

Topology and dynamics in biological neural networks

Alejandro F. Bujan, Jyotika Bahuguna

BNN Course, November 30, 2016

Outline

1 Introduction

- Dynamics
- Random connectivity
- Non-random connectivity

2 Effect of topology on network dynamics

- Degree distribution
- Dale versus hybrid connectivity
- Distance dependent connectivity
- Clustered networks and metastability

3 Applications to real data

- Stimulus induced variability reduction
- Complex spatio-temporal dynamics during reaching

4 Summary

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Measure of Network dynamics

- Firing rate

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- Variability:

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 - Inter-spike intervals (CV)

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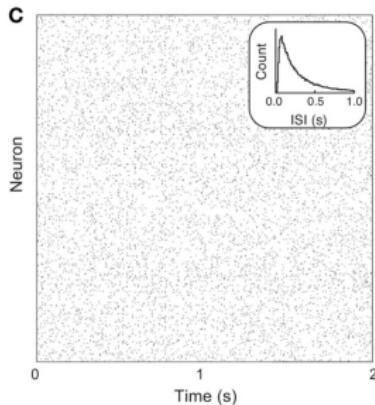
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 - Higher order correlations (between triplets, quadruplets,...)

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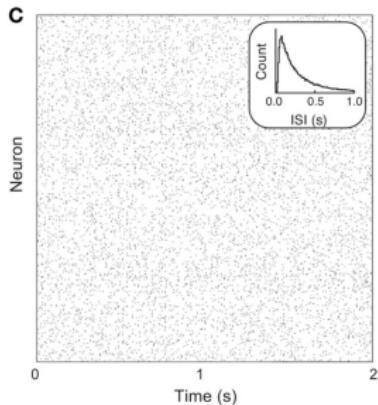
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 - Power spectrum (frequency domain)

Is random good enough? (I): Cortical activity



[Doiron & Litwin-Kumar, 2014]

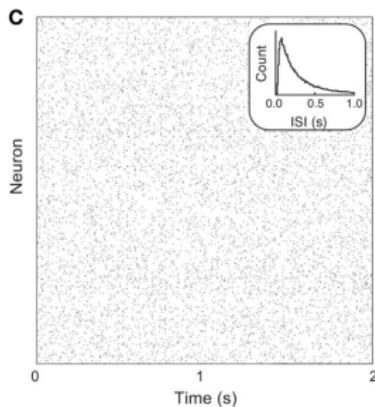
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Cortical activity in awake behaving animals:

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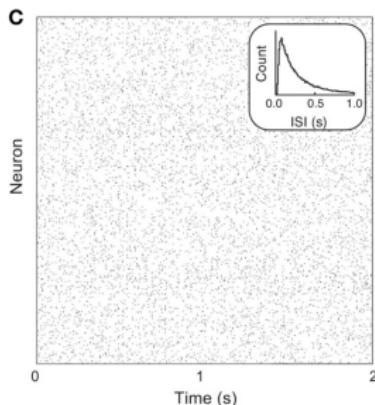


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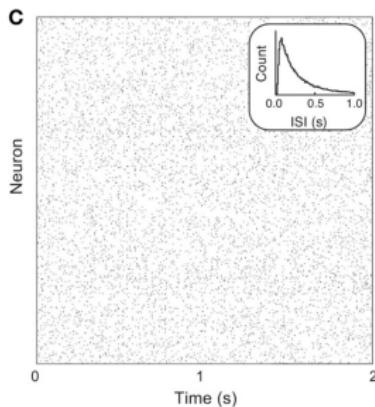


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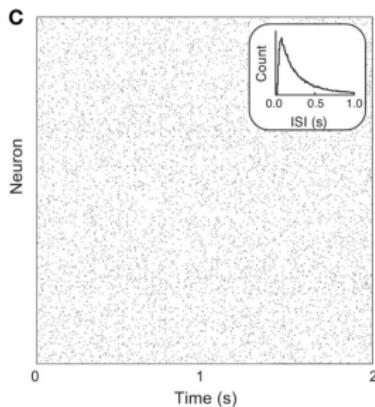


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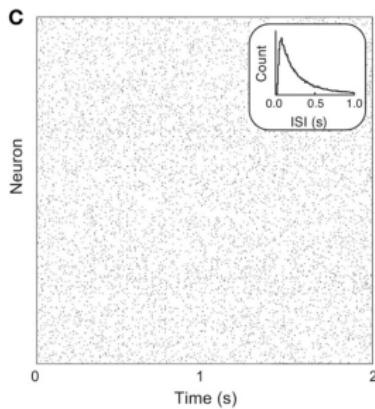


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- Asynchronous

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Is random good enough? (II): Cycle skipping

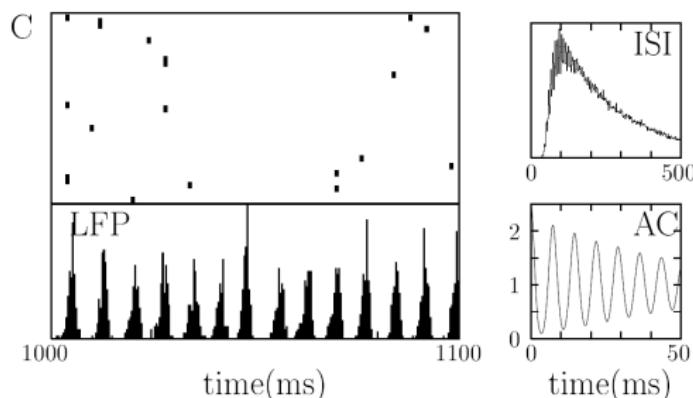
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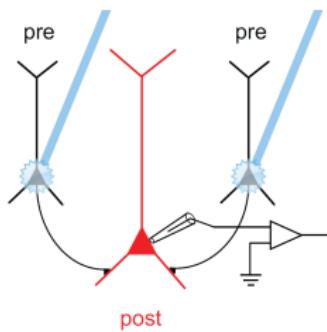
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Brunel & Hakim 1999

Random is not enough (I)

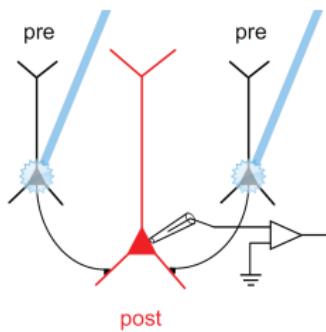
- Distance dependent connectivity



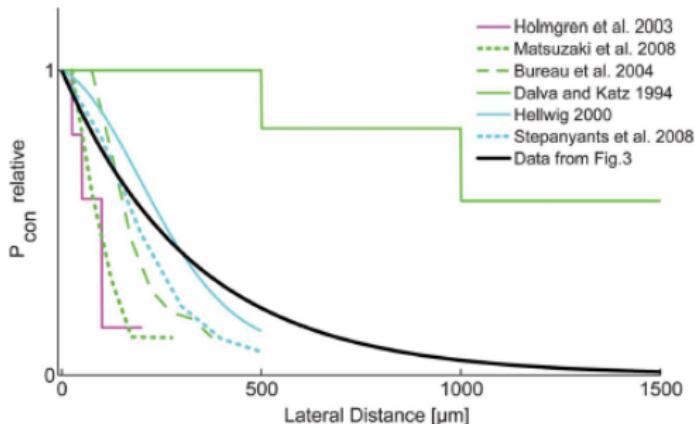
[Boucsein et al. 2011]

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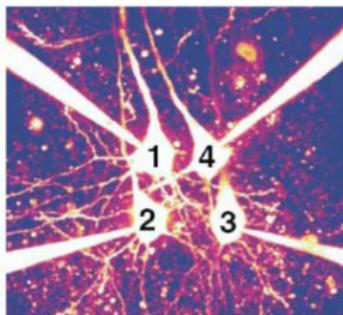


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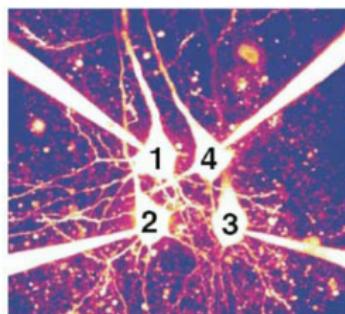
- Highly non-random distribution of connectivity motifs



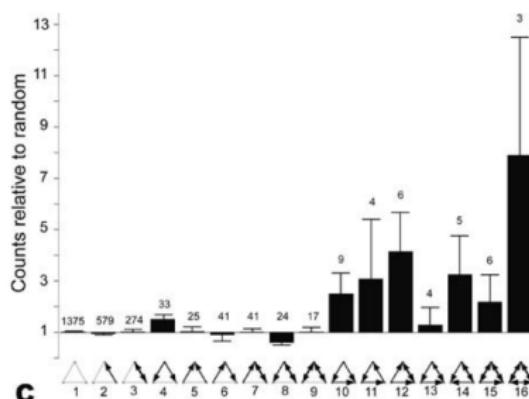
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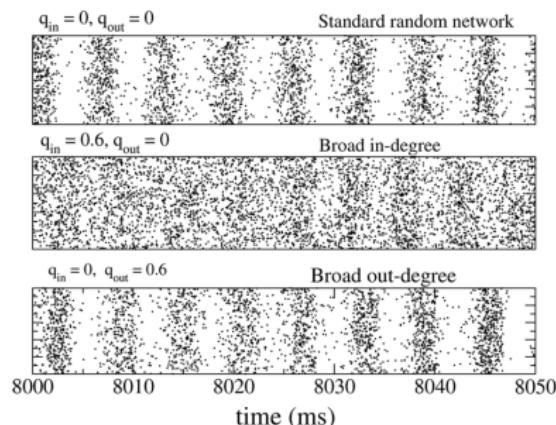
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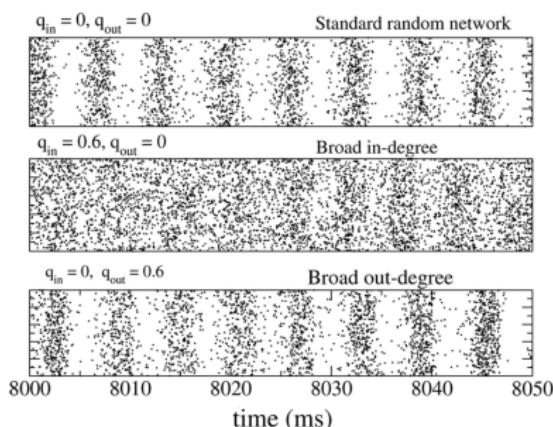
Inh



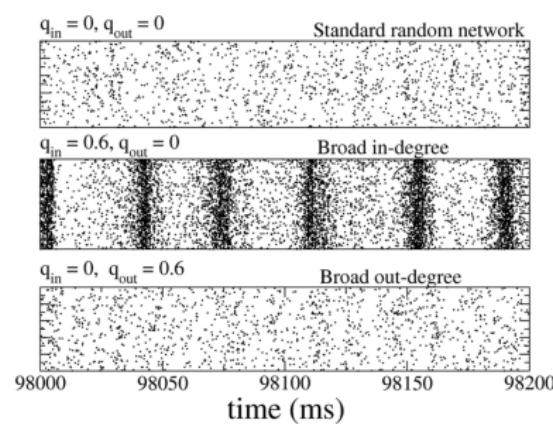
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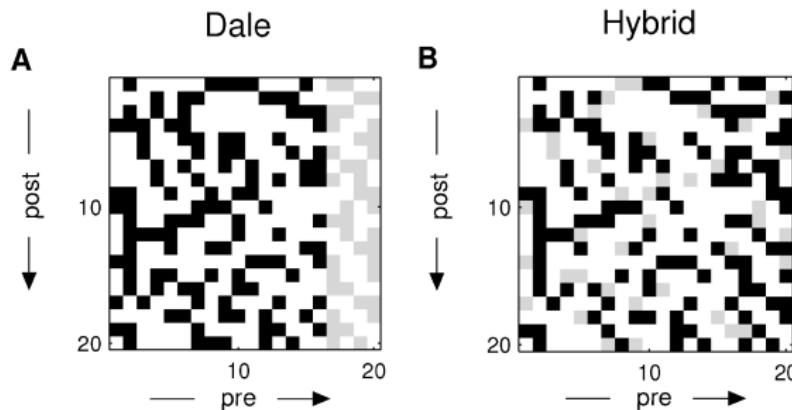


Exc-Inh



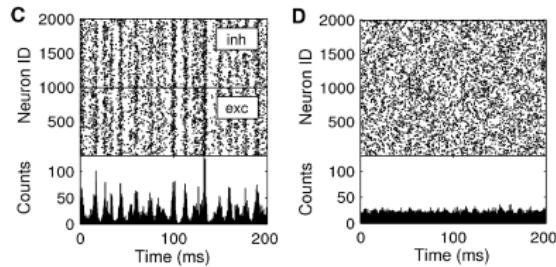
[Roxin, 2011]

Dale versus hybrid connectivity

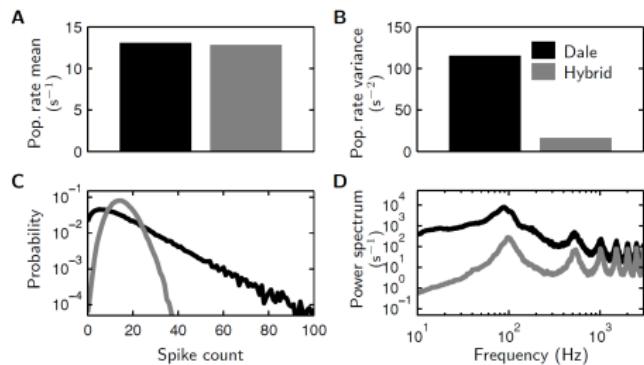
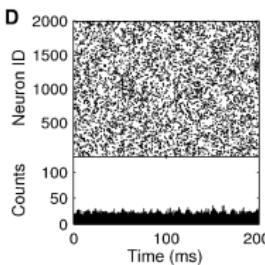
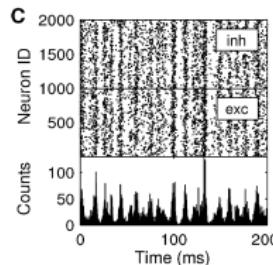


[Kriener et al., 2008]

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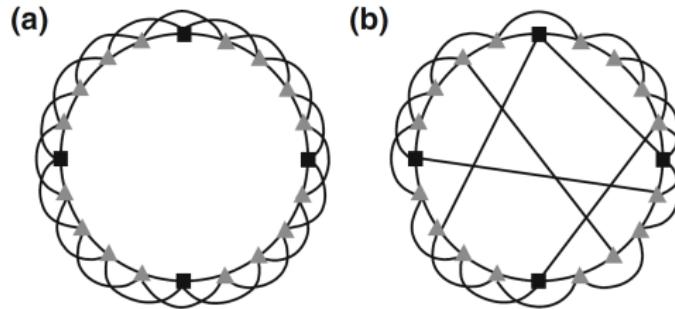
Dale versus hybrid connectivity



[Kriener et al., 2008]

- Same mean firing rate
- Hybrid less synchronous than Dale

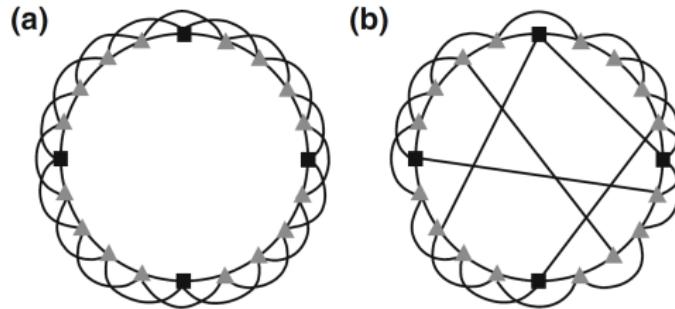
Distance dependent connectivity



[Kriener et al., 2009]

- Probability of rewiring p_r

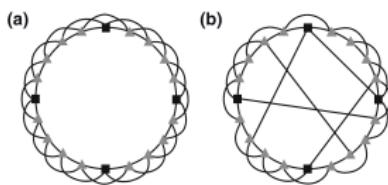
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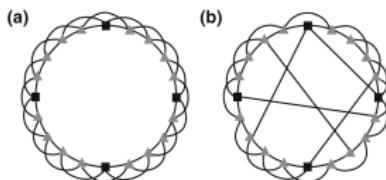
- Probability of rewiring p_r
- $0 < p_r < 1 \rightarrow$ “small-world” network ([Watts & Strogatz, 1998])

Distance dependent connectivity

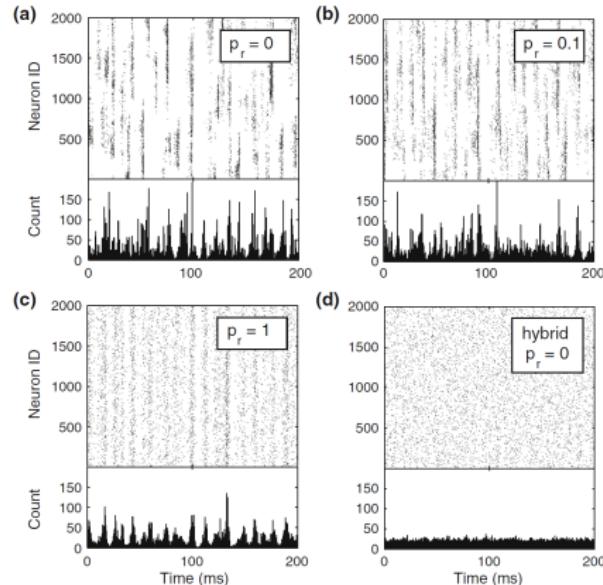


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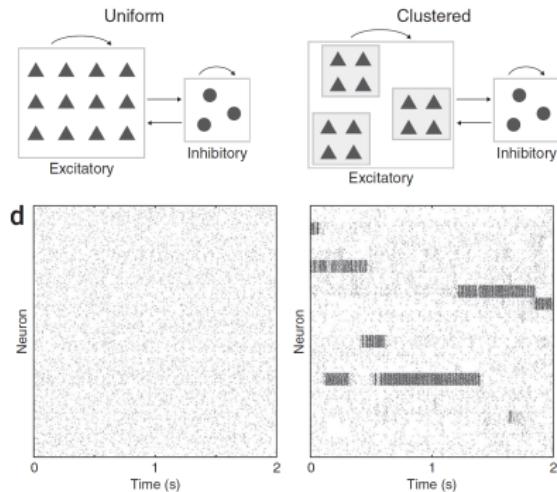


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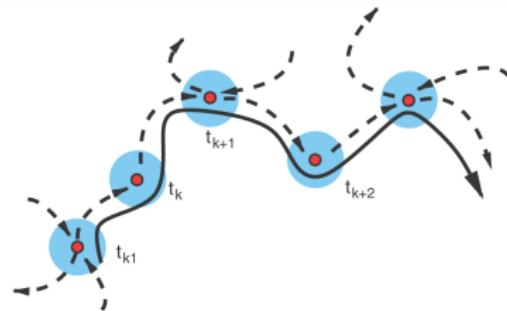
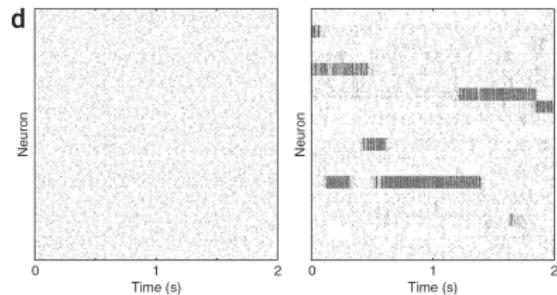
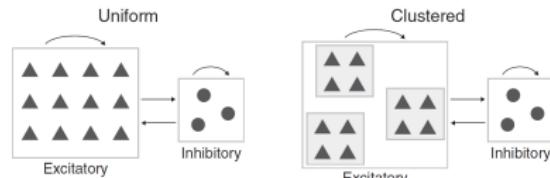
- Clustered networks are “locally” more synchronous.
- Hybrid beats local connectivity!

Clustered networks and metastability



[Litwin-Kumar & Doiron, 2012]

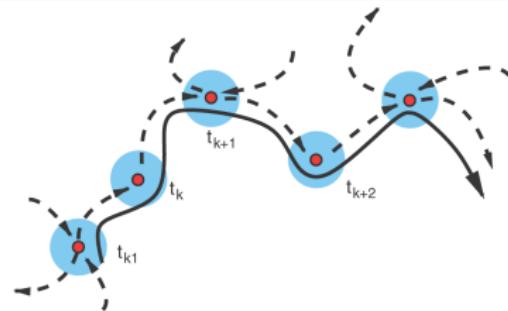
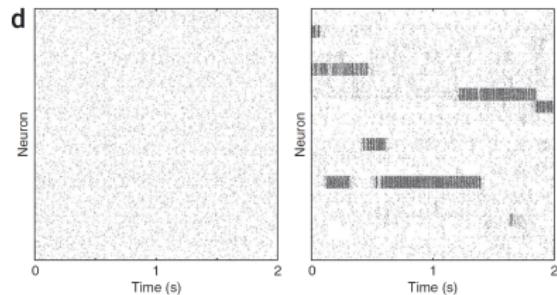
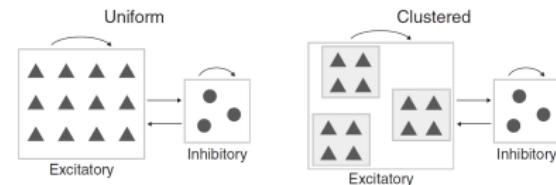
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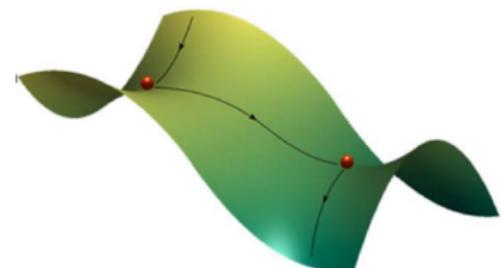
Rabinovich et al. 2008

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Rabinovich & Varona 2011

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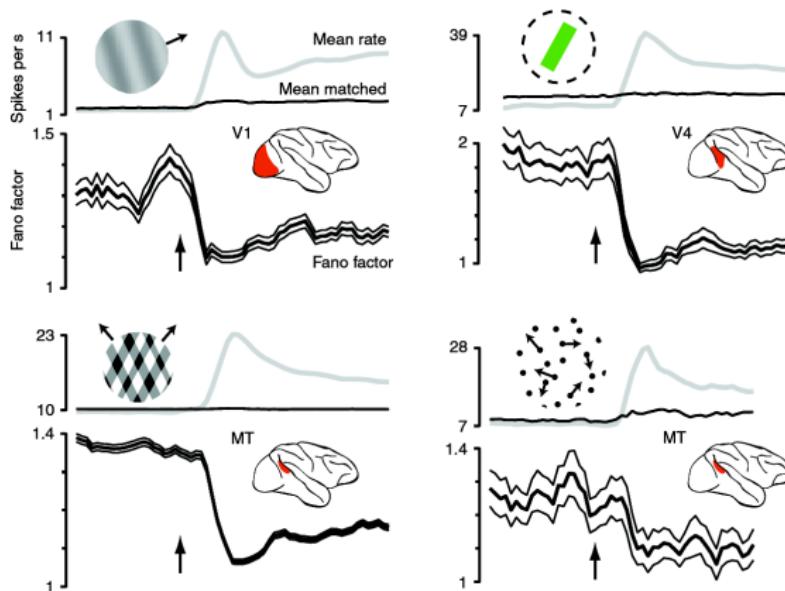
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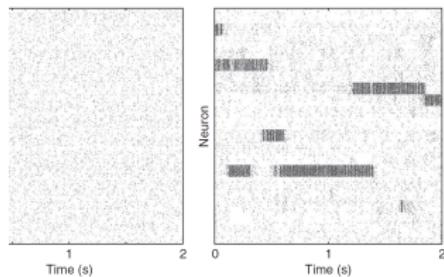
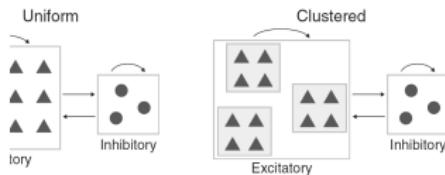
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Stimulus-induced variability reduction

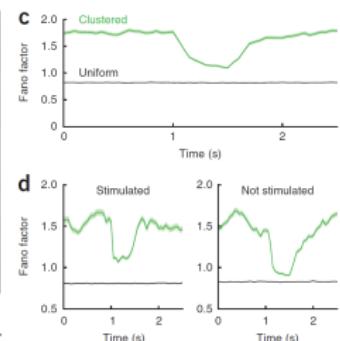
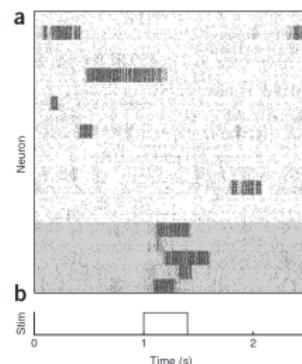
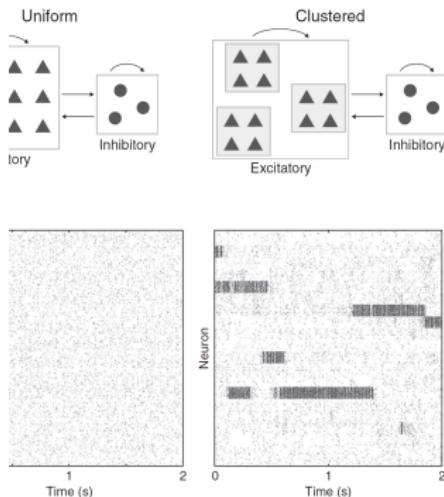


[Churchland et al. 2010]

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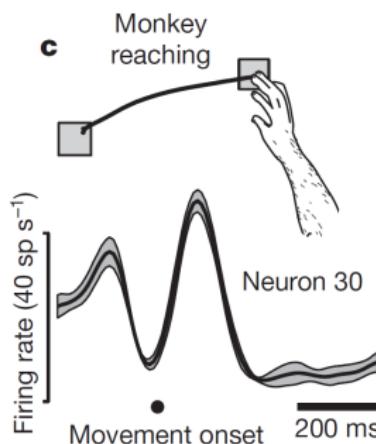
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Neural dynamics during reaching

- Neurons in motor cortex produce complex spatio-temporal patterns during reaching movements.

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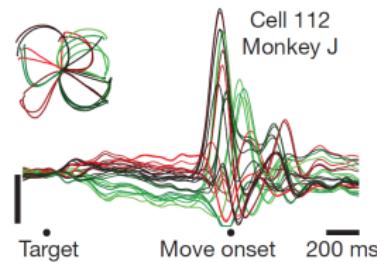
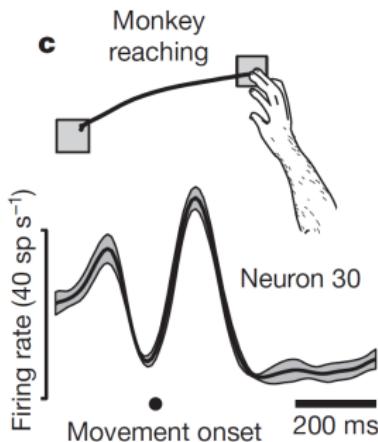
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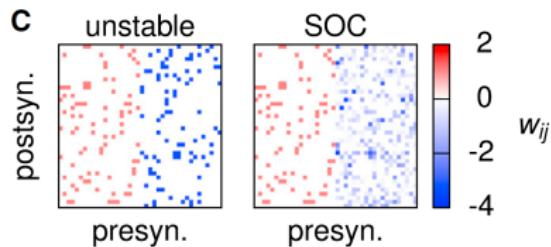
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Detailed balance connectivity

- “Detailed balance” connectivity stabilizes the network dynamics.

Detailed balance connectivity

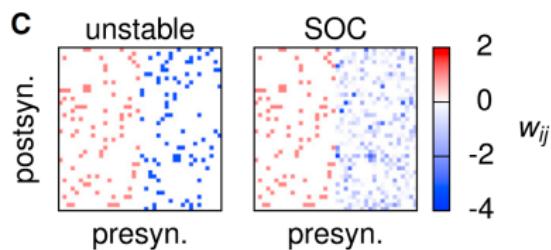
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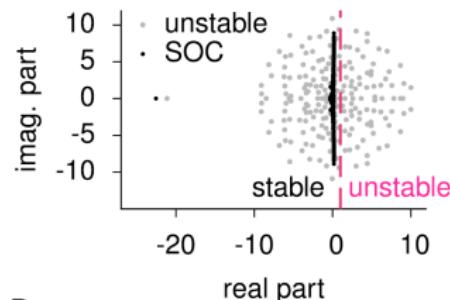
[Hennequin et al., 2014]

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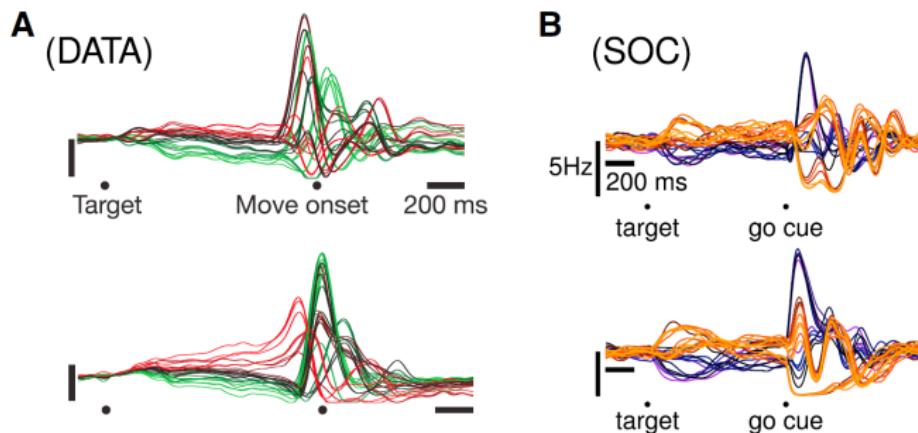


Detailed balance connectivity

- “Detailed balance” networks can reproduce the complex spatio-temporal neural activity patterns found in motor cortex.

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- The stimulation of a cluster in a clustered network can reproduce the stimulus-induced drop in firing rate variability.

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- The stimulation of a cluster in a clustered network can reproduce the stimulus-induced drop in firing rate variability.
- A detailed balance connectivity can reproduce the complex spatio-temporal neural activity patterns found in motor cortex.

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