



Mixed selectivity and reservoir computing

Omri Barak

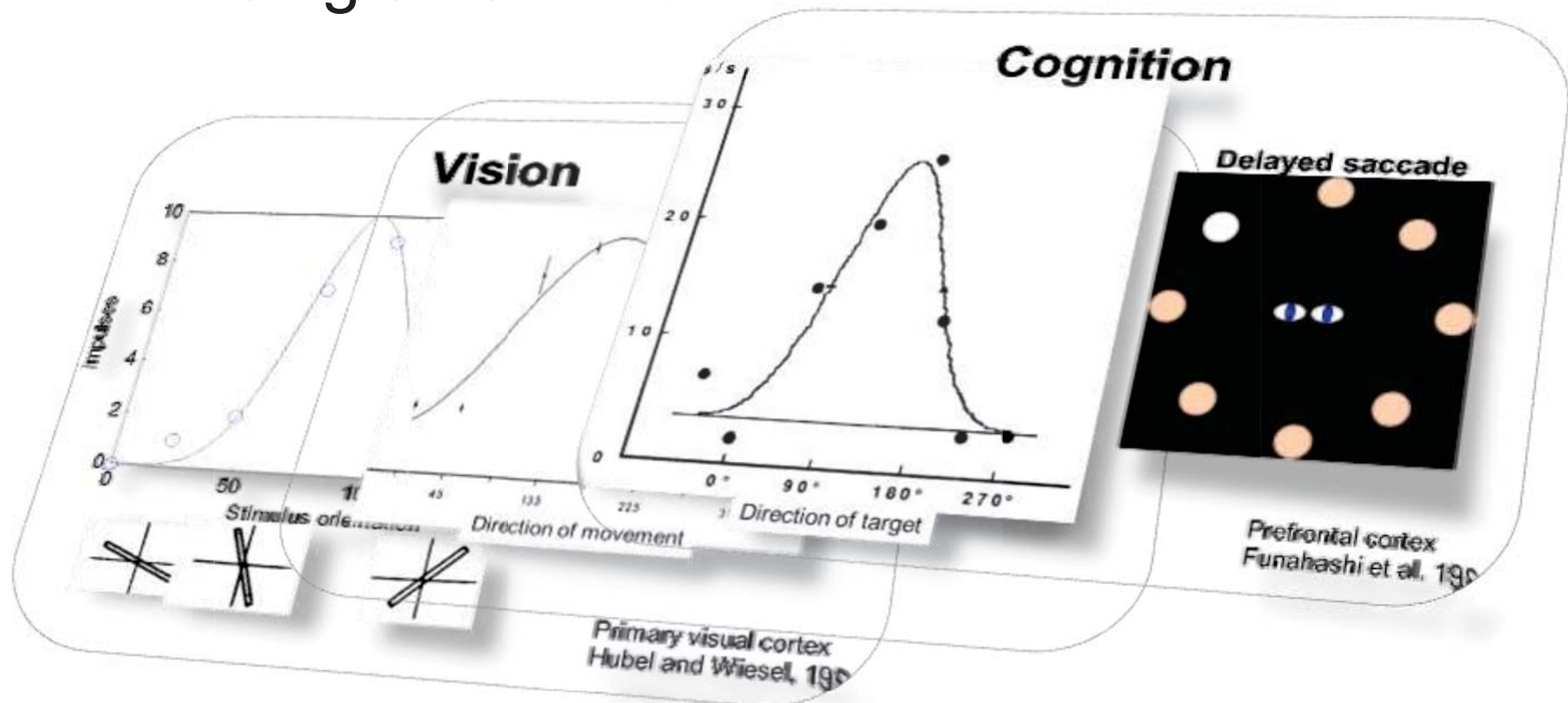
October, 2016

Understanding the brain

- Neural correlates of behavior
- A model (more or less formal) that links neural activity to behavior

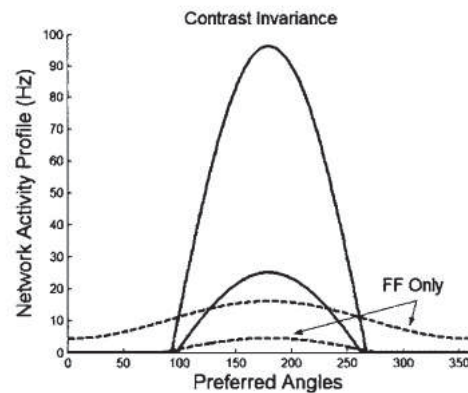
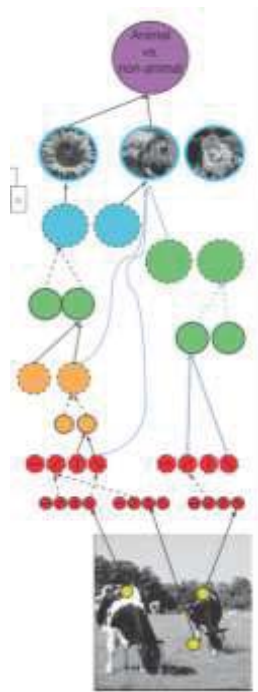
Neural correlates

- Traditionally answered by considering single neurons.



Nice neurons for nice models

- Clear (pure) selectivity inspires models



B

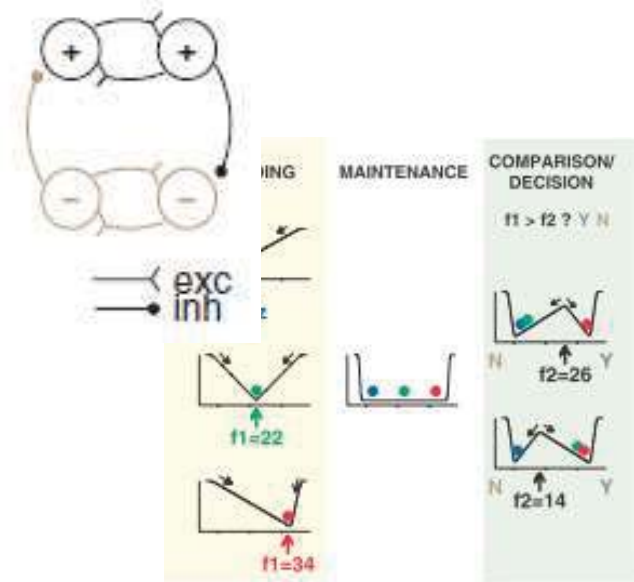
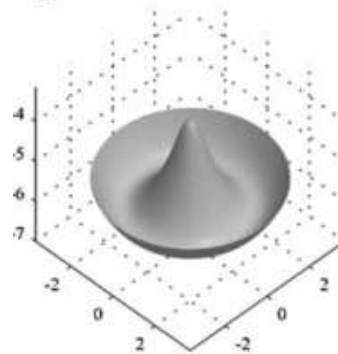
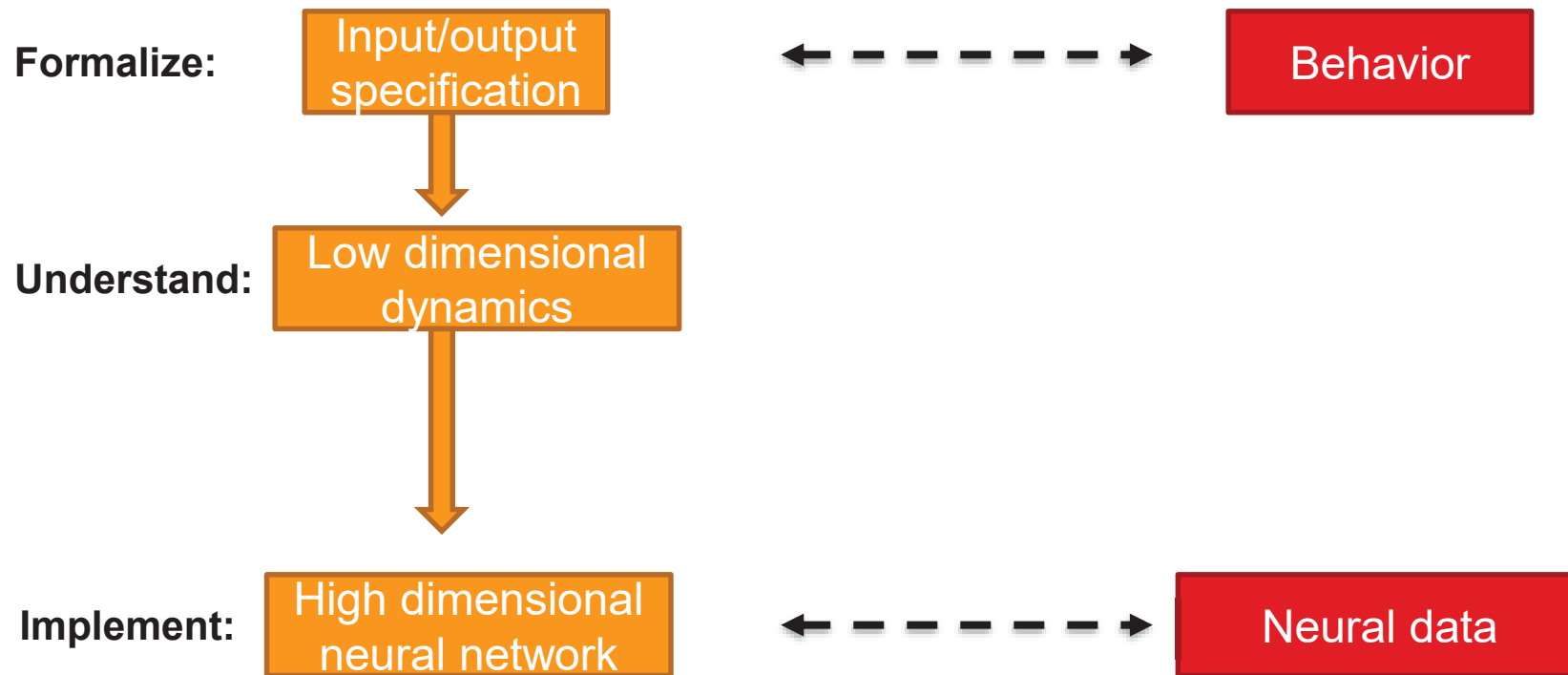


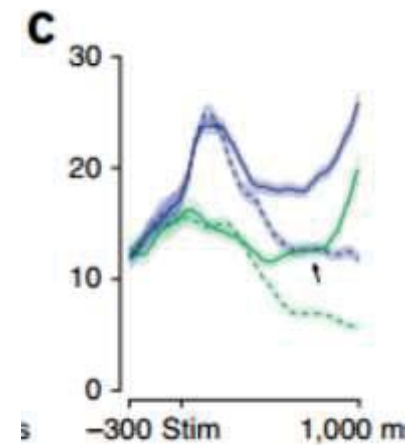
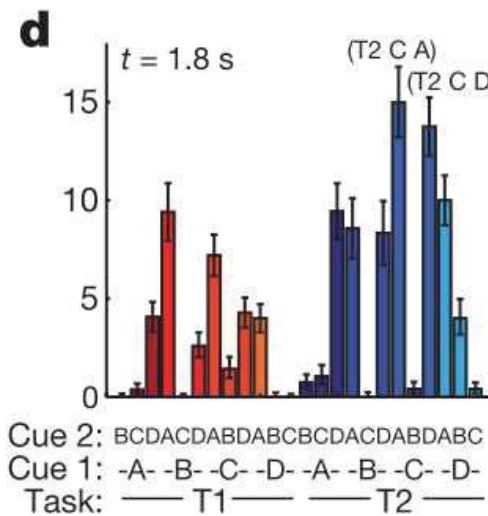
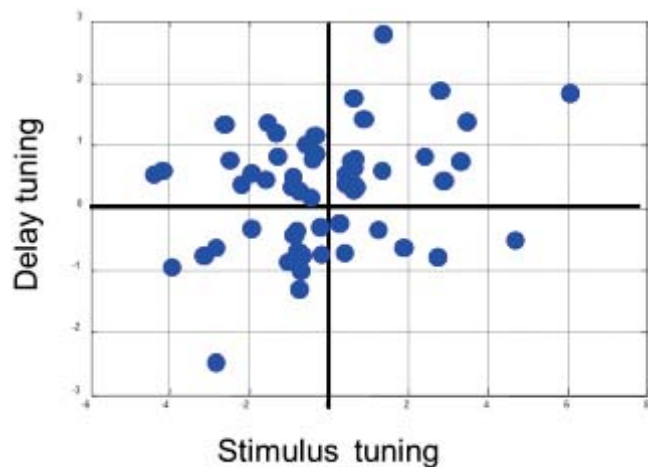
Fig. 2. One-dimensional dynamical algorithm for
Serre, Oliva, Poggio 2007
Ben Yishai et al 1995
Blumenfeld et al 2006
Machens et al 2005

The conventional way of understanding



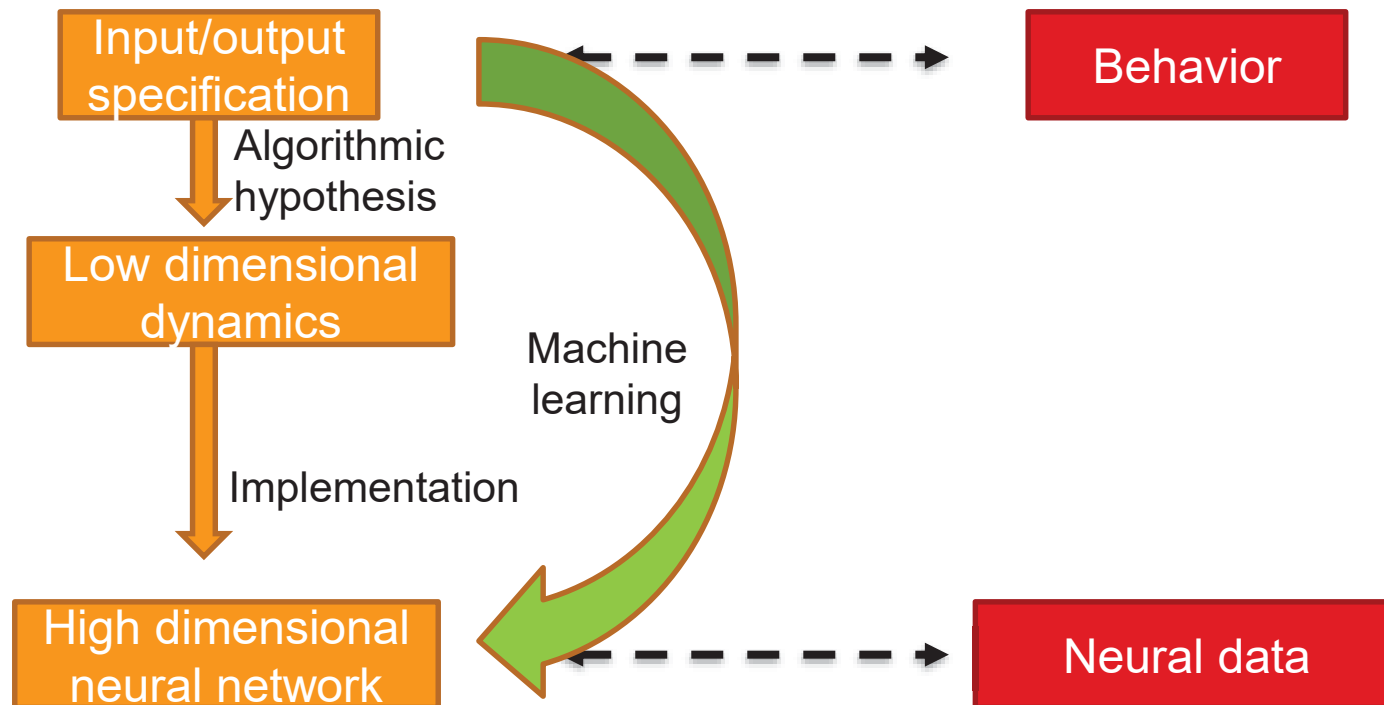
Mixed selectivity

Neurons change their tuning based on context.



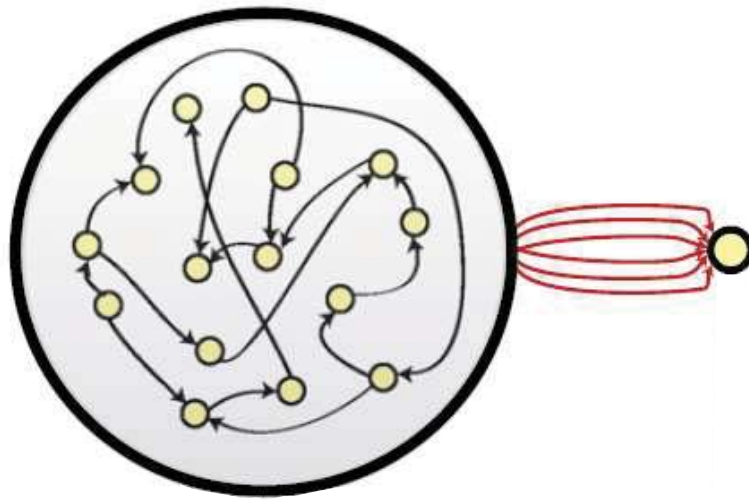
Barak et al 2010
 Rigotti et al 2013
 Raposo et al 2014

The conventional way of understanding



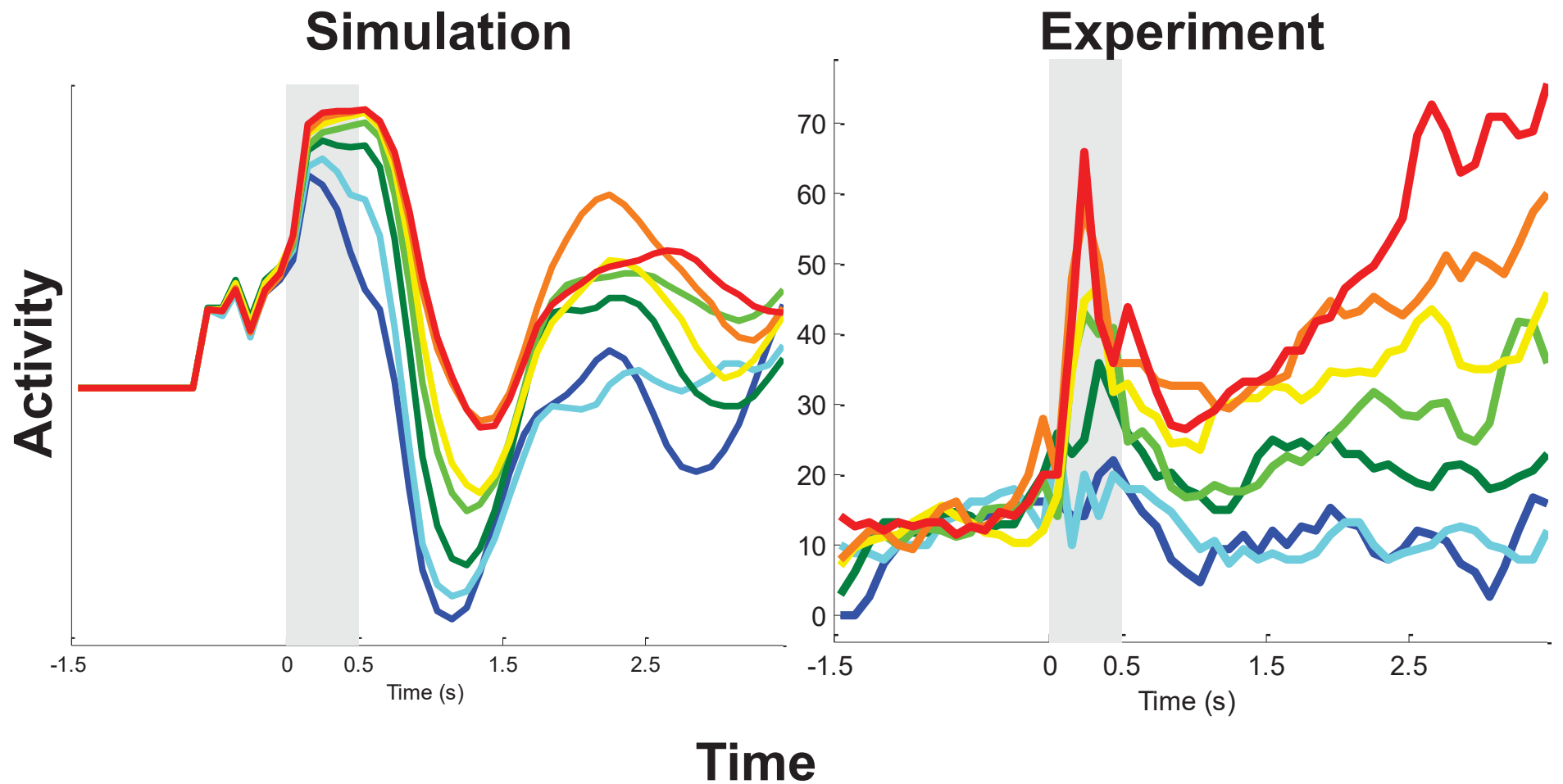
Recurrent neural networks

(Echo state, Liquid state, Reservoir)

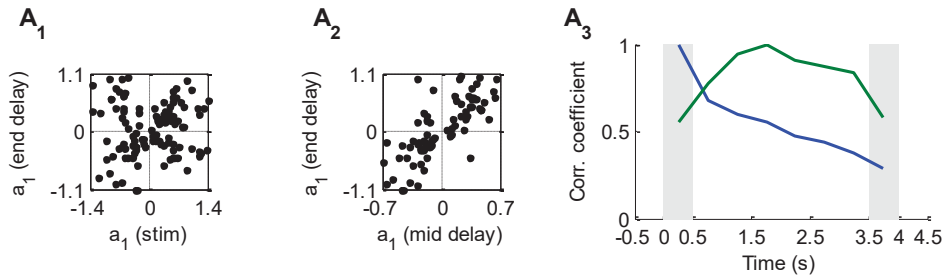


Dominey et al 1995
Buonomano and Merzenich 1995
Jaeger 2001
Maass et al 2002

Comparison to experiment

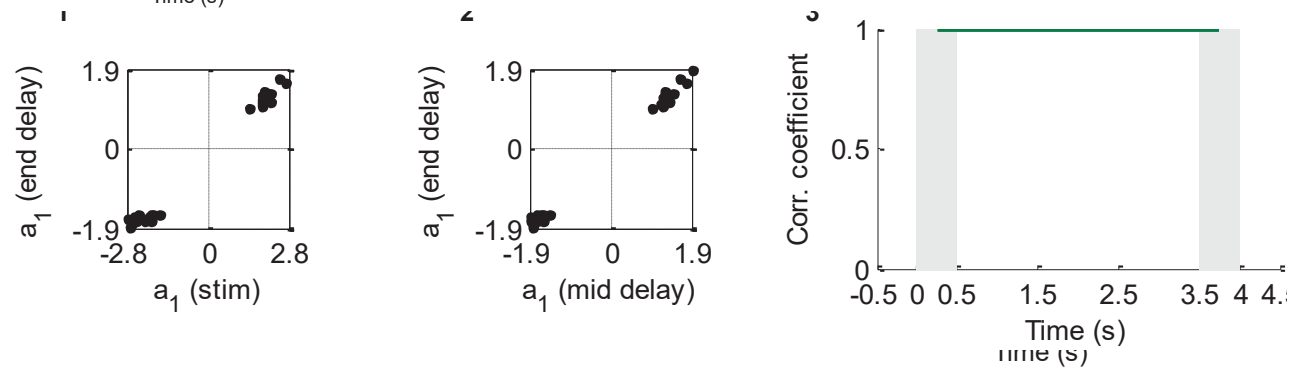


Mixed selectivity

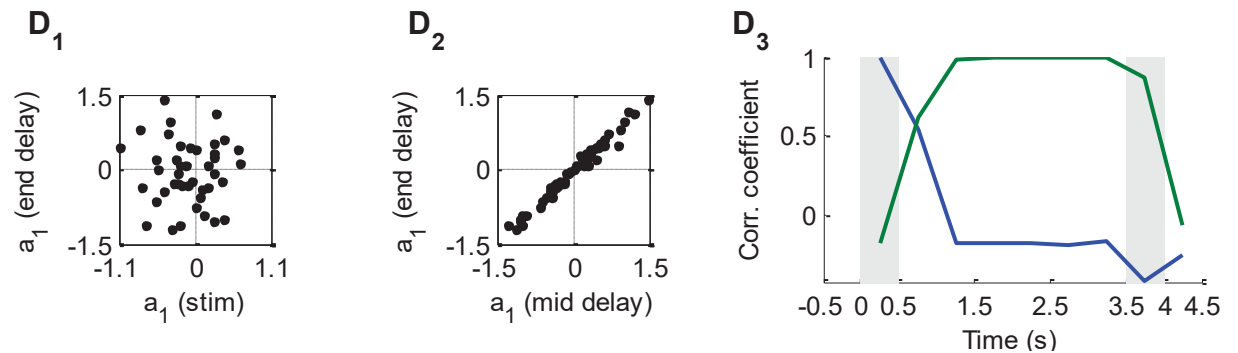


← Data

Engineered:

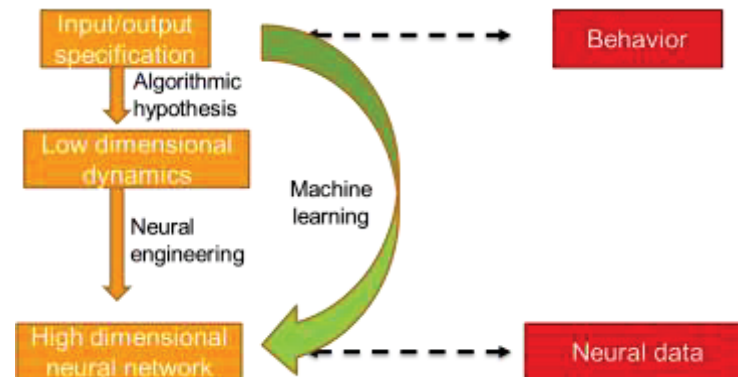


Trained:

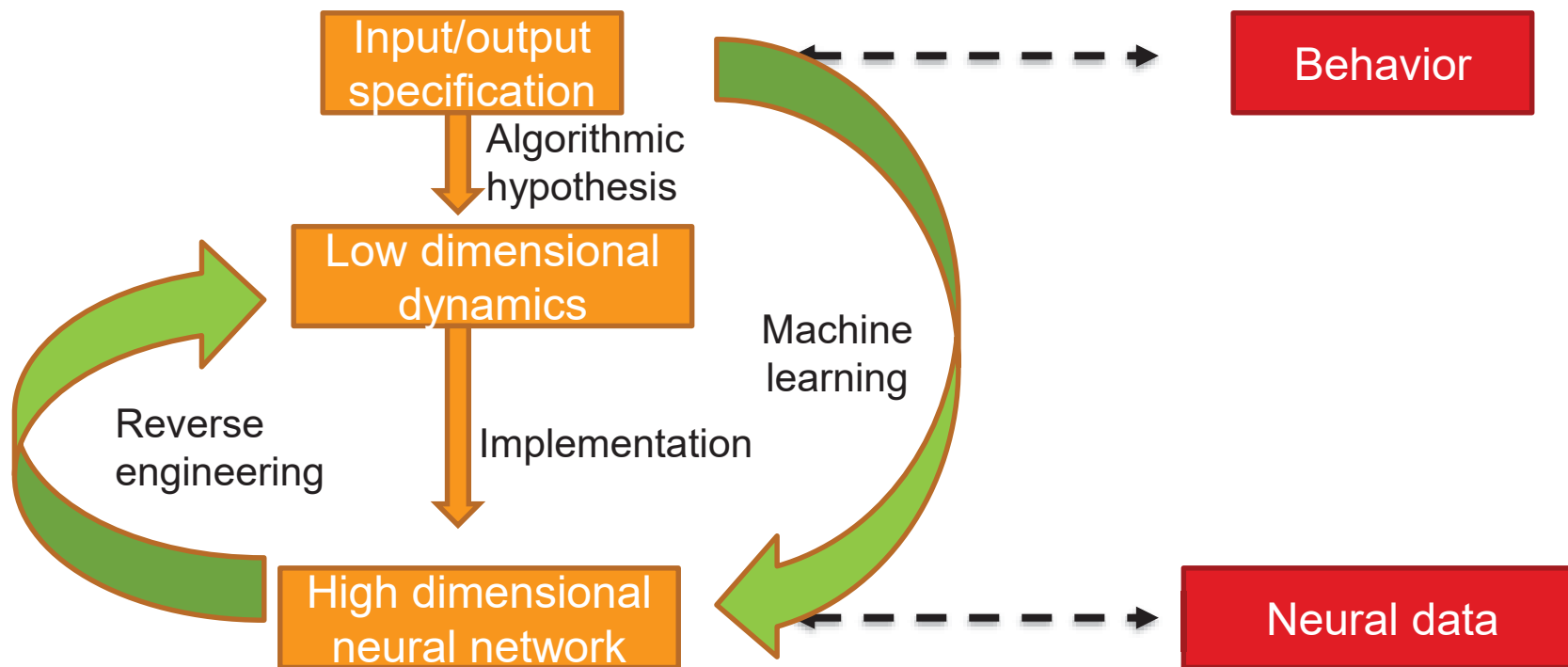


The Machine learning way (Recurrent neural networks)

- Train
- It works!
- It has some stuff that looks like neurons!
- We have no clue how it works...



But how does it work??



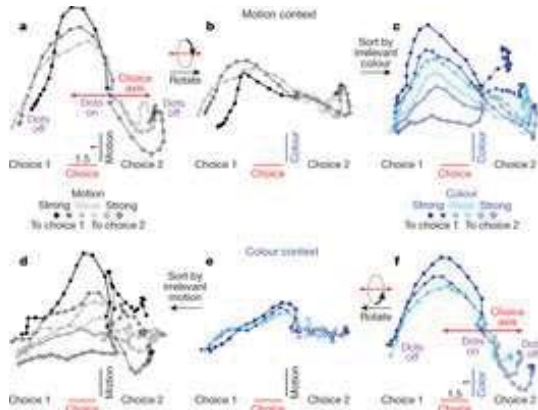
Opening the black box

- We developed an algorithm to find fixed points in trained neural networks.

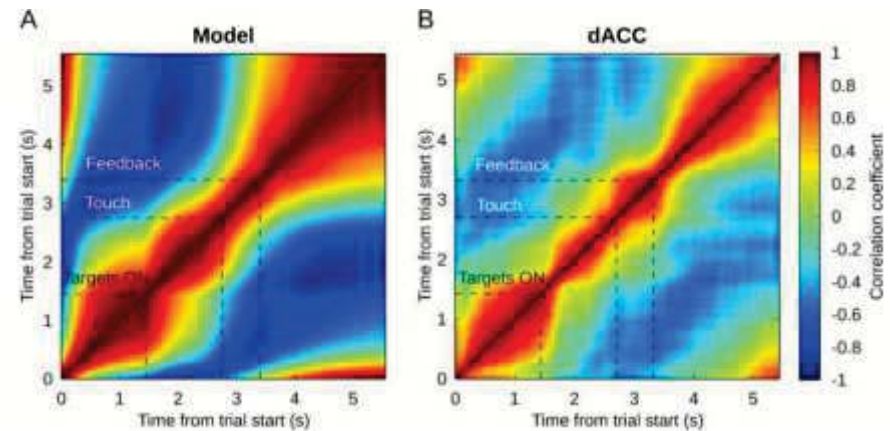
Sussillo & Barak 2013

RNNs explain data & mechanism

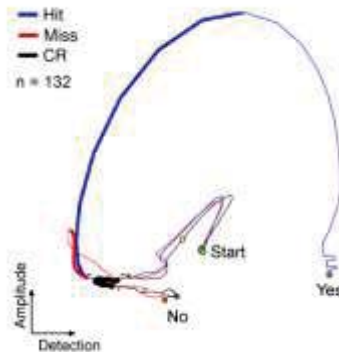
Context dependent computation
Mante et al. Nature 2013



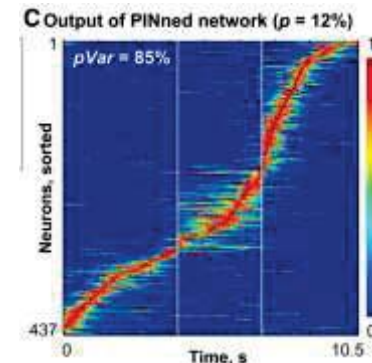
Dynamics of dACC during complex task
Enel et al. PLoS Comp Bio 2016



Representing temporal expectations
Carnevale et al. Neuron 2015



Sequene generation
Rajan et al. Neuron 2016



Similar work is being done in deep (feedforward) neural networks (DiCarlo).

What is missing?

- Trajectory vs. dynamics
- Invariance of solutions
- Limits of the approach
- Design considerations
- A good forward model help reverse engineering

... Theory

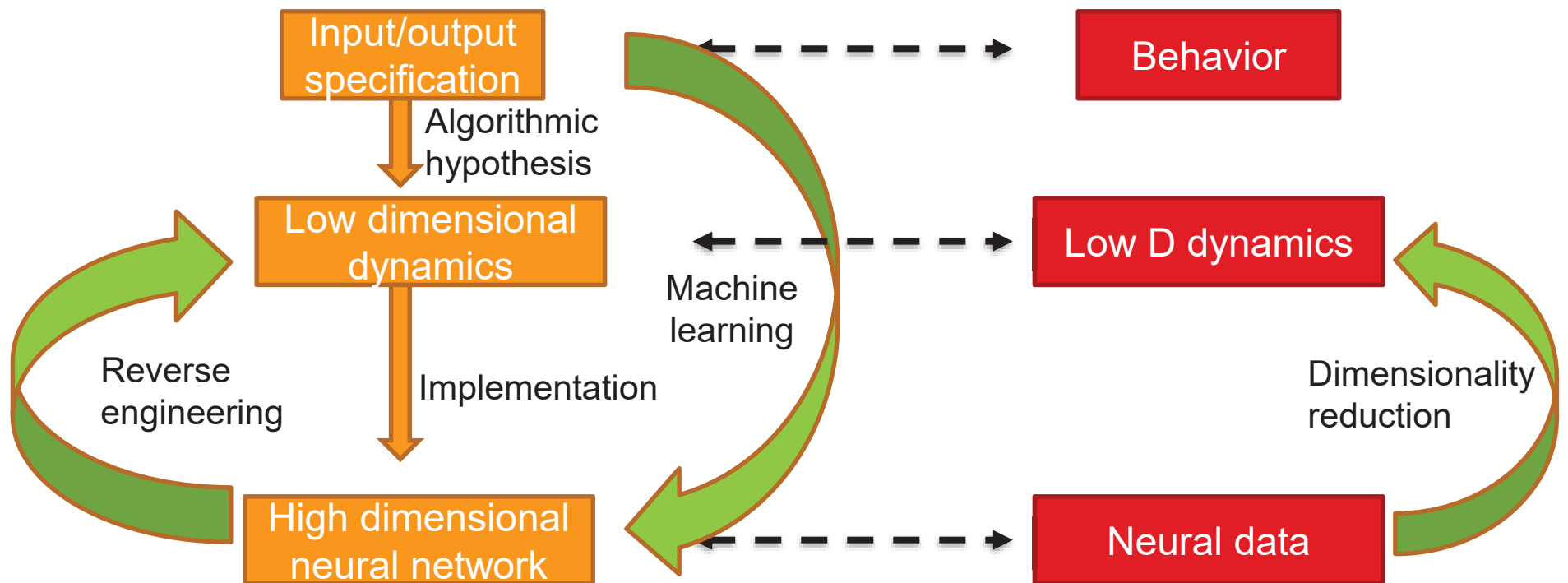
Our approach

- Thorough understanding of very simple tasks.
 - Analytical solutions
 - Building block for more complex tasks.

Conclusions

- Focusing on single neurons has its limits.
- Understanding population dynamics is a hard task.
- Combining machine learning and dynamical systems can lead to new insights.
- Doing this properly requires theory
- Low-D dynamics can be the relevant quantity to look for in models & data.

Conceptual framework



Thank you

Lab members:

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Xu Tie

Collaborators:

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Stefano Fusi
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Earl Miller
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Nestor Parga

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Fondation Adelis;

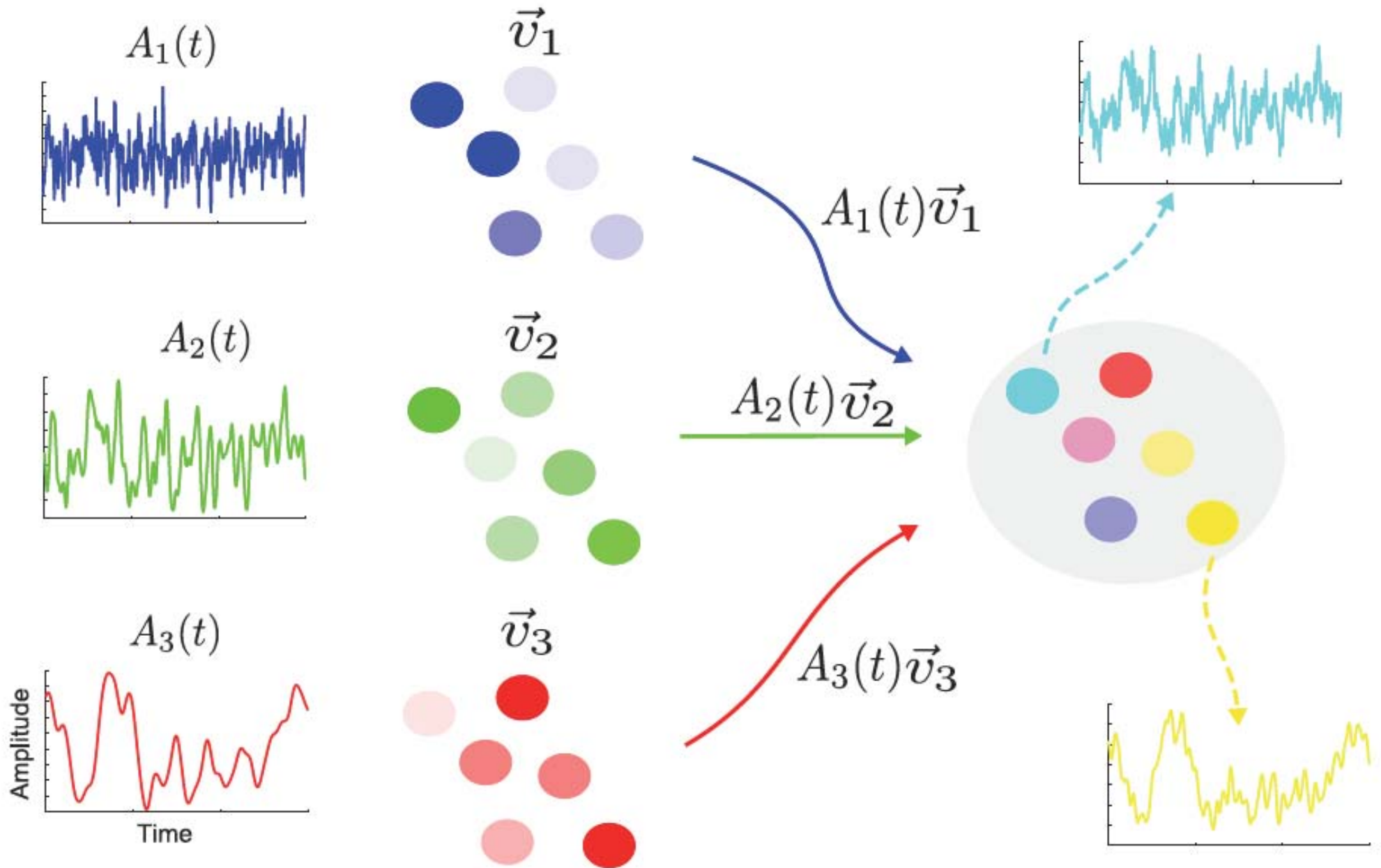


Interpreting high dimensional dynamics

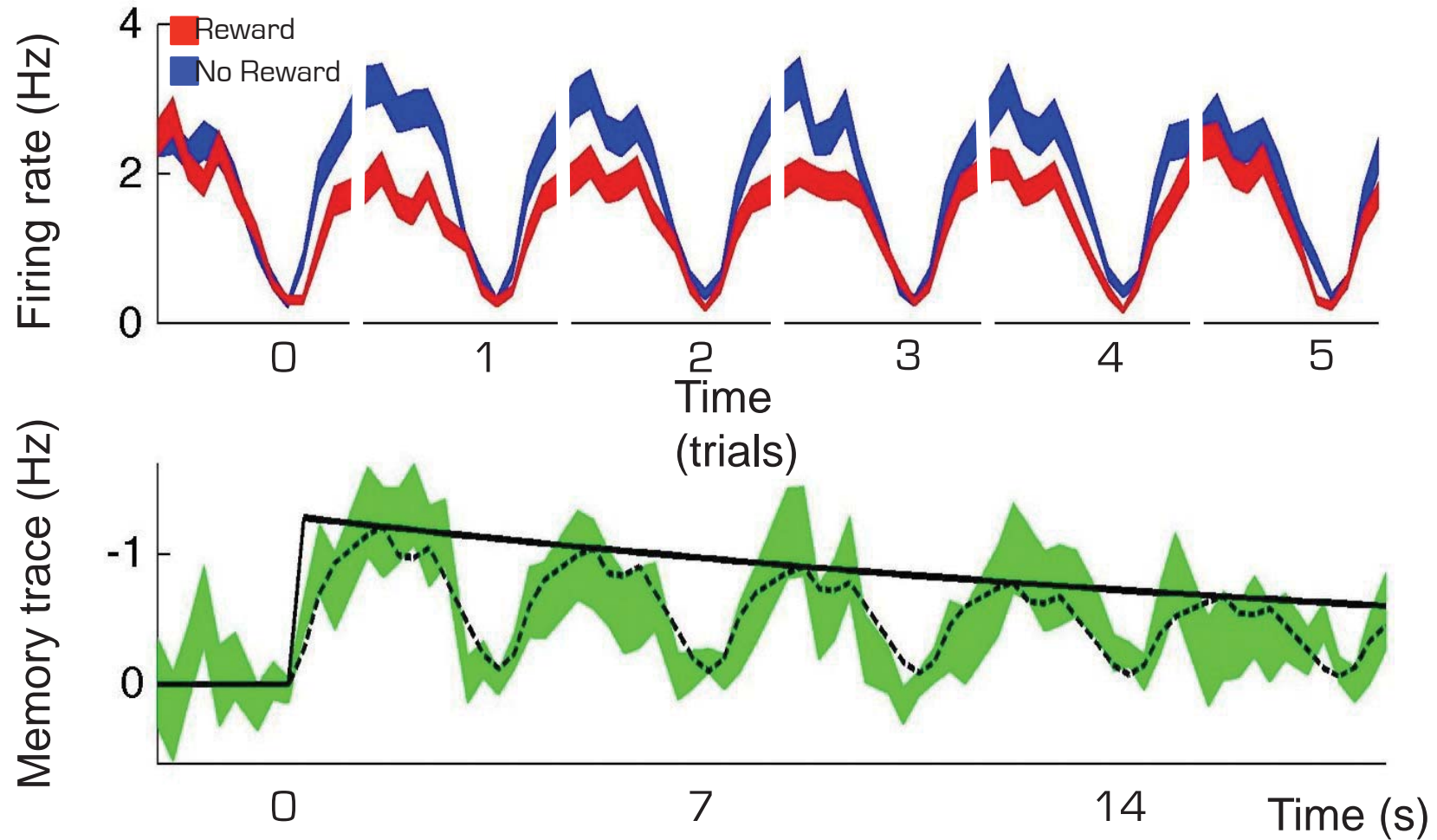
Alberto Bernacchia



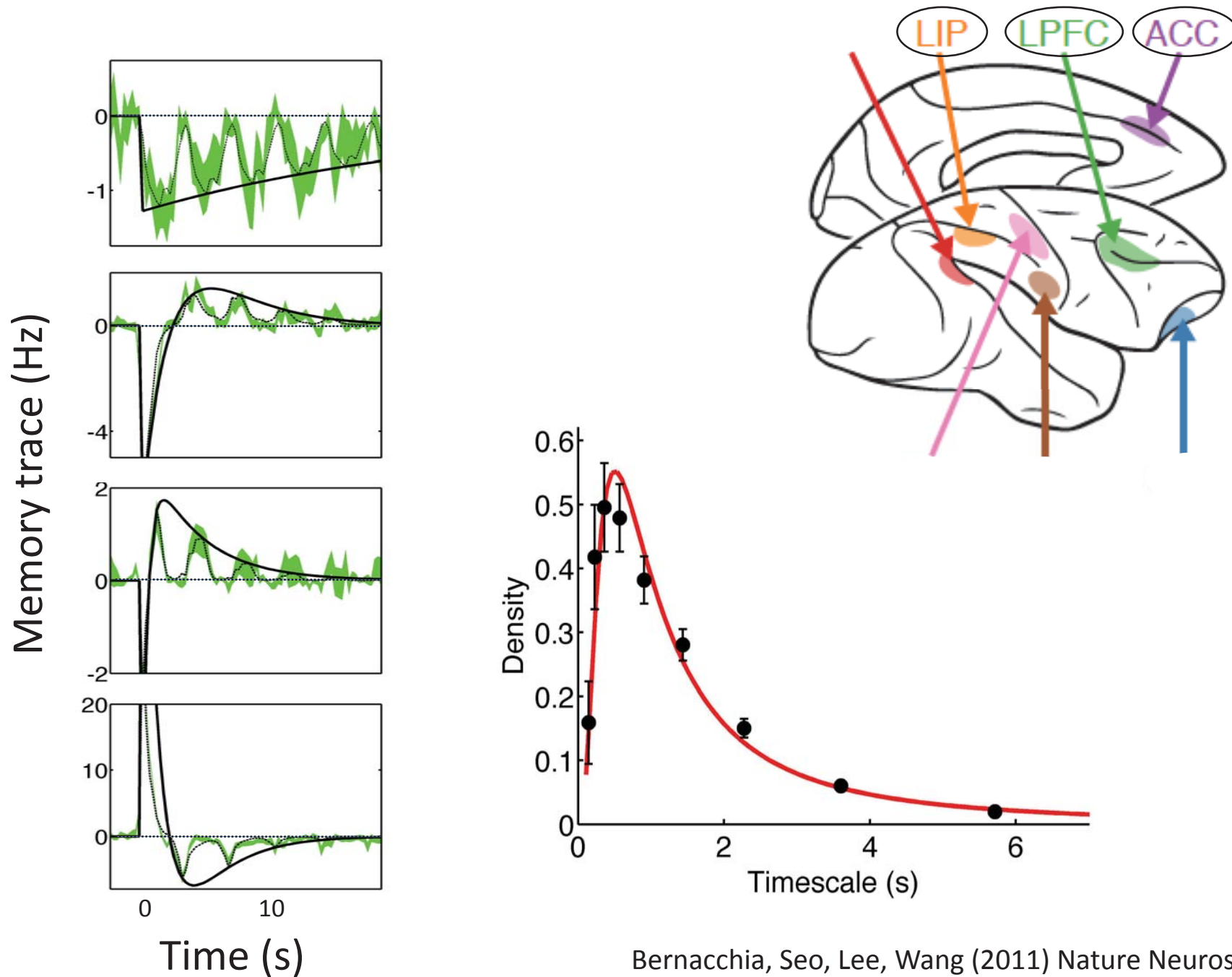
Timescales of neural activity



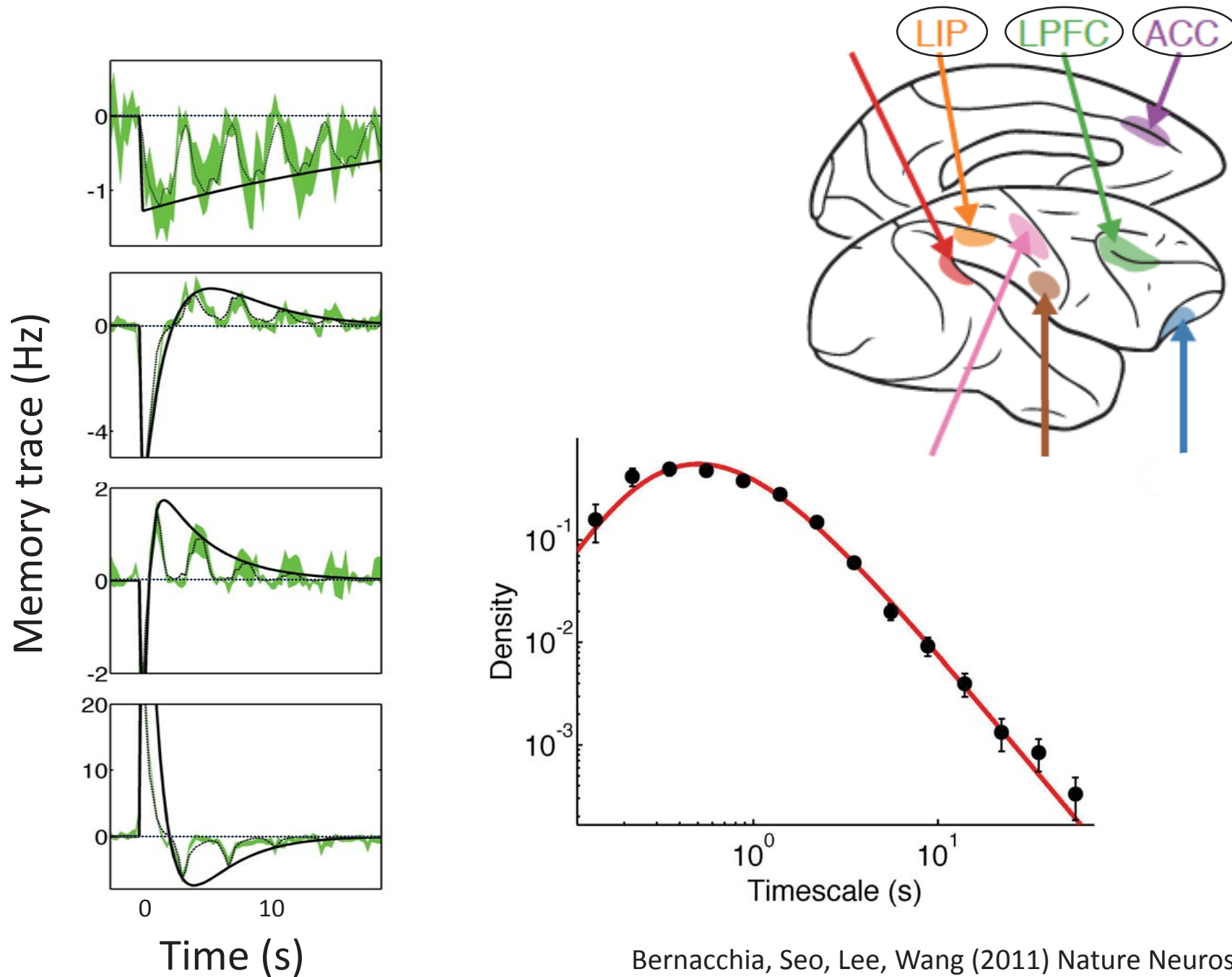
Timescales of neural activity



Timescales of neural activity

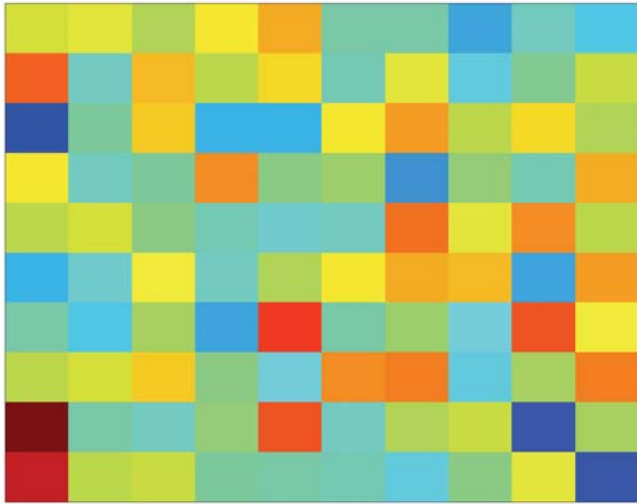


Timescales of neural activity

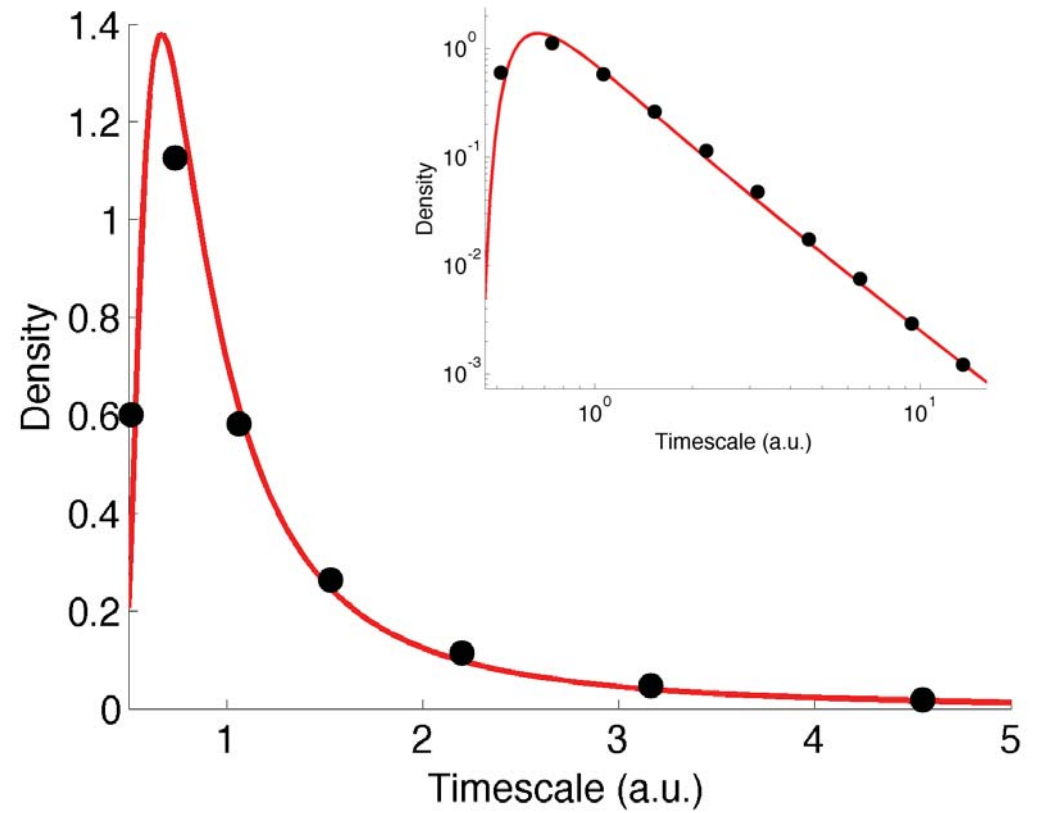
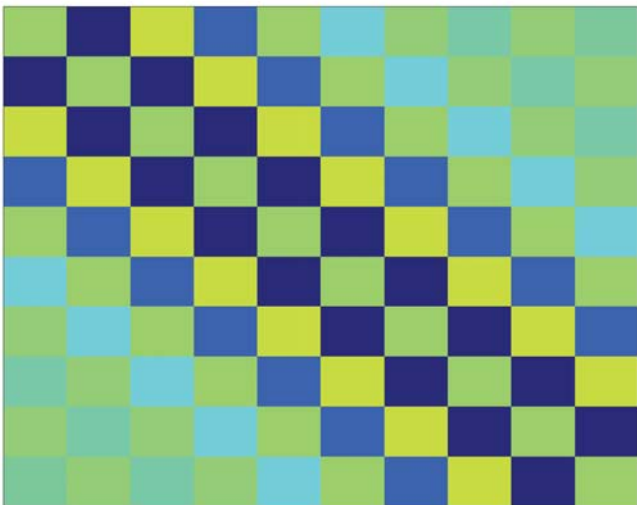


Timescales of neural activity

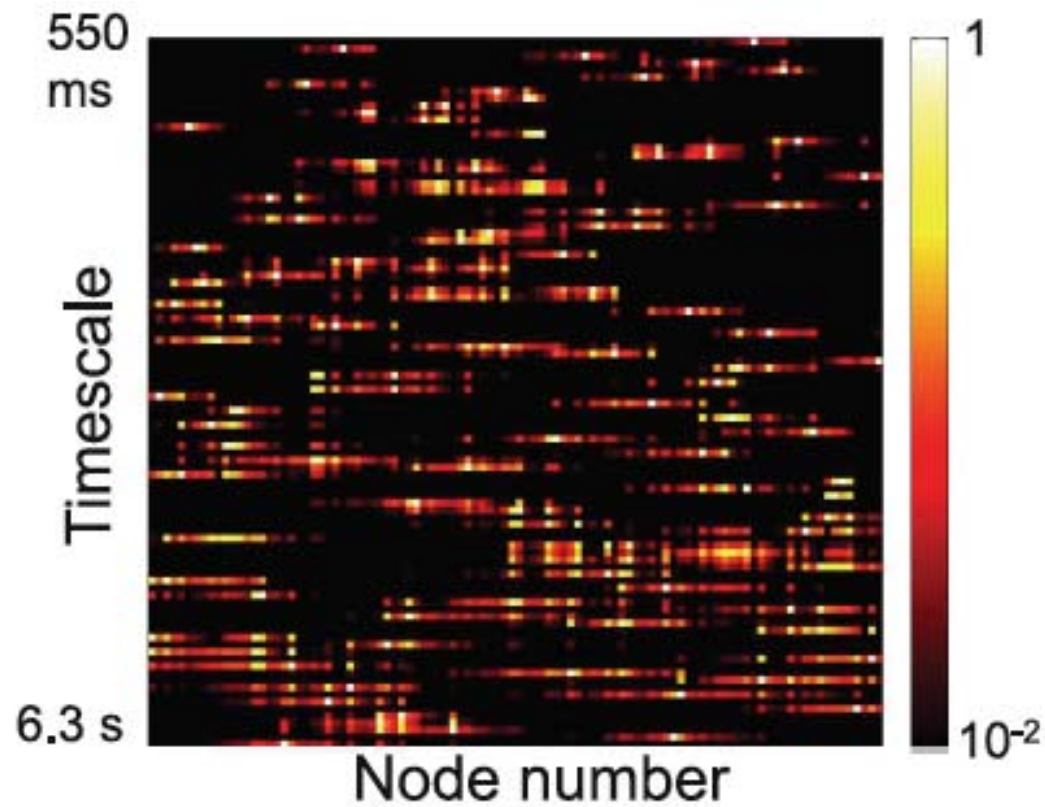
Random



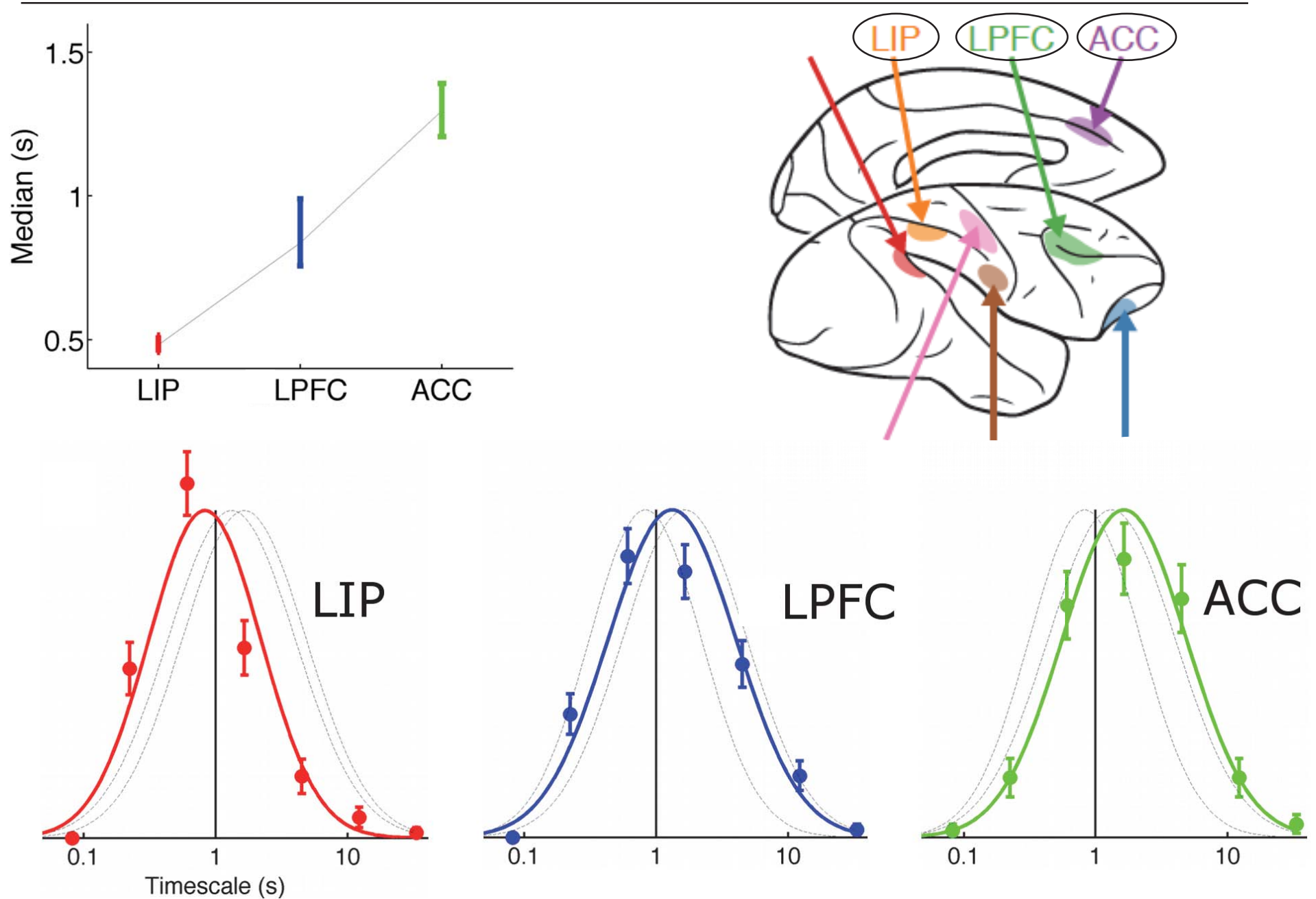
Local



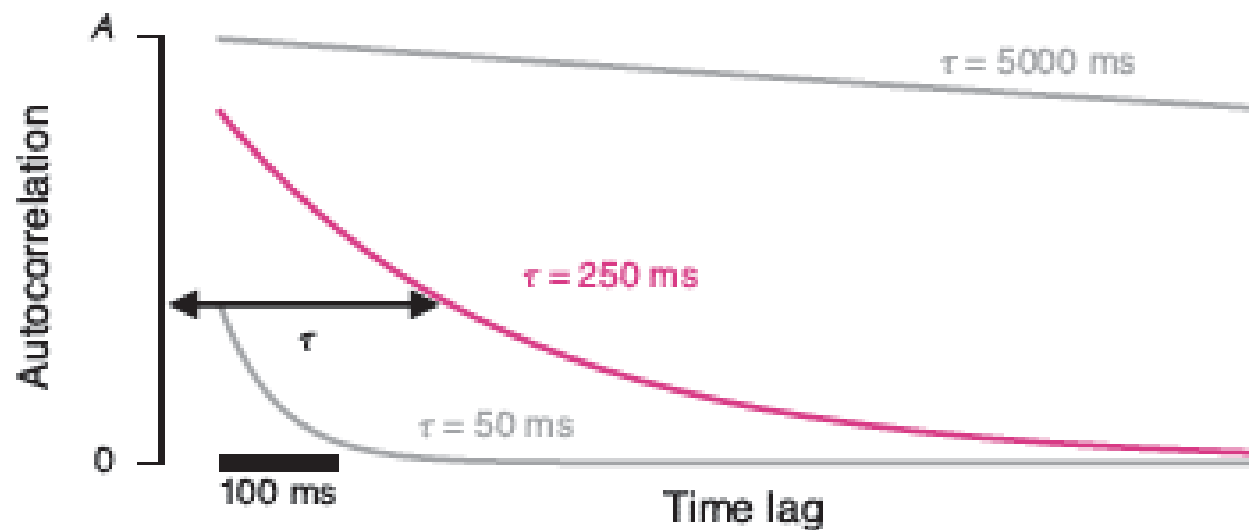
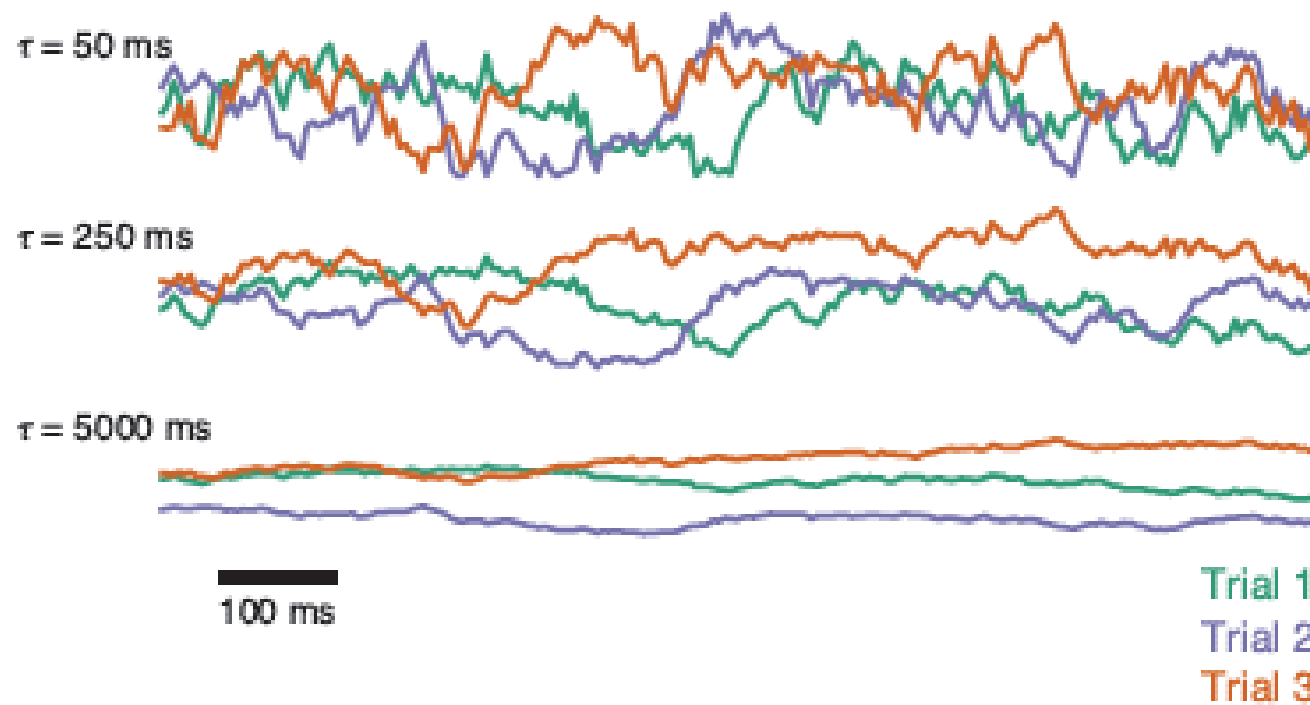
Timescales of neural activity



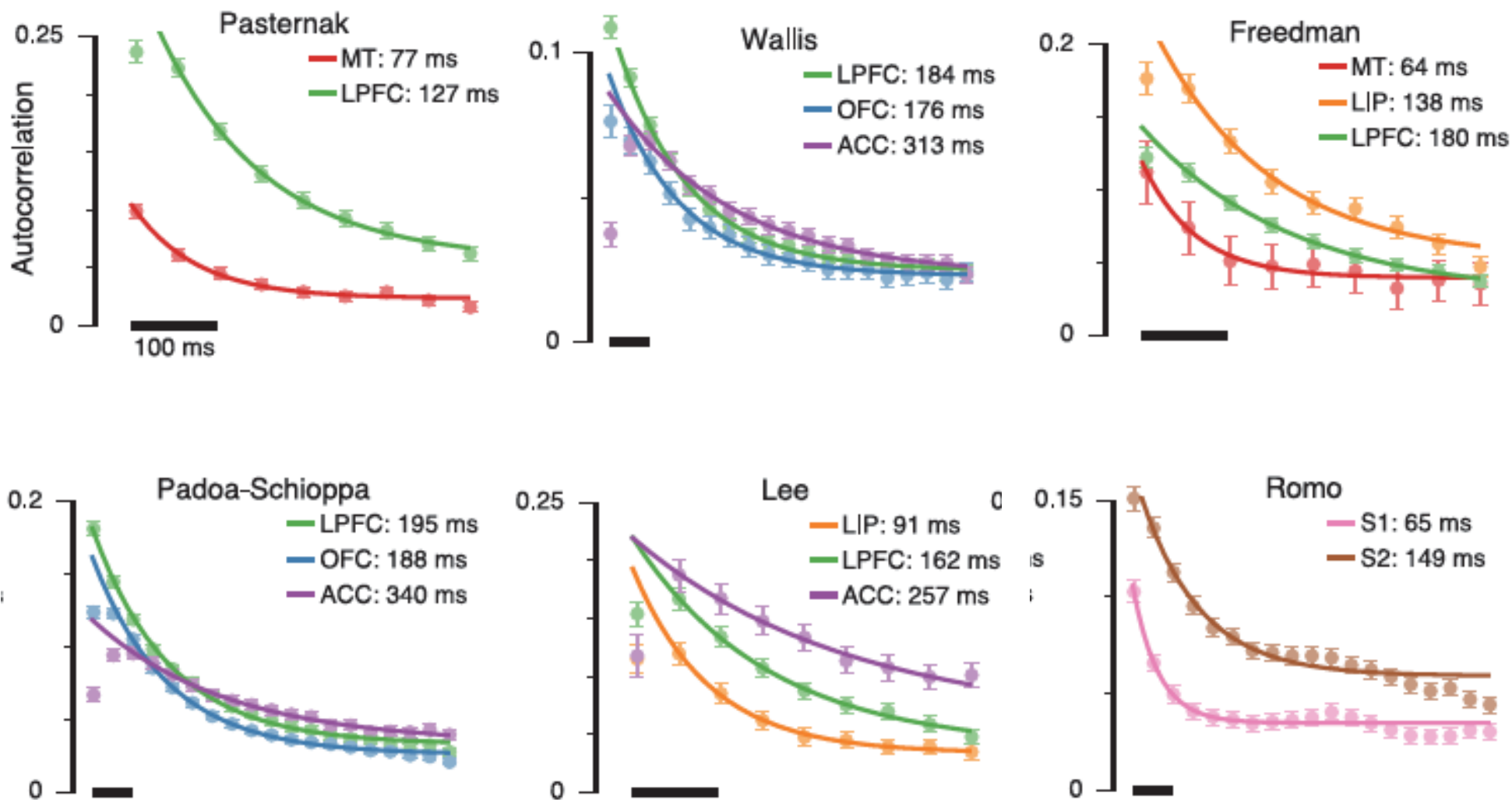
Timescales across cortical areas



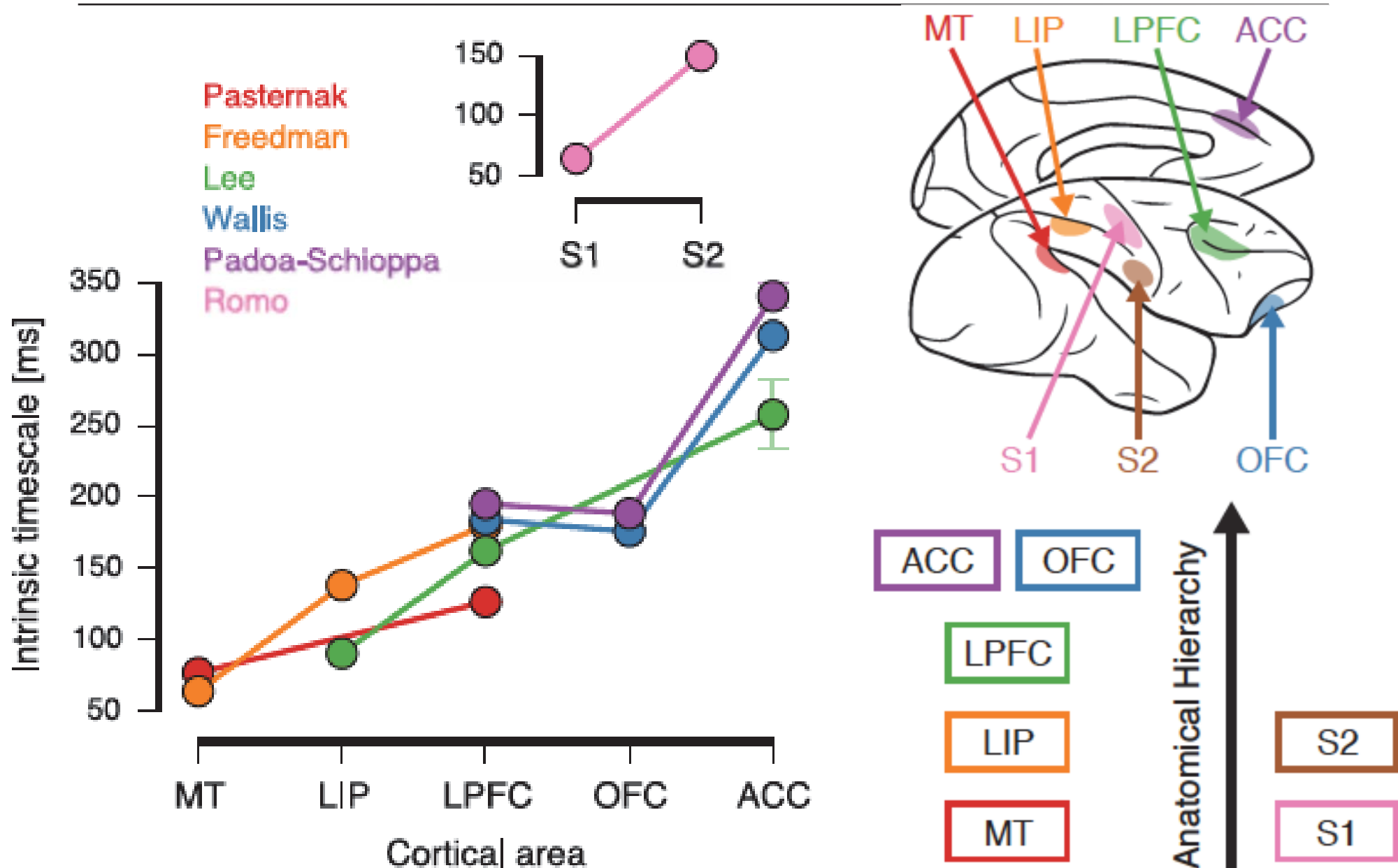
Timescales across cortical areas



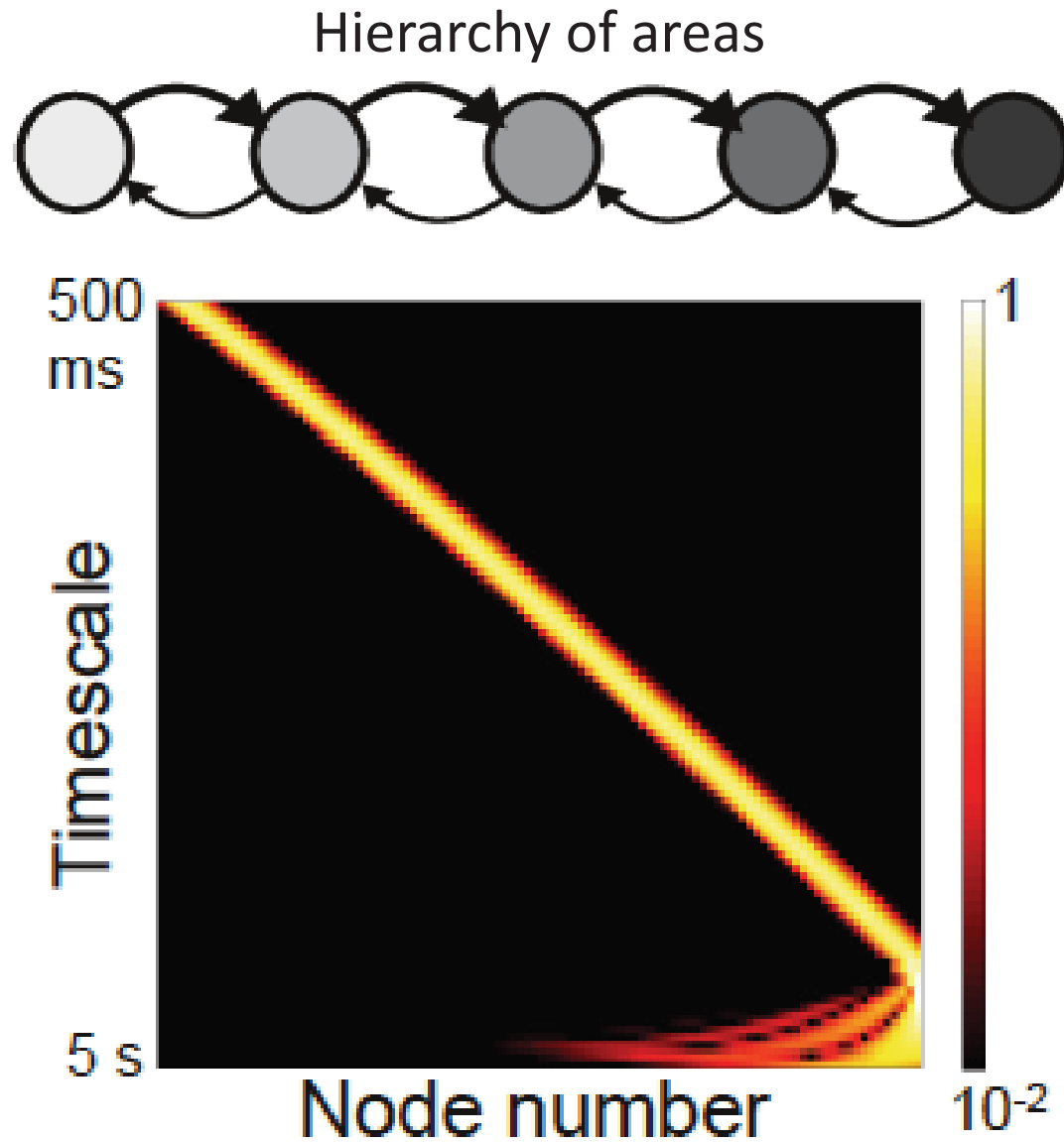
Timescales across cortical areas



Timescales across cortical areas



Timescales across cortical areas



Summary

Timescales of neural dynamics are heterogeneous within areas

Mean timescales are ordered across areas

What kind of neural circuit structure explains the distribution of timescales?

What is the function of the hierarchy of timescales?

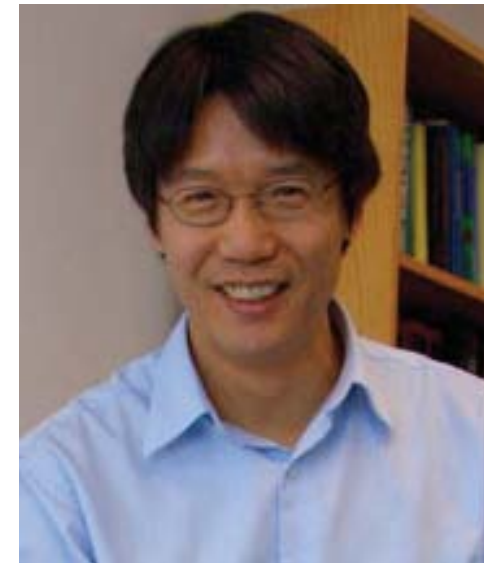
Credits



Rishidev Chaudhuri

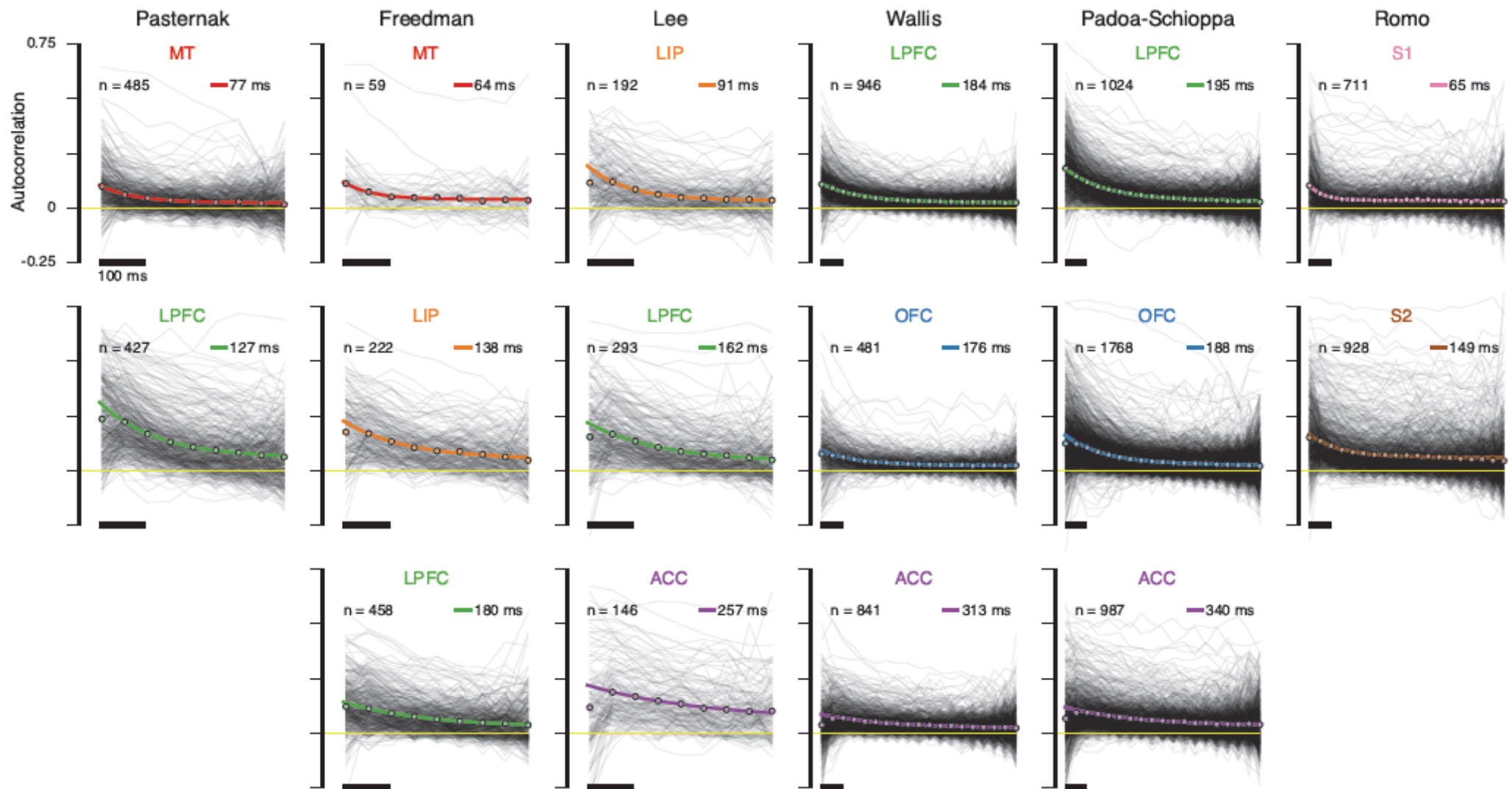


John Murray

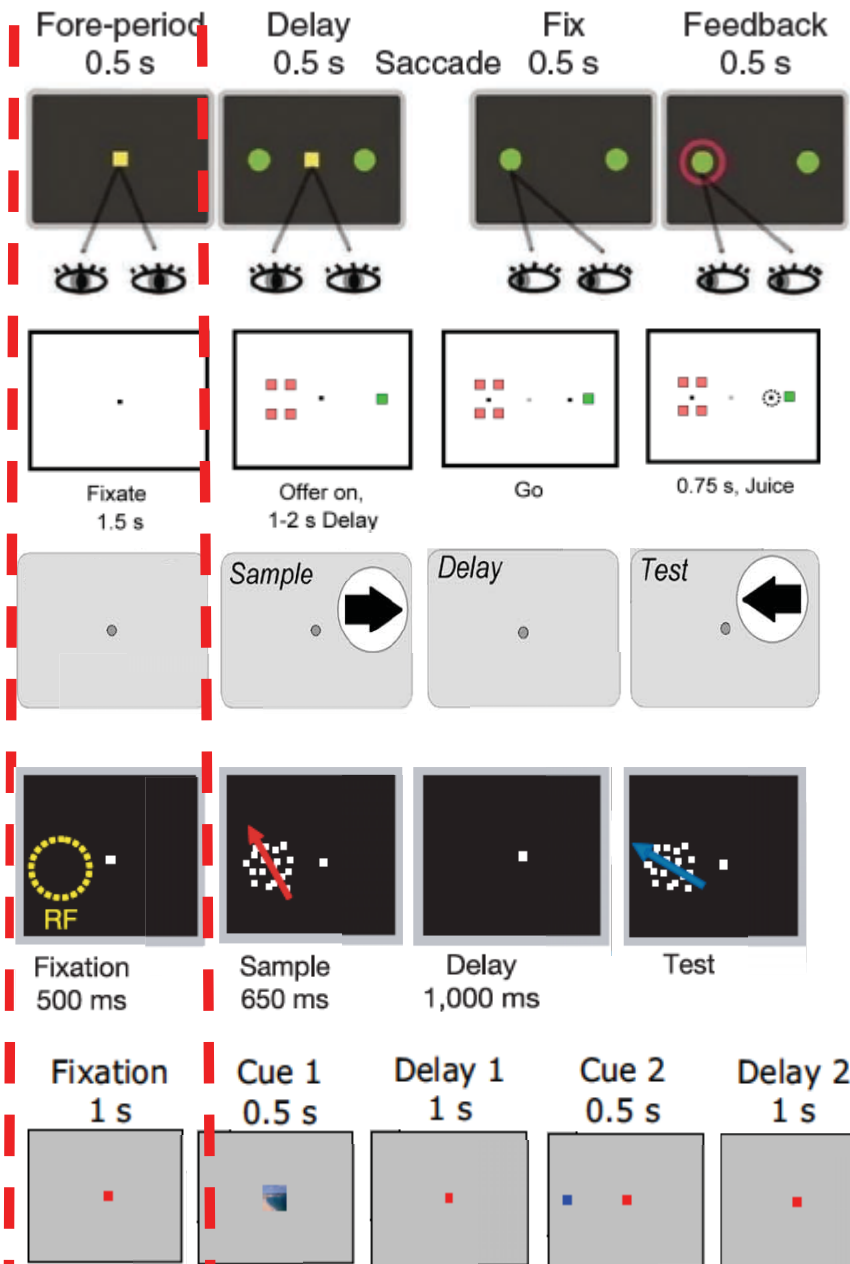


Xiao-Jing Wang

Autocorrelations of neural activity



Hierarchy of timescales



Bernacchia, Seo, Lee, Wang 2011
LIP, LPFC, ACC

Padoa Schioppa 2009
 Cai & Padoa-Schioppa 2012
LPFC, OFC, ACC

Zaksas, Pasternak 2006
MT, LPFC

Freedman & Assad 2006
 Swaminathan & Freedman 2012
MT, LIP, LPFC

Kennerley & Wallis 2009 jnp
 Kennerley & Wallis 2009 jns
LPFC, OFC, ACC