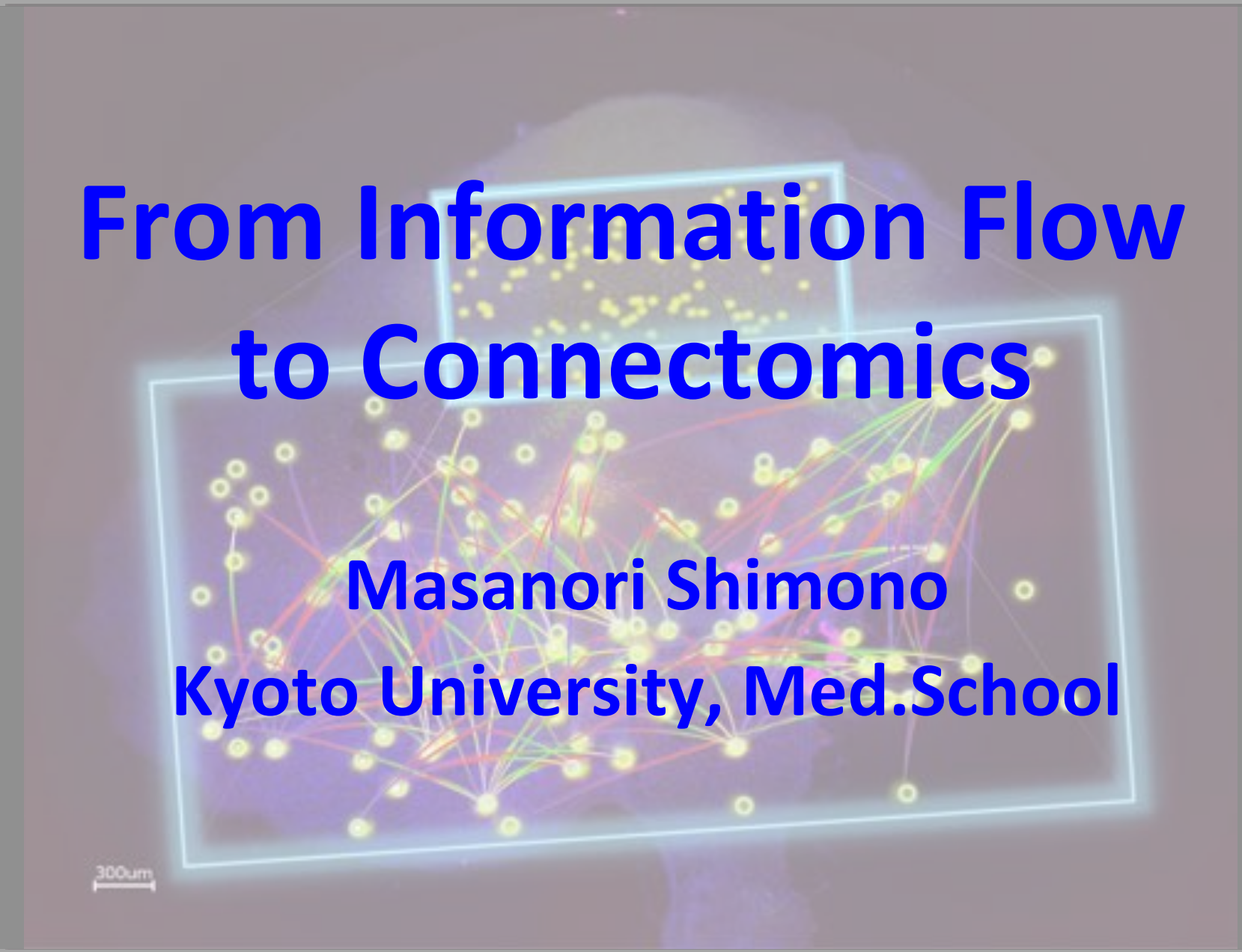
From Information Flow to Connectomics



Masanori Shimono
Kyoto University, Med.School

Contents

1. Causality and Information flow

- Arrow of time in Physics and in biology?

2. Function and Structure

- Natural correspondence between structural networks and effective networks.
- Physiological reliability.

3. Microconnectome

- Beyond simple statistical properties
- As one many body problem
- Nodes are generally neurons
- The detailed design of the network organization

- Degree, Hub, Cluster, Community, Rich Club

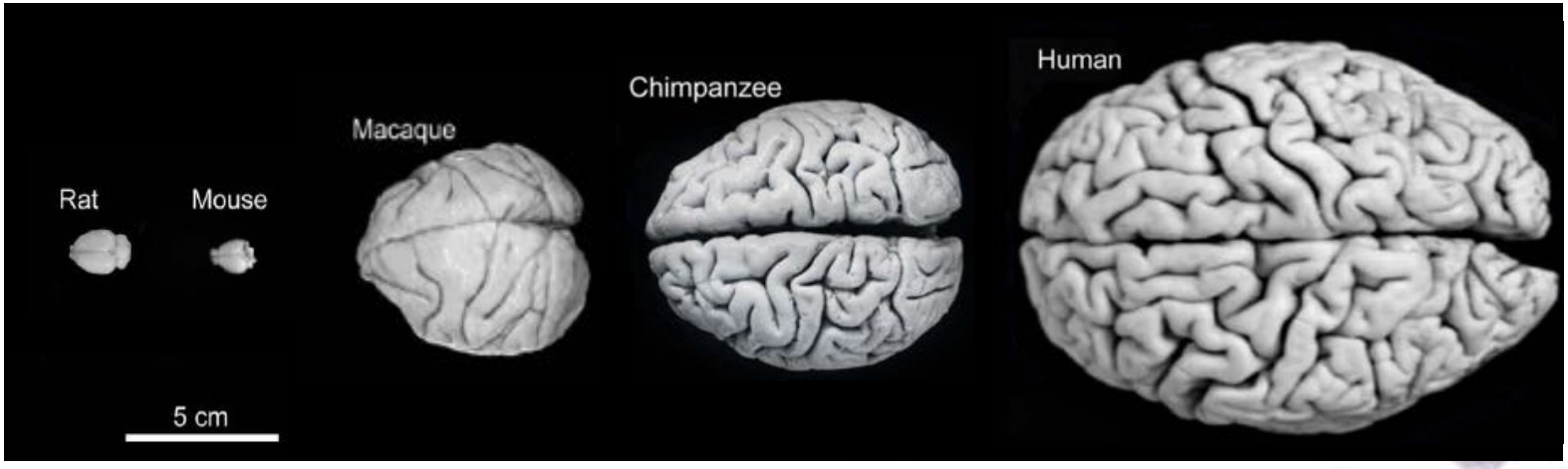
1. Causality and Information flow

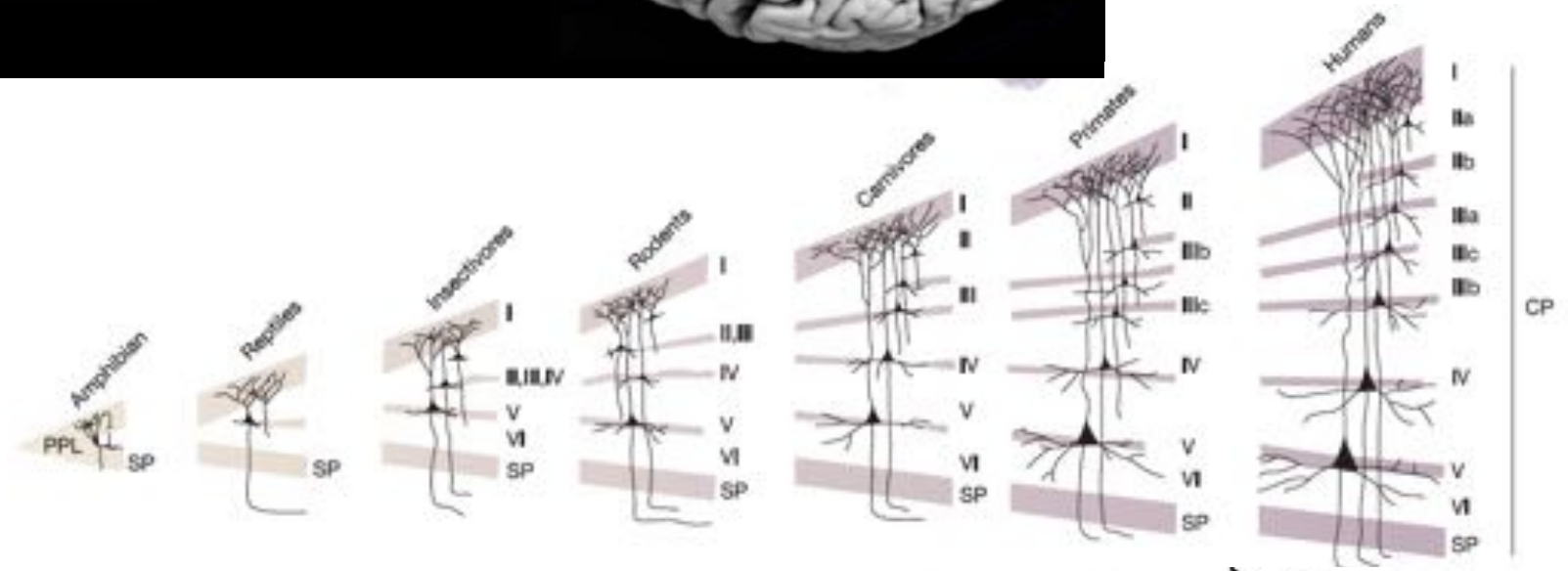
Arrow of time in Physics

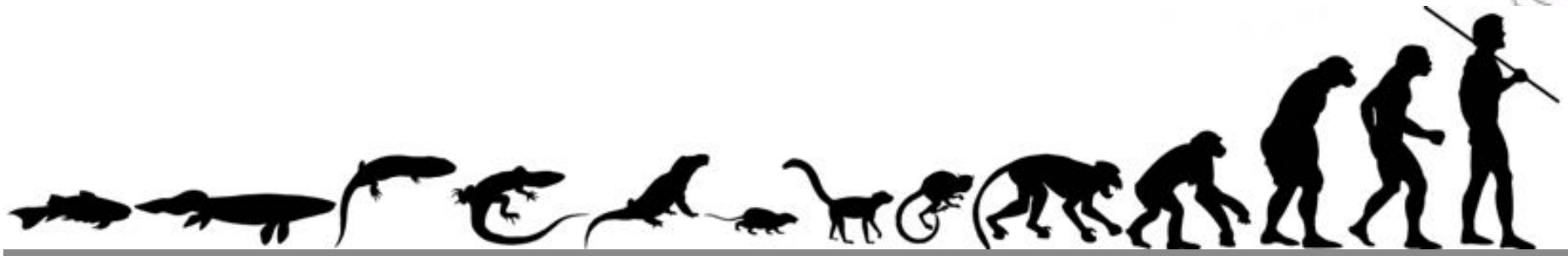
Entropy

http://i.kinja-img.com/gawker-media/image/upload/ynzdjeav7eakmgzamtpe.jpg

Arrow of time in Biology







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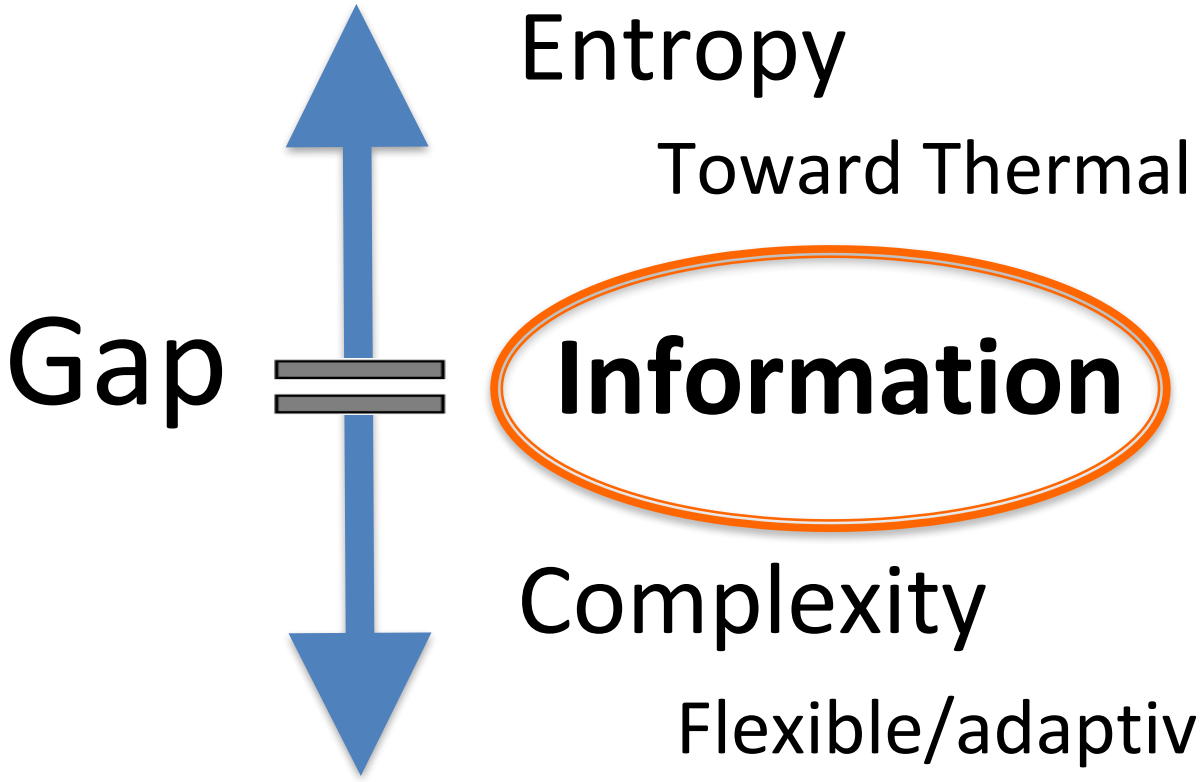
DeFellipe (2011) Frontiers in Neuroanatomy

Causality

Time arrow in Physics



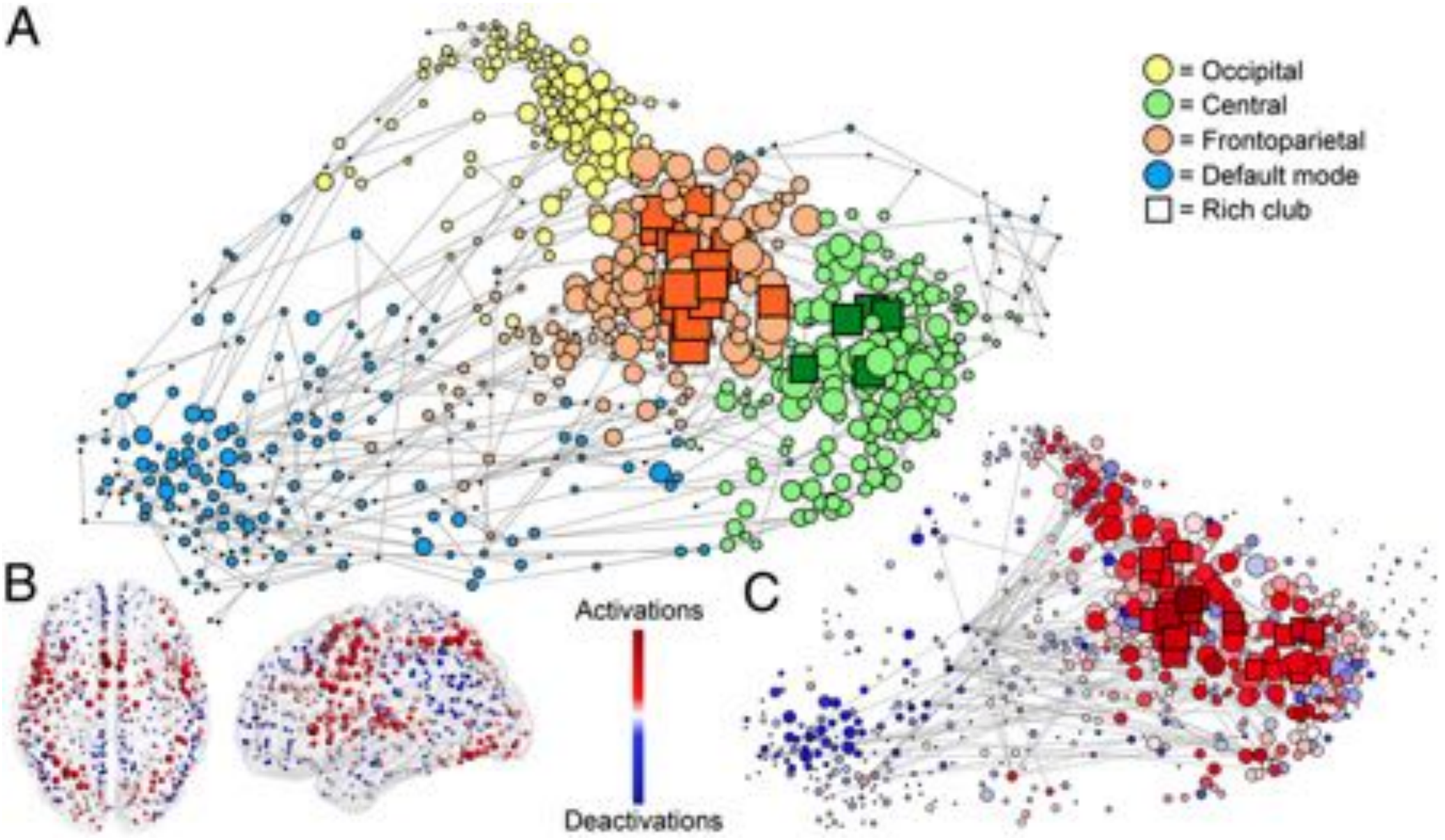
Time arrow in Biology

Causality

Causalities in biological system is intertwined

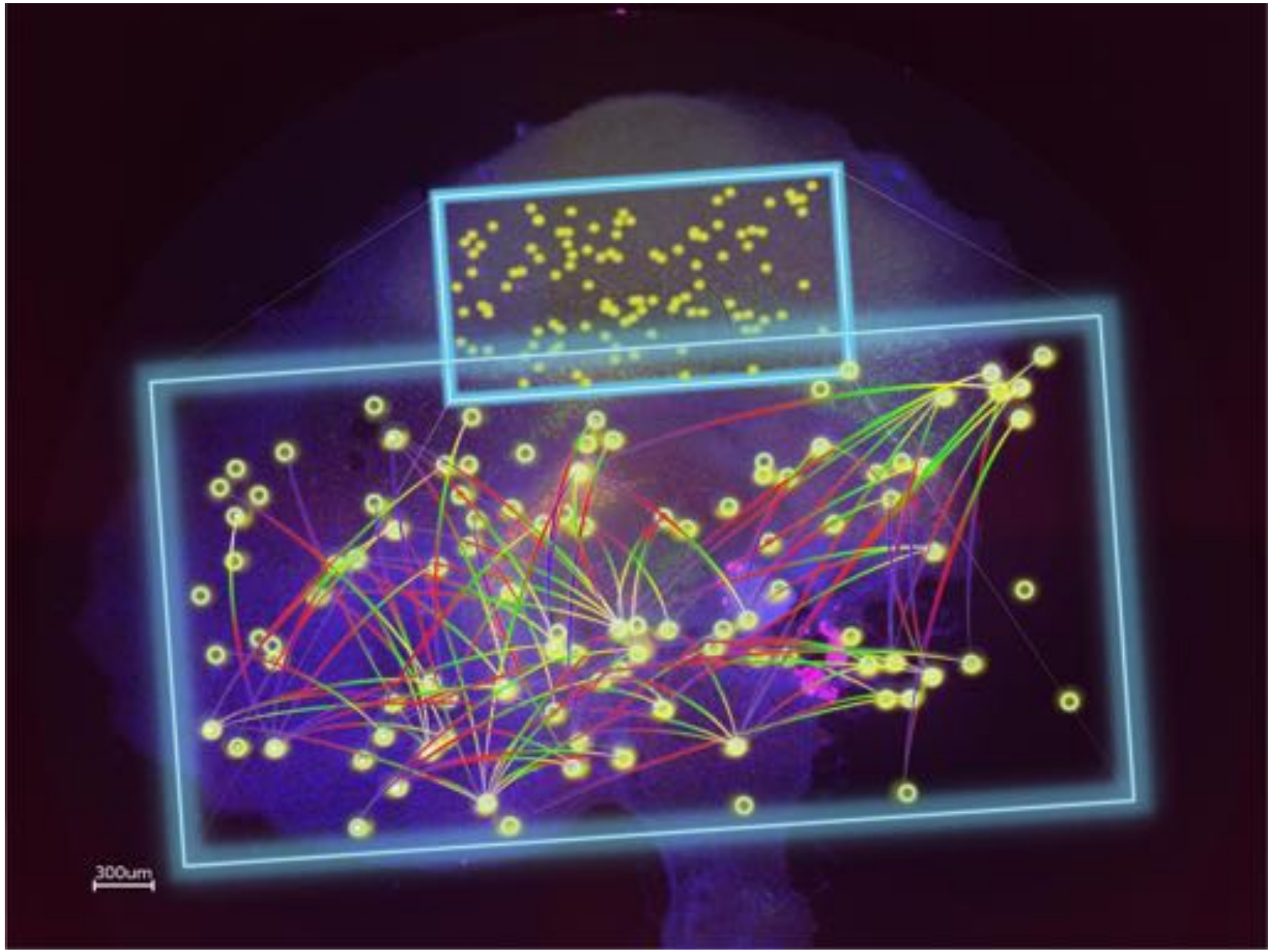
Yildirim et al. (2007) *Nature Biotechnology* – Drug-target network

Causality in brain is complex



Crossley et al. (2013) *PNAS*

Causal interactions among neurons



Shimono, Beggs (2014) *Cerebral Cortex*

2. The non-uniformity
- Comparisons with structure -

Three types of networks

■ Structural networks

A set of physical or structural (anatomical) connections linking neural elements (Cajal, 1905; Fellman and Van Essen, 1991).

■ Functional networks

Deviations from statistical independence between distributed and often remote neuronal units (e.g. Gerstein and Perkel, 1969; Singer and Gray, 1995)

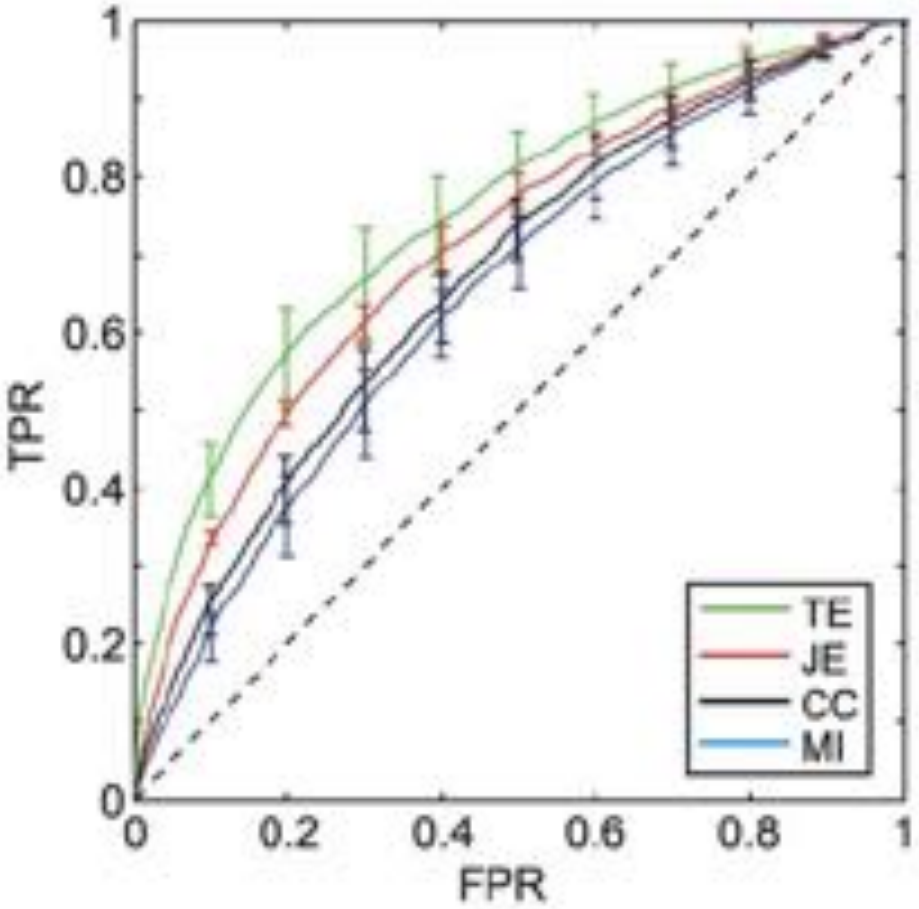
■ Effective networks

The networks of causal effects between neural elements (Adertsen et al., 1989; Friston, 1994)

Structural connectivity and effective connectivity

Evaluation in computational models

- Predicting structural connectivity from effective connectivity

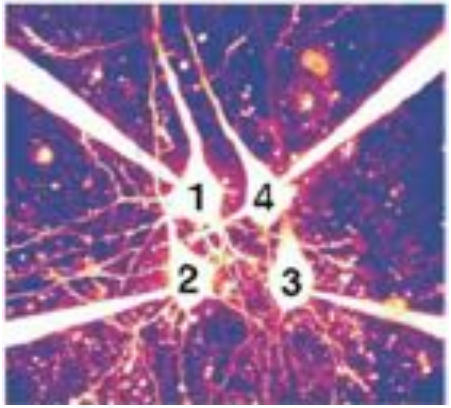


Transfer Entropy is the current champion.

Garofalo *et al.* (2009) *PLOS ONE*

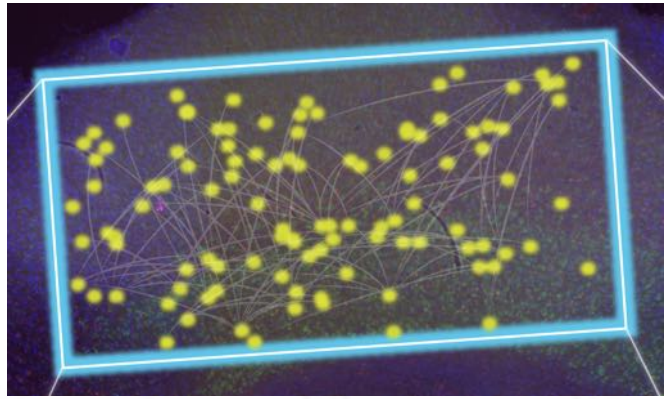
Ito *et al.* (2011) *PLOS ONE*

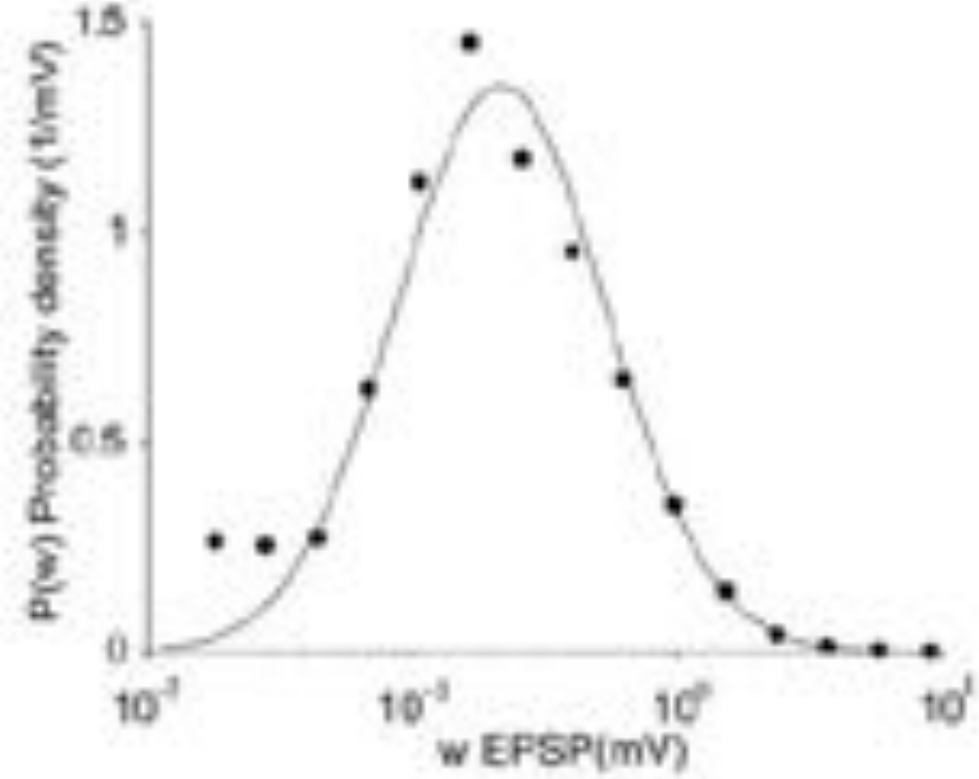
Complex network

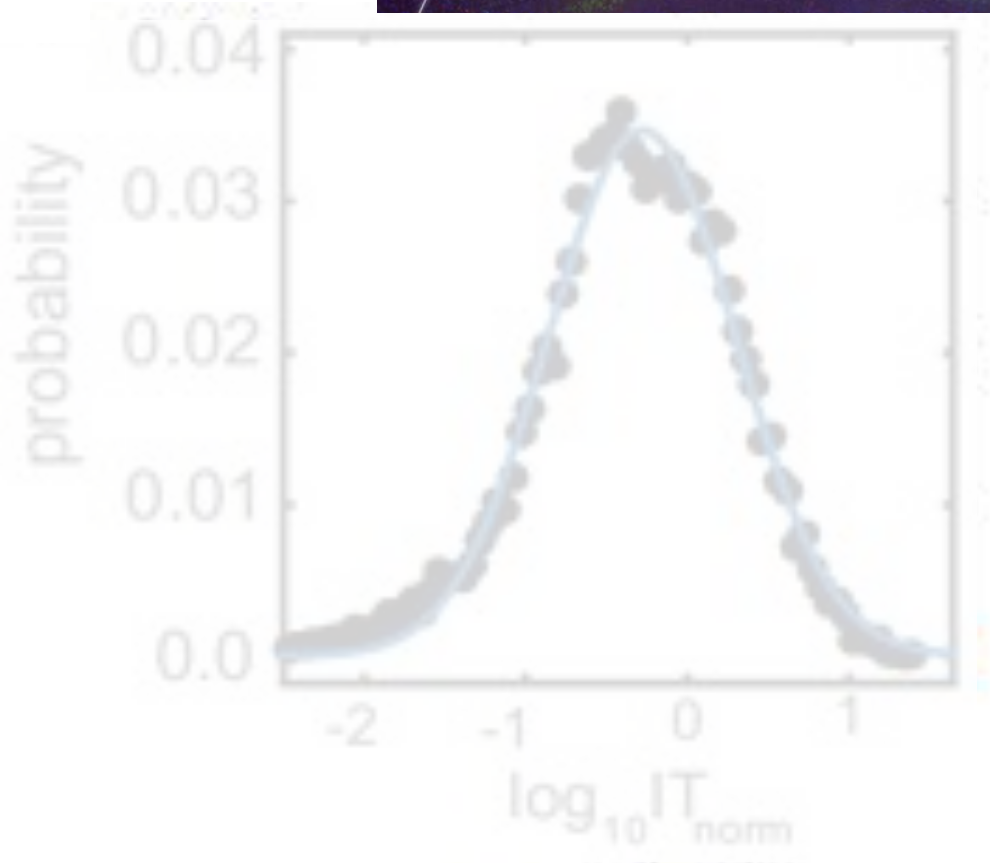


Patch-clamp method

Multi-electrode recording



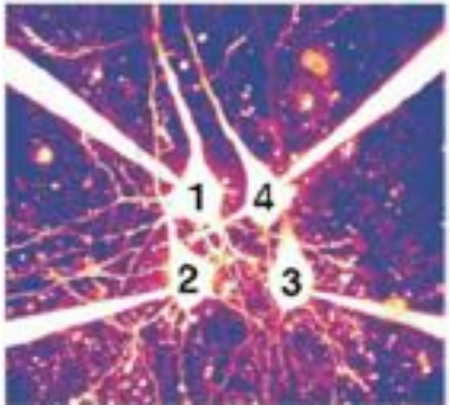




Song et al. (2009) *PLOS Biol.*

Sunny, Shimono,,, Sporns, Beggs (2016)
J Neurosci

Complex network



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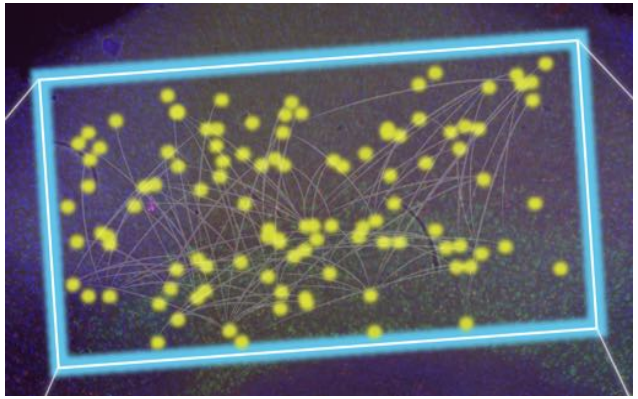
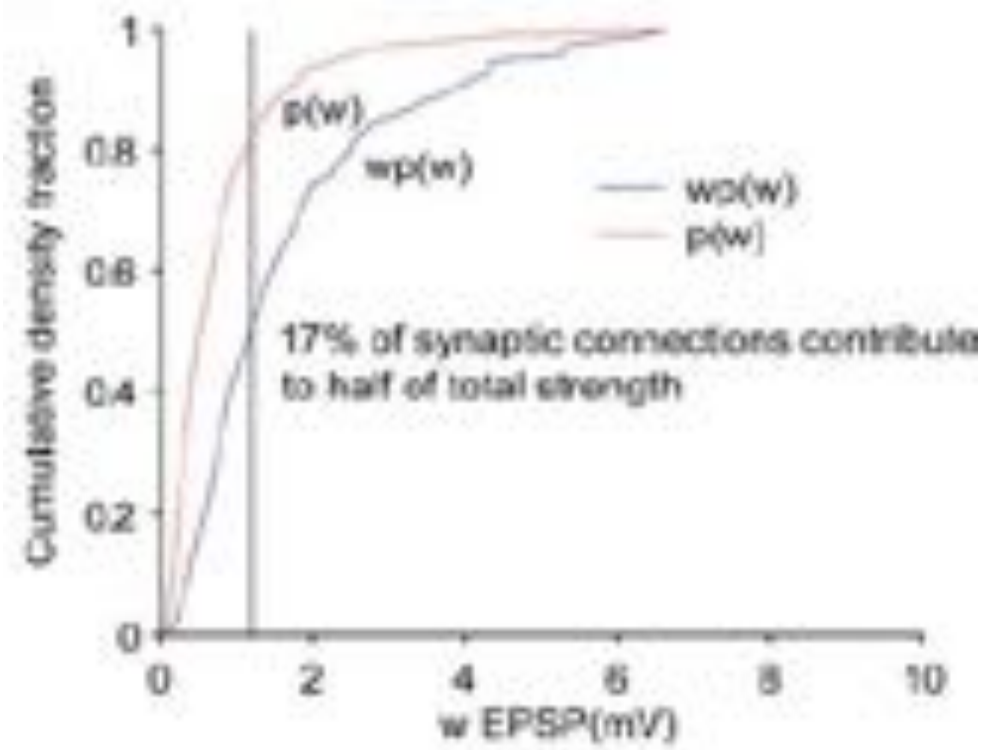




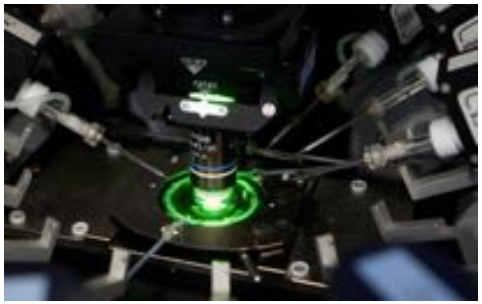
Song et al. (2009) *PLOS Biol.*

Sunny, Shimono,,, Sporns, Beggs (2016)
J Neurosci

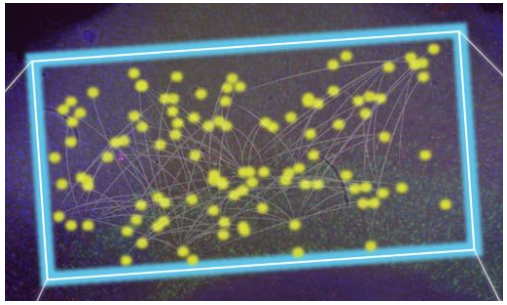
3. Microconnectome

- Beyond simple statistical properties
- The detailed design of the network organization
- Nodes are generally neurons
- As one many body problem

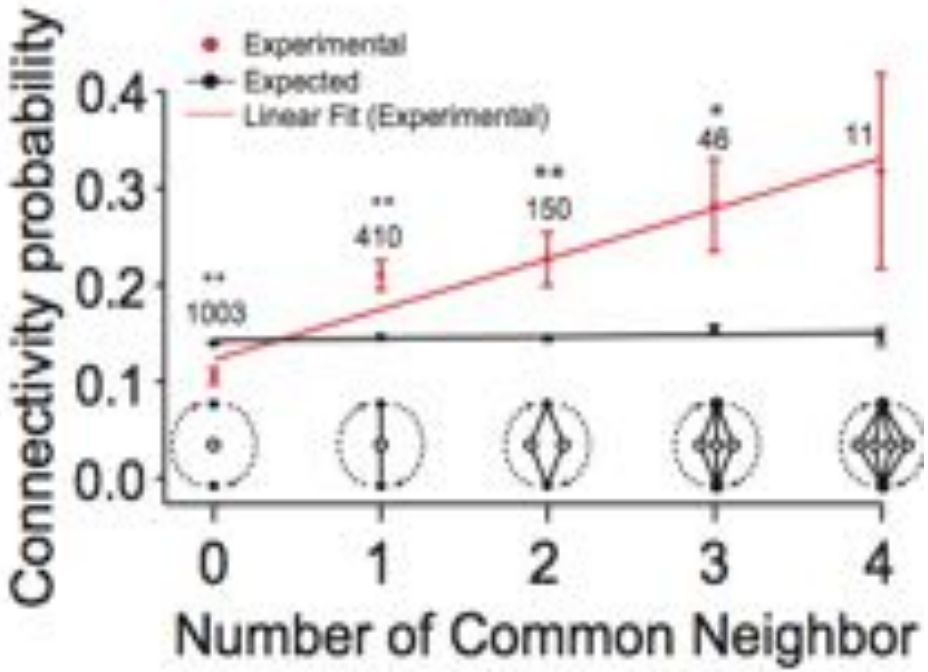
Common neighbor effect



Patch-clamp experiment



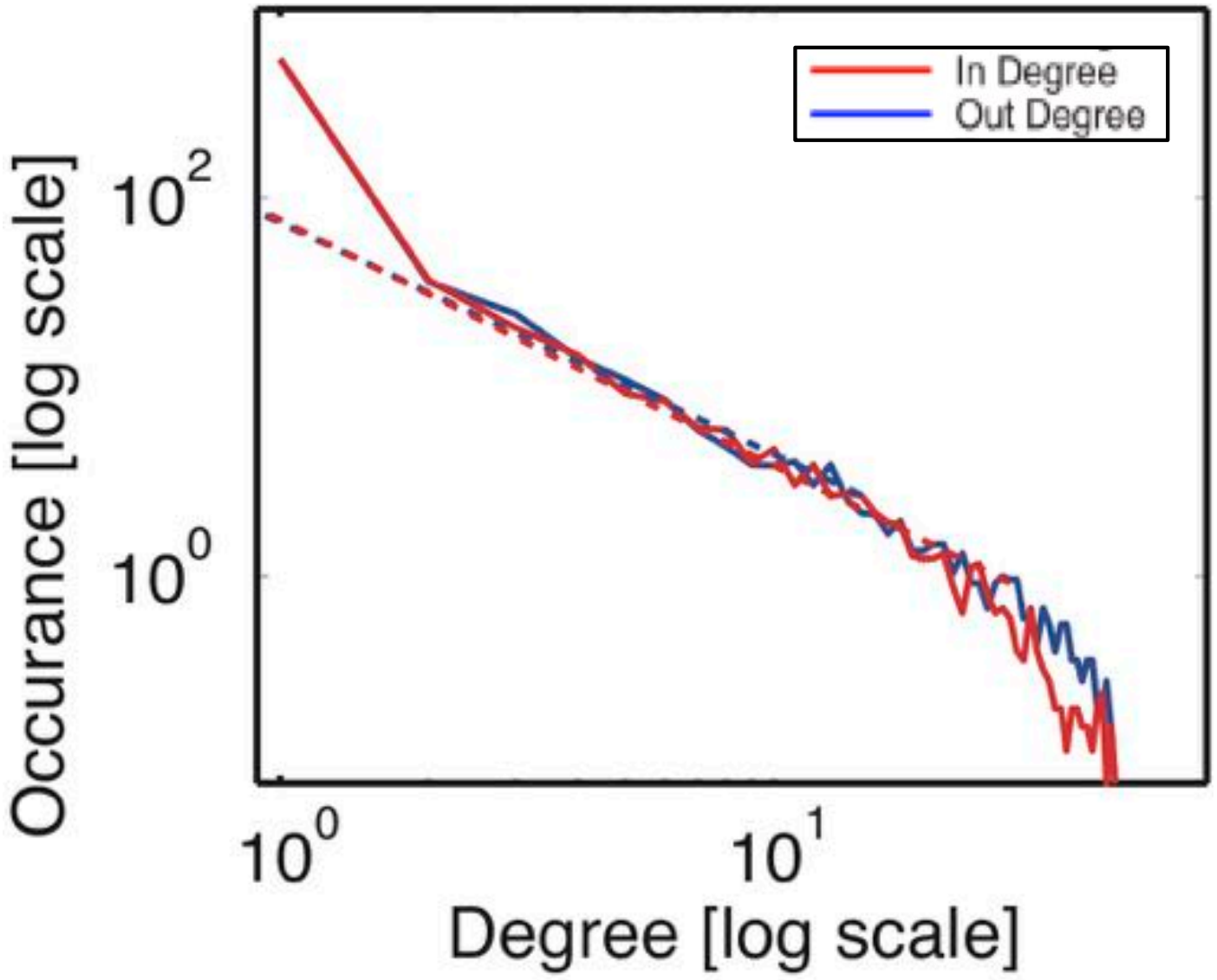
Multi-electrode array



Perin, Berger, Malkram (2009)

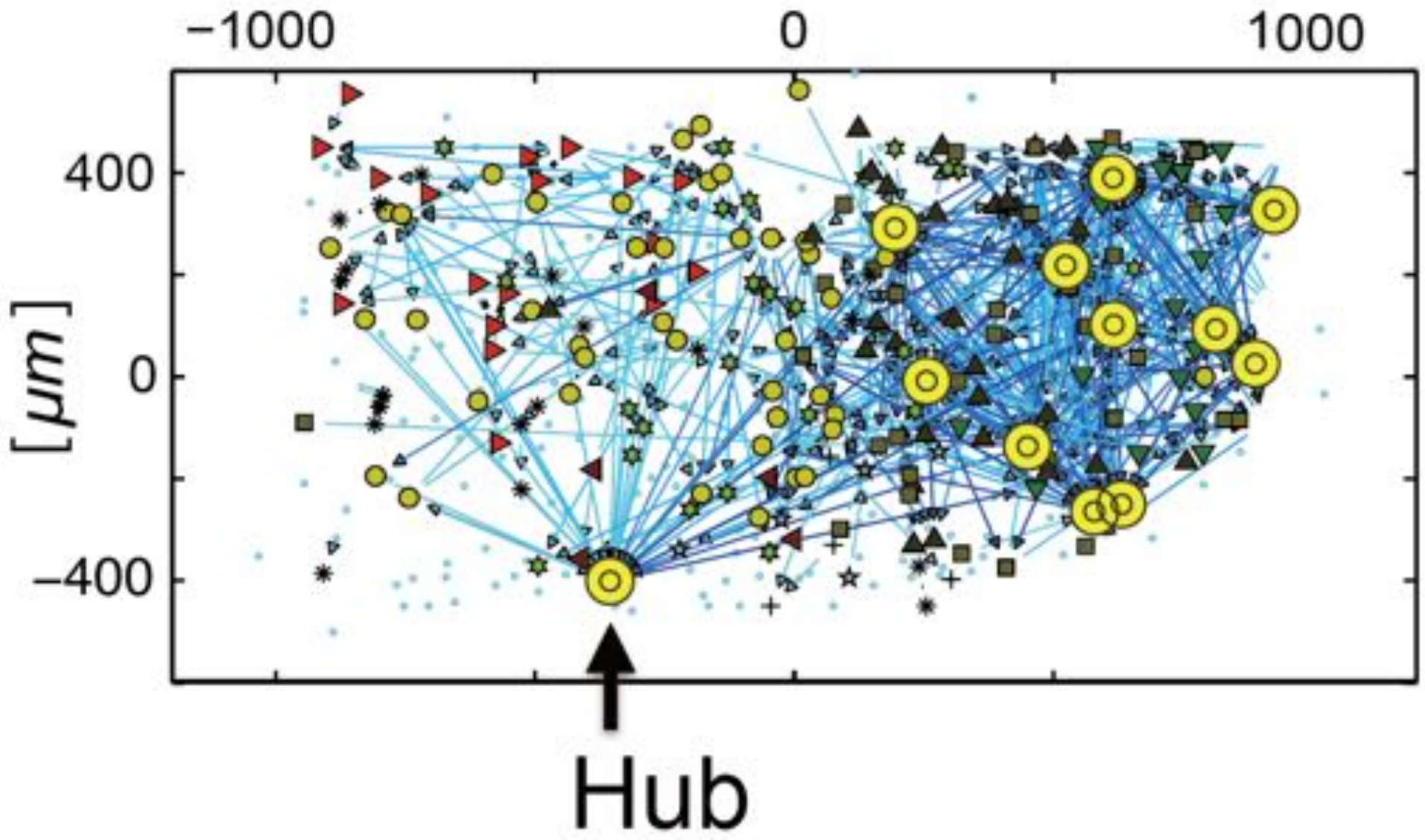
Shimono, Beggs (2011)

Degree histogram

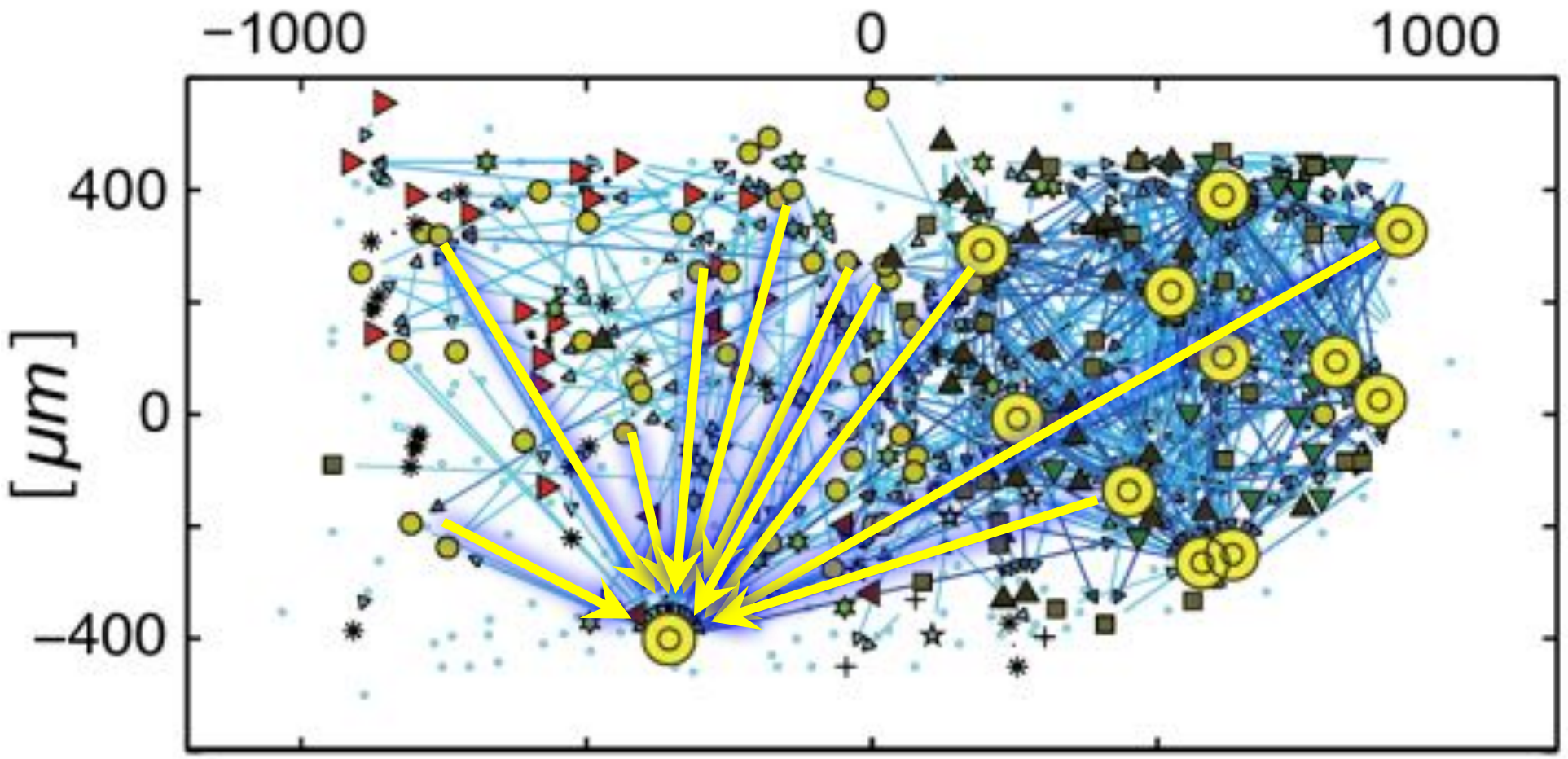


Shimono, Beggs (2014) *Cerebral Cortex*

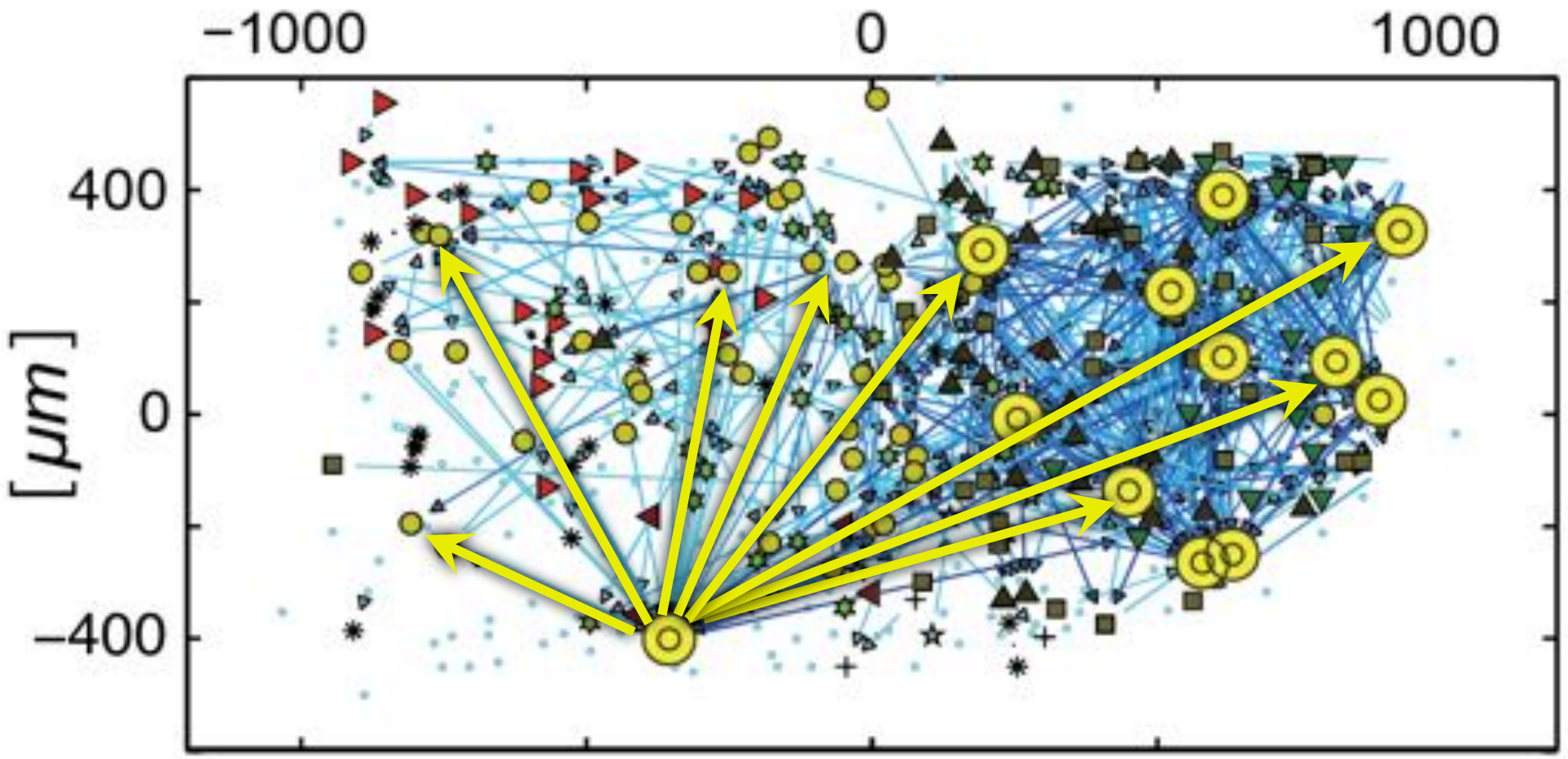
Hubs



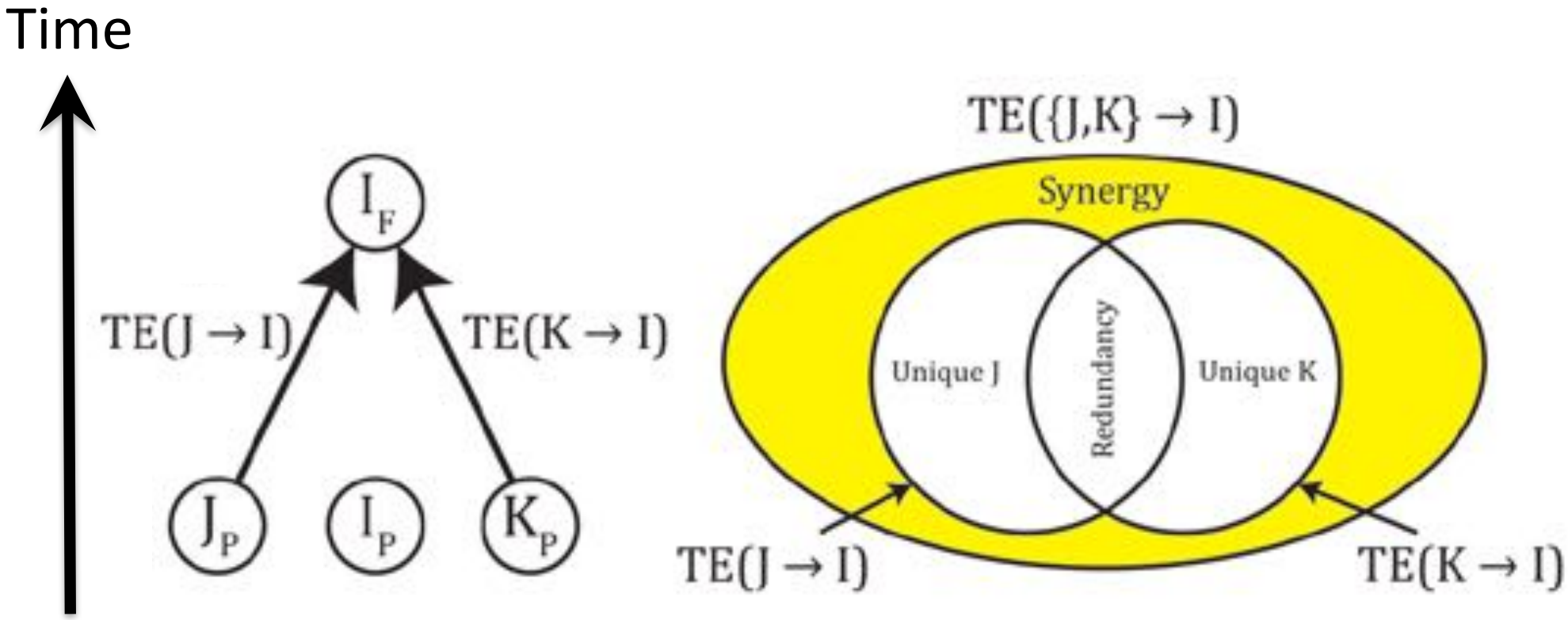
In-degree



Out-degree



Synergy

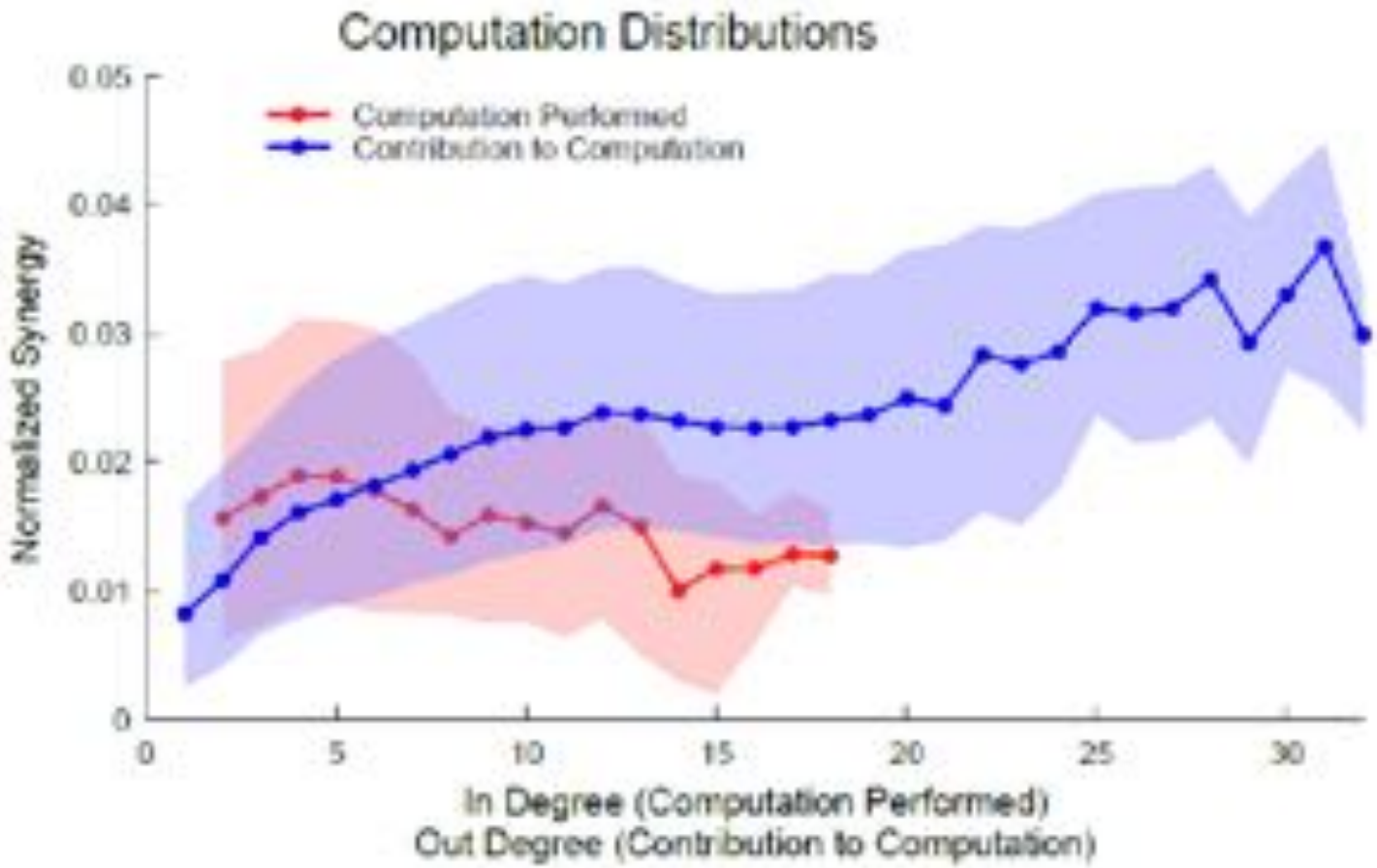


$$TE(\{J,K\} \rightarrow I) = Synergy(\{J,K\} \rightarrow I) + Unique(K; J \rightarrow I)$$

$$+Unique(J; K \rightarrow I) + Redundancy(\{J,K\} \rightarrow I)$$

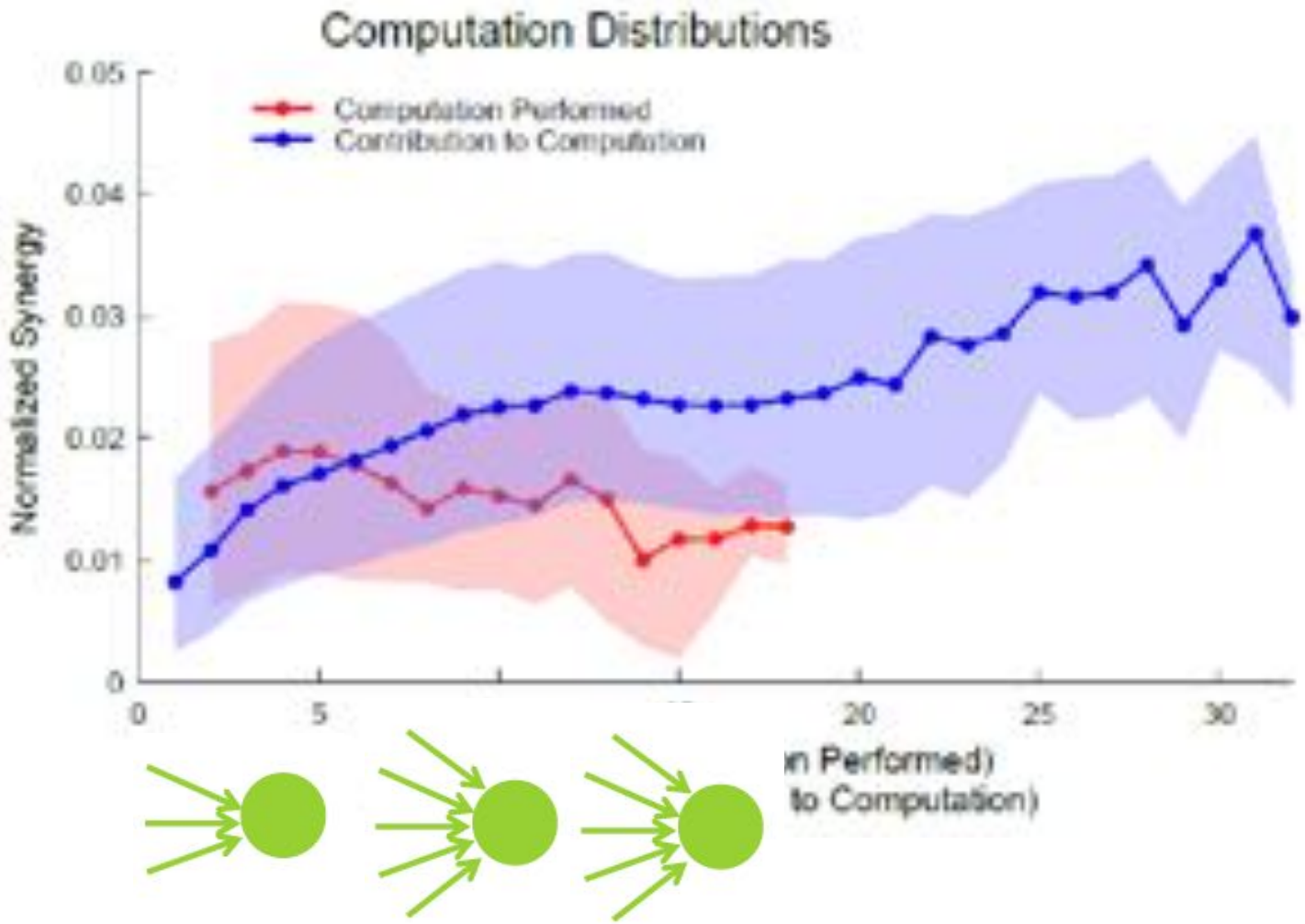
Timme et al. (2016) *PLOS Comput.Biol.*

Degree vs. Synergy



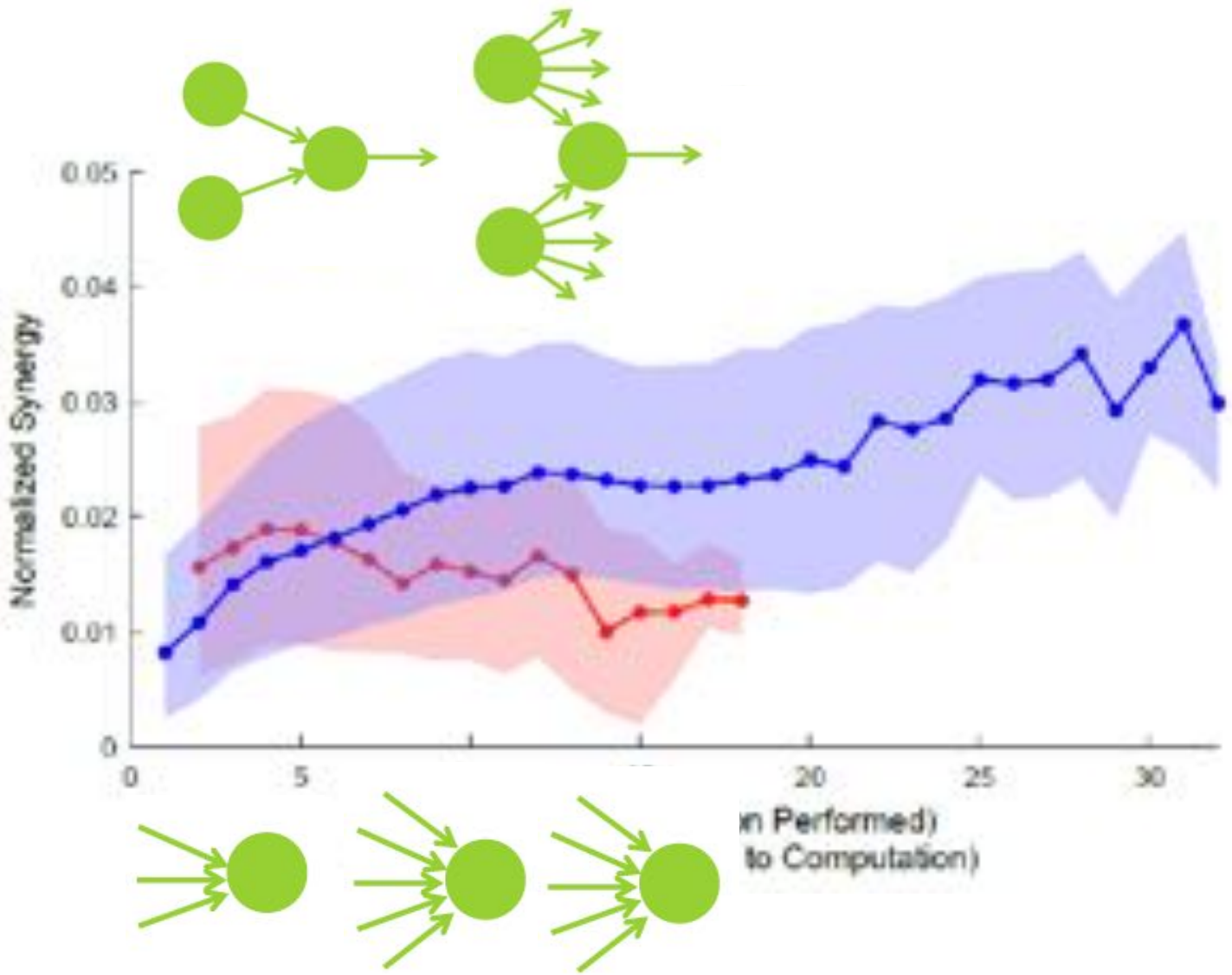
Timme et al. (2016) *PLOS Comput.Biol.*

Degree vs. Synergy



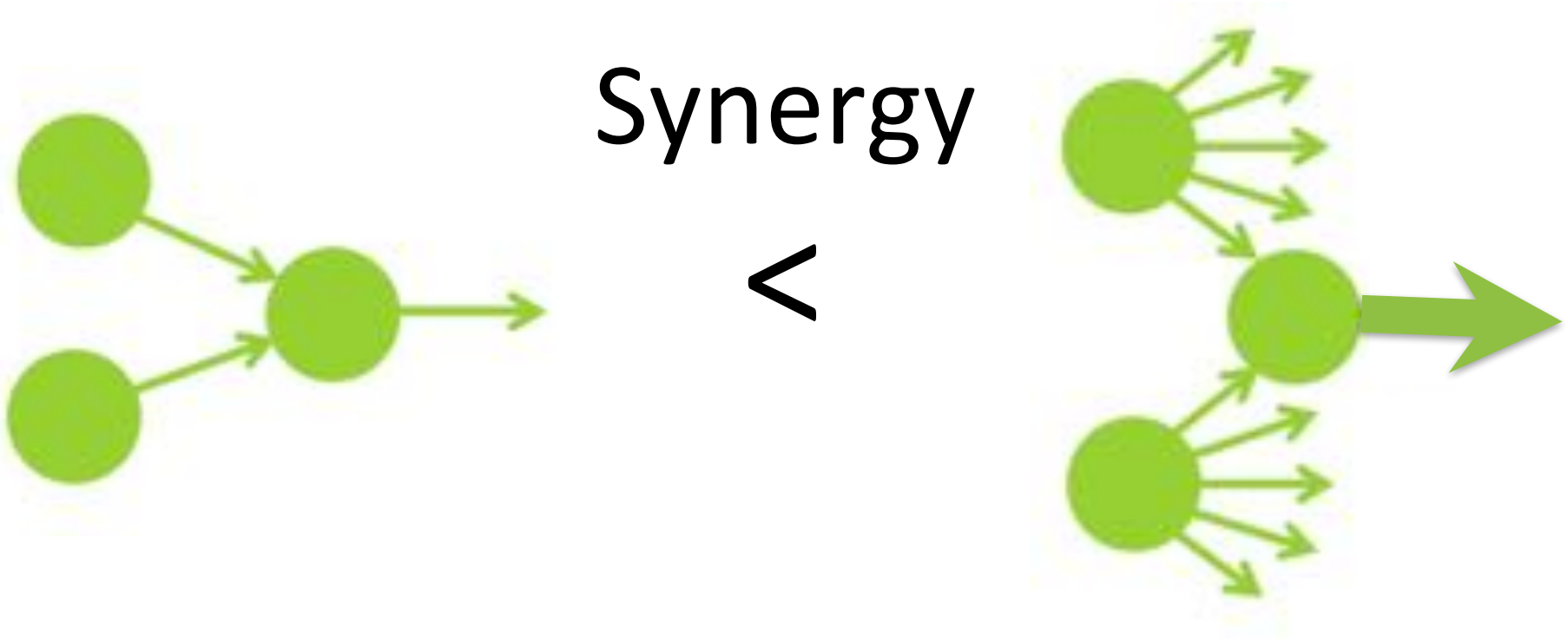
Timme et al. (2016) *PLOS Comput.Biol.*

Degree vs. Synergy



Timme et al. (2016) *PLOS Comput.Biol.*

Role of nodes receiving inputs from out-put hubs

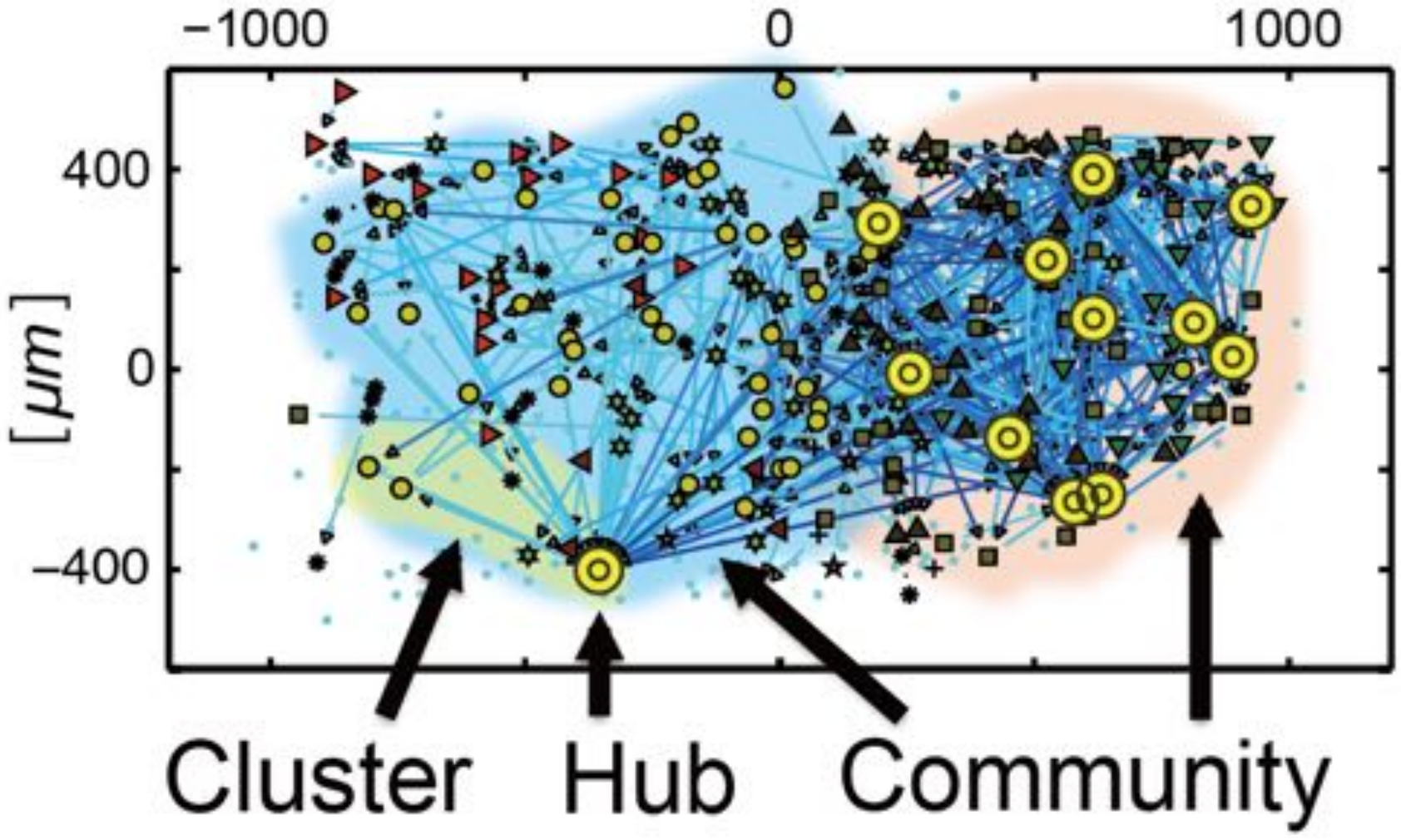


Inputs from less out-degree nodes

Inputs from more out-degree nodes

Timme et al. (2016) *PLOS Comput.Biol.*

Community



Question

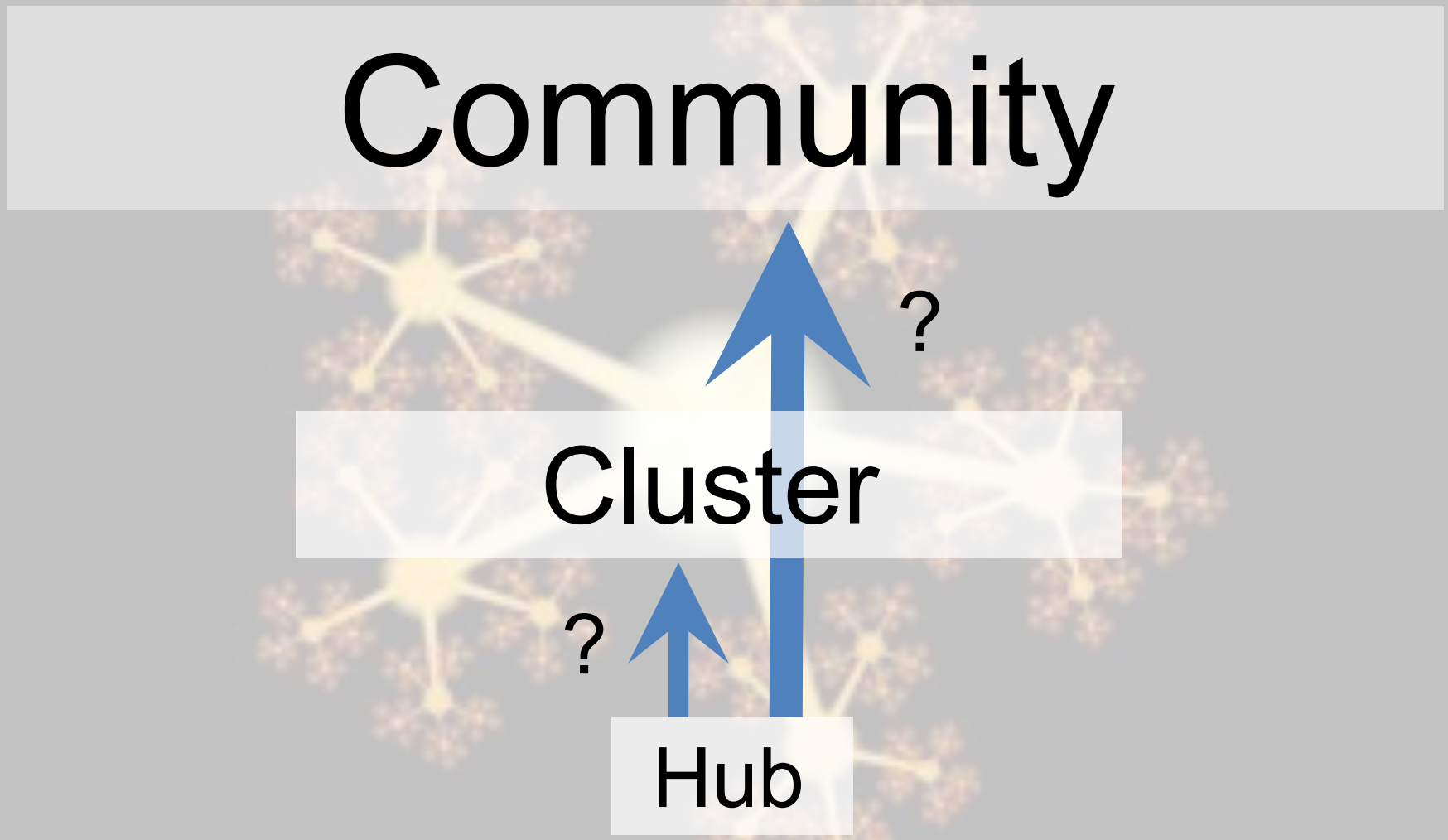
50~100 neuron scale

3-5 neuron scale

1 neuron scale

Shimono, Beggs (2014) *Cerebral Cortex*

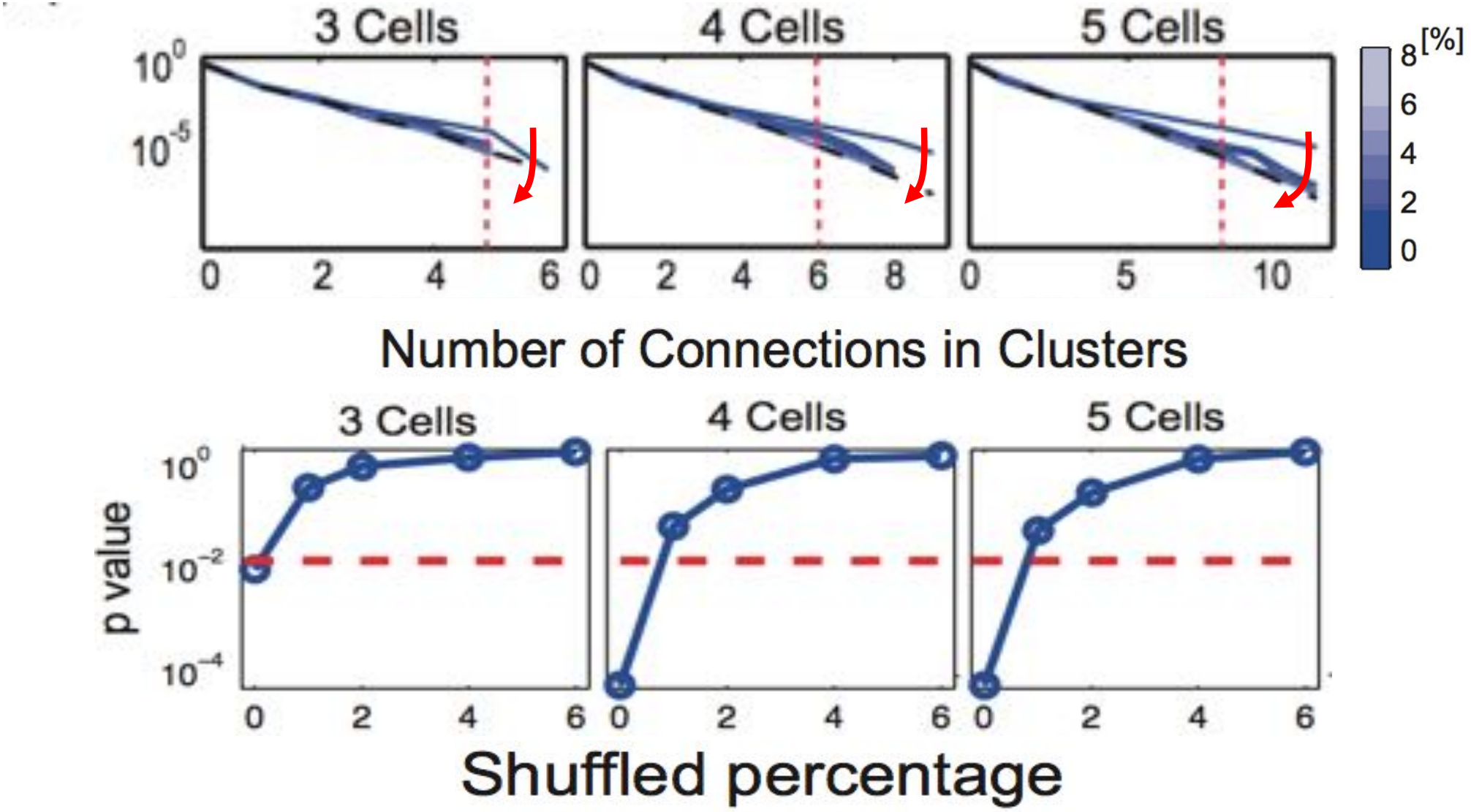
Question



Shimono, Beggs (2014) *Cerebral Cortex*

Influences of hubs on clusters

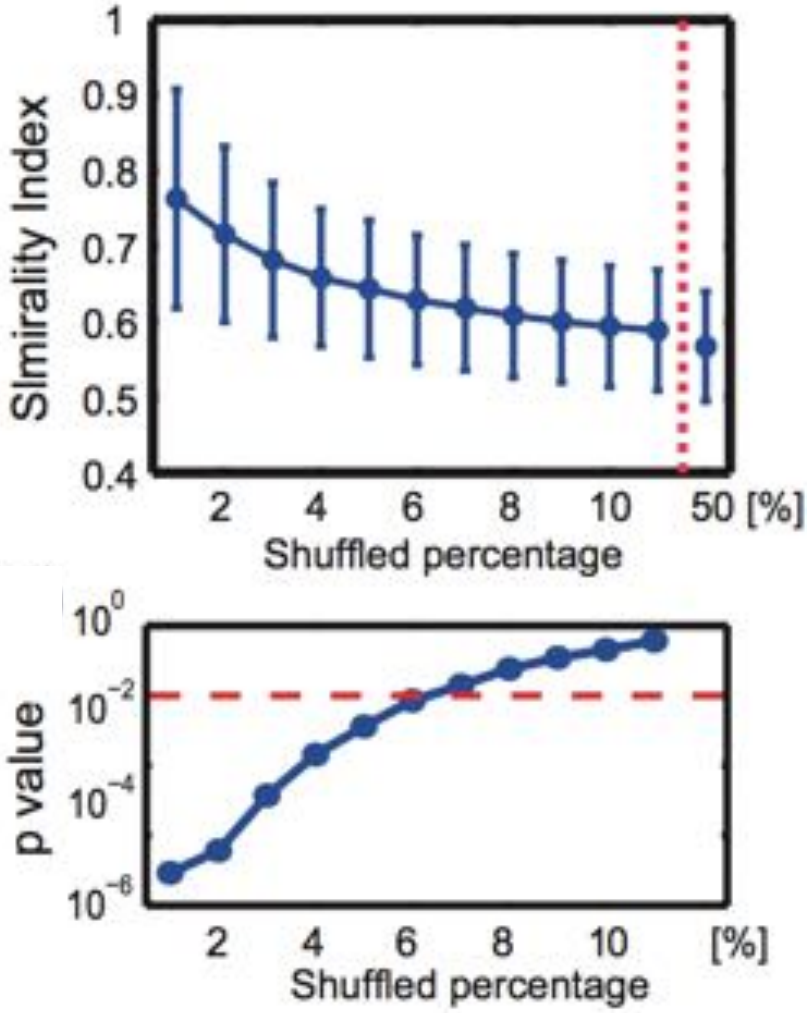
Effects of swapping on clusters



Shimono, Beggs (2014) *Cerebral Cortex*

Influences of hubs on communities

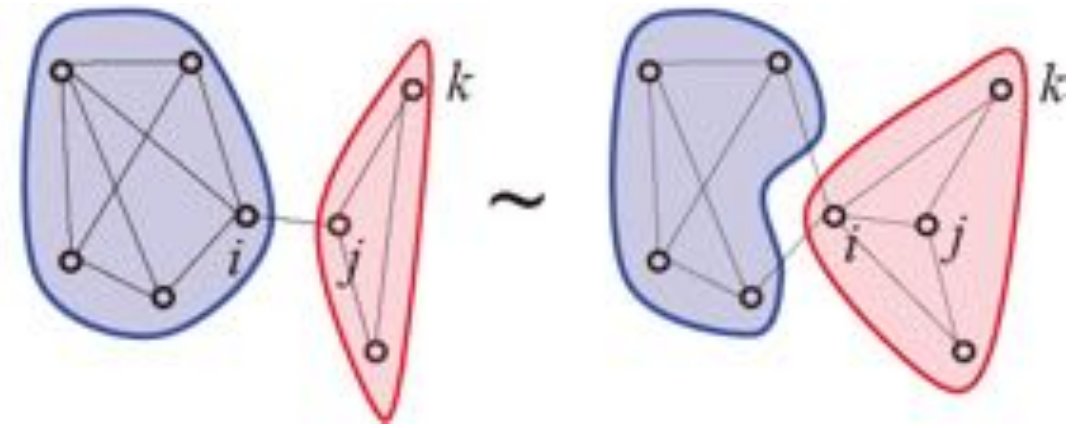
Effects of swapping on communities



$$Similarity\ Index \propto \sum_{i,j} \delta\left(\delta_{before}\left(i,j\right),\delta_{after}\left(i,j\right)\right)$$

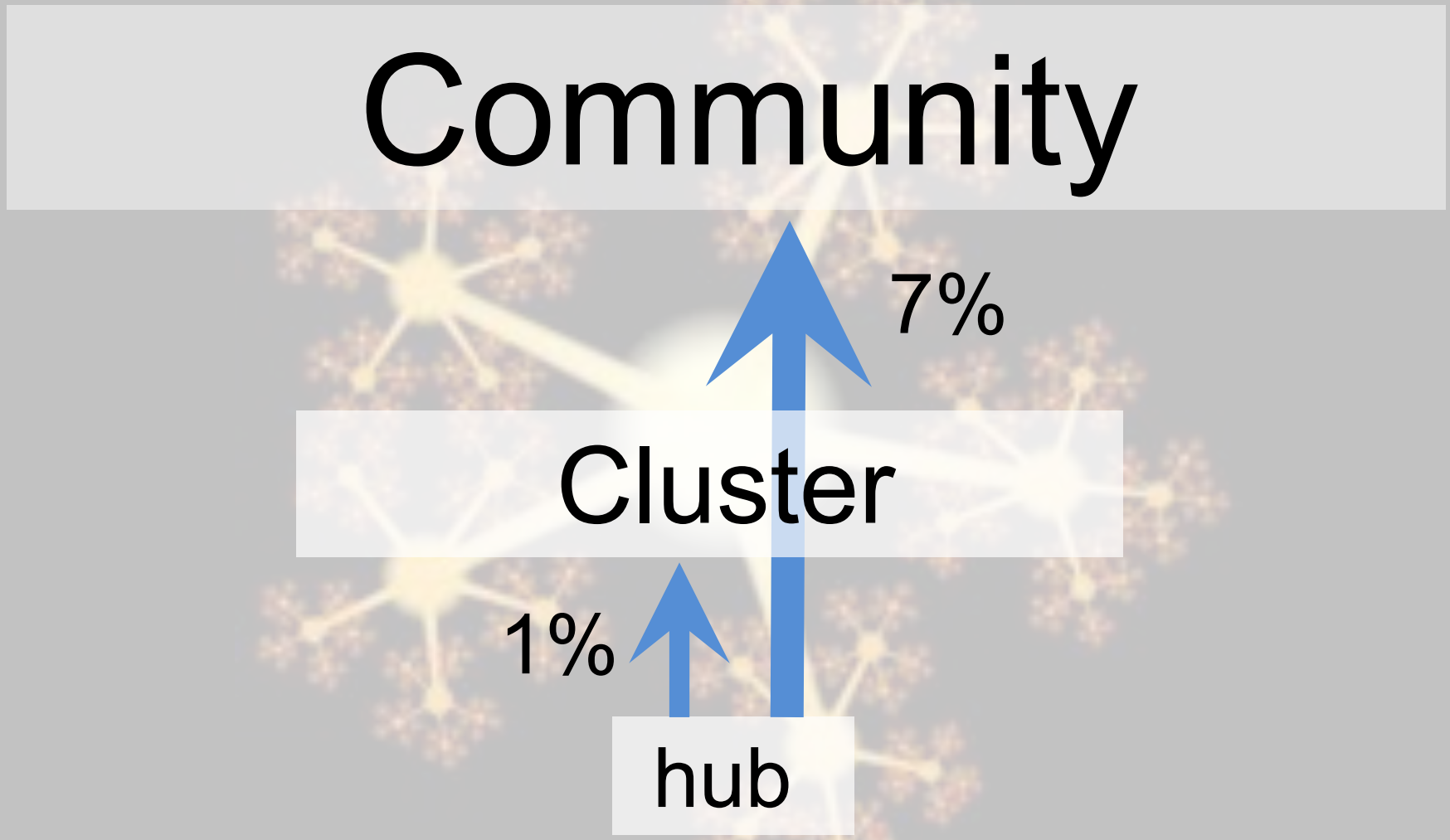
Before swapping

After swapping



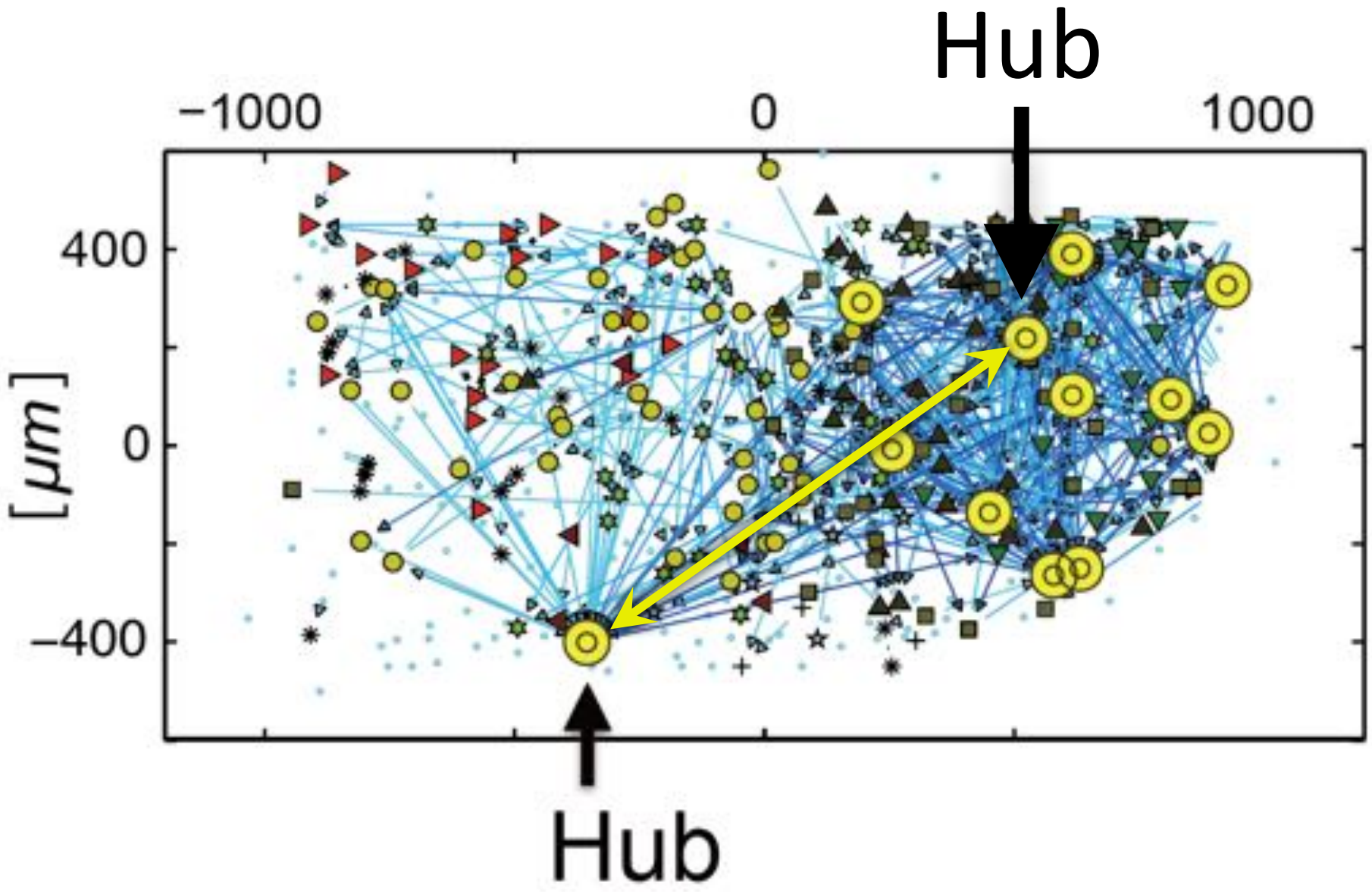
Shimono, Beggs (2014) *Cerebral Cortex*

Summary



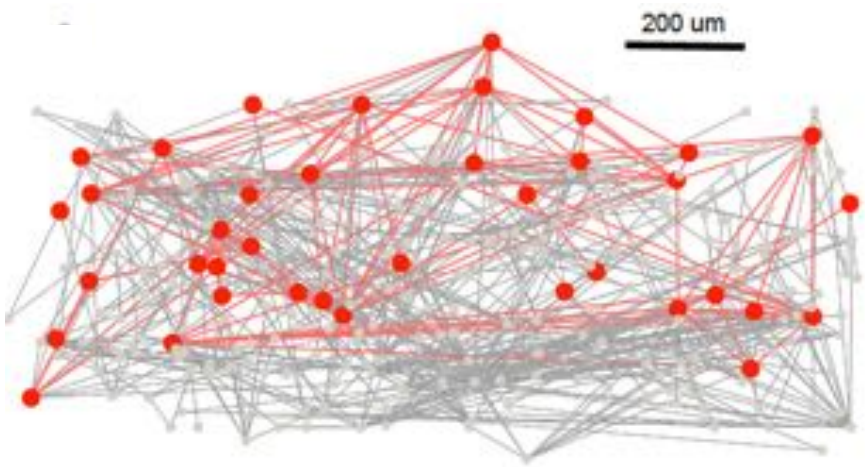
Shimono, Beggs (2014) *Cerebral Cortex*

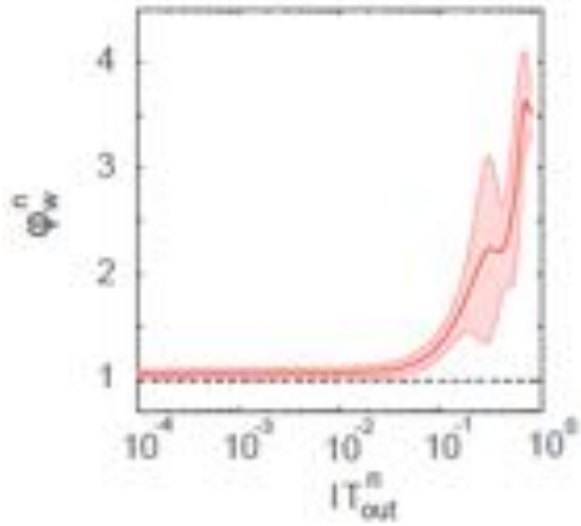
Group of hubs



Rich club effect

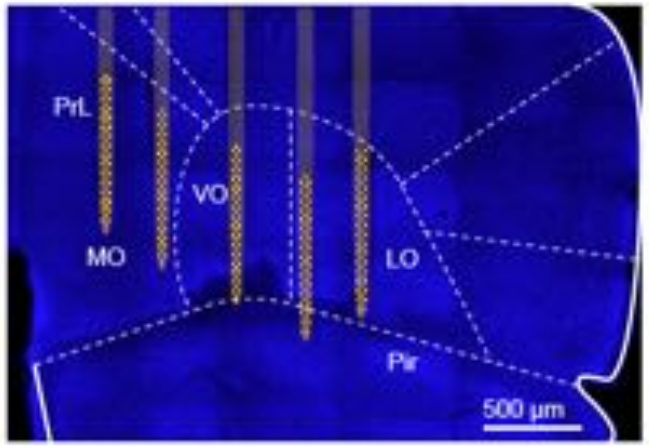
How do hubs connect each other?

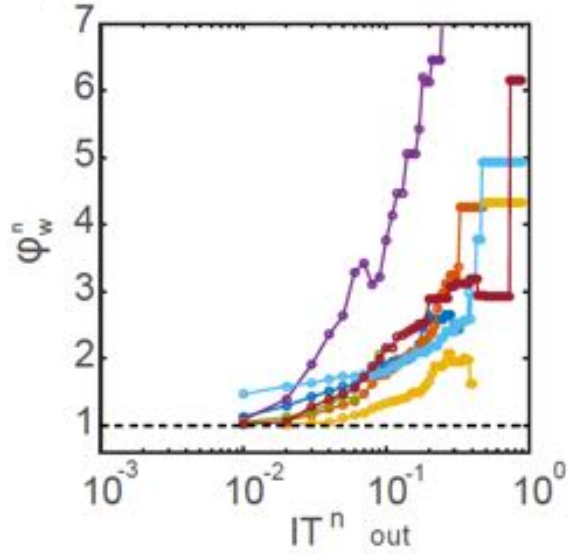




In vitro

W. Smith & S. C. Masmanidis



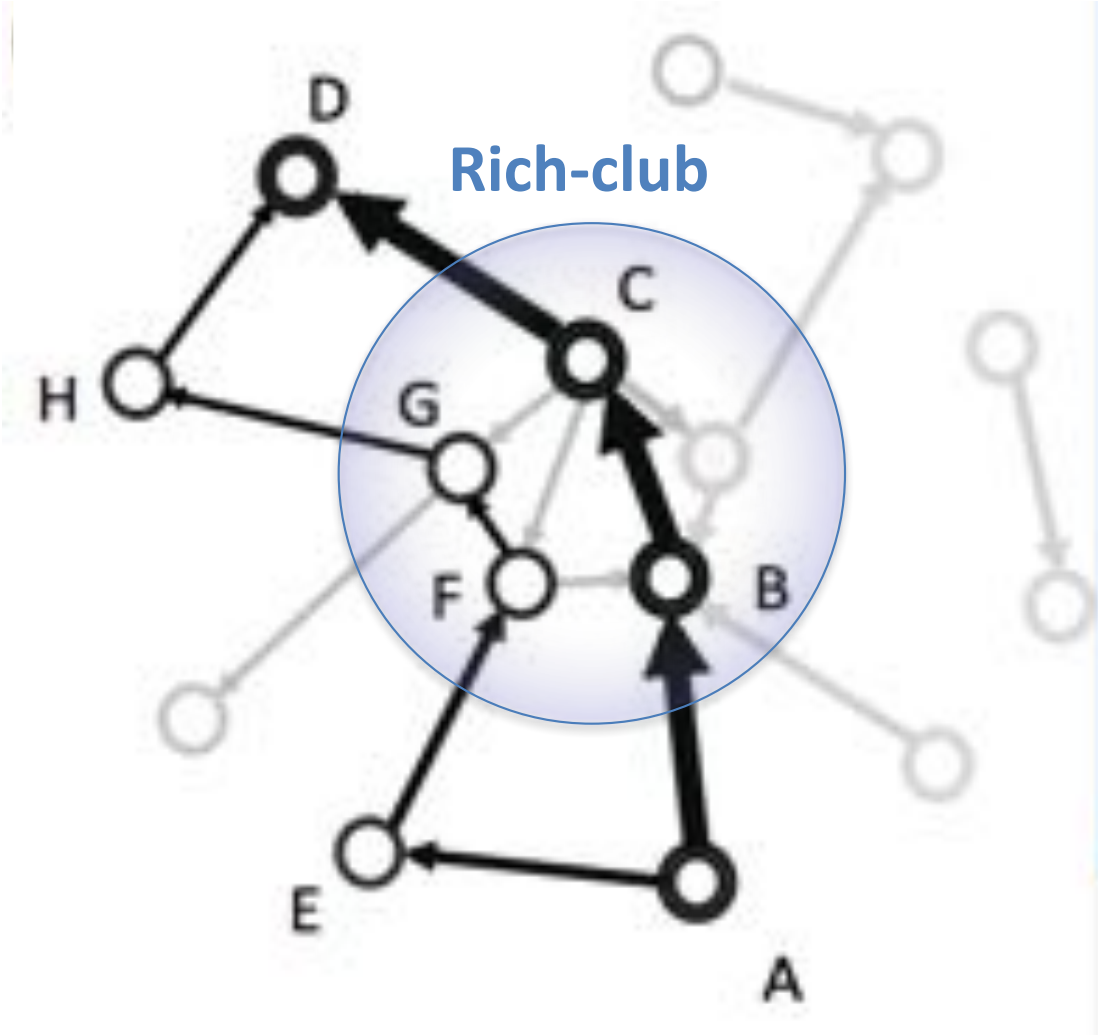


In vivo

Sunny Shimono,,, Sporns, Beggs (2016) *J.Neurosci.*

Rich club effect

How do hubs connect each other?



Sunny Shimono,,, Sporns, Beggs (2016) *J.Neurosci.*

Remarks

Basic statistical properties

- Lognormal weights
  - 20% nodes govern 70% information.
- Long-tailed distribution → Scale-free?

Microconnectome

- Hubs exist in informatic Microconnectome.
- Hubs are surrounded by multiscale structures.
  → Clusters, Communities
- Group of hubs produce Rich-club.
- Commonly driven nodes by hubs gain information
  → Synegetic non-hub nodes


Fin.