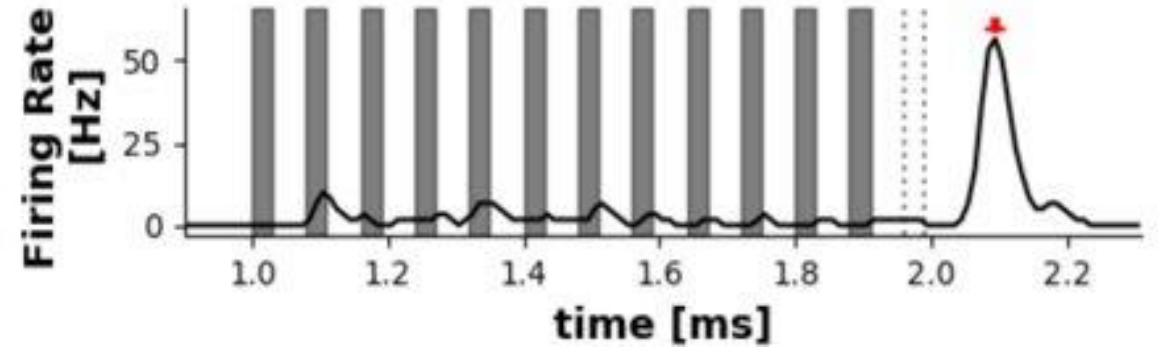
# Outline

- **Visual information processing in the Retina**
- Anticipation and Surprise in the Retina
- A computational Model with Dynamic Inhibitory Coupling



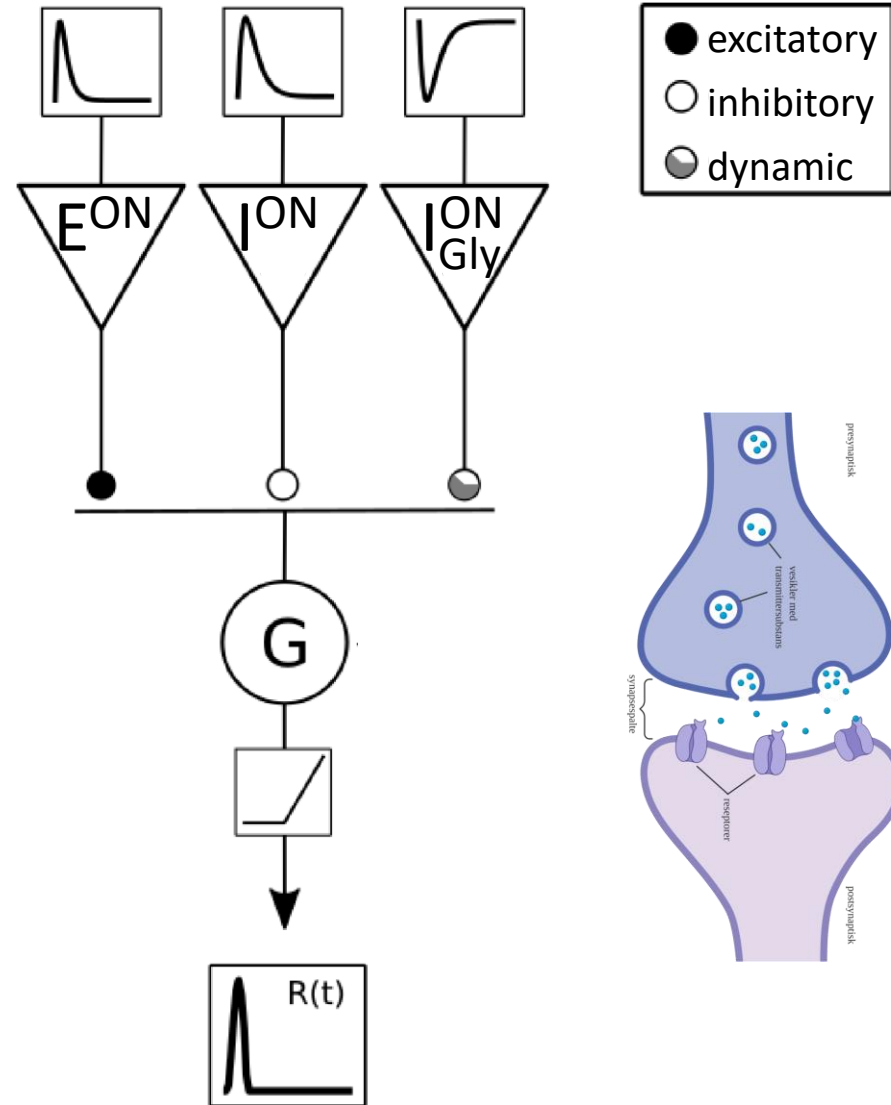
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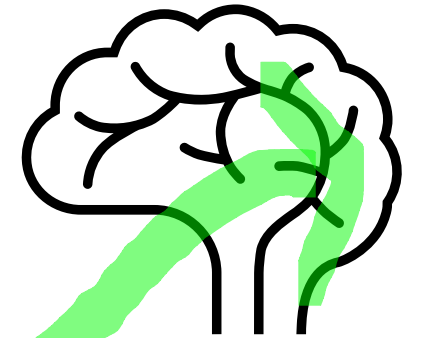
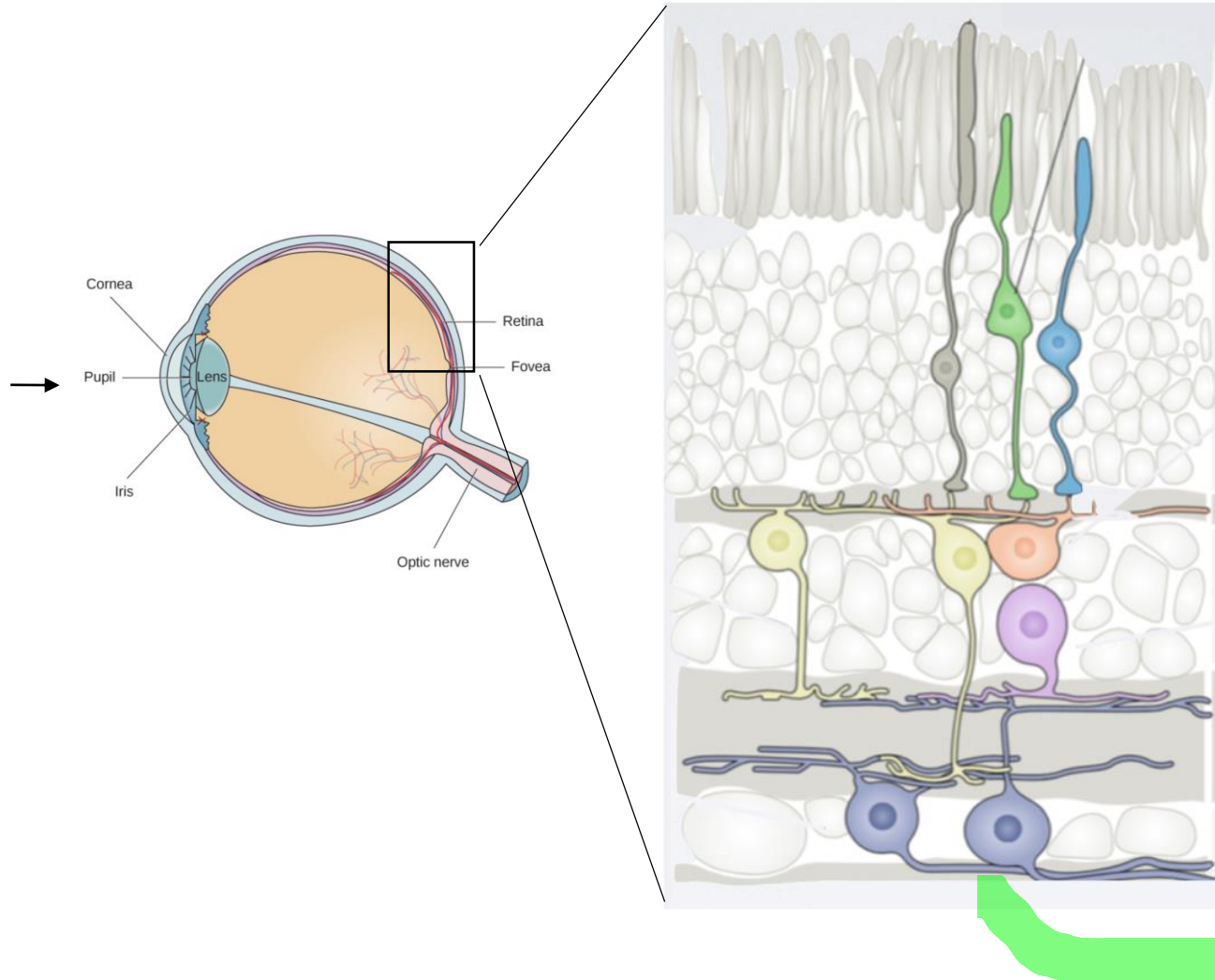


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- **A computational model with dynamic inhibitory coupling**



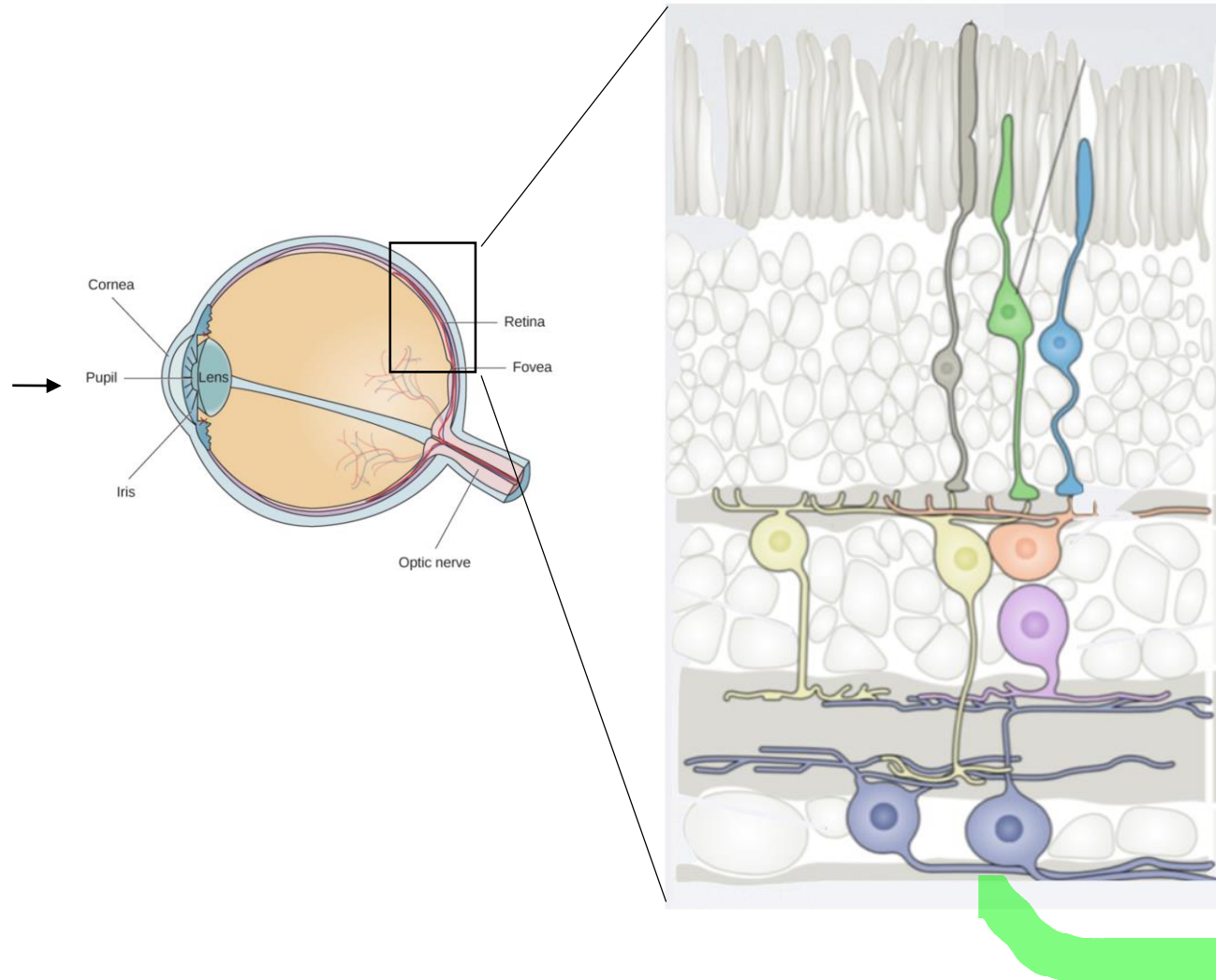
# Information Processing in the Retina





# Information Processing in the Retina

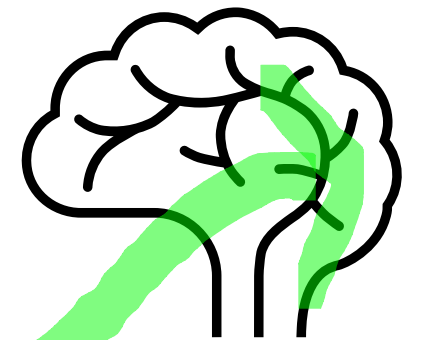
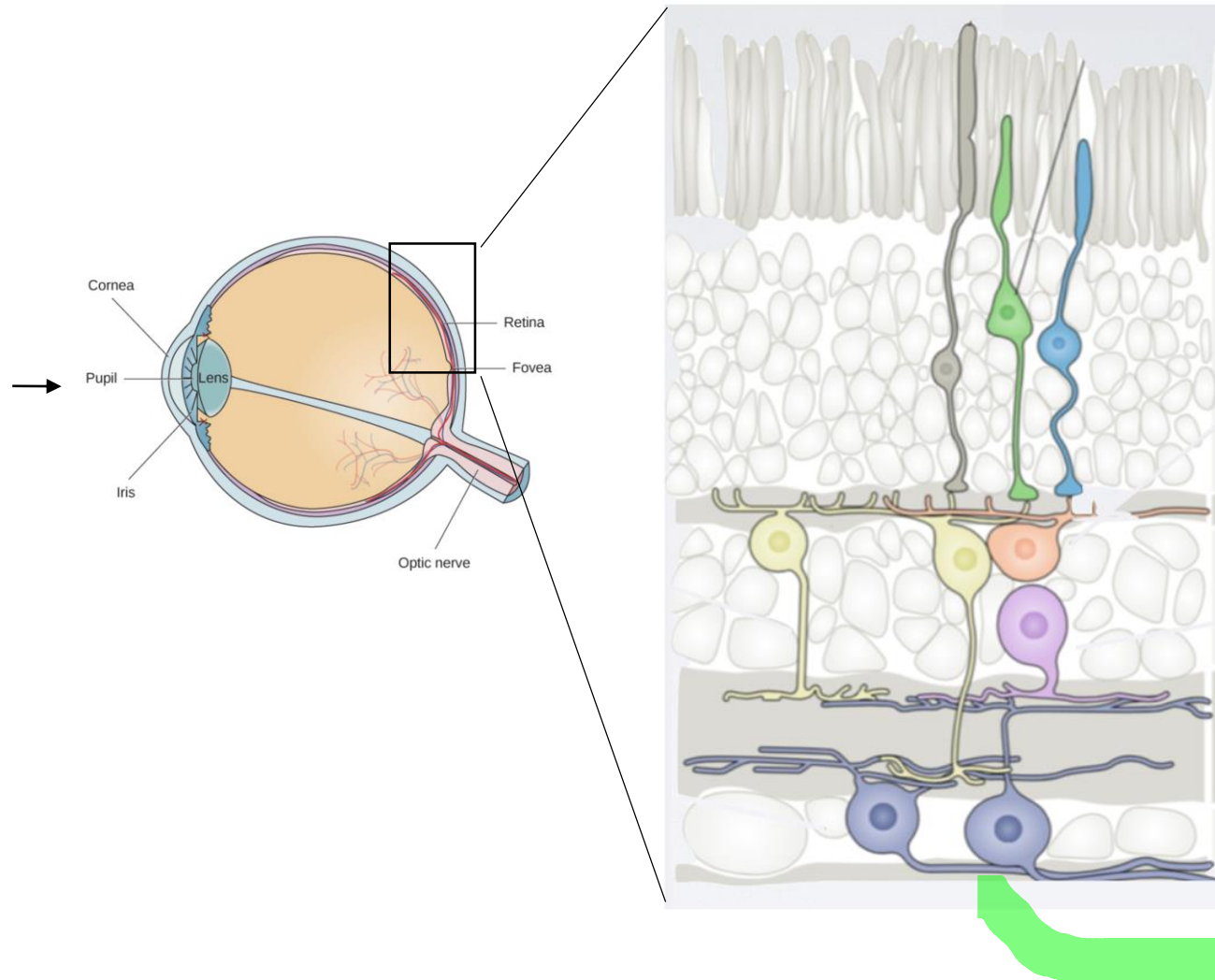
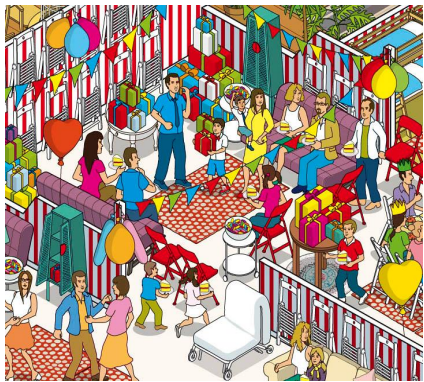
- Transforms visual inputs into neuronal responses



# Information Processing in the Retina

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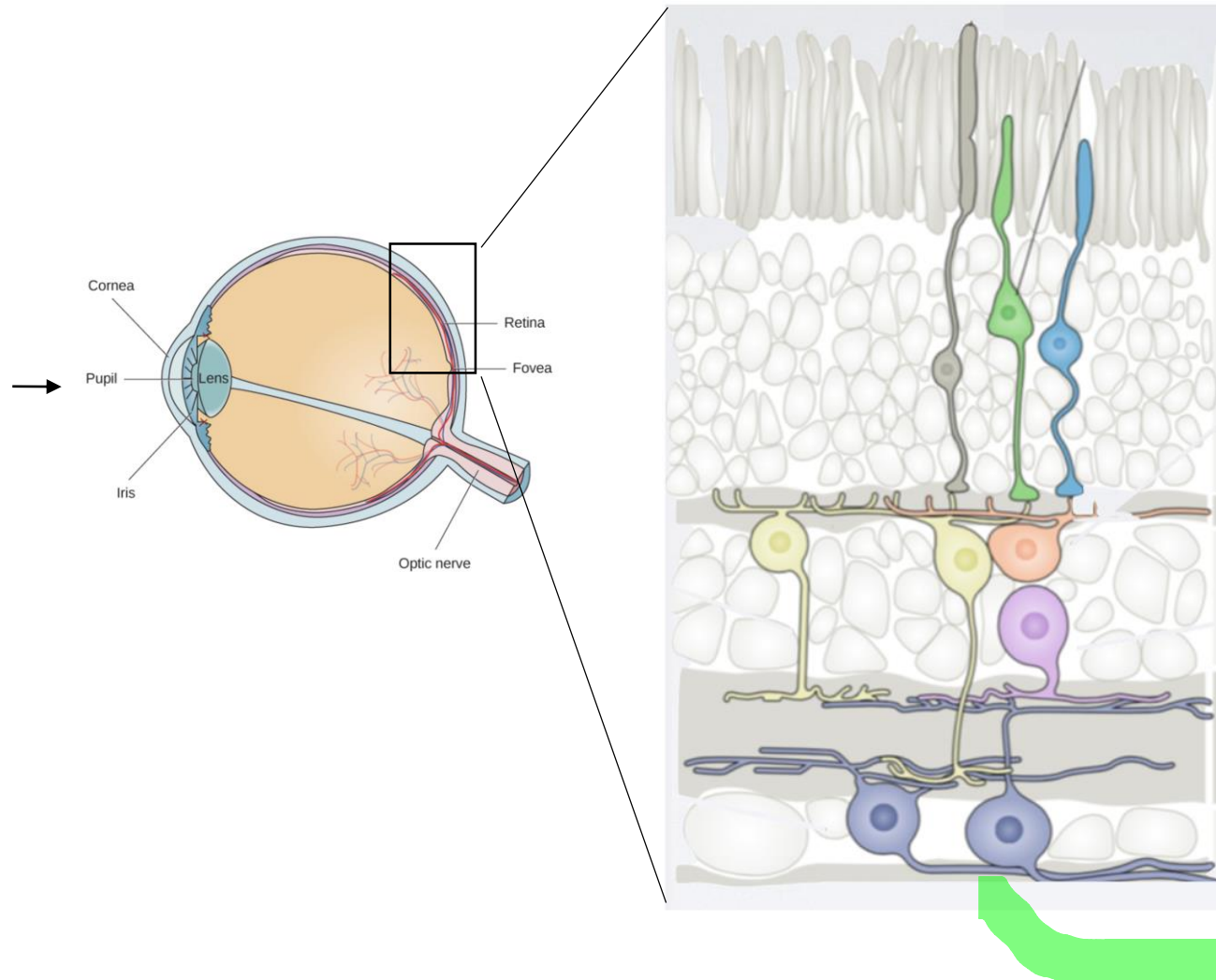
- Multi-layered dynamical system



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# Information Processing in the Retina

- Transforms visual inputs into neuronal responses
- Multi-layered dynamical system
- Complex Network of excitatory and inhibitory cells that extracts relevant information



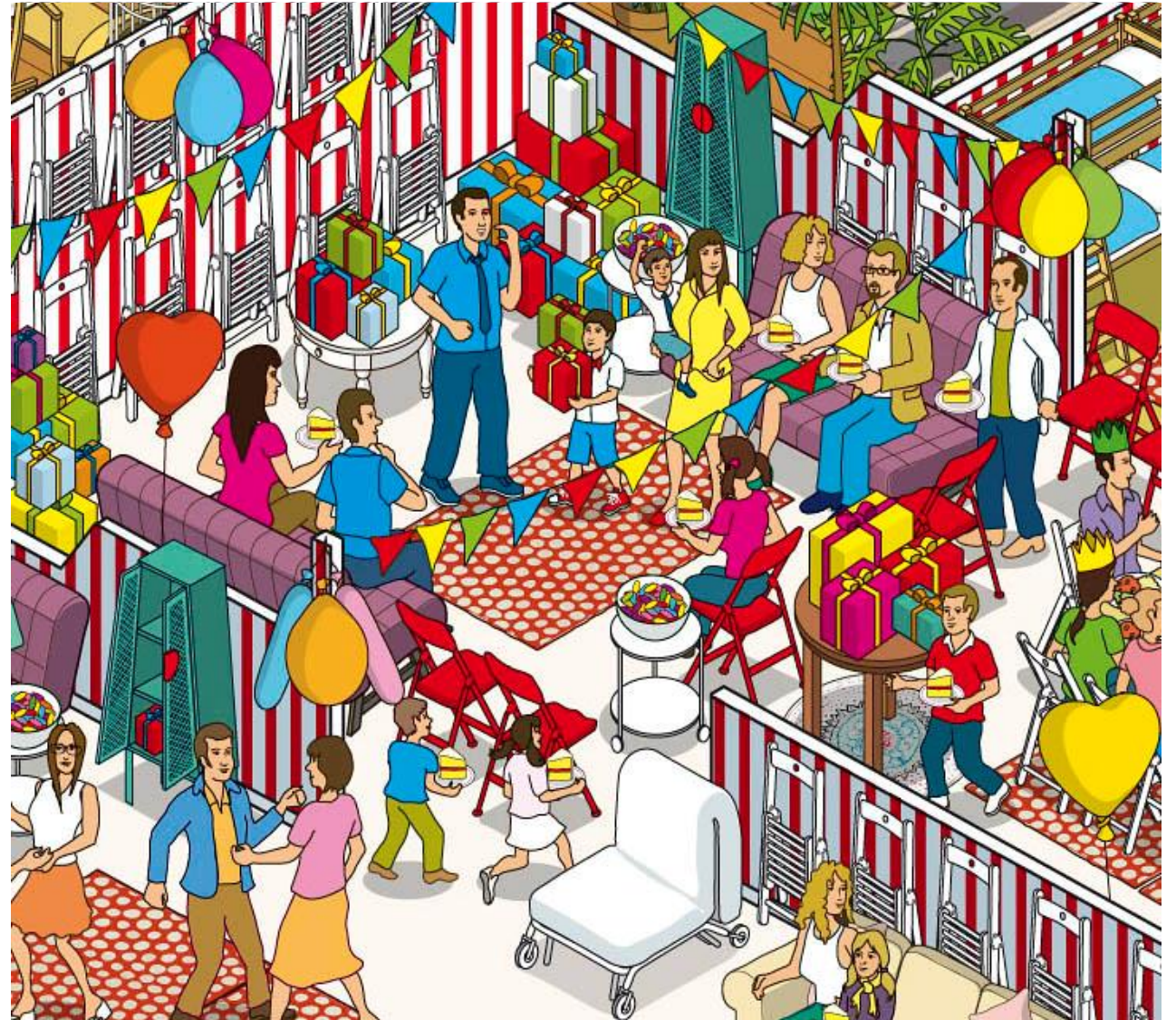
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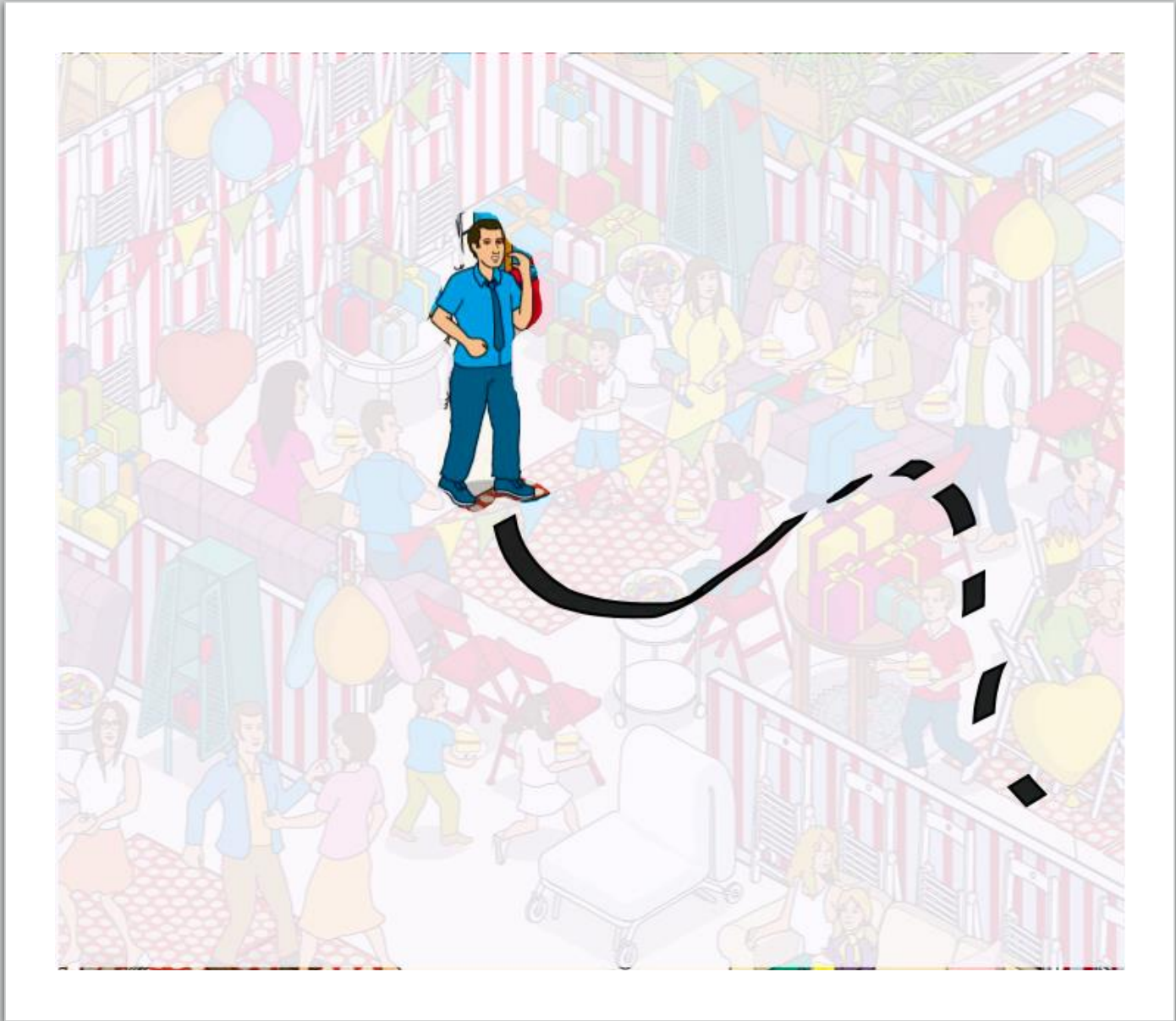
# Prediction and Surprise in the Retina

- The retina does not encode the visual scene *per se*



# Prediction and Surprise in the Retina

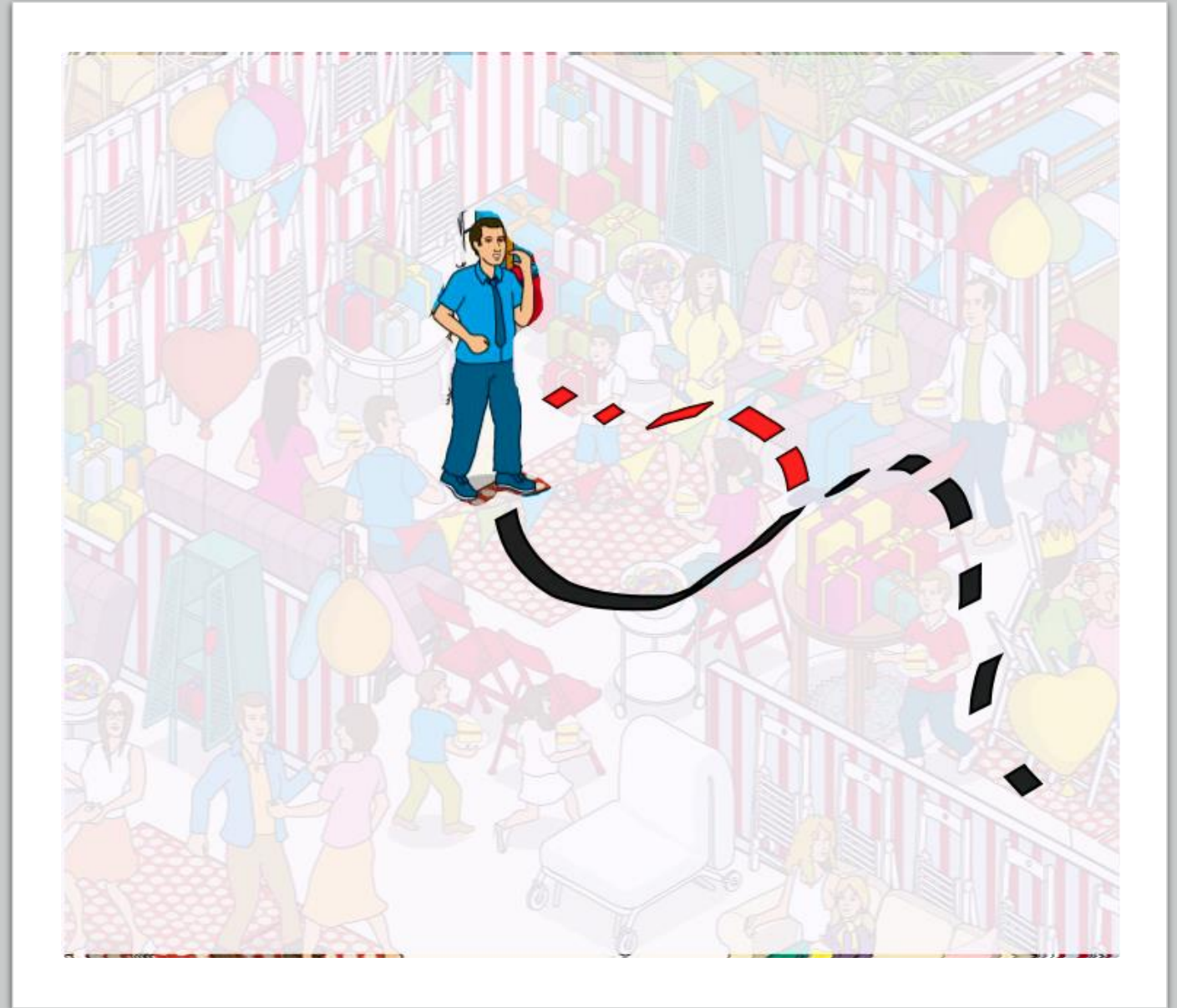
- The retina does not encode the visual scene *per se*
- but forms predictions about future stimuli





# Prediction and surprise in the Retina

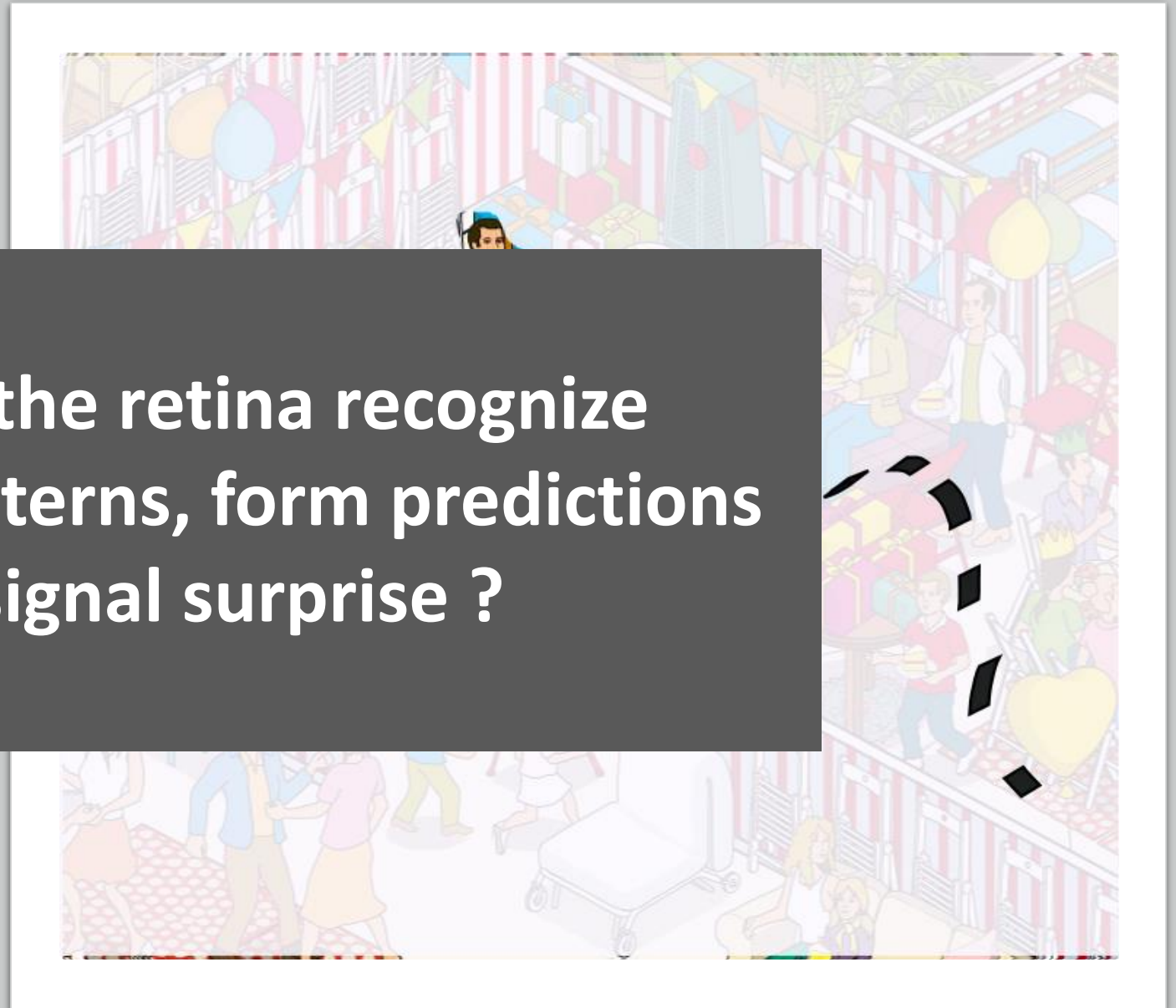
- The retina does not encode the visual scene *per se*
- but forms predictions about future stimuli
- and signalling surprise about unpredicted inputs (= error signal)



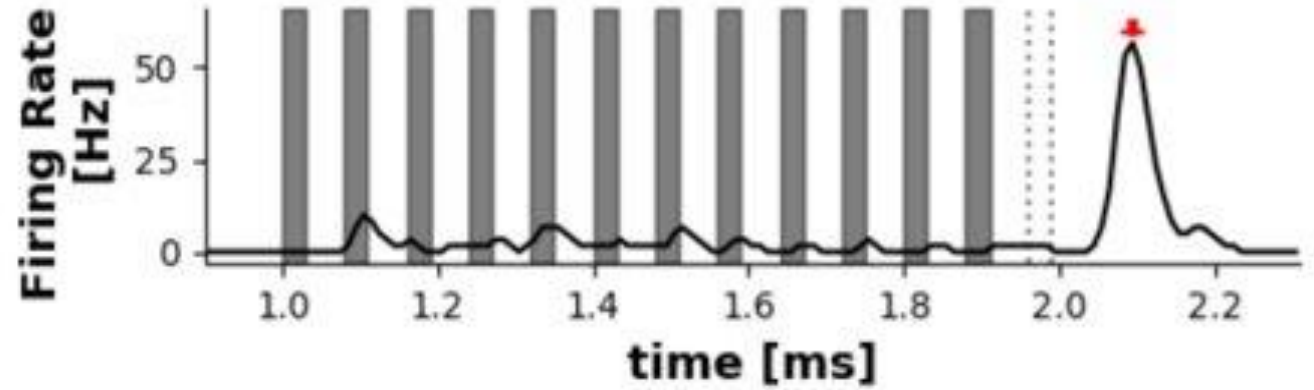
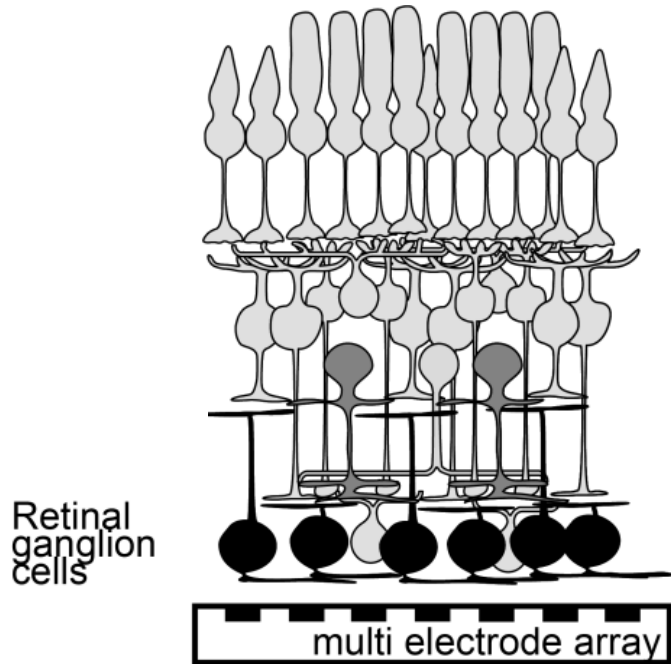
# Prediction and surprise in the Retina

- The retina does not just passively receive the visual scene
- but forms predictions about future stimuli
- and signalling surprise about unpredicted inputs (= error signal)

**How can the retina recognize temporal patterns, form predictions and signal surprise ?**



# Surprise Response in the Retina

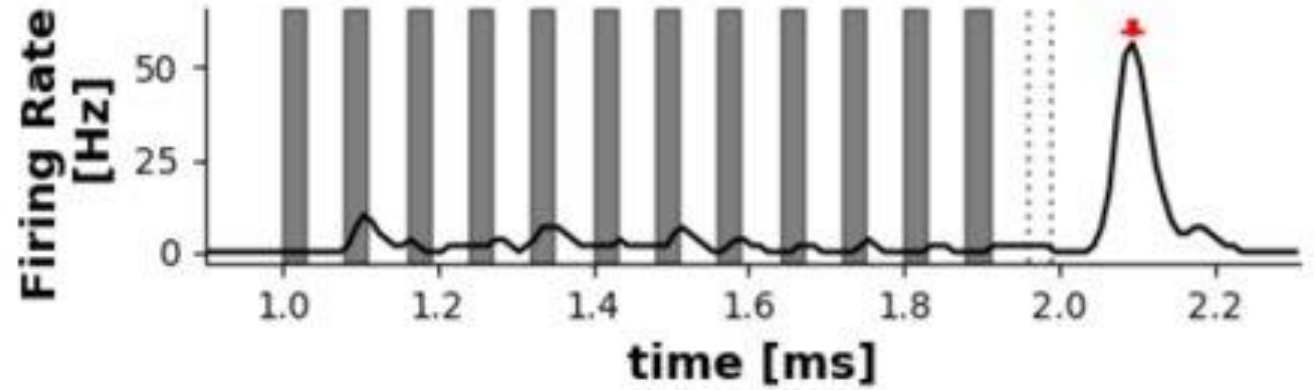
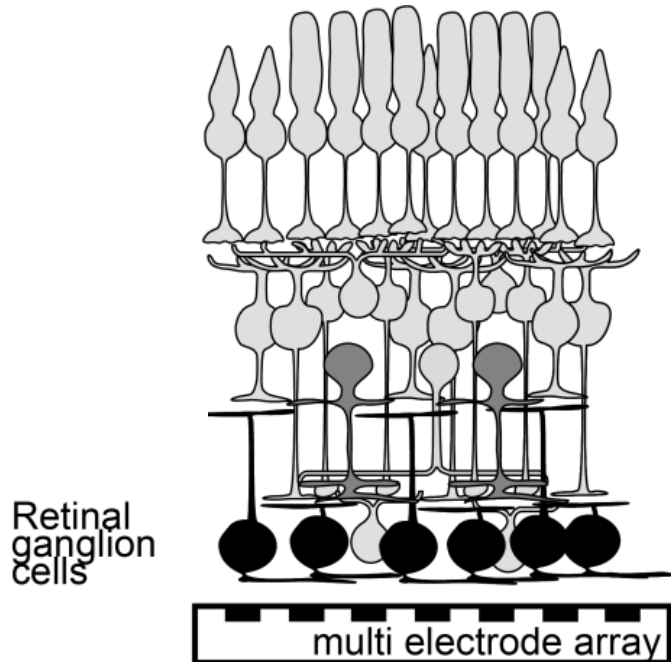


- periodic flash sequence
- omitted flash
- ↓ pulse of activity signaling the missing stimulus

first observed by Schwartz et al, 2007



# Surprise Response in the Retina



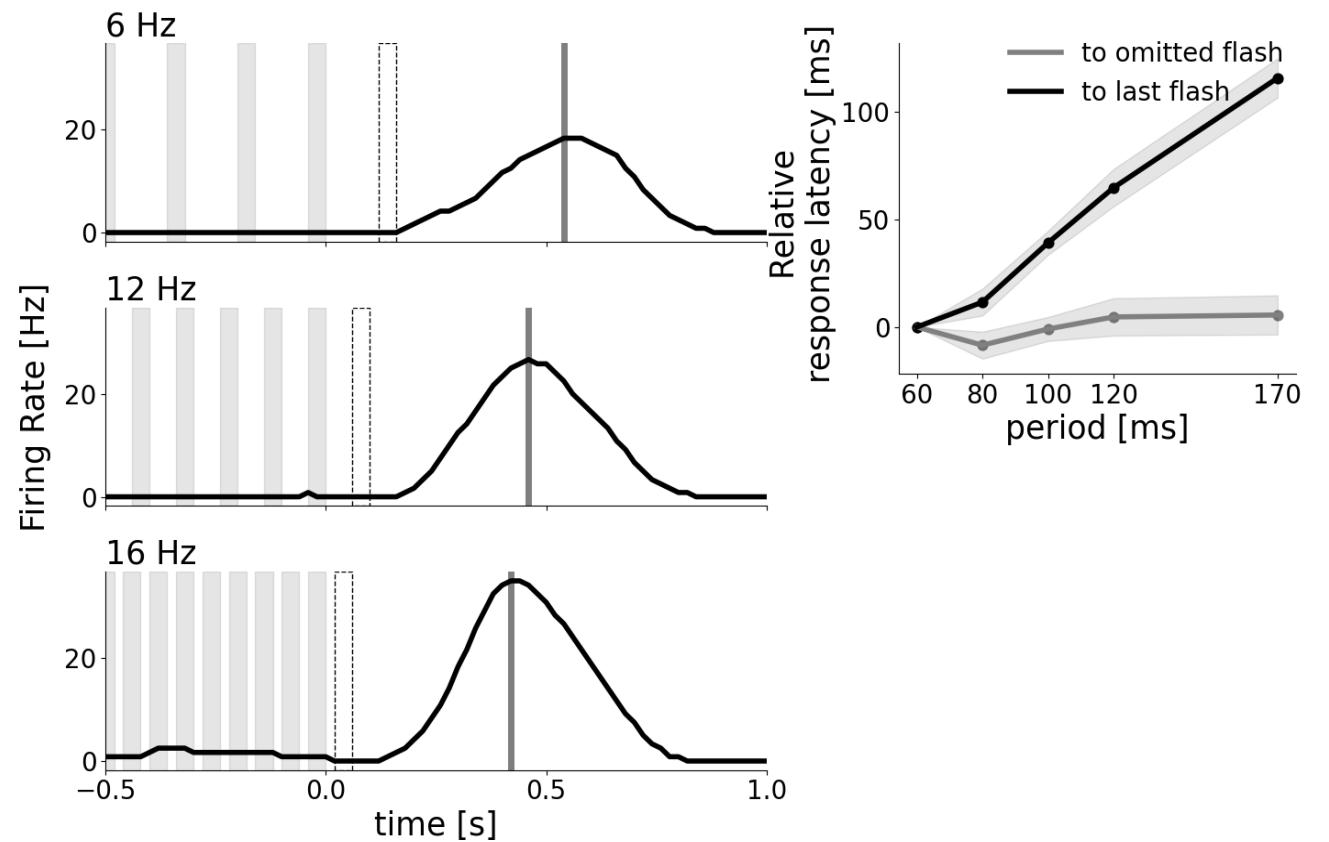
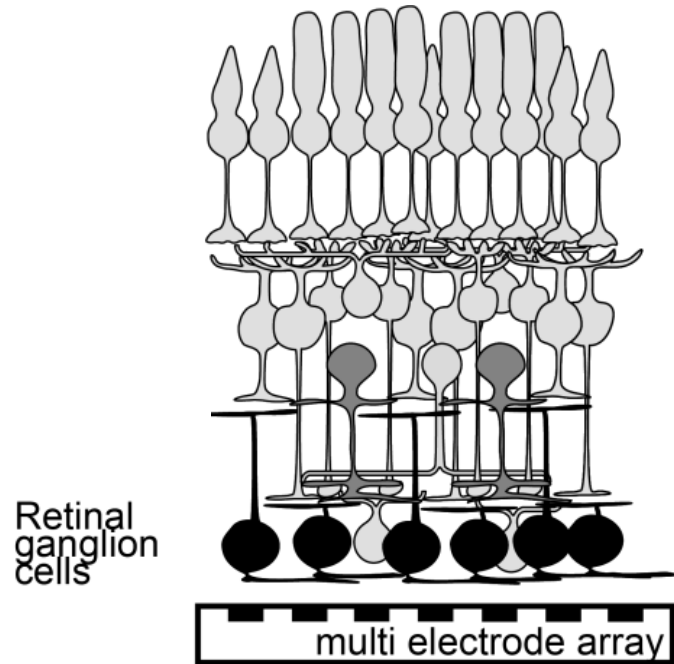
- periodic flash sequence
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The retina emits an **Omitted Stimulus Response** when an expected stimulus in a periodic sequence is missing.

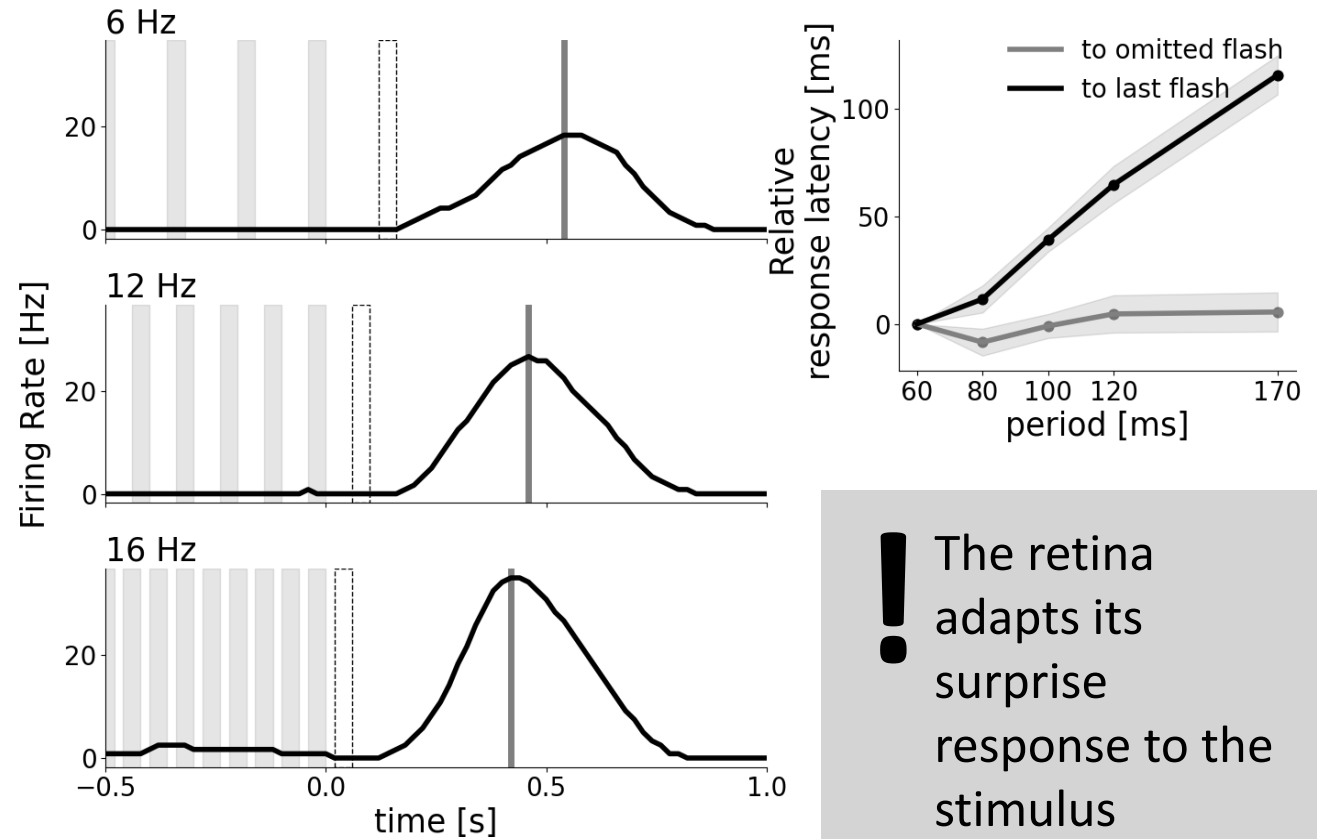
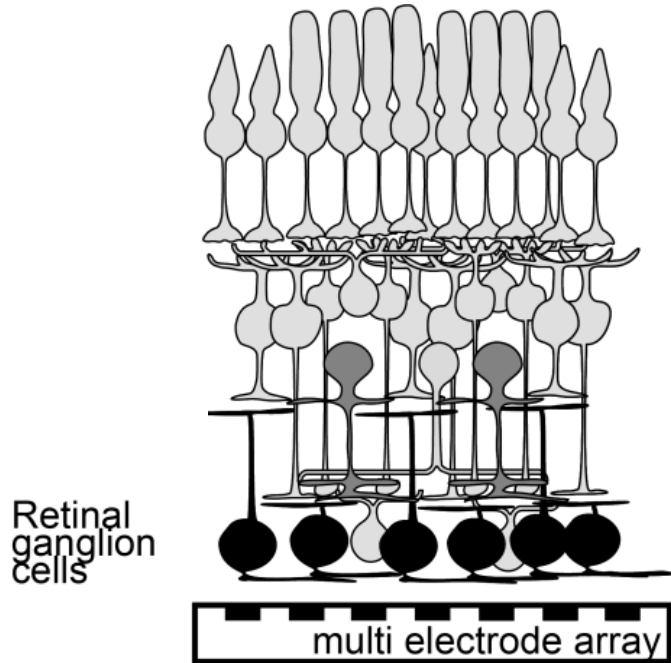
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# Response latency shifts with stimulus period



first observed by Schwartz et al, 2007

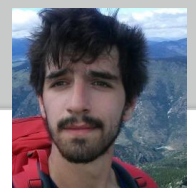
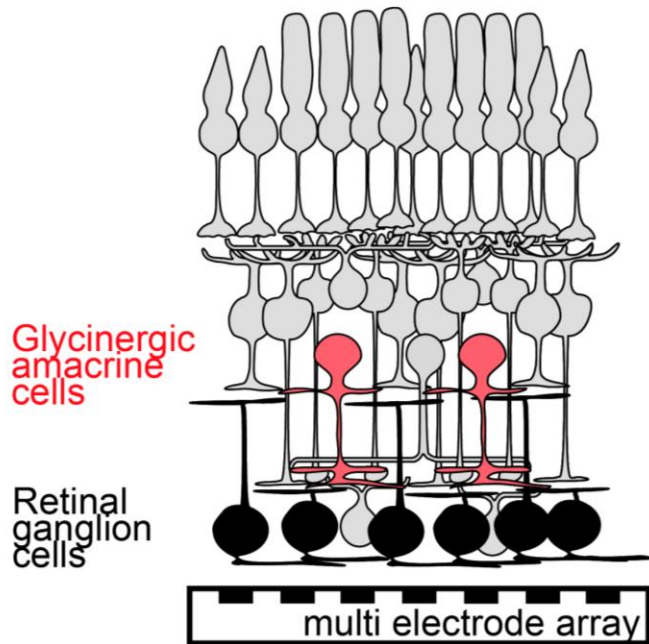
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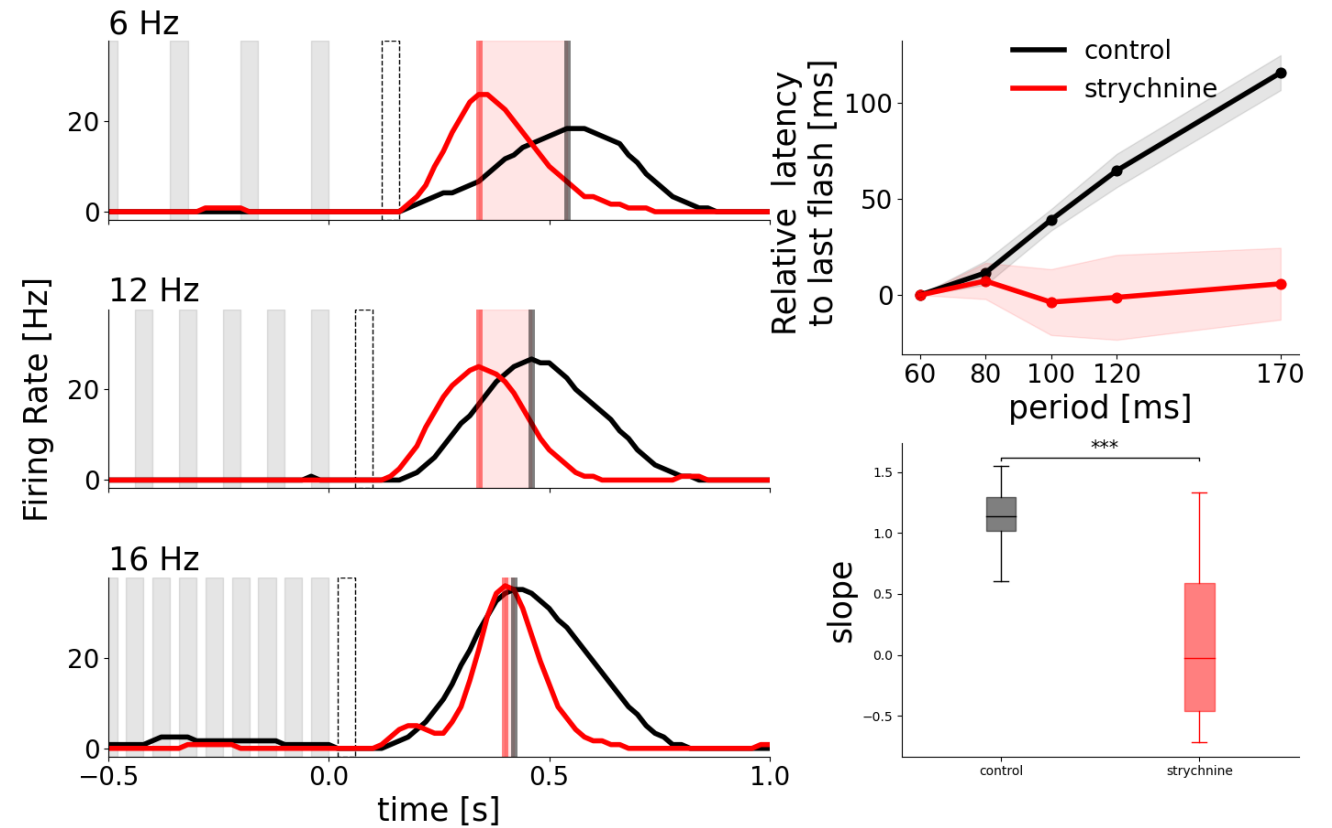
! The retina adapts its surprise response to the stimulus

first observed by Schwartz et al, 2007

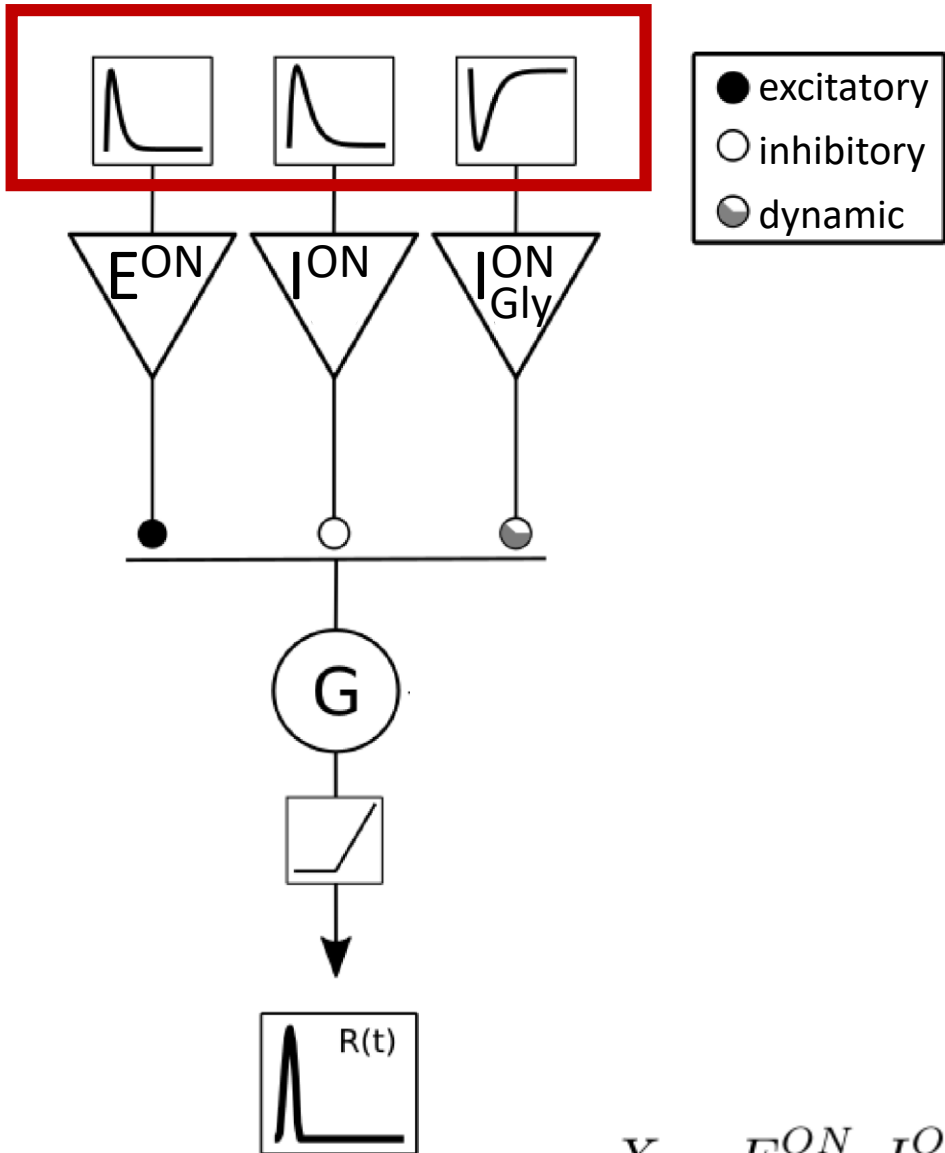
# Inhibition is necessary for latency scaling



Thomas Buffet



# Dynamic Network Model of the Retina



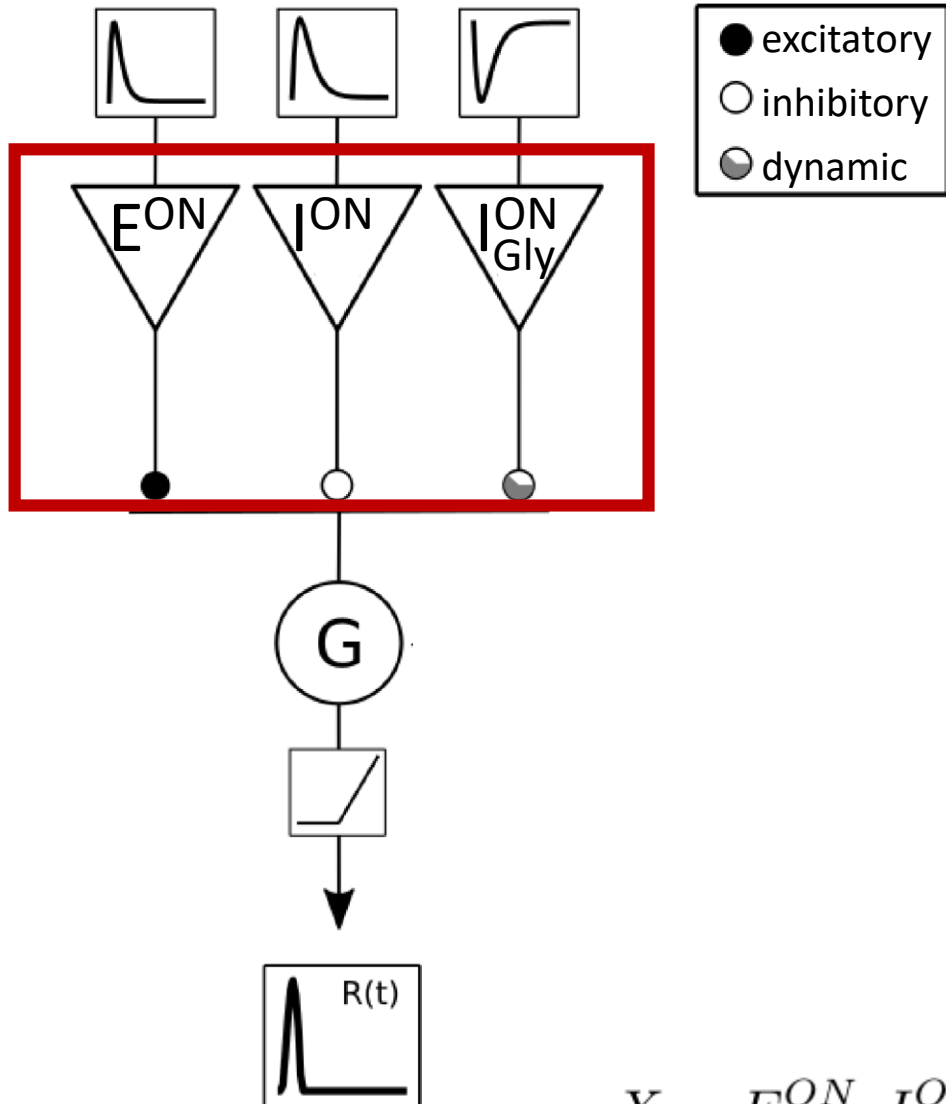
## 1. Convolution of stimulus and temporal kernel

$$F_X(t) = S_X[\alpha_X * s](t)$$

$$X = E^{ON}, I^{ON}, I_{Gly}^{OFF}$$



# Dynamic Network Model of the Retina



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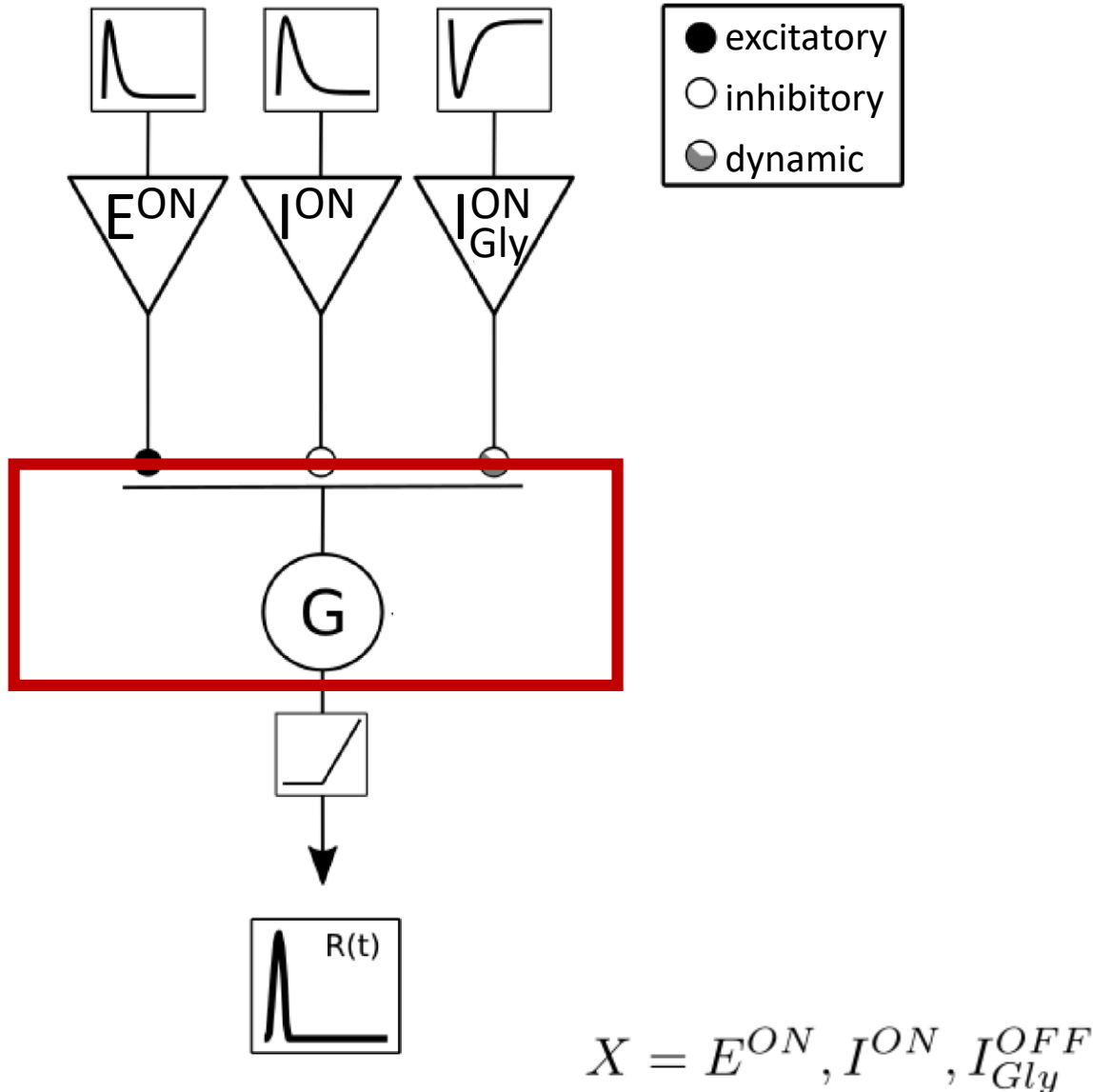
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## 2. Intermediate units integrate the signal

$$\frac{dV_X}{dt} = -\frac{V_X}{\tau_X} + F_X(t)$$

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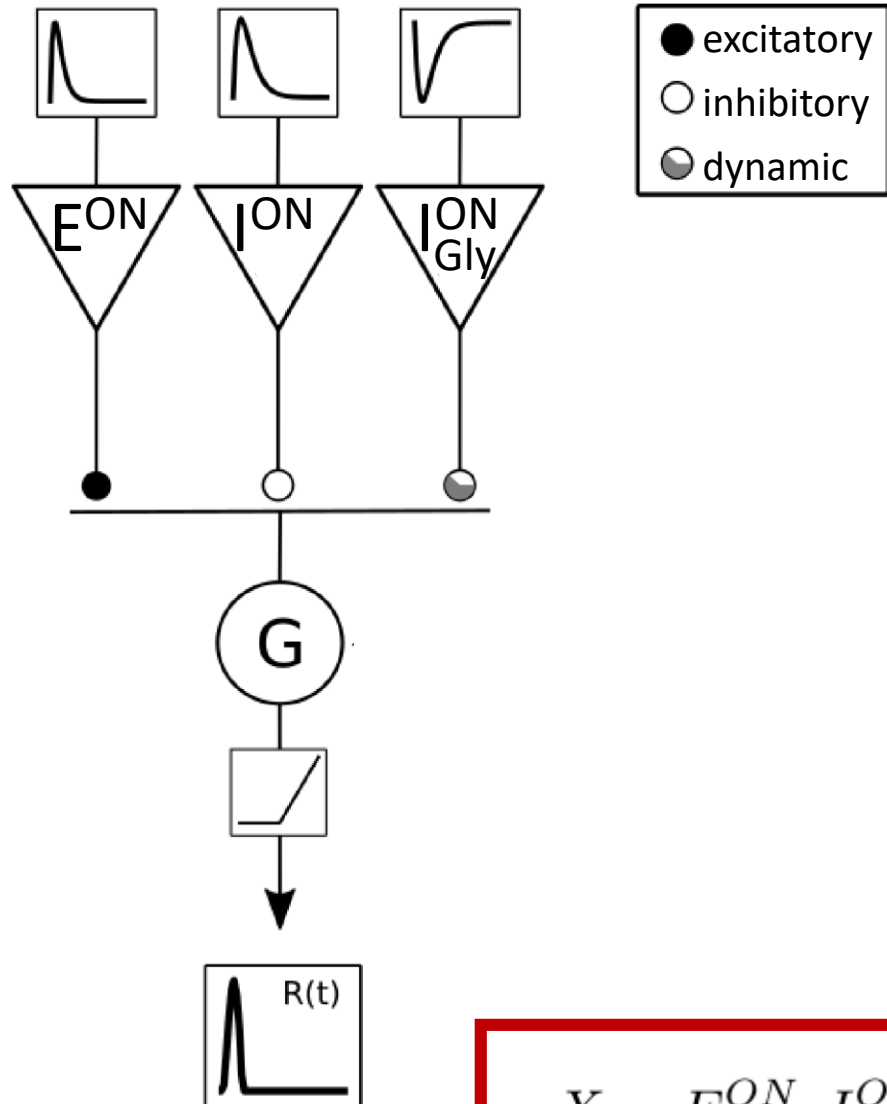
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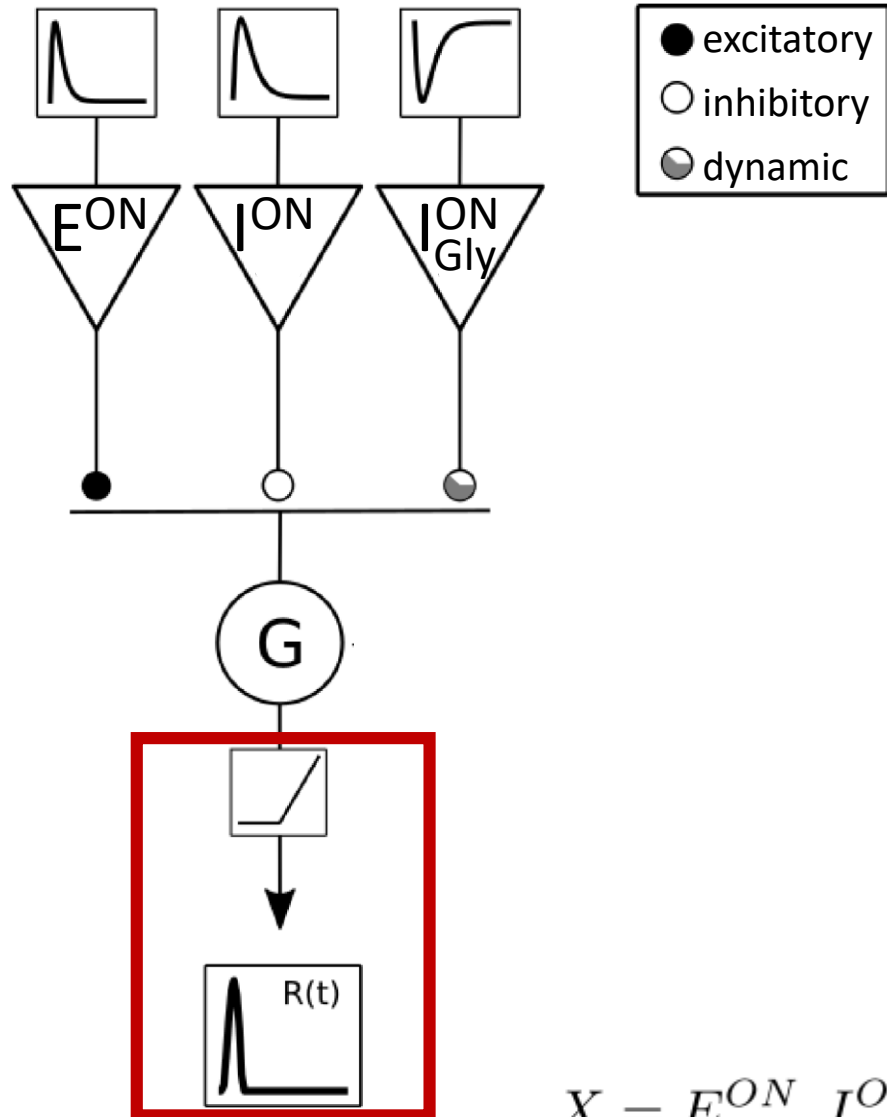
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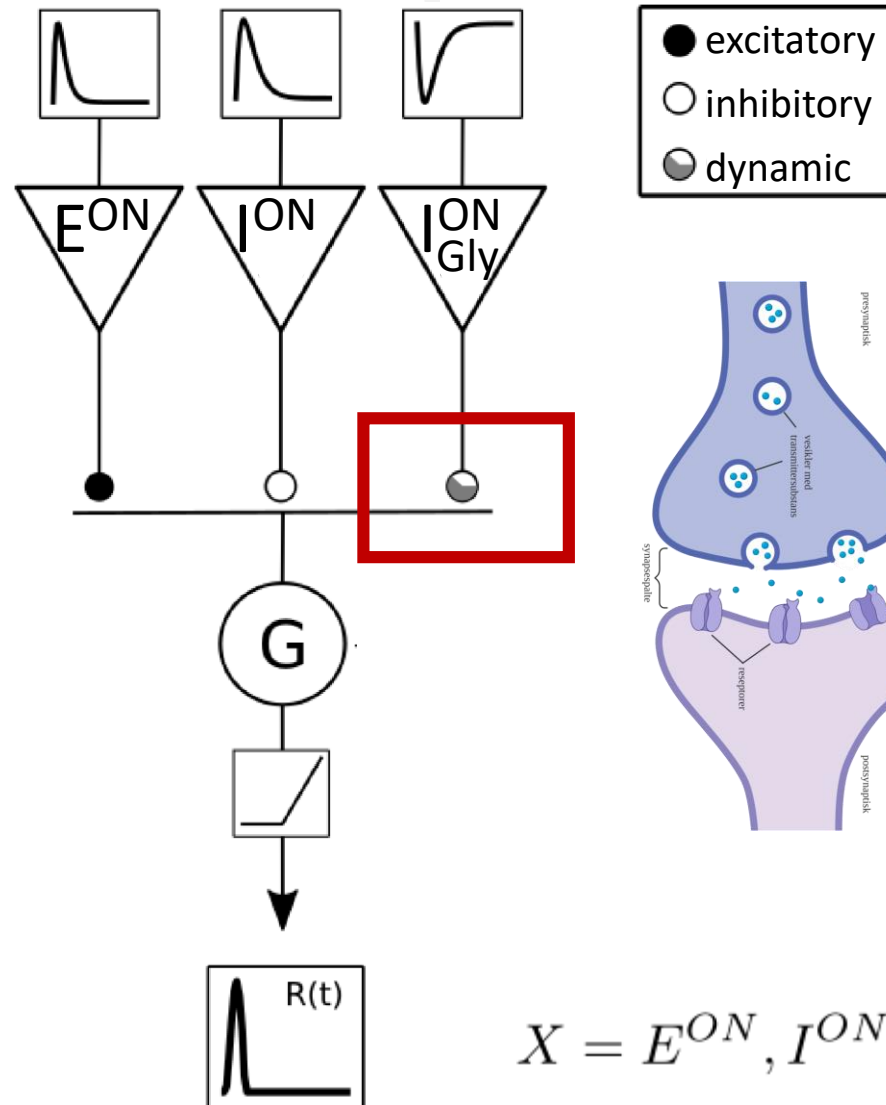
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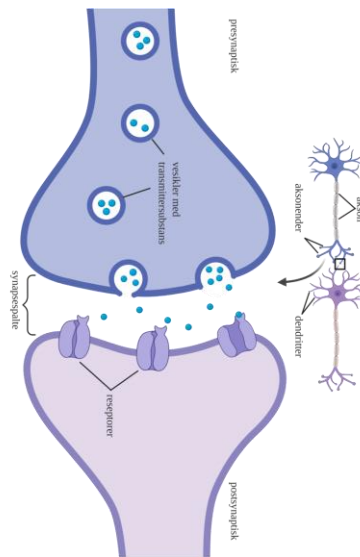
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# Input-dependent Adaptive Coupling via Short-term Depression



1. The variable  $n$  adapts dynamically to the input

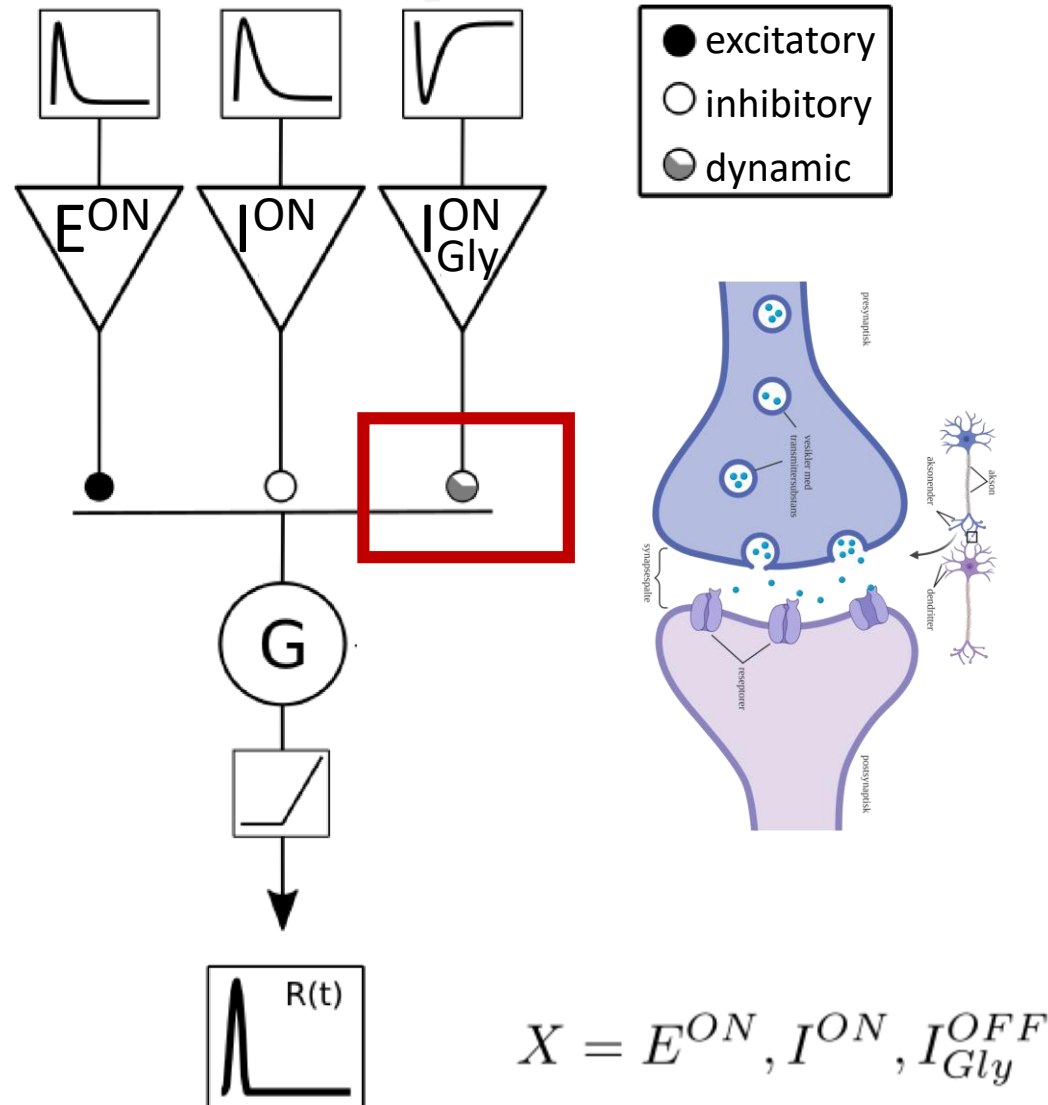
$$\frac{dn}{dt} = (1 - n)k_{rec} - \beta k_{rel} p(V_{I_{Gly}^{OFF}}, \theta_{I_{gly}^{OFF}}) n$$



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# Input-dependent Adaptive Coupling via Short-term Depression

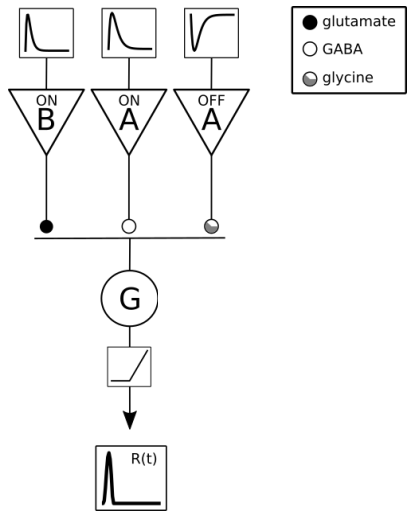


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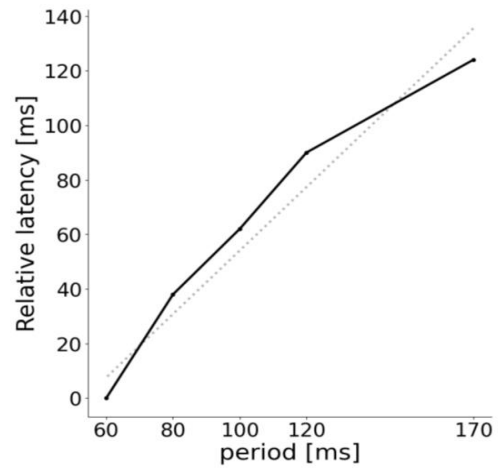
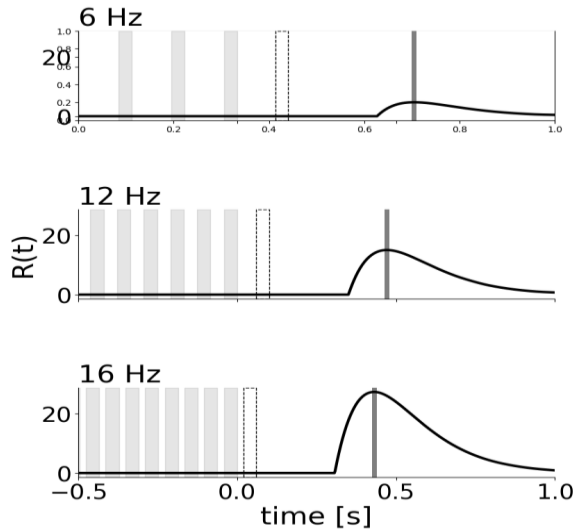
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2. The synaptic weight is scales by  $n$

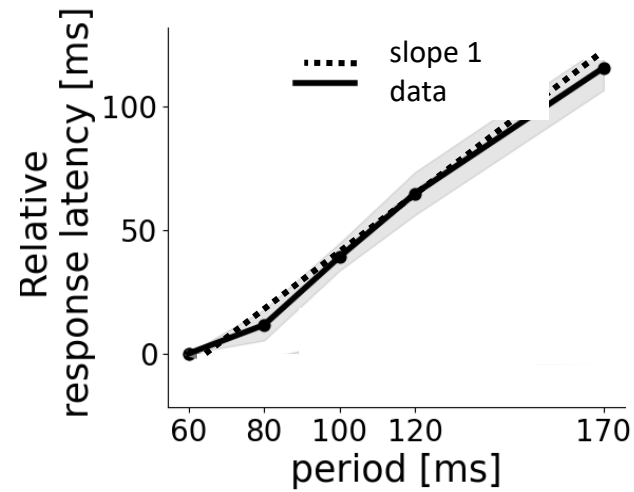
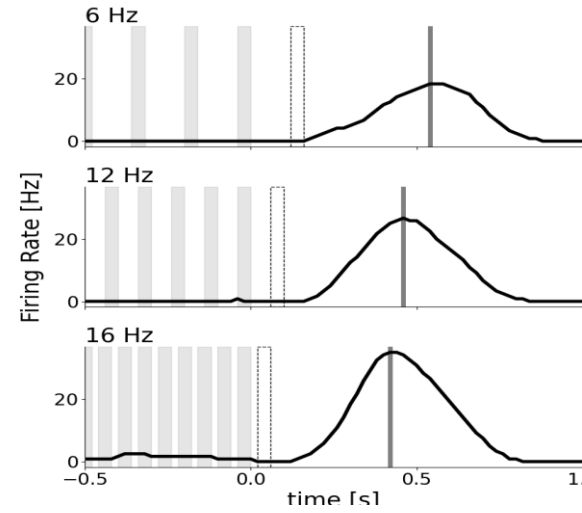
$$w(t) = \bar{w} n(t)$$



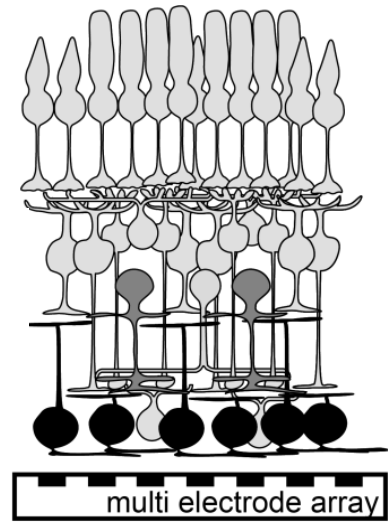
# Model

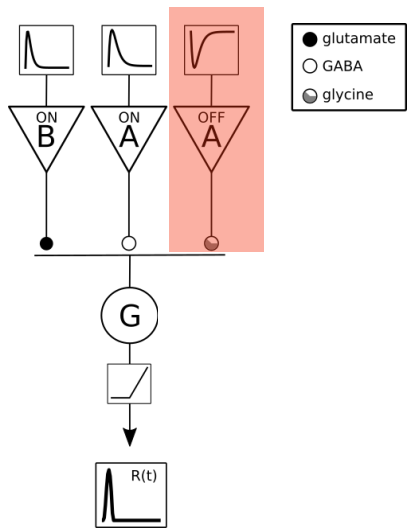


# Experiments

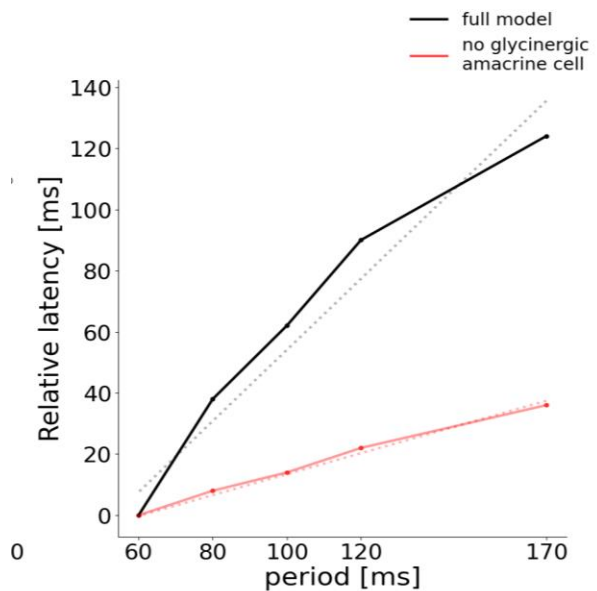
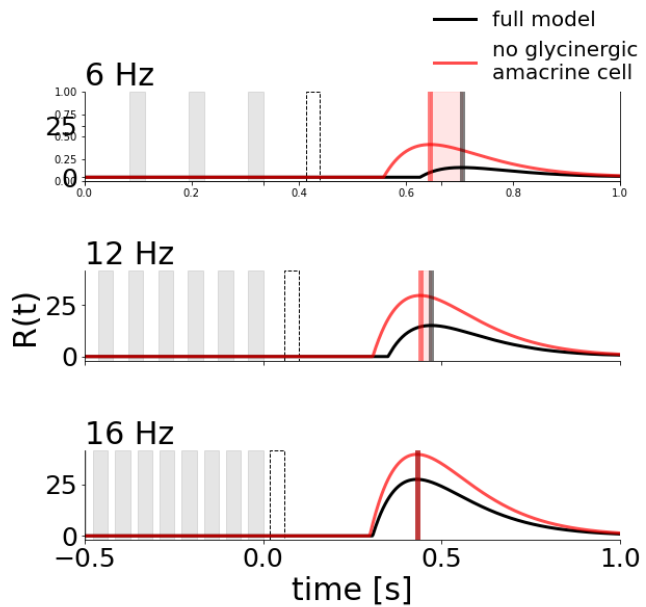


Retinal ganglion cells

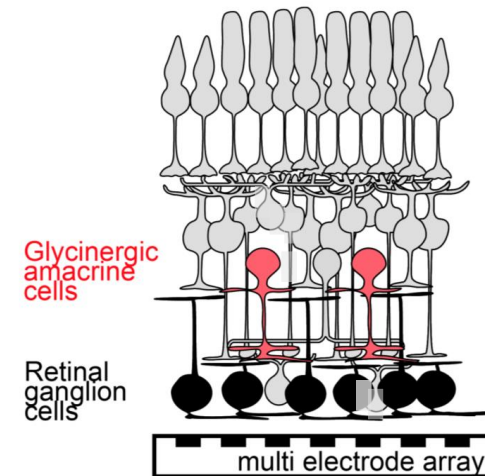
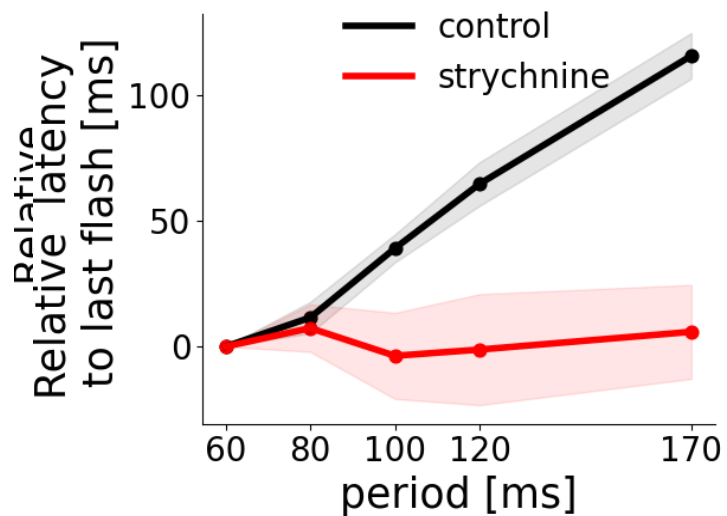
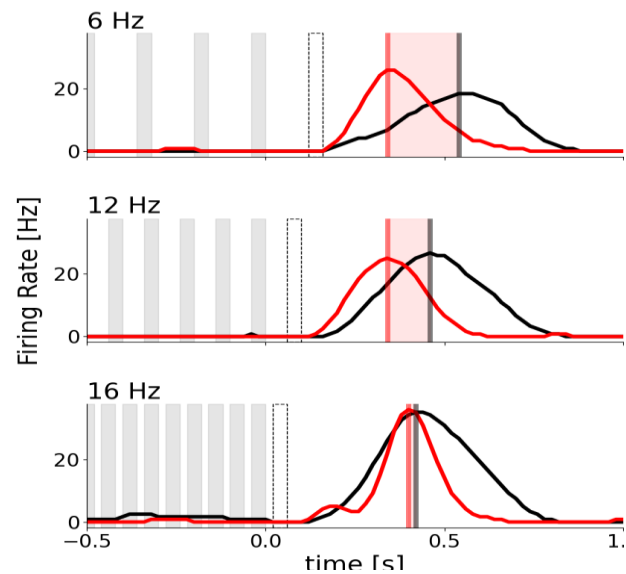




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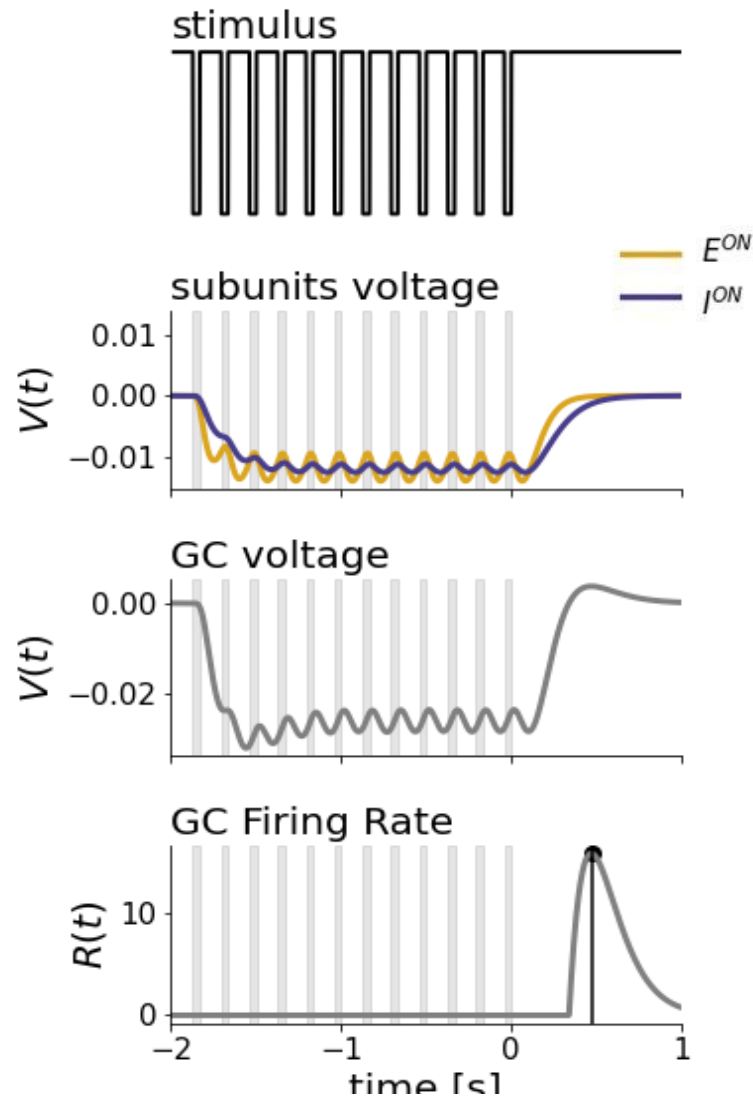


# Experiments



# Surprise adapts to the stimulus via synaptic plasticity

Model produces **error signal** via excitation and slower inhibition

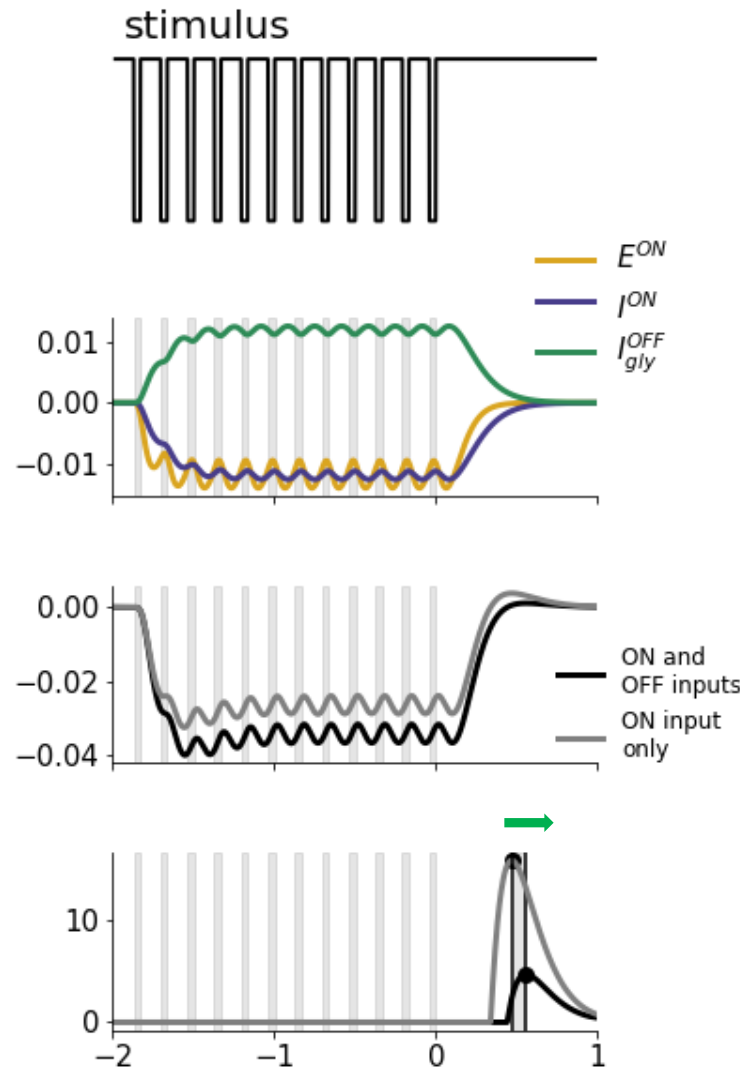


$$\frac{dV_G}{dt} = -\frac{V_G}{\tau_G} + w_{EON} V_{EON} + nw_{I_{Gly}^{OFF}} p(V_{I_{Gly}^{OFF}}, \theta_{I_{Gly}^{OFF}}) + w_{ION} V_{ION}$$

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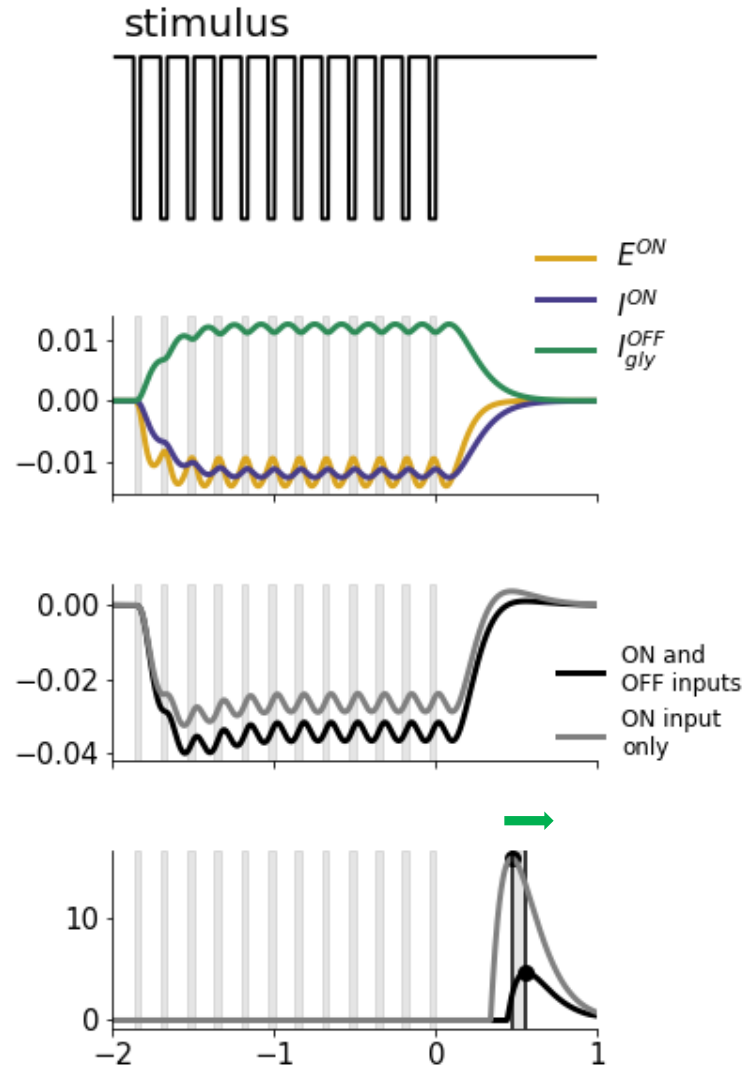
Model produces **error signal** via ON excitation and slower inhibition

Additional inhibition increases the **latency**

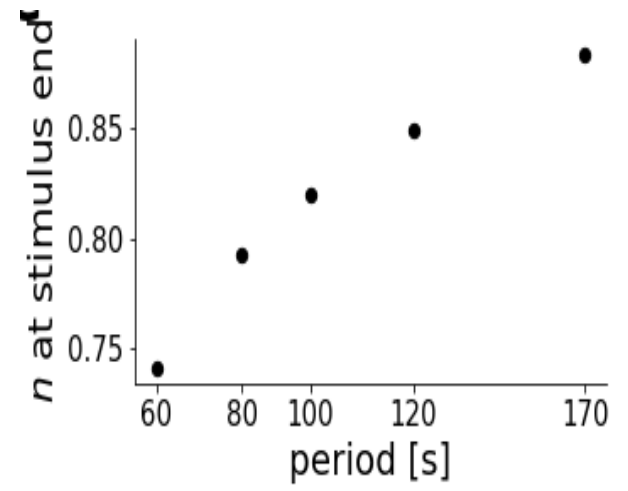


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# Surprise adapts to the stimulus via synaptic plasticity



The amount of depression varies with stimulus frequency



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# Conclusion

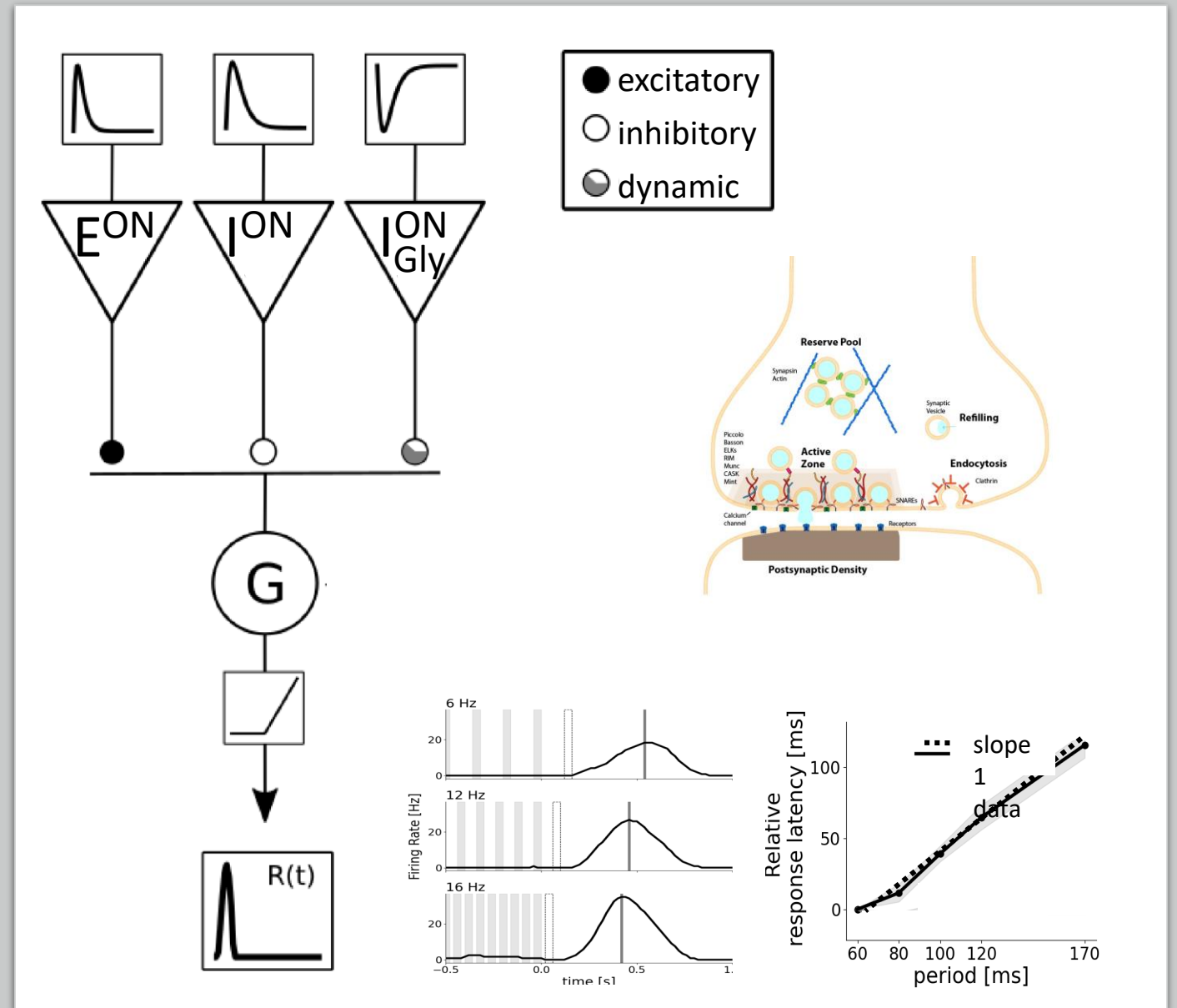
- Retina forms **predictions** about its future inputs and signals **surprise** when they are violated





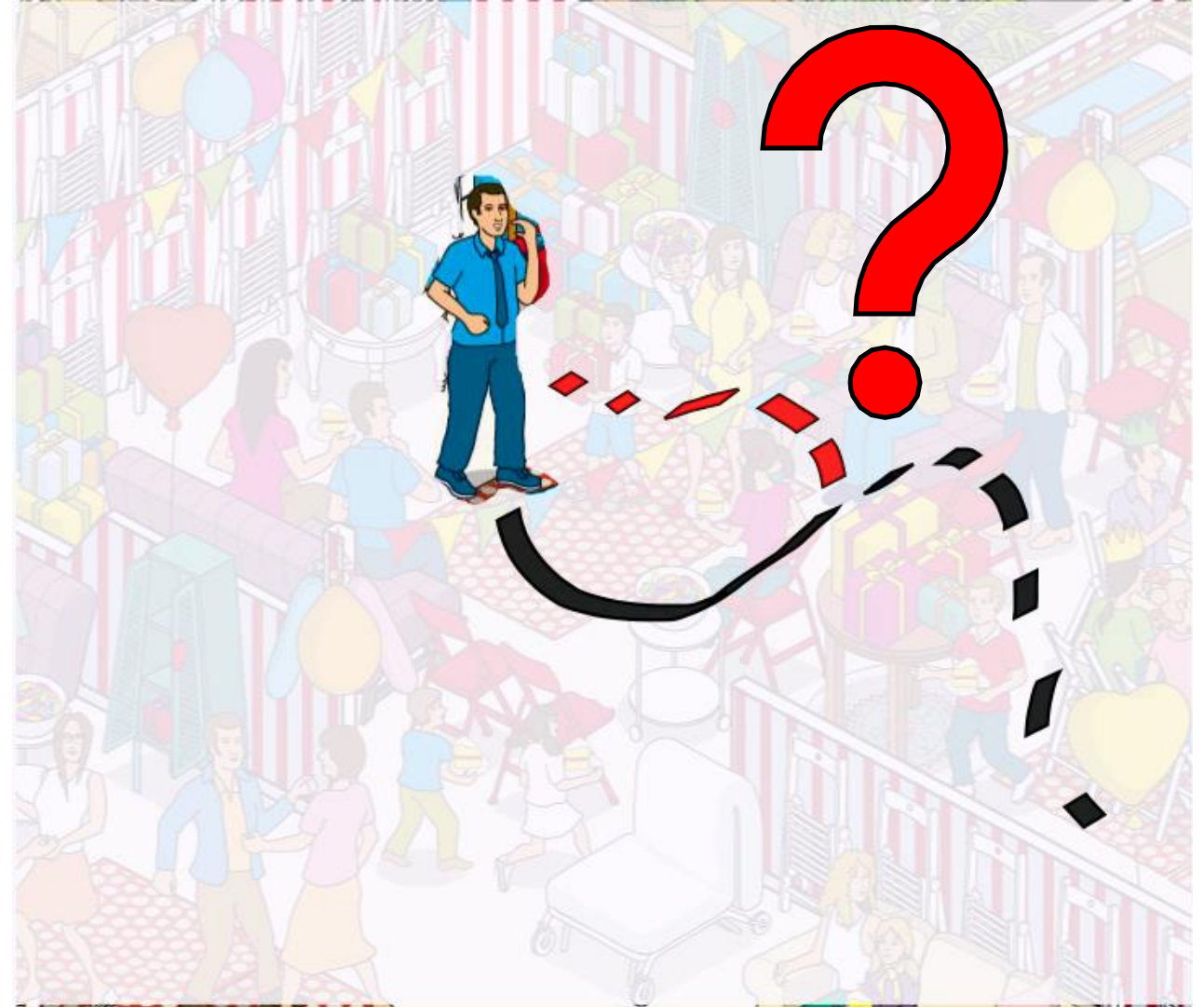
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- We show how this may be implemented via **dynamic synaptic adaptation**



# Conclusion

- Retina forms **predictions** about its future inputs and signals **surprise** when they are violated
- We show how this may be implemented via **dynamic synaptic adaptation**
- How is surprise to **more complex stimulus motion** with sudden changes in trajectories shaped



# Thank you !

**Bruno Cessac**

Pierre Kornprobst

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Jerome Emonet

Florent Robert

Clement Bergmann

Jeremy Termoz-Masson

**Olivier Marre**

**Thomas Buffet**

B. Semihchan Sermet



Ebert et al., 2023,  
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