

# An Introduction to Network Analysis & EEG Interpretation

AES Engineering/Neurostimulation SIG  
December 2018

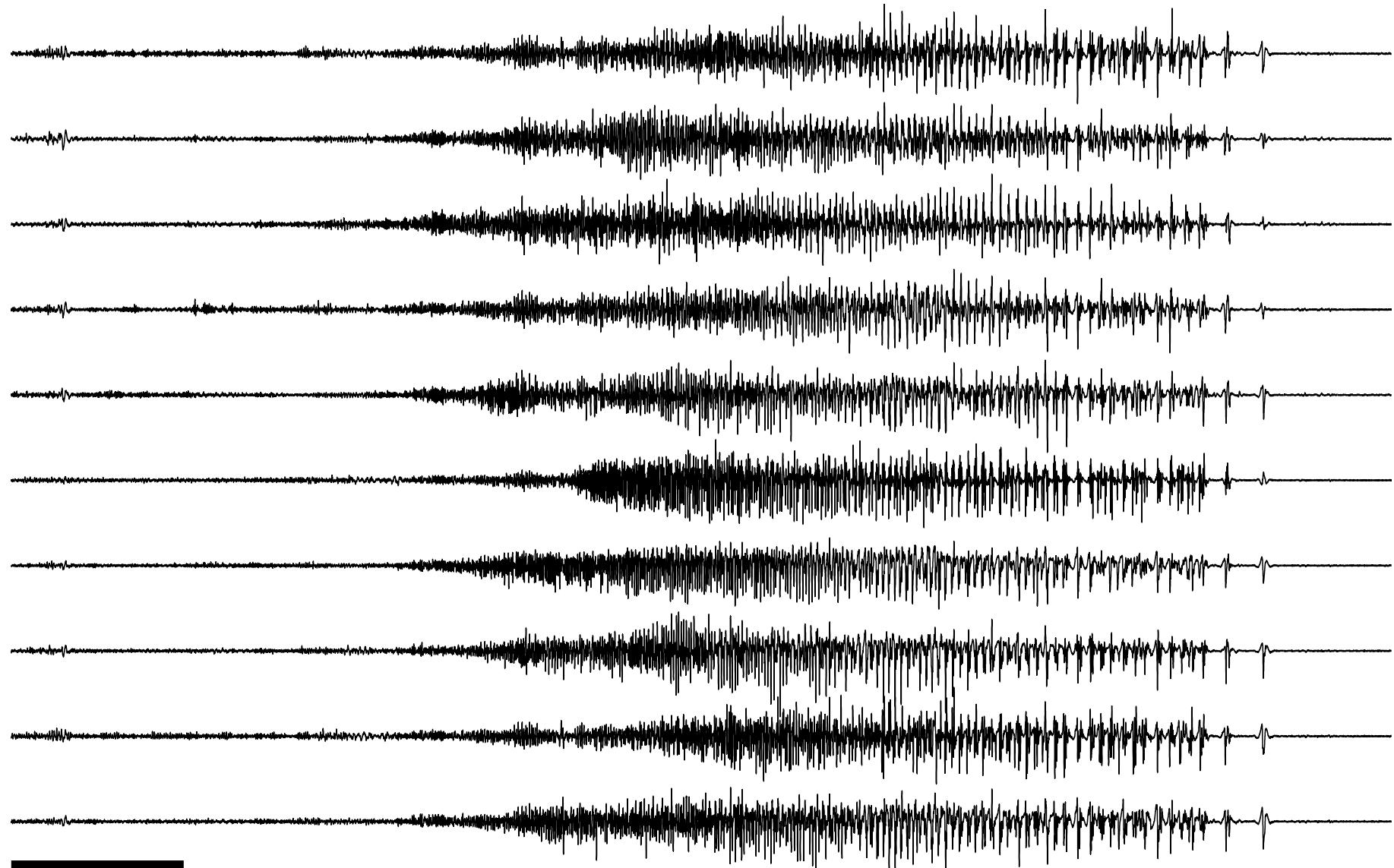
**Mark Kramer, Uri Eden, Eric Kolaczyk, Elizabeth Spencer, Nathan Perkins, Wes Viles, Boston University, USA**

Catherine Chu, Sydney Cash, Louis-Emmanuel Martinet, Harvard University and Massachusetts General Hospital, USA

# Outline

- Example: Functional connectivity (in epilepsy)
- Data analysis pipeline: data → network
- Hands-on tutorial / example

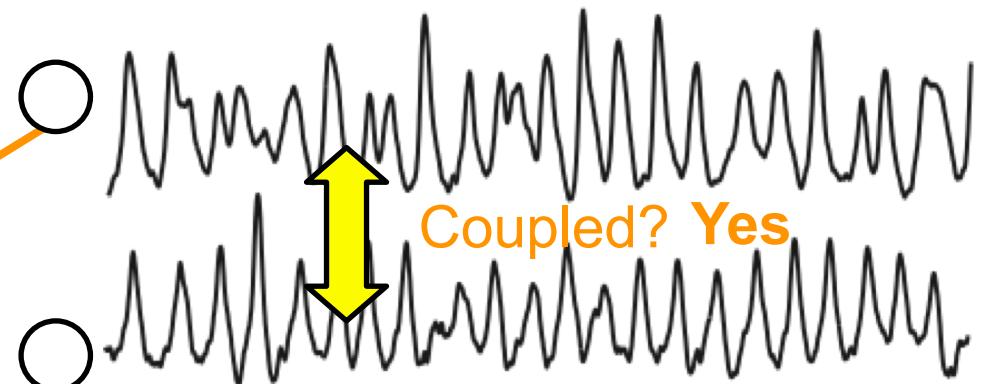
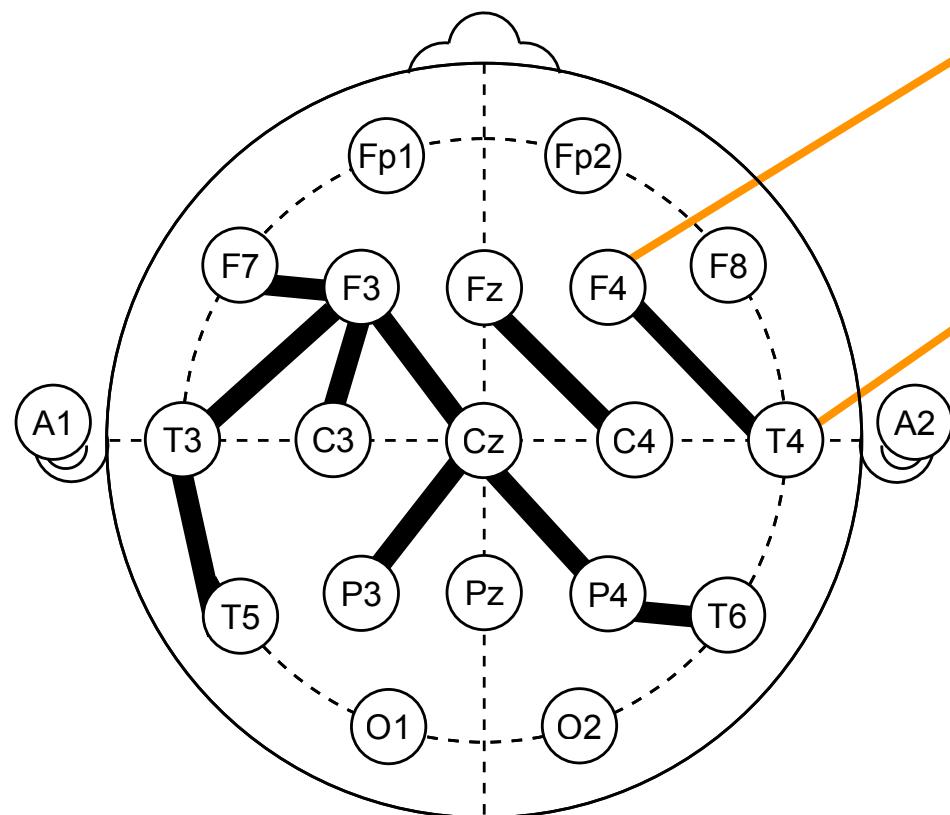
# Patient Data



Which signals are coupled, and when?

# Functional Connectivity

Multiple electrodes



Long history

[Brazier, 1972 & 1973; Gotman, 1981 & 1983; ...]

Many coupling measures

[Pereda et al, 2005; Greenblatt et al, 2012]

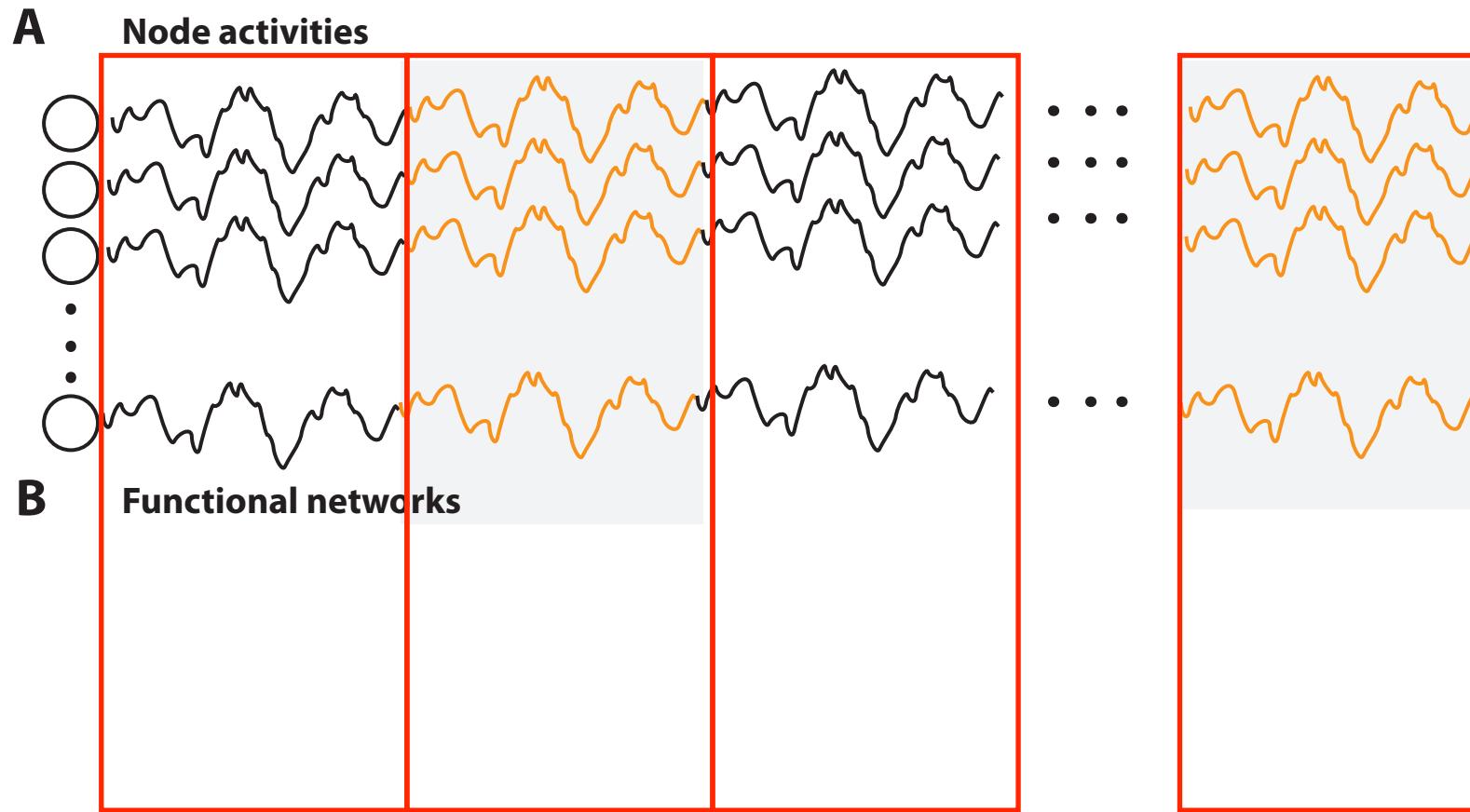
Repeat for all electrode pairs:

Functional network:



# Functional Connectivity

Networks evolving in time



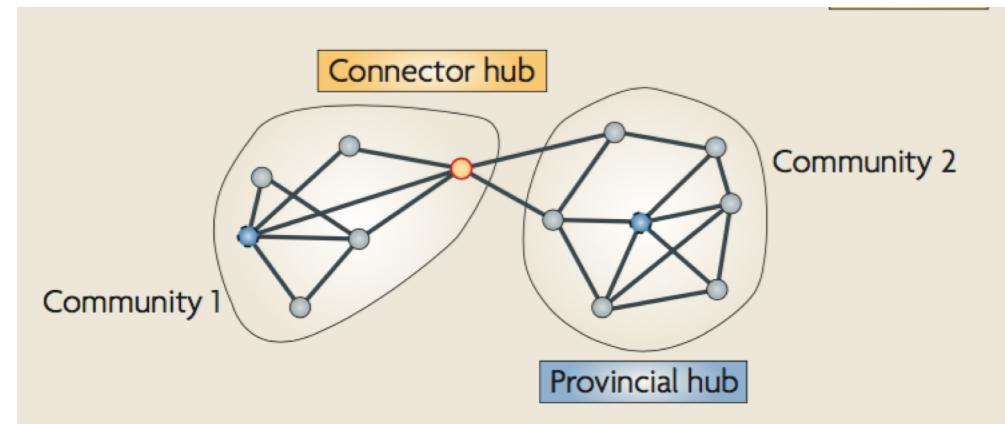
Q: How do functional networks evolve during seizure?

[Kramer and Cash, 2012]

One example ...

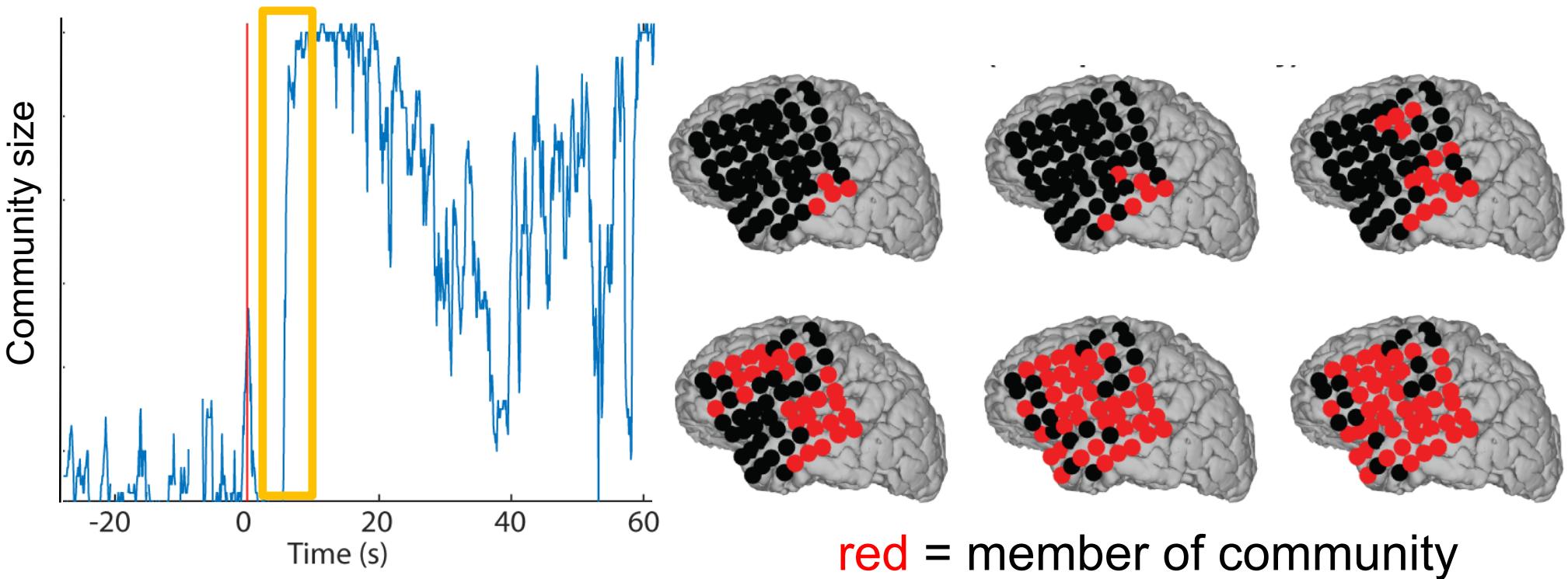
# Example

... sudden emergence of a large community at seizure onset.



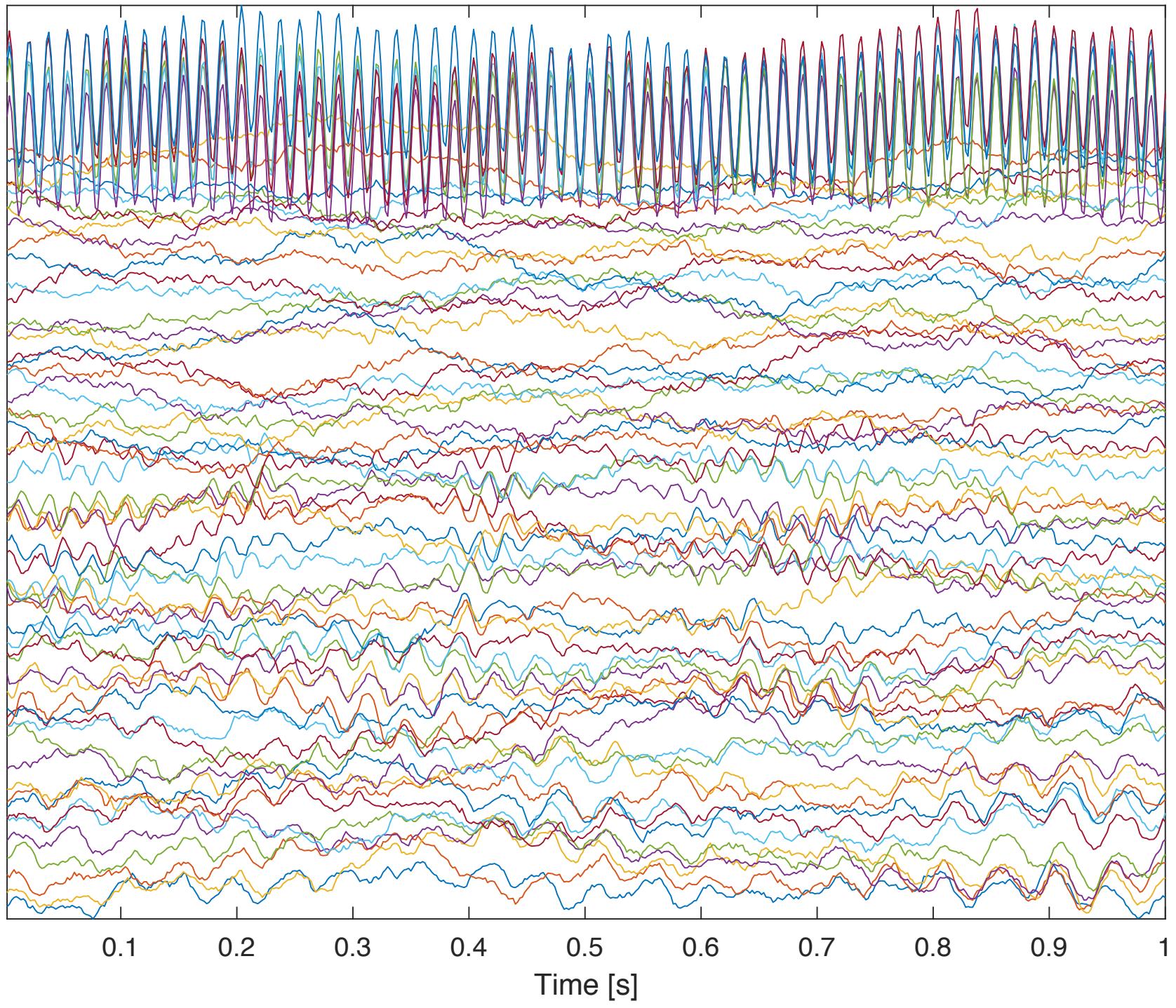
Large community suddenly forms

[Bassett and Sporns 2017]



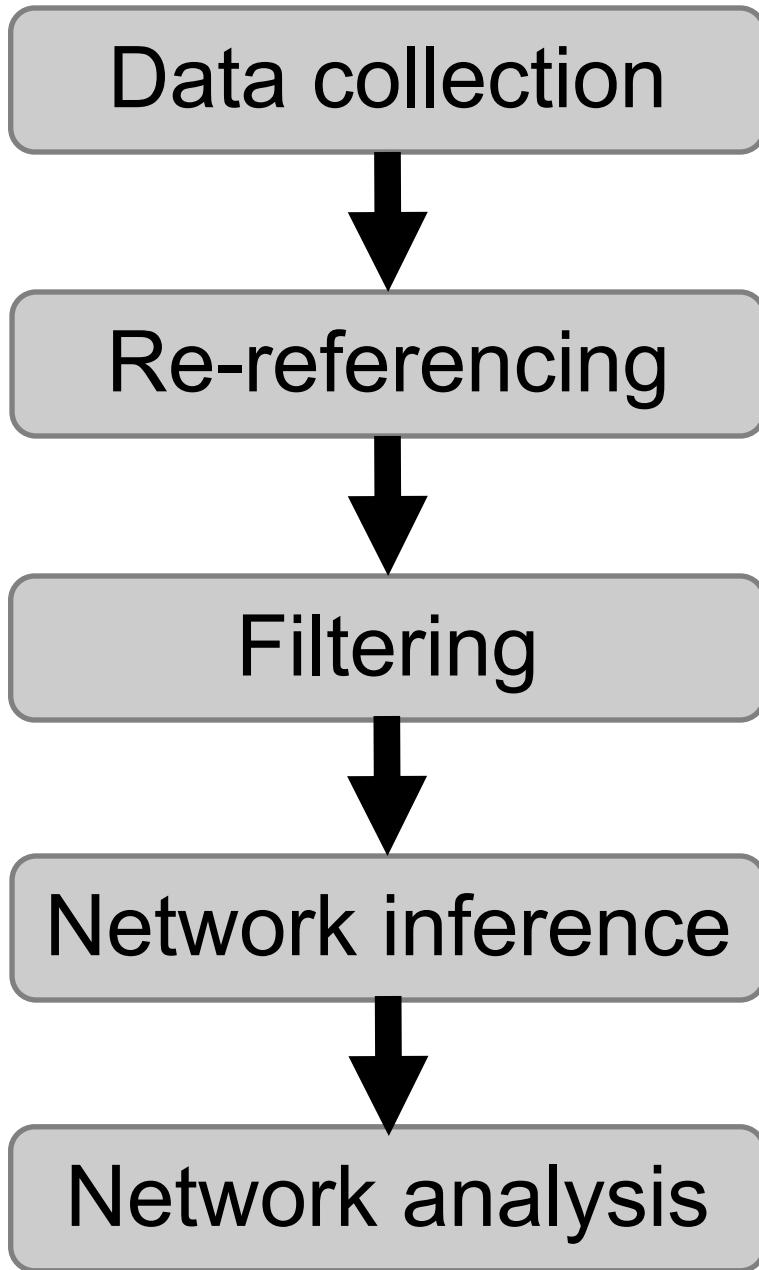
How seizure spreads on cortex? [Martinet, Kramer et al., under review]

Additional motivation to follow ...



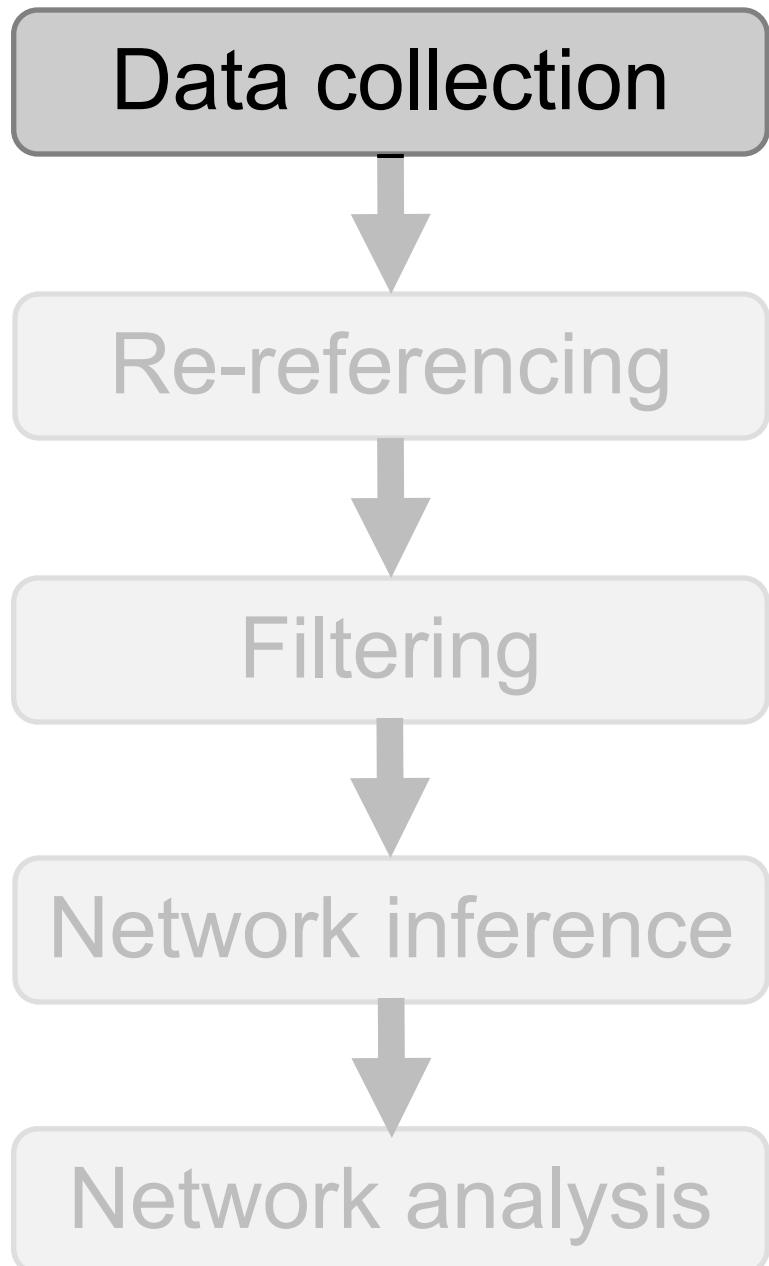
Which electrodes are coupled?

# Pipeline

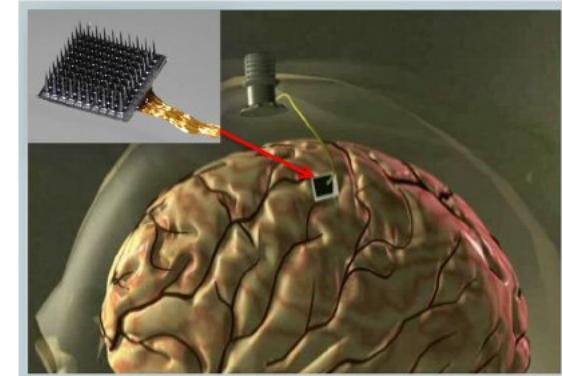
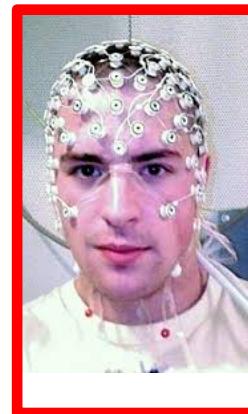


Each step, a new challenge

# Pipeline



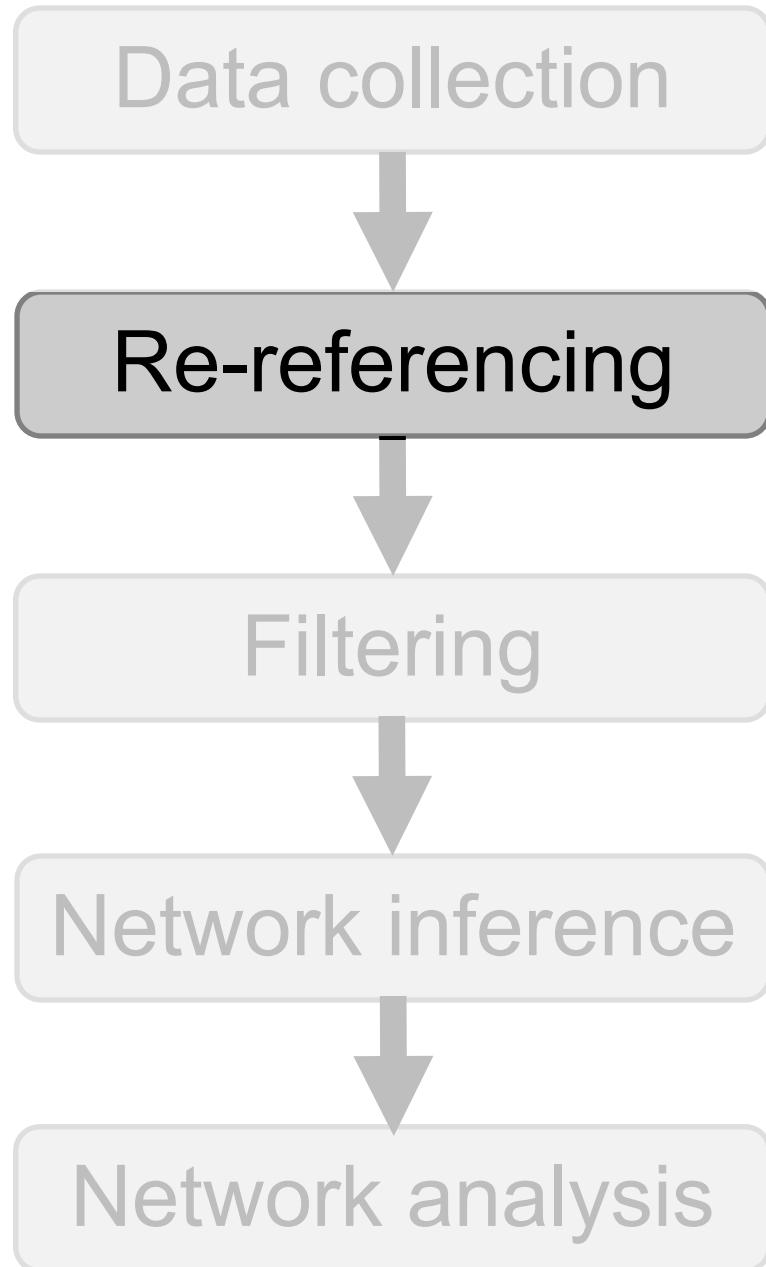
- Spatial sampling vs brain coverage.



[Nurmikko et al, 2010]

- EEG: high or low density  
... nodes in the network
- Sampling rate  
... rhythms observable

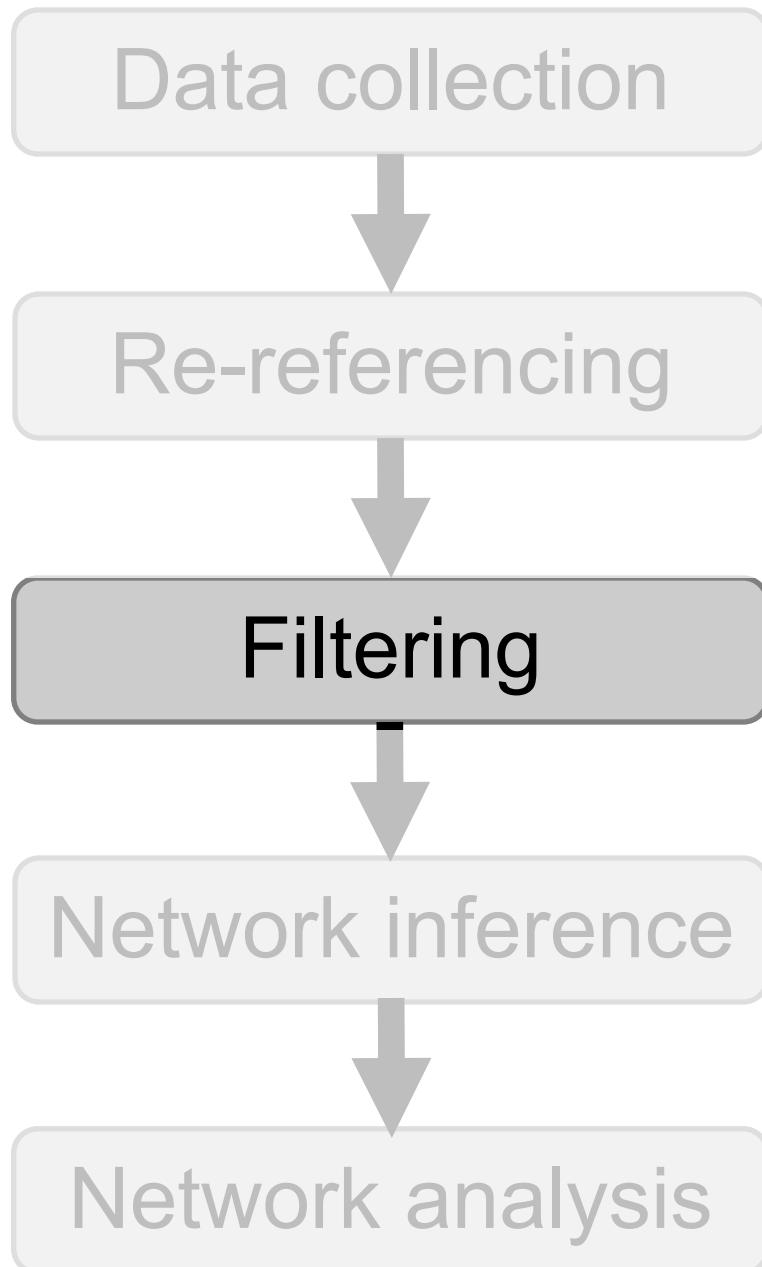
# Pipeline



- Physical
- Bipolar
  - ... reduces number of nodes.
- Common average
  - ... introduces shared signal?
- Laplacian
- Reference electrode standardization technique (REST)

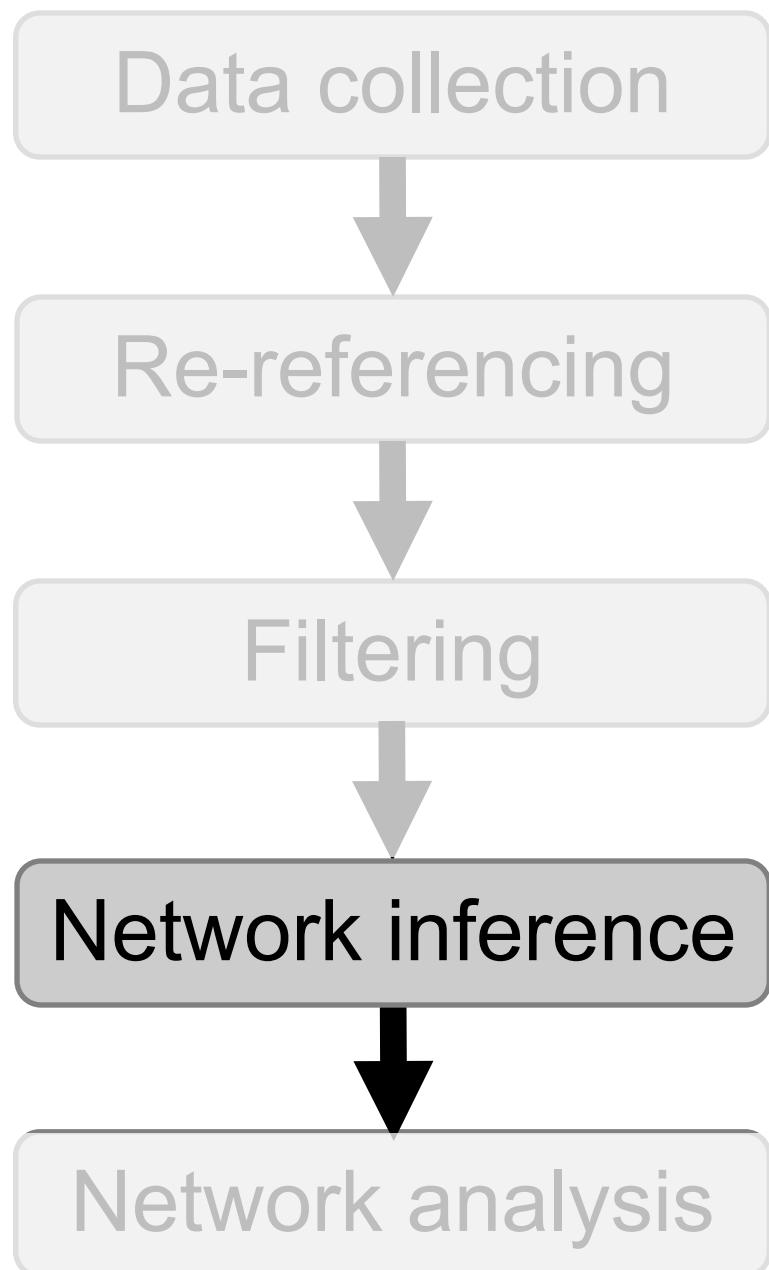
[Chella et al, J Neural Eng, 2016]  
[Nunez & Srinivasan, 2005]

# Pipeline



- Which frequency band?
  - ... to keep: delta, HFO
  - ... to remove: sweat artifact, 60 Hz
- Filter parameters
  - Type:
    - FIR, IIR, ...
    - High-pass, low-pass, ...

# Pipeline

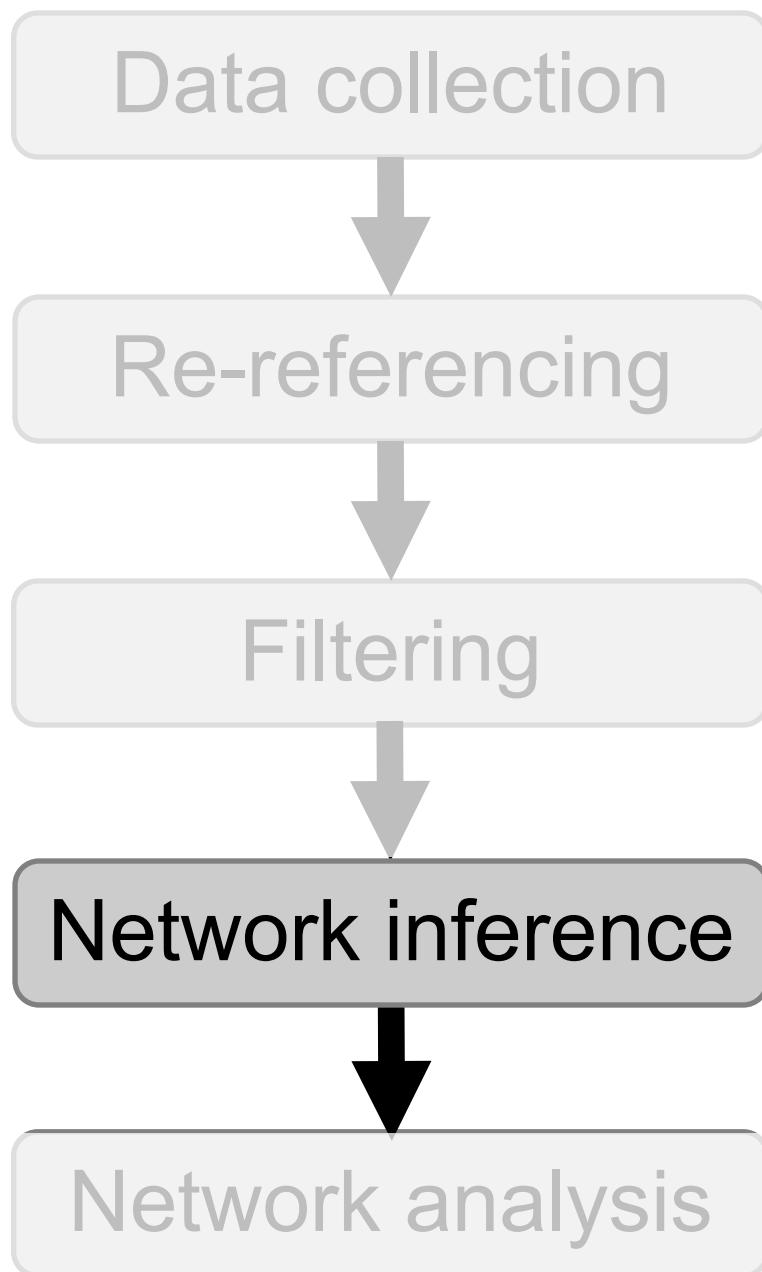


## Coupling measure

- **Linear (correlation)**  
... simple, fast, well understood
- **Nonlinear (information)**  
... powerful, more complex
- **Model based (Granger)**  
... address confounds, slow

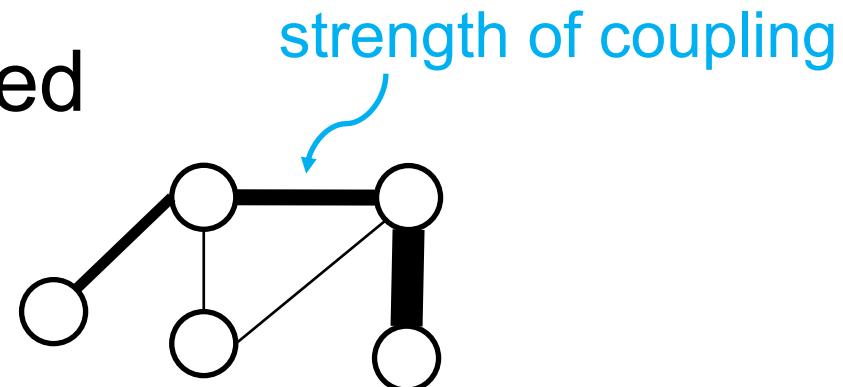
[Greenblatt et al 2012; Pereda et al 2005; Nunez et al, 1997]

# Pipeline

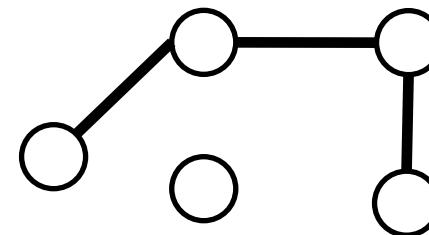


Apply the coupling measure,  
then create the network:

Weighted



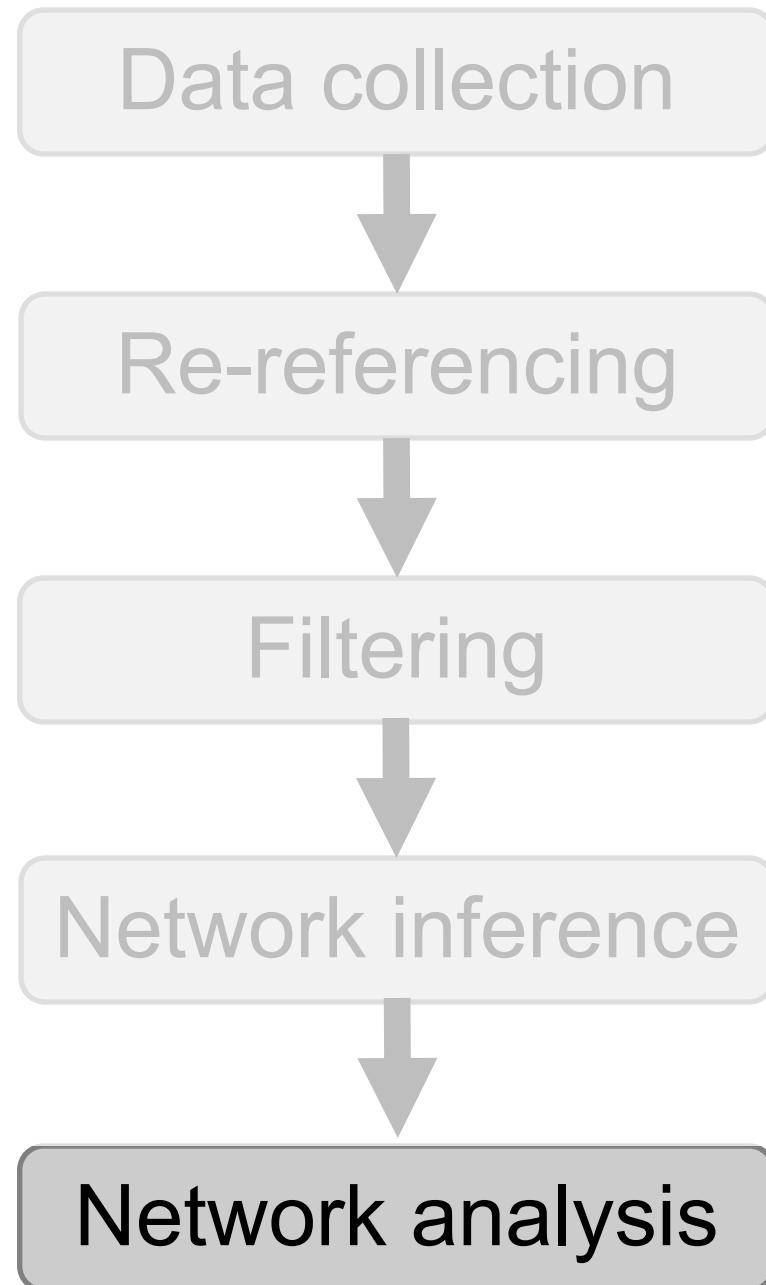
Binary



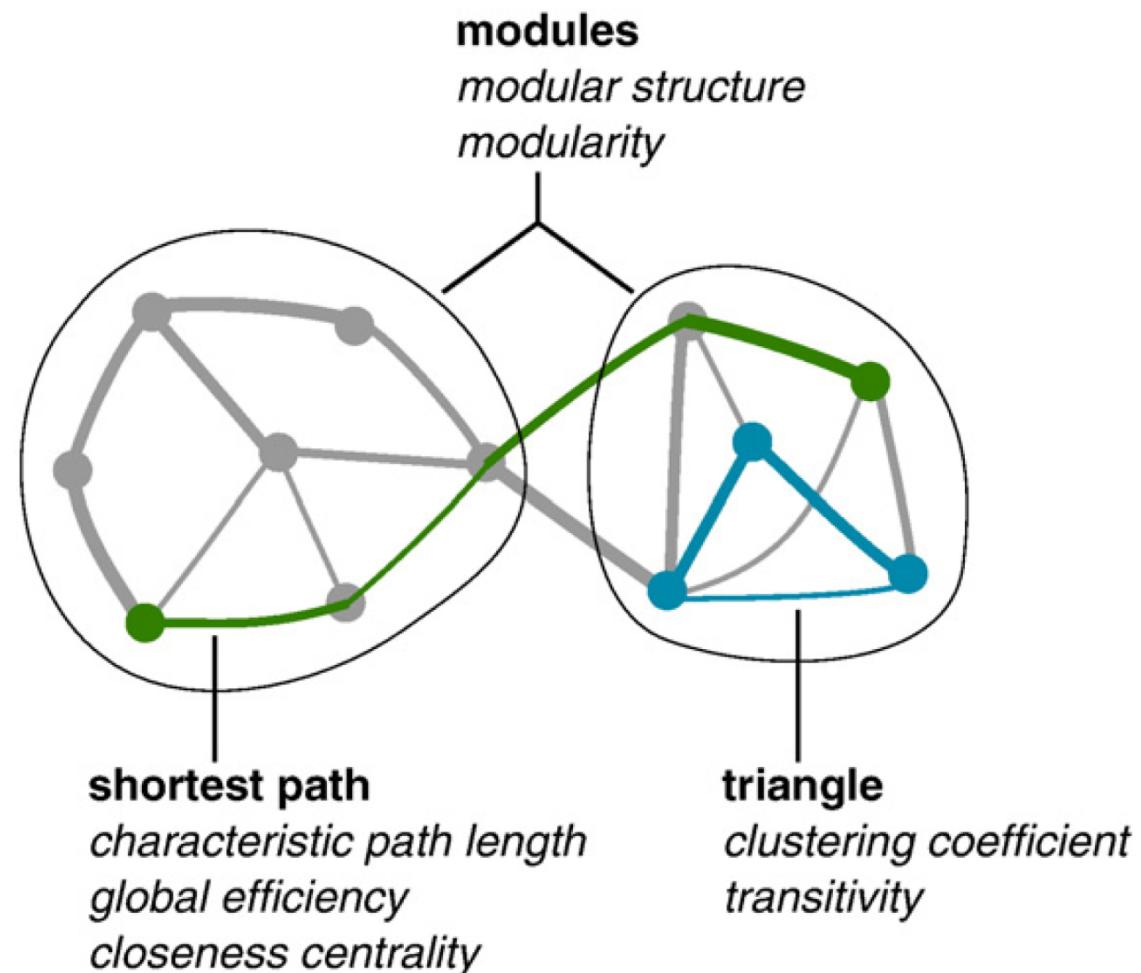
Threshold:

- Coupling measure
- p-value

# Pipeline

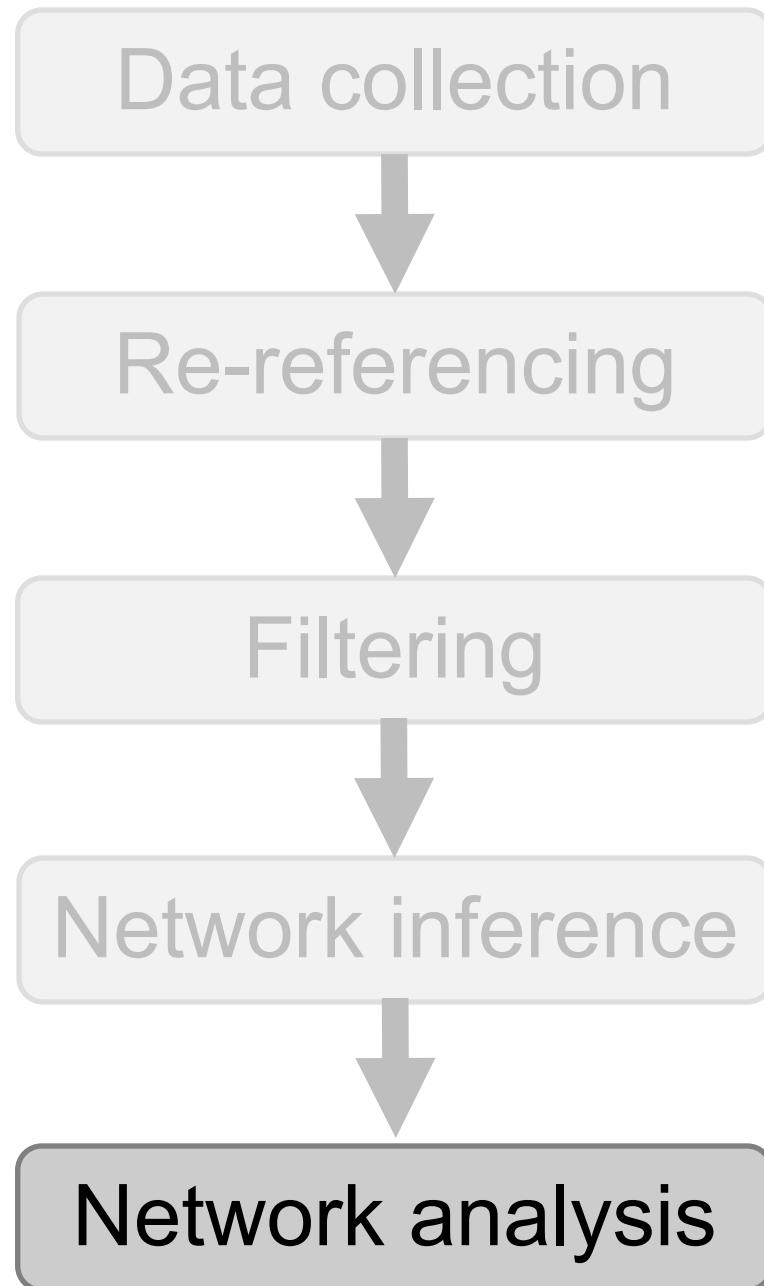


- Static network measures

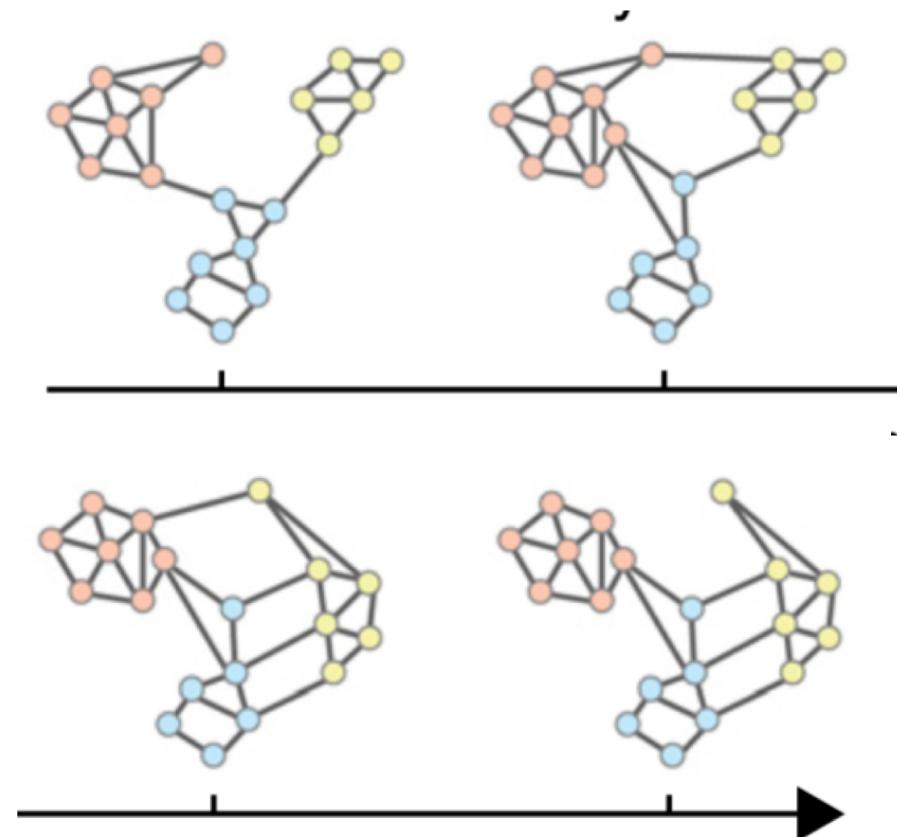


[Rubinov & Sporns, 2010]

# Pipeline

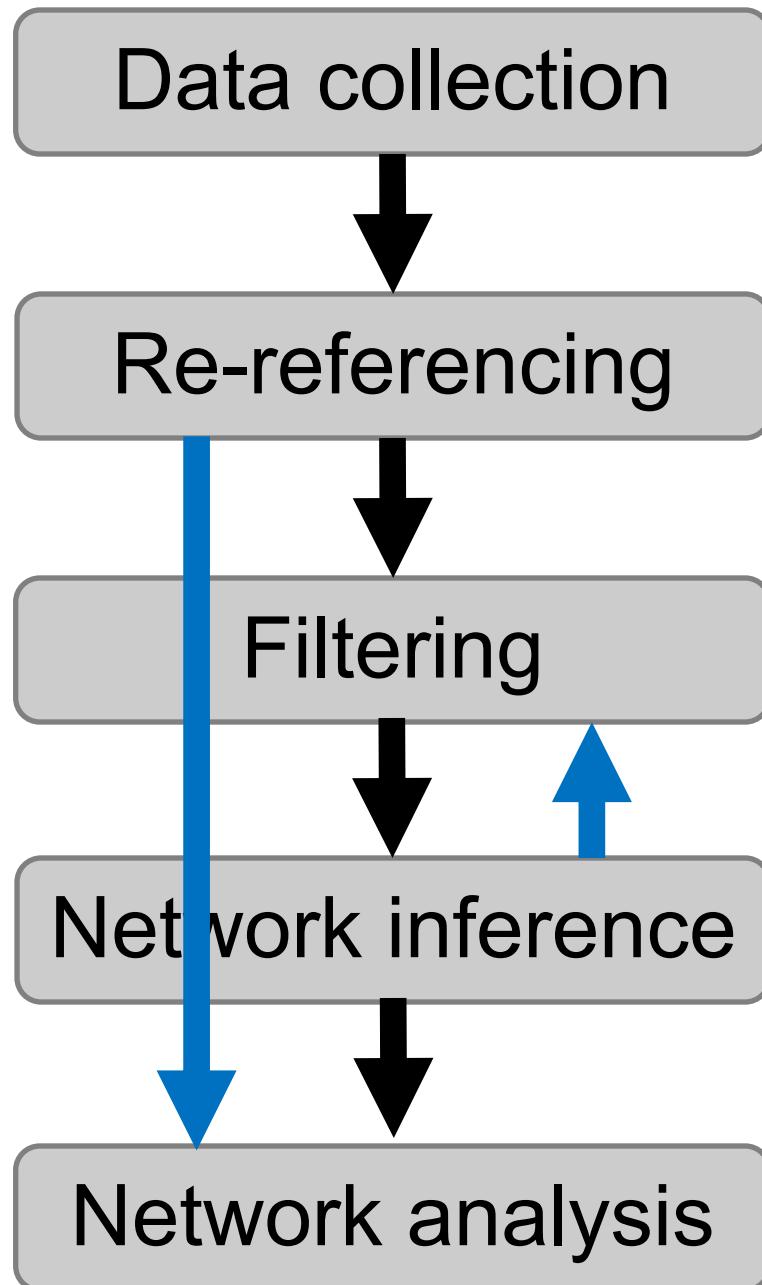


- Dynamic network measures



[Bassett & Sporns, 2017]

# Pipeline

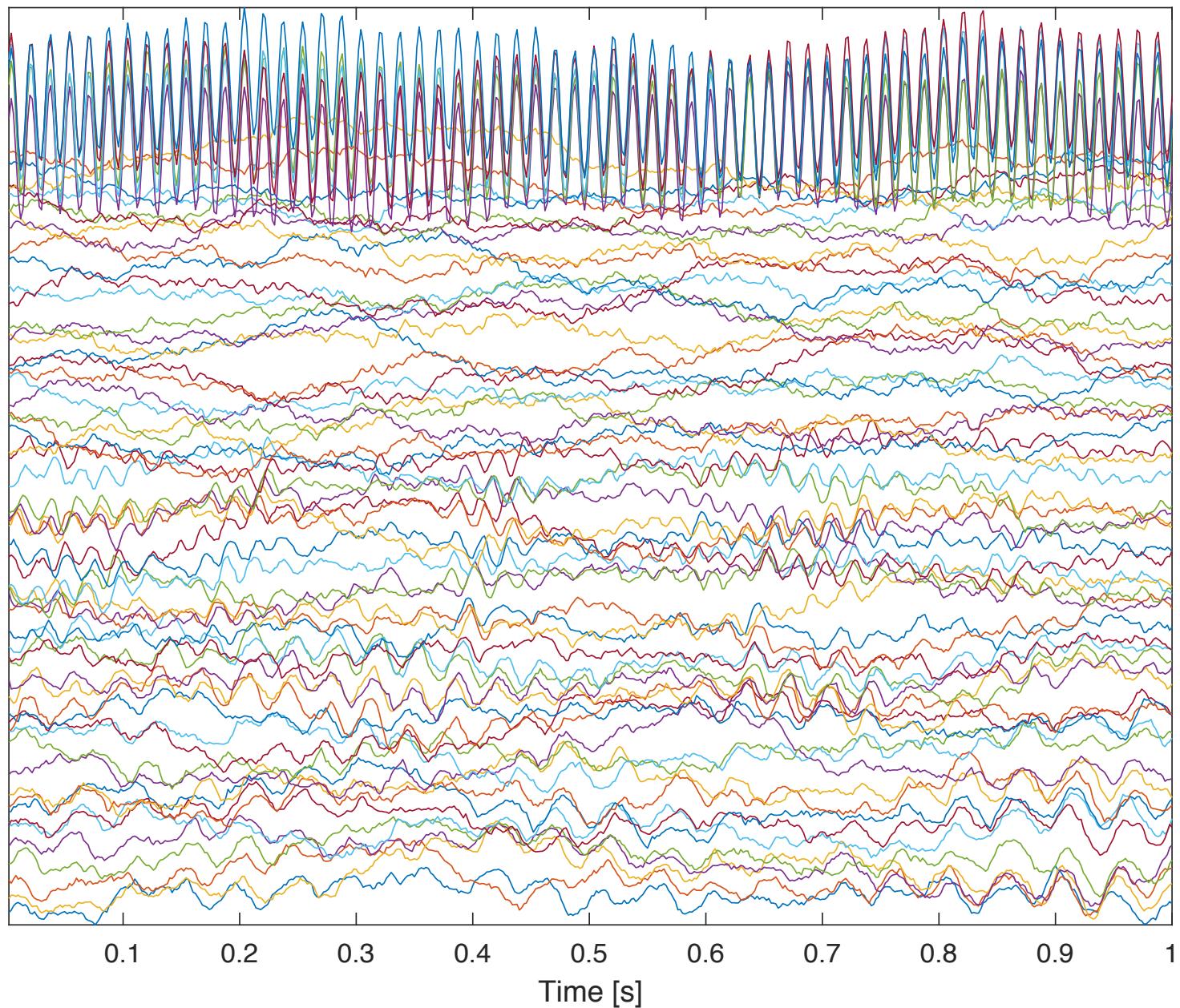


are interconnected ...

Reference choice impacts  
network result.  
... common average reference.

Network inference method  
may impact filtering choice  
... coherence in a specific band.

# Implement the pipeline in an example ...



# Example

<https://github.com/Mark-Kramer/AES-SIG-2018>

## AES-SIG-2018

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### An Introduction to Network Analysis & EEG Interpretation

This repository includes an example data set

`AES_data.mat`

and an example script to analyze these data

`AES_data_analysis_pipeline.m`

Open the script and run it to implement specific choices for a data analysis pipeline, which begins with a multielectrode recording and ends with a functional network, and analysis of that network.

The analysis pipeline illustrates one example approach. There are many others.

# Example

<https://github.com/Mark-Kramer/AES-SIG-2018>

```
11 % Step 1. Data collection -----
12 %
13 %
14 load('AES_data.mat'); % Load the data
15 % d = the data [ time, electrodes ]
16 % t = the time axis, in units of seconds.
17 figure(); eeg_plot(t,d) % It's always a good idea to look at the raw data.
18 title('EEG data'); xlabel('Time [s]')
19 %
20 % Step 2. Re-referencing -----
21 %
22 %
23 d_car=common_average_reference(d); % Apply the common average reference,
24 figure(); eeg_plot(t,d_car) % ... and plot it.
25 title('EEG with common average reference')
```

# Example

<https://github.com/Mark-Kramer/AES-SIG-2018>

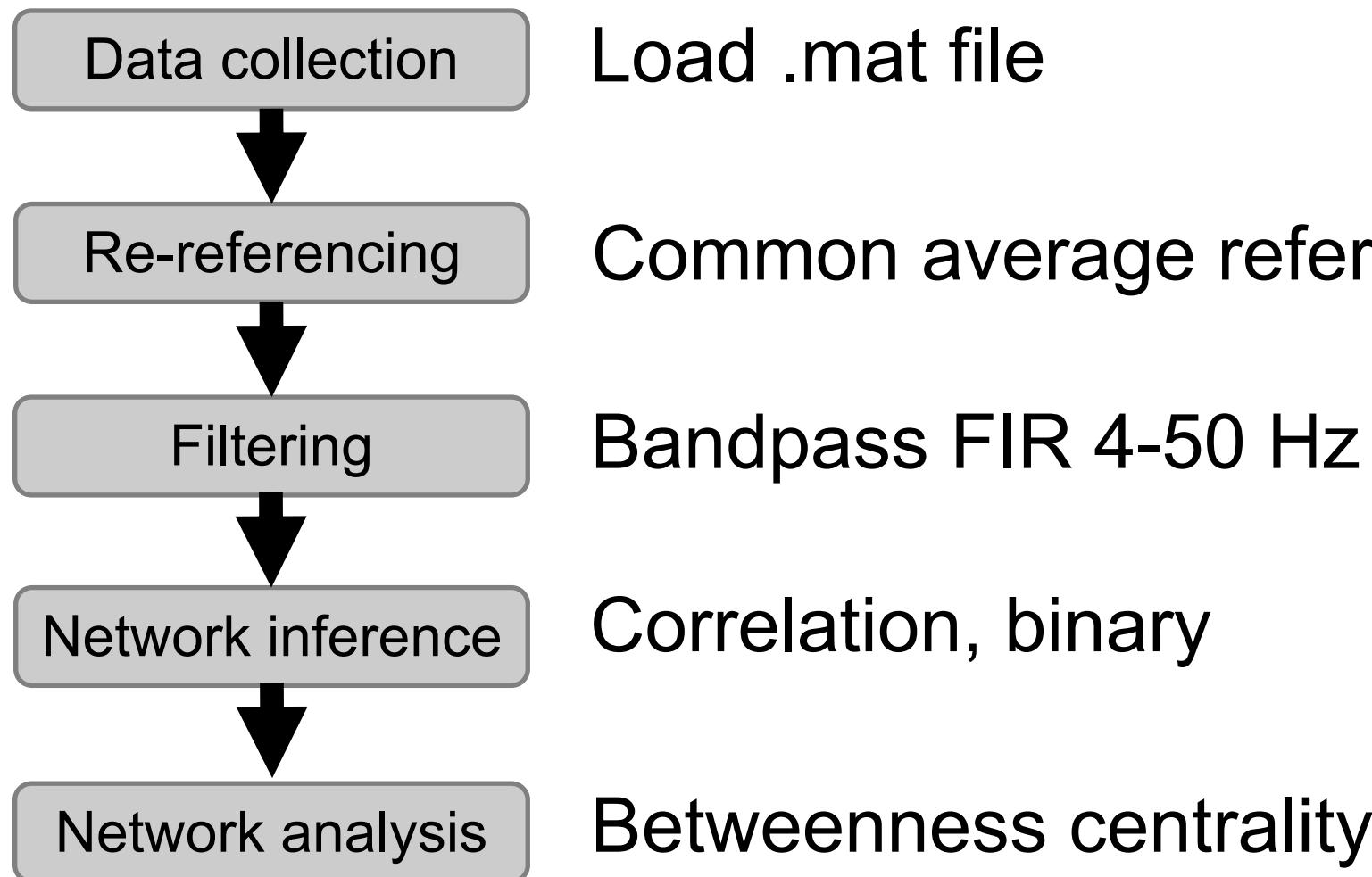
```
% Step 3. Filtering -----
%
%
Wn = [4,50]; % Choose filter range from [4,50] Hz,
d_filtered = simple_filter(t,d,Wn); % ... apply the filter,
figure(); eeg_plot(t,d_filtered) % ... and plot it.
title('EEG with filtering')

% Step 4. Network inference -----
%
% Infer the functional connectivity,
[C] = infer_network_correlation(d_filtered);
figure(); imagesc(C) % ... and visualize it.
xlabel('Node number'); ylabel('Node number')

% Step 5. Network analysis -----
%
% Download the Brain Connectivity Toolbox, https://sites.google.com/site/bctnet/
%
BC = betweenness_bin(C); % Compute a property of the network.
figure(); plot(BC) % ... and display it.
xlabel('Node number'); ylabel('Betweenness centrality');
```

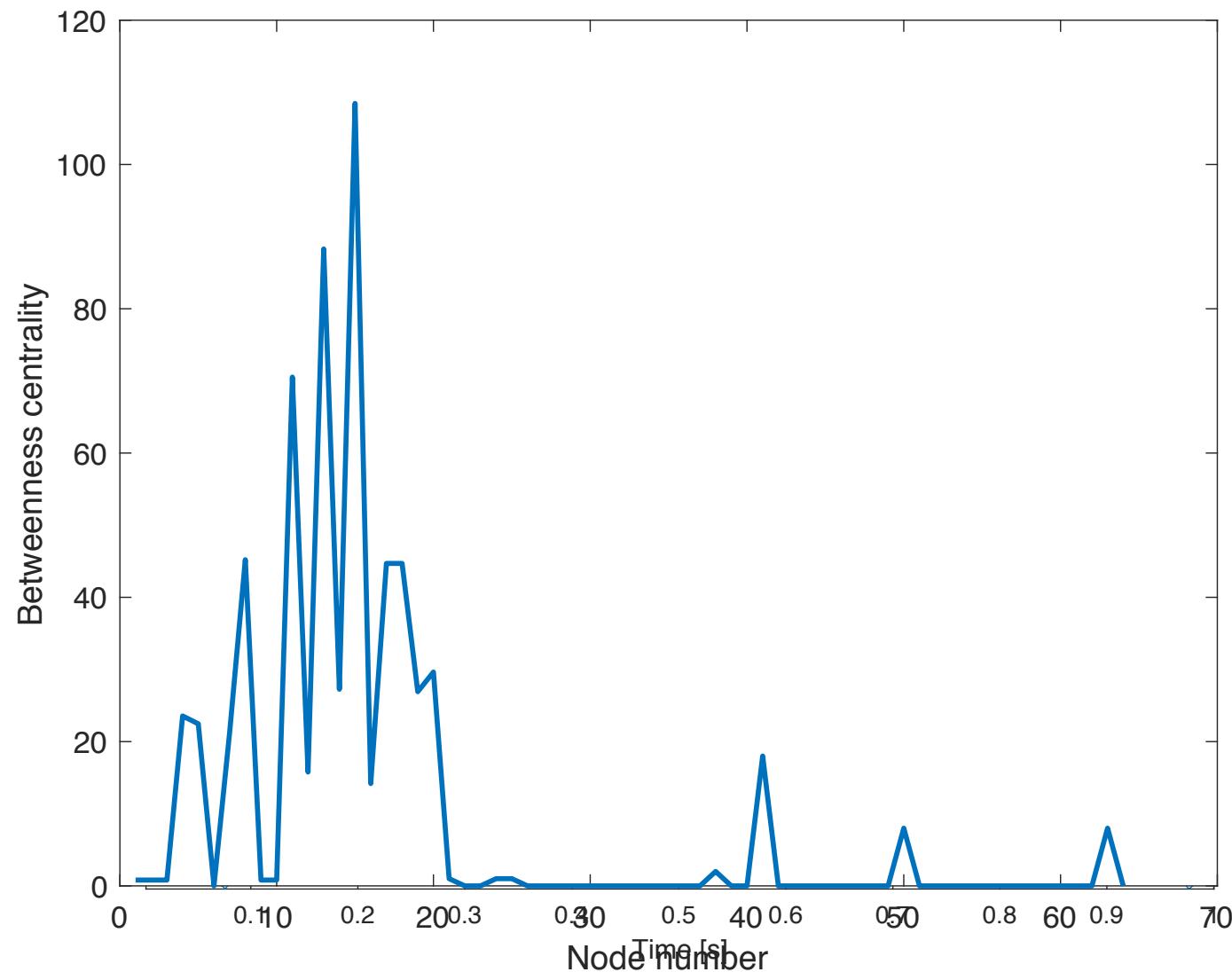
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# Example

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- Note, not all choices here are good.
- Use this as a guide, not a solution.

# Thank you

Prof. Staba, Prof. Stacey

The patients and hospital staff

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<http://math.bu.edu/people/mak/>