

# How not to construct functional brain networks: Node definition

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*Aalto Brain & Mind Computational Seminar*

*17.11.2020*

Slides: <https://github.com/onerva-korhonen/presentations/blob/master/aalto-brain-mind-computational-seminar-20201117.pdf>



**Aalto University  
School of Science**



**CTB**

center for  
biomedical  
technology

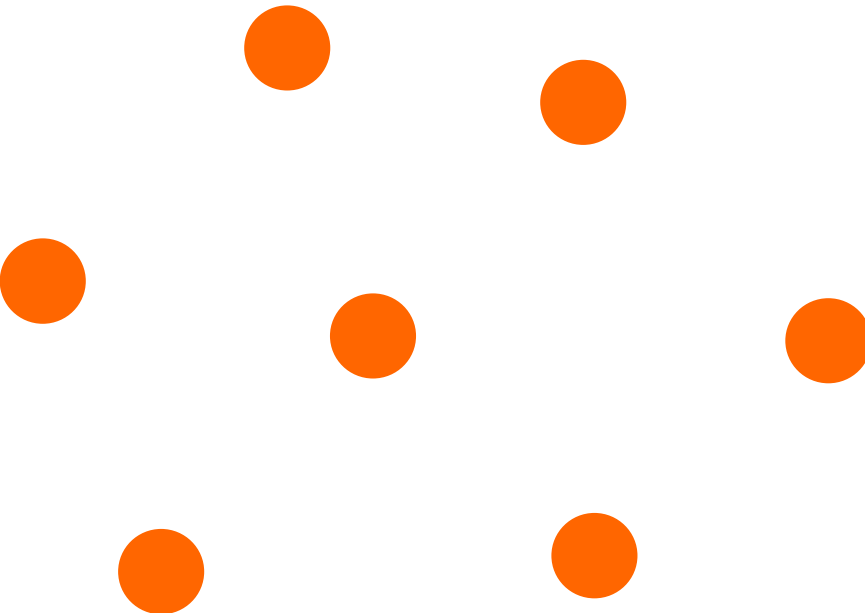


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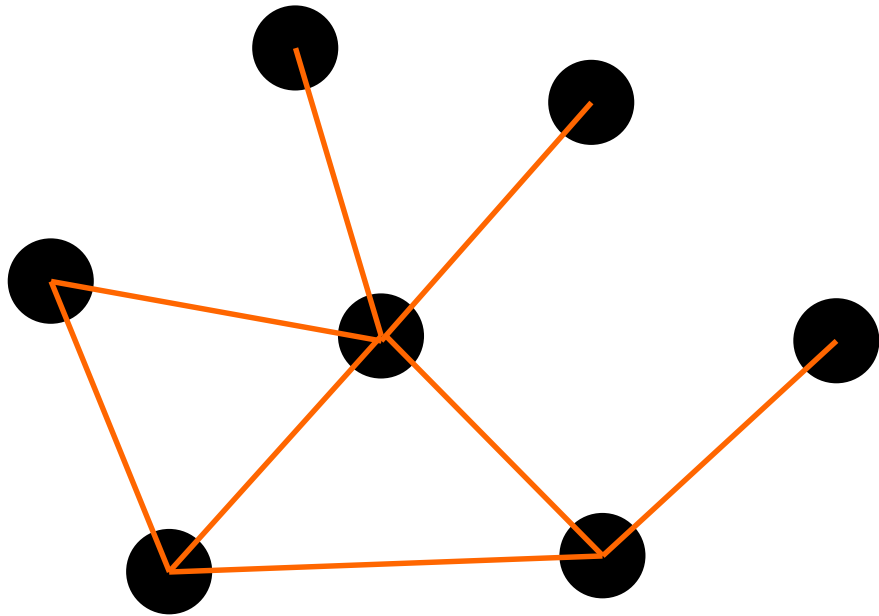
# Networks: what and why?

- **Network:** a model of connections and interactions
  - Internet, public transport, social networks

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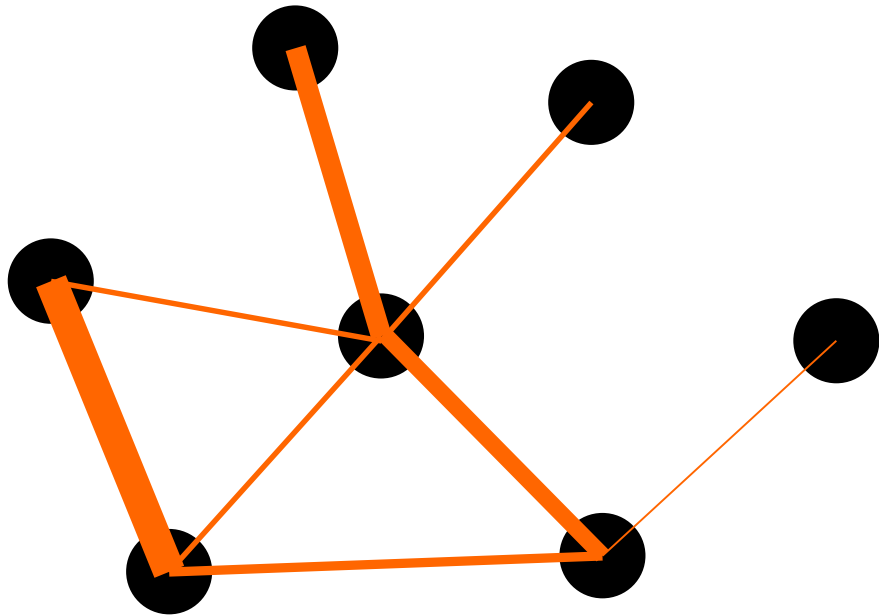
- 
- A decorative graphic consisting of seven solid orange circles of uniform size, arranged in a loose, abstract pattern on the left side of the slide. One circle is at the top left, another slightly below and to the right, then one further right, one below that, one to the left of the center, one at the bottom left, and one at the bottom right.
- **Network:** a model of connections and interactions
    - Internet, public transport, social networks
  - **Nodes:** network's basic elements
    - Web pages, stops, people

# Networks: what and why?



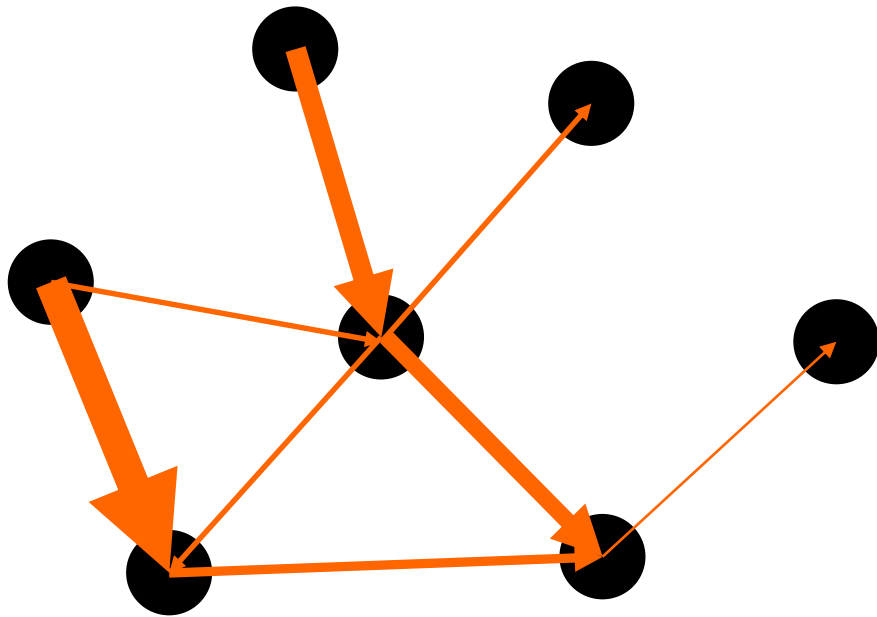
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  - Weights?

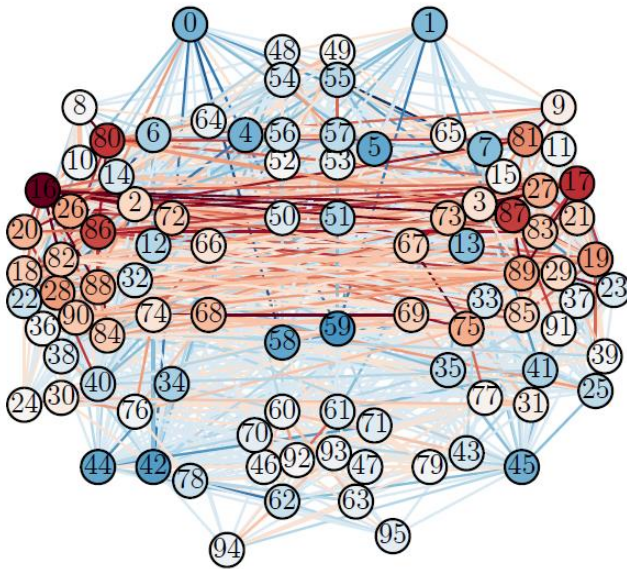
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  - Weights?
  - Direction?

# Why is the brain a network?

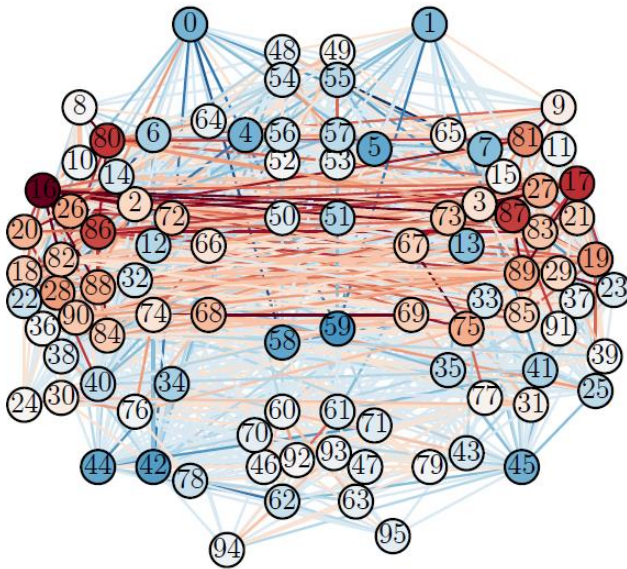
Fig: Alakörkkö et al. 2017,  
*European Journal of Neuroscience*



- Brain = a system of neurons
  - Separated neurons tend to reconnect
- Axon bundles connect brain areas
- Cognitive tasks require collaboration of brain areas

# Network neuroscience

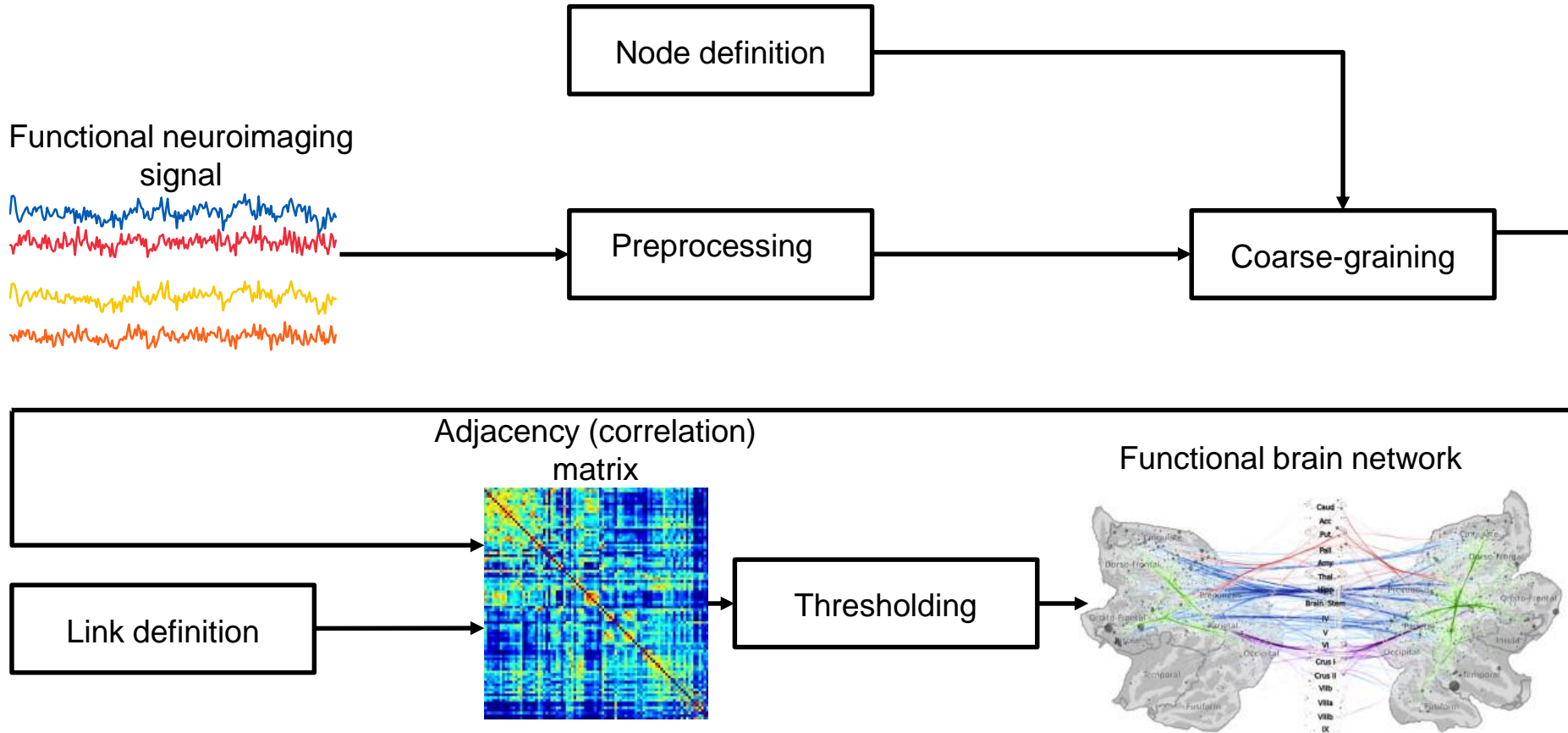
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- Network neuroscience = applying network tools on the brain
- Two aims:
  1. Understand the healthy brain
  2. Find causes of diseases
- Broad scales:
  - Molecule – neuron – brain area – human
  - Milliseconds – years
- Different brain networks:
  - Structural: anatomic connections
  - **Functional**: temporal coactivation
  - Effective: causality

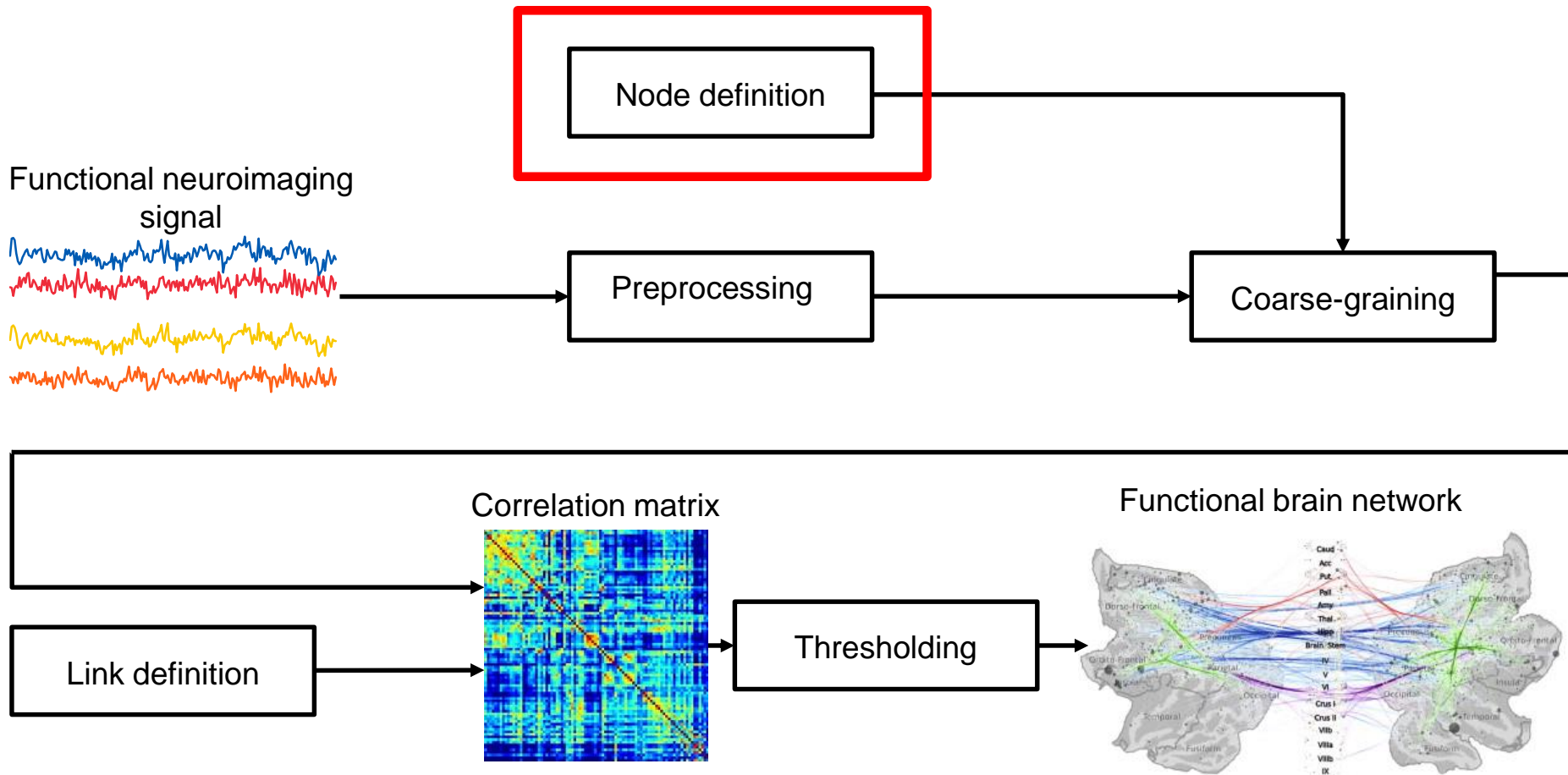


# Functional brain networks: how-to?



Network from Nummenmaa et al. 2014, *NeuroImage*, by permission

# Functional brain networks: how-to?



Network from Nummenmaa et al. 2014, *NeuroImage*, by permission

# The problem of node definition

- No natural candidates above the level of neurons
- Node selection affects network properties
- Some commonly used nodes:
  - Voxels/vertices
  - Random clumps of voxels/vertices
  - Regions of Interest (**ROIs**): collections of voxels/vertices

# Voxels vs ROIs

## Voxels:

- fMRI imaging resolution
- noisy signals?
- ~10.000 nodes
- large computational load

## ROIs:

- collections of voxels
- defined by anatomy, function, connectivity, ...
- **homogeneous** (= all voxels are similar)?
- ROI time series to represent voxel dynamics:

$$X_I = \frac{1}{N_I} \sum_{i \in I} x_i$$

**Violent?**

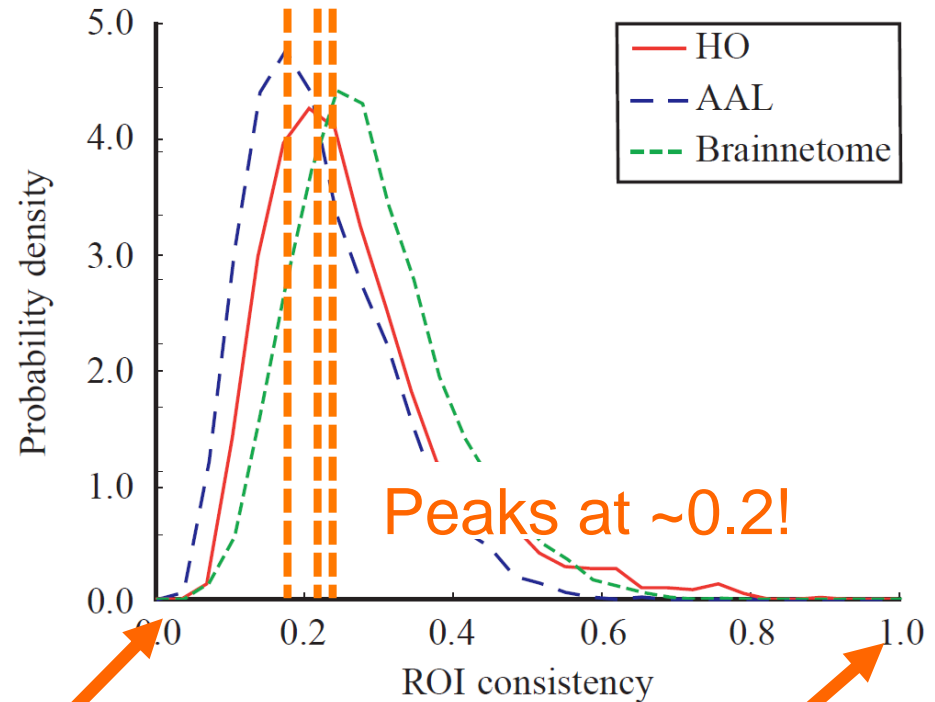
# How homogeneous are ROIs?

- **Spatial consistency**  
= measure of functional homogeneity:

$$\varphi_{spat}(I) = \frac{1}{N_I(N_I - 1)} \sum_{i, i' \in I} C(x_i, x_{i'})$$

- Straightforward to calculate
- Easy to interpret

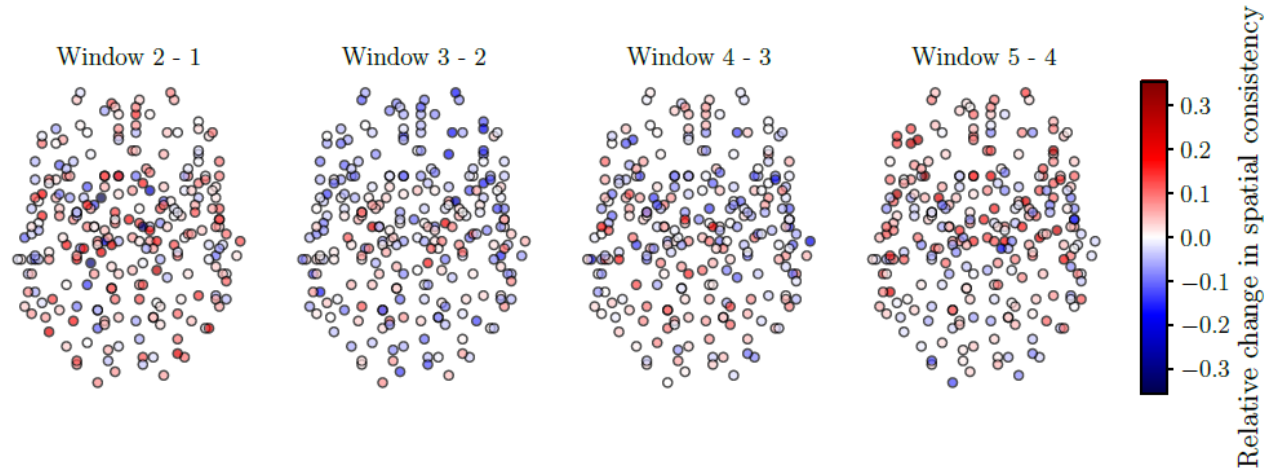
Korhonen et al., 2017. *Network Neuroscience*



Lack of  
homogeneity

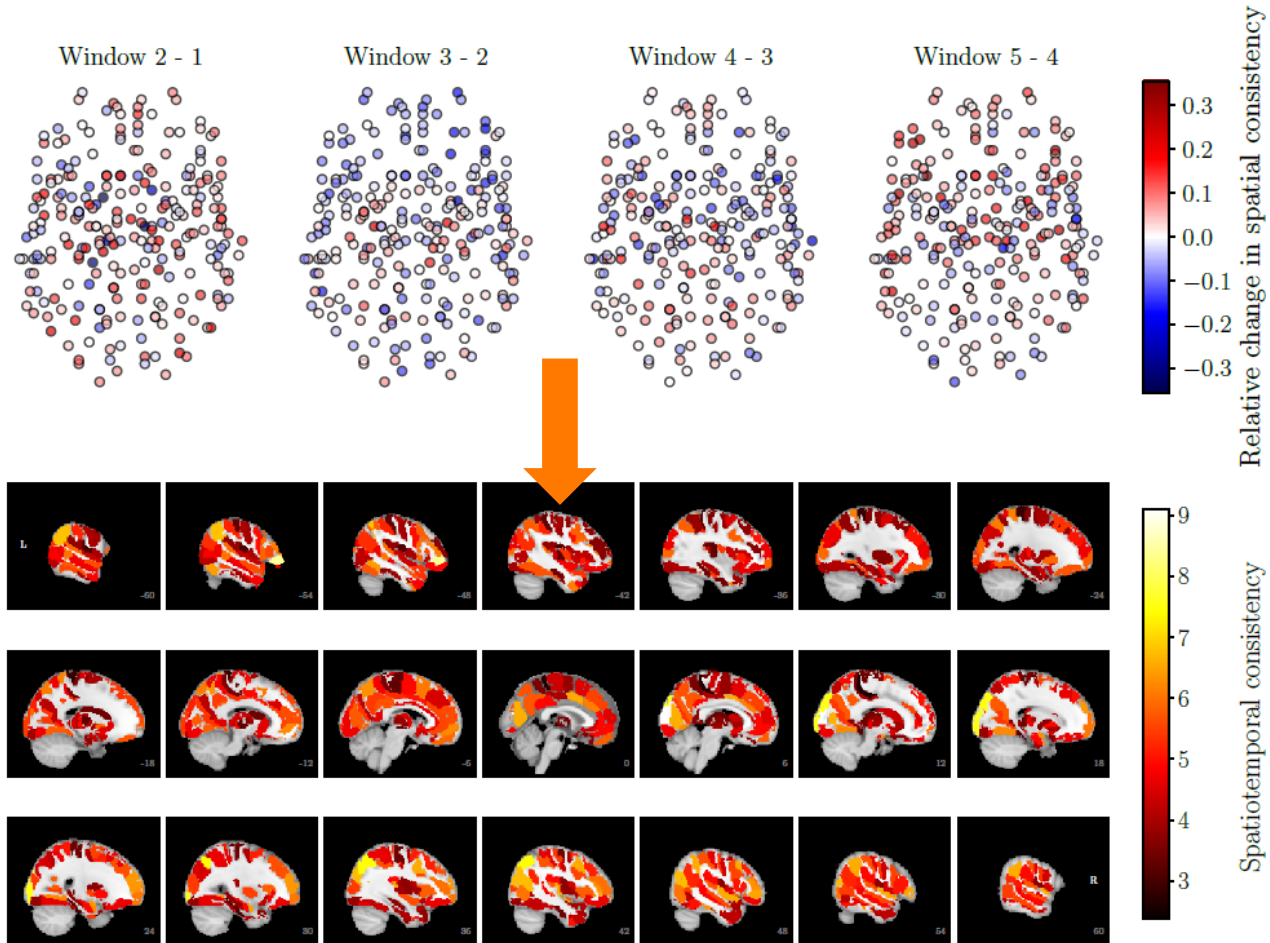
Perfect  
homogeneity

# Spatial consistency changes in time



Ryppö et al., 2018. *Network Neuroscience*

# Spatial consistency changes in time



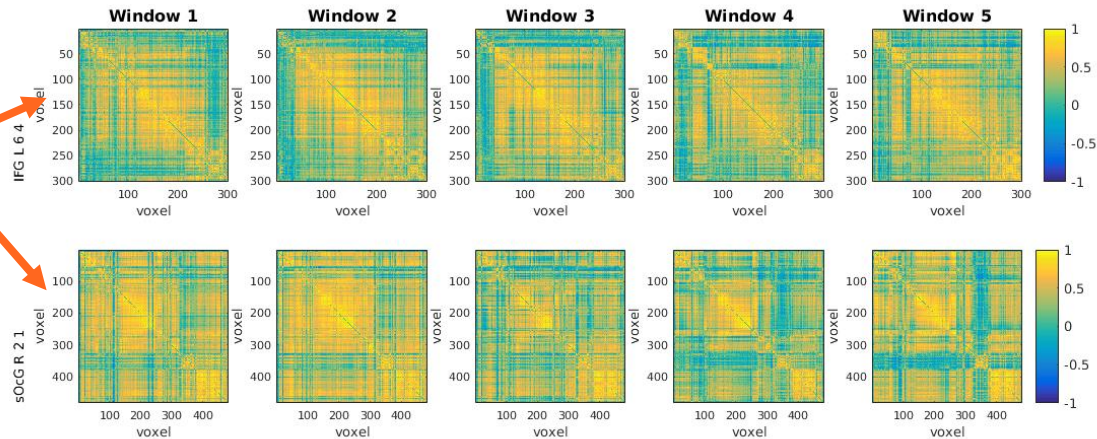
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**Spatiotemporal consistency**  
= stability of spat. consistency

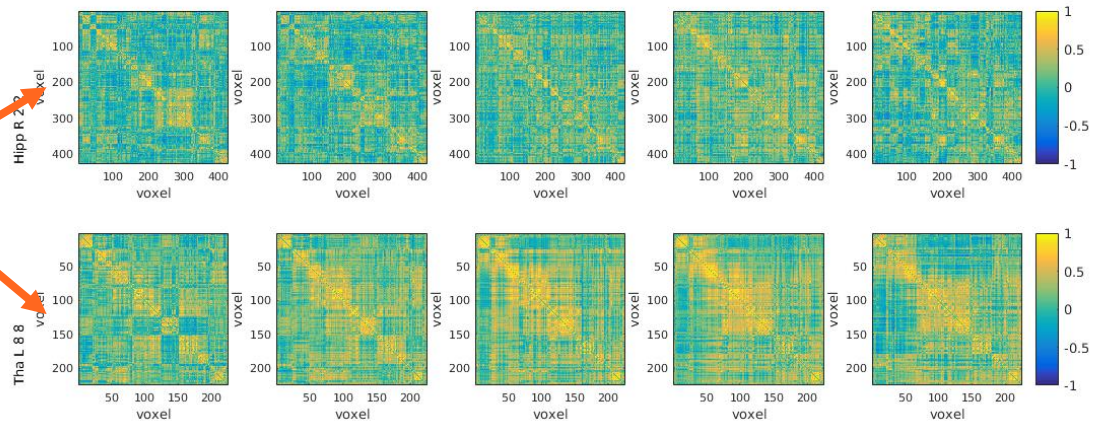


# ROIs have rich internal connectivity structure

High spatial consistency



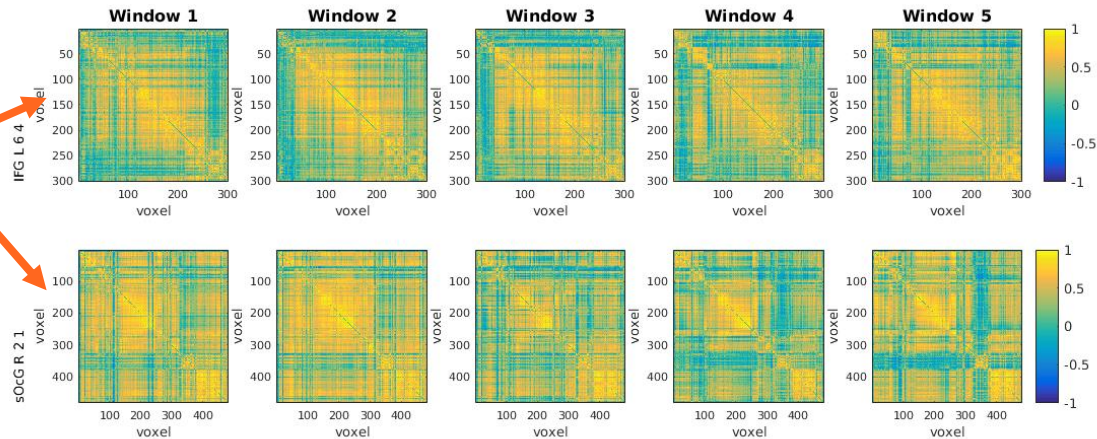
Low spatial consistency



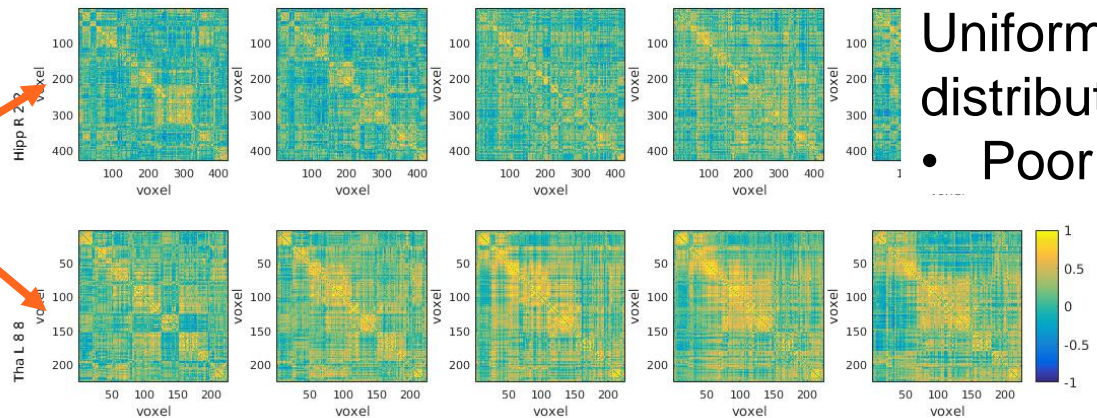


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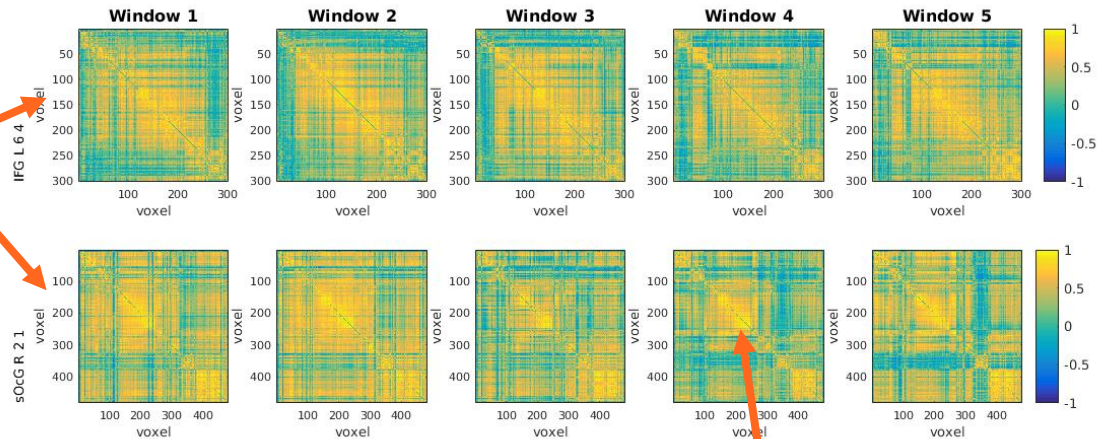


Uniform correlation distribution

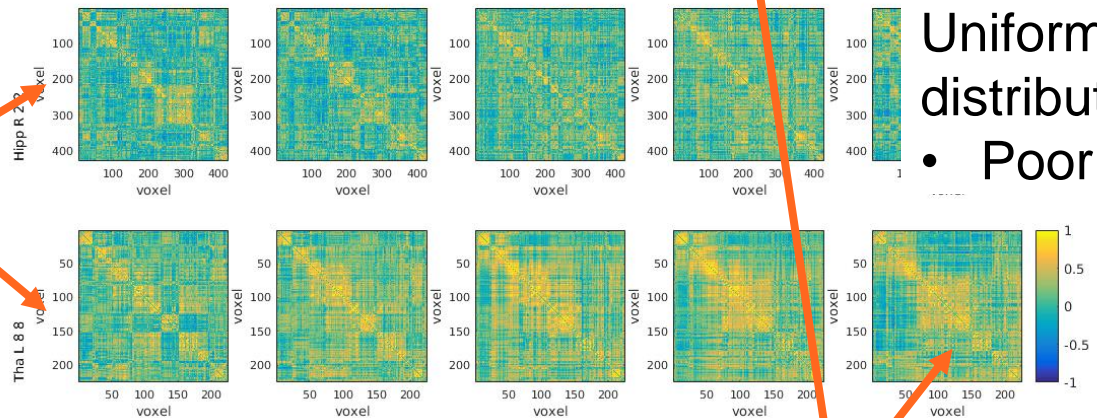
- Poorly defined ROI?

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Low spatial consistency



Uniform correlation distribution

- Poorly defined ROI?

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Intra-ROI modules

- Network topology?

# Consistency predicts topology

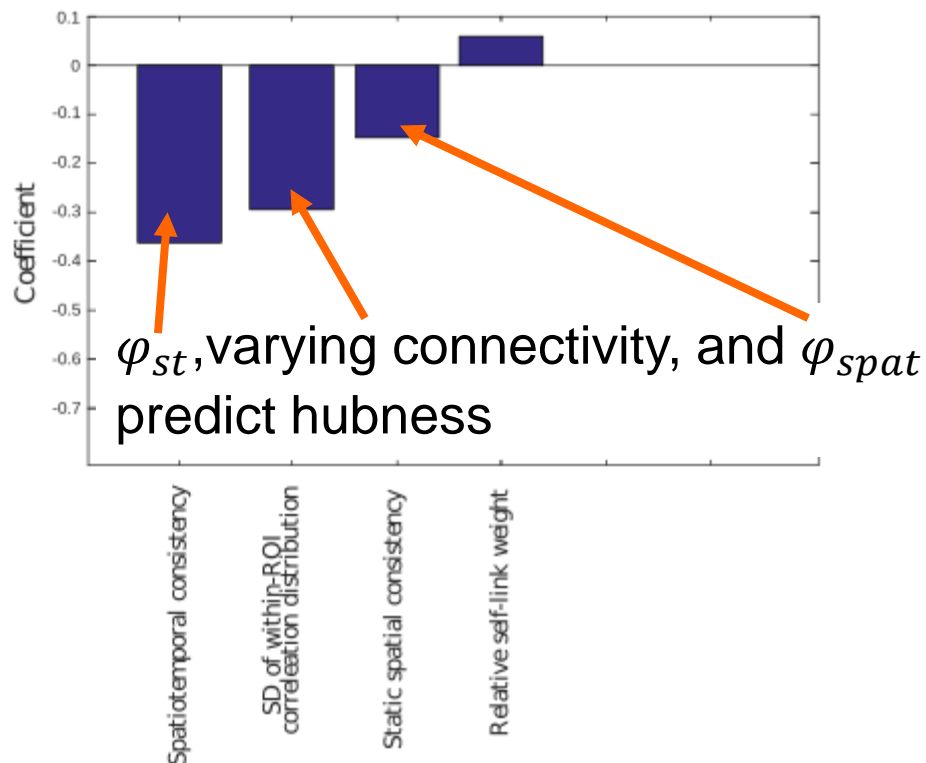
## Hub vs non-hub:

Accuracy:

Training 64.22%

Test 62.31%

(> Random 55.01%)



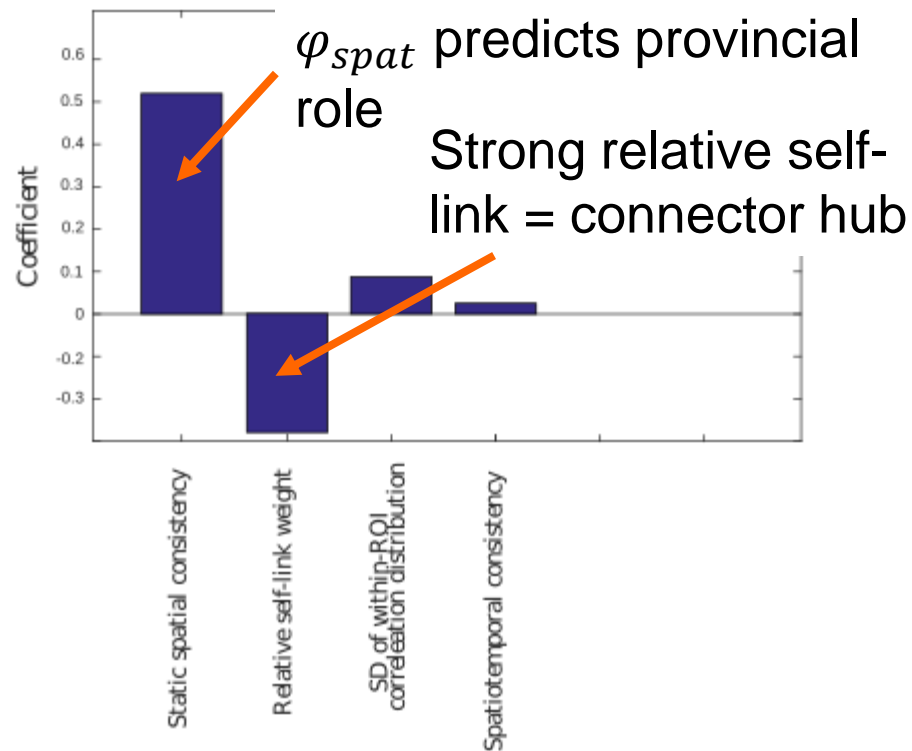
## Provincial vs connector hub

Accuracy:

Training 61.26%

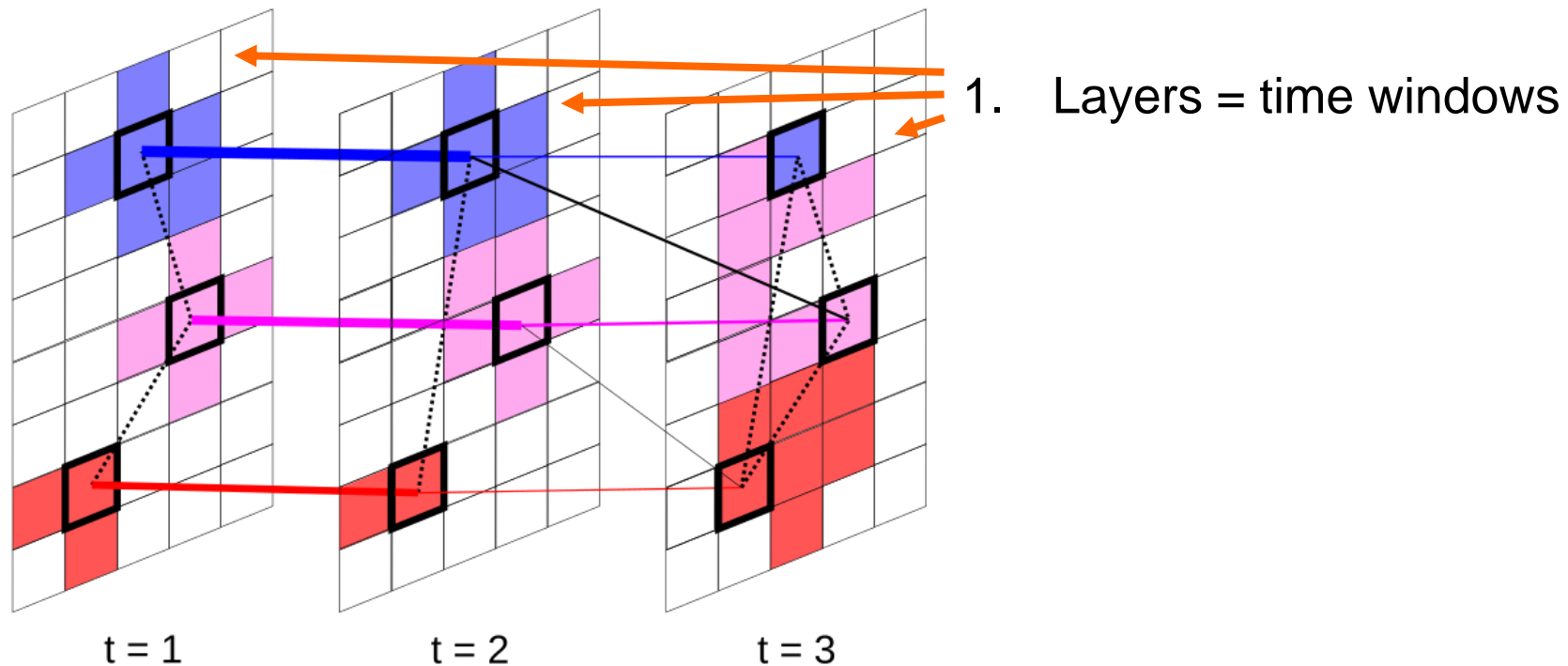
Test 60.85%

(> Random 50.20%)



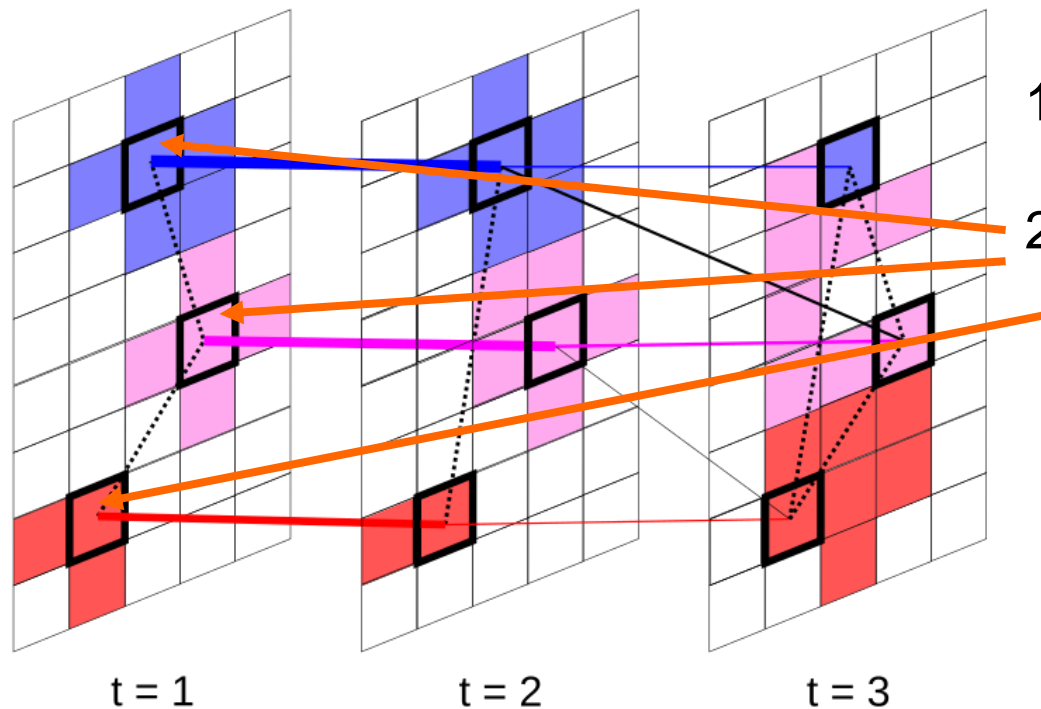
# Network model with flexible nodes

- Based on multilayer networks (= different connections in the same network)



# Network model with flexible nodes

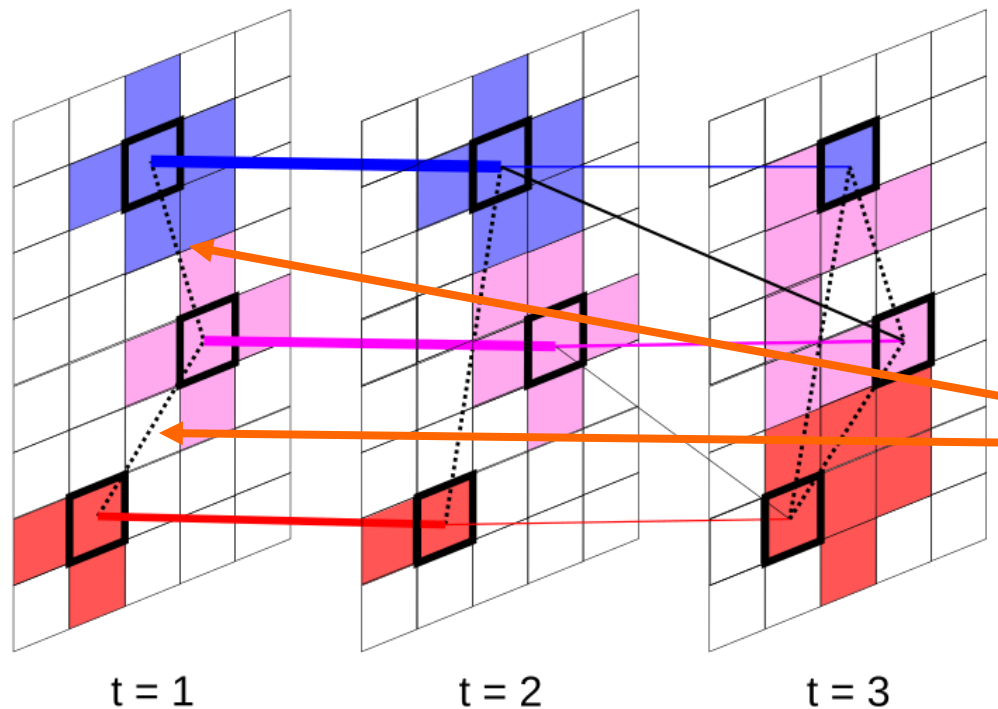
- Based on multilayer networks (= different connections in the same network)



1. Layers = time windows
2. ROIs optimized inside layers for maximal consistency

# Network model with flexible nodes

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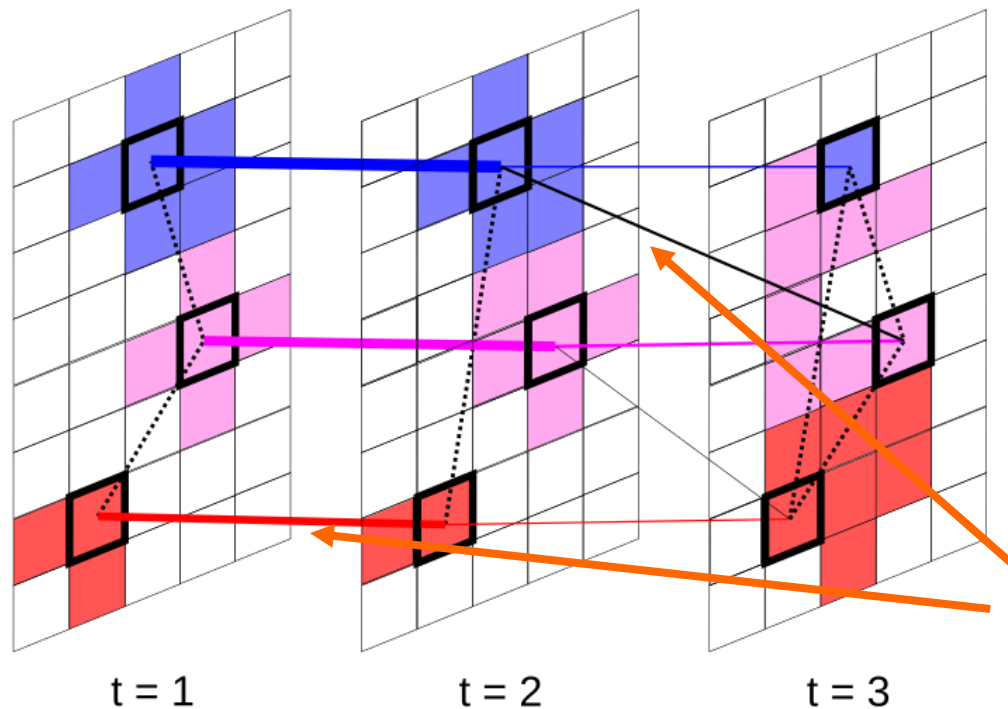


1. Layers = time windows
2. ROIs optimized inside layers for maximal consistency
3. Interlayer links = Pearson correlation



# Network model with flexible nodes

- Based on multilayer networks (= different connections in the same network)



1. Layers = time windows
2. ROIs optimized inside layers for maximal consistency
3. Interlayer links = Pearson correlation
4. Intralayer links = spatial overlap

# Conclusions

- It's not trivial to construct a functional brain network
  - **Know your methods!**
- Currently used nodes are not functionally homogeneous
  - Data lost in averaging
  - Can we trust observed connectivity?
- Homogeneity changes in time
  - Changes relate to function
- Low homogeneity isn't a technical flaw
  - ⇒ Can't be fixed by new static nodes
  - ⇒ **Flexible nodes needed!**





**Thank you!**

**Questions, comments?**

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