Introduction to EEG, MEG and analysis with the FieldTrip toolbox

Mats van Es

Donders Institute, Radboud University, Nijmegen, NL

What is FieldTrip

a MATLAB toolbox for the analysis of MEG, EEG and animal electrophysiology data

can import data from many different file formats

contains algorithms for spectral analysis, source reconstruction, statistics, connectivity, …

Talk outline

What kind of signals are generated in the brain

How do we record those signals

Analyzing those signals with FieldTrip

Background on the FieldTrip toolbox

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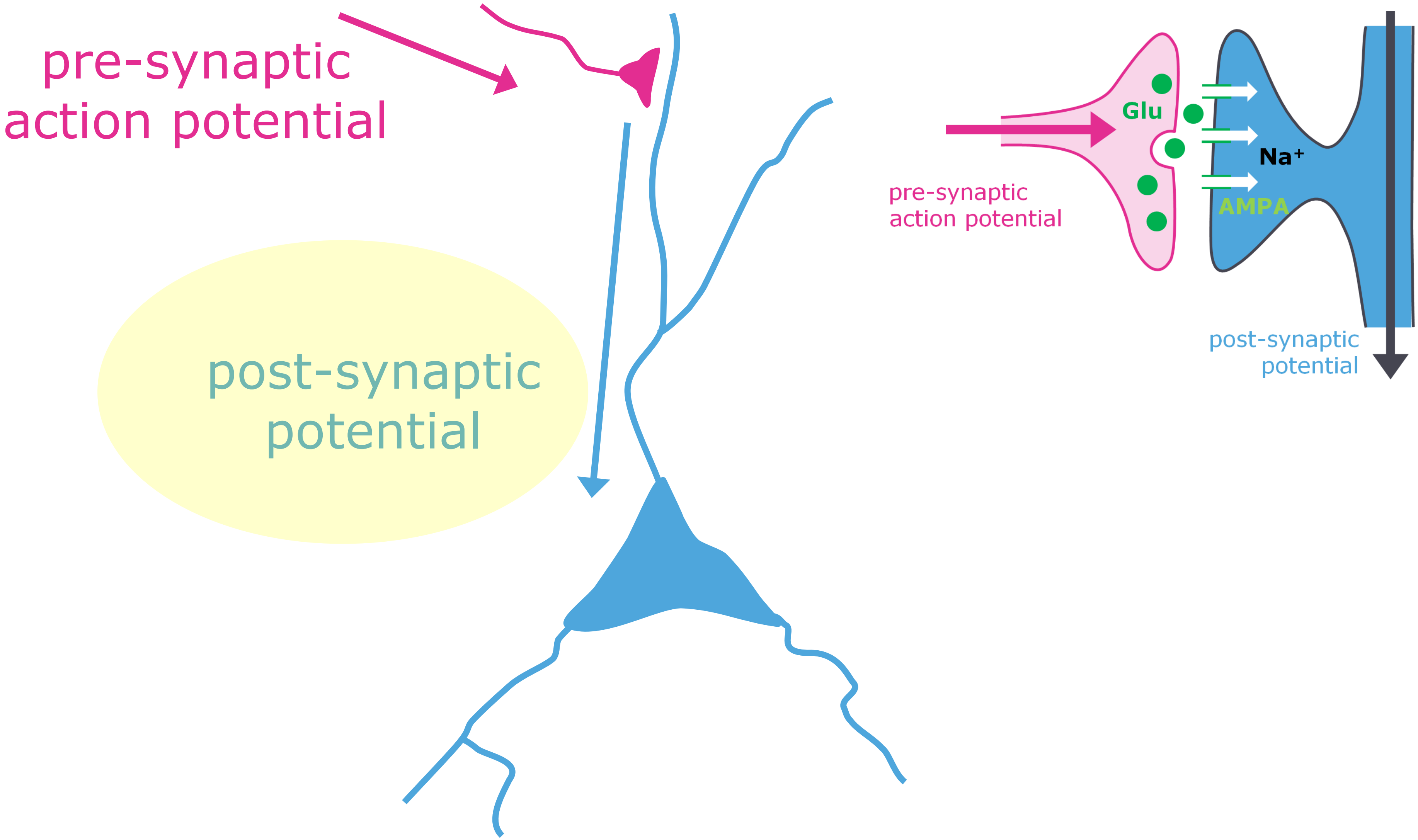
What kind of signals are generated in the brain

We measure the scalp potentials or field associated with post-synaptic potentials in pyramidal neurons

These PSPs represent the exitatory and inhibitory input that these neurons receive

Usually we study this neuronal input following the presentation of a stimulus or following a cognitive event

What produces the electric current and magnetic field?



pre-synaptic action potential

post-synaptic potential

Glu

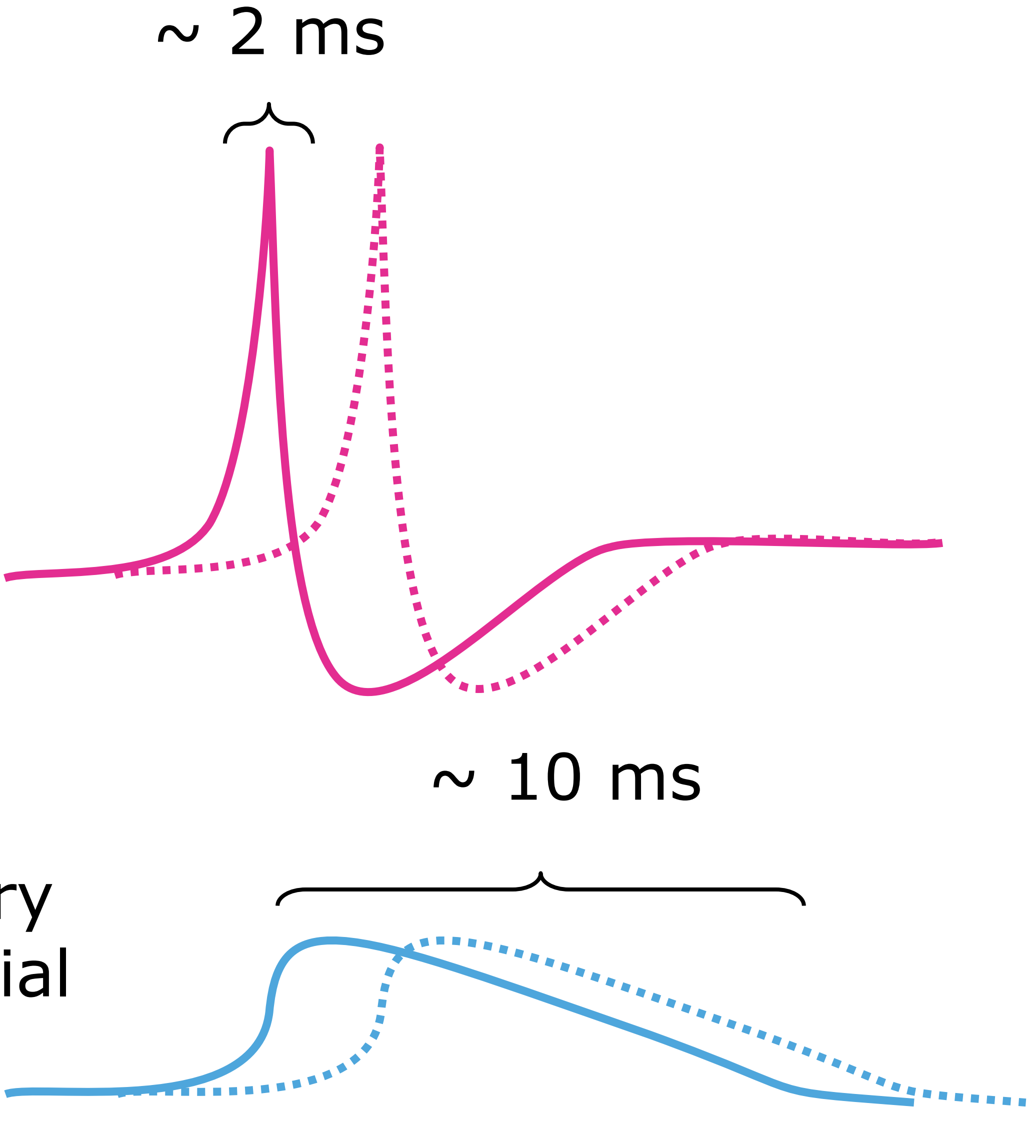
Na+

AMPA

pre-synaptic action potential

post-synaptic potential

What produces the electric current and magnetic field



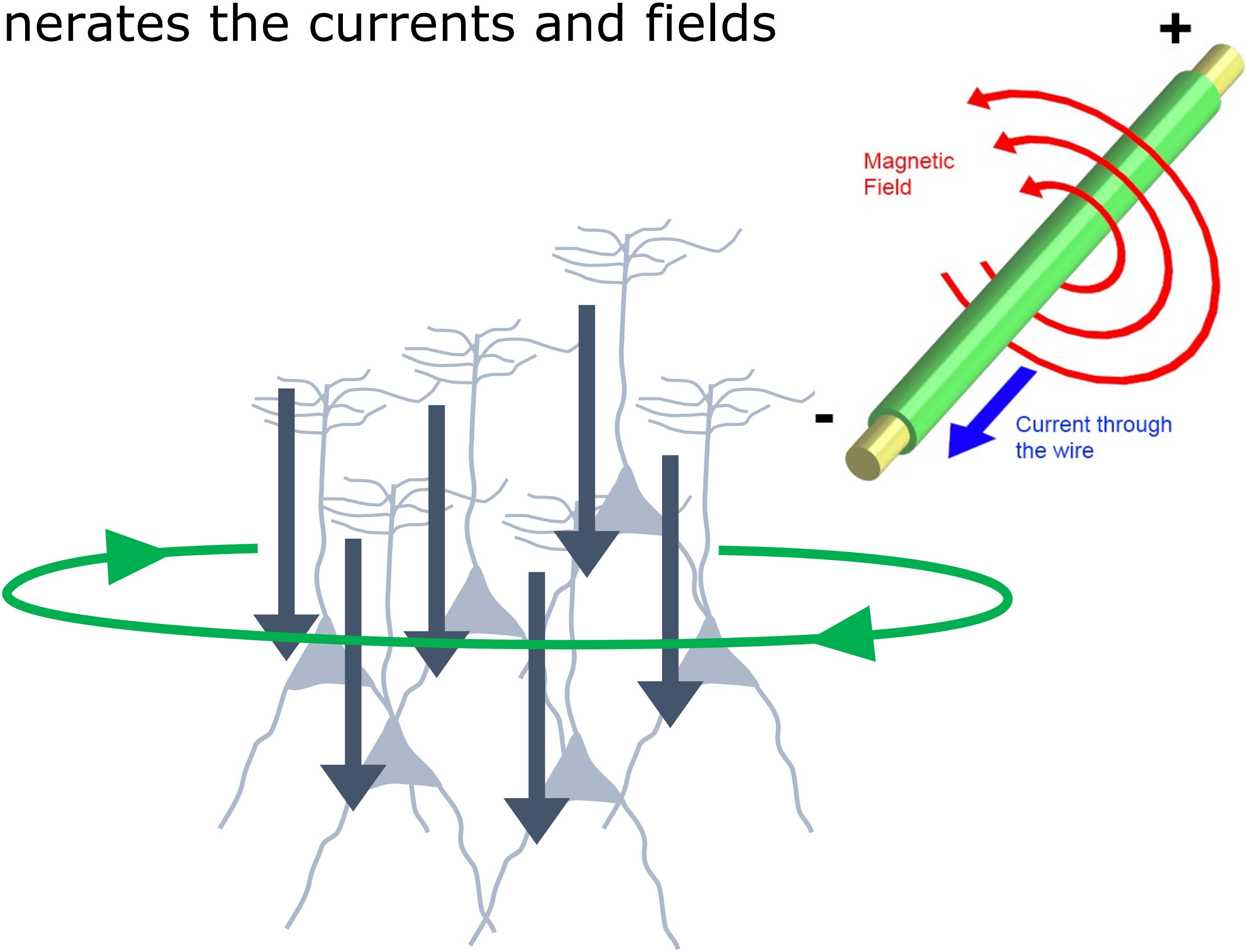
~ 2 ms

action potential

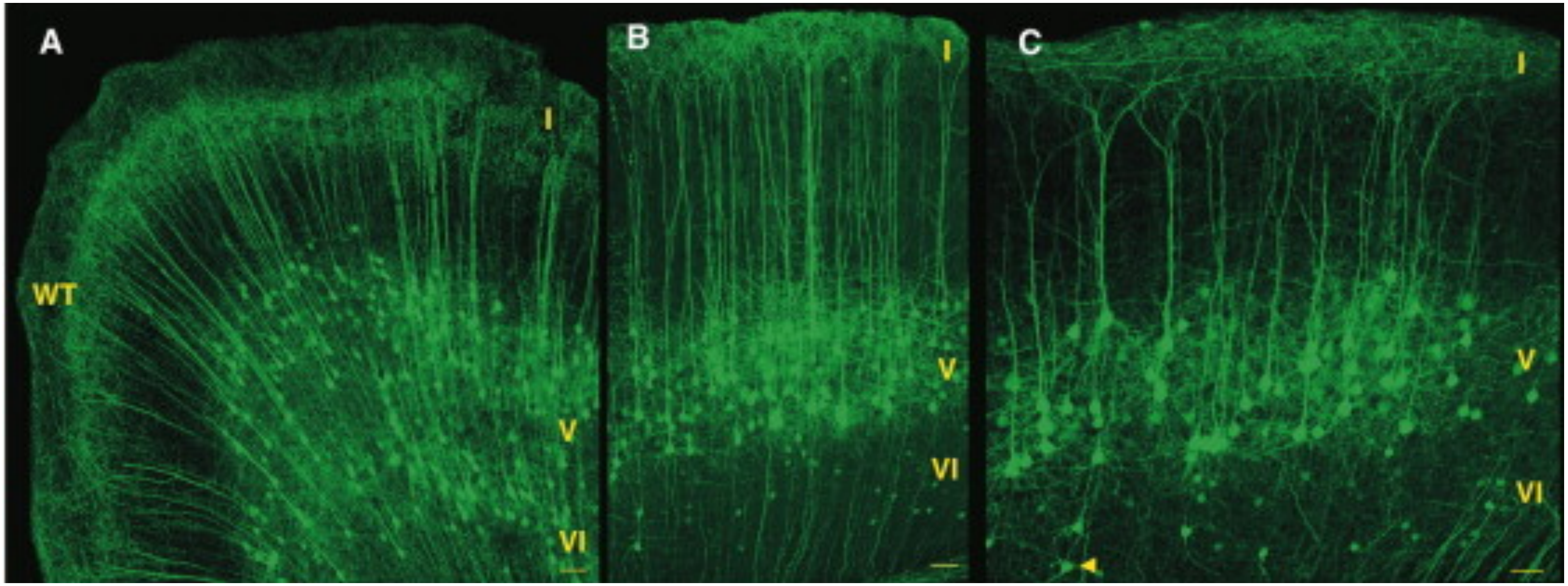
~ 10 ms

exitatory or inhibitory
post-synaptic potential

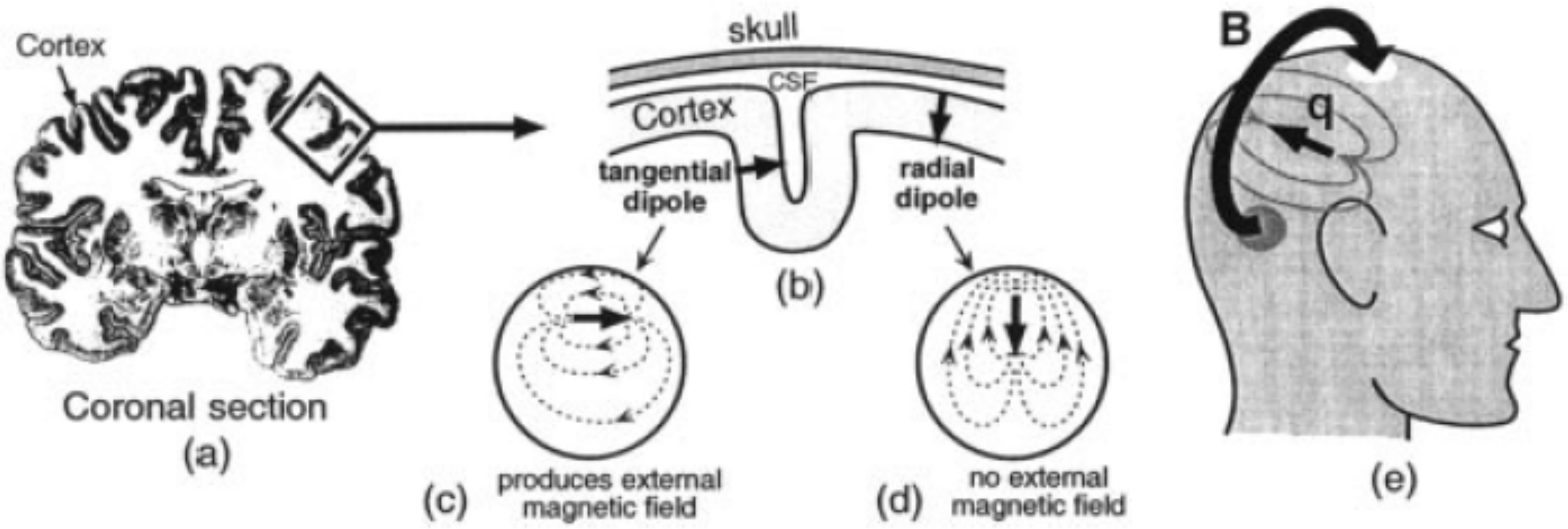
What generates the currents and fields



What generates the currents and fields

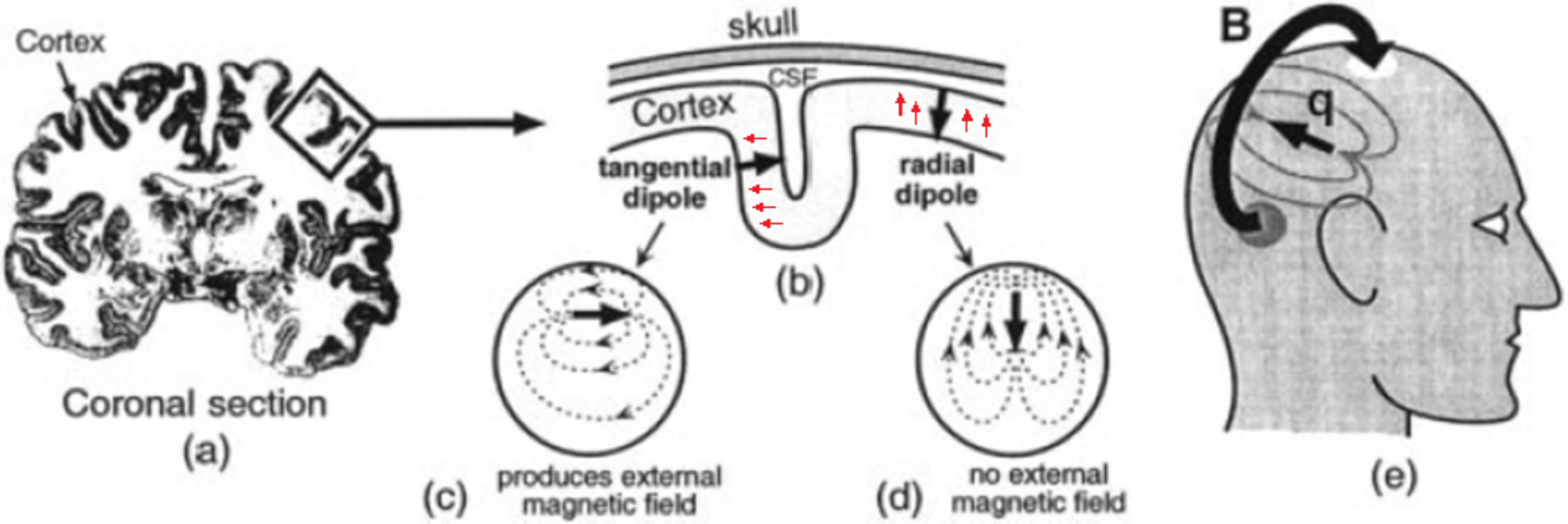


What generates the currents and fields



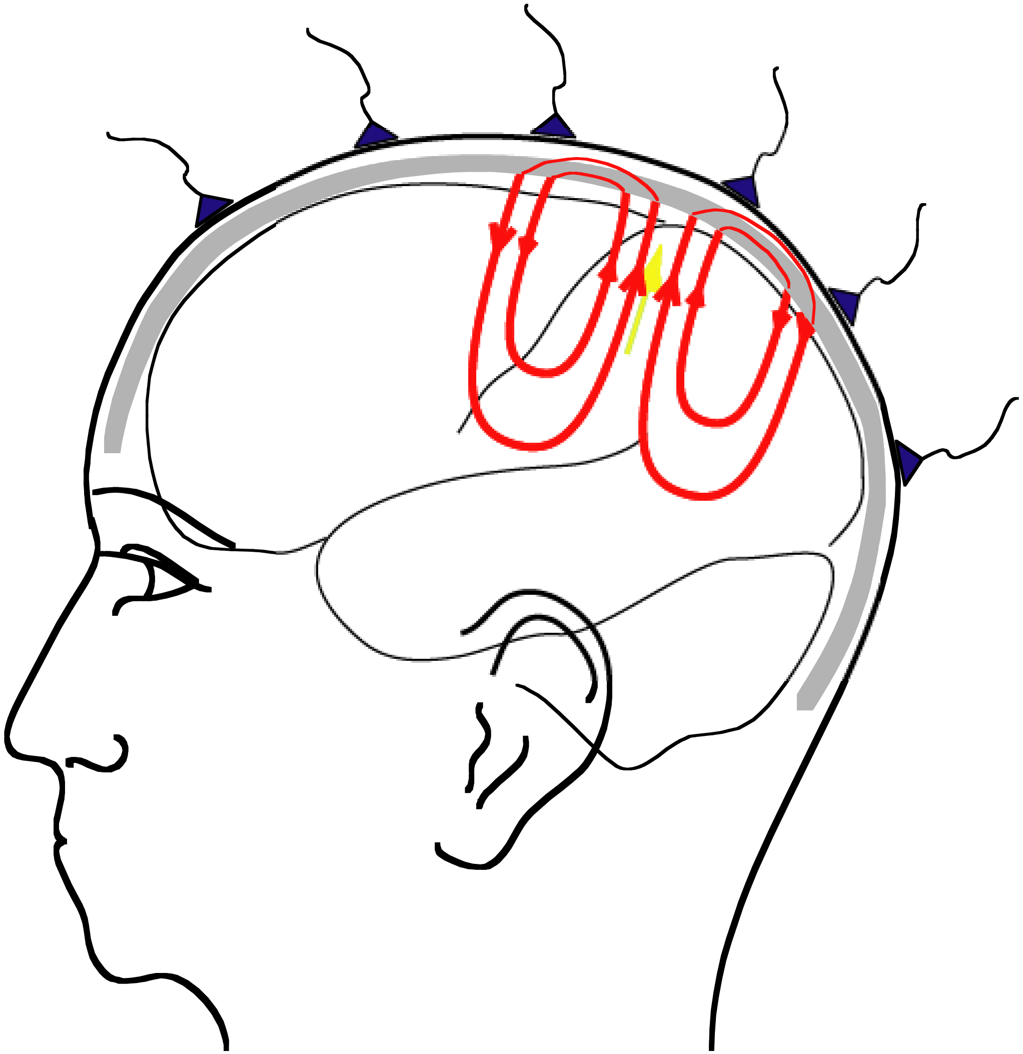
Vrba, 2001

What generates the currents and fields

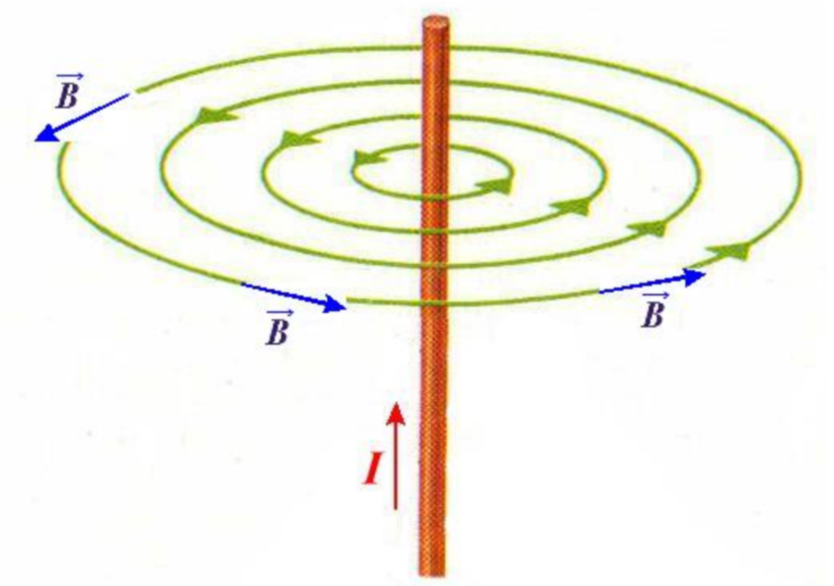


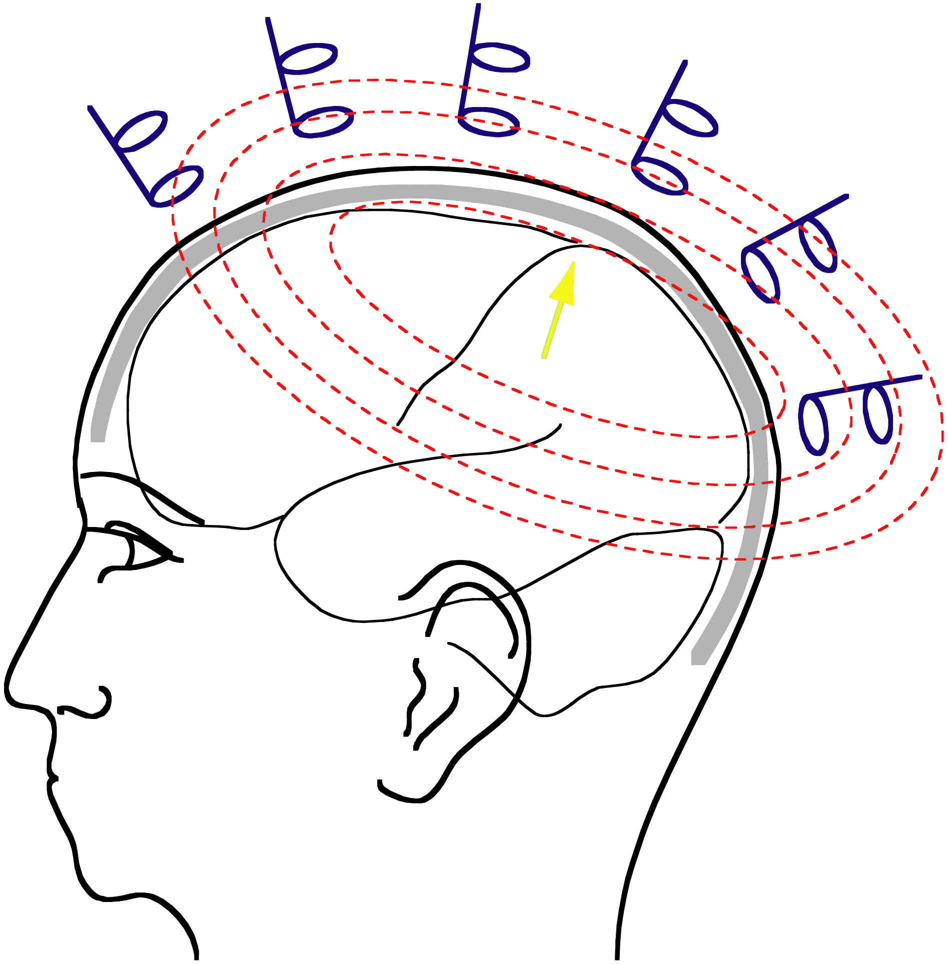
Vrba, 2001

EEG volume conduction



Electric current → magnetic field





Talk outline

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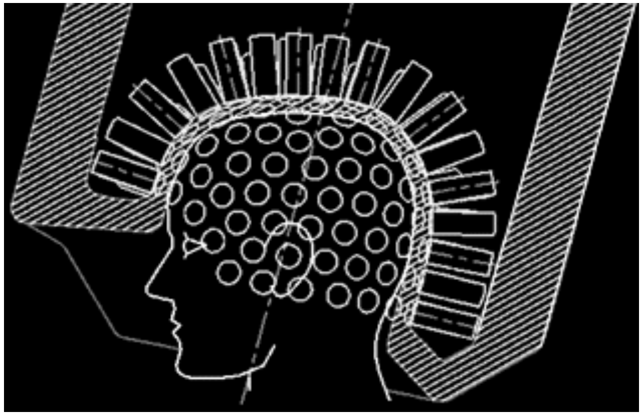
How can we measure brain signals (non-invasively)?

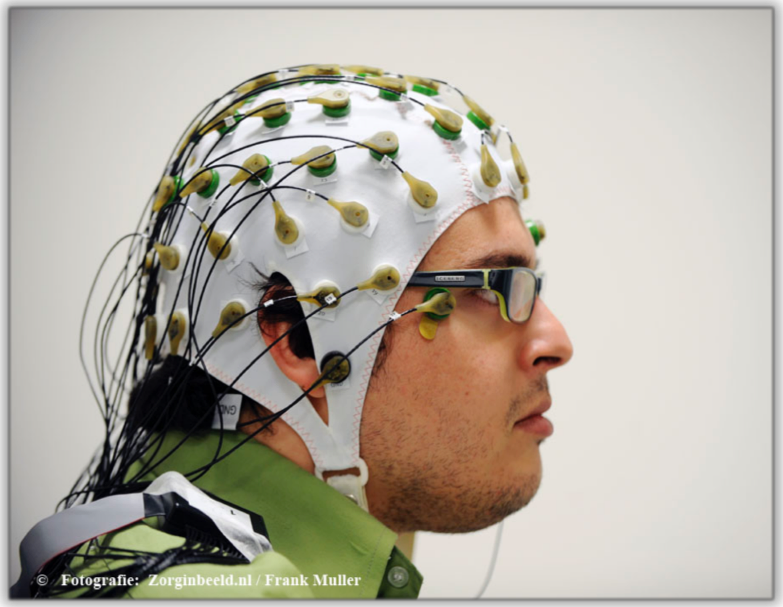
Electroencephalography (EEG)

10,000-1 Million
neurons

Magnetoencephalography (MEG)



EEG apparatus


© Fotografie: Zorginbeeld.nl / Frank Muller

- Sensors
  - Conductivity and smearing
  - Electrode positioning
  - Referencing

- Noise (environmental and internal)
  - Shielding
  - Movement (eyes, heart beat, muscle)

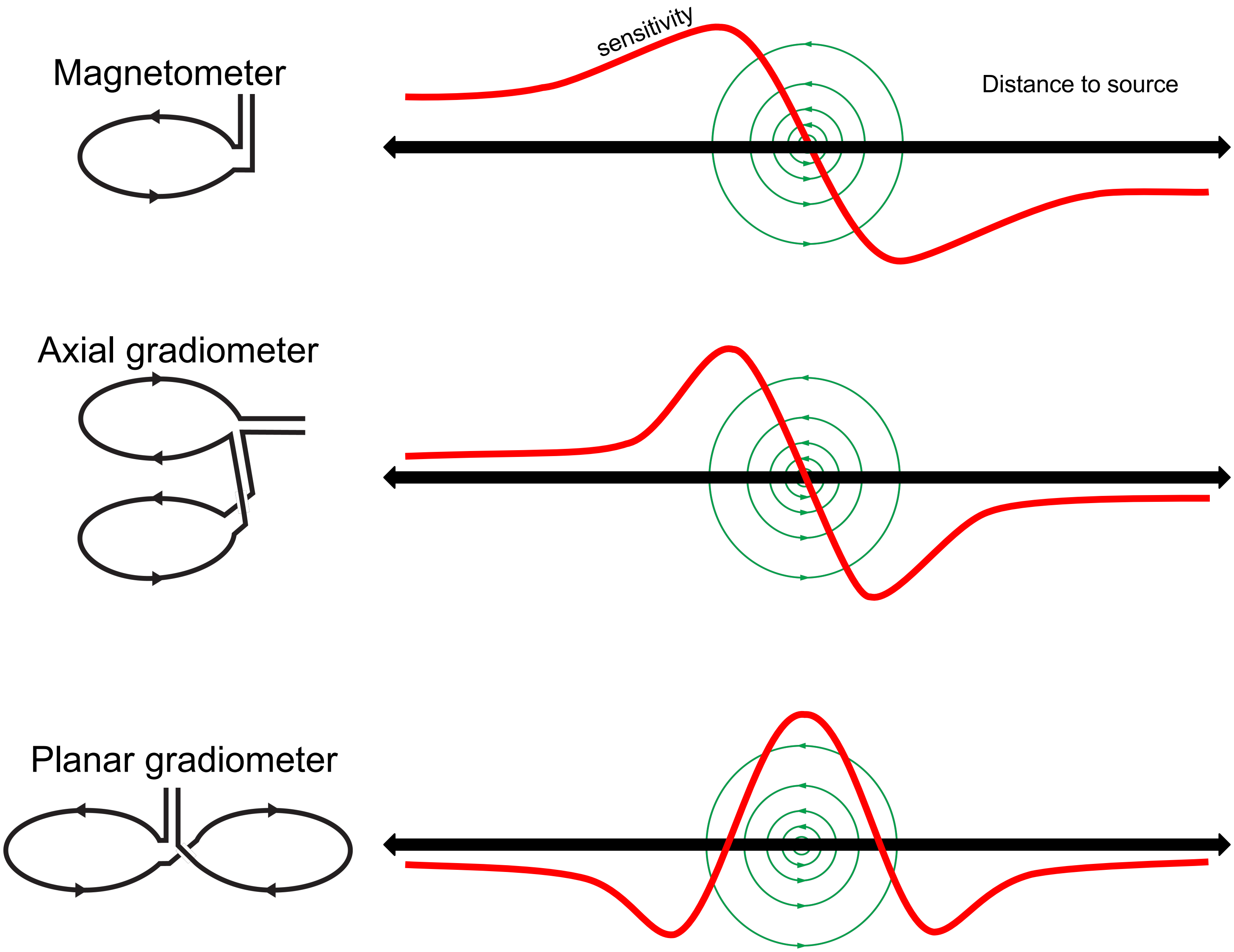
MEG acquisition system

Magnetic detectors: magnetometers, or planar/axial gradiometers

Whole head coverage: 100-300 sensors

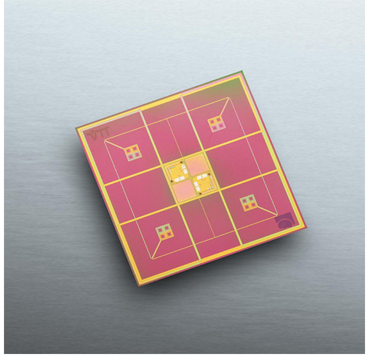
Magnetically shielded room

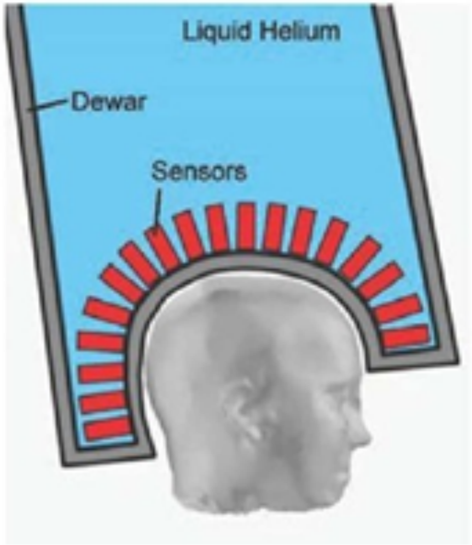
MEG sensor – sensitivity profile

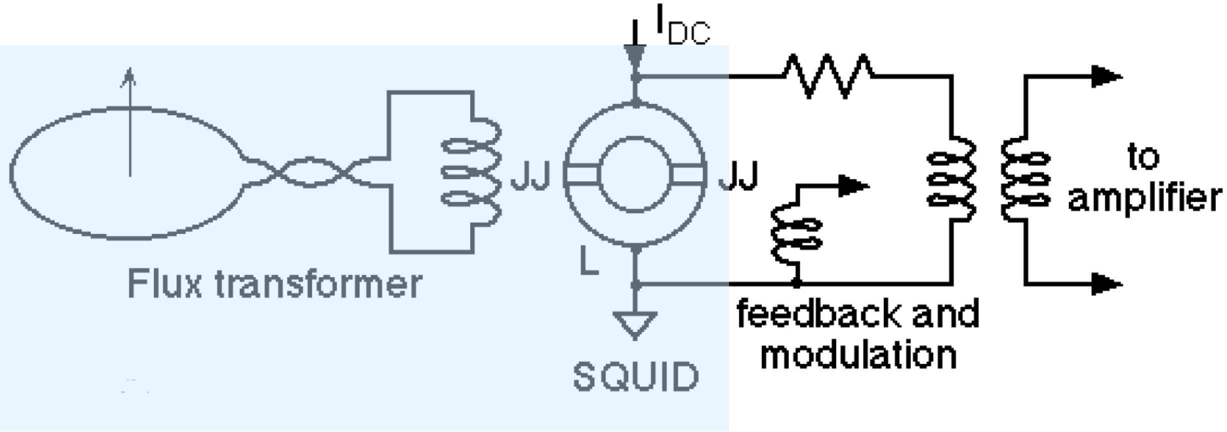


Magnetic field detectors

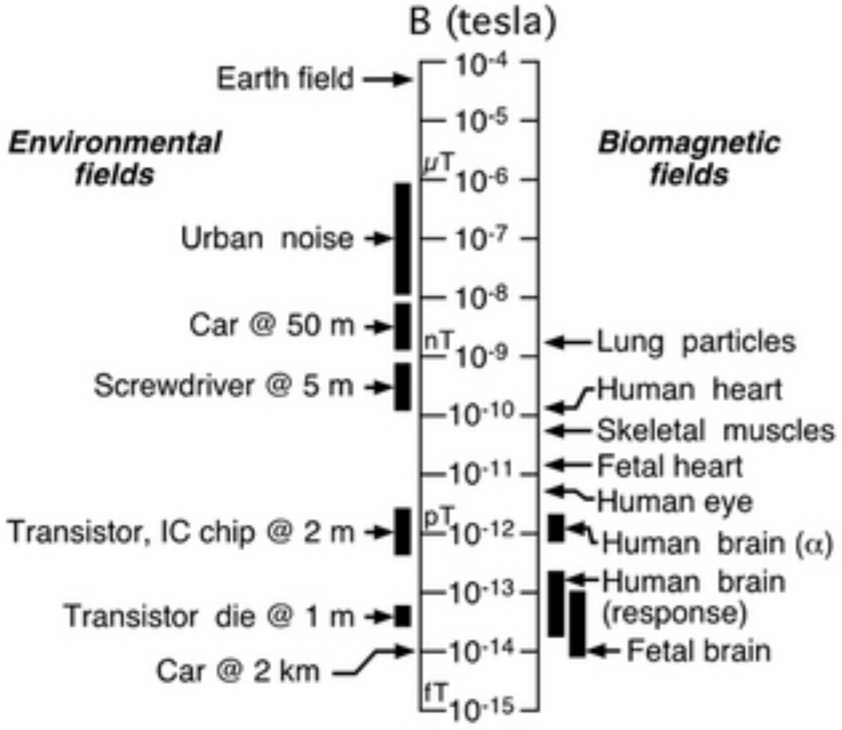
Superconducting **QU**antum **I**nterference **D**evice







Technical challenges of MEG - Noise



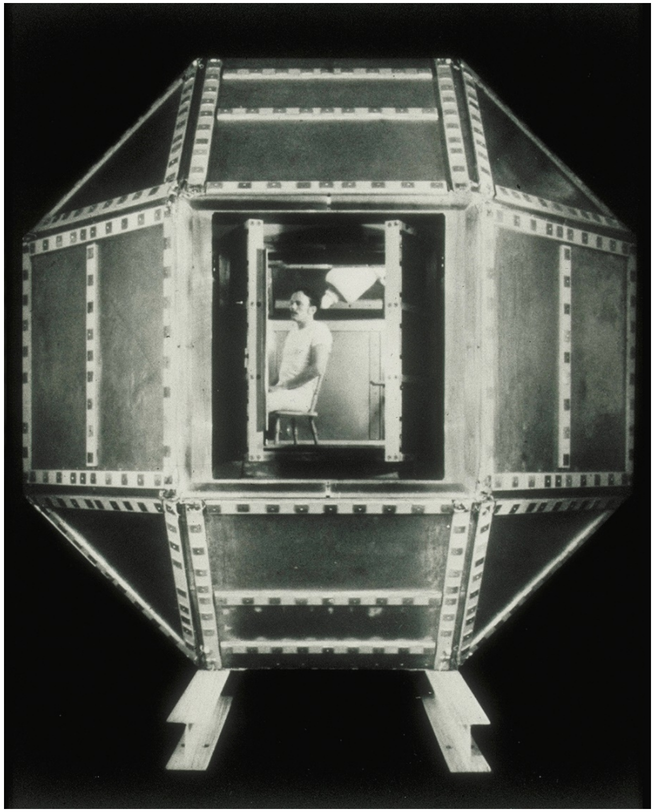
Technical challenges of MEG

Requires sensitive magnetic detectors

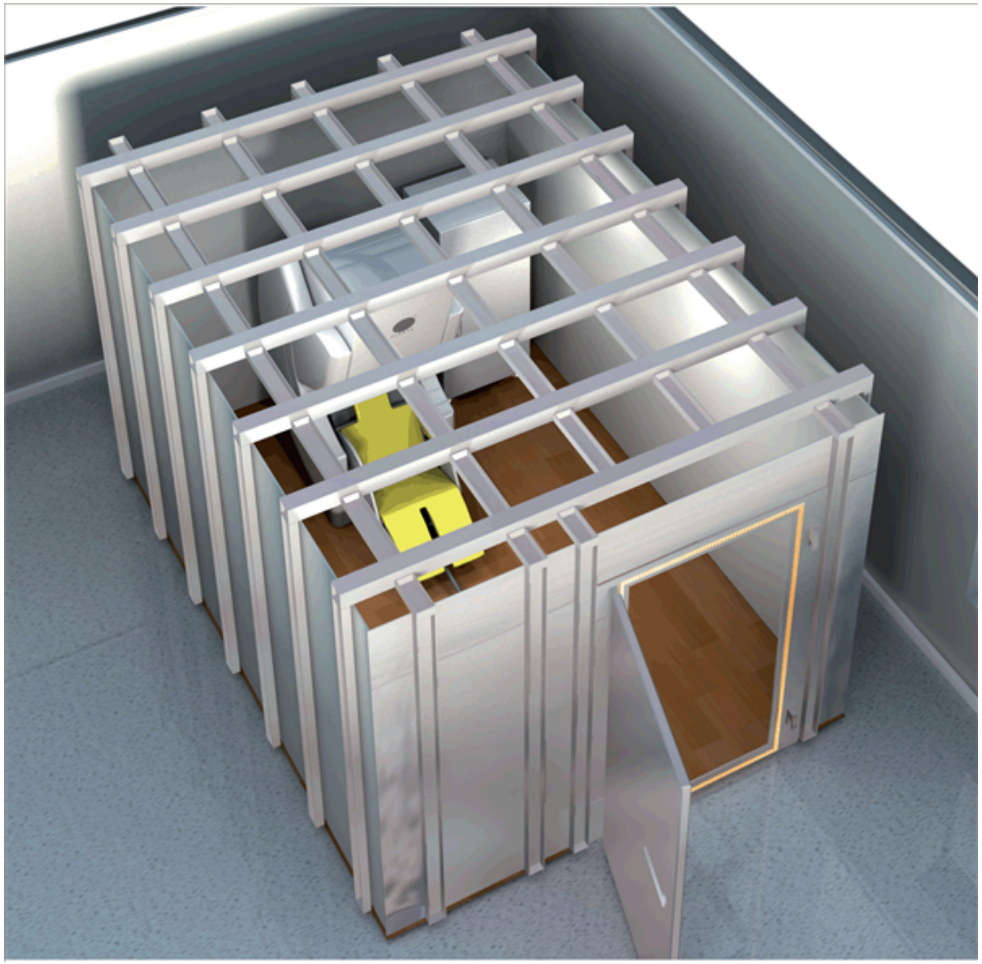
Deal with environmental noise

- shielding
- sensor design
- reference sensors for noise subtraction

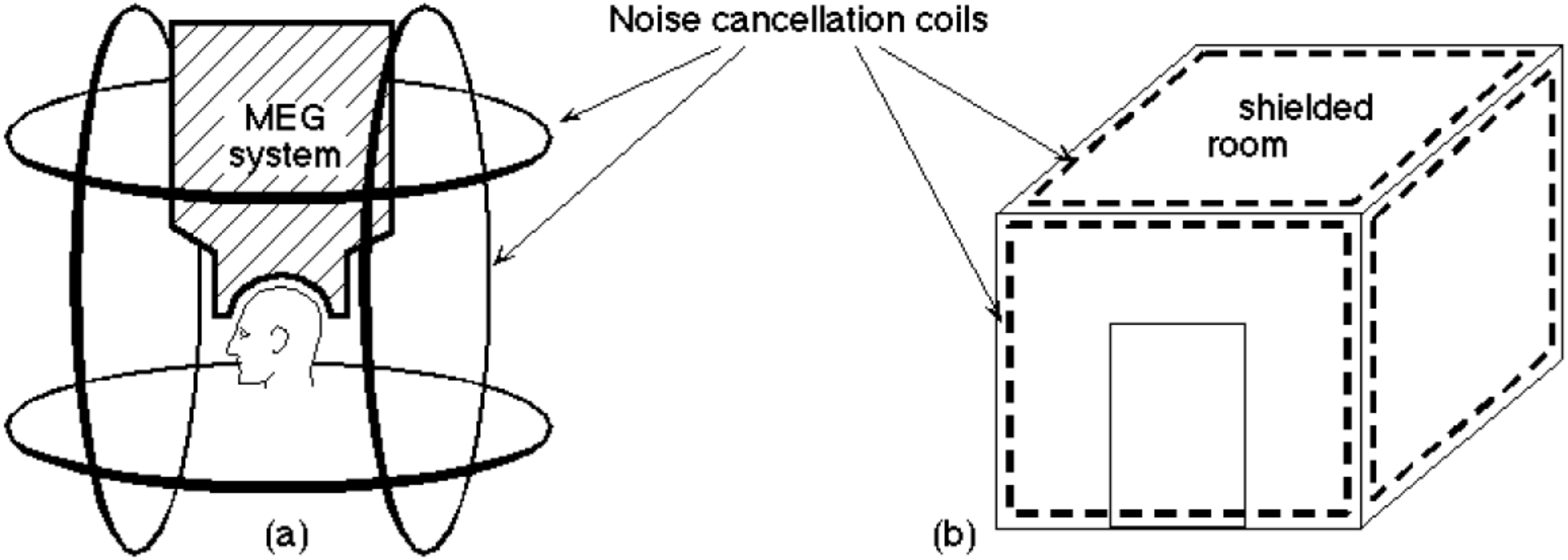
Shielding - passive



The magnetically shielded room built by David Cohen at MIT's Francis Bitter National Magnet Laboratory in 1969.



Shielding - active



EEG vs. MEG

EEG

- Direct measure of neuronal activity
- High temporal resolution

MEG

- Direct measure of neuronal activity
- High temporal resolution

EEG vs. MEG

- Direct measure of neuronal activity
- High temporal resolution

- Direct measure of neuronal activity
- High temporal resolution
- Only sensitive to neurons that are not perpendicular to the head

EEG vs. MEG

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- Direct measure of neuronal activity
- High temporal resolution
- More sensitive to deep sources

MEG

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EEG vs. MEG

– Direct measure of neuronal activity	– Direct measure of neuronal activity
– High temporal resolution	– High temporal resolution
– More sensitive to deep sources	– Only sensitive to neurons that are not perpendicular to the head
– Spatial smearing because of distortion by scalp and skull	– Sources can be localized better

EEG vs. MEG

EEG

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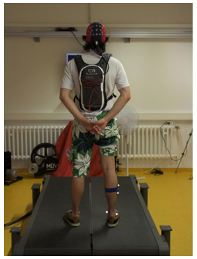
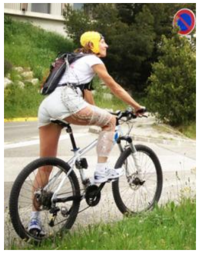
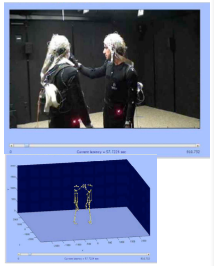
- High temporal resolution







- Transportable
- A lot of preparation time needed

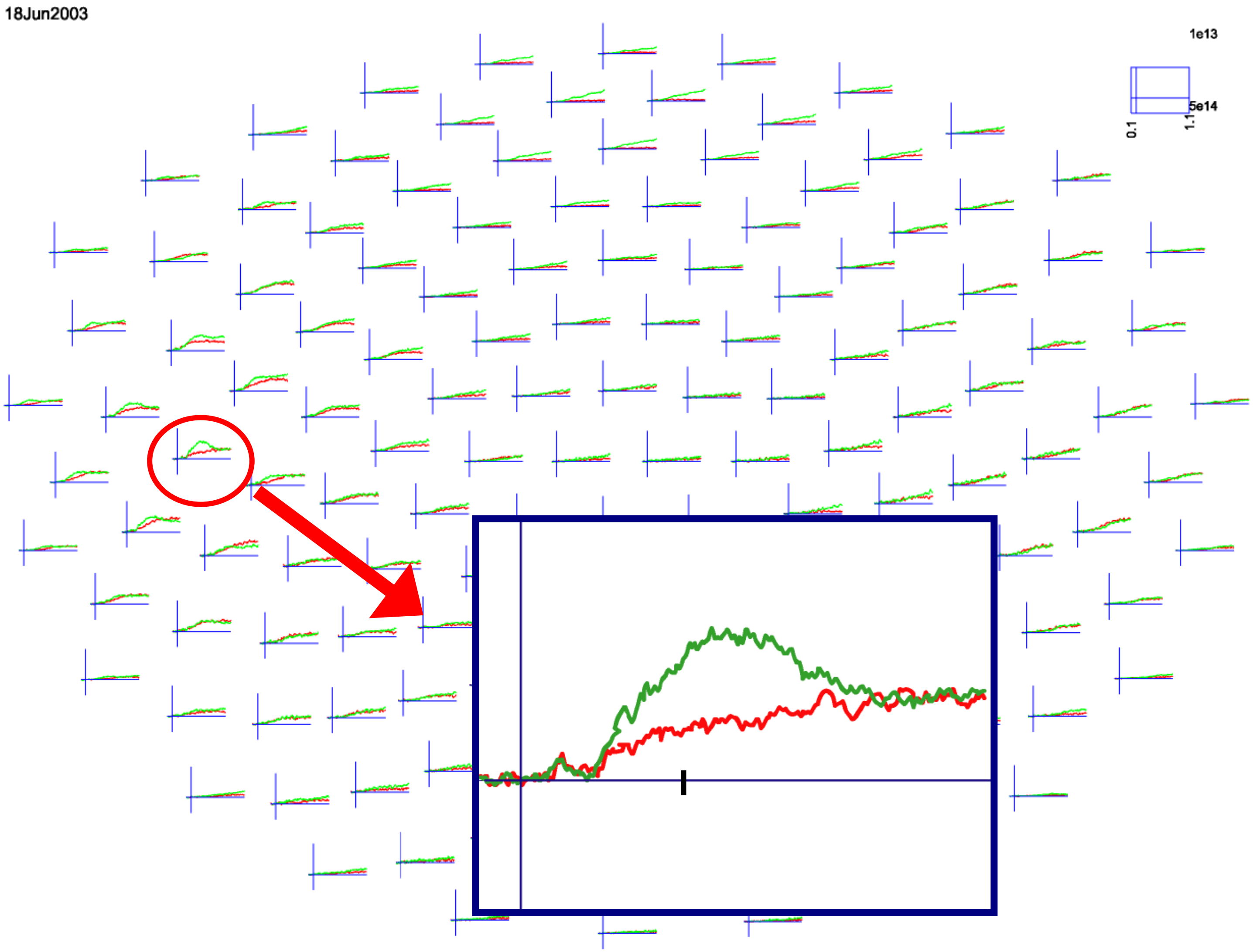
MEG

- Direct measure of neuronal activity
- High temporal resolution
- Only sensitive to neurons that are not perpendicular to the head
- Sources can be localized better

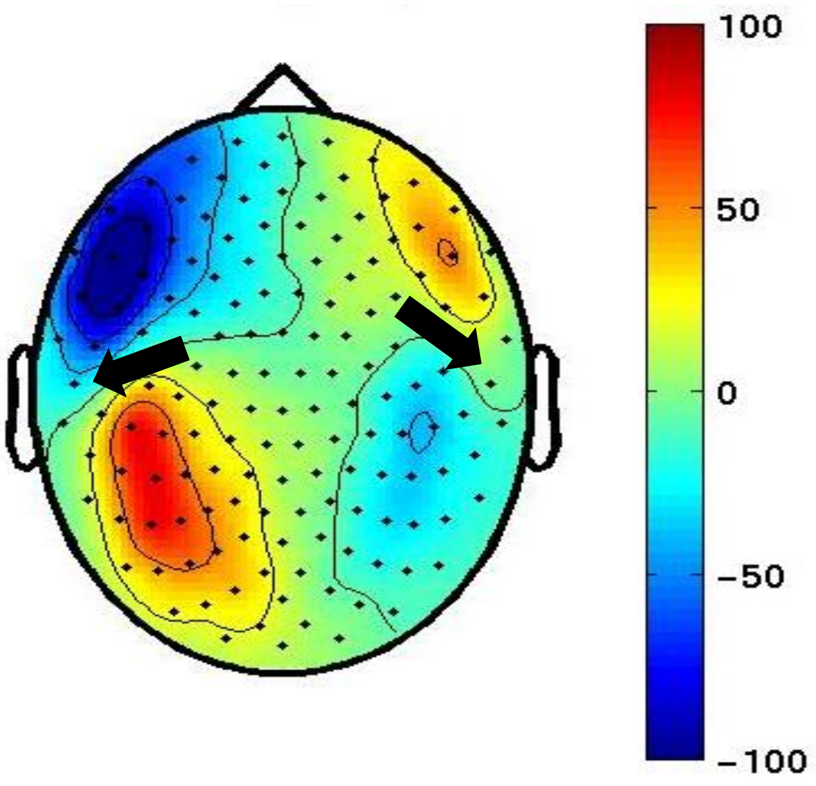
EEG vs. MEG

EEG	MEG
– Direct measure of neuronal activity	– Direct measure of neuronal activity
– High temporal resolution	– High temporal resolution
– More sensitive to deep sources	– Only sensitive to neurons that are not perpendicular to the head
– Spatial smearing because of distortion by scalp and skull	– Sources can be localized better
– Transportable	– More expensive
– A lot of preparation time needed	

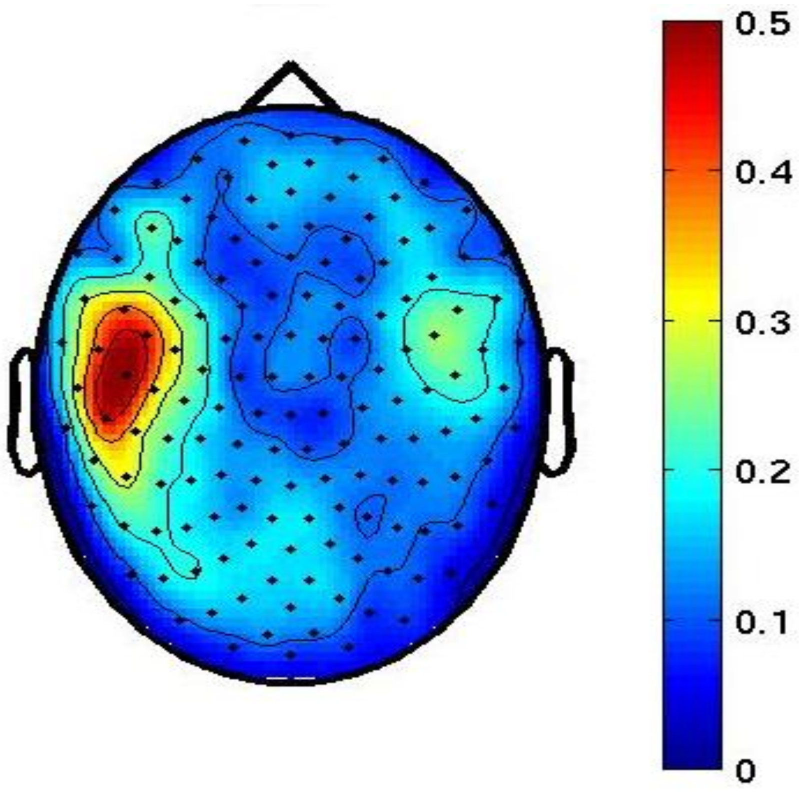
N400 response in MEG



N400 response - compared between MEG systems



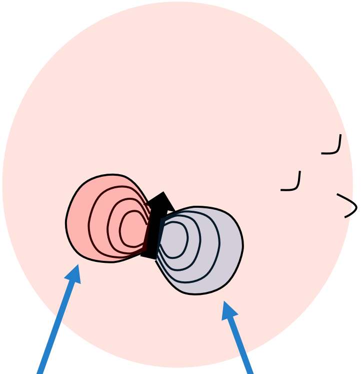
axial gradient



planar gradient

N400 response - EEG Compared to MEG

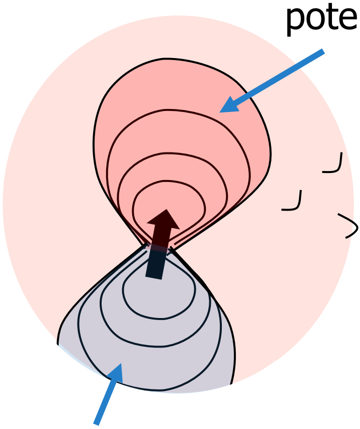
MEG



field out of head 'out'

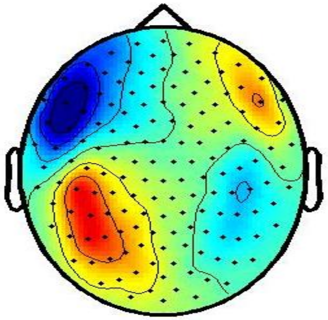
field into head 'in'

EEG

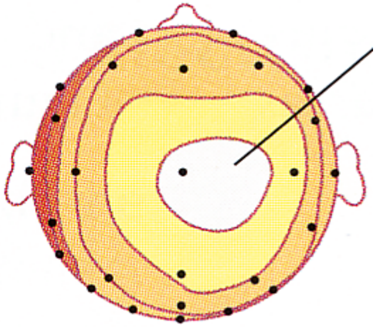


positive potential

negative potential



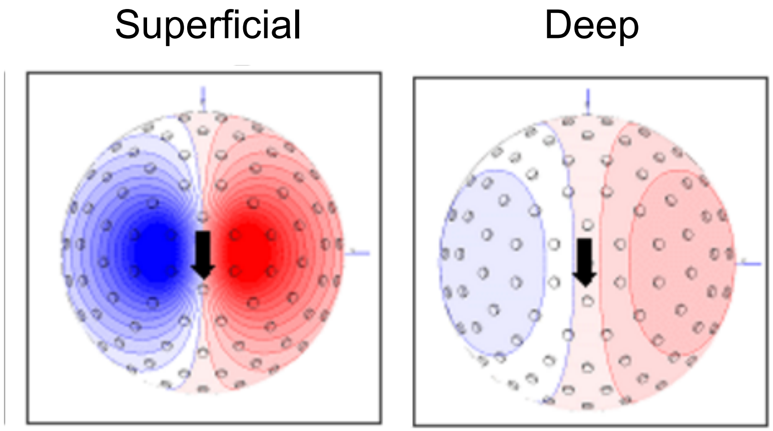
M400 field map



N400 field map

What affects the MEG/EEG signal? Neural Current Depth

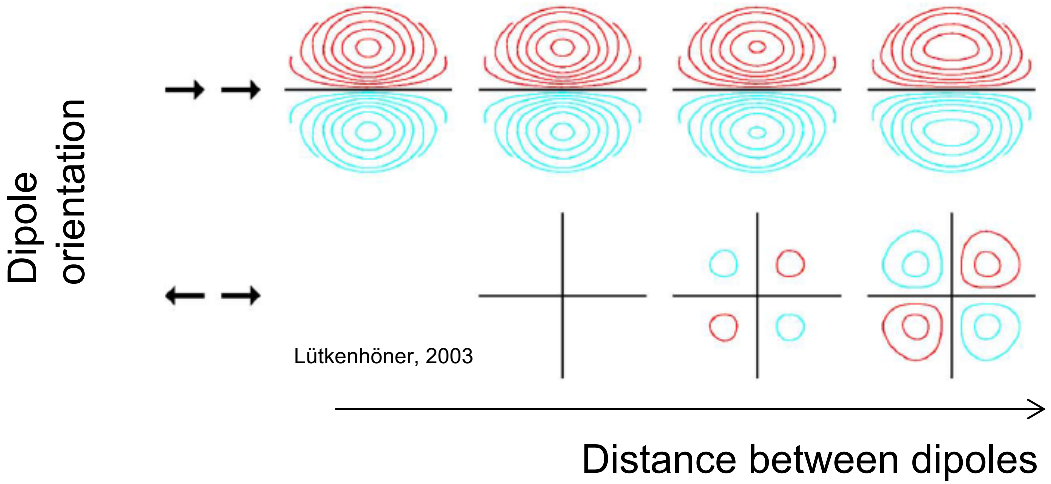
Deep source are difficult to measure



http://imaging.mrc-cbu.cam.ac.uk/meg/IntroEEGMEG#eegrecordings

Sources close together can cancel out

- Perceived as one source
- Reduce signal amplitude



Lütkenhöner, 2003

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Analyzing those signals with FieldTrip

Background on the FieldTrip toolbox

M/EEG signal characteristics considered during analysis

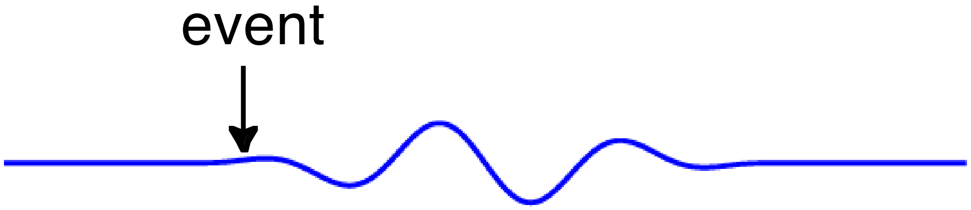
timecourse of activity
-> ERP

spectral characteristics
-> power spectrum

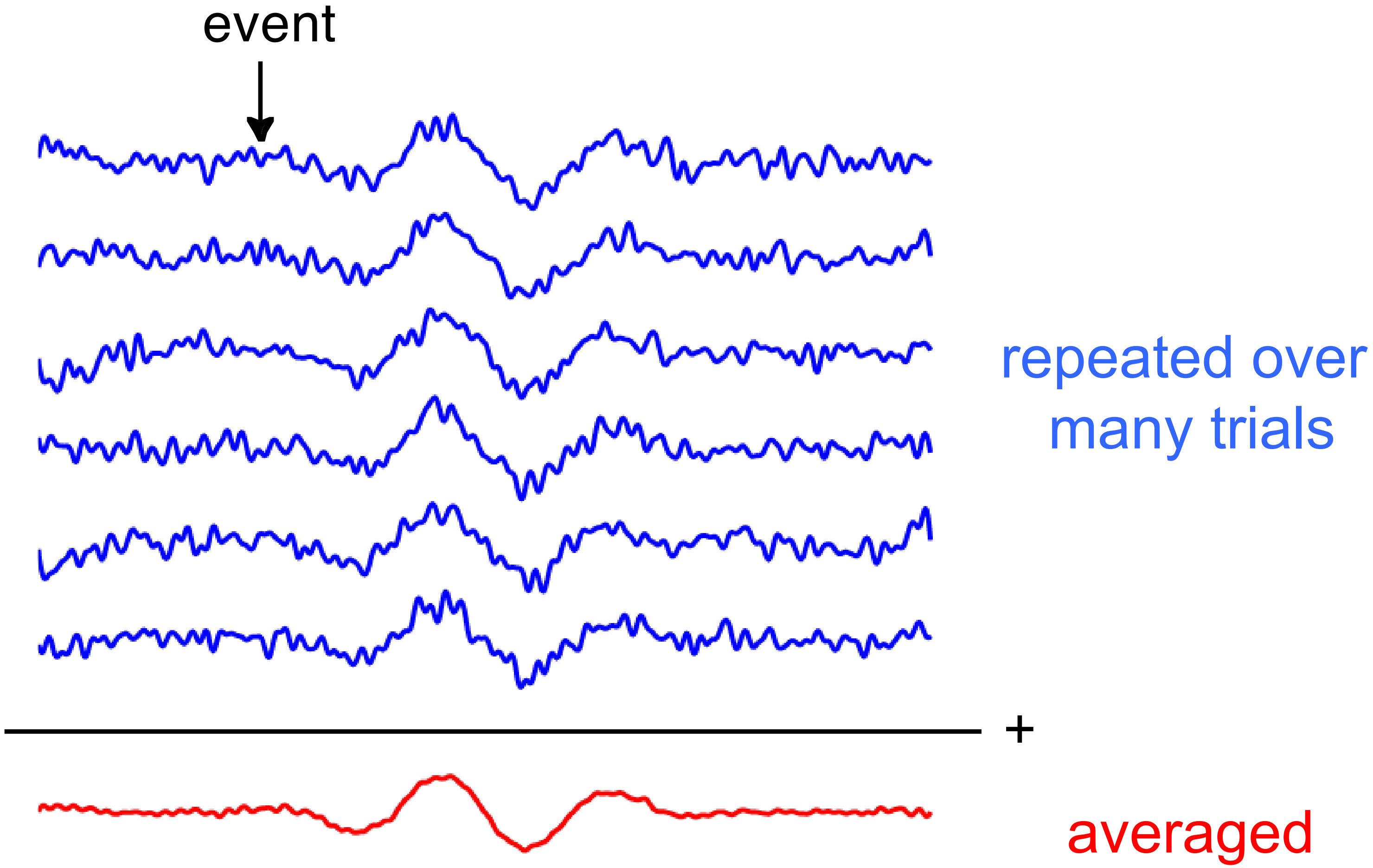
temporal changes in power
-> time-frequency response (TFR)

spatial distribution of activity over the head
-> source reconstruction

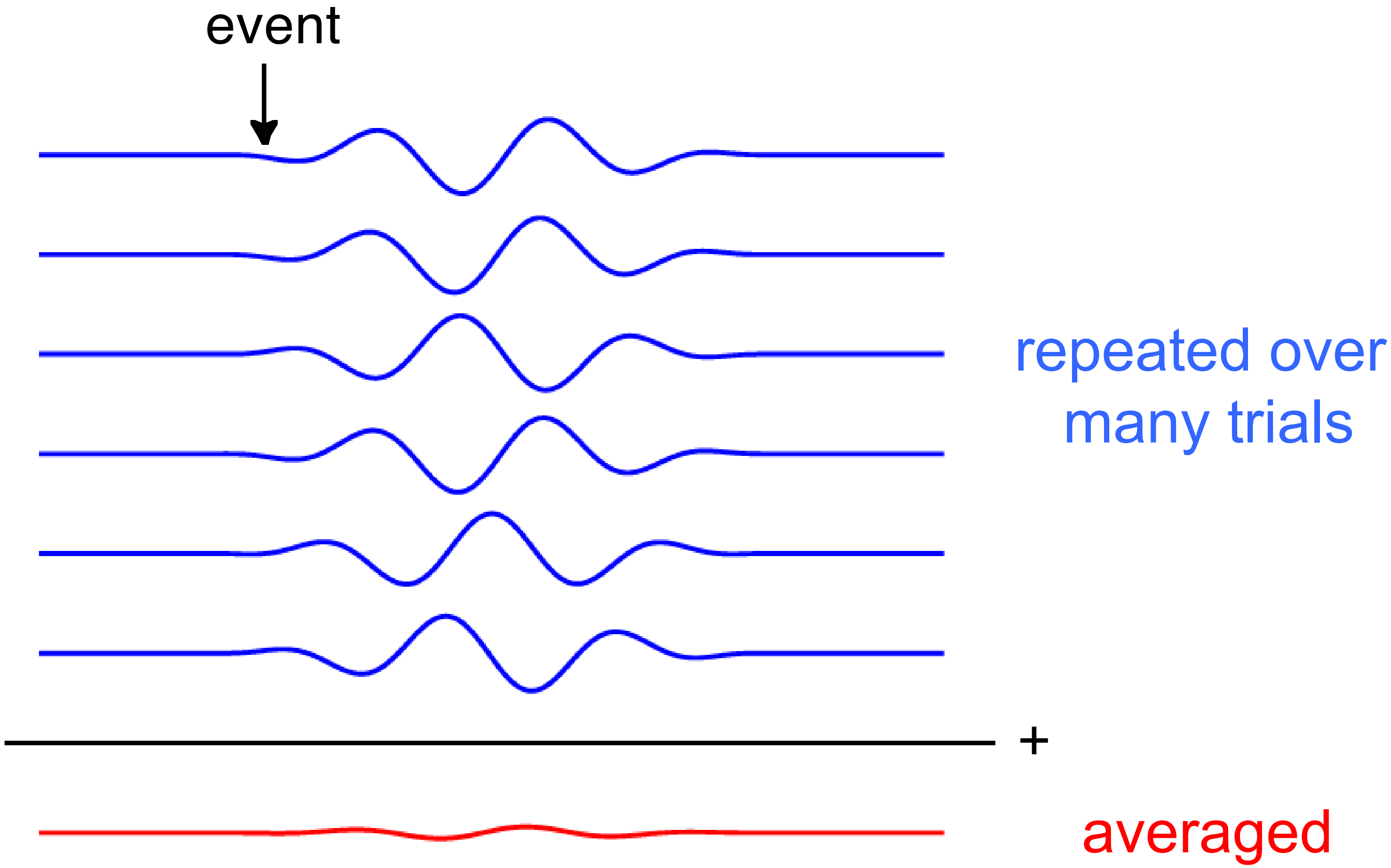
Evoked activity



Evoked activity



Induced activity



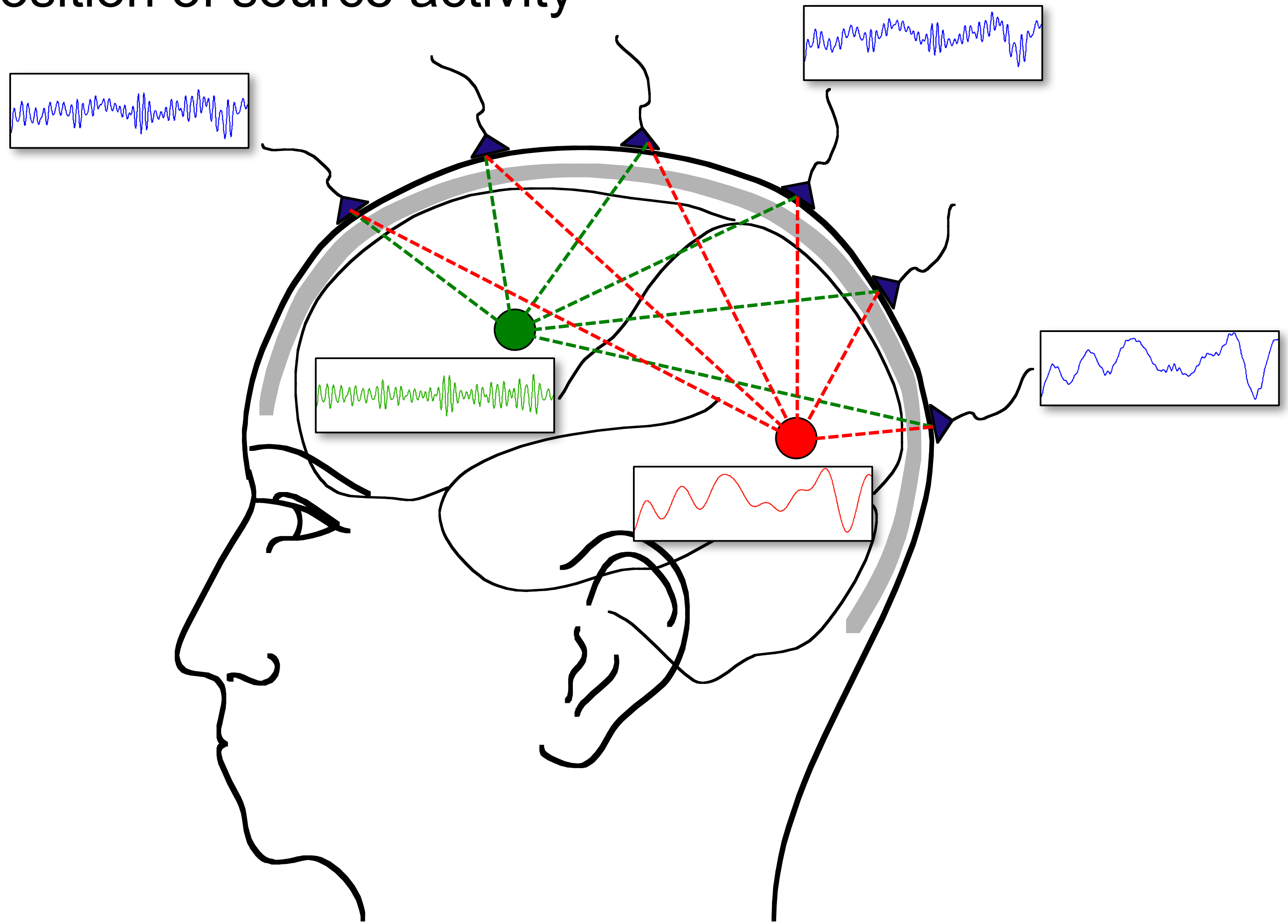
event

repeated over many trials

+

averaged

Superposition of source activity



What is FieldTrip?

A MATLAB toolbox for electrophysiological analysis

Some FieldTrip basics

MATLAB default

```
dataout = functionname(datain, ‘key1’, ‘value1’, …)
```

FieldTrip defaults

```
dataout = functionname(cfg, datain, …)

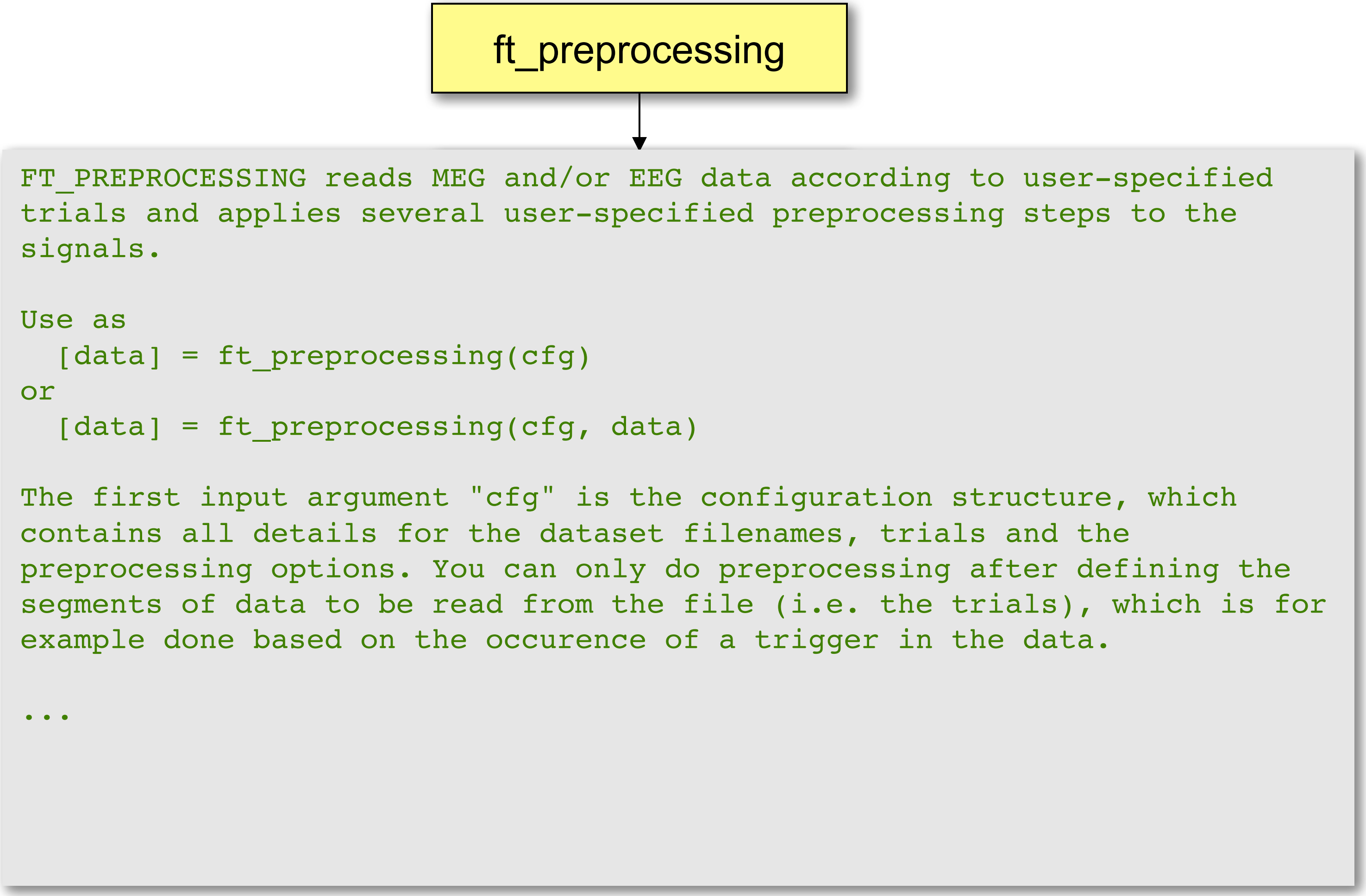
functionname(cfg, datain, …)

dataout = functionname(cfg)
```

the “cfg” argument is a configuration structure, e.g.

```
cfg.channel = {‘C3’, C4’, ‘F3’, ‘F4’}
cfg.foilim = [1 70]
```

Using functions in an analysis protocol



ft_preprocessing

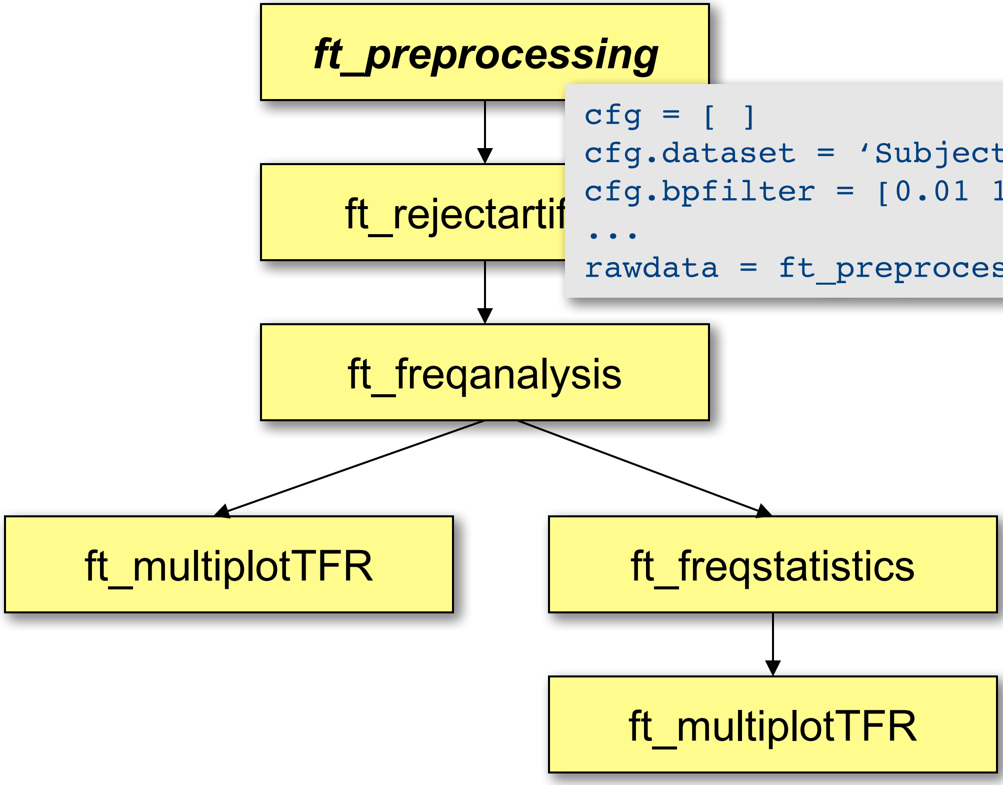
```
FT_PREPROCESSING reads MEG and/or EEG data according to user-specified
trials and applies several user-specified preprocessing steps to the
signals.

Use as
  [data] = ft_preprocessing(cfg)
or
  [data] = ft_preprocessing(cfg, data)

The first input argument "cfg" is the configuration structure, which
contains all details for the dataset filenames, trials and the
preprocessing options. You can only do preprocessing after defining the
segments of data to be read from the file (i.e. the trials), which is for
example done based on the occurence of a trigger in the data.

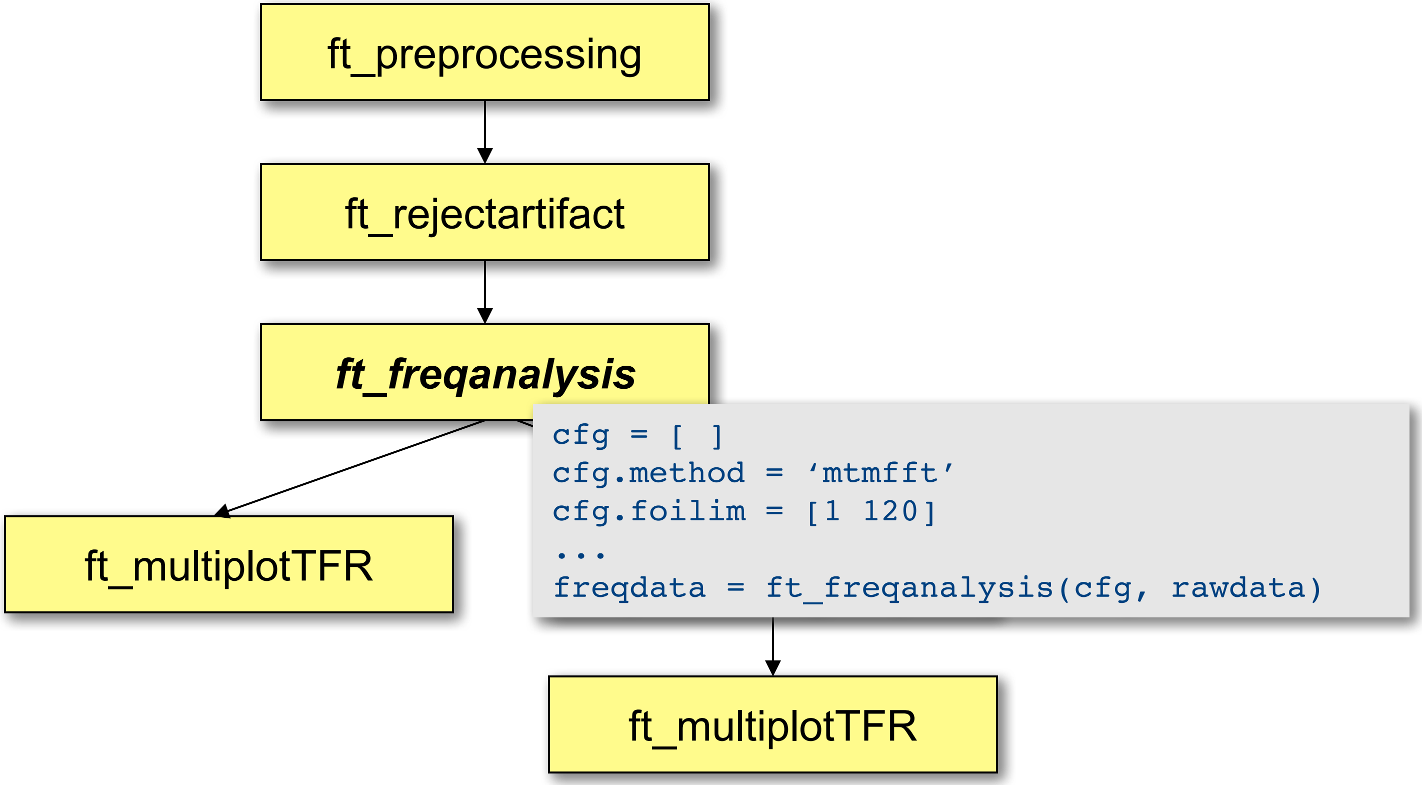
...
```

Using functions in an analysis protocol



```
cfg = [ ]
cfg.dataset = ‘Subject01.ds’
cfg.bpfilter = [0.01 150]
...
rawdata = ft_preprocessing(cfg)
```

Using functions in an analysis protocol



```
cfg = [ ]
cfg.method = ‘mtmfft’
cfg.foilim = [1 120]
...
freqdata = ft_freqanalysis(cfg, rawdata)
```

Raw data structure

```
rawData =
      label: {151x1 cell}
      trial: {1x80 cell}
       time: {1x80 cell}
    fsample: 300
        hdr: [1x1 struct]
        cfg: [1x1 struct]
```

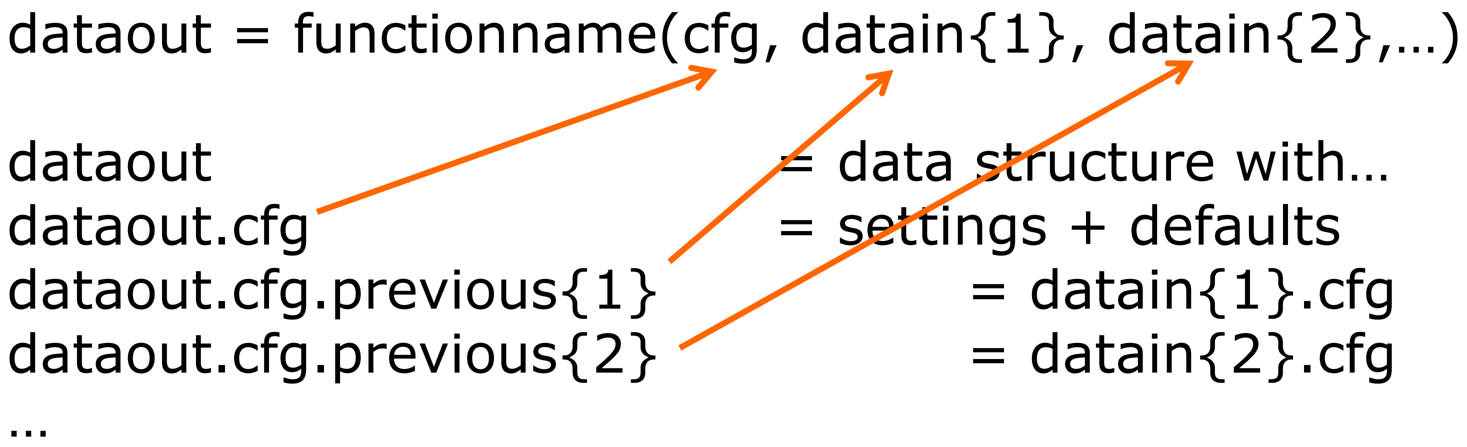
Event related response

```
erpData =
      label: {151x1 cell}
        avg: [151x900 double]
        var: [151x900 double]
       time: [1x900 double]
     dimord: 'chan_time’
        cfg: [1x1 struct]
```

Keeping track of your analysis

input cfg structure specifies parameters

output cfg structure keeps history



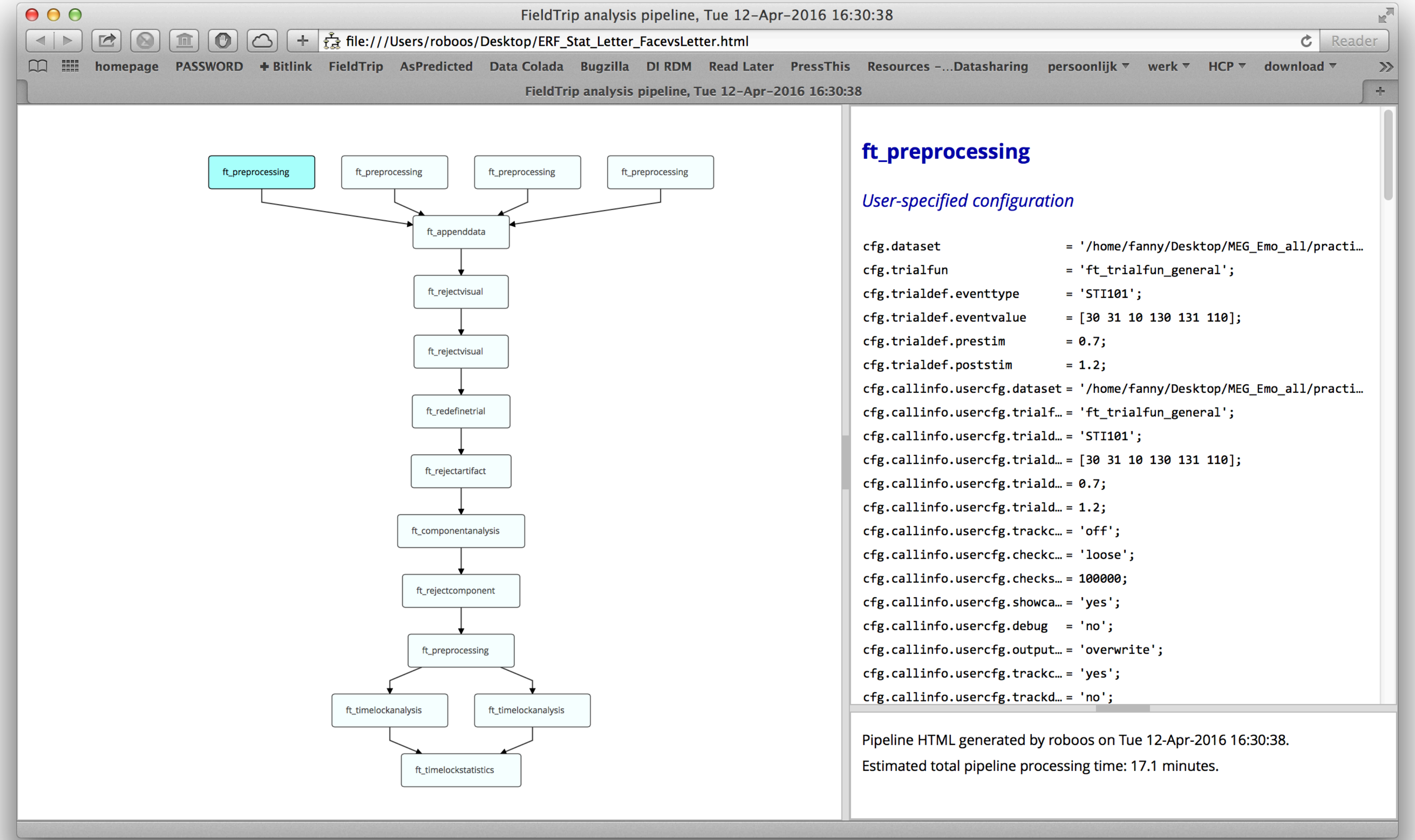
```
dataout = functionname(cfg, datain{1}, datain{2},…)

dataout                          = data structure with…
dataout.cfg                      = settings + defaults
dataout.cfg.previous{1}                = datain{1}.cfg
dataout.cfg.previous{2}                = datain{2}.cfg
…
```

details of computations are kept with data

previous data is not kept, but can be reconstructed using cfg.previous.previous…

Keeping track of your analysis



ft_preprocessing

User-specified configuration

```
cfg.dataset                 = '/home/fanny/Desktop/MEG_Emo_all/practi…
cfg.trialfun                = 'ft_trialfun_general';
cfg.trialdef.eventtype      = 'STI101';
cfg.trialdef.eventvalue     = [30 31 10 130 131 110];
cfg.trialdef.prestim        = 0.7;
cfg.trialdef.poststim       = 1.2;
cfg.callinfo.usercfg.dataset = '/home/fanny/Desktop/MEG_Emo_all/practi…
cfg.callinfo.usercfg.trialf… = 'ft_trialfun_general';
cfg.callinfo.usercfg.triald… = 'STI101';
cfg.callinfo.usercfg.triald… = [30 31 10 130 131 110];
cfg.callinfo.usercfg.triald… = 0.7;
cfg.callinfo.usercfg.triald… = 1.2;
cfg.callinfo.usercfg.trackc… = 'off';
cfg.callinfo.usercfg.checkc… = 'loose';
cfg.callinfo.usercfg.checks… = 100000;
cfg.callinfo.usercfg.showca… = 'yes';
cfg.callinfo.usercfg.debug  = 'no';
cfg.callinfo.usercfg.output… = 'overwrite';
cfg.callinfo.usercfg.trackc… = 'yes';
cfg.callinfo.usercfg.trackd… = 'no';
```

Pipeline HTML generated by roboos on Tue 12-Apr-2016 16:30:38.

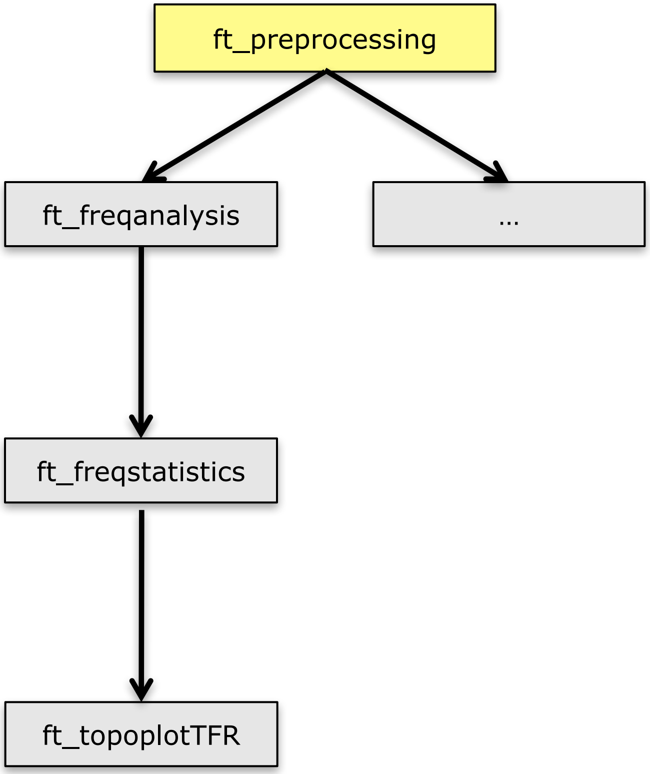
Estimated total pipeline processing time: 17.1 minutes.

Example use in scripts

```
cfg = []
cfg.dataset = ‘Subject01.ds’
cfg.bpfilter = [0.01 150]
...
rawdata = ft_preprocessing(cfg)
```

```
cfg = []
cfg.method = ‘mtmfft’
cfg.foilim = [1 120]
...
freqdata = ft_freqanalysis(cfg, rawdata)
```

```
cfg = []
cfg.method = ‘montecarlo’
cfg.statistic = ‘indepsamplesT’
cfg.design = [1 2 1 2 2 1 2 1 1 2 ... ]
...
freqstat = ft_freqstatistics(cfg, freqdata)
```



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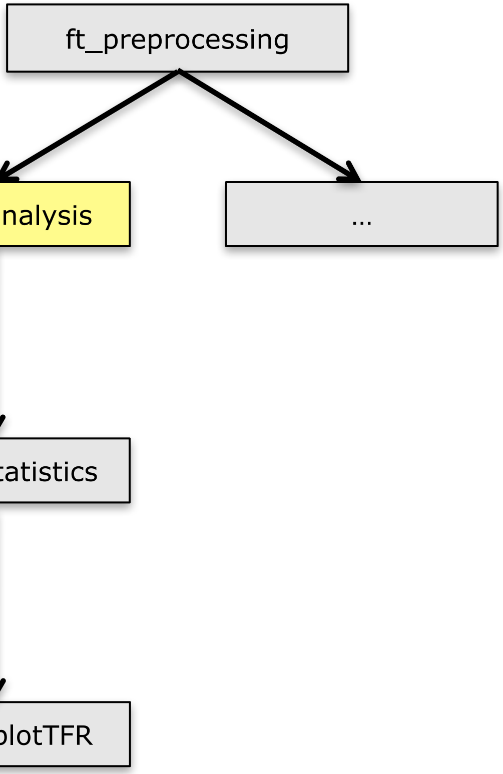

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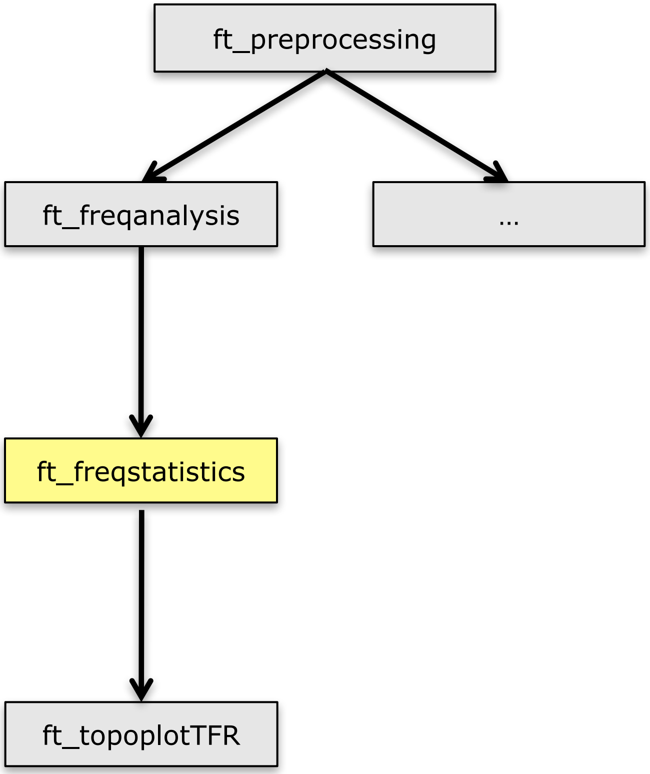

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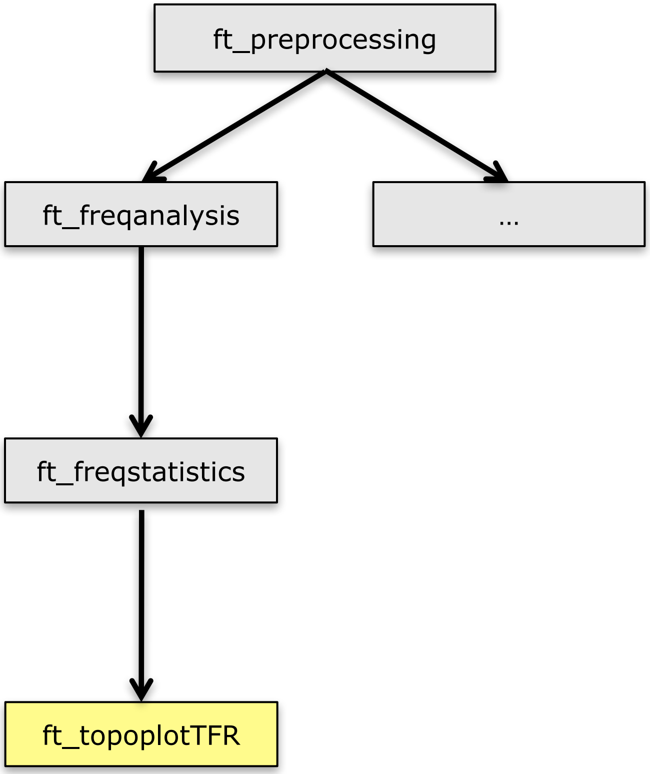

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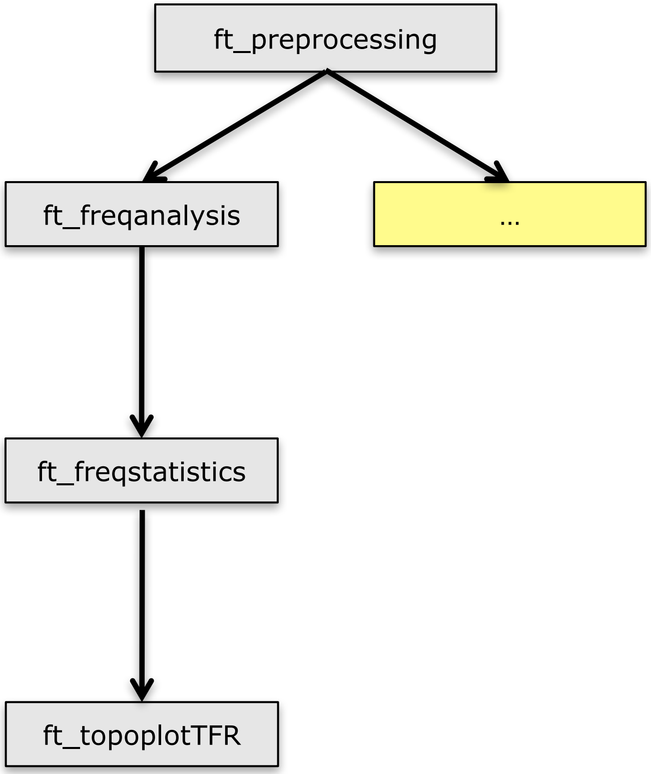
freqstat = ft_freqstatistics(cfg, freqdata)
```



ft_preprocessing

ft_freqanalysis

...

ft_freqstatistics

ft_topoplotTFR

Example use in scripts

```
subj = {‘S01.ds’, ‘S02.ds’, …}
trig = [1 3 7 9]

for s=1:nsubj
for c=1:ncond

  cfg = []
  cfg.dataset  = subj{s}
  cfg.trigger  = trig(c)
  rawdata{s,c} = ft_preprocessing(cfg)

  cfg = []
  cfg.method    = ‘mtmfft’
  cfg.foilim    = [1 120]
  freqdata{s,c} = ft_freqanalysis(cfg, rawdata{s,c})

end
end
```

Example use in scripts

```
subj = {‘S01.ds’, ‘S02.ds’, …}
trig = [1 3 7 9]

for s=1:nsubj
for c=1:ncond

  cfg = []
  cfg.dataset   = subj{s}
  cfg.trigger   = trig(c)
  rawdata{s,c} = ft_preprocessing(cfg)

  cfg = []
  cfg.method     = ‘mtmfft’
  cfg.foilim     = [1 120]
  freqdata{s,c} = ft_freqanalysis(cfg, rawdata{s,c})

end
end
```

Example use in scripts

```
subj = {‘S01.ds’, ‘S02.ds’, …}
trig = [1 3 7 9]

for s=1:nsubj
for c=1:ncond

  cfg = []
  cfg.dataset   = subj{s}
  cfg.trigger   = trig(c)
  rawdata       = ft_preprocessing(cfg)


  filename = sprintf(‘raw%s_%d.mat’, subj{s}, trig(c));
  save(filename, ‘rawdata’)


end
end
```

Example use in distributed computing

```
subj = {‘S01.ds’, ‘S02.ds’, …}
trig = [1 3 7 9]

for s=1:nsubj
for c=1:ncond

  cfgA{s,c} = []
  cfgA{s,c}.dataset    = subj{s}
  cfgA{s,c}.trigger    = trig(c)
  cfgA{s,c}.outputfile = sprintf(‘raw%s_%d.mat’, subj{s}, trig(c))

  cfgB{s,c} = []
  cfgB{s,c}.dataset    = subj{s}
  cfgB{s,c}.trigger    = trig(c)
  cfgB{s,c}.inputfile  = sprintf(‘raw%s_%d.mat’, subj{s}, trig(c));
  cfgB{s,c}.outputfile = sprintf(‘freq%s_%d.mat’, subj{s}, trig(c));

end
end

dfeval(@ft_preprocessing, cfgA)
dfeval(@ft_freqanalysis,  cfgB)
```

FieldTrip is a toolbox

- the data and the separate functions are in your hands

- the scripts depend on the data properties, your computer and on your programming skills and style

- scripts correspond to analysis protocols
  - scripts can be reviewed by supervisors
  - scripts are often shared with colleagues
  - scripts can be published/released

Finding your way around in the FieldTrip toolbox

Matlab

help functionname

edit functionname

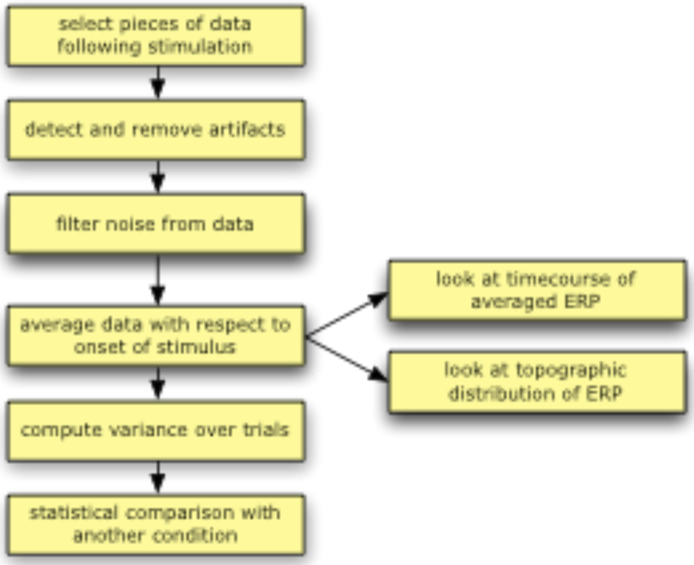
Website

http://www.fieldtriptoolbox.org

Email discussion list

Expertise in your local group

One-to-one mapping between analysis steps and toolbox functions



select pieces of data following stimulation

detect and remove artifacts

filter noise from data

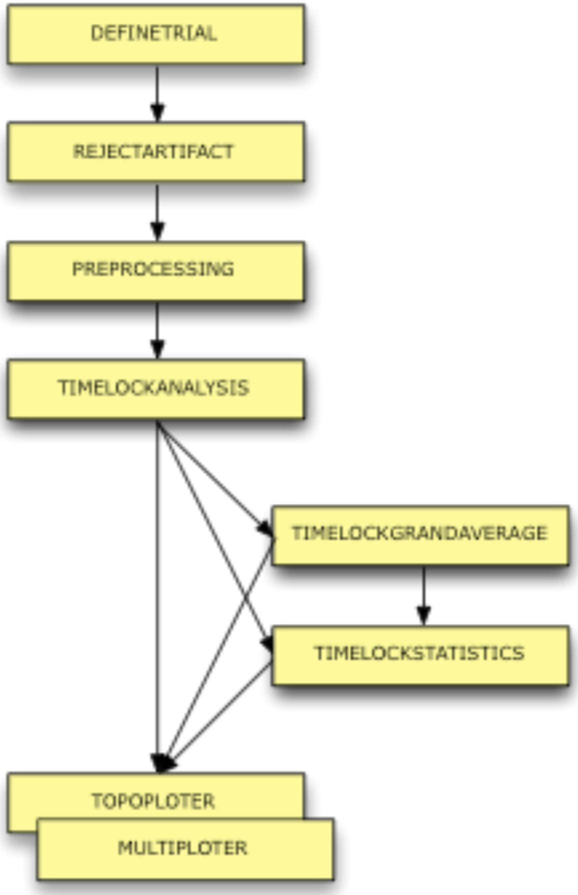
average data with respect to onset of stimulus

compute variance over trials

statistical comparison with another condition

look at timecourse of averaged ERP

look at topographic distribution of ERP



DEFINETRIAL

REJECTARTIFACT

PREPROCESSING

TIMELOCKANALYSIS

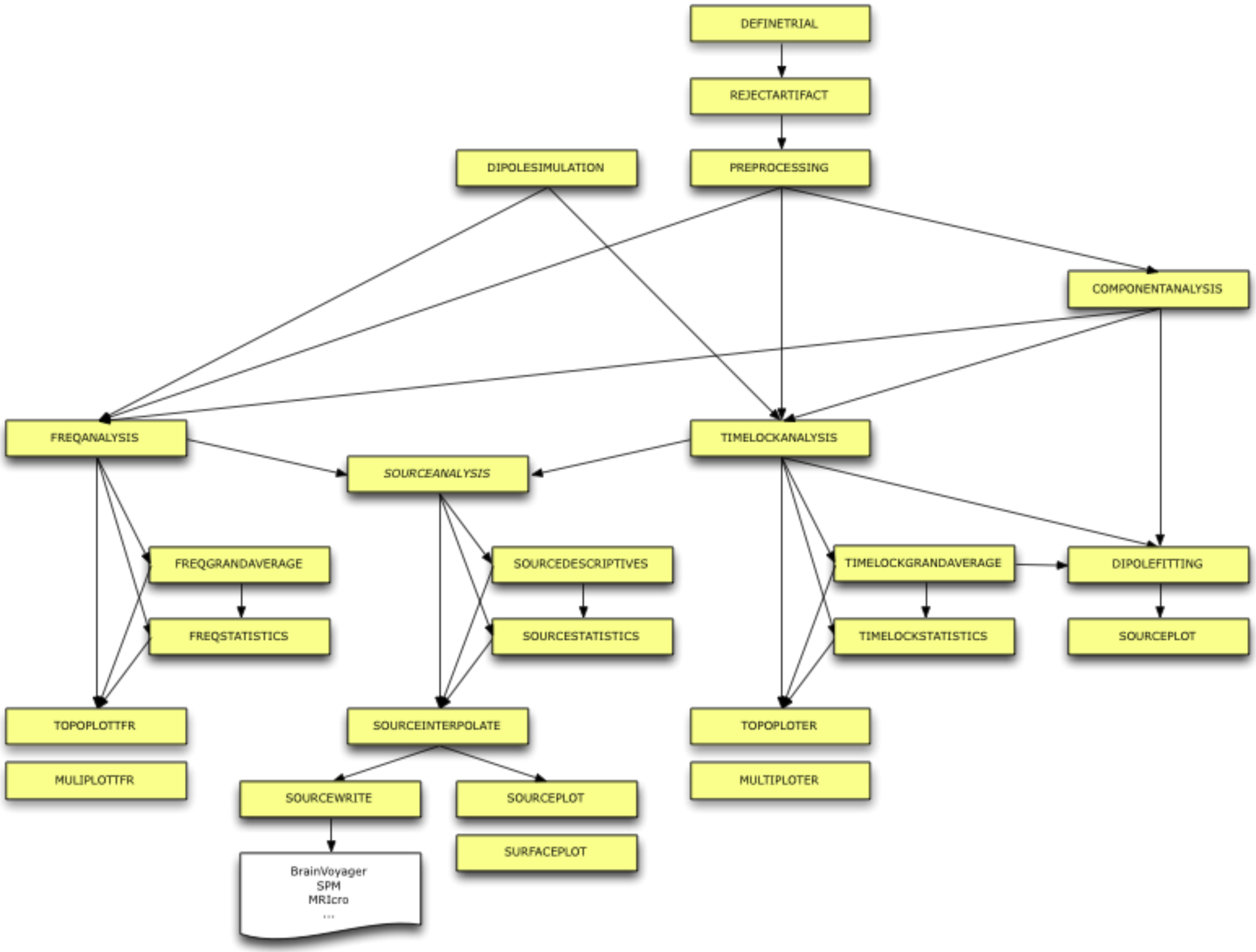
TIMELOCKGRANDAVERAGE

TIMELOCKSTATISTICS

TOPOPLOTER

MULTIPLOTER

Overview of main functions



Talk outline

What kind of signals are generated in the brain

How do we record those signals

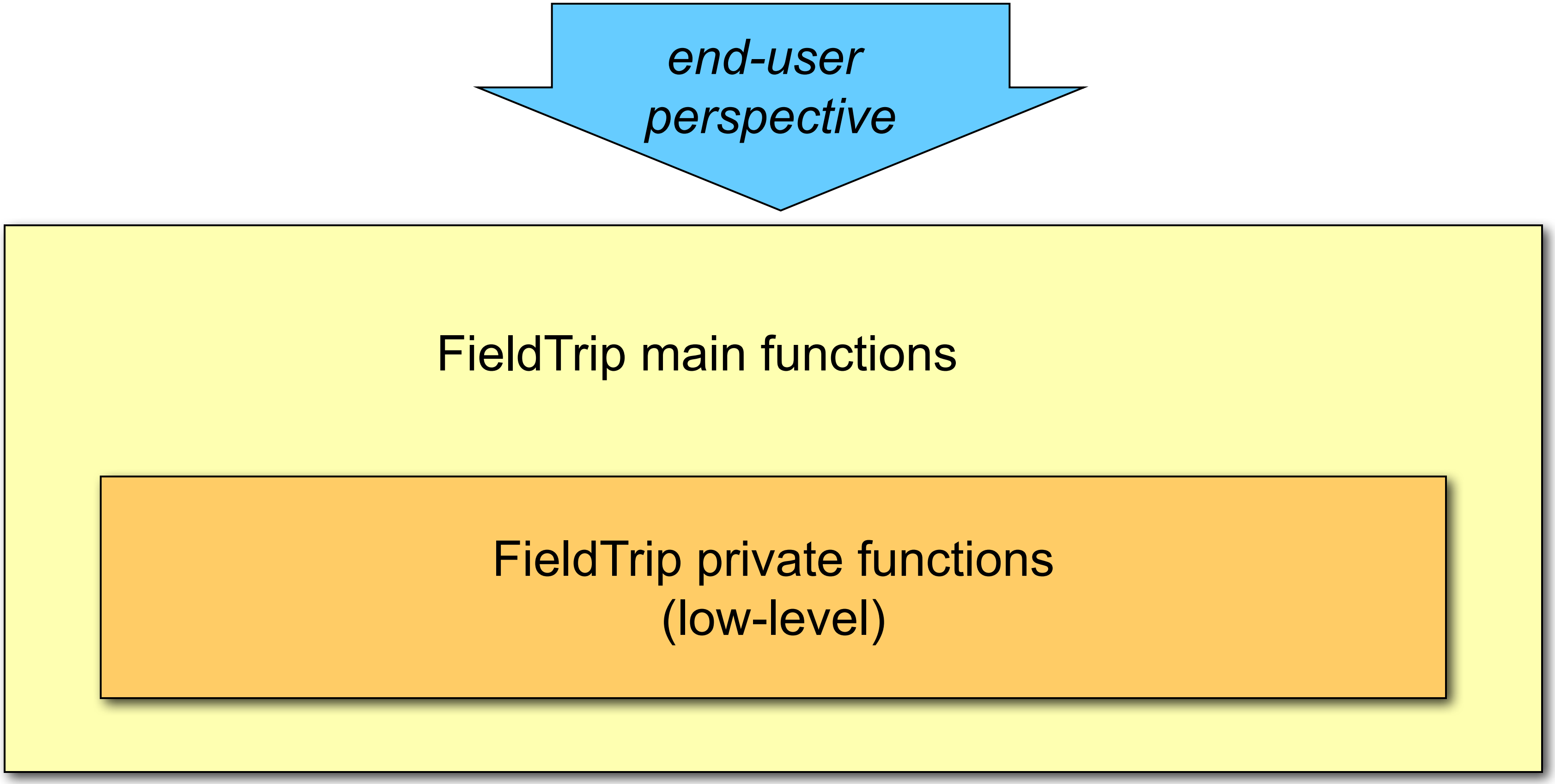
Analyzing those signals with FieldTrip

Background on the FieldTrip toolbox

Who is the audience?

- experimental neuroscientists
  - no graphical user interface
  - more dedicated and ambitious researchers
- developers of other software packages
  - SPM
  - EEGLAB
  - BESA
  - BCI2000
- developers of analysis tools and methods
  - SIMBIO
  - OpenMEEG

FieldTrip toolbox structure - at a glance

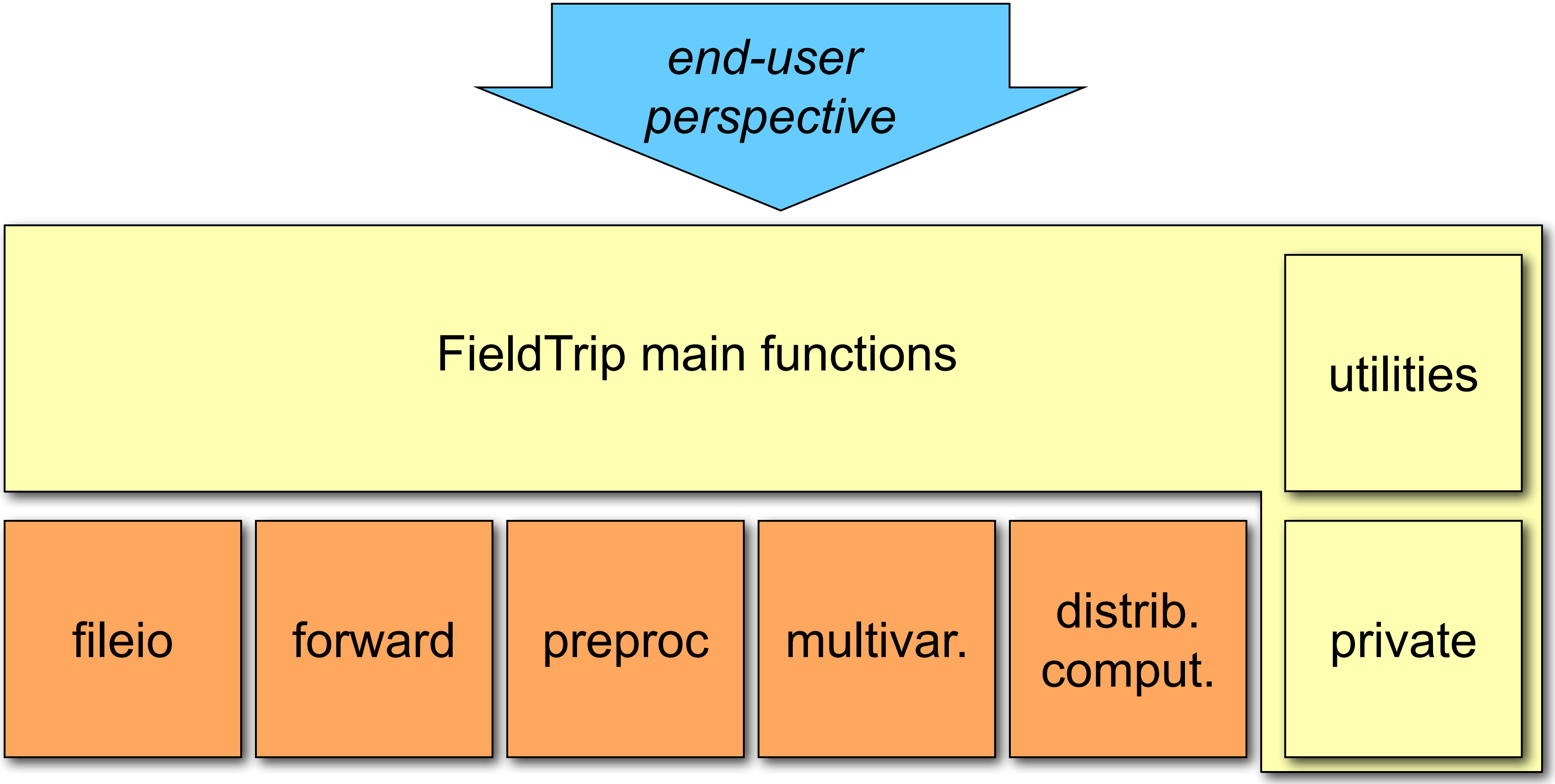


end-user perspective

FieldTrip main functions

FieldTrip private functions (low-level)

FieldTrip toolbox structure - a closer look



end-user perspective

FieldTrip main functions

utilities

fileio

forward

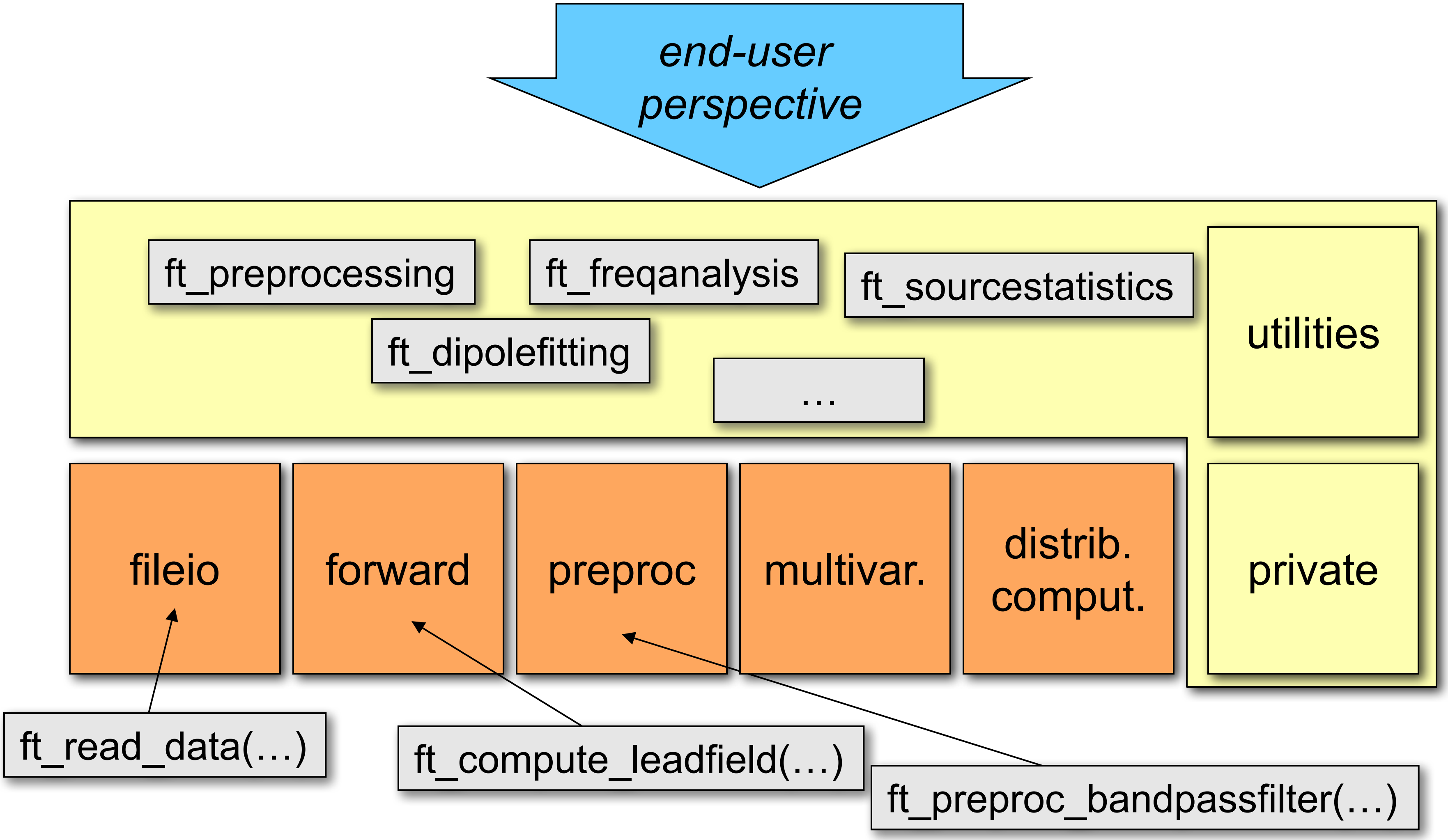
preproc

multivar.

distrib. comput.

private

FieldTrip toolbox structure - a closer look



end-user perspective

ft_preprocessing

ft_freqanalysis

ft_sourcestatistics

ft_dipolefitting

...

utilities

fileio

forward

preproc

multivar.

distrib. comput.

private

ft_read_data(...)

ft_compute_leadfield(...)

ft_preproc_bandpassfilter(...)

Summary

What kind of signals are generated in the brain

How do we record those signals

Analyzing those signals with FieldTrip

Background on the FieldTrip project

After lunch: hands-on

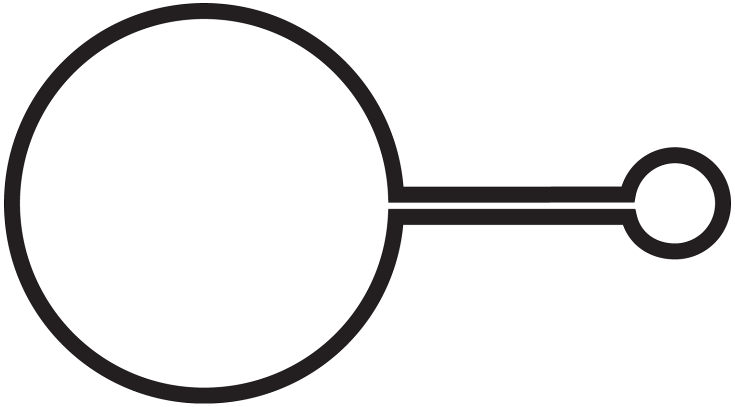
Selecting segments of data

Reading and preprocessing

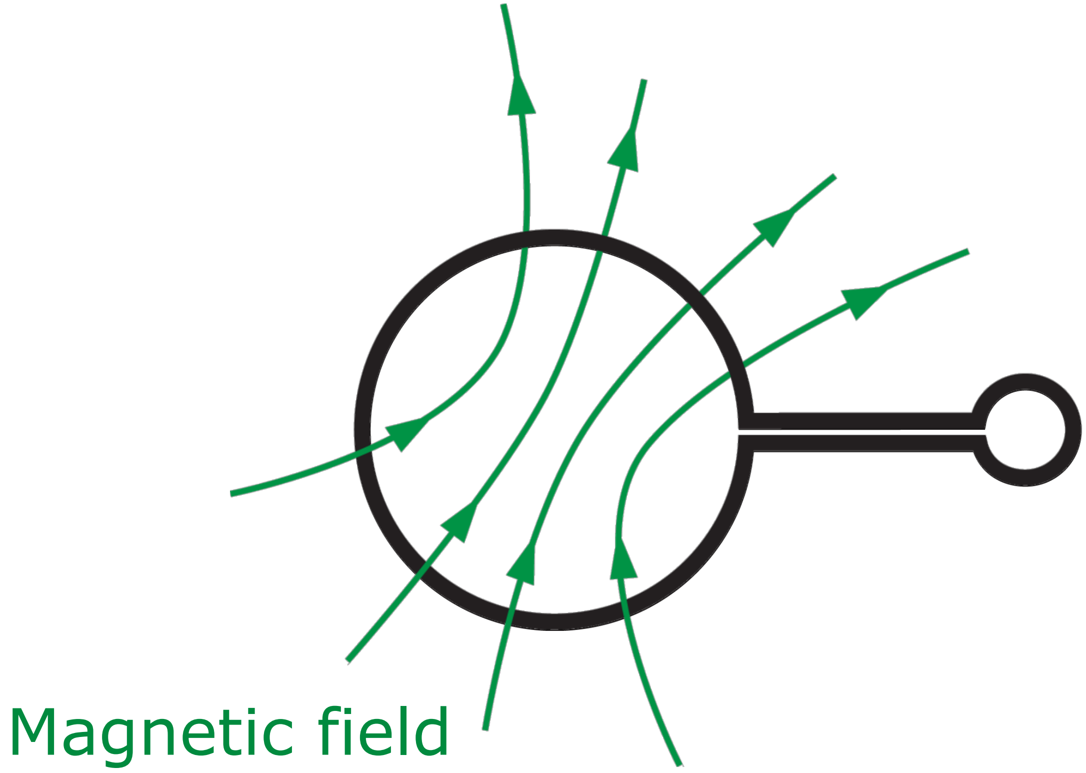
Averaging

Plotting

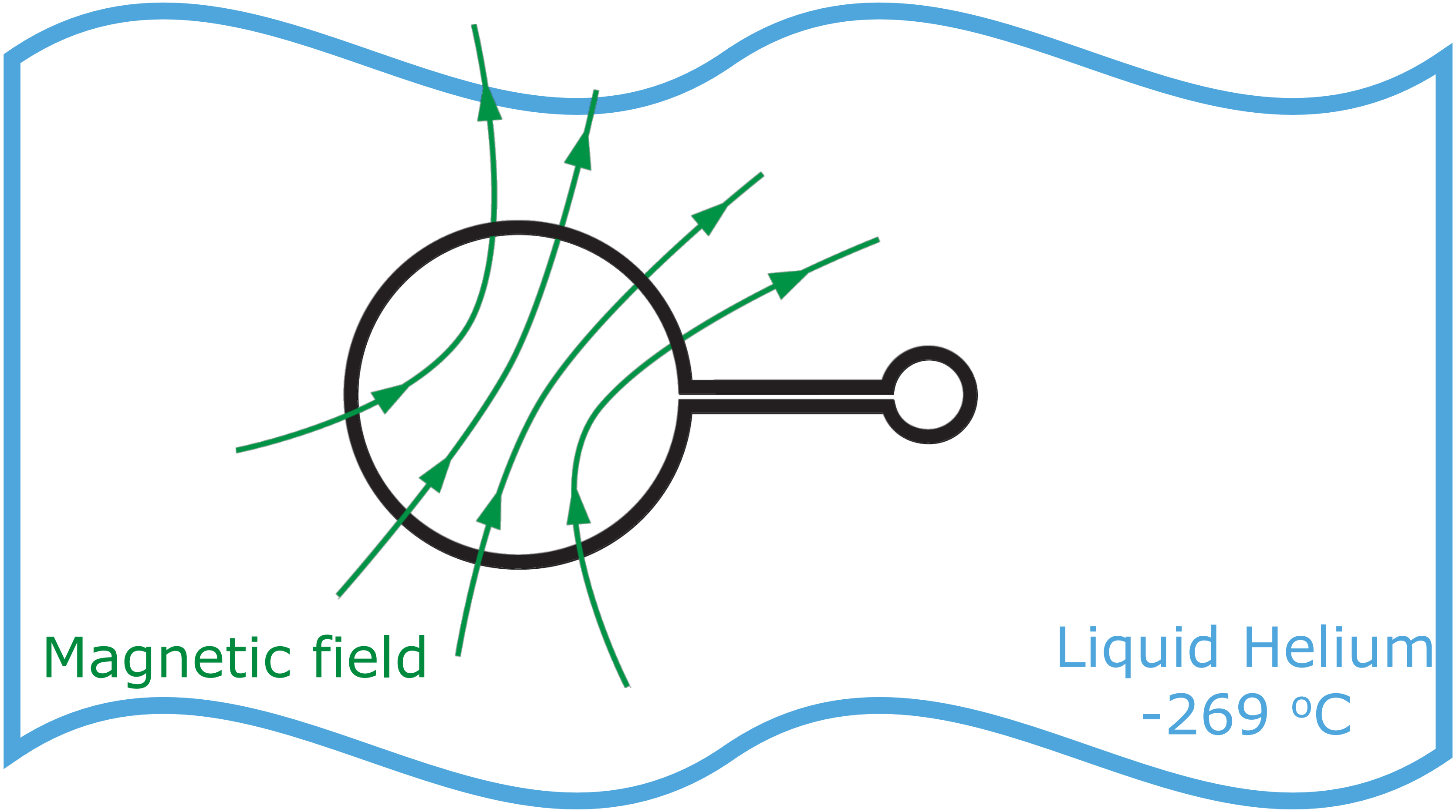
Recording small magnetic fields



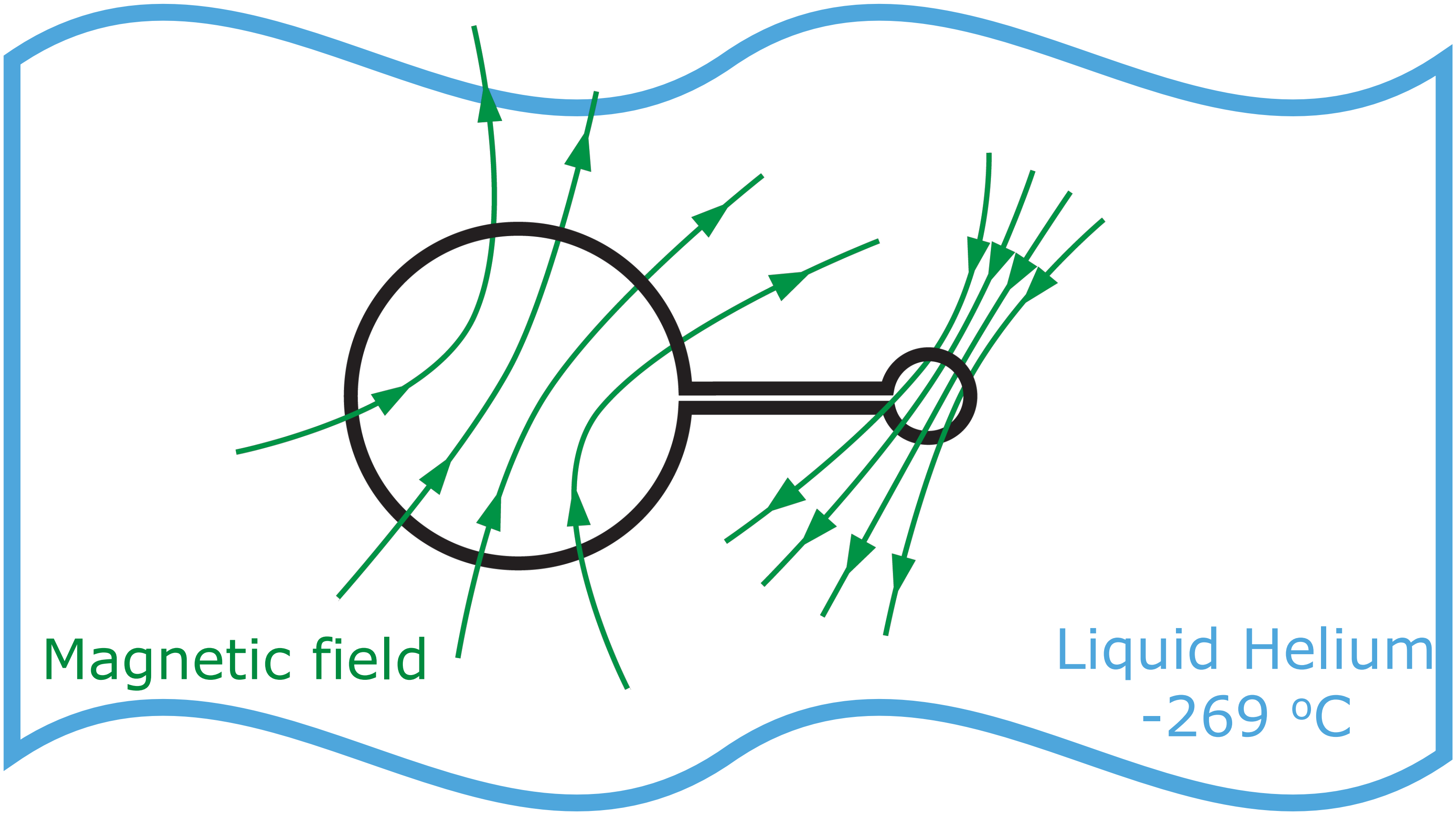
Recording small magnetic fields



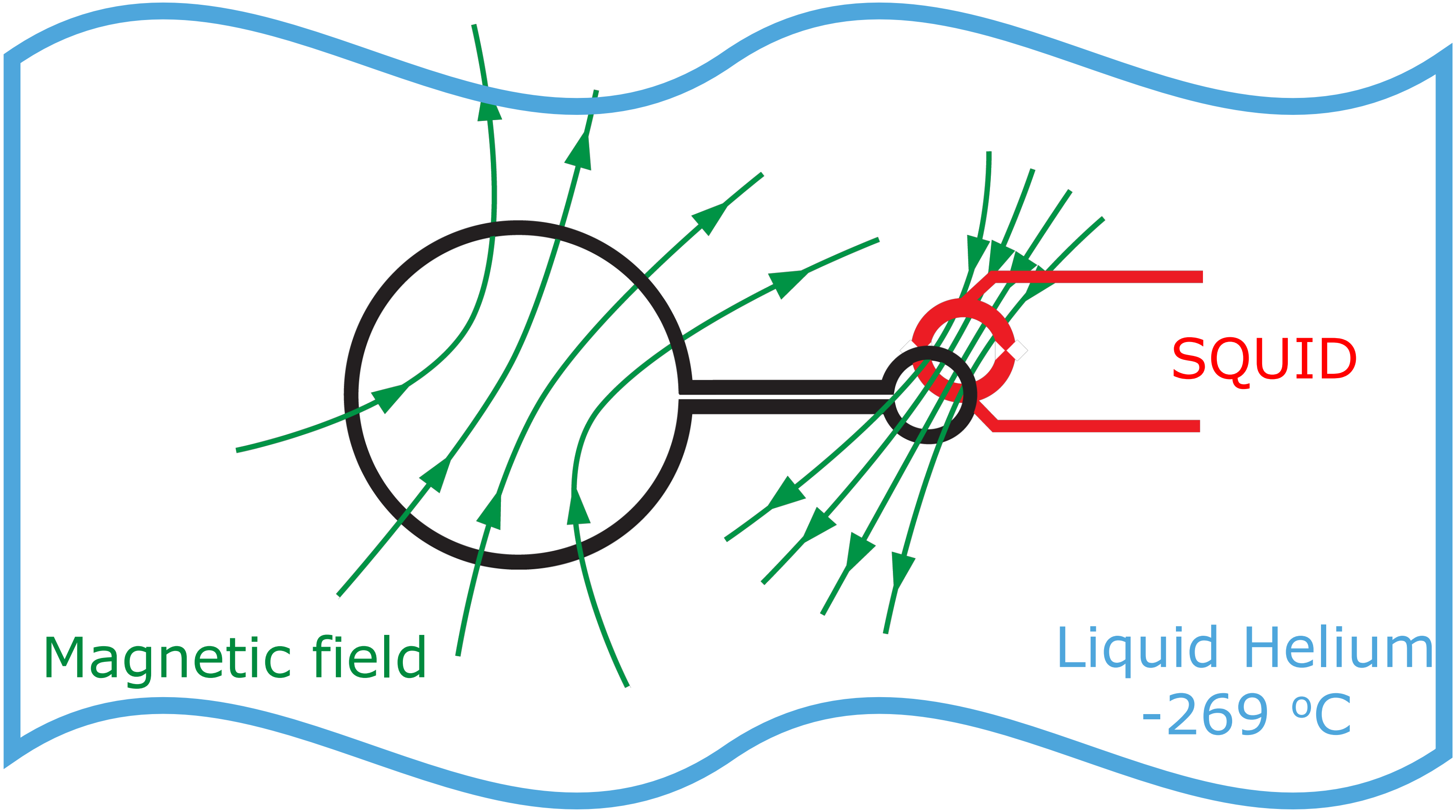
Recording small magnetic fields



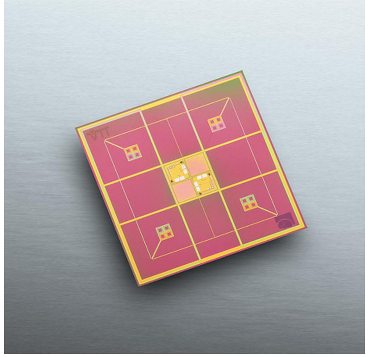
Recording small magnetic fields

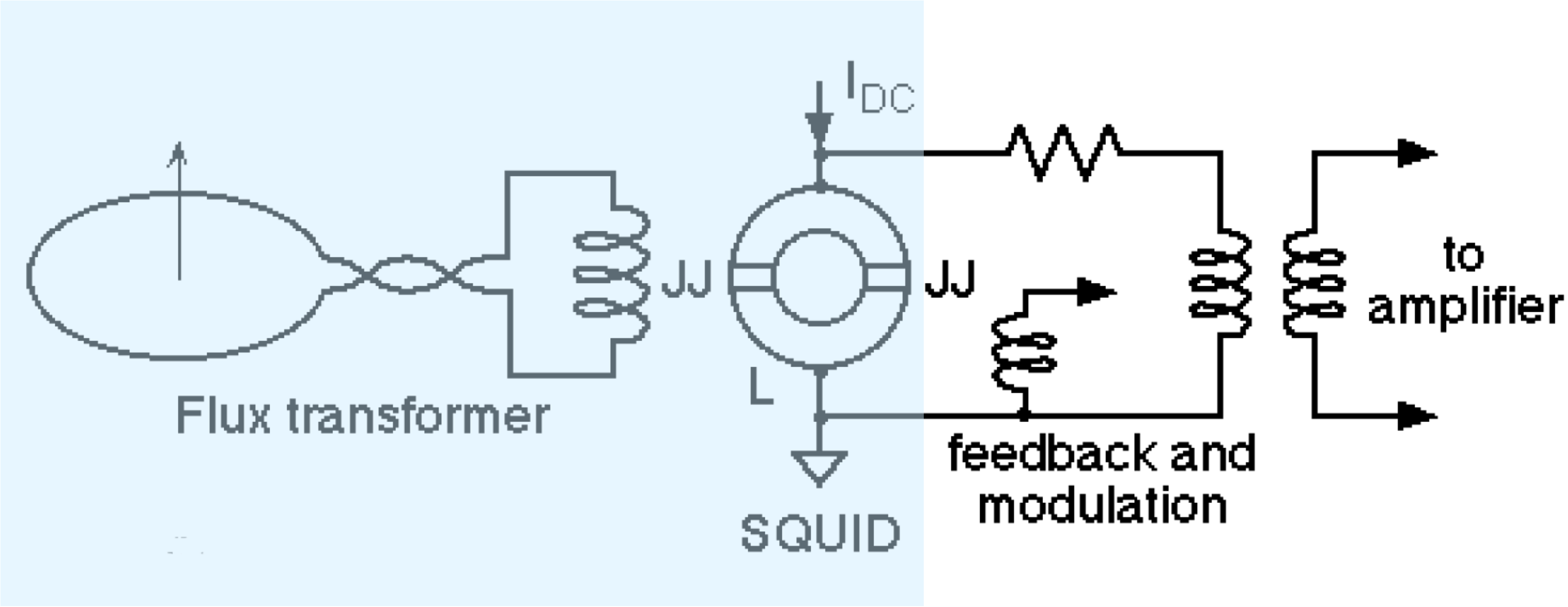


Recording small magnetic fields

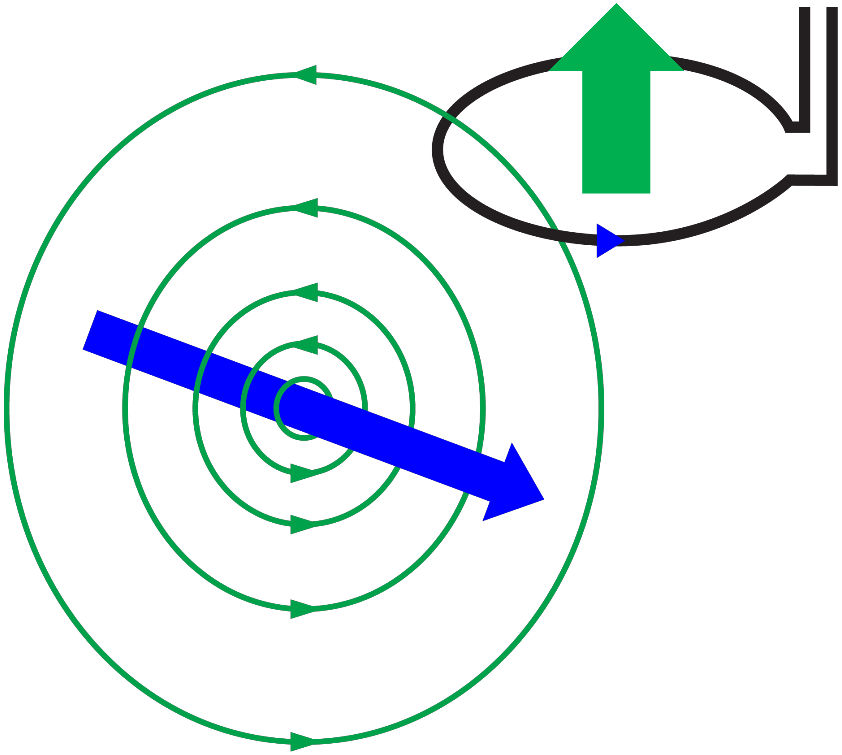


Magnetic field detectors
Superconducting **QU**antum **I**nterference **D**evice

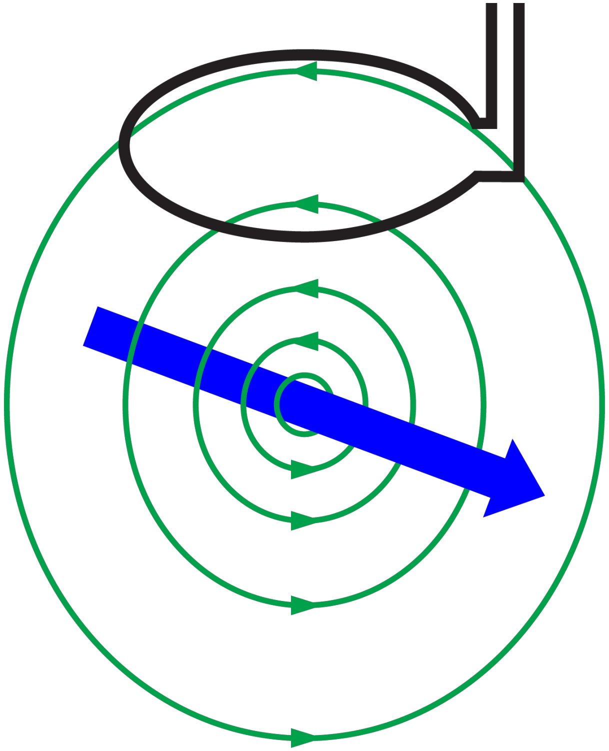




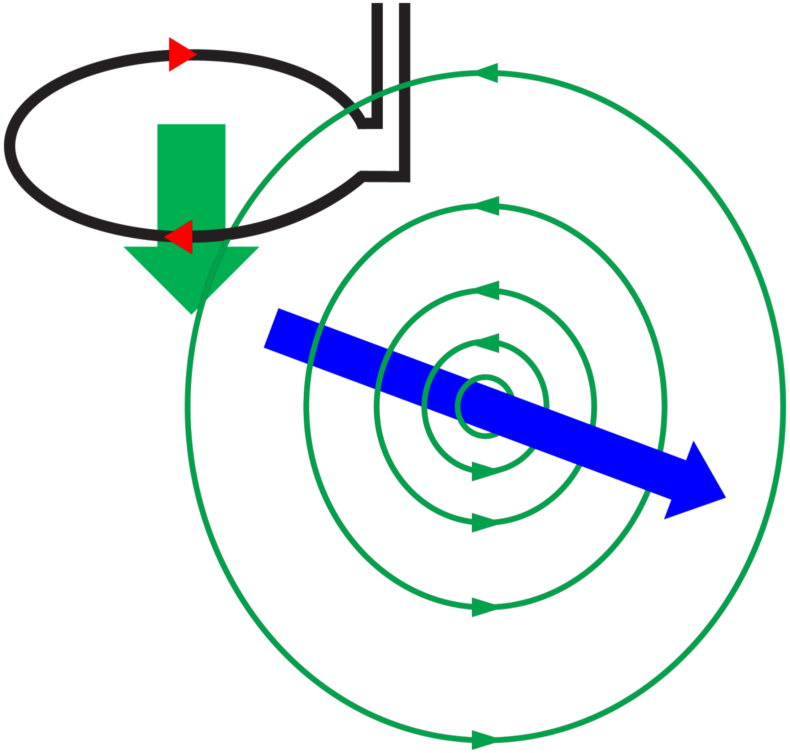
Magnetometer



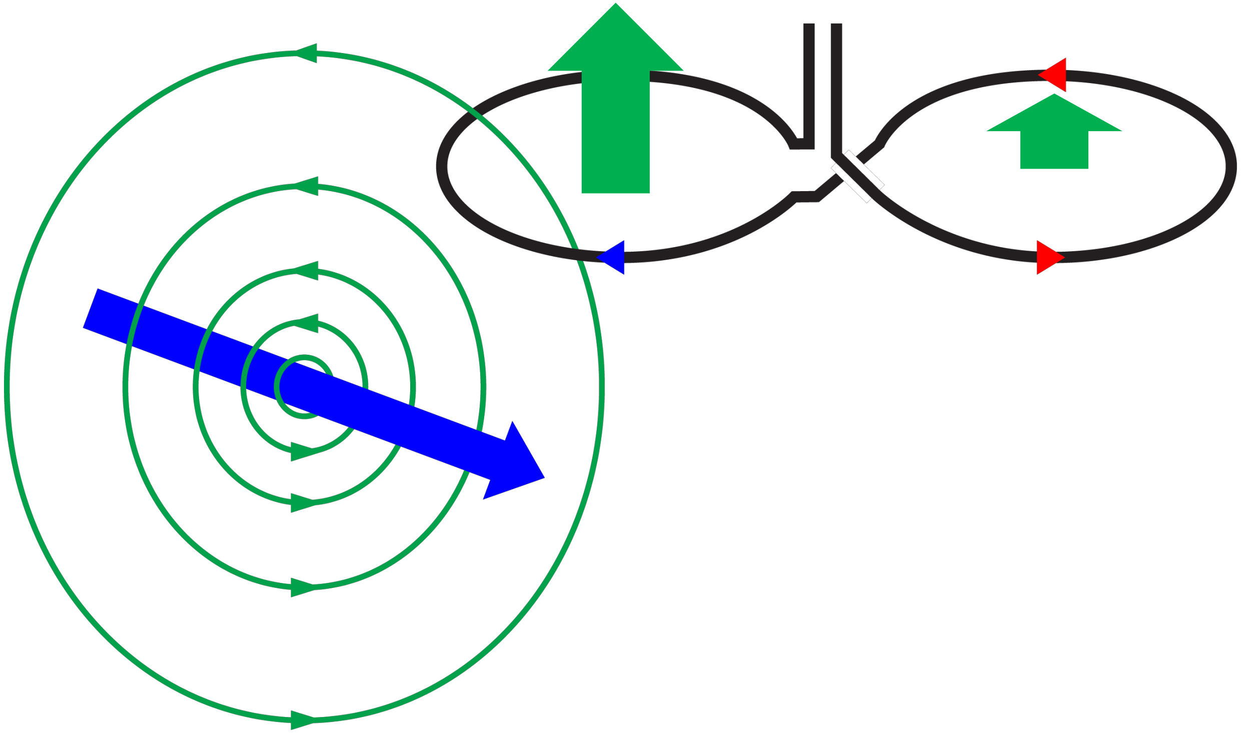
Magnetometer



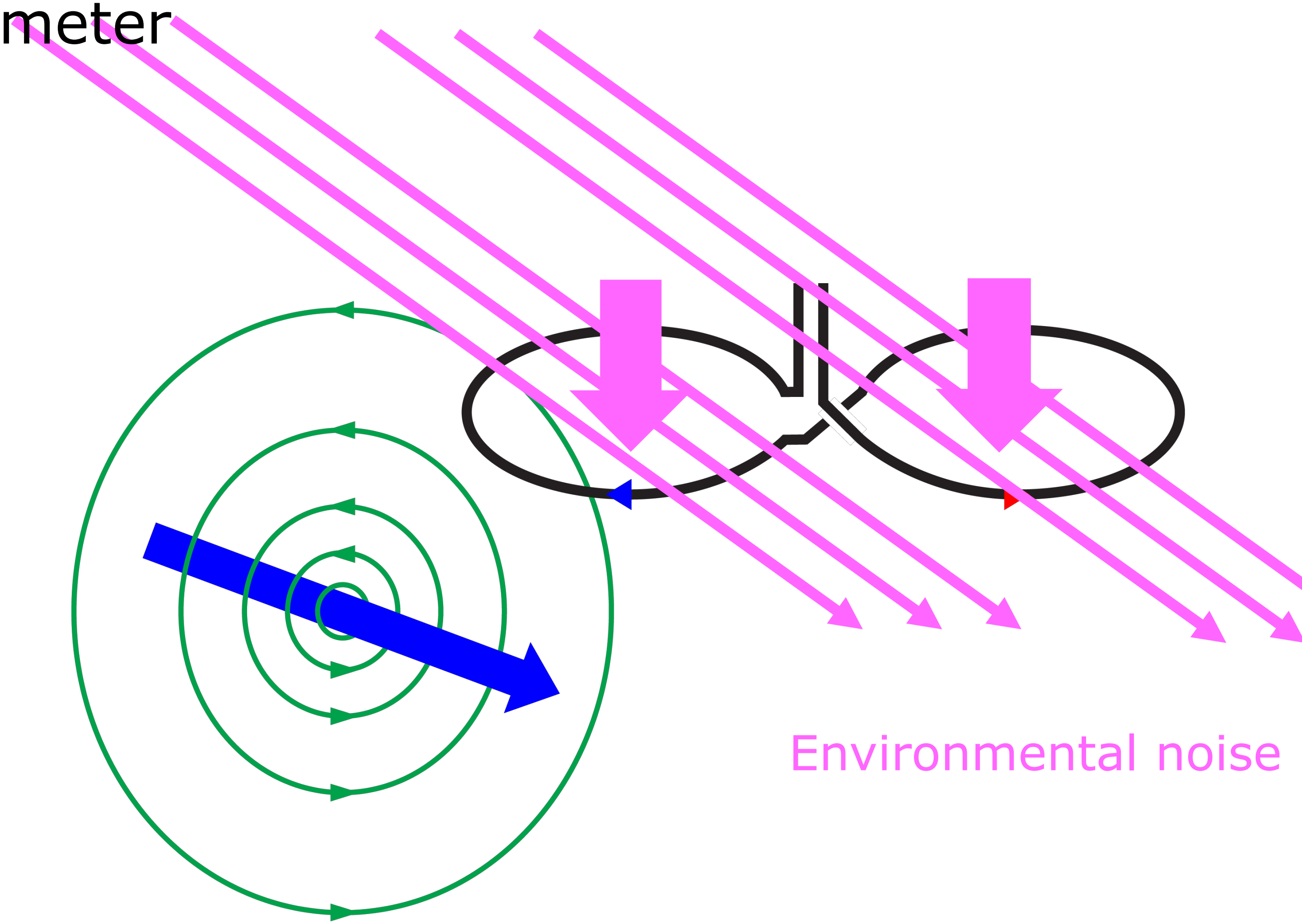
Magnetometer



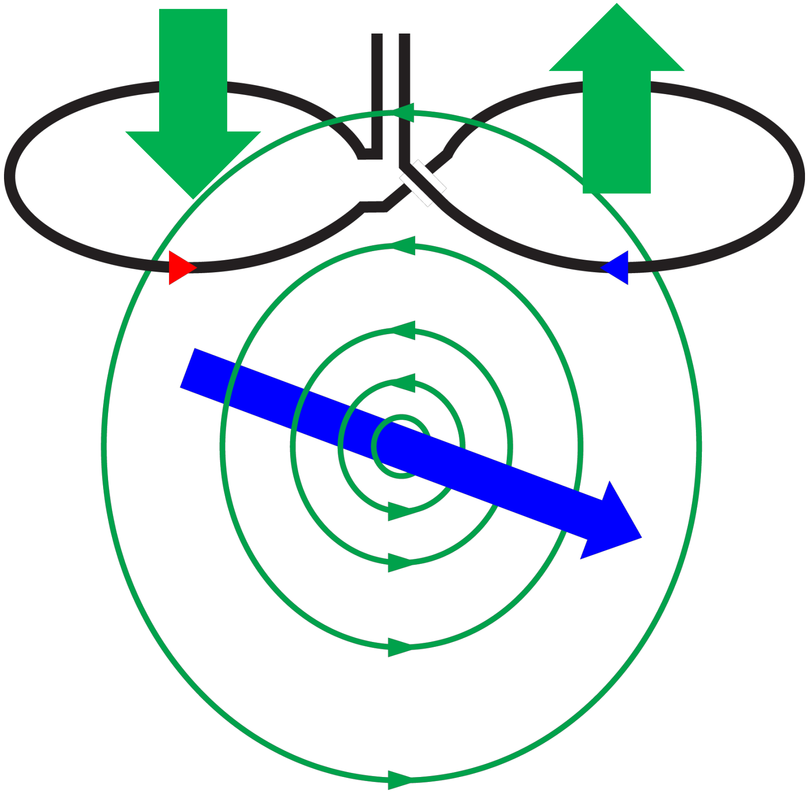
Planar gradiometer



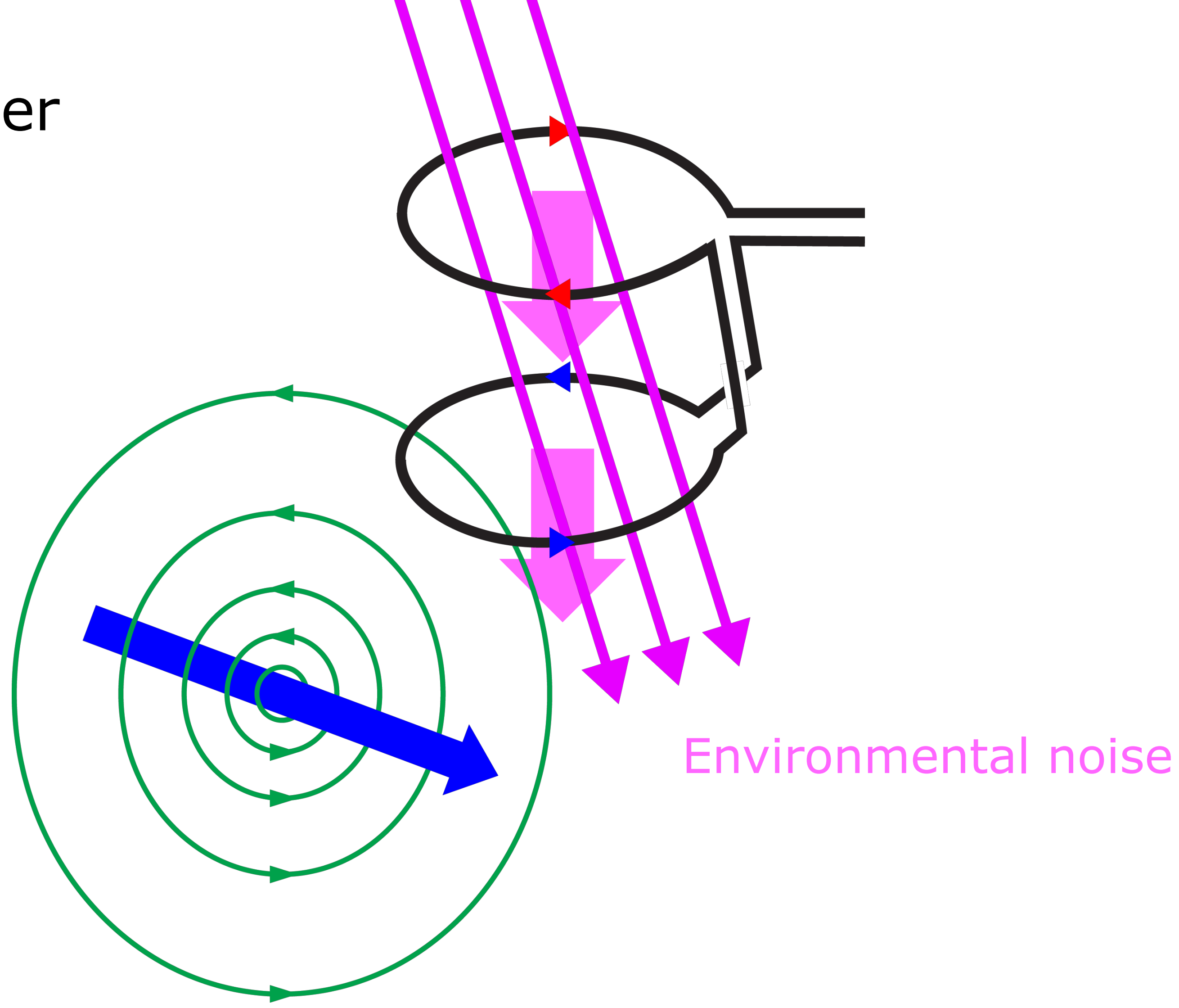
Planar gradiometer



Planar gradiometer



Axial gradometer



Environmental noise