A mechanism for persistence of information in oscillatory networks

Michael Rule

September 9, 2014

Hypothesis

- Attractor networks are hypothesized to store information in the brain

Hypothesis

- Attractor networks are hypothesized to store information in the brain
    - Real networks have a tendency to oscillate due to the latency of inhibitory feedback

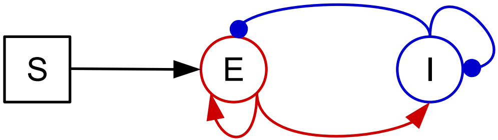
Hypothesis

- Attractor networks are hypothesized to store information in the brain
    - Real networks have a tendency to oscillate due to the latency of inhibitory feedback
    - How do we stabilize information in an oscillatory network?

Hypothesis

- Attractor networks are hypothesized to store information in the brain
  - Real networks have a tendency to oscillate due to the latency of inhibitory feedback
  - How do we stabilize information in an oscillatory network?
- **Can shared oscillatory drive can activate a mode with distinct stable trajectories rather than fixed points?**

A rate model E-I oscillator

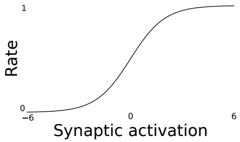


$$\tau_e \dot{E} = -E + f(A_{ee}E - A_{ei}I + \theta_e + S(t) + \eta_e(t))$$

$$\tau_i \dot{I} = -I + f(A_{ie}E - A_{ii}I + \theta_i + \eta_i(t))$$

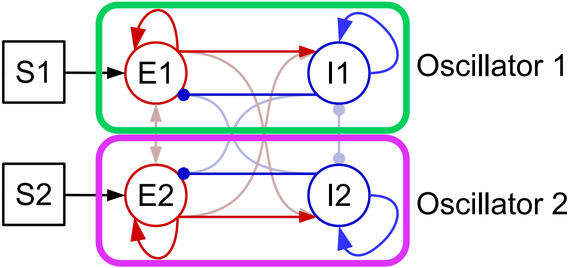
$$\eta \sim \mathcal{N}(0, \sigma^2)$$

$$f(x) = \frac{1}{1 + e^{-x}}$$



Each E-I pair displays a damped oscillation

Weakly coupled oscillators



Weakly coupled oscillators: "experiment"

- System begins at steady state, no difference between population activity

Weakly coupled oscillators: "experiment"

- System begins at steady state, no difference between population activity
- An input arrives to **one** population, driving its activity up
    - This sets up initial conditions of the system

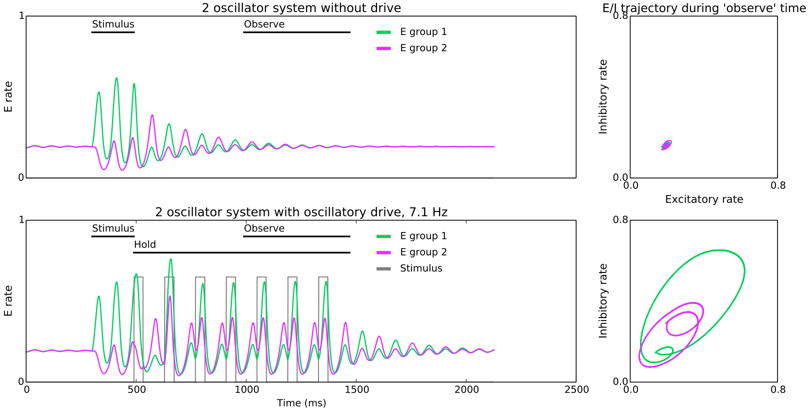
Weakly coupled oscillators: "experiment"

- System begins at steady state, no difference between population activity
- An input arrives to **one** population, driving its activity up
    - This sets up initial conditions of the system
- The input is removed, and the network is driven with **shared** oscillatory drive

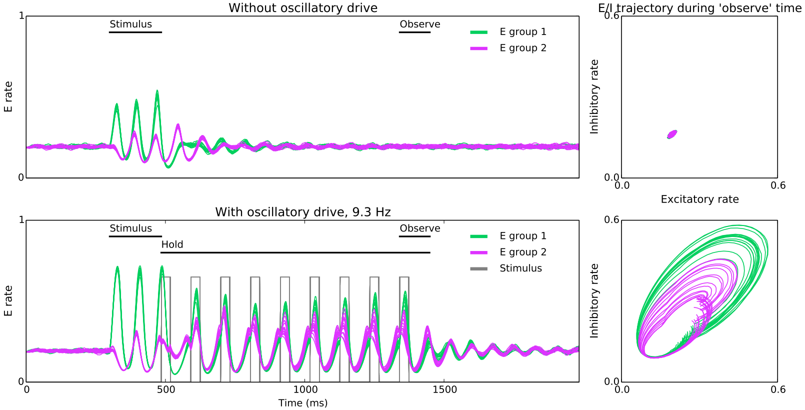
Weakly coupled oscillators: "experiment"

- System begins at steady state, no difference between population activity
- An input arrives to **one** population, driving its activity up
  - This sets up initial conditions of the system
- The input is removed, and the network is driven with **shared** oscillatory drive
- After a delay, can we read out the initial conditions based on the firing rates of the E populations?

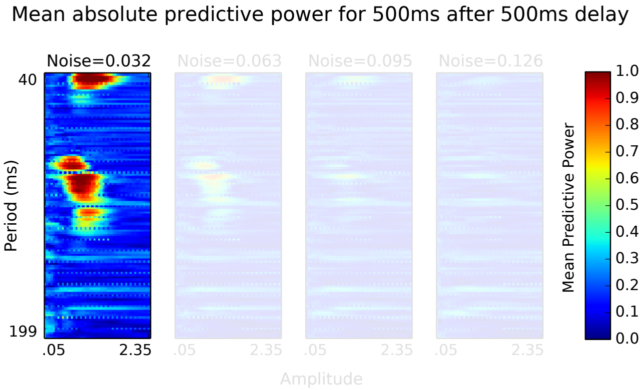
Two weakly coupled oscillators



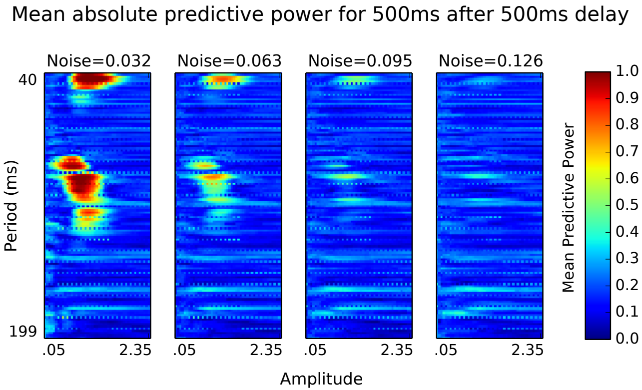
Storing information in an ensemble of 30 oscillators



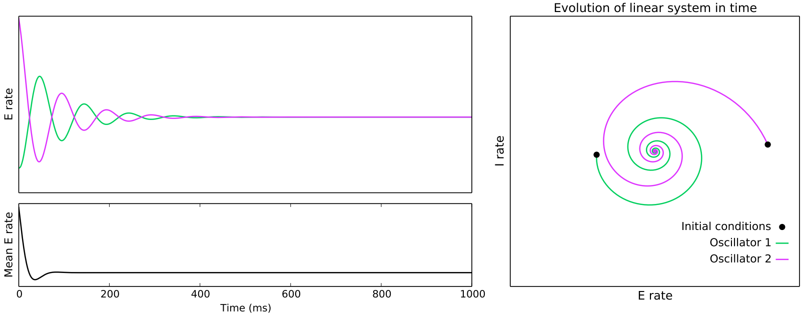
Two islands of encoded assembly stability



Two islands of encoded assembly stability

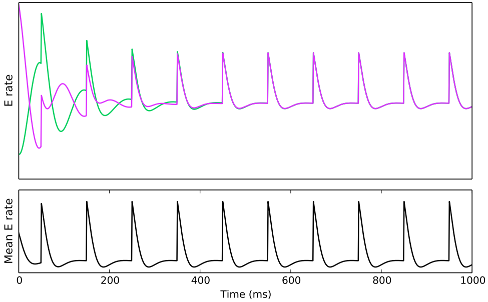


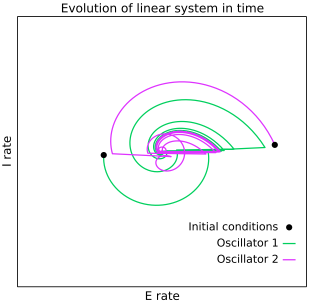
Can we think of this as a damped, driven linear system?



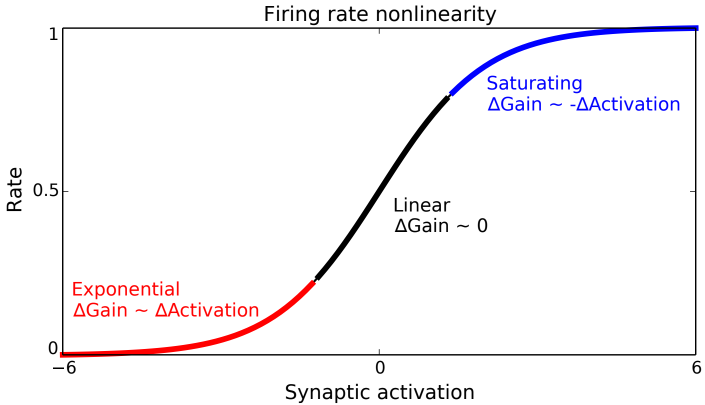
- 4D linear system
- Stable $\Re(\lambda) < 0$
- Set dominant mode to be an asynchronous, stable oscillation

Synchronous drive cannot excite an asynchronous mode



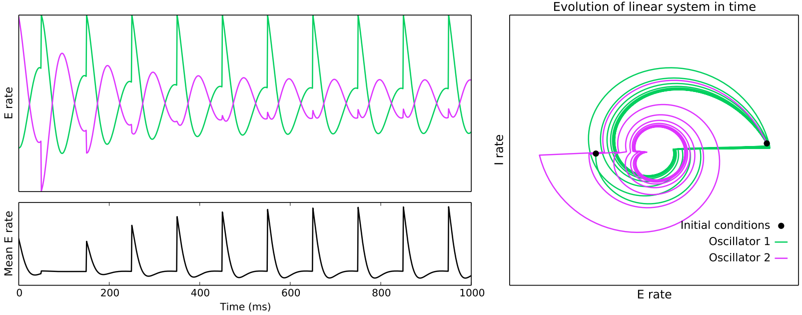


The firing rate nonlinearity is important



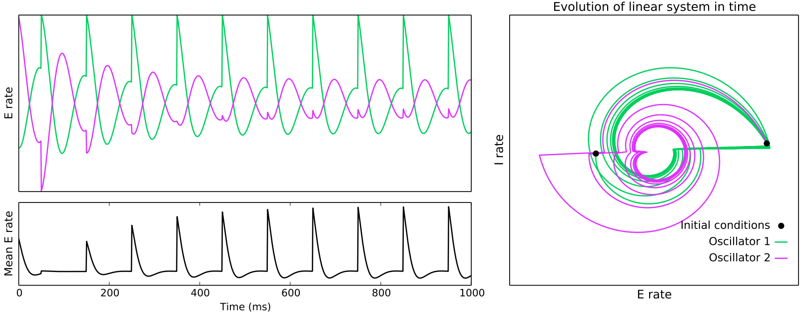
The nonlinear system occupies the exponential portion of the firing rate nonlinearity, in which an increase in drive leads to an increase in gain.

Linear analogy to two coupled oscillator model



Periodic modulation of E-E coupling **and** periodic forcing, with a limit on the maximum rate, qualitatively resembles nonlinear system

Linear analogy to two coupled oscillator model



Periodic modulation of E-E coupling **and** periodic forcing, with a limit on the maximum rate, qualitatively resembles nonlinear system

- Limit the maximum rate to prevent instability

Summary:

- Slow inhibitory feedback can create a damped, asynchronous oscillation in inhibitory-coupled oscillators

Summary:

- Slow inhibitory feedback can create a damped, asynchronous oscillation in inhibitory-coupled oscillators
- Periodically increasing the gain can prevent this mode from decaying

Summary:

- Slow inhibitory feedback can create a damped, asynchronous oscillation in inhibitory-coupled oscillators
- Periodically increasing the gain can prevent this mode from decaying
- For low rates, the firing rate nonlinearity is supralinear, and increasing input also increases gain

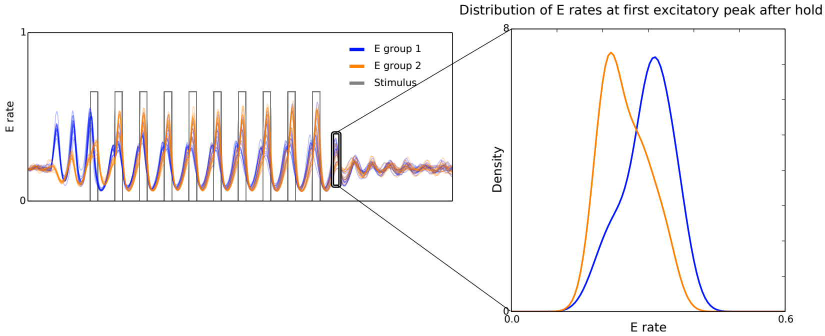
Thanks!

Michale Fee - **Mark Goldman** - Tom Chartrand - Emily Mackevicius - **James Fitzgerald** - Srini Turaga - **Ann Kennedy** - Adrienne Fairhall - Sara Solla - Braden Brinkman - Kelsey Allen - Evi Kopelowitz - Nimrod Shaham - Lane McIntosh - Tuğçe Taşci - Noah Young - Adrien Jouary - Karin Knudson - Yi-Ju Chen - Andrei Khilkevich - Manisha Sinha - Etienne Serbe - Christophe Dupre - Alison Duffy - Jennifer Blackwell - Ali Weber - Rainer Engelken - Itamar Landau - Mikhail Proskurin - Wu-Jung Lee - Gabrielle Gutierrez - Alex Batchelor - Max Manakov - Bard Ermentrout - John Rinzel - Michael Hines - Greg Gage - Bartlett Mel - Jonathan Pillow - Jack Gallant - Stephen Baccus - Peter Latham - Dmitri Chklovskii - Surya Ganguli - Carlos Brody - David Tank - Bill Bialek - Loren Frank - Ila Fiete - Eve Marder - Tim Lewis - David Kleinfield - **Haim Sompolinsky** - Nathan Sawtell - Larry Abbott - Nathaniel Daw - Maurice Smith - John Rubin - John Lisman - David Redish - Misha Tsodyks - Terry Sejnowski

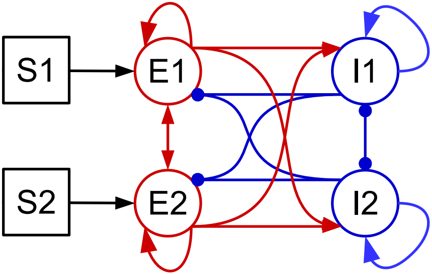
End

Extra slides....

Assessing assembly stability



Mutually inhibitory oscillators



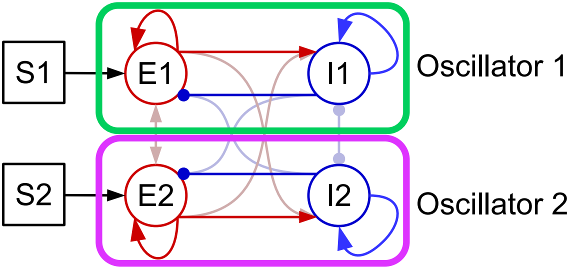
$$\tau_e \dot{E}_1 = -E_1 + f(A_{ee}^{self} E_1 - A_{ei}^{self} I_1 - A_{ei}^{other} I_2 + \theta_e + g_e S(t))$$

$$\tau_e \dot{E}_2 = -E_2 + f(A_{ee}^{self} E_2 - A_{ei}^{self} I_2 - A_{ei}^{other} I_1 + \theta_e + g_e S(t))$$

$$\tau_i \dot{I}_1 = -I_1 + f(A_{ii}^{self} I_1 - A_{ie}^{self} E_1 - A_{ie}^{other} E_2 + \theta_i)$$

$$\tau_i \dot{I}_2 = -I_2 + f(A_{ii}^{self} I_2 - A_{ie}^{self} E_2 - A_{ie}^{other} E_1 + \theta_i)$$

Weakly coupled oscillators



$$\tau_e \dot{E}_1 = -E_1 + f(A_{ee}^{self} E_1 + A_{ee}^{other} E_2 - A_{ei}^{self} I_1 - A_{ei}^{other} I_2 + \theta_e + g_e S(t))$$
$$\tau_e \dot{E}_2 = -E_2 + f(A_{ee}^{self} E_2 + A_{ee}^{other} E_1 - A_{ei}^{self} I_2 - A_{ei}^{other} I_1 + \theta_e + g_e S(t))$$
$$\tau_i \dot{I}_1 = -I_1 + f(A_{ii}^{self} I_1 + A_{ii}^{other} I_2 - A_{ie}^{self} E_1 - A_{ie}^{other} E_2 + \theta_i)$$
$$\tau_i \dot{I}_2 = -I_2 + f(A_{ii}^{self} I_2 + A_{ii}^{other} I_1 - A_{ie}^{self} E_2 - A_{ie}^{other} E_1 + \theta_i)$$

Effective coupling is stronger than individual coupling

$$S_e = \sigma_e \langle E_{other} \rangle + (1 - \sigma_e) E_{self}$$

In limit of large N, for the bistable mode, some fraction γ of E_i will be part of the same ensemble as E_j, call E_{self}, and the rest will occupy an E_{other}

$$S_e = \sigma_e(\gamma E_{self} + (1 - \gamma) E_{other}) + (1 - \sigma_e) E_{self}$$

$$S_e = \sigma_e(1 - \gamma) E_{other} + (1 - \sigma_e(1 - \gamma)) E_{self}$$

There is a new effective coupling constant $\sigma_e' = \sigma_e(1 - \gamma)$.