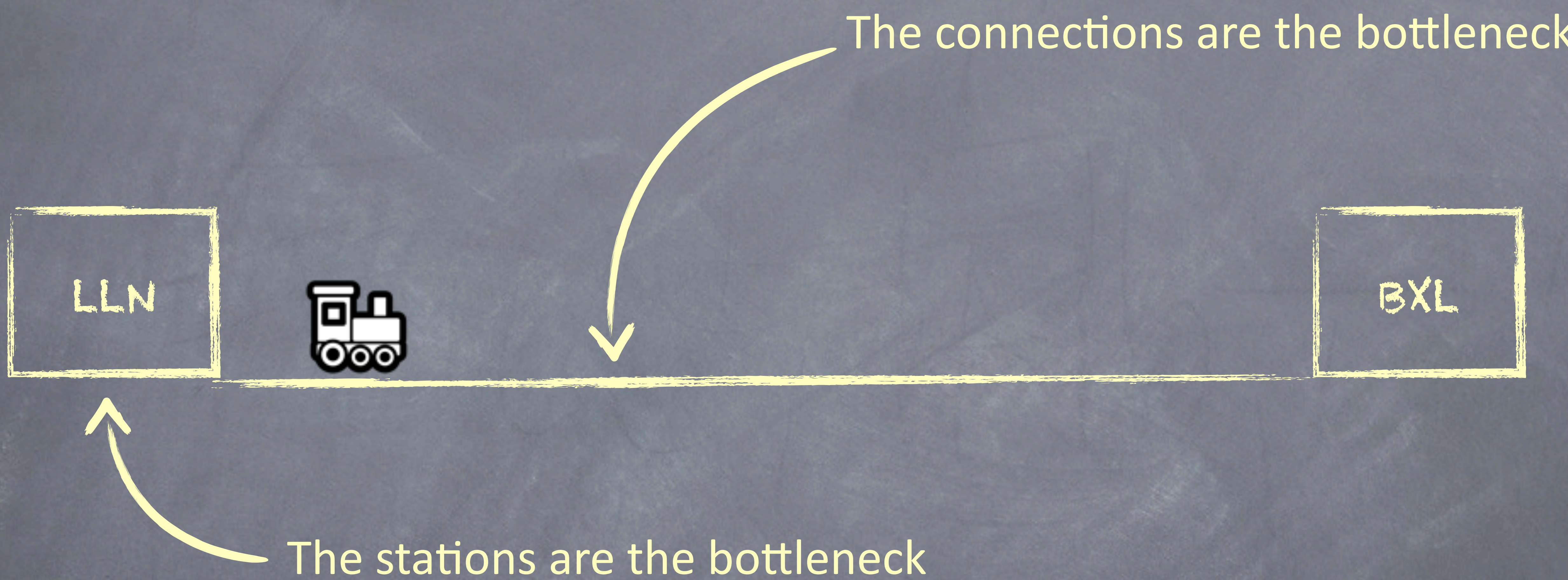
Measuring the brain connectivity

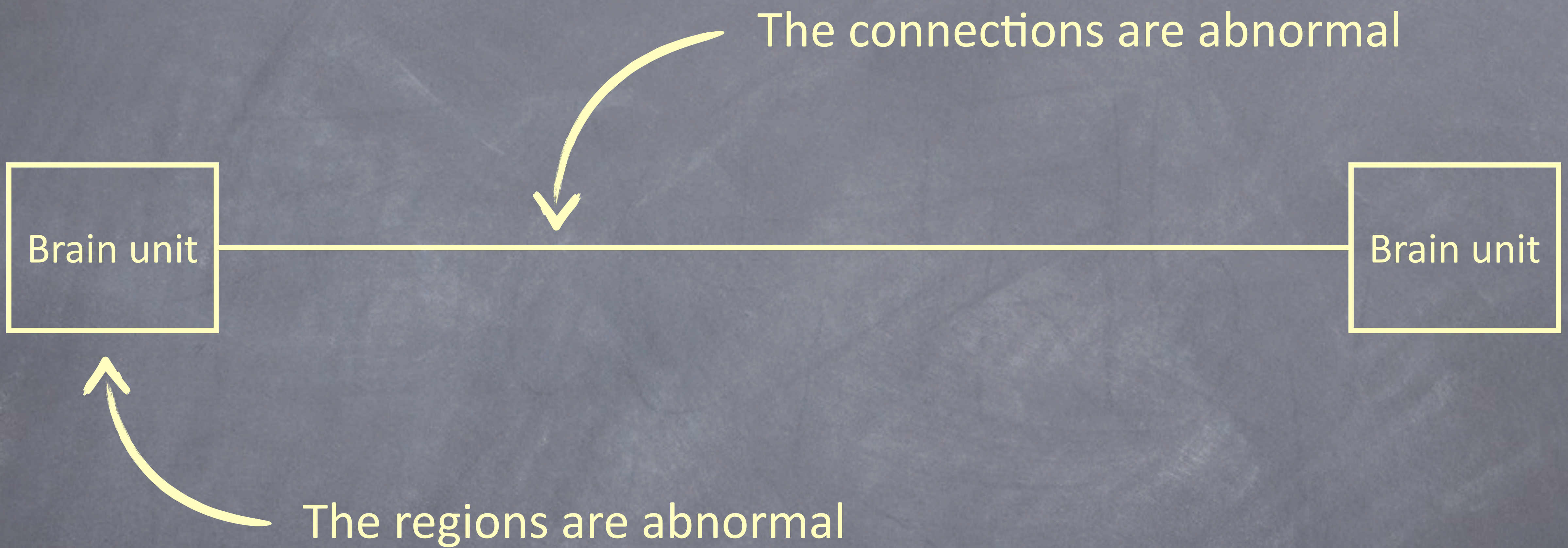
Image and Signal Processing Seminars
November 2012

Maxime Taquet

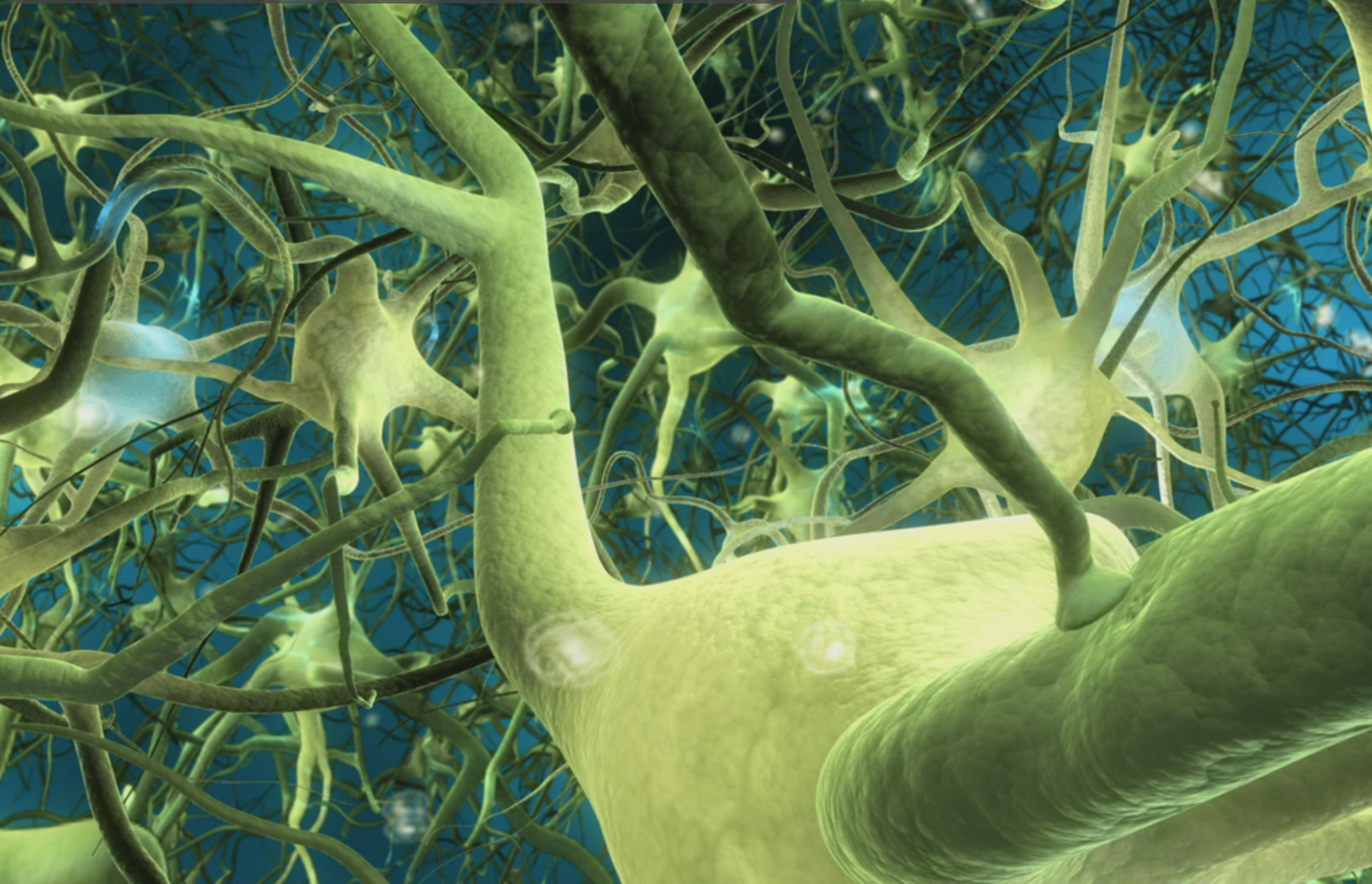

YET·948
KMV·102


DEPART
18 30
HEURE
DESTINATION
NATURE
VOIE
REM.
17:35 WAVRE P 6 +0H57
17:53 BRUXELLES BINCHE IR 2 +0H50
17:55 NAMUR JEMELLE P 3 +0H31
18:02 CHARLEROI-SUD P 9 +0H30
18:09 LOUVAIN-LA NEUVE IR 3 +0H24
18:15 NAMUR LUXEMBOURG IC 3
18:20 WAVRE L 5 +0H21
18:21 BRUXELLES NIVELLES CR ***
TRAIN SUPPRIME
18:33 WAVRE P 5 +0H10
18:45 LIEGE-LIERS DINANT IC 3
18:47 BRUXELLES-MIDI IC 2 +0H11

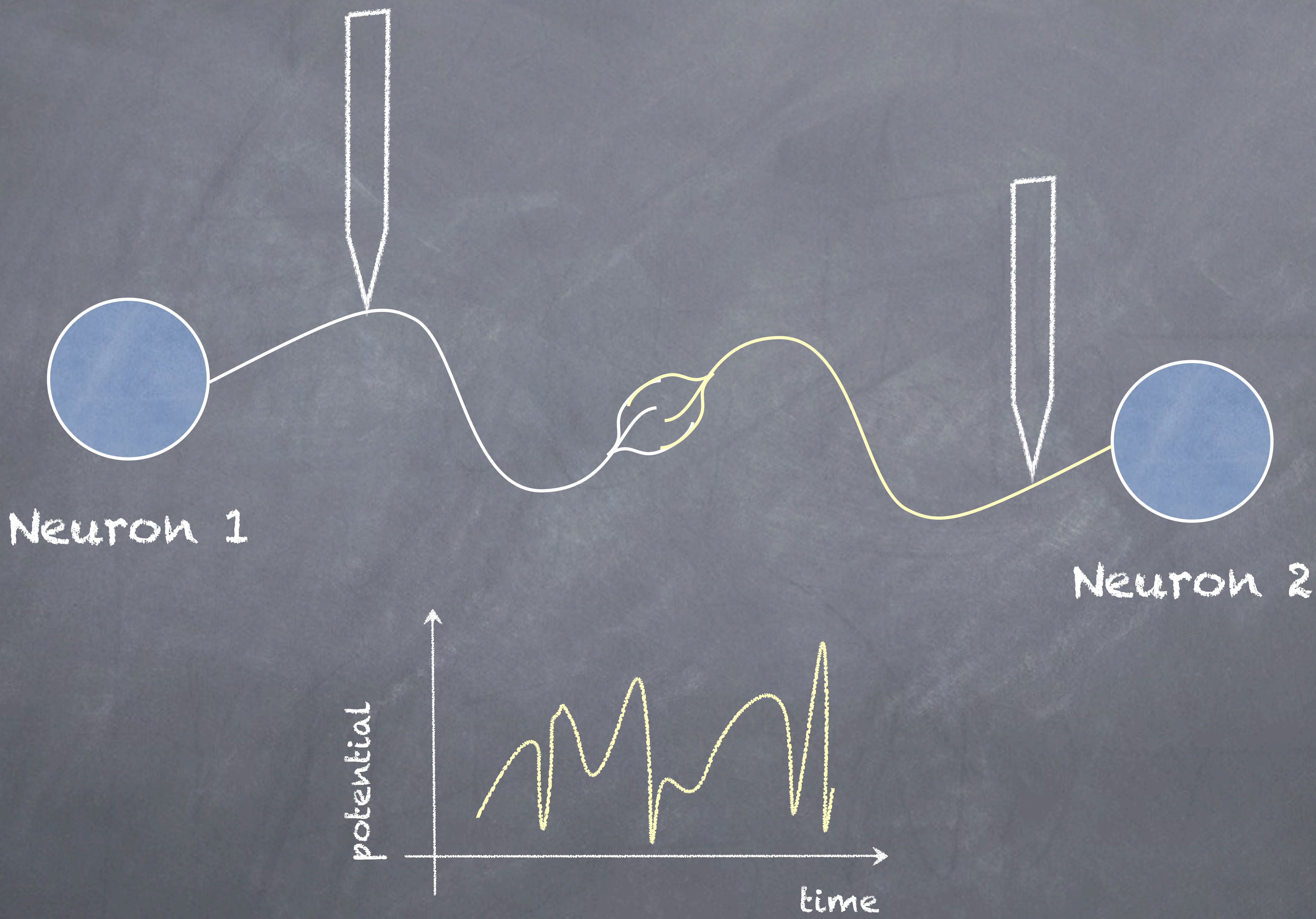

The connections are the bottleneck
LLN
BXL
The stations are the bottleneck


The connections are abnormal
Brain unit
Brain unit
The regions are abnormal

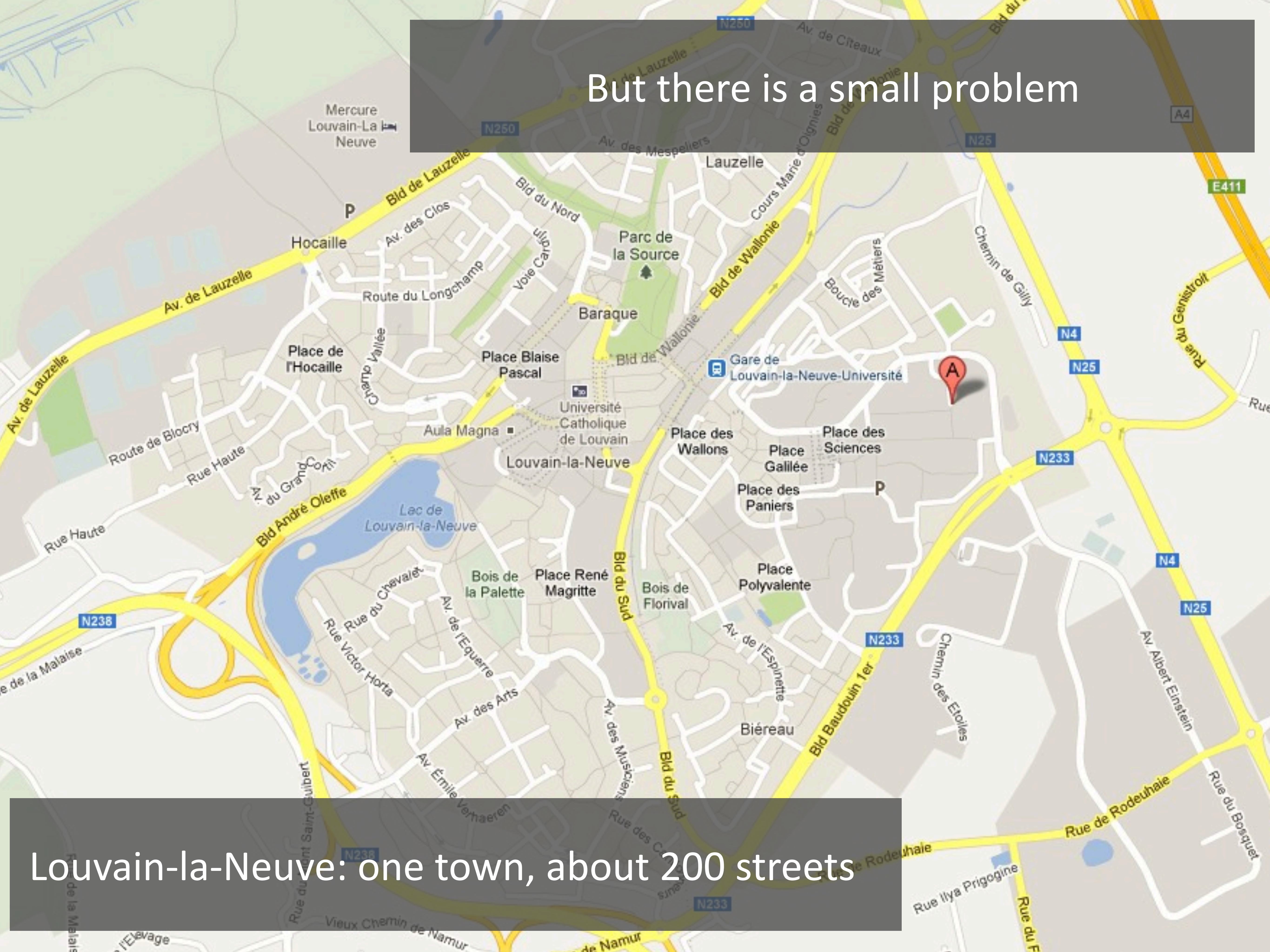
Our brain is made (in part) of neurons



Ideally, we would like to measure the activity of each individual connection



But there is a small problem



Louvain-la-Neuve: one town, about 200 streets

But there is a small problem

Belgium: about 10 000 towns, 2 000 000 streets


But there is a small problem
Europe: about 500 000 towns, 100 000 000 streets
Ísland
Sverige
Norge
Finland
Oslo
Stockholm
Helsinki
Санкт-Петербург
Tallinn
Eesti
Baltic Sea
Latvija
North Sea
Danmark
Lietuva
Vilnius
Минск
Москва
United Kingdom
Ireland
Éire
Hamburg
Беларусь
Nederland
Berlin
Polska
London
Deutschland
Belgique
Київ
Харків
Praha
Kraków
Česká rep
Paris
Celtic Sea
Wien
Slovensko
Україна
Дніпропетровськ
Zürich
Österreich
Moldova
Донецьк
France
Magyarország
Zagreb
Milano
Одеса
România
Bay of Biscay
Hrvatska
Torino
Србија
București
Italia
Black Sea
Marseille
България
Roma
Istanbul
Portugal
Madrid
Barcelona
Napoli
Ankara
Türkiye
Alger
Tunis
Αθήνα

Tysiąclecia Plac (Poland)

Calle de Valle de Alcúdia,
Ciudad Real (Spain)

Åsgatan, Jokkmok (Sweden)

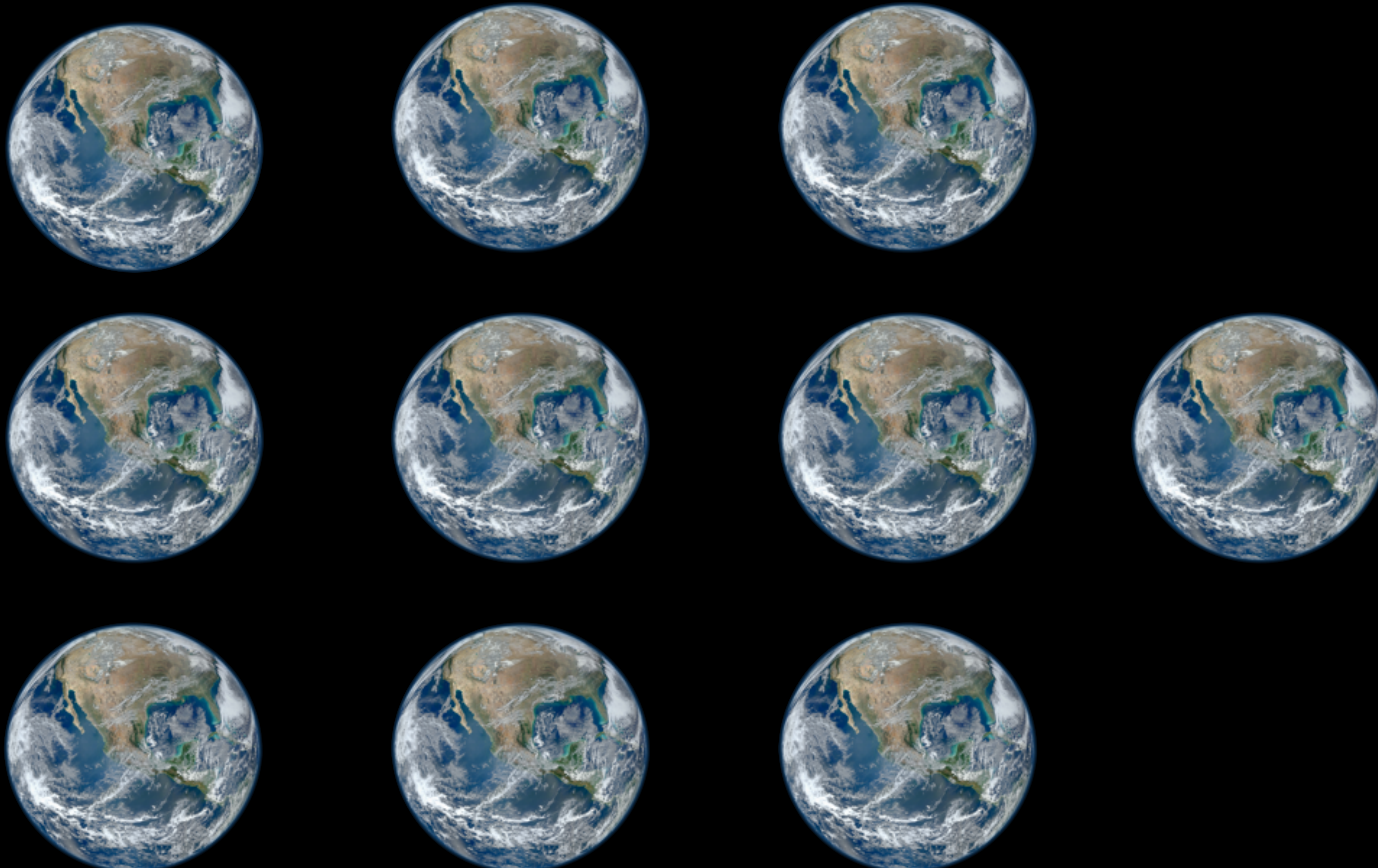
But there is a small problem

Europe: about 500 000 towns, 100 000 000 streets

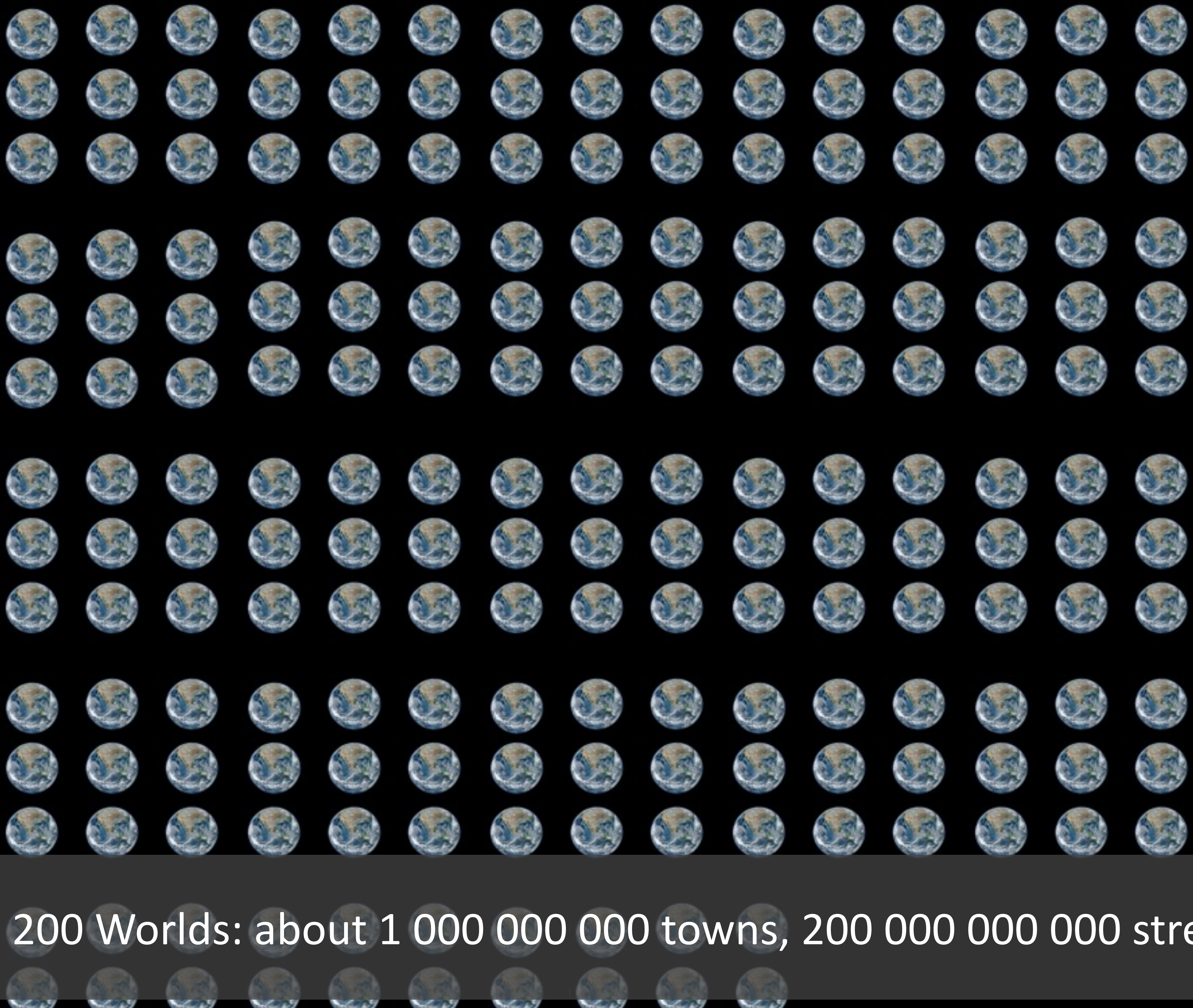
But there is a small problem

World: about 5 000 000 towns, 1 000 000 000 streets


But there is a small problem
World: about 5 000 000 towns, 1 000 000 000 streets

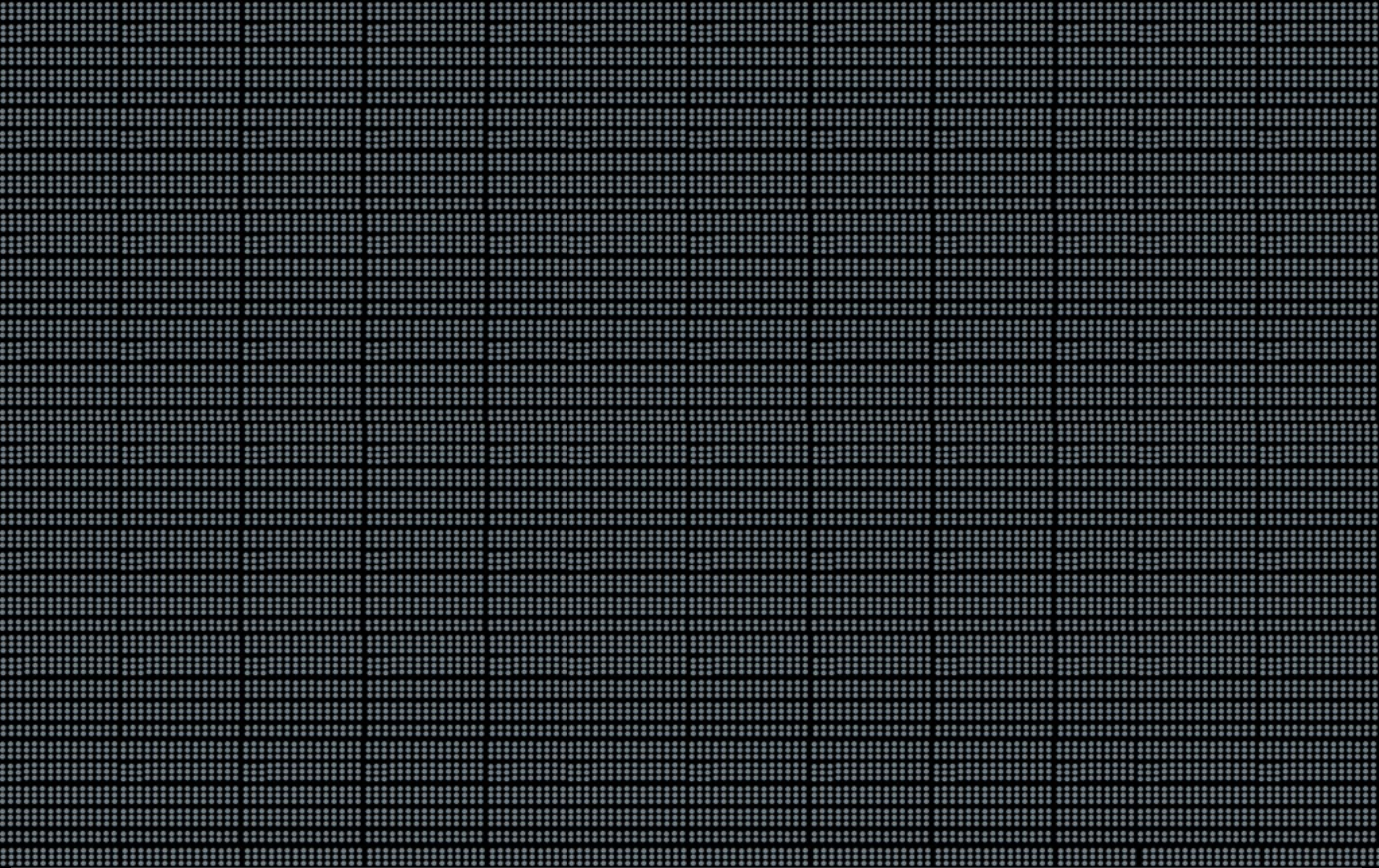


10 Worlds: about 50 000 000 towns, 10 000 000 000 streets

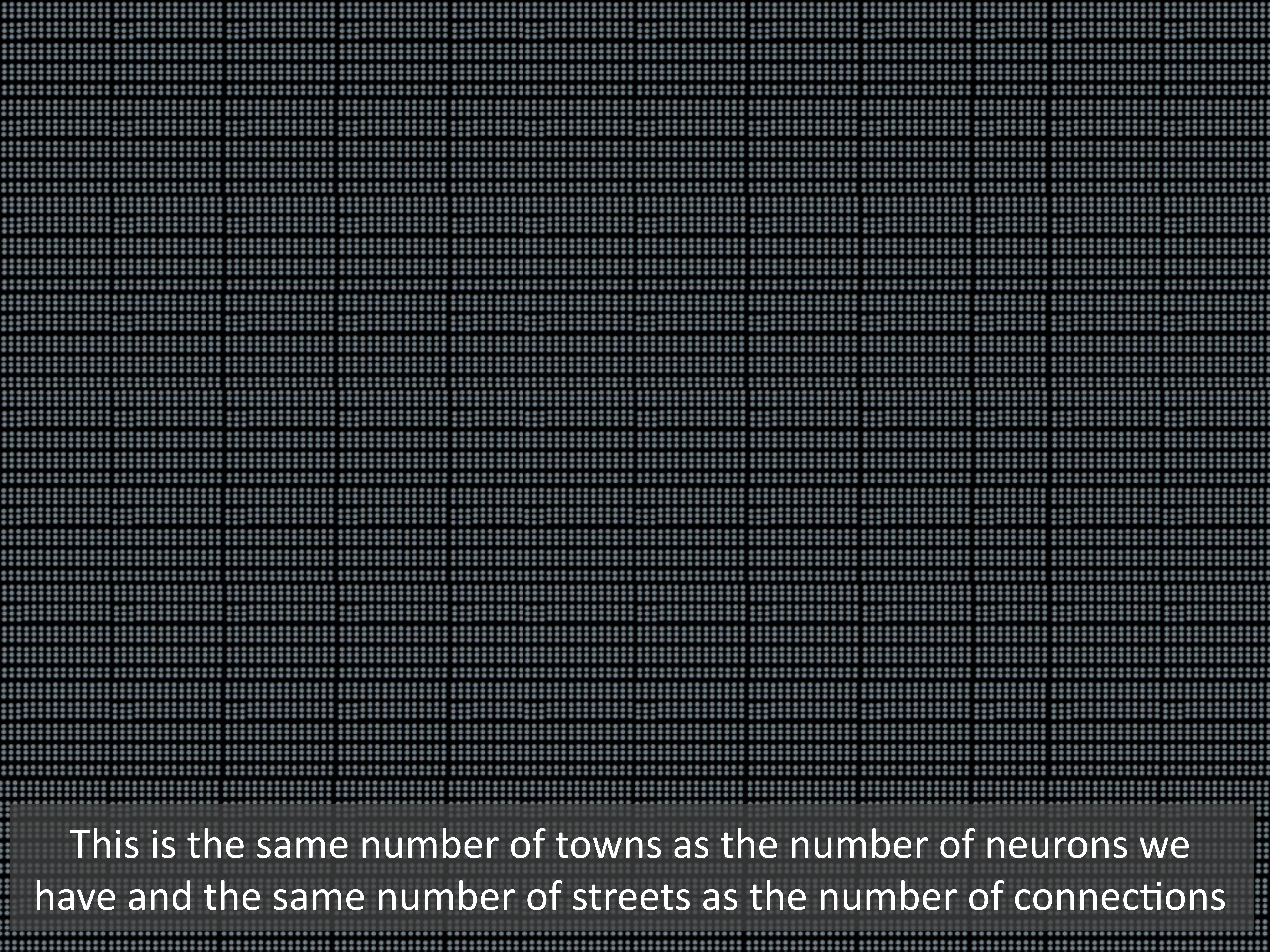


200 Worlds: about 1 000 000 000 towns, 200 000 000 000 streets

4000 Worlds: about 20 000 000 000 towns, 4 000 000 000 000 streets

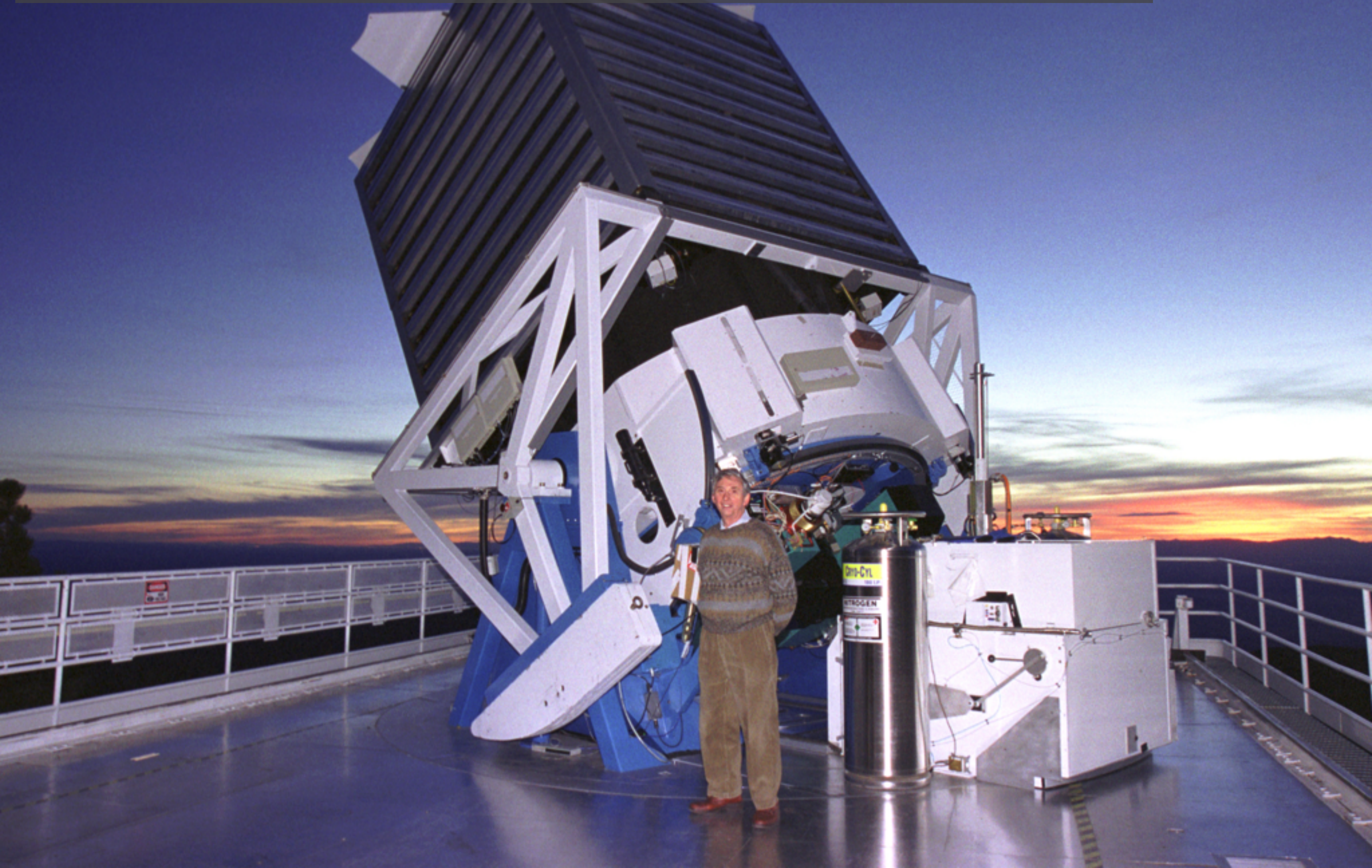


About 100 billion towns, 100 000 billions streets



This is the same number of towns as the number of neurons we have and the same number of streets as the number of connections

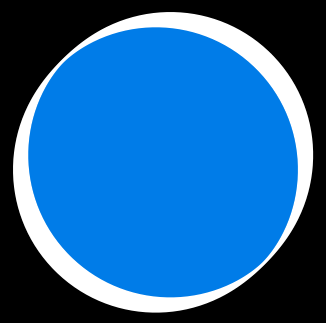
We need other tools to measure connectivity in the brain



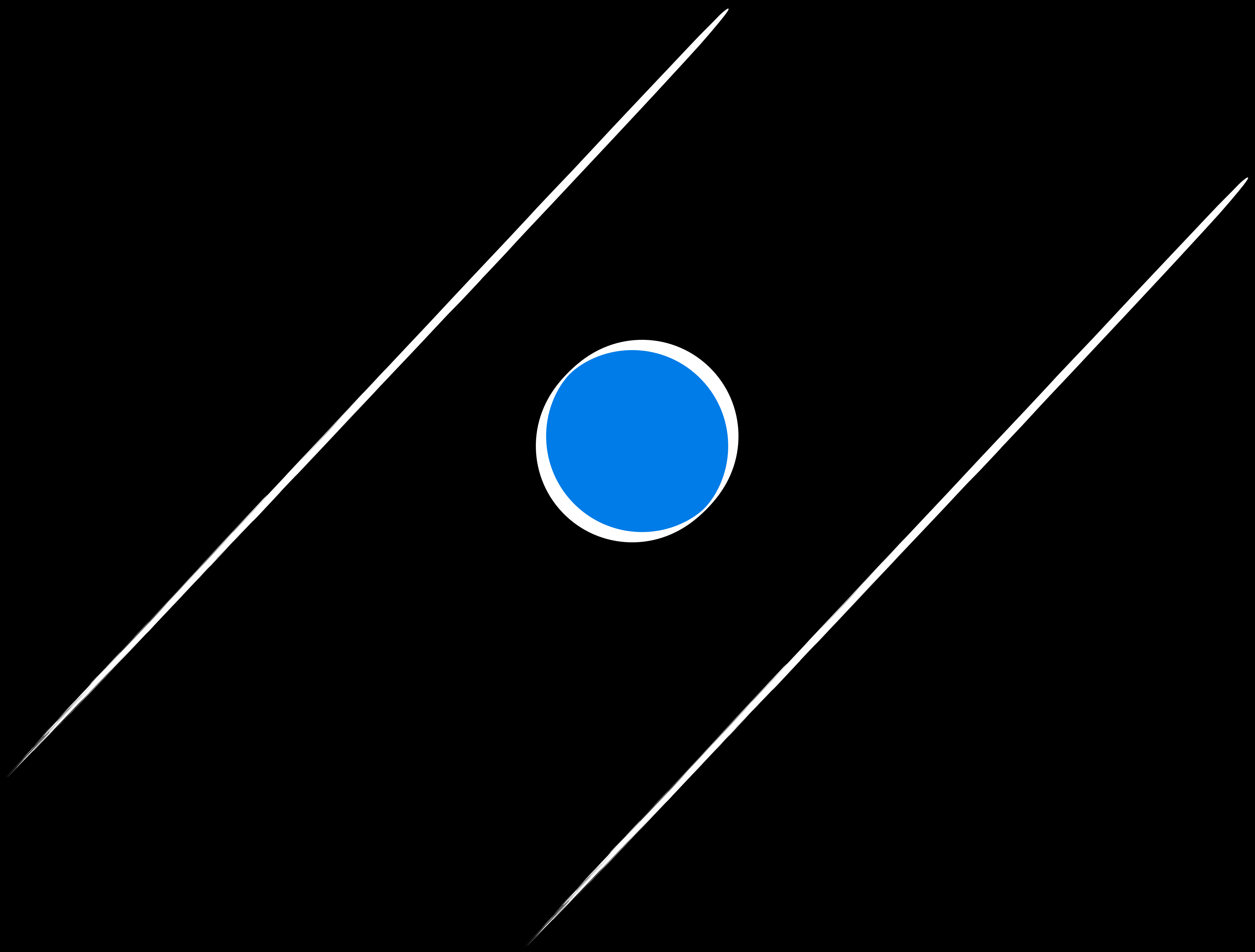
We can measure the brain connections with imaging

We can model the brain network and its properties

Water molecules never stay still

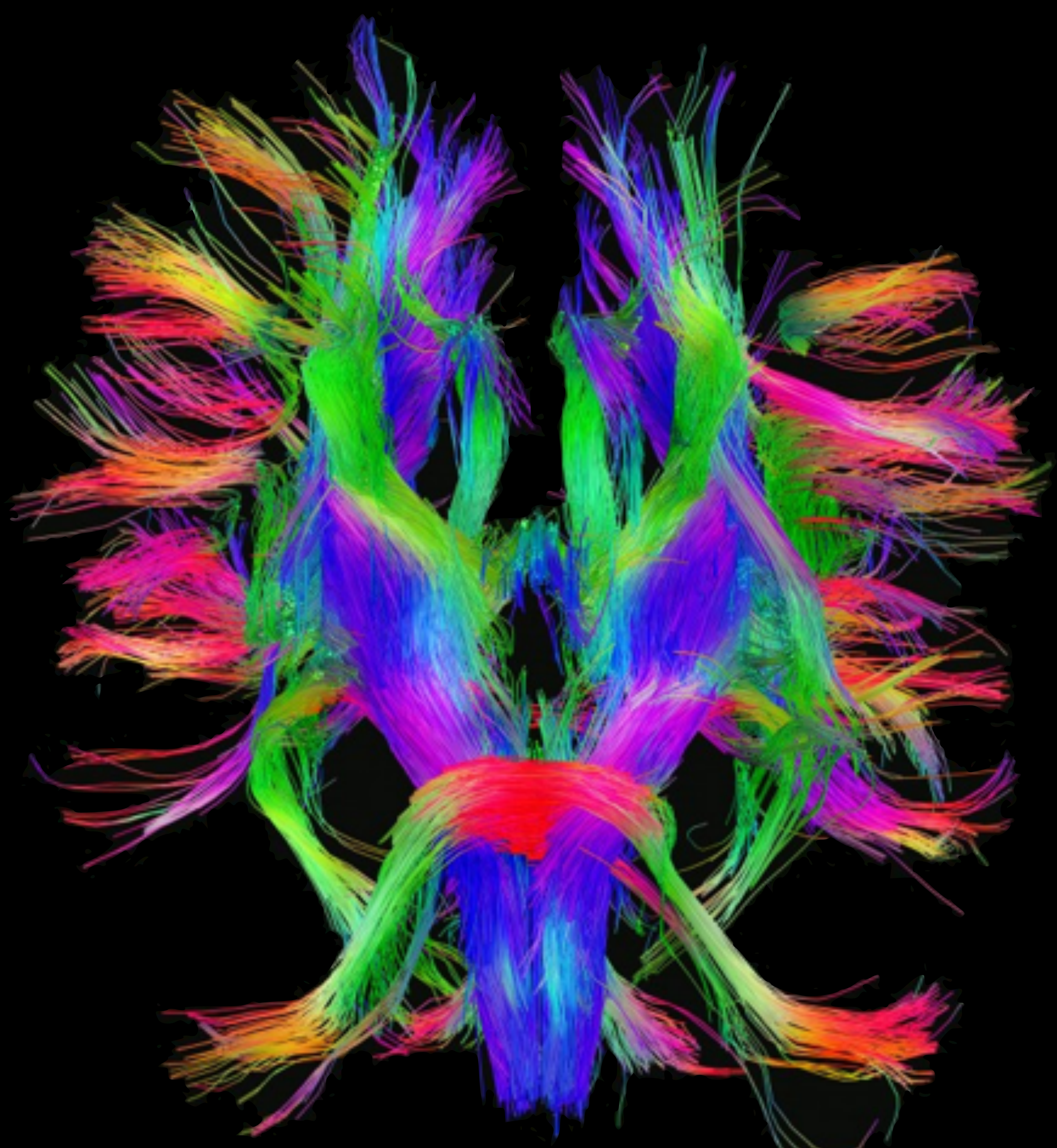


Their diffusion is constrained by the environment

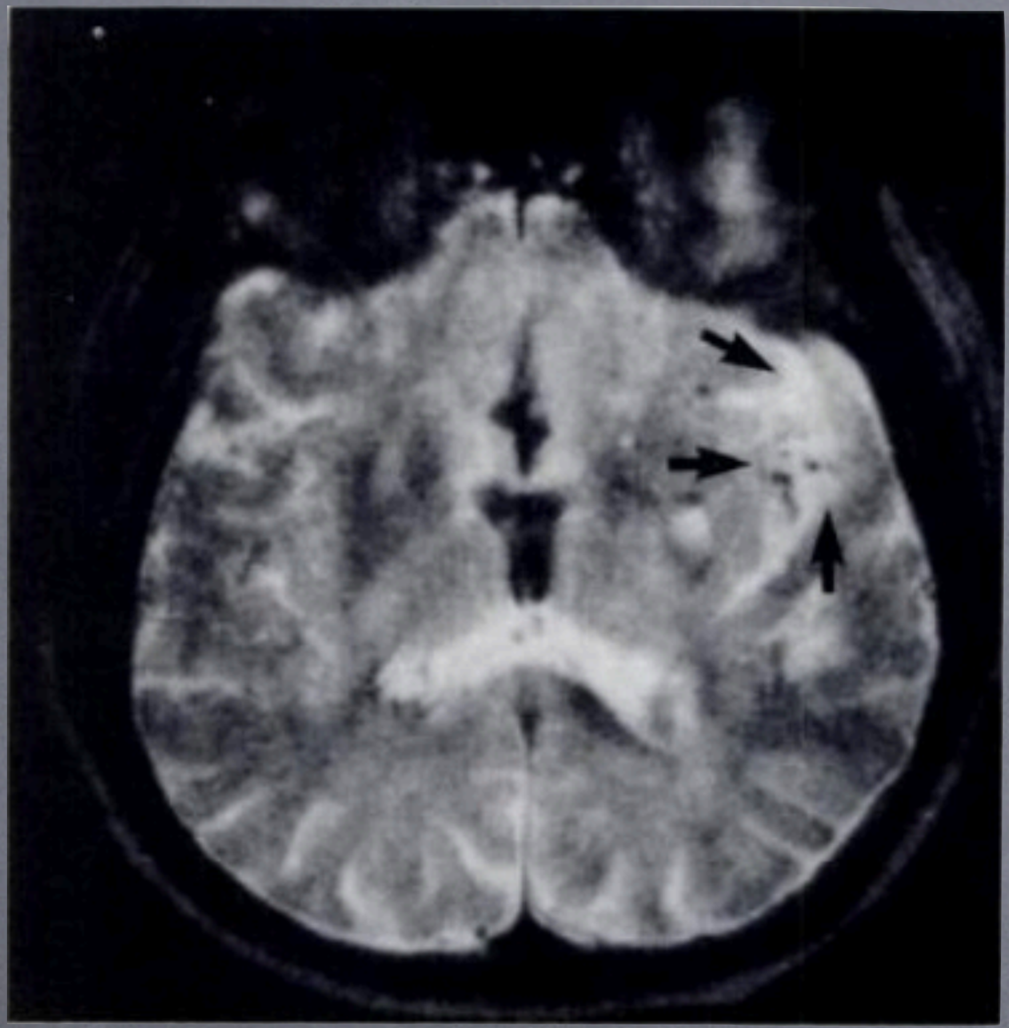


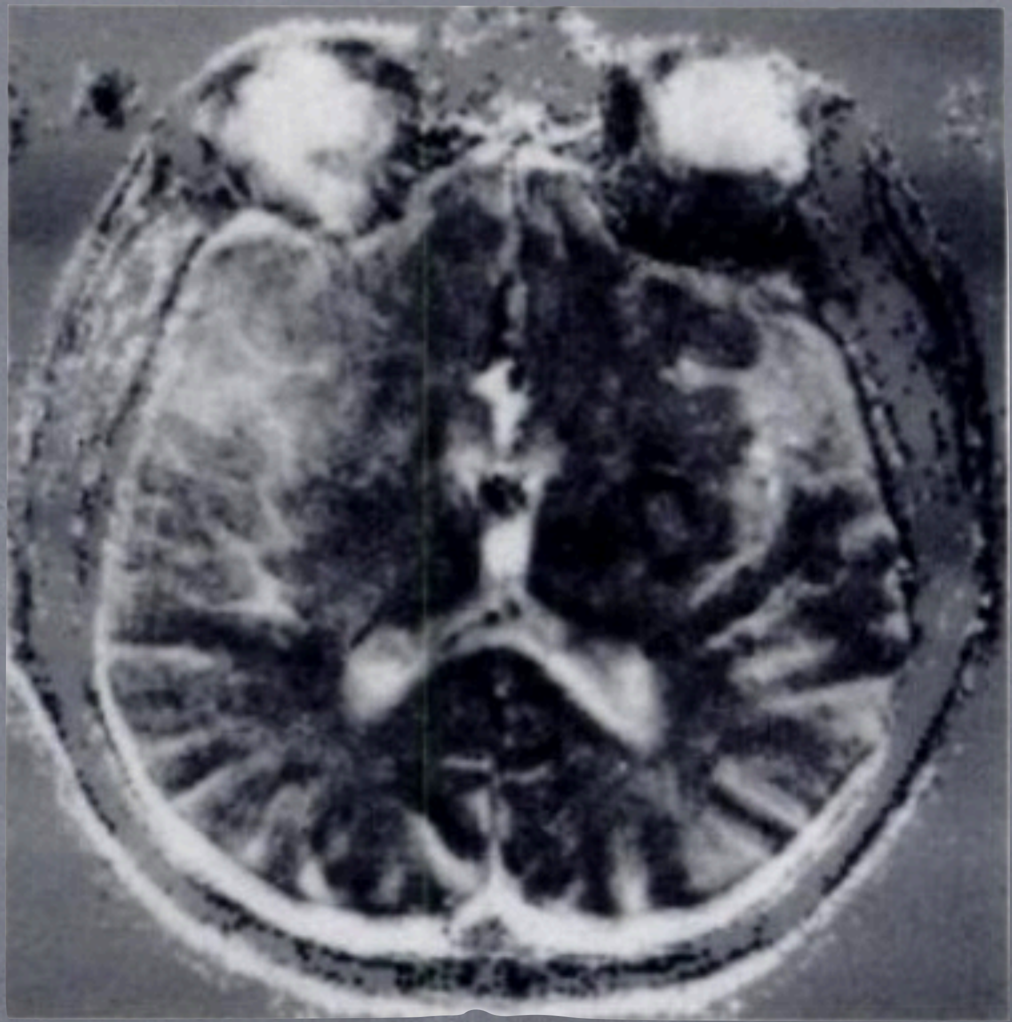
Our brain is filled with water molecules

White matter fibers constrain their diffusion



MRI can be weighted by the water molecules diffusion



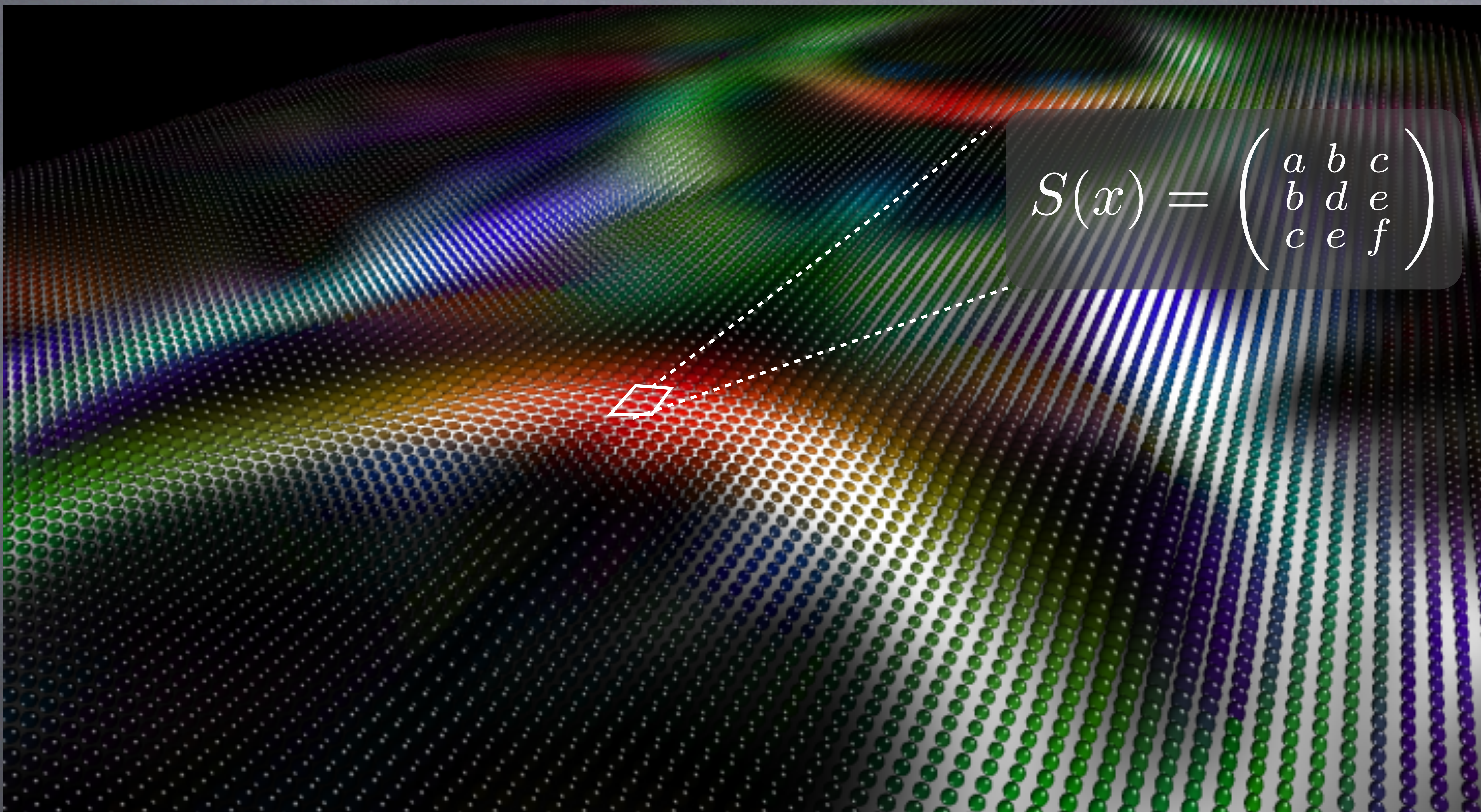


Traditional T2w MRI

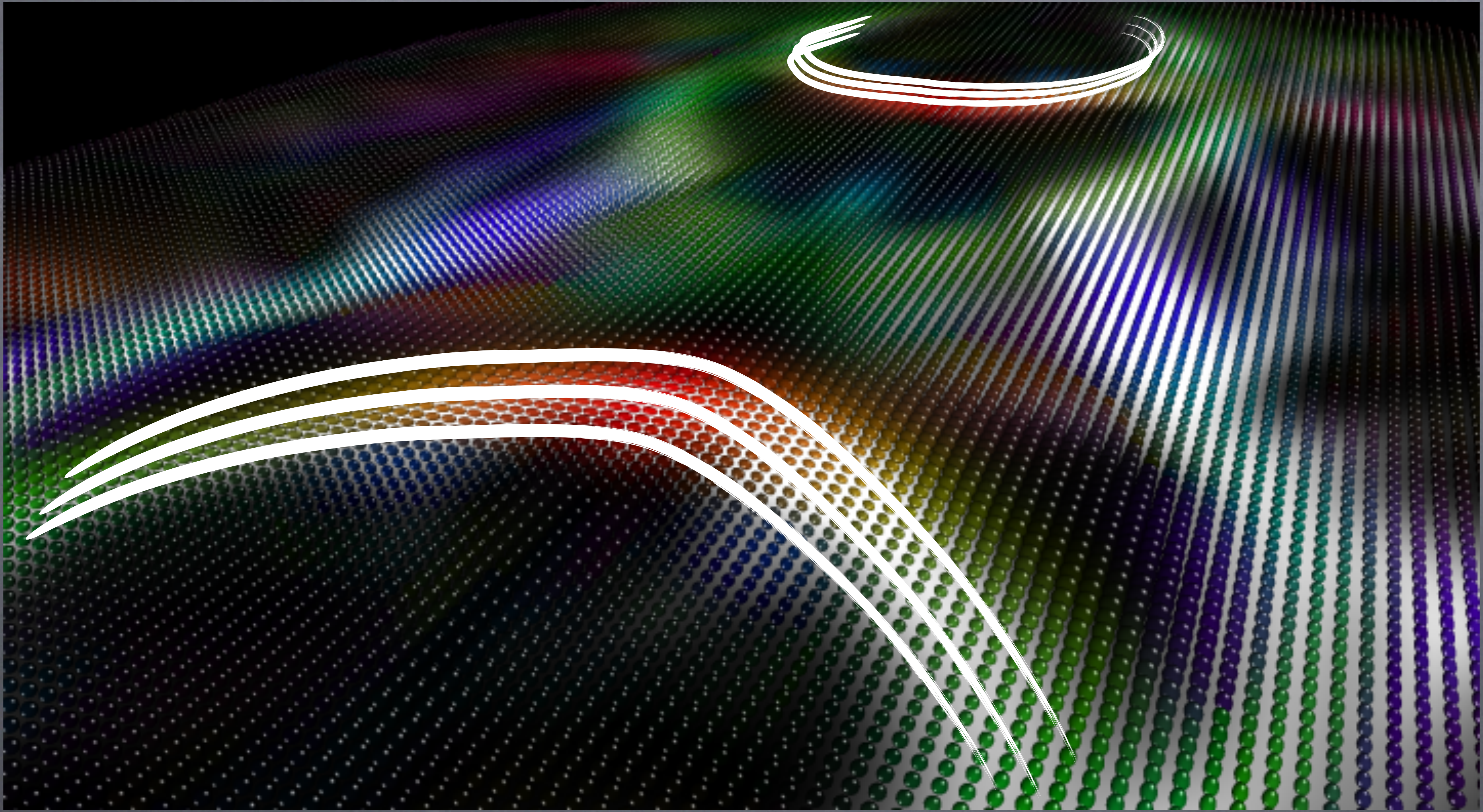
Diffusion weighted MRI

Le Bihan et al., 1992

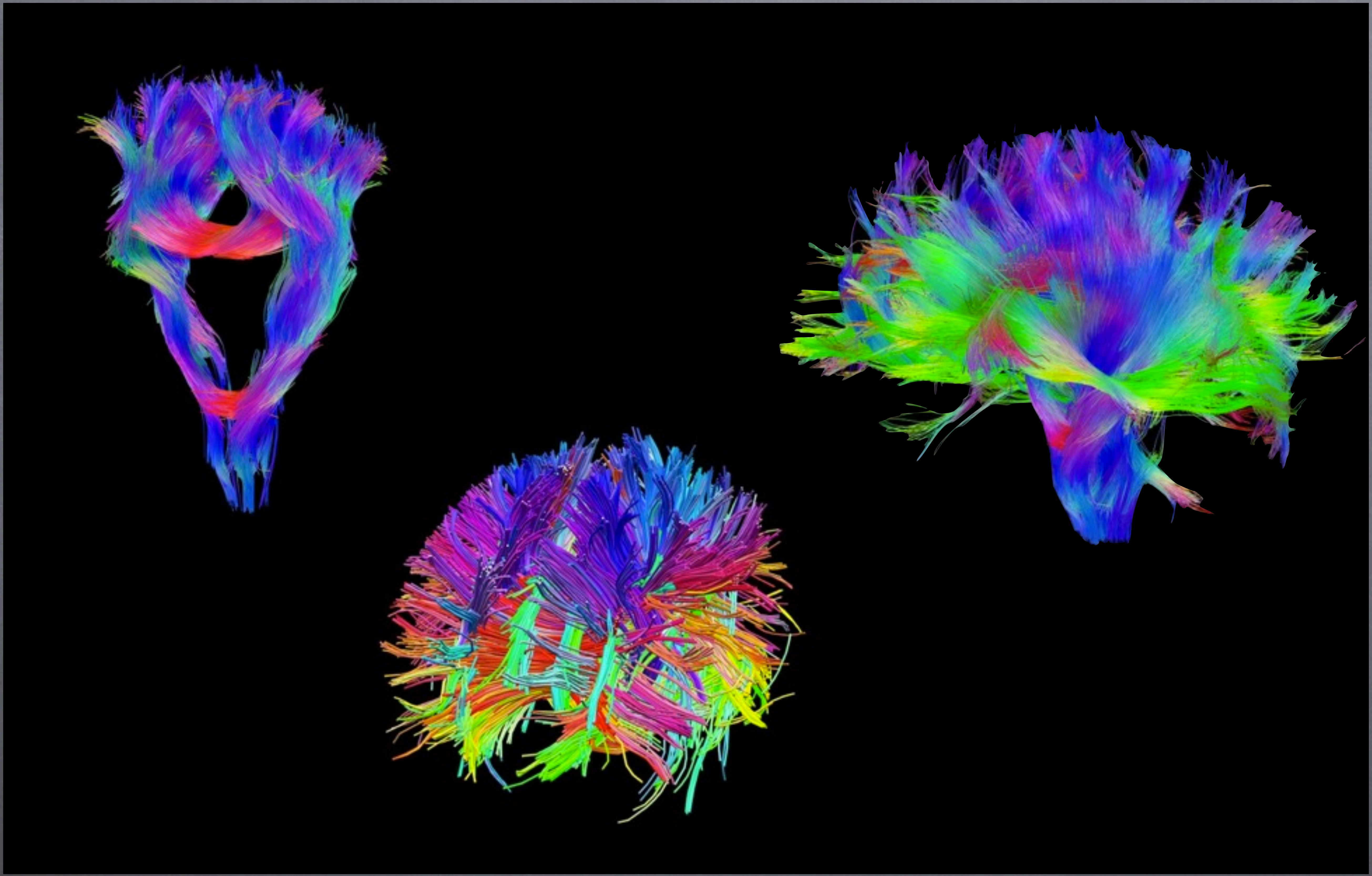
With multiple acquisitions, we can reconstruct diffusion models



Tractography algorithms can be used to reconstruct the fascicles



Whole brain tractography reveals the connections between brain regions



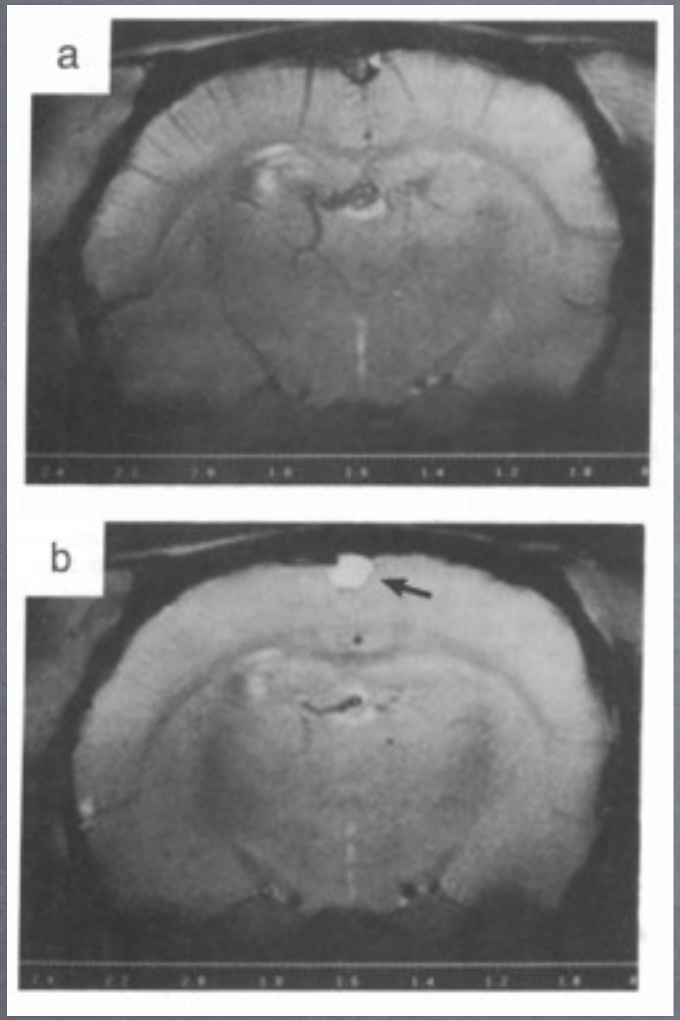
What if the detected rail is a ghost town rail?

Ottignies

Brussels

If we observe the same train at two different locations, their must be an active connection between them

We can detect the concentration of oxygen in the brain blood



MRI when the rat breathes 100% oxygen

MRI when the rat breathes 90% oxygen + 10% CO_2

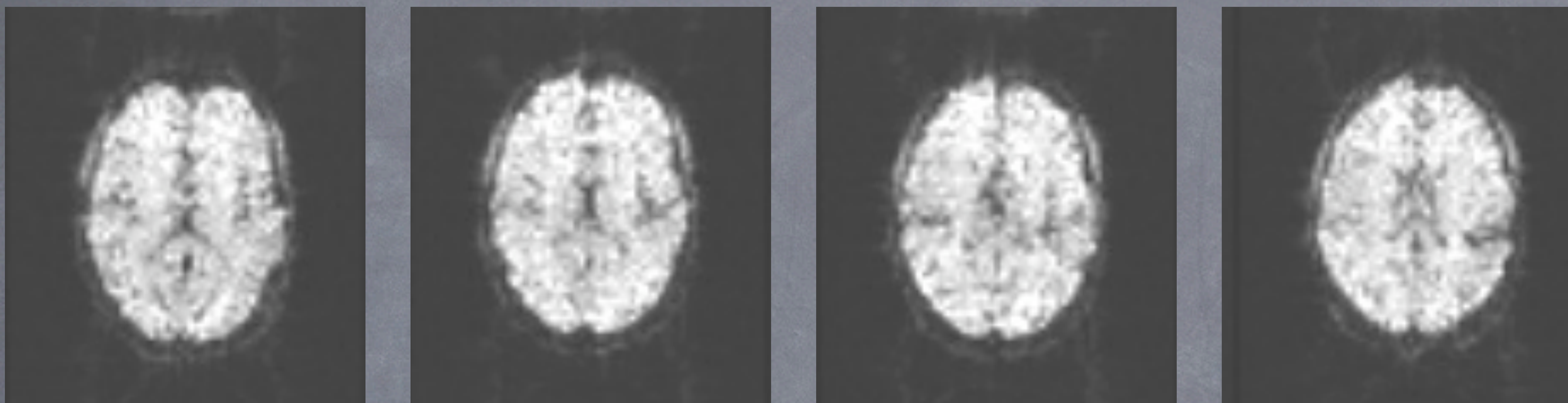
BOLD Contrast (Blood Oxygen Level Dependent)

"MRI contrast depends on the concentration of oxygen"

Ogawa *et al*, 1990

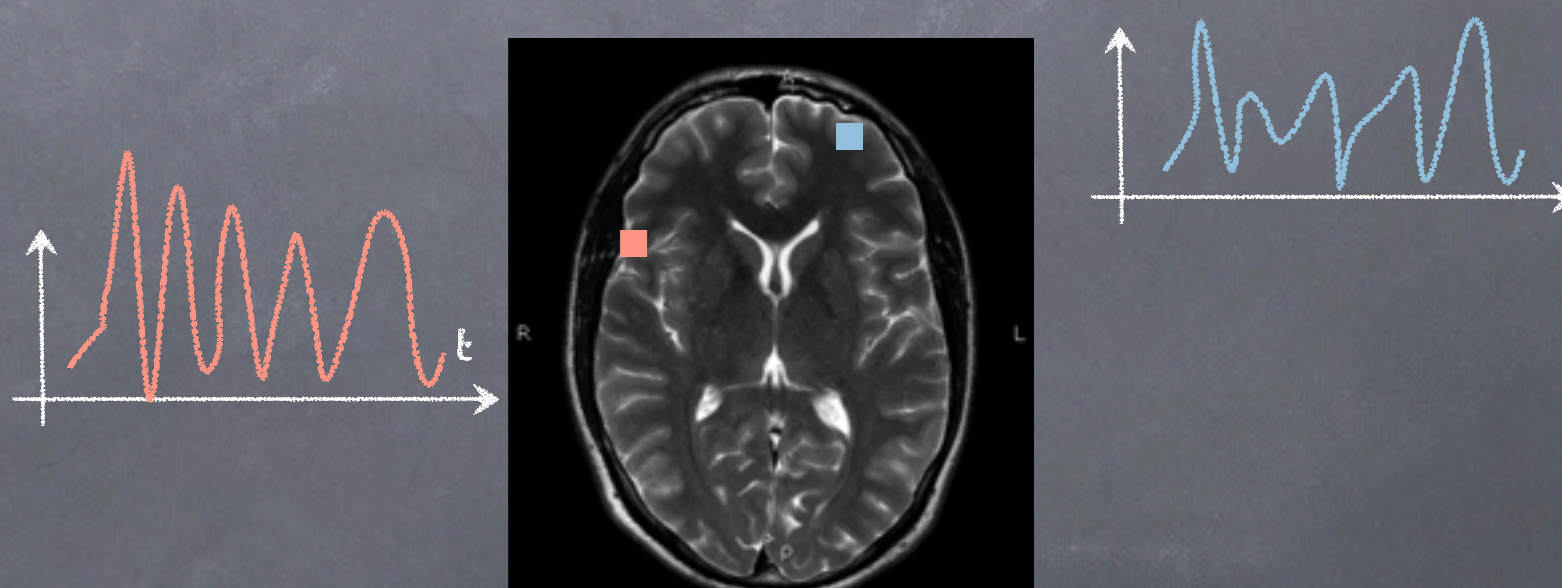
We obtain 3D movies of the brain activity

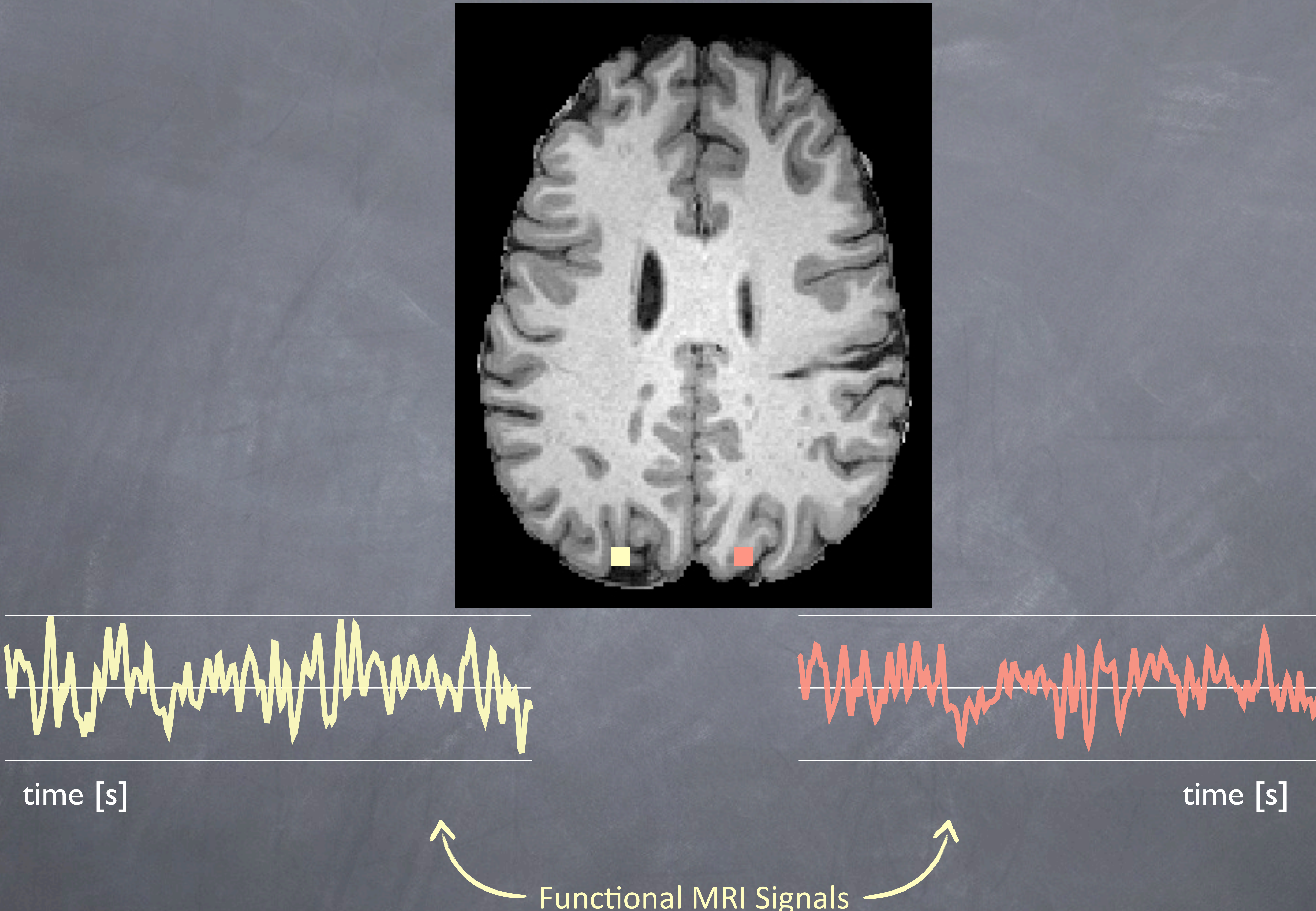
3D+time image

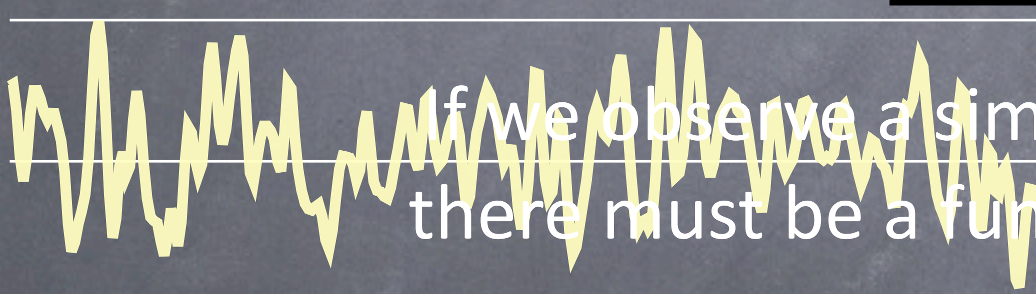


t 1 t 2 t 3 t 4

Equivalent representation:
a time series in each voxel

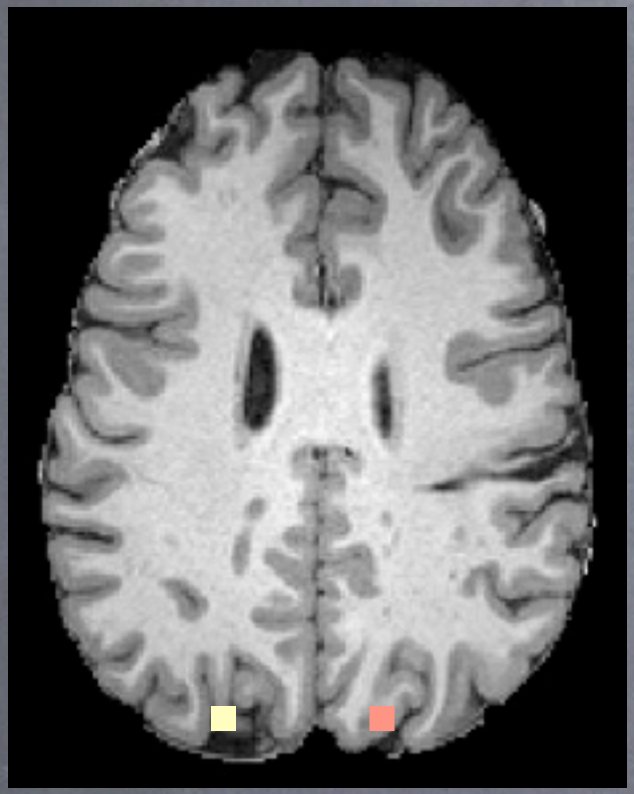


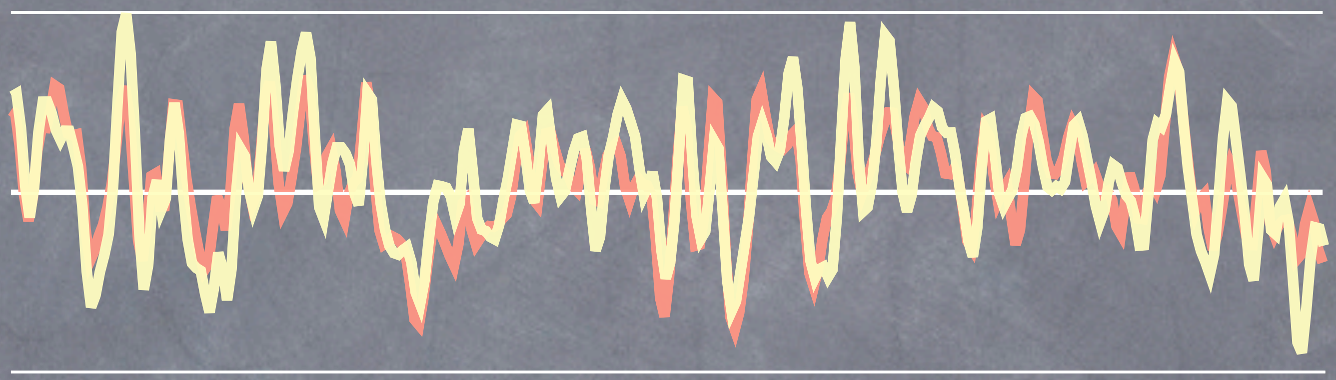

time [s]
time [s]
Functional MRI Signals



If we observe a similar signal at two different locations, there must be a functional connection between the two

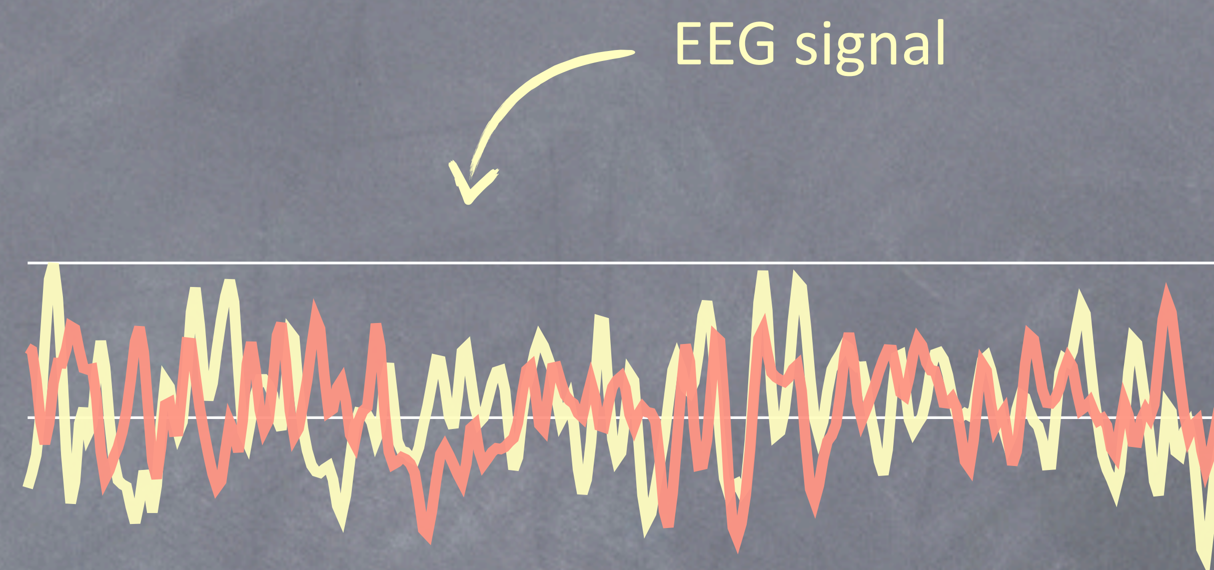
The correlation coefficient between the time series may quantify the connectivity strength





Time series strongly correlated → Strong functional connection

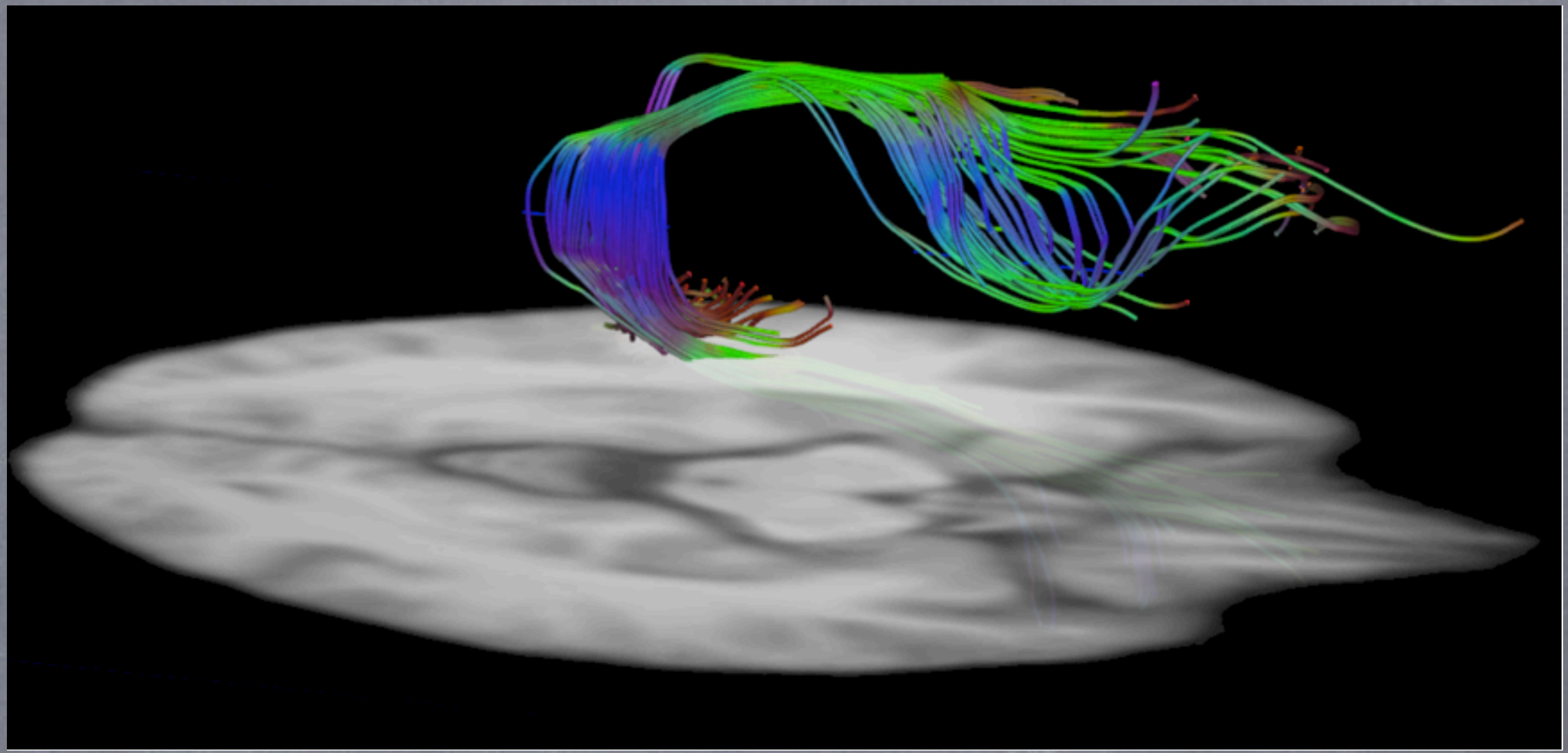
Functional connectivity can also be probed by EEG

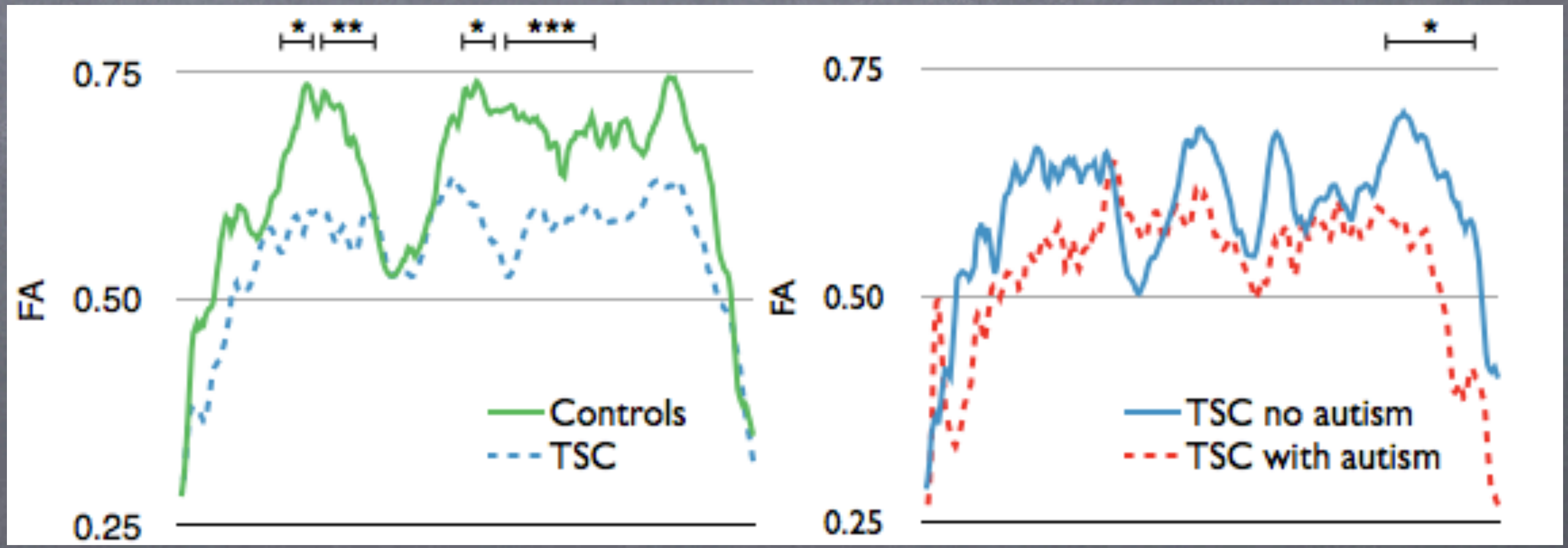


- ✓ high temporal resolution → may detect causation
- ✗ low spatial resolution and volume conduction

Autistic children have altered arcuate fasciculus

- Structural connectivity
- Novel diffusion model
- Arcuate fasciculus
- Autism Spectrum Disorder Tuberous Sclerosis Complex



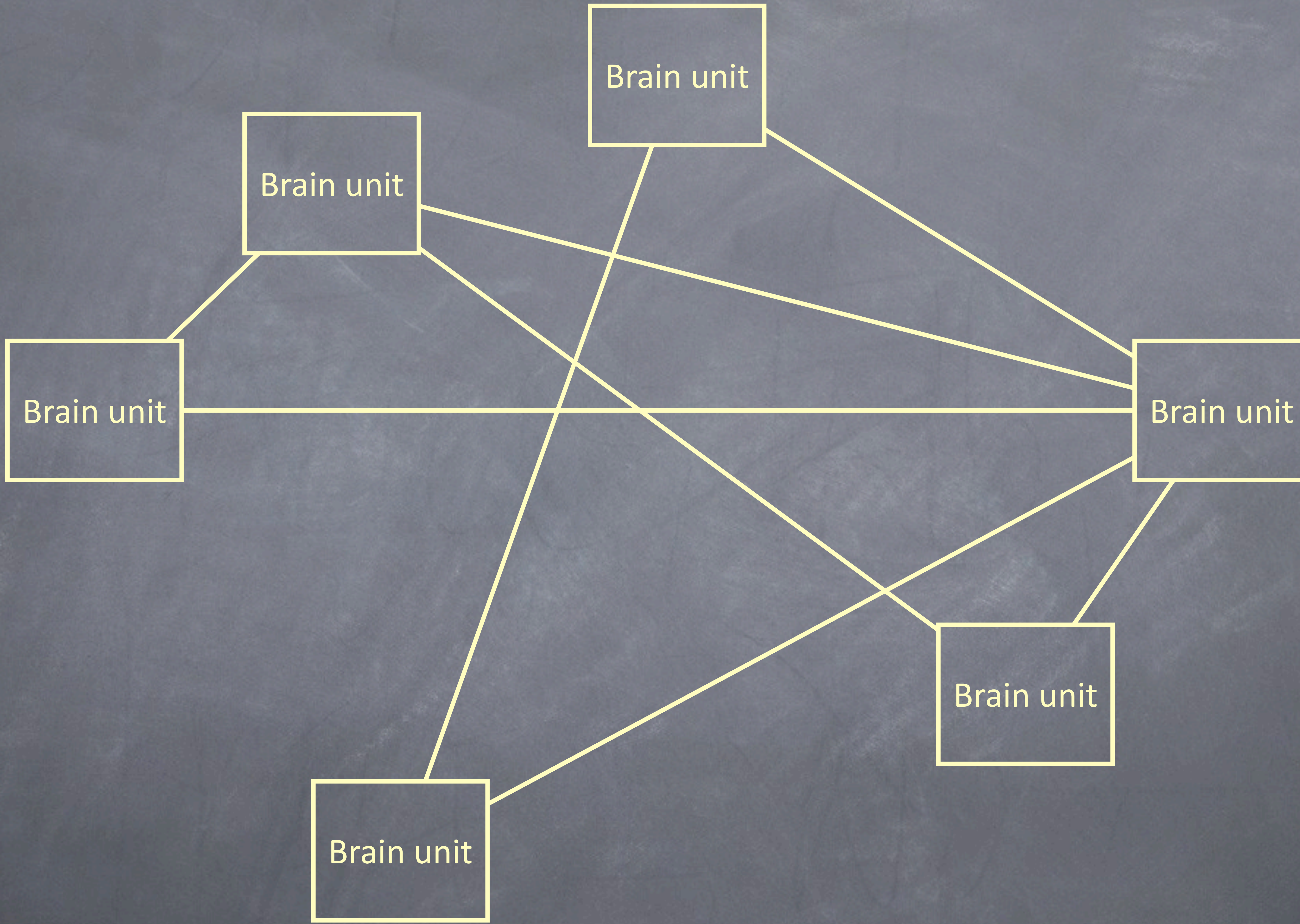


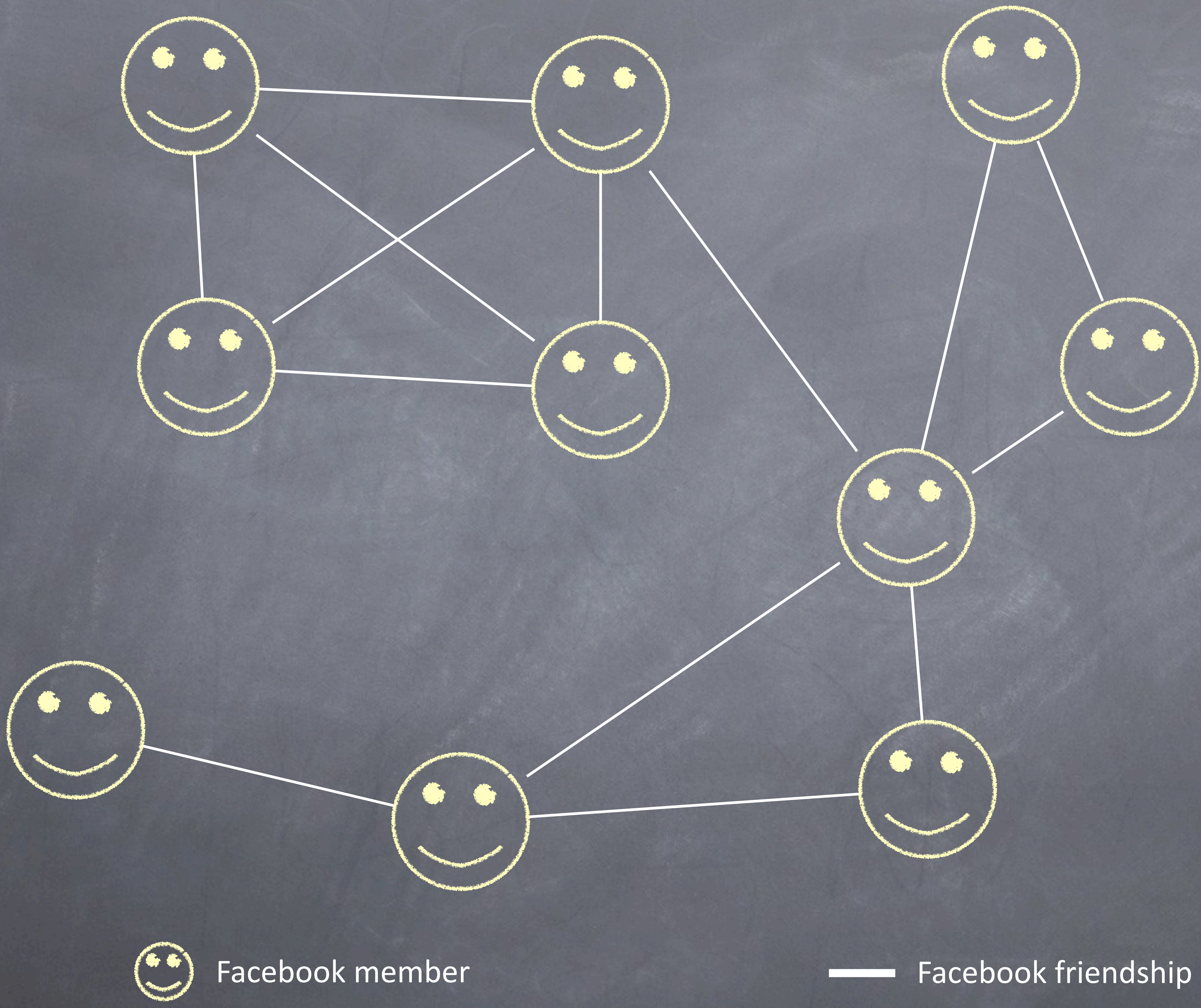
Taquet *et al.*, 2012

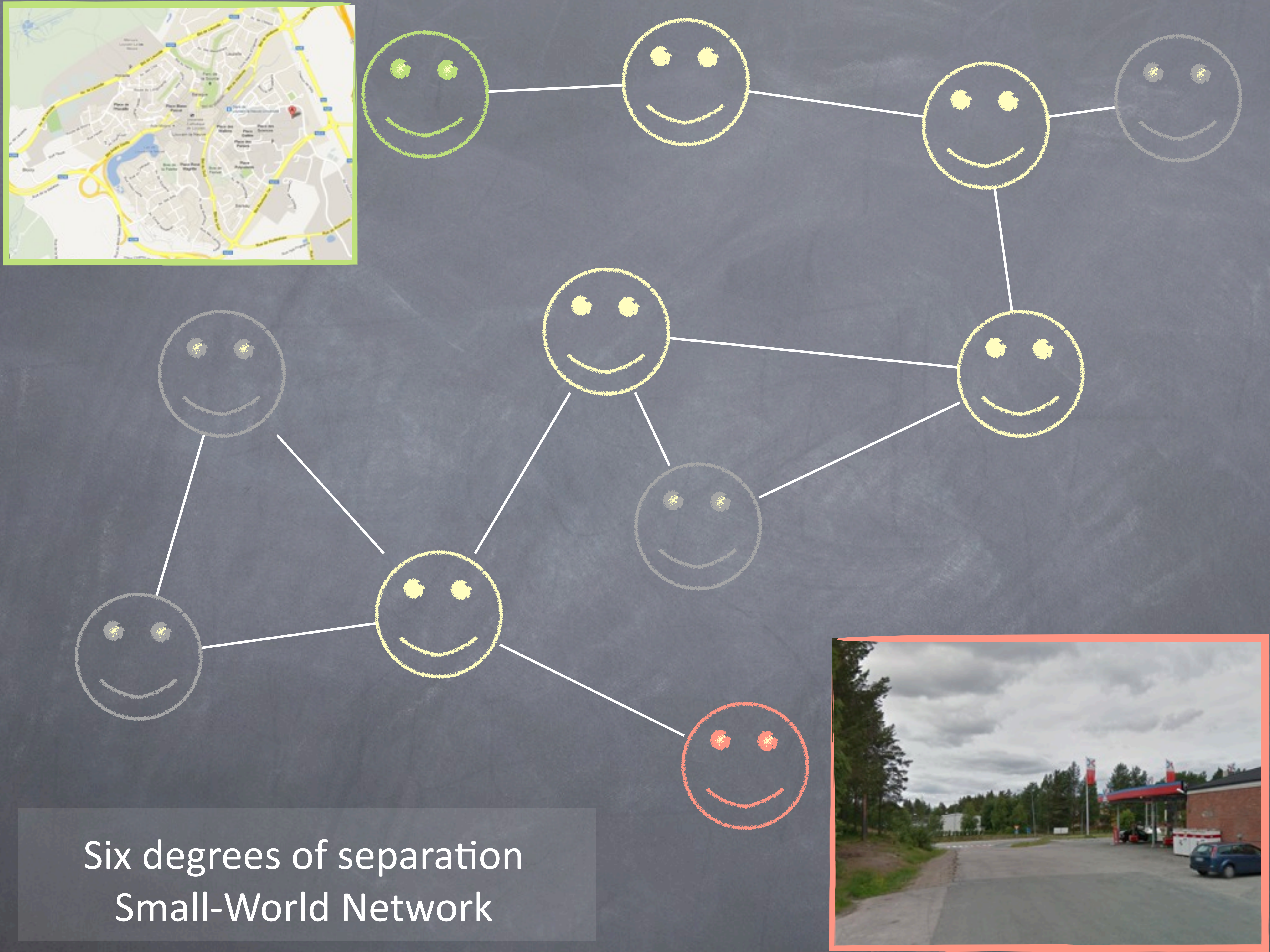
We can probe the brain connections with imaging

We can model the brain network and its properties

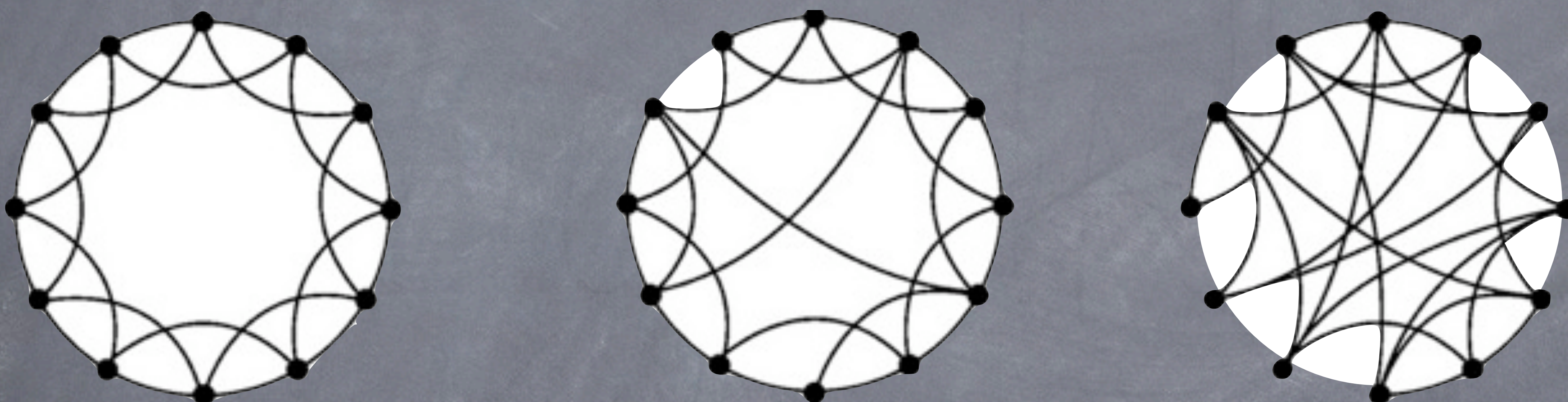

Brain unit
Brain unit


Brain unit
Brain unit
Brain unit
Brain unit
Brain unit
Brain unit


Facebook member
Facebook friendship

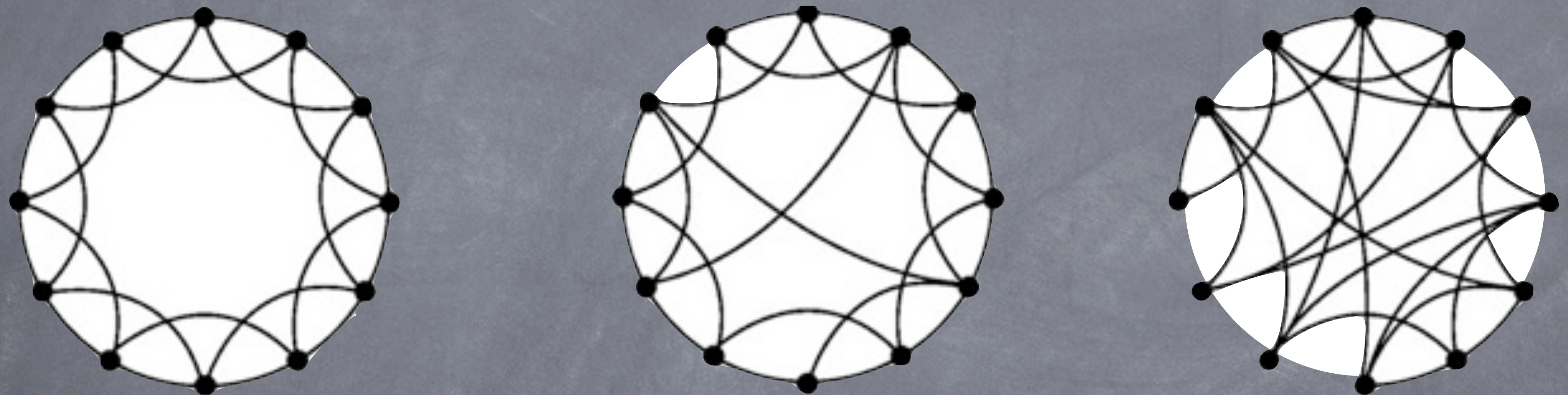

Six degrees of separation
Small-World Network

Small-World Networks are characterized by a high clustering coefficient and a small average path length



Regular grid
High Clustering
High average path length

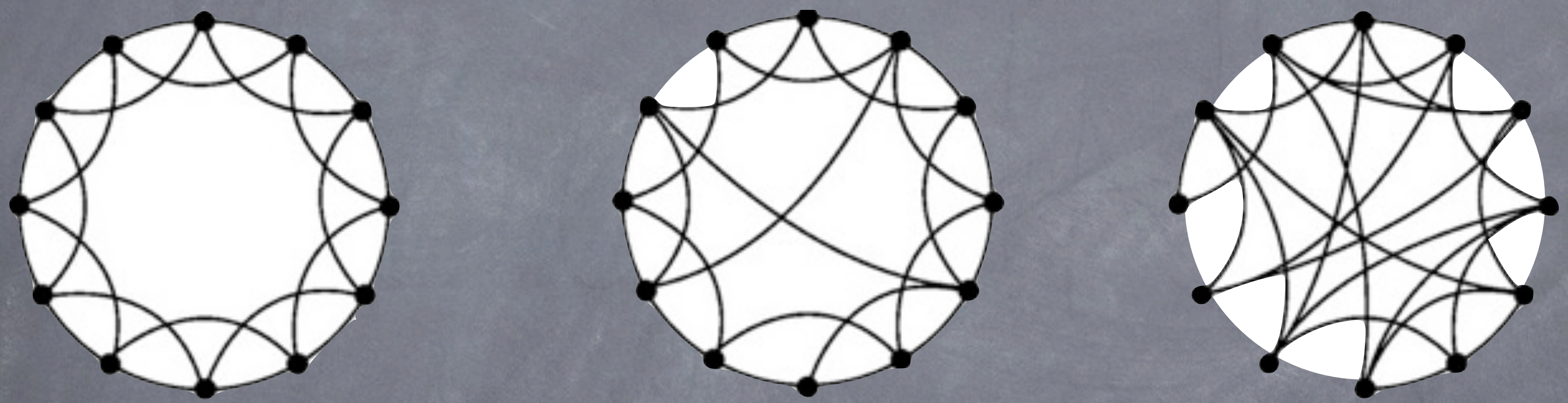
Small-World Networks are characterized by a high clustering coefficient and a small average path length



Regular grid
High Clustering
High average path length

Random network
Low Clustering
Low average path length

Small-World Networks are characterized by a high clustering coefficient and a small average path length

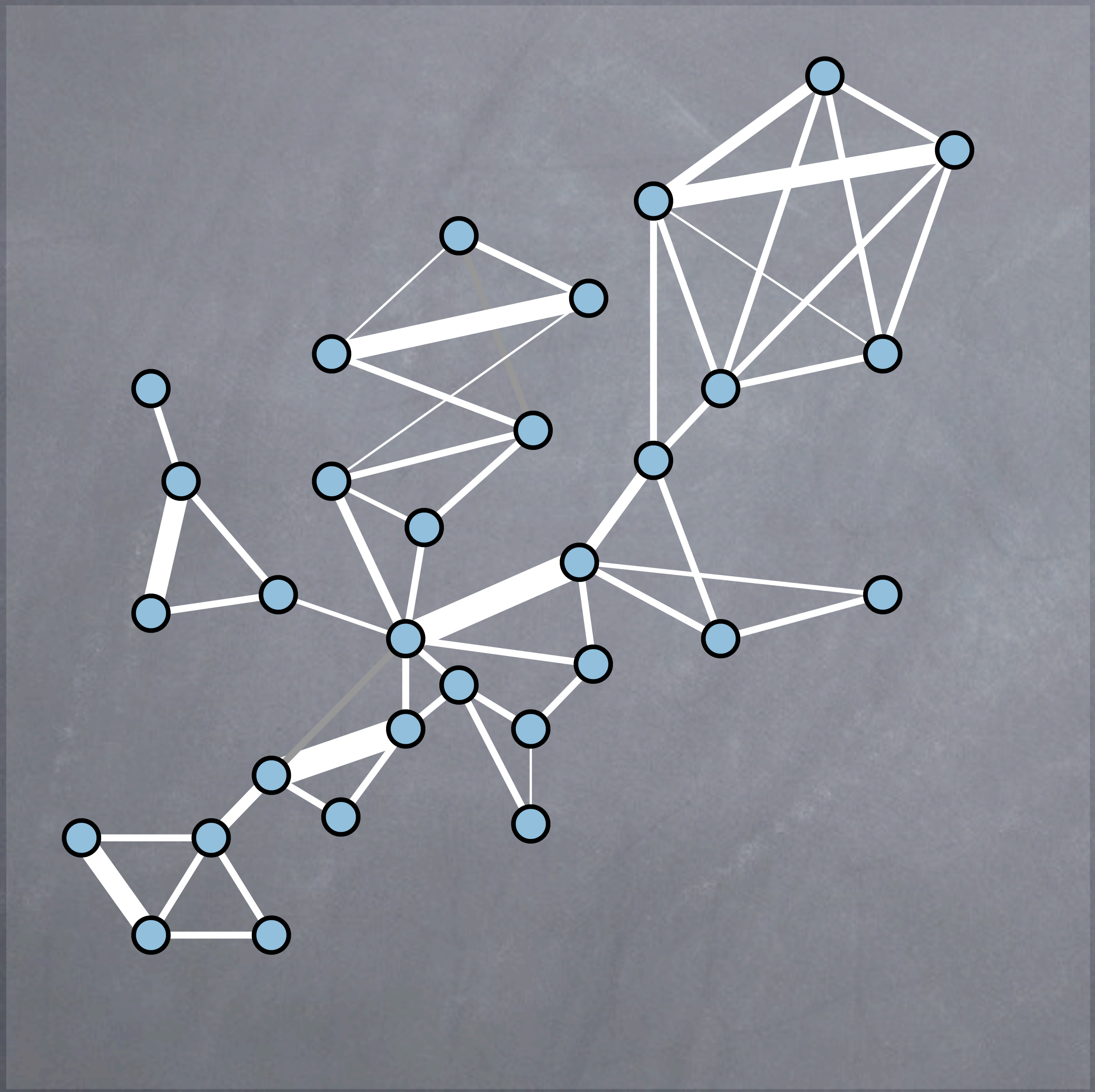


Regular grid
High Clustering
High average path length

Small World
High Clustering
Low average path length

Random network
Low Clustering
Low average path length

Networks are made of nodes and edges



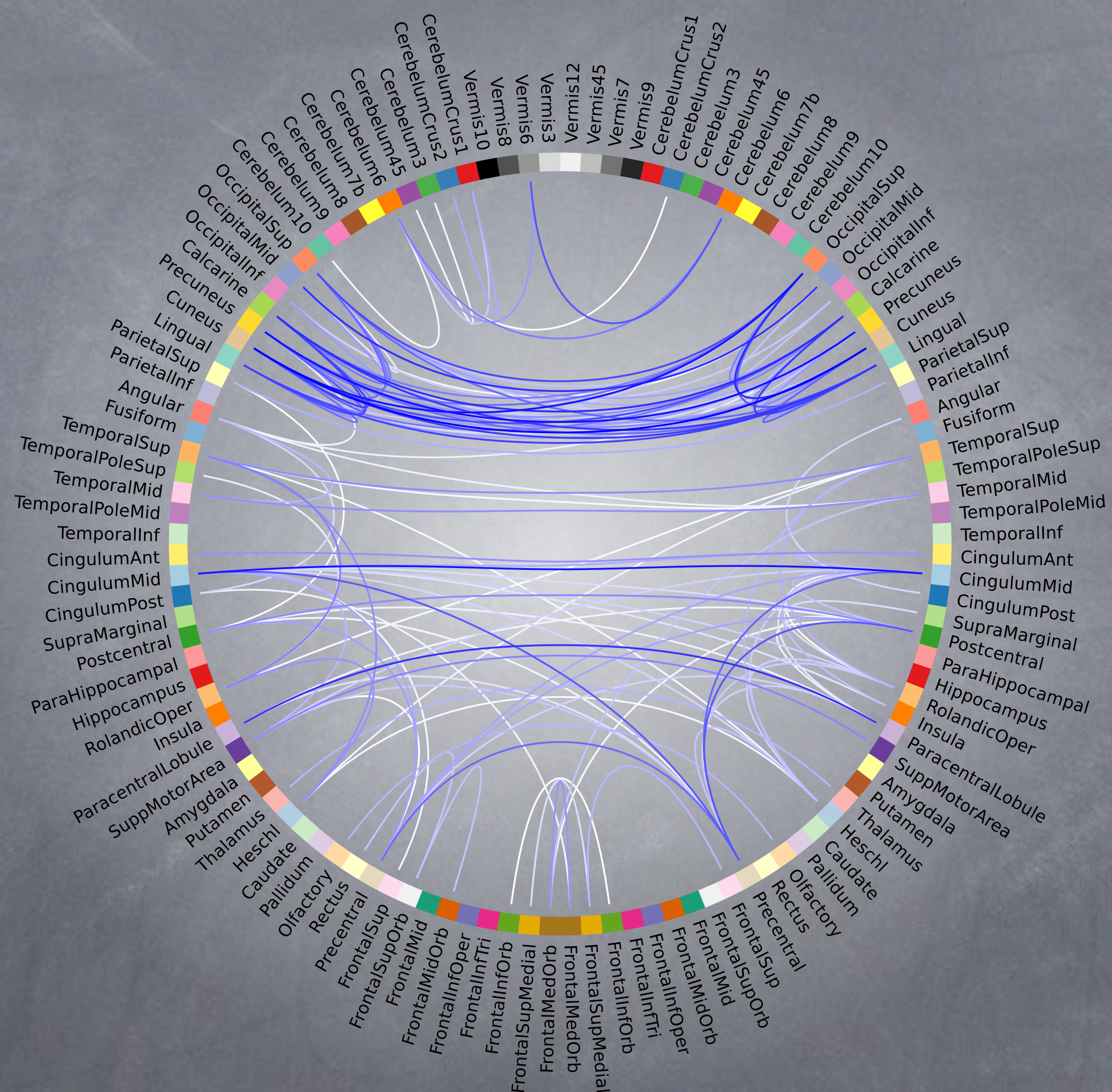
Nodes: representation of brain units

- Parcellation of the brain
- Electrodes
- Every voxel of the image

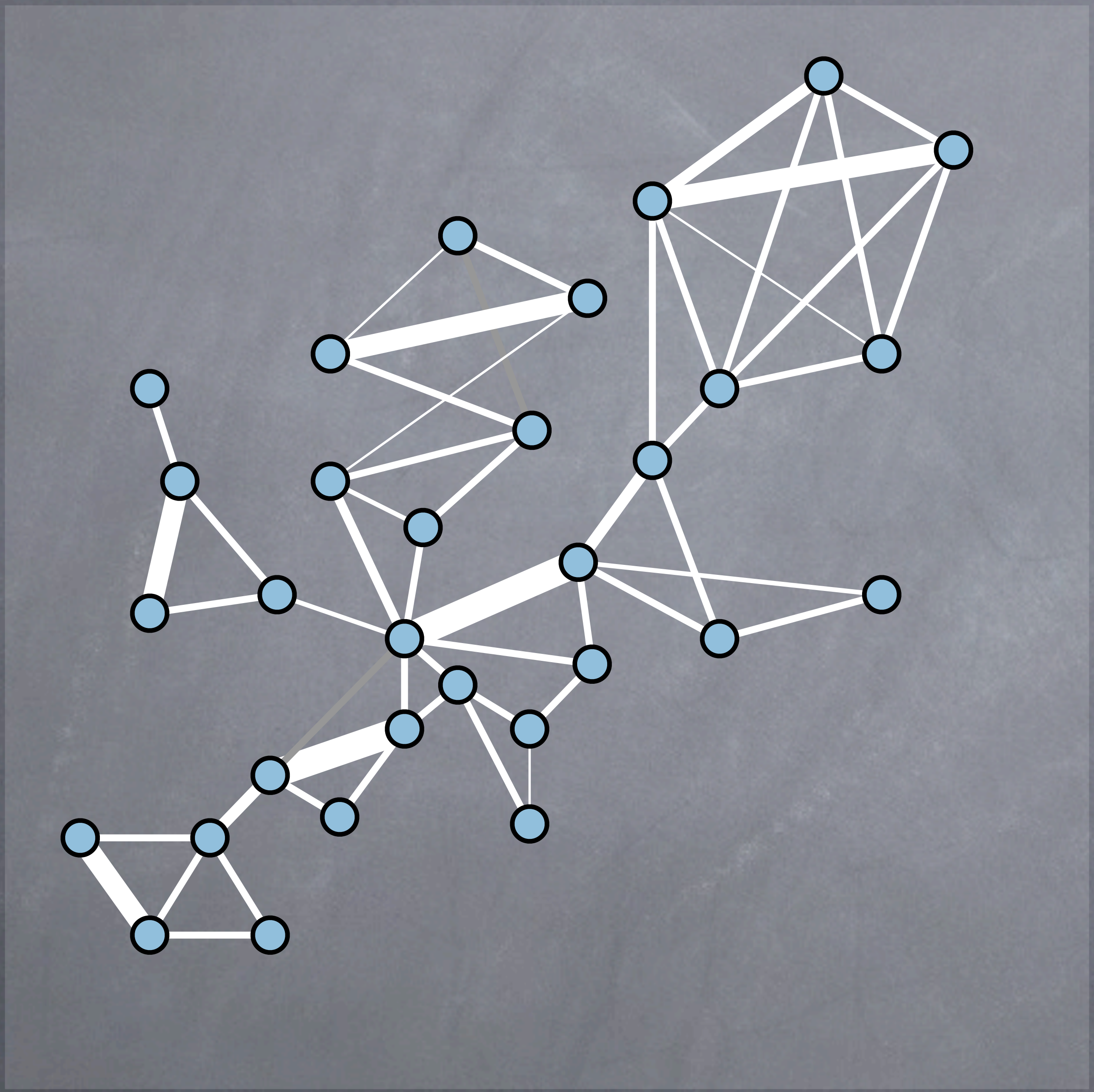
Edges: representation of connections

- Correlation between time series
- Presence of a WM fascicle
- Property of the fascicle

The brain network as measured by fMRI and dMRI is a small world



We can investigate the global properties of the network



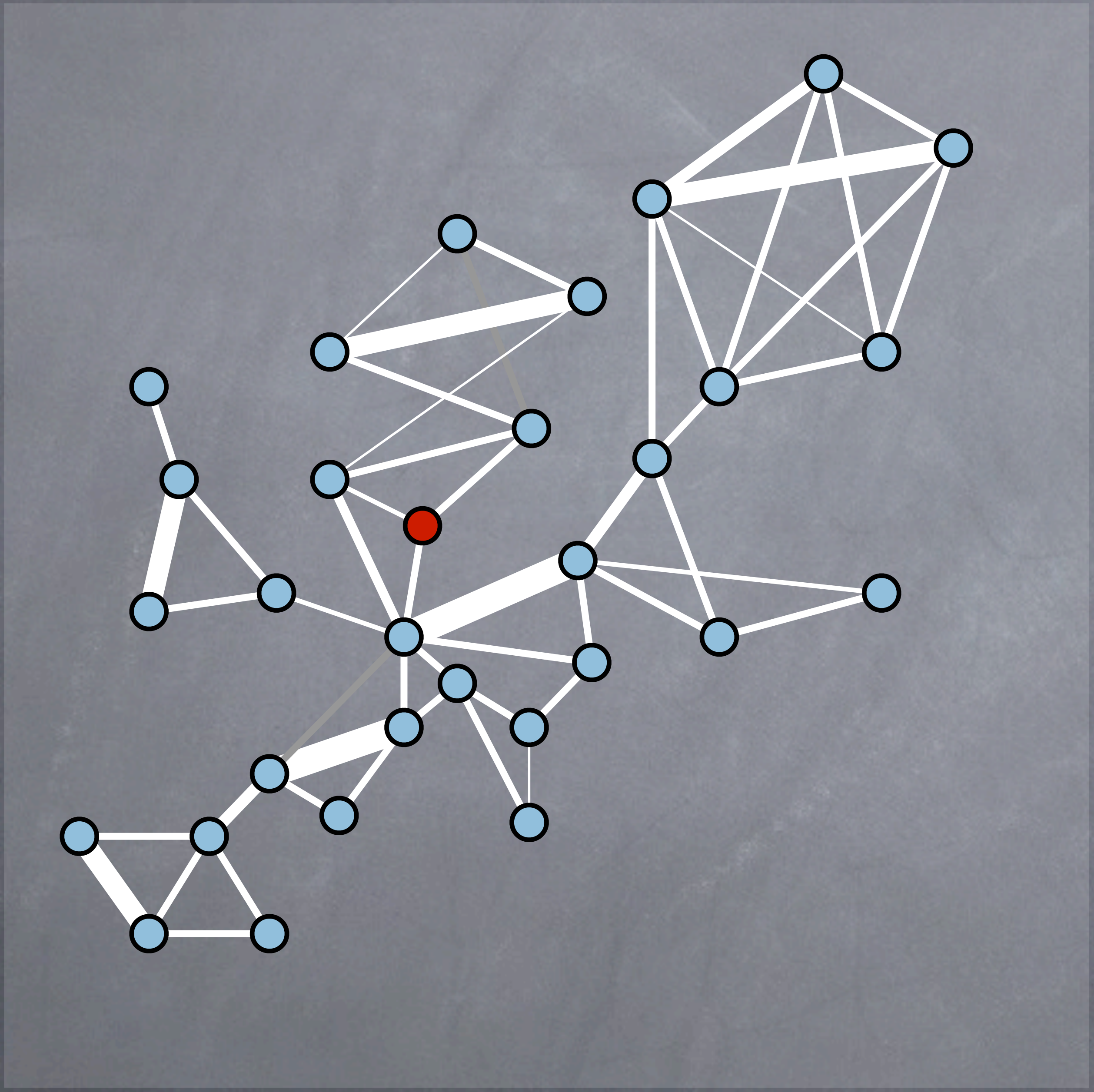
→

Small-Worldness

Characteristic Path Length

Global efficiency

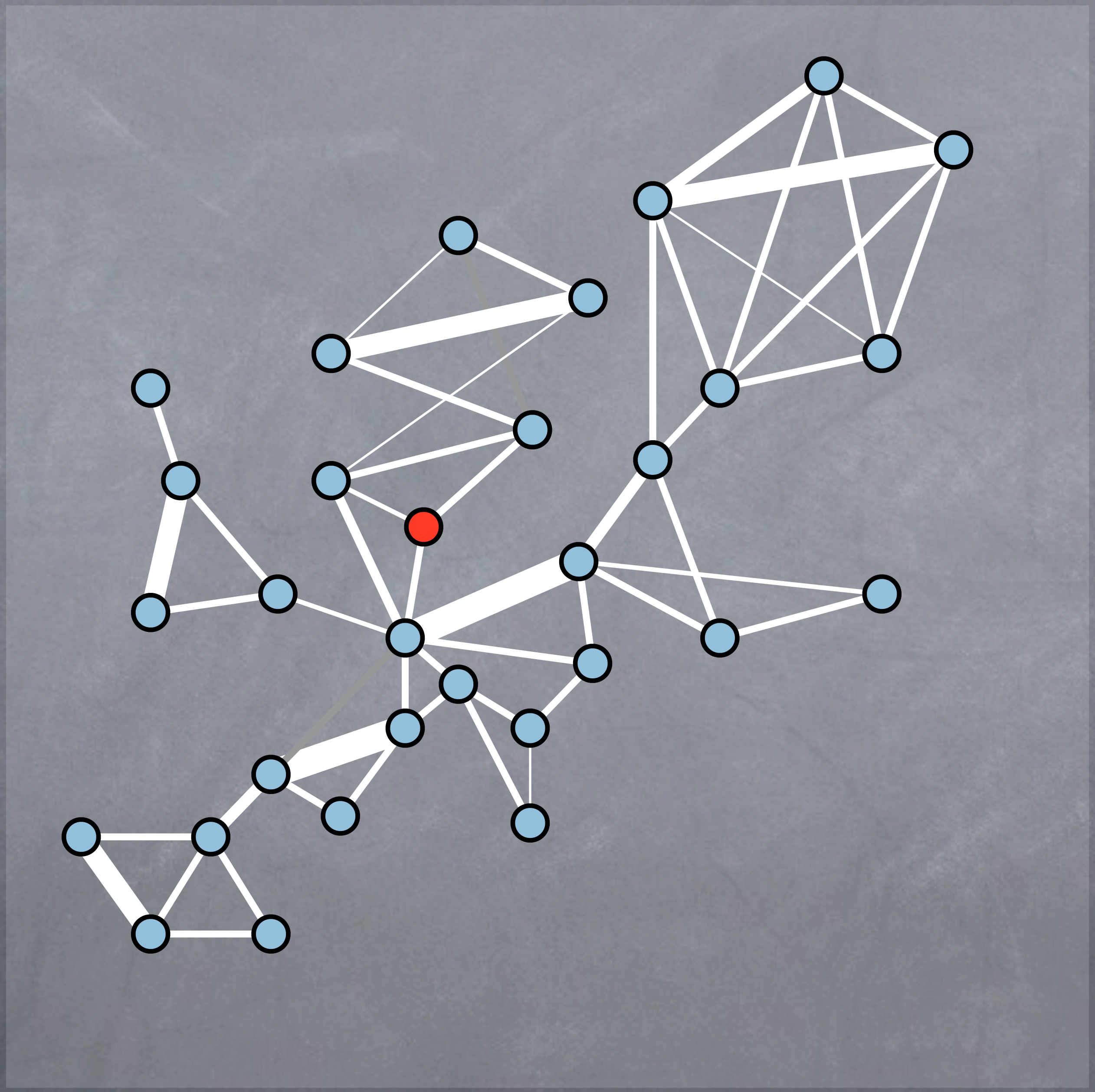
We can model the dynamic impact of a lesion



→ What happens to the network ?

A brain unit is lesioned

The current model of brain resilience ignores plasticity



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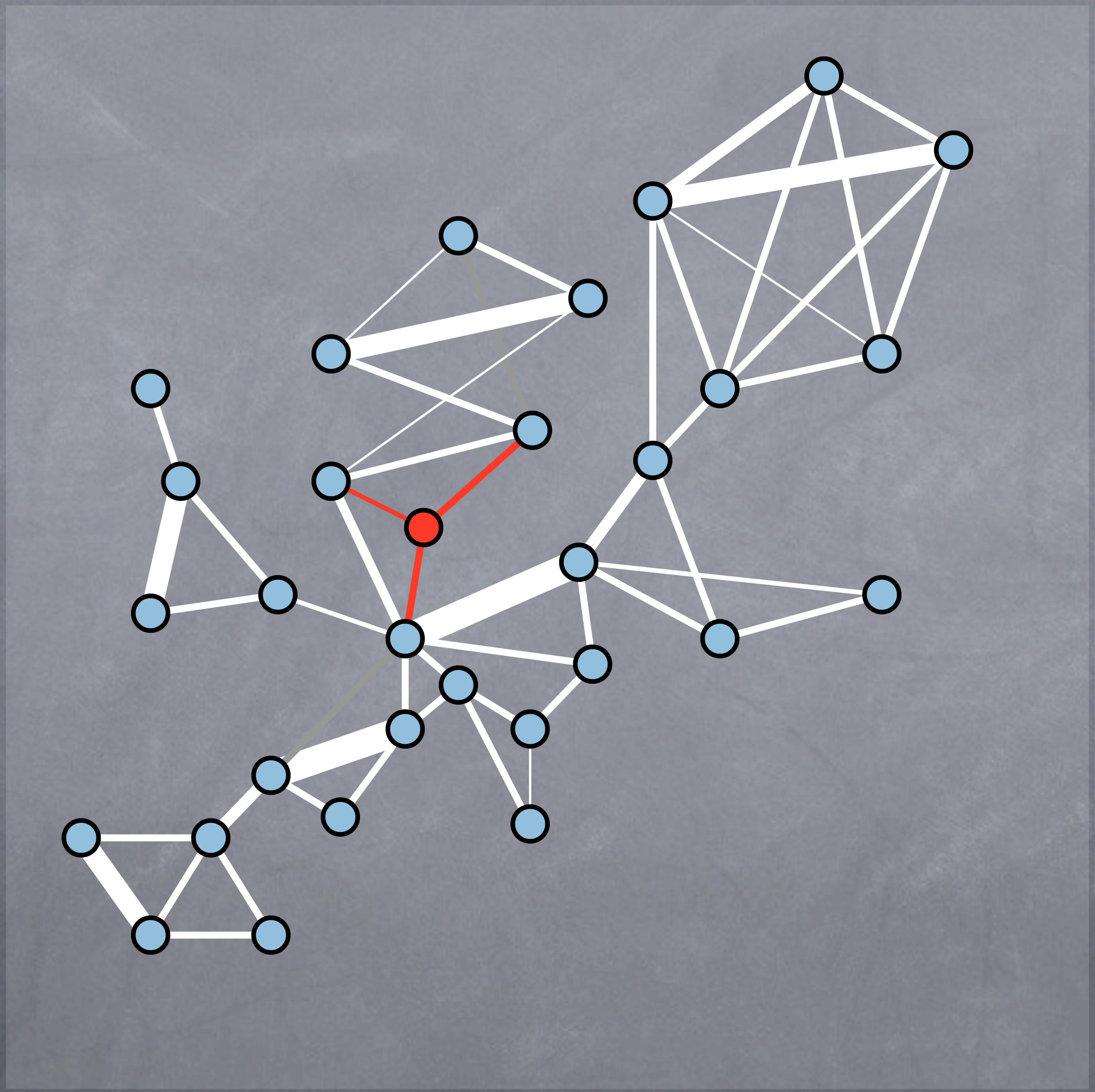

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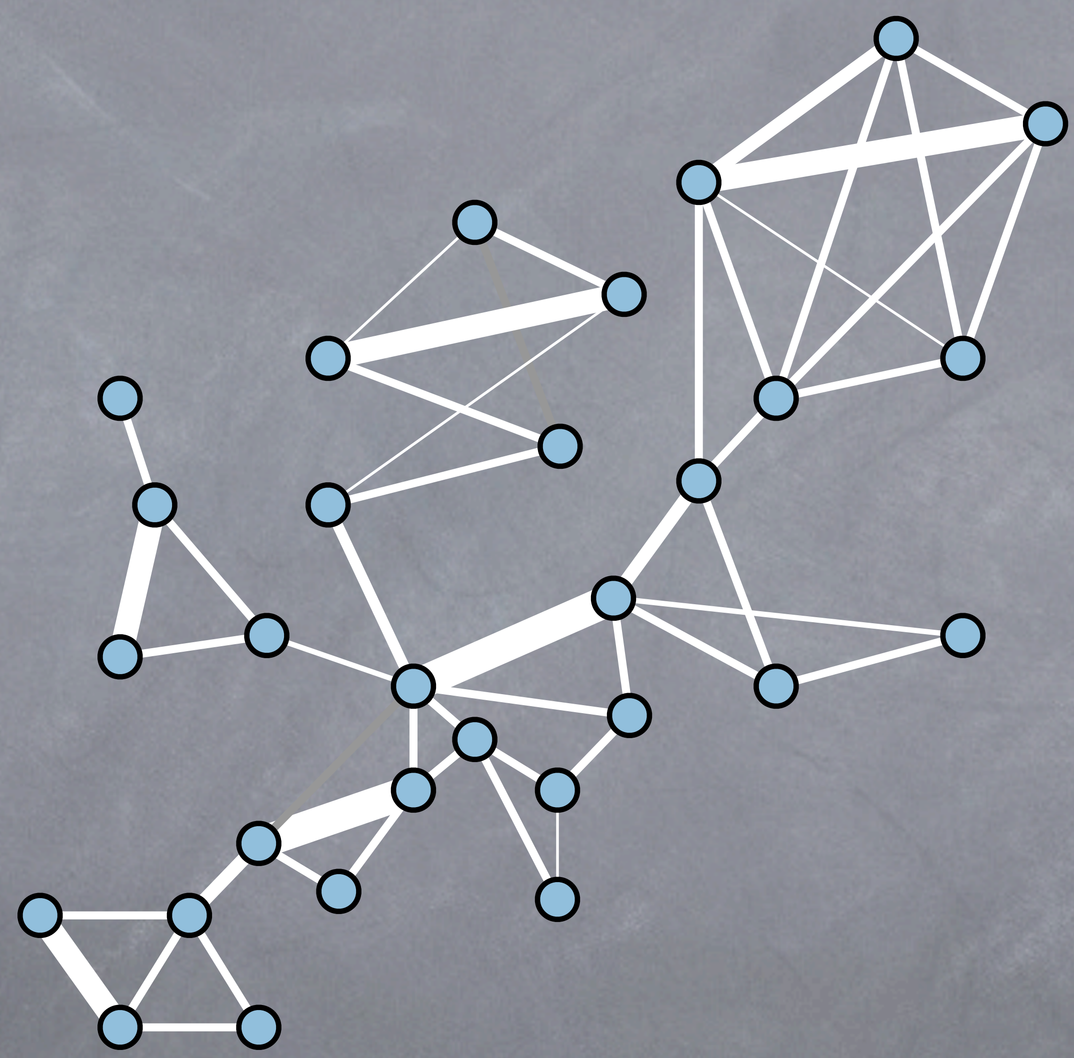
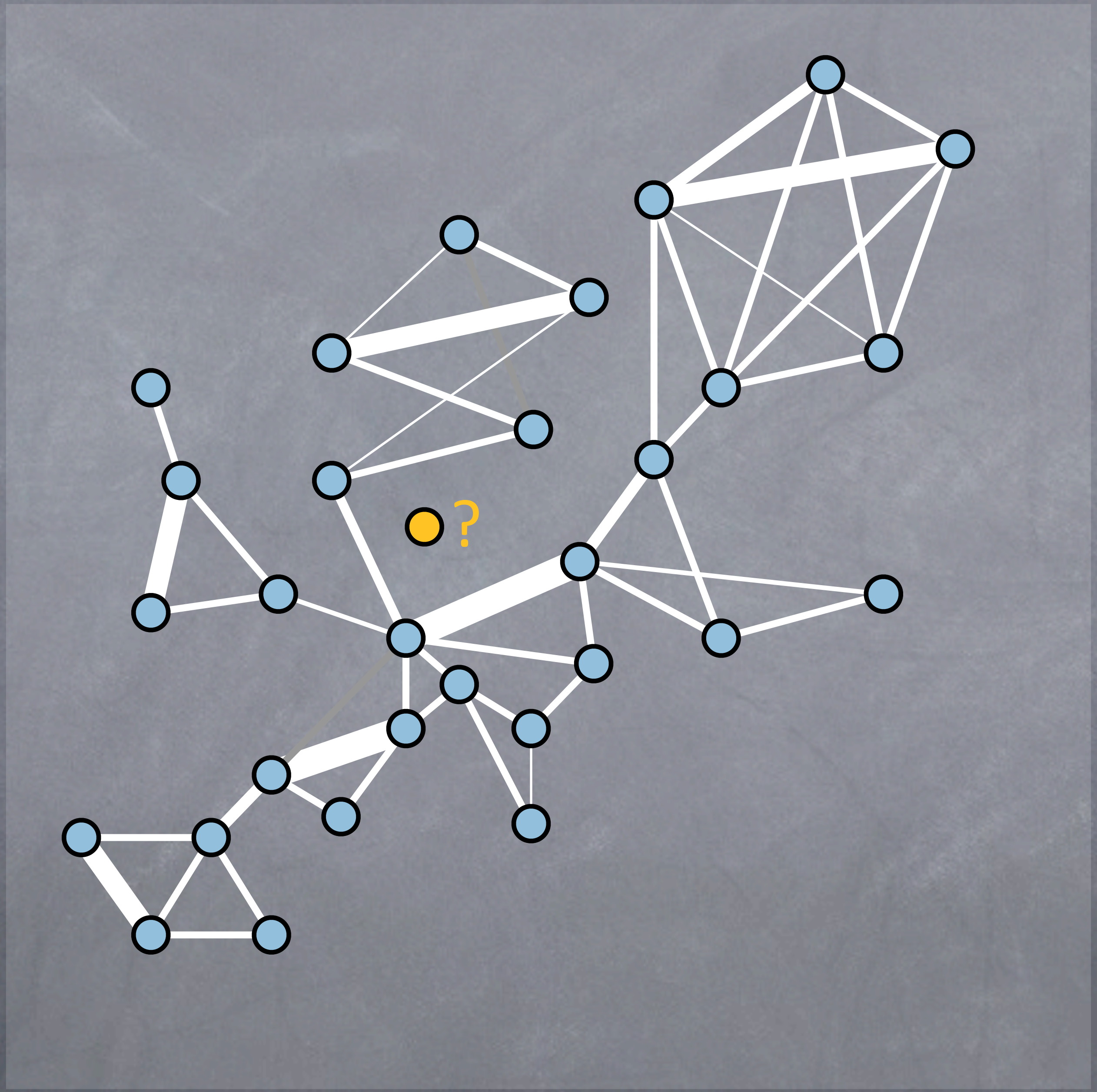


What if that was not the end of the story ?



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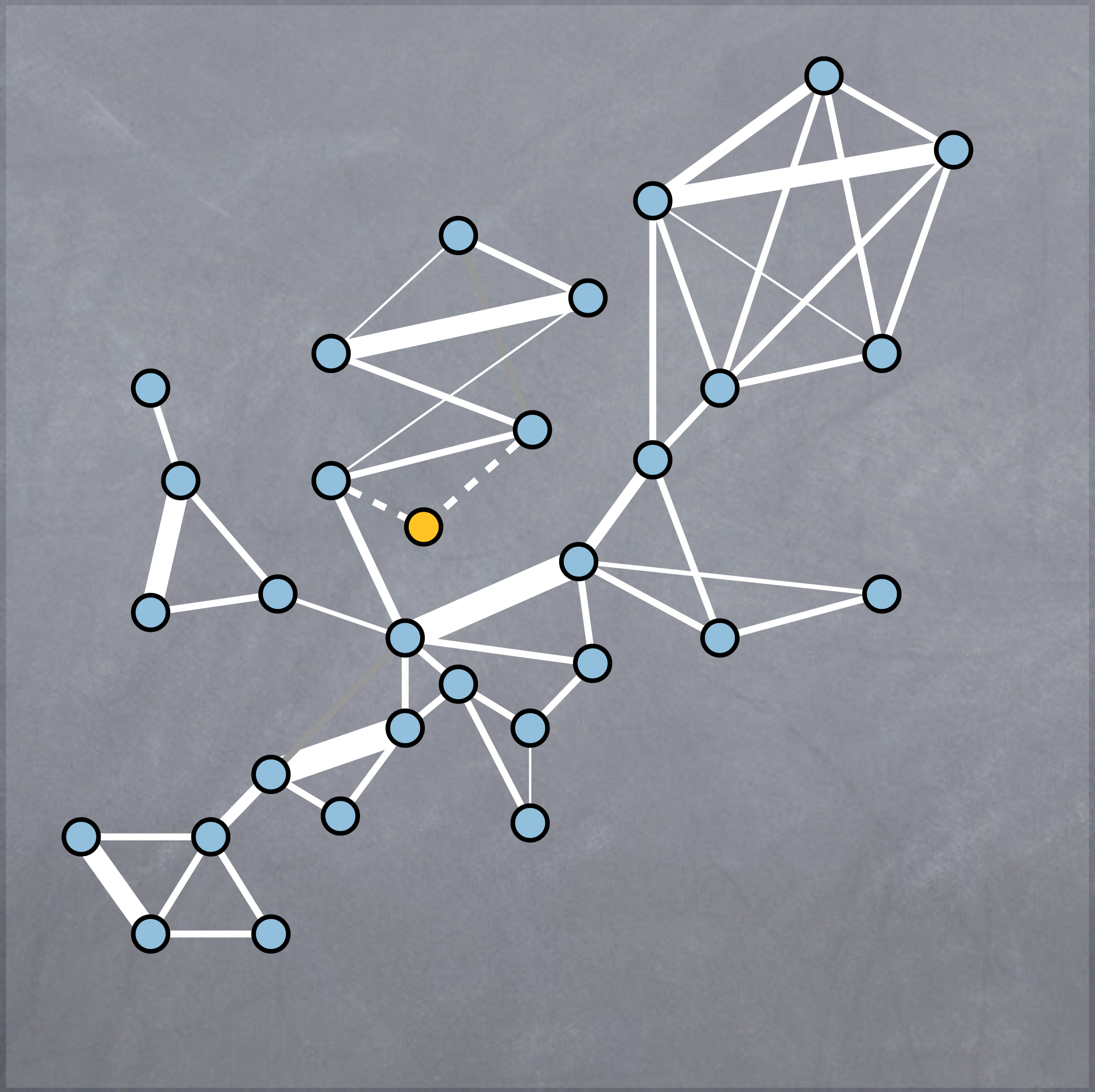
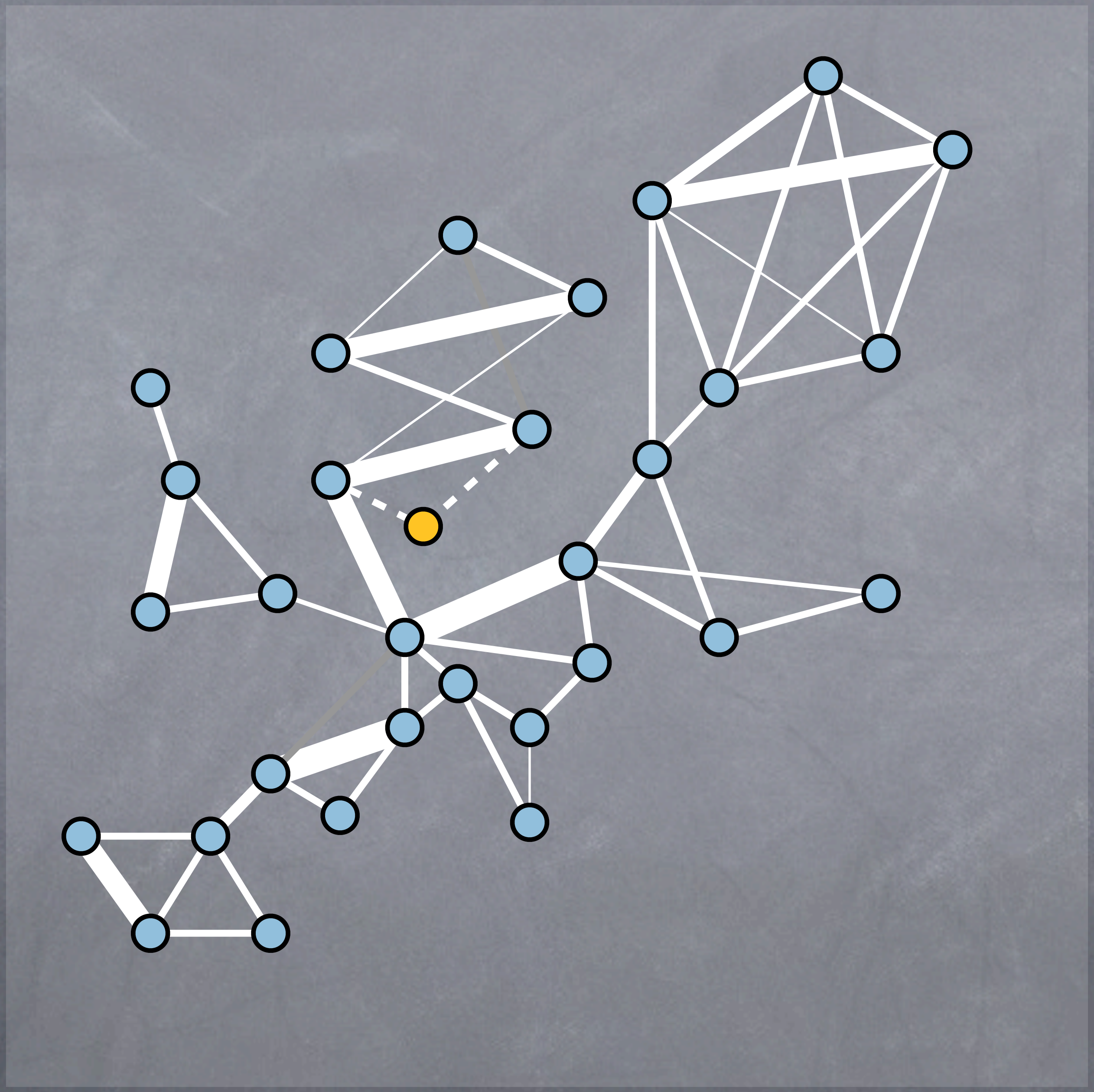


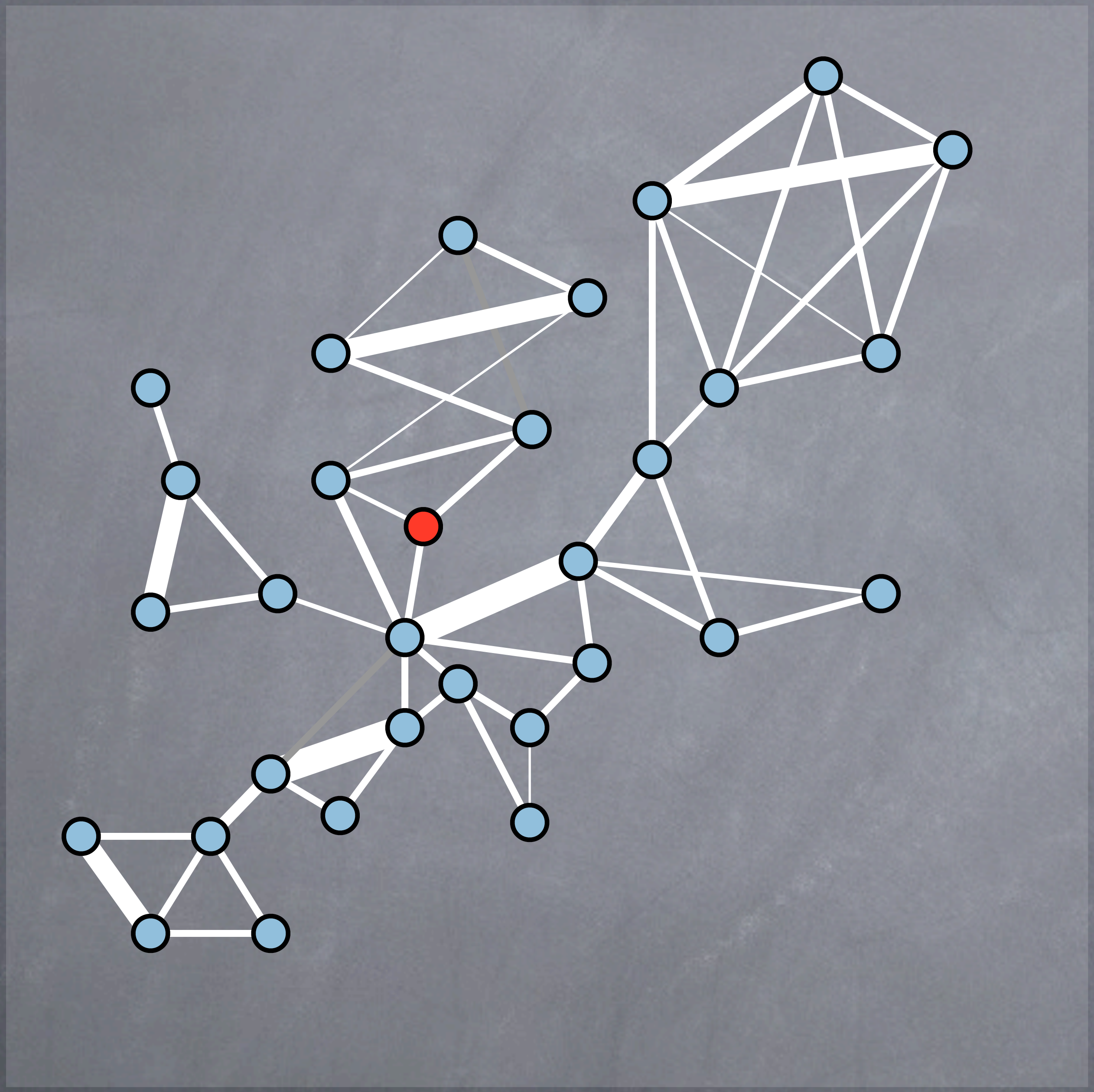
Could some connections be regenerated ?

What if that was not the end of the story ?

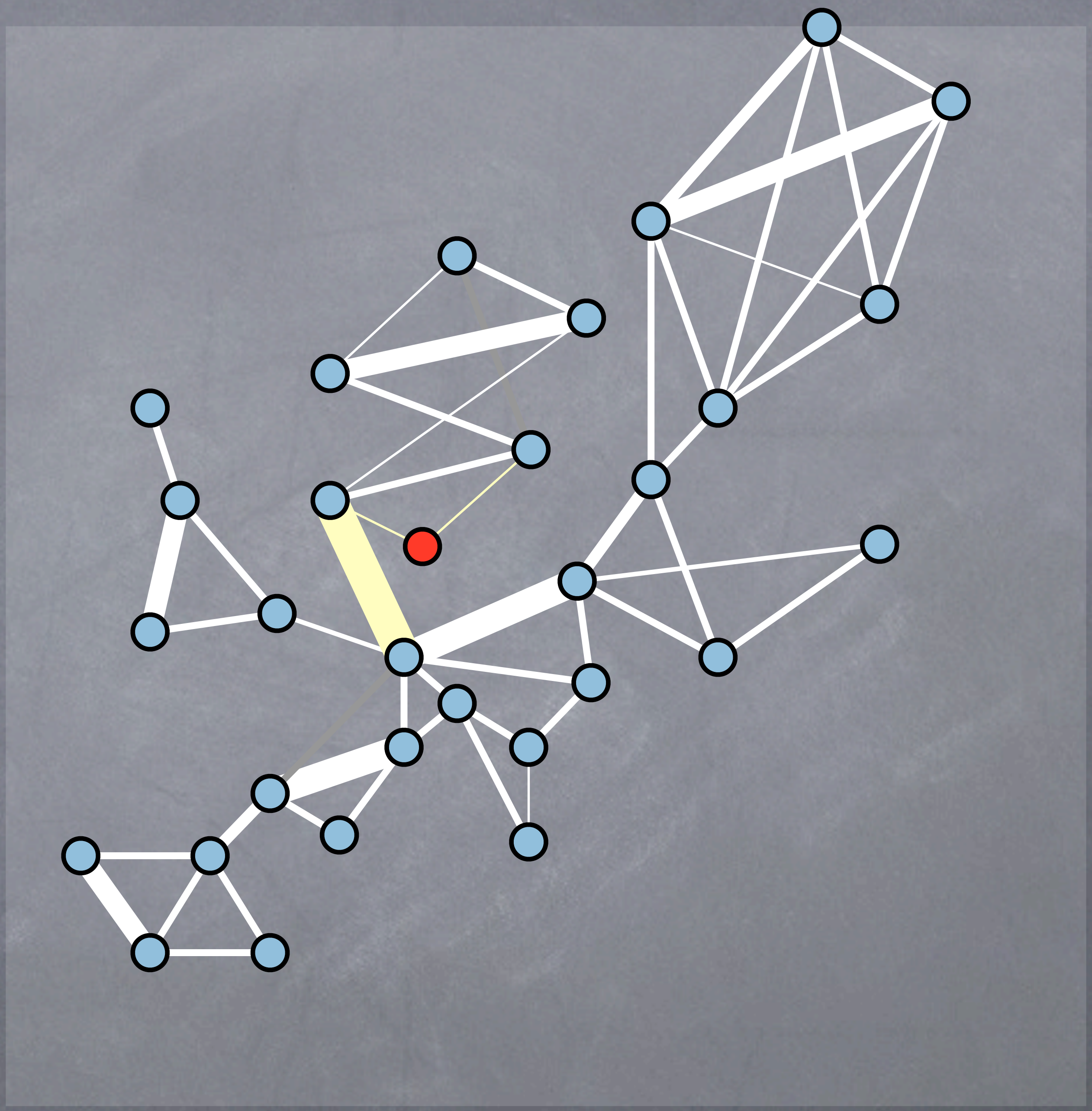


Could some alternative paths be strengthen ?

We can validate the models based on animal experiment



before

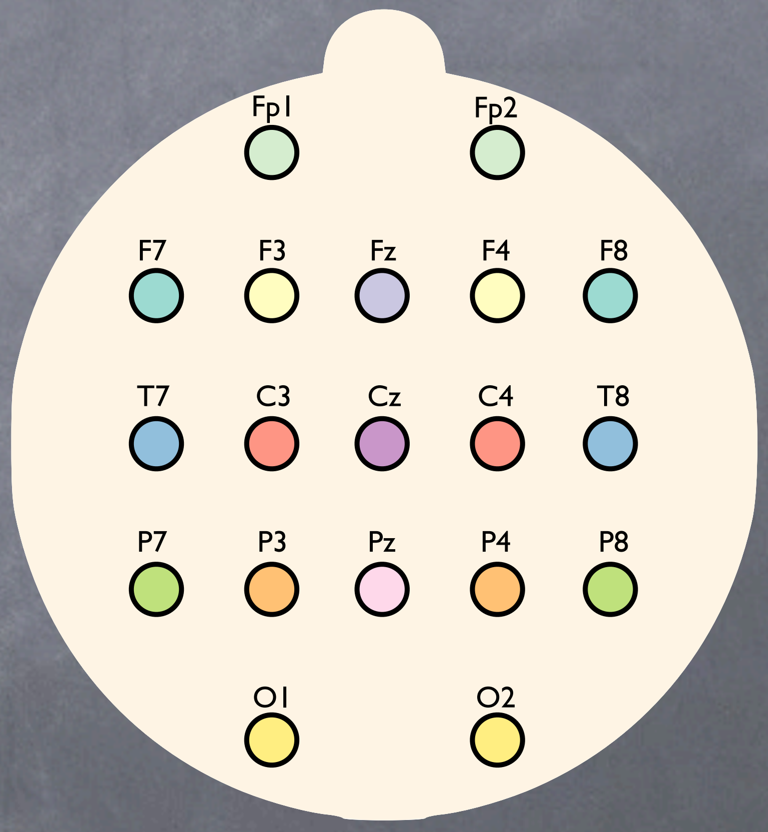


after

Autistic children have a specific alteration of functional network

- Functional connectivity
- EEG coherence
- Whole brain
- Autism Spectrum Disorder Tuberous Sclerosis Complex

Controls n = 46	TSC n = 29
ASD n = 16	TSC+ASD n = 14



Taquet, Peters *et al.*, 2012

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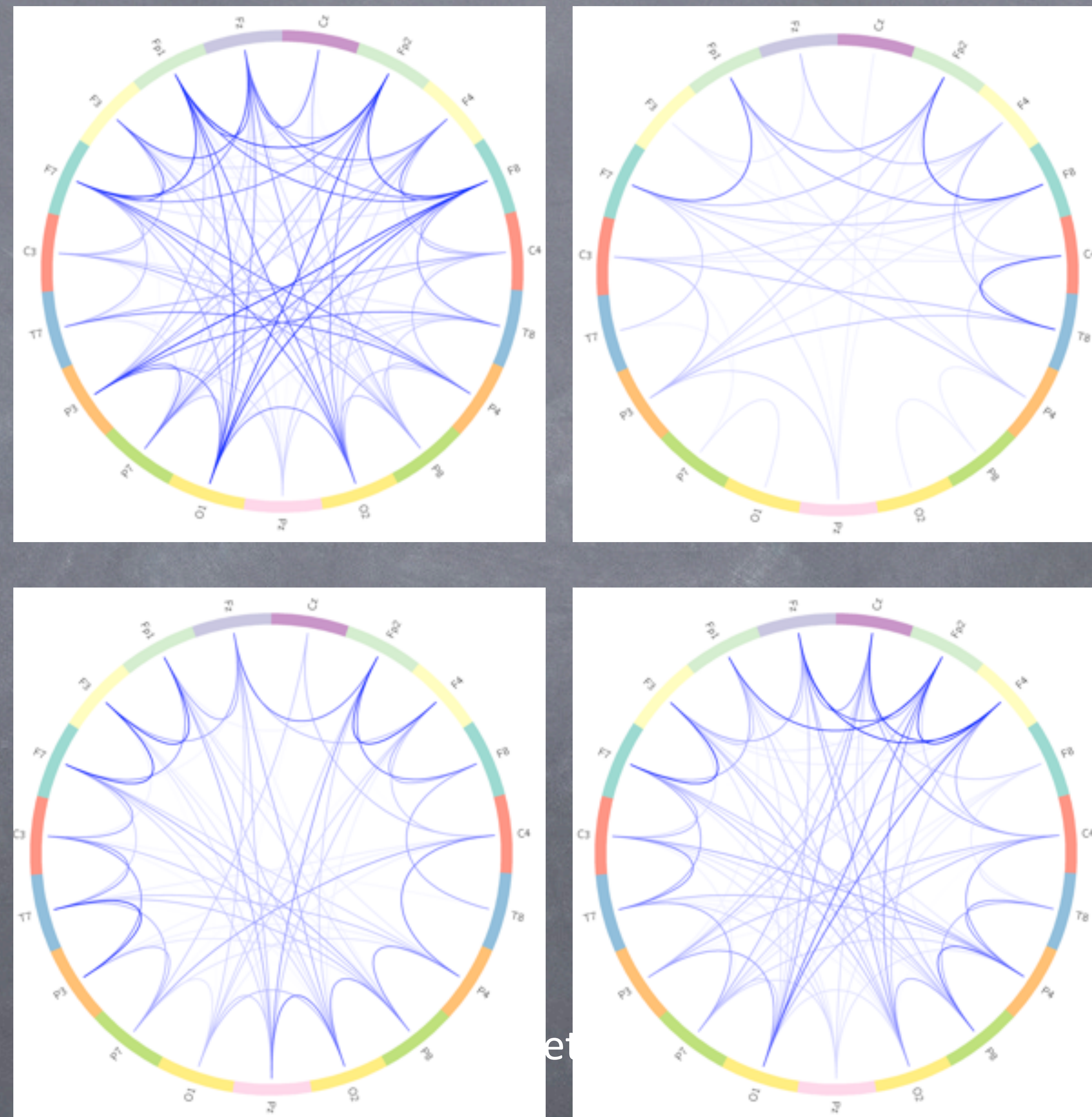

Taquet, Peters *et al.*, 2012

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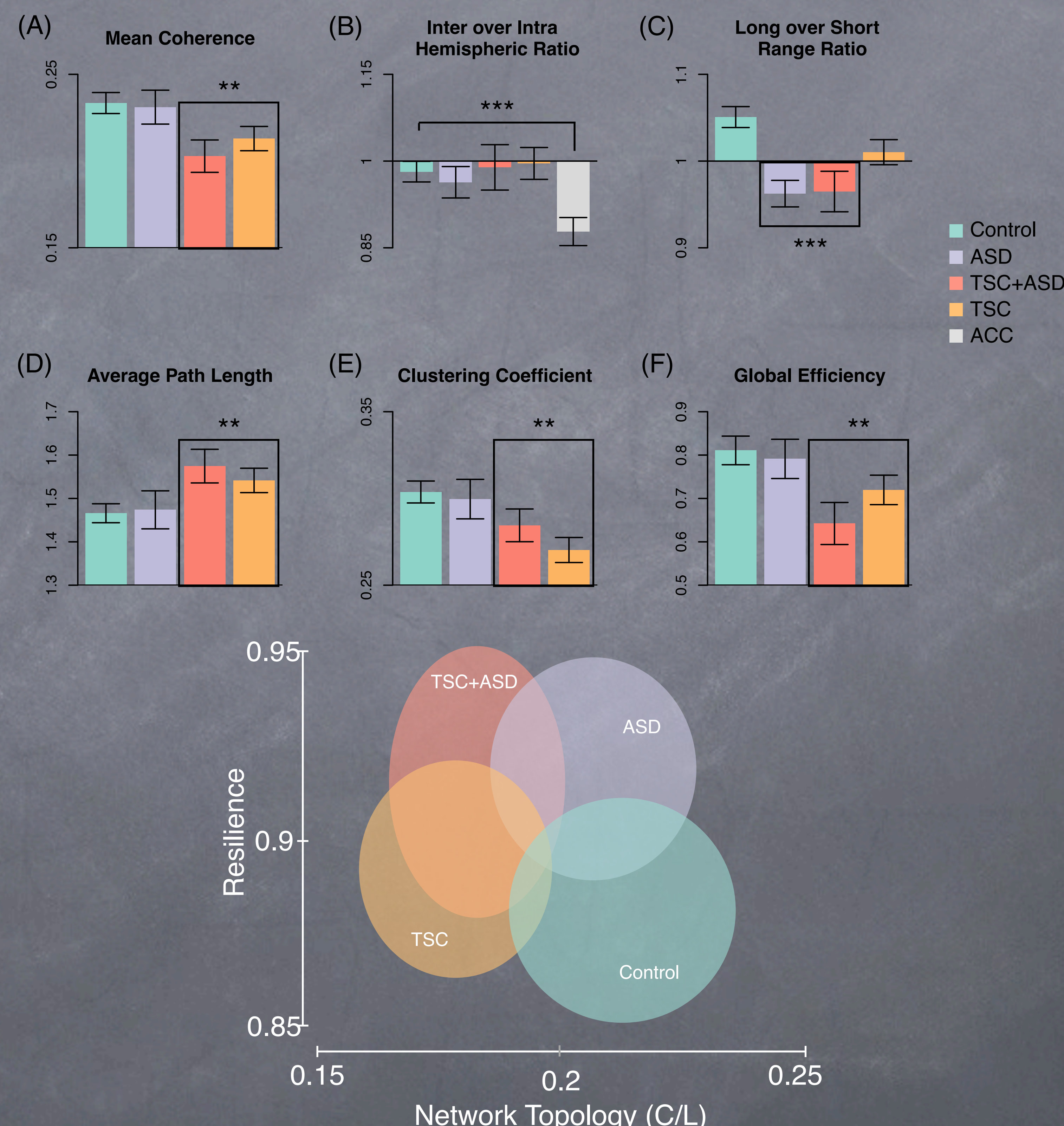

Taquet, Peters *et al.*, 2012

We can probe the brain connections with imaging

We can model the brain network and its properties

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icteam

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Thank you !

www.maximetaquet.com