Synchronization approach to data analysis

An Introduction

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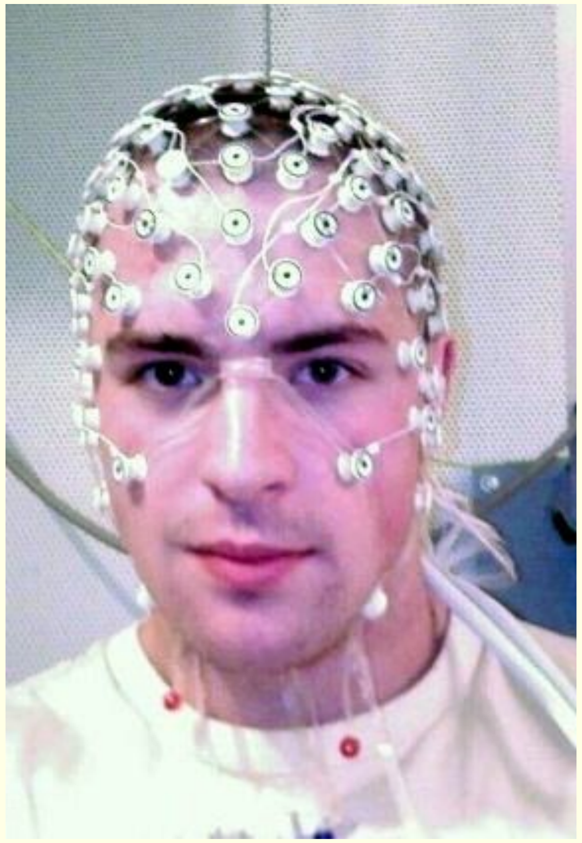
Synchronization (coupled oscillators) approach: what is it about?

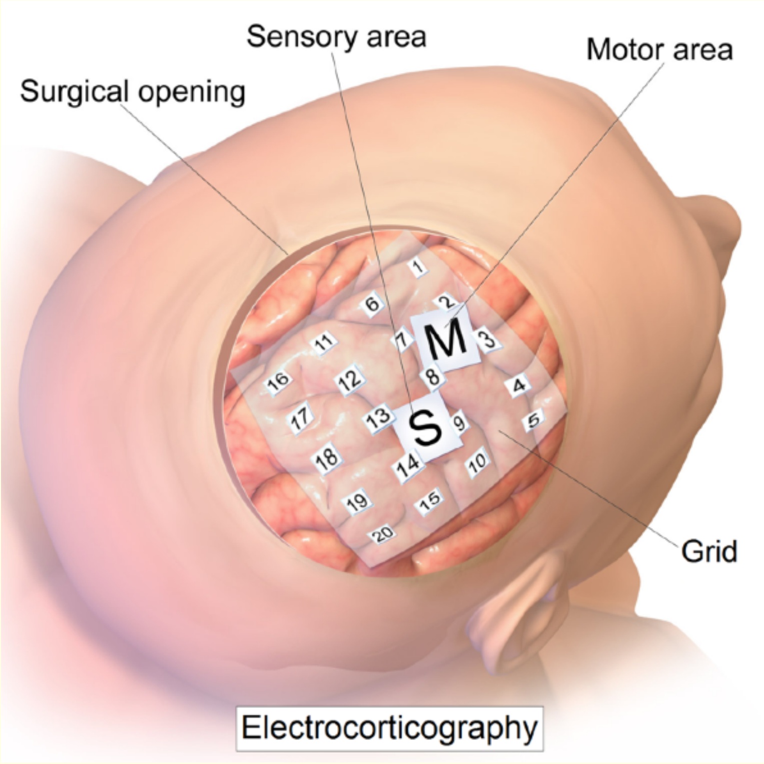
- It is about **multichannel time series**
  An example: Electro- or Magnetoencephalography (EEG/MEG)

Scalp electrodes measurements



Wikipedia

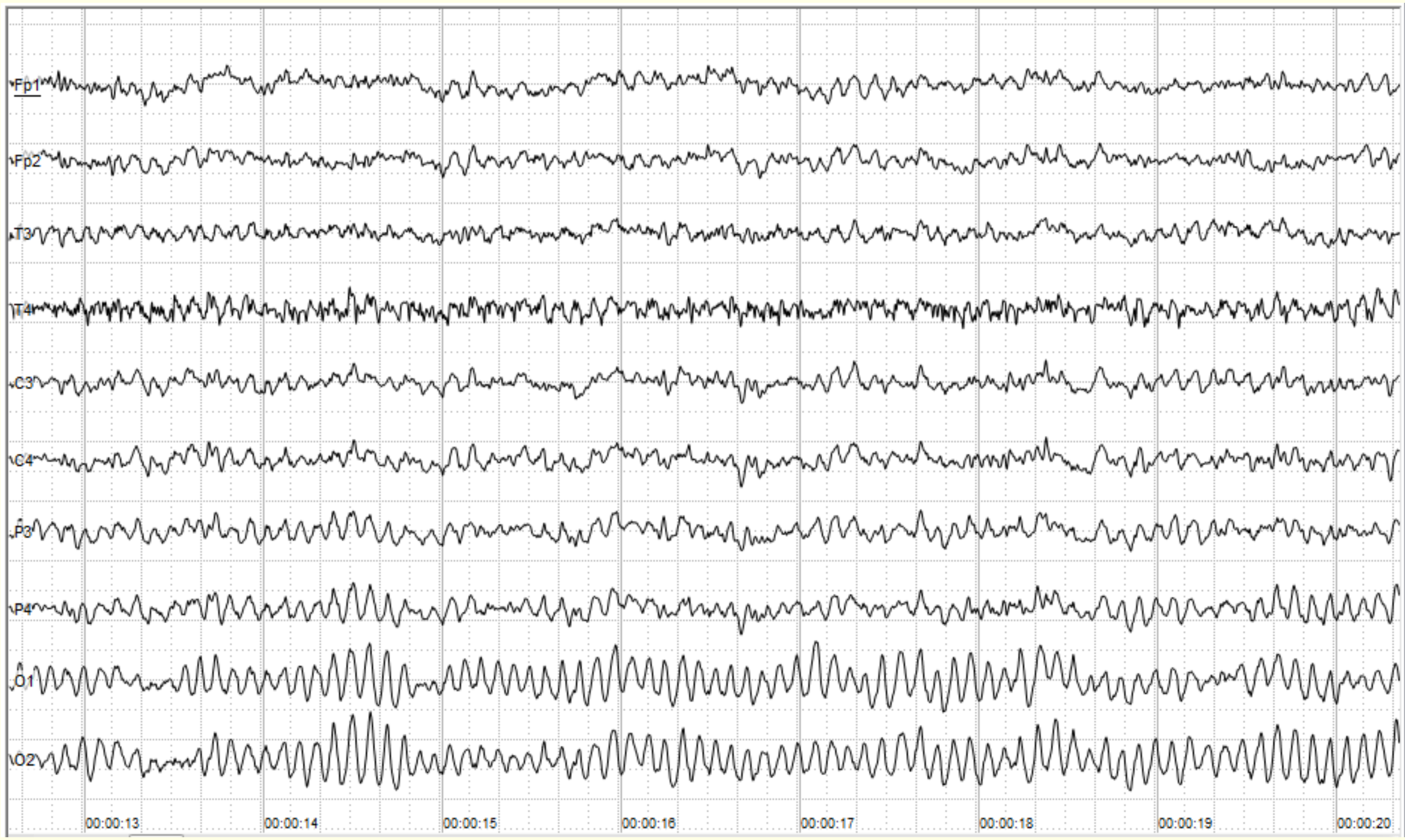
Intracranial measurements



Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine.

Multichannel time series (EEG)

IMAGE: WIKIPEDIA



up to ~ 100 channels, high resolution (1 kH and more)

long records (~30 minutes) or even continuous monitoring

$$x_k(j\Delta t), \;\; k = 1, \ldots, N_{channel},$$

$$j = 1, \ldots, N_{points}$$

sampling interval

Multichannel time series: further examples

- Weather measurements
- Seismic activity measurements
- Measurements from various physical networks, e.g. from power grids
- Other physiological measurements, e.g. time series of **cardio-respiratory interaction**
- neuronal spike trains
- …

Multichannel time series: problem formulation and analysis

- **Interrelation between the channels:**
  - linear cross-correlation or coherence in frequency domain
  - phase locking value (constancy of phase shift between narrow-band-filtered components)
  - …

- **Directional relation:**
  - information transfer (mutual information, transfer information, …
  - causality (Granger causality)
  - …

Granger causality

Clive Granger, 1934-2009
Nobel Memorial Prize in Economic Sciences

Photo: Wikipedia

Granger causality

Suppose we have two time series $\boldsymbol{x_1}, \boldsymbol{x_2}$

First, we use a **univariate predictor** to quantify the predictability of $\boldsymbol{x_1}$, i.e. we compute the prediction error $\boldsymbol{E_1}$

Next, we use a **bivariate predictor** to quantify the predictability of $\boldsymbol{x_1}$, i.e. we use **both** $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$ and compute the prediction error $\boldsymbol{E_{12}}$

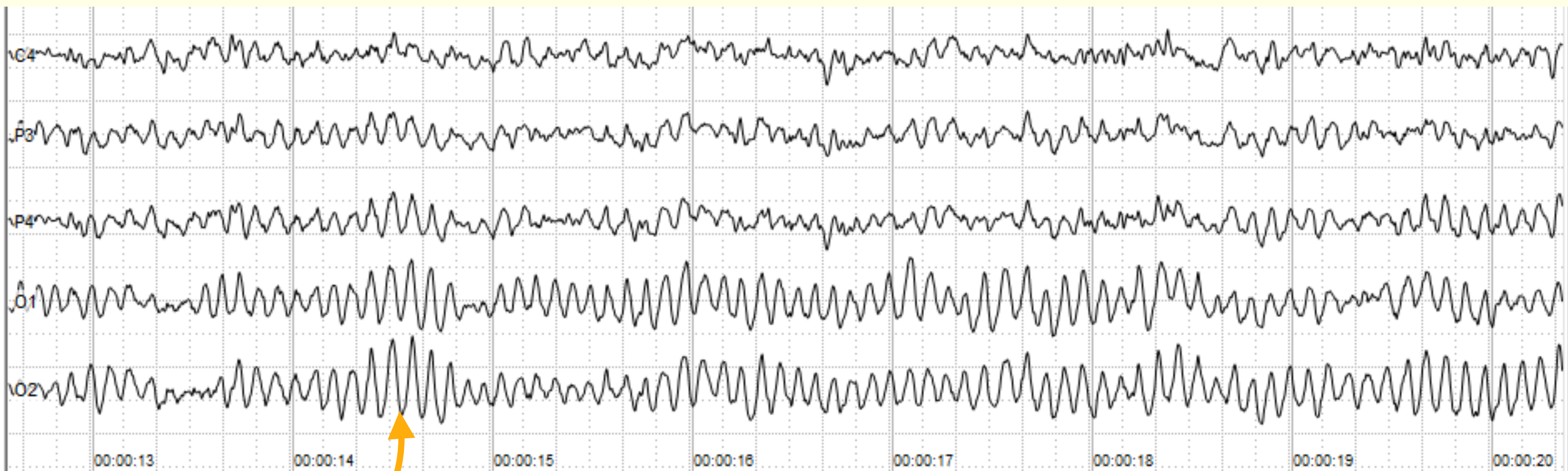
Predictability improvement $E_{12} - E_1$ quantifies causal relation $\boldsymbol{x_2 \rightarrow x_1}$

Coupled oscillators approach: what is it about?

- It is about **multichannel time series**
- It is about **rhythmical processes**

IMAGE: WIKIPEDIA

EEG data



alpha-rhythm

Band-pass filter ==> rhythmical component

EEG Frequency bands: Improved definitions [53]

Band	Frequency (Hz)
Delta	< 4
Theta	≥ 4 and < 8
Alpha	≥ 8 and < 14
Beta	≥ 14

WIKIPEDIA

Synchronization approach: what is it about?

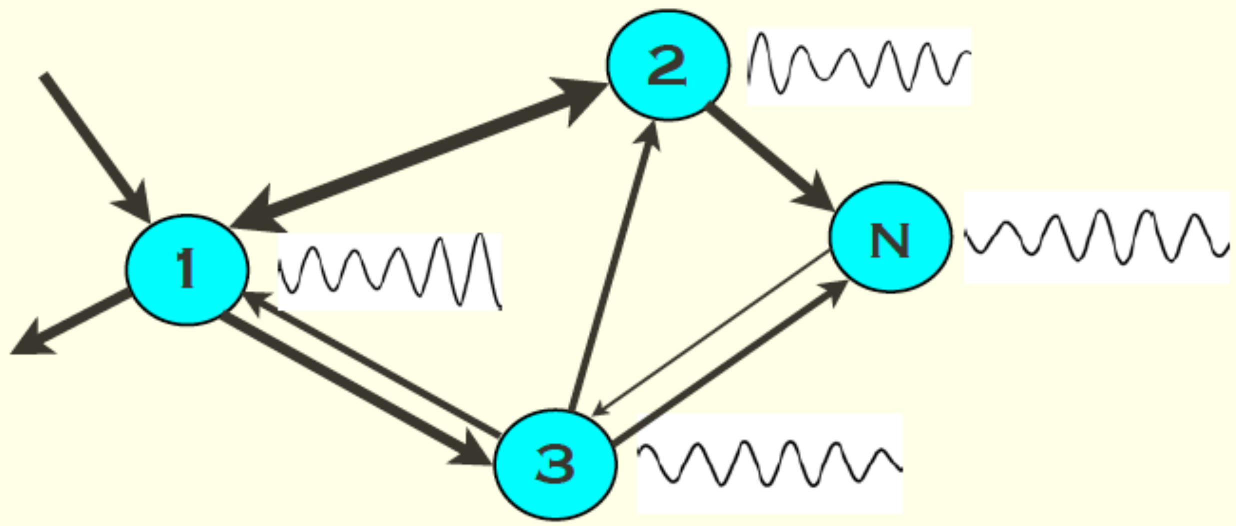
- It is about **multichannel time series**
- It is about **rhythmical processes**
- It is about **model-based analysis**

Model-based vs non-model-based techniques

- Many techniques: no assumption about the origin of the signals, e.g. correlation analysis

- Assumption: **input-output systems**; different interpretation of cross-correlation or cross-spectral analysis

- Assumption: signals are generated by **coupled active oscillators**



Model-based vs non-model-based techniques II

- Disadvantage of model-based techniques:
  we rely on assumptions that sometimes cannot be verified

- Advantage of model-based techniques:
  relatively simple interpretation of the results

Our model: **coupled active oscillators**

Coupled oscillators approach: what is it about?

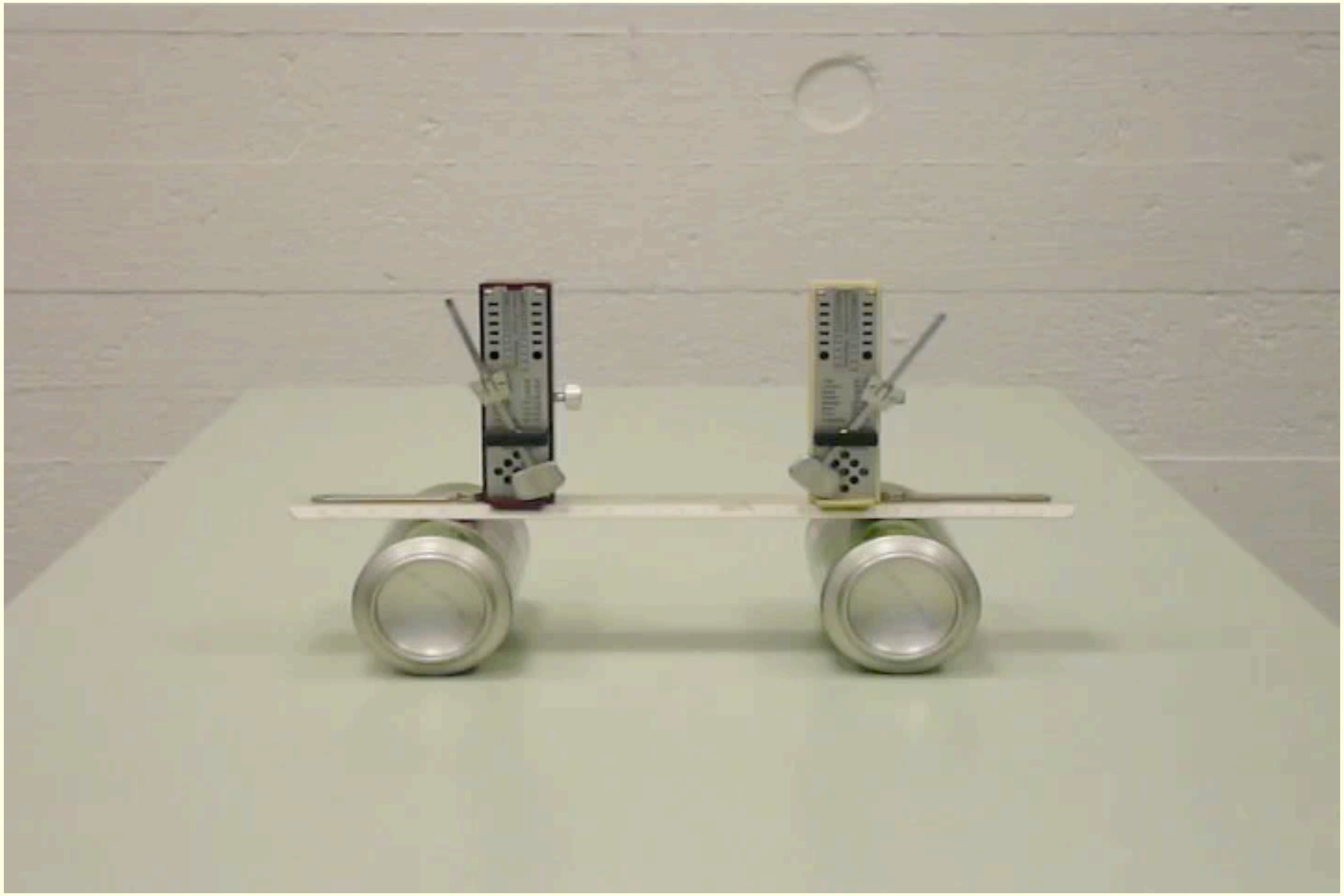
- It is about **multichannel time series**
- It is about **model-based analysis**
- It is about **rhythmical processes**
- It is about **models of coupled active oscillators**

Theory of coupled oscillators and of their **synchronization**

is an important branch of nonlinear science

Synchronization: adjustment of rhythms of interacting active oscillators

Synchronization: an example



two coupled oscillators

Coupled oscillators: an inverse problem

We have only the measurements from the interacting objects and want to find out as much as possible about the oscillators and their couplings

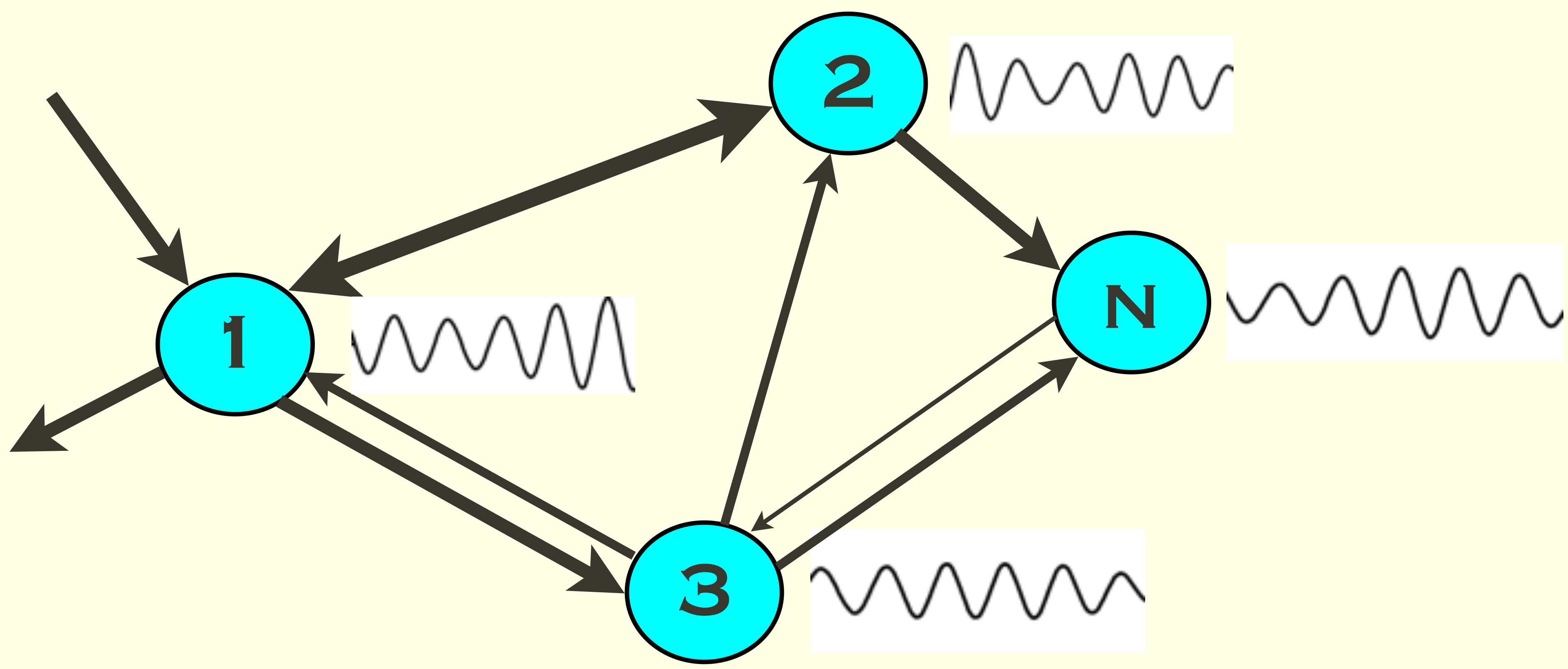
Two types of experiments:

- **active experiment:** we have an access to the parameters of the systems/couplings and can repeat the measurements for different parameters
- **passive experiment:** we do not have an access to the parameters and can only observe the systems under free-running conditions

The case of **active experiments** is relatively simple;

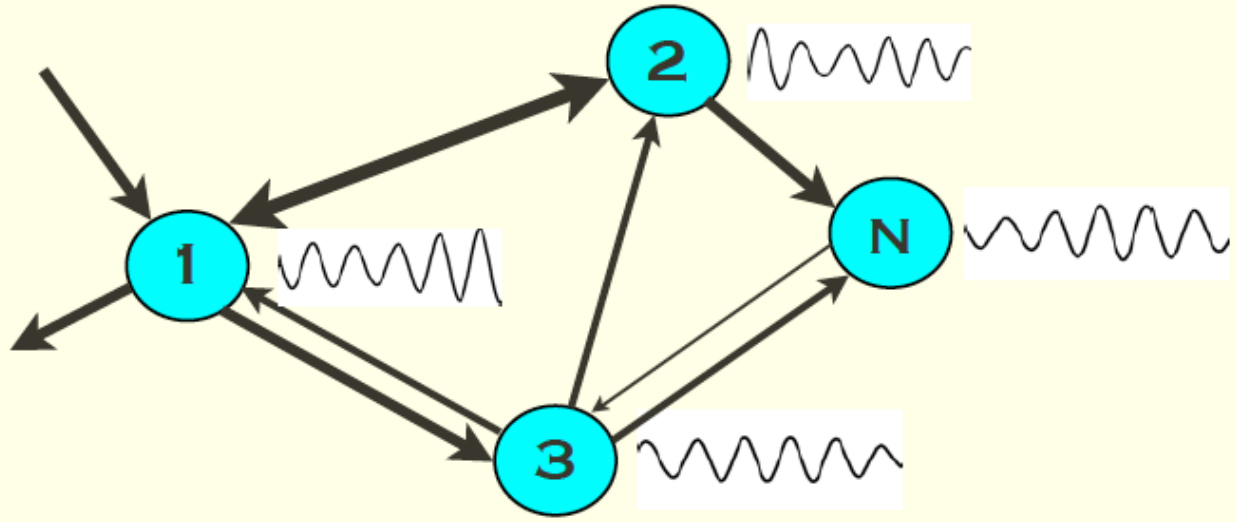
the case of **passive experiments** is very complicated!

Formulation of the problem



- Data: we have oscillatory signals measured from several units
- Assumption 1: the units are **self-sustained** oscillators
- Assumption 2: the interaction between the units is not too strong
- Assumption 3: signals are good for **estimation of phases**
  (later we will relax this requirement)

Formulation of the problem II



- Synchronization analysis: quantification of the strength of the interaction (degree of the phase locking)
- Connectivity analysis: recovery of the **directed** connectivity via reconstruction of phase dynamics from data
- Model reconstruction: estimation of some parameters of the interacting units

For all these tasks we have to estimate phases from measurements