Optimal time interval reproduction in a neural circuit model

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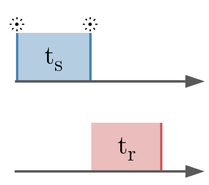
Introduction

Sensory information is combined with expectations (based on prior knowledge) to drive behaviors.
The interaction of current sensory input and expectations is likely subject to error minimization.

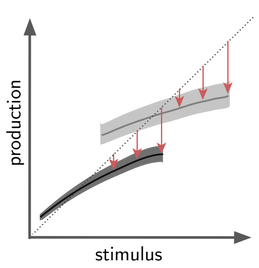
Psychophysical characteristics of magnitude estimation

Magnitude estimation shows characteristic effecs:

- Regression effect
- Scalar variability
- Range effect
- Sequential effect



Time reproduction is one of the behavioral methods to investigate error minimization and related optimal behavioral strategies.



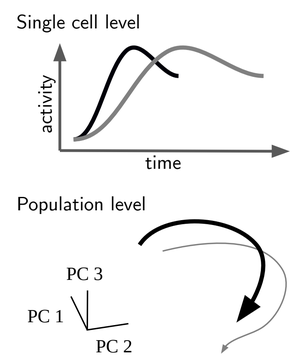
Timing by temporal scaling

Recordings in the medial frontal cortex (MFC) show:

- Firing rate profiles are temporally scaled to match the produced intervals
- Population activity evolves along an invariant neural trajectory at different speeds
- Controling timing of future movements by adjusting an internal speed command
- Speed command is updated after stimulus presentation based on the error between prediction (derived from a simulated motor plan) and the actual stimulus duration.

Circuit model

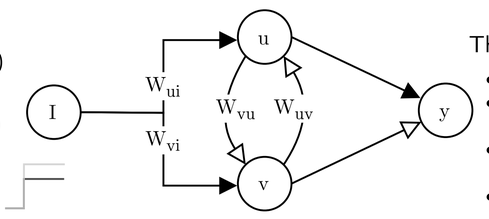
- Coordinates movement times using ramping activity towards a threshold.
- Update of speed comand based on error signal to minimize timing errors.



Model Description

Basic circuit

$$\tau \frac{du}{dt} = -u + \theta(W_{uI} I - W_{uv} v + \eta_u)$$
$$\tau \frac{dv}{dt} = -v + \theta(W_{vI} I - W_{vu} v + \eta_v)$$
$$\tau \frac{dy}{dt} = -y + W_{yu} u - W_{yv} v + \eta_y$$

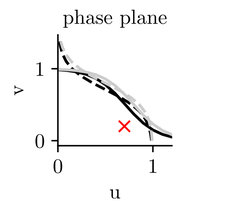


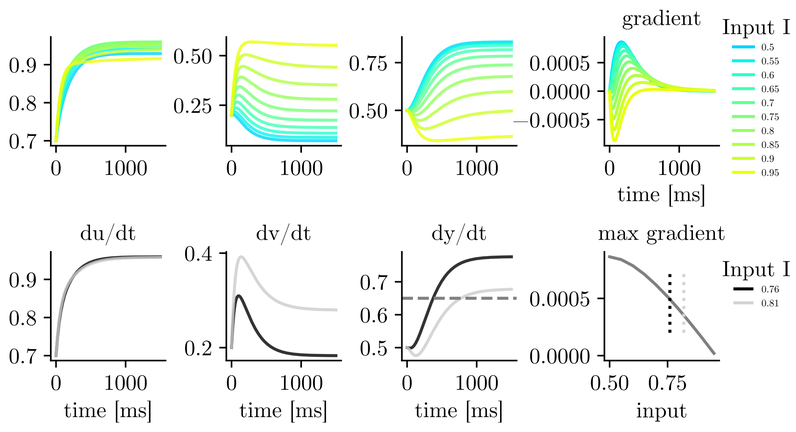
Three units:

- two mutually inhibitory units u, v
- inputs to u, v governed by sigmoidal activation function
- readout unit y receives inhibitory and excitatory inputs
- shared tonic input I to u and v

The input to the circuit controls at which speed the readout unit increases its activity.

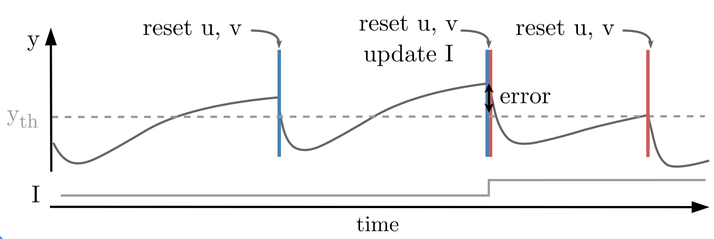
Input regime





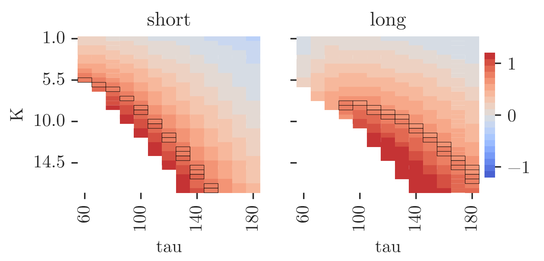
Update mechanism

scales its responses such that a threshold is reached at different times.



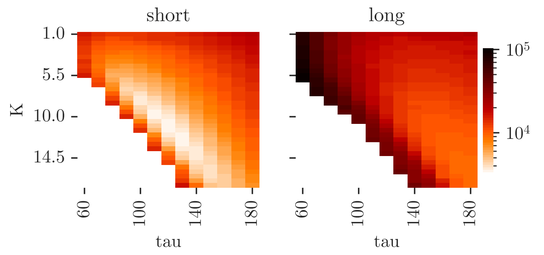
Parameter Tuning

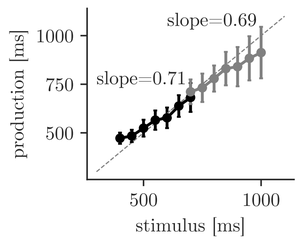
Behavioral plausible slopes

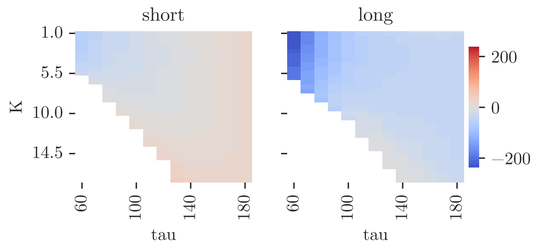


Optimal update parameter

$$\text{MSE} = \text{BIAS}^2 + \text{VAR}$$
$$\text{BIAS}^2 = \frac{1}{S}\sum_{i=1}^{S}(\bar{t_{r_i}} - t_{s_i})^2$$
$$\text{VAR} = \frac{1}{S}\sum_{i=1}^{S}(\sigma_i^2)$$







Simulation

Conclusion

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