

How not to construct functional brain networks: Node definition

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Aalto Brain & Mind Computational Seminar

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



**Aalto University
School of Science**



center for
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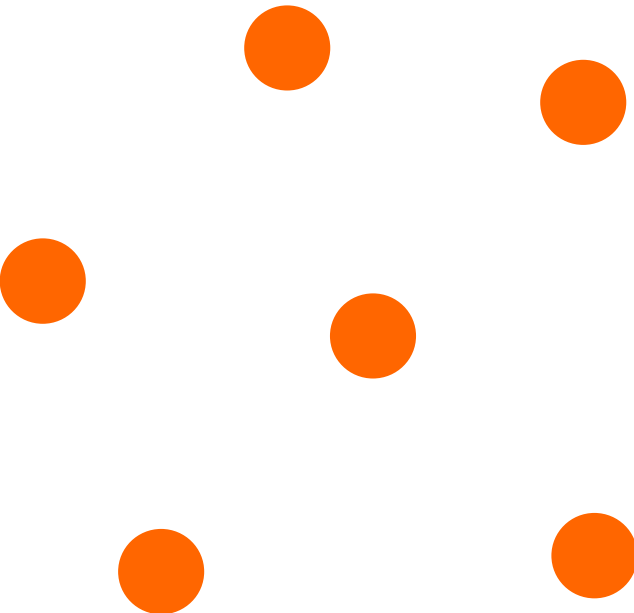


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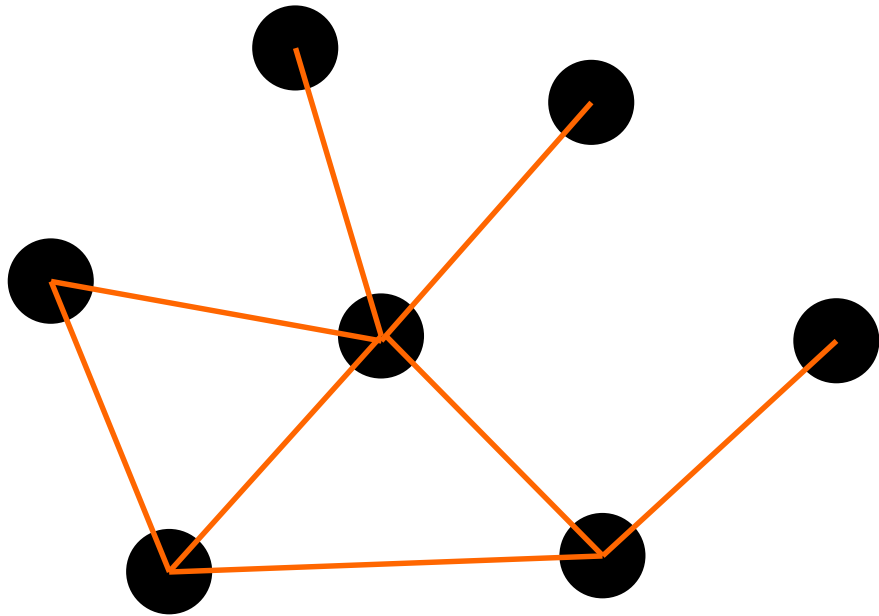
Networks: what and why?

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

Networks: what and why?

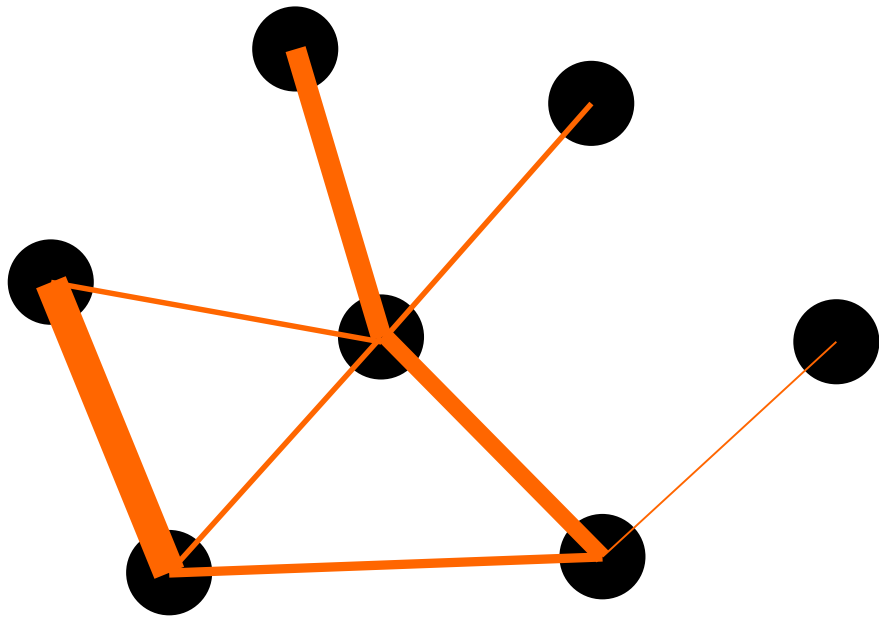
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- A decorative graphic consisting of seven solid orange circles of uniform size, arranged in a loose, abstract pattern on the left side of the slide.
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 - Internet, public transport, social networks
 - **Nodes:** network's basic elements
 - Web pages, stops, people

Networks: what and why?



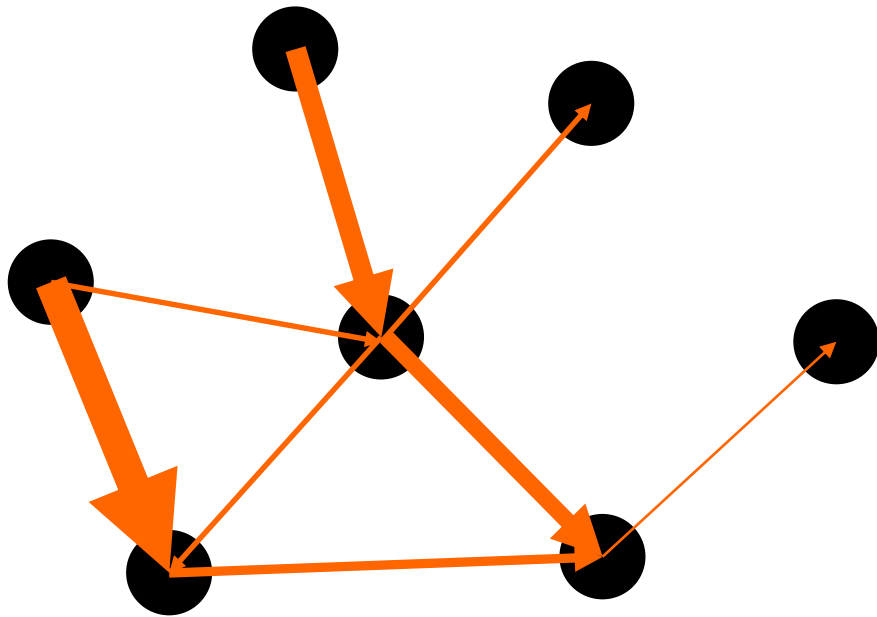
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 - Weights?

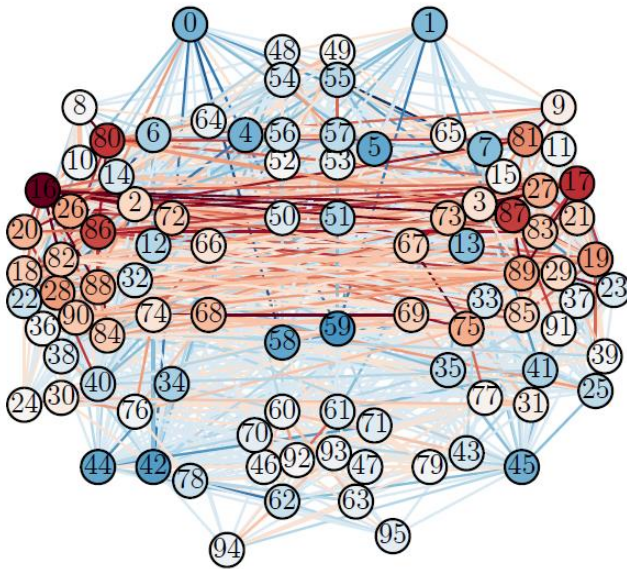
Networks: what and why?



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 - Weights?
 - Direction?

Why is the brain a network?

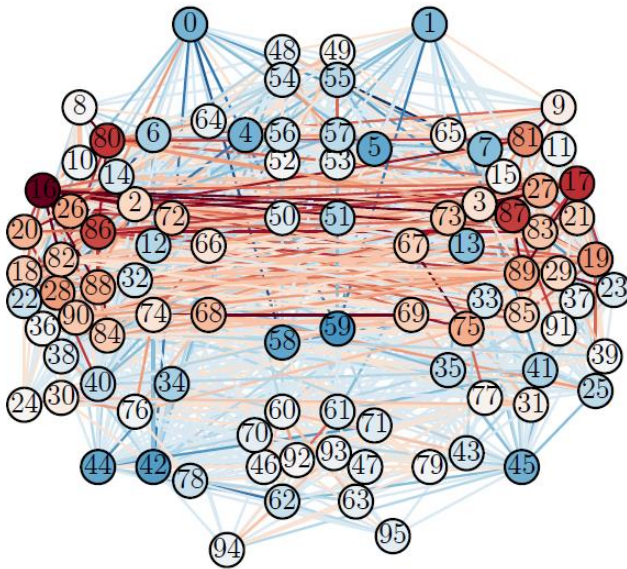
Fig: Alakörkkö et al. 2017,
European Journal of Neuroscience



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

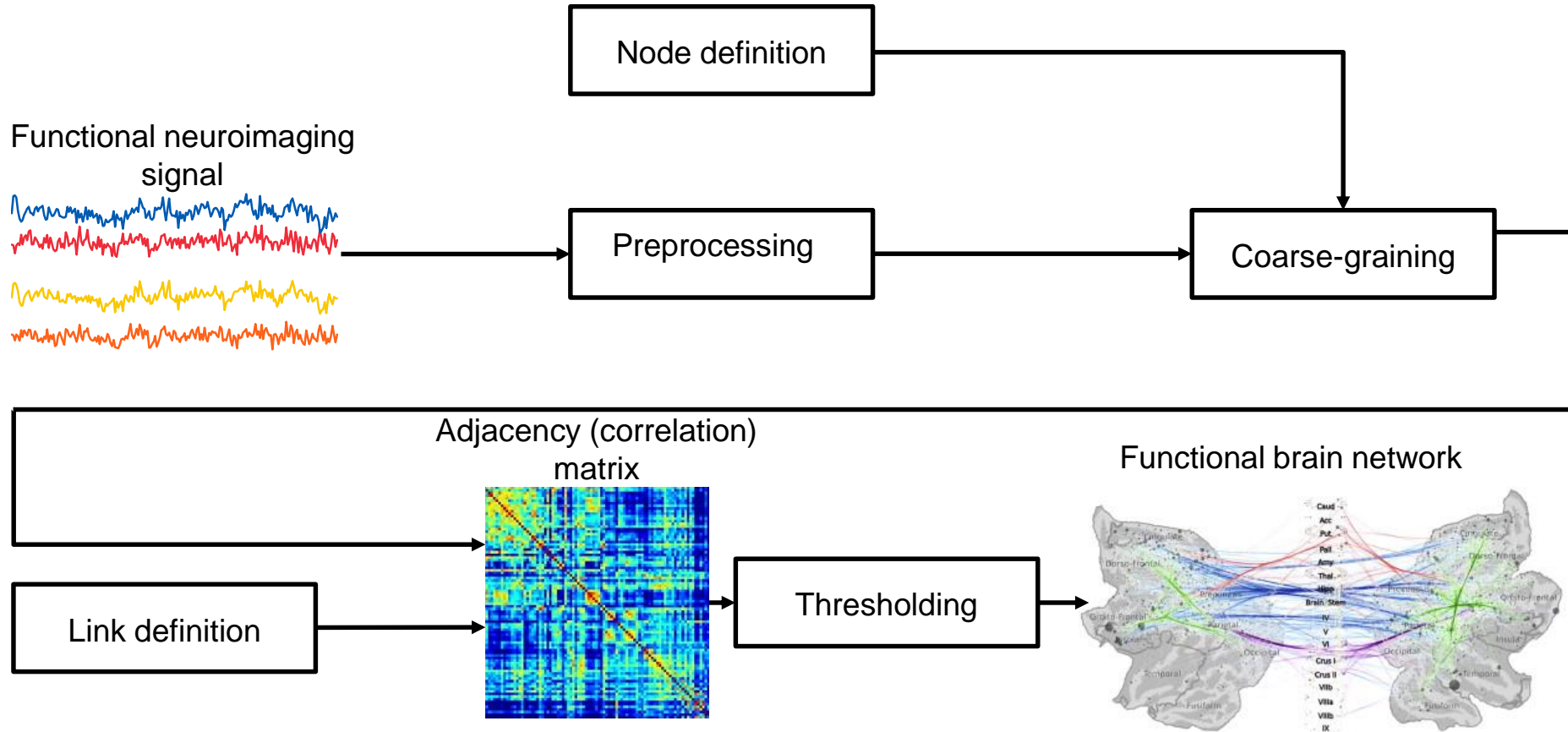
Network neuroscience

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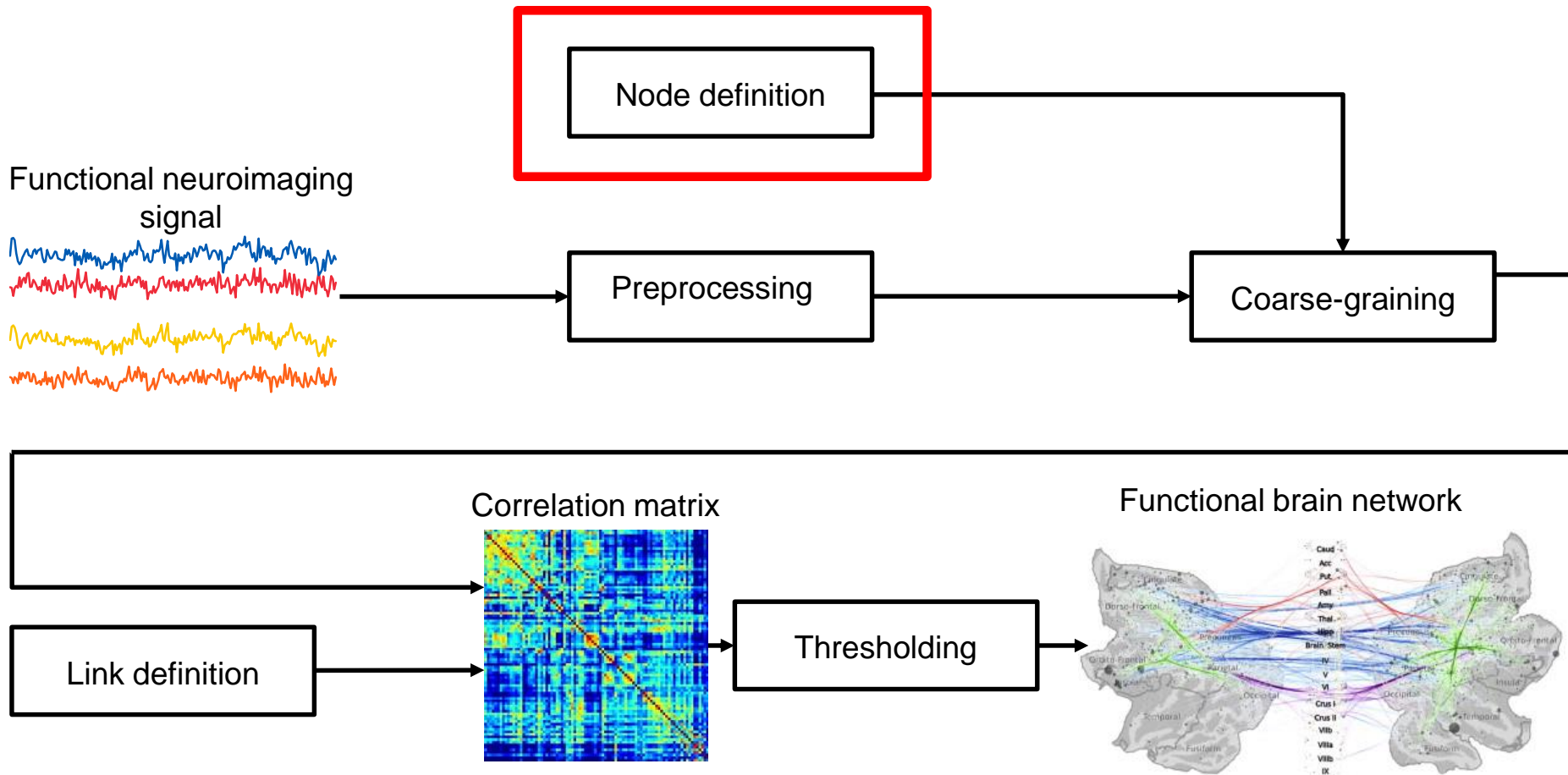
- Network neuroscience = applying network tools on the brain
- Two aims:
 1. Understand the healthy brain
 2. Find causes of diseases
- Broad scales:
 - Molecule – neuron – brain area – human
 - Milliseconds – years
- Different brain networks:
 - Structural: anatomic connections
 - **Functional**: temporal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

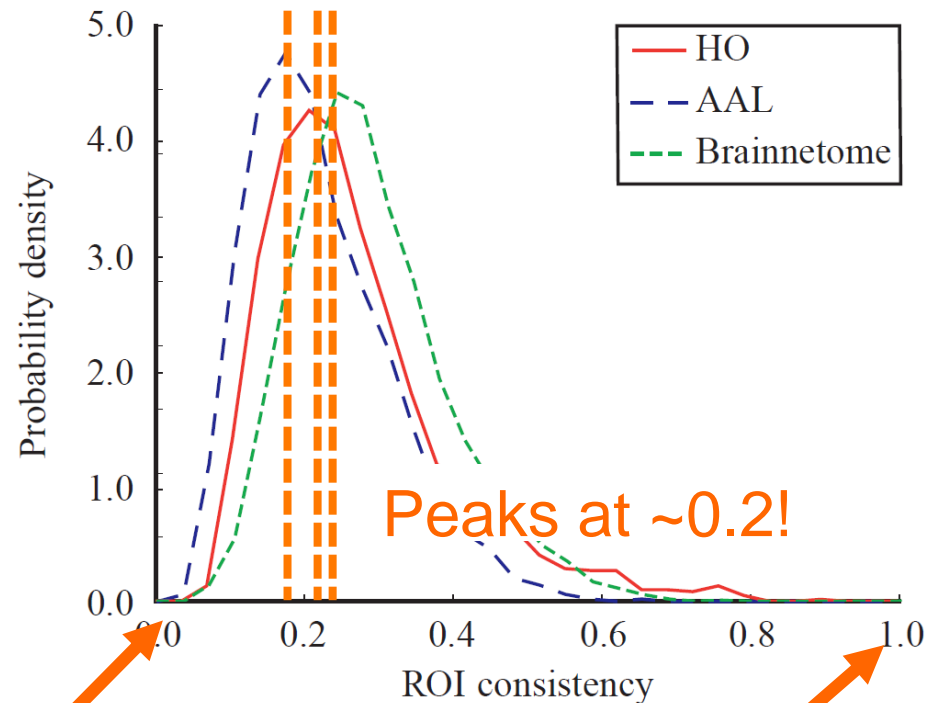
How homogeneous are ROIs?

- **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

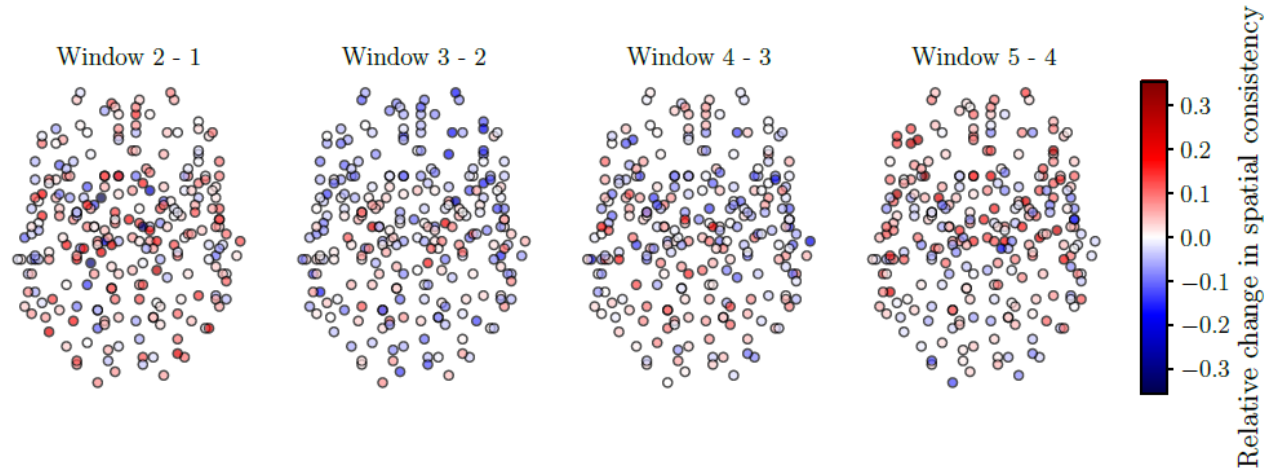
Korhonen et al., 2017. *Network Neuroscience*



Lack of
homogeneity

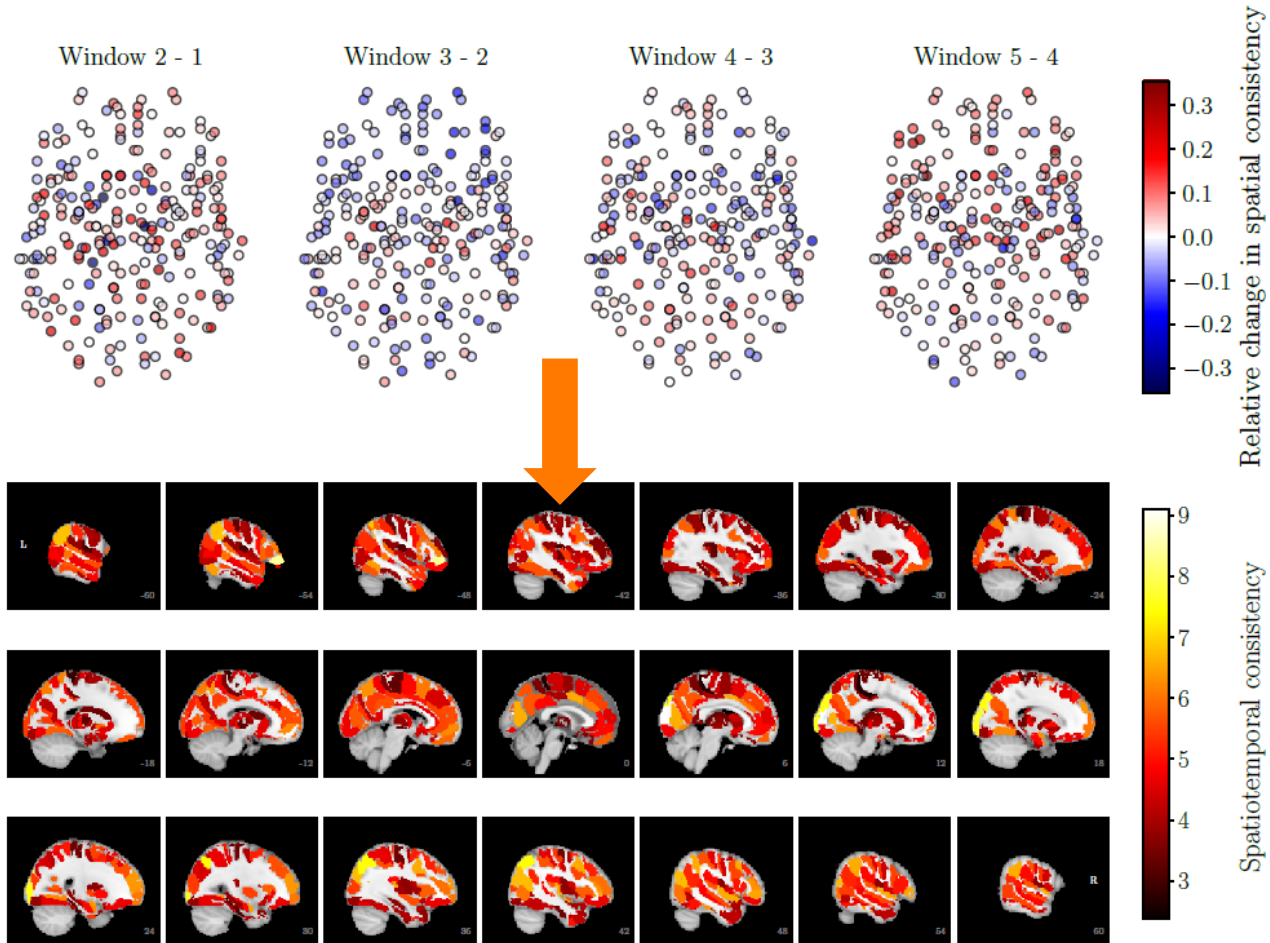
Perfect
homogeneity

Spatial consistency changes in time



Ryppö et al., 2018. *Network Neuroscience*

Spatial consistency changes in time

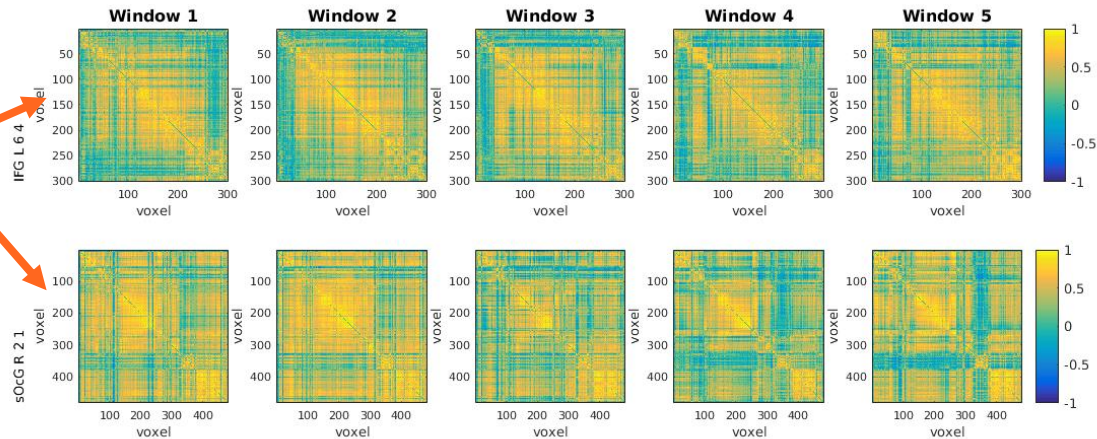


Ryppö et al., 2018. *Network Neuroscience*

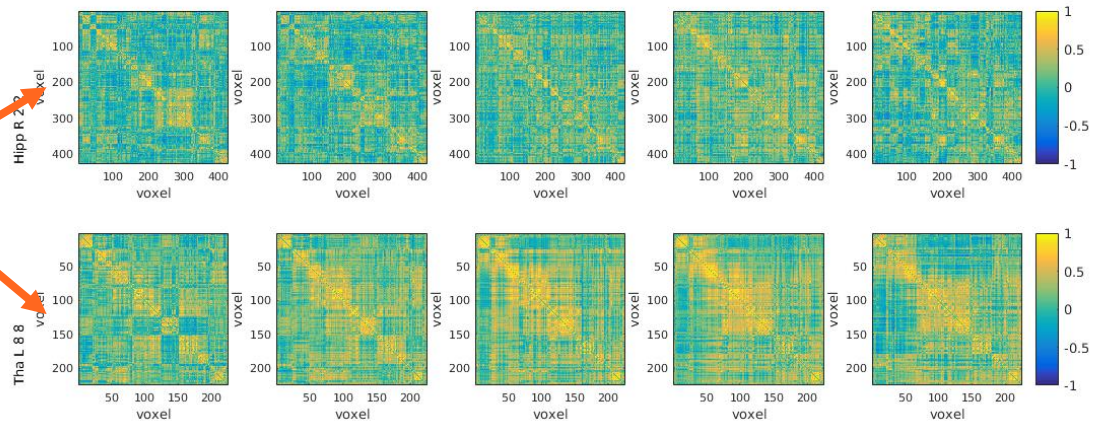
Spatiotemporal consistency
= stability of spat. consistency

ROIs have rich internal connectivity structure

High spatial consistency

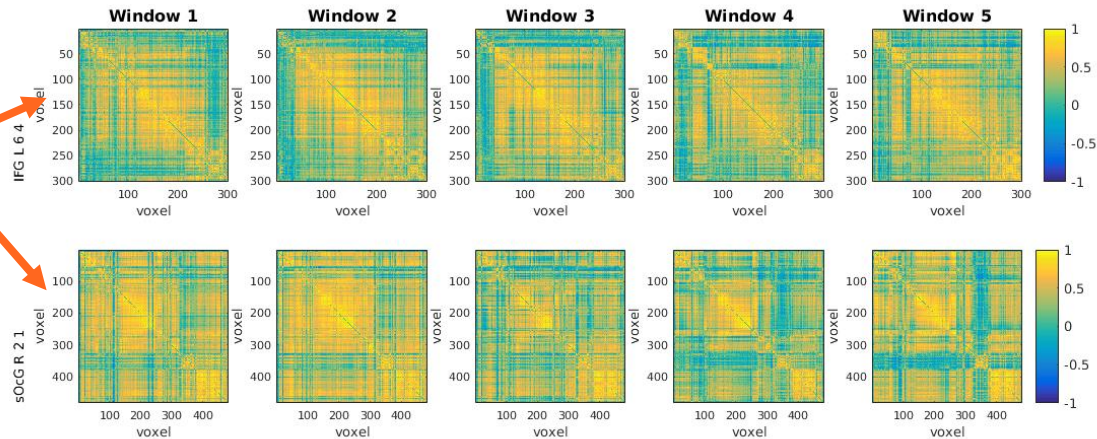


Low spatial consistency

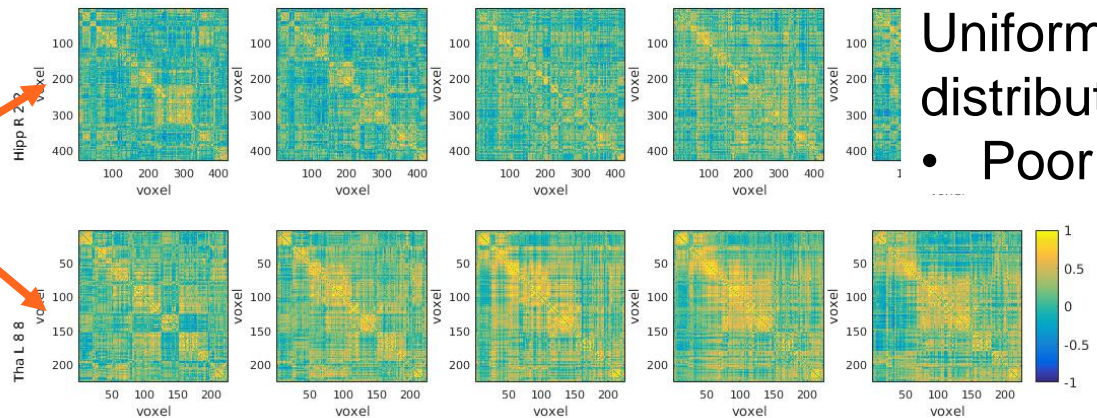


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Low spatial consistency

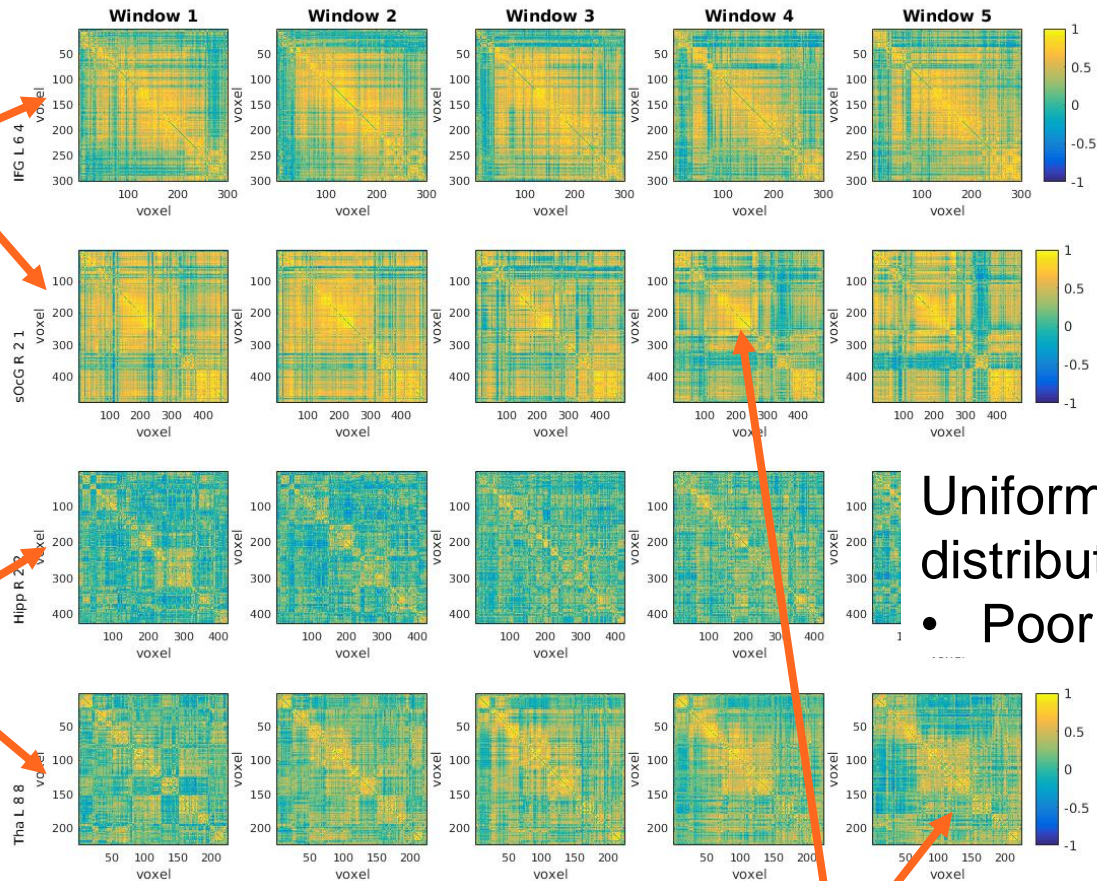


Uniform correlation distribution

- Poorly defined ROI?

ROIs have rich internal connectivity structure

High spatial consistency



Low spatial consistency

Uniform correlation distribution

- Poorly defined ROI?

Intra-ROI modules

- Network topology?

Consistency predicts topology

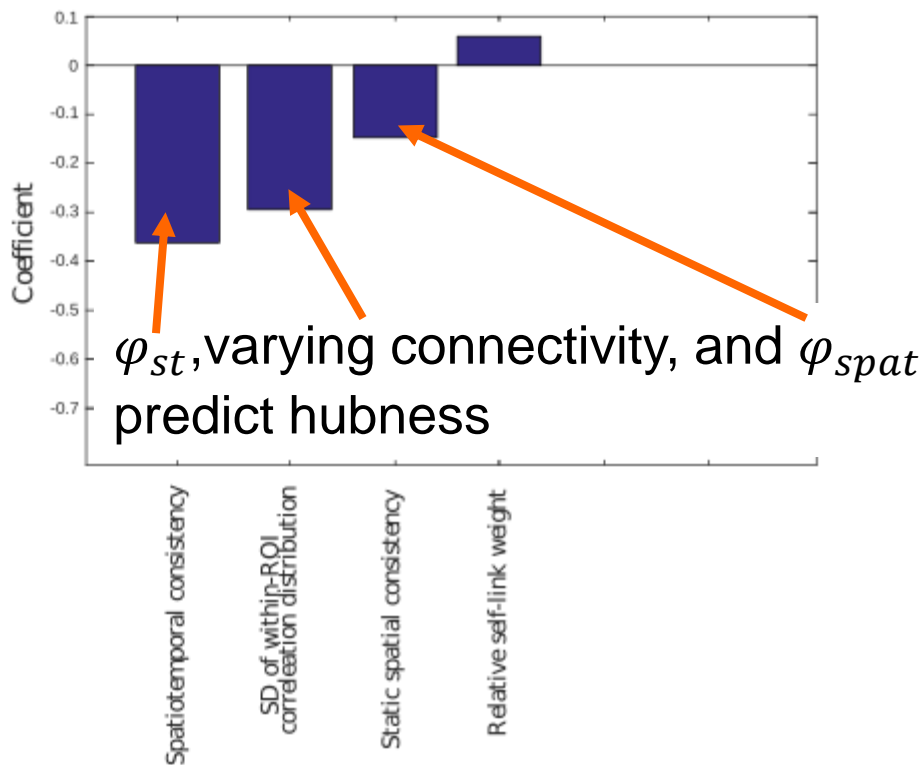
Hub vs non-hub:

Accuracy:

Training 64.22%

Test 62.31%

(> Random 55.01%)



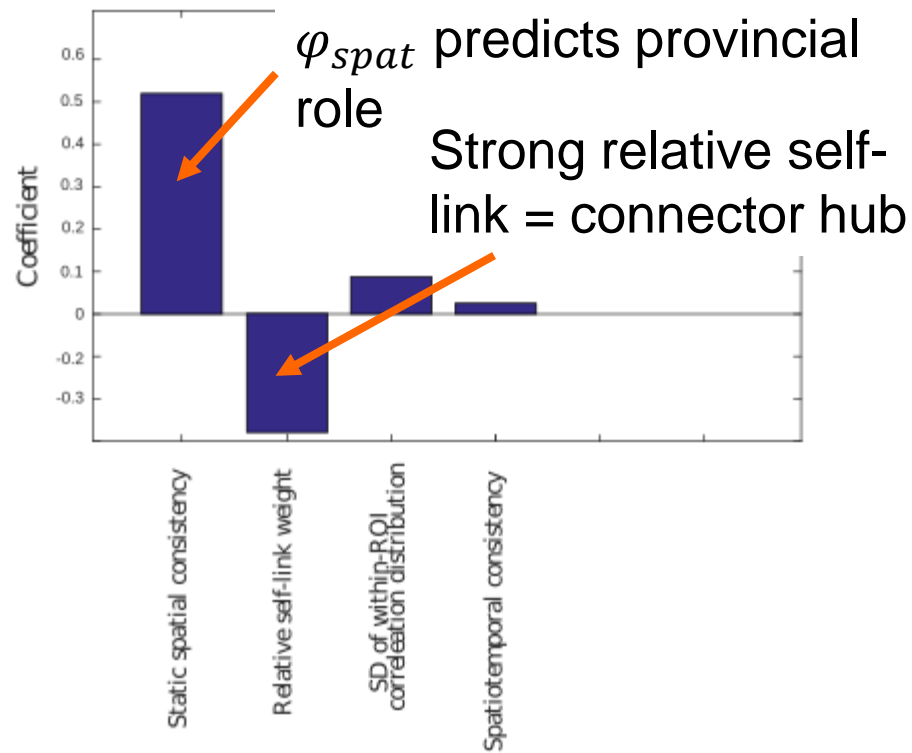
Provincial vs connector hub

Accuracy:

Training 61.26%

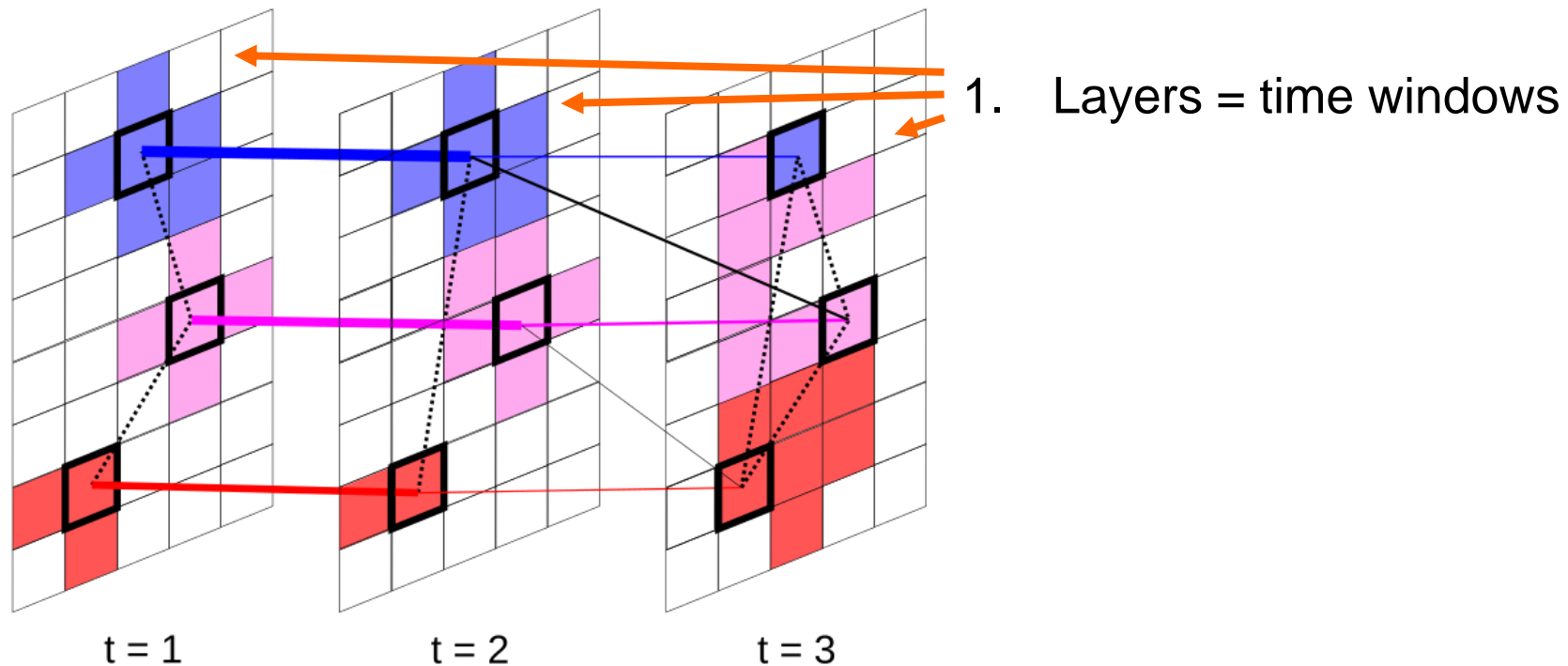
Test 60.85%

(> Random 50.20%)



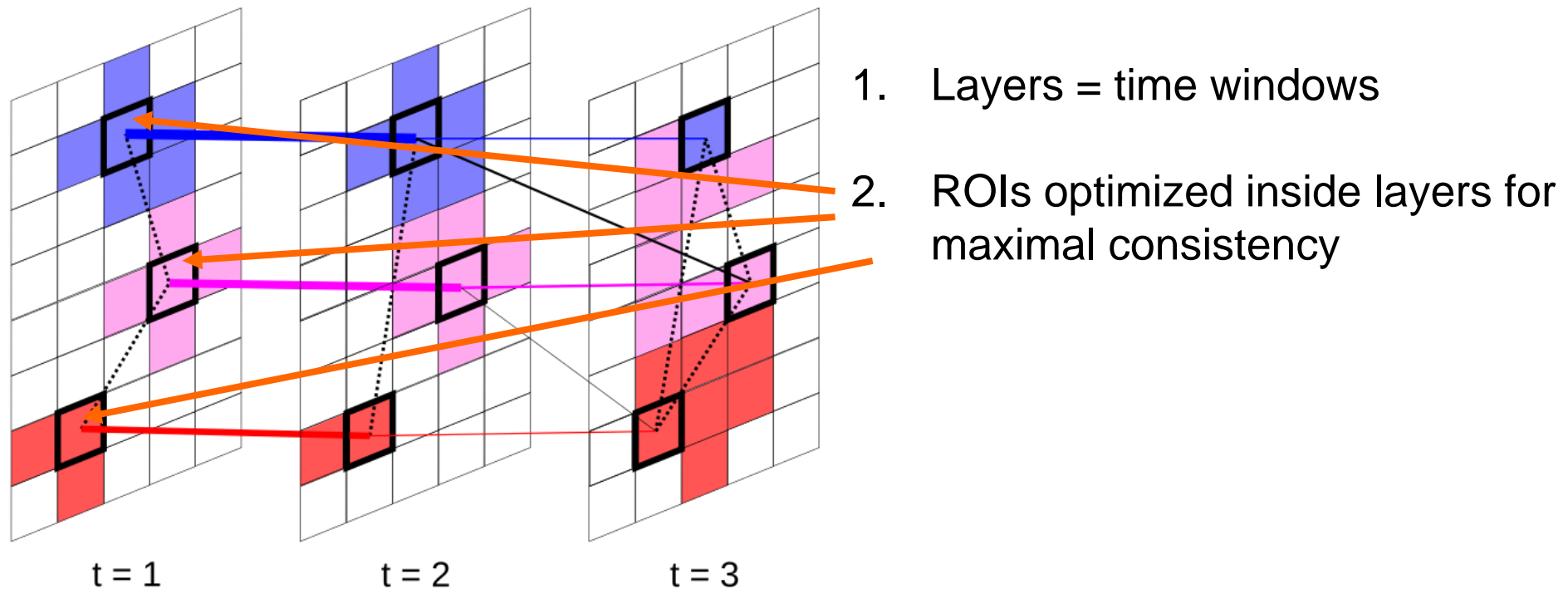
Network model with flexible nodes

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



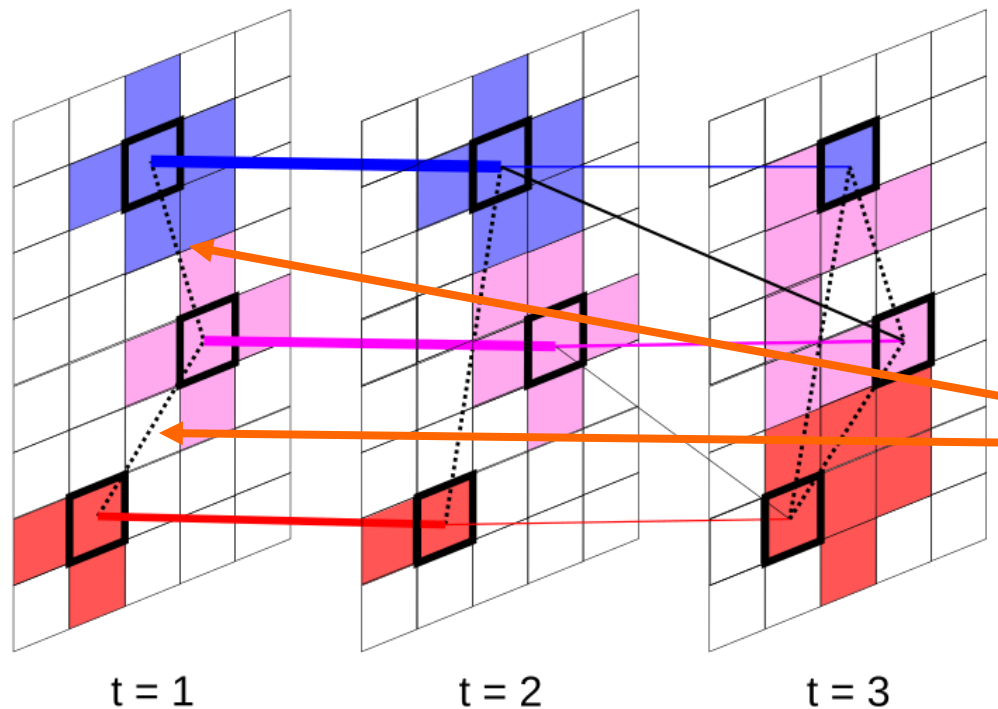
Network model with flexible nodes

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Network model with flexible nodes

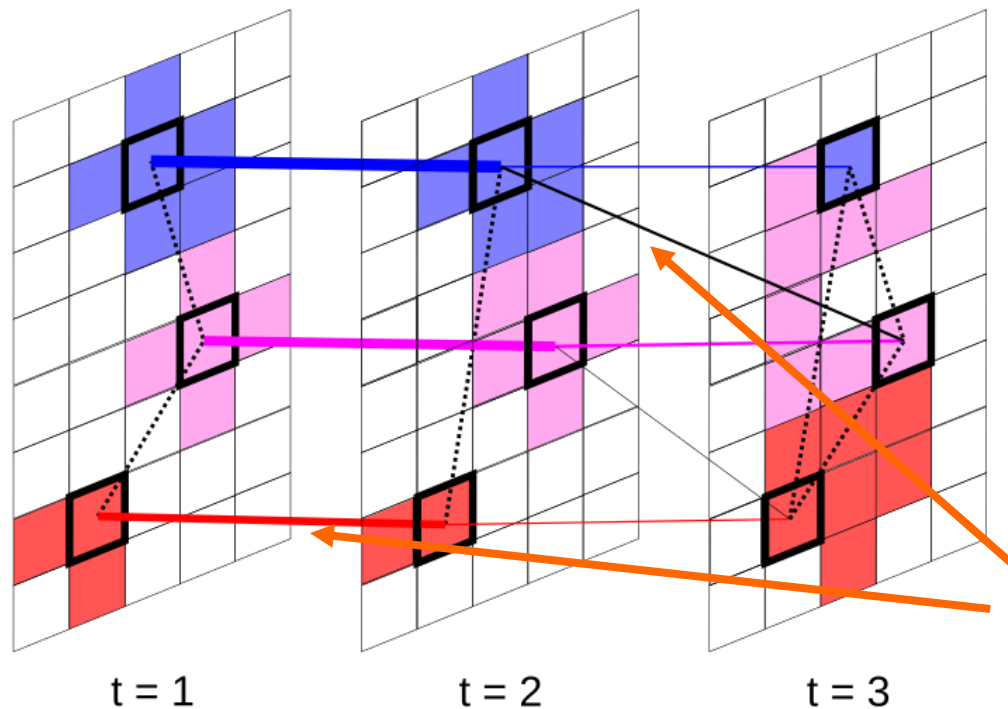
- Based on multilayer networks (= different connections in the same network)



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

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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