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TRENTOOL: An open source toolbox to estimate neural directed interactions with transfer entropy

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download at WWW.TRENTOOL.DE

BIC Brain Imaging Center Frankfurt am Main

MAX-PLANCK-GESELLSCHAFT

NeFF - Neuronale Koordination Forschungsschwerpunkt Frankfurt M.

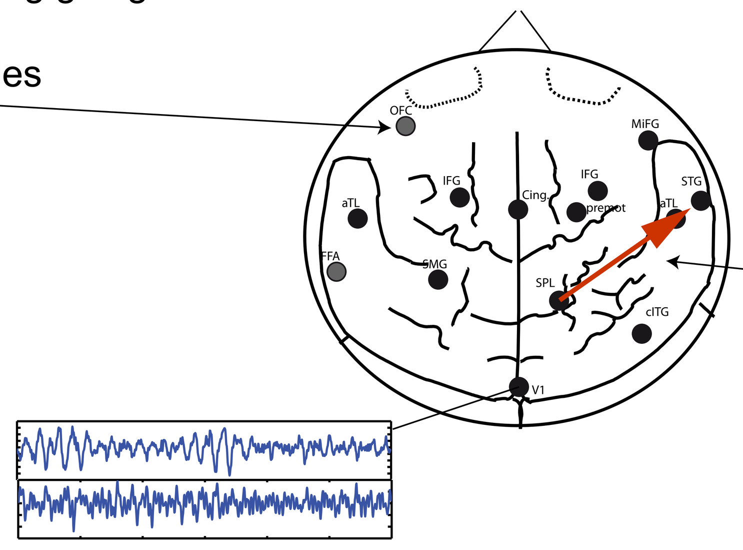
FIAS Frankfurt Institute for Advanced Studies

1 What does it need to *understand* network activity ?

Where is something going on?
Determination of the network's nodes

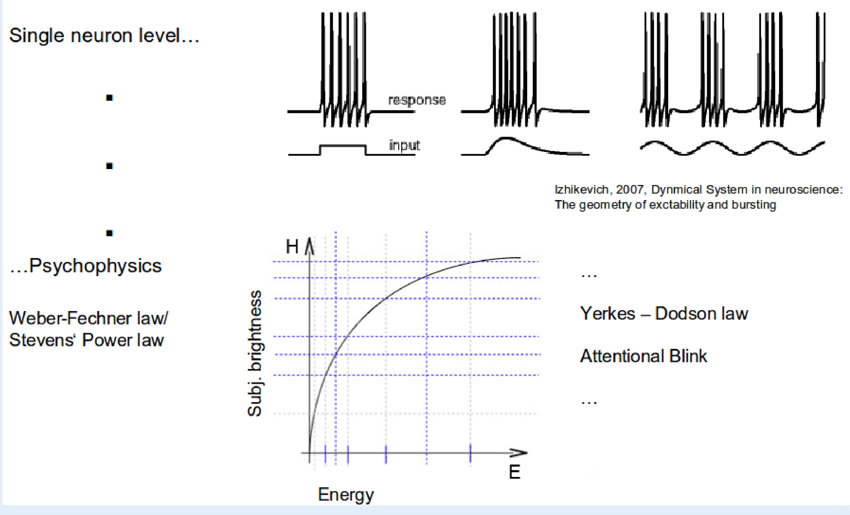
What's going on?
Determination of time courses of nodes' actvities

Why is it happening? Analysis of directed interactions = sender-receiver relationships

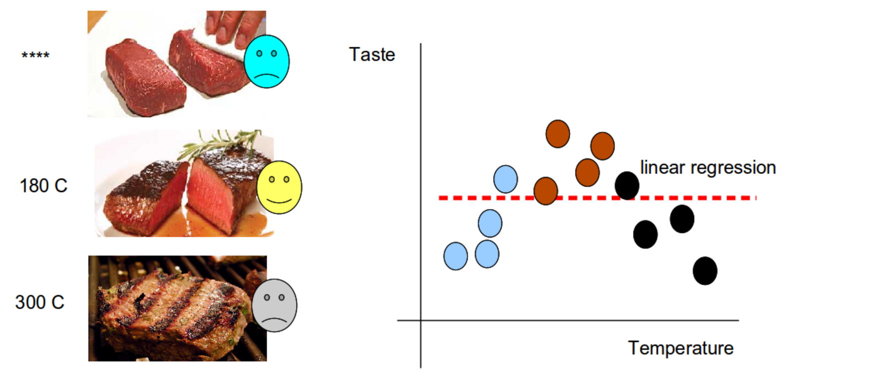


2 Why a model free analysis of directed *neural* interactions ?

(A) Neural systems respond nonlinearly on many scalles



(B) Linear analyses applied to nonlinear phenomena may go wrong ... since we do not know the nonlinearity we have to use model free analyses.



3 Transfer entropy is model free ... and the most natural implementation of Wiener's principle of causality for directed interactions

Information theoretic point of view

Wiener (1956): *„For two simultaneously measured signals (X,Y) if one can predict the second singal (Y) better by incorporating the past INFORMATION from the first signal (X) than using only past INFORMATION from the second signal, then the first signal can be called causal to the second one.“*

If we write out this statement in terms of a *conditional* mutual information we directly obtain transfer entropy: $I(Y_{t+u};\mathbf{X}_t^{d_x}|\mathbf{Y}_t^{d_y}) =$

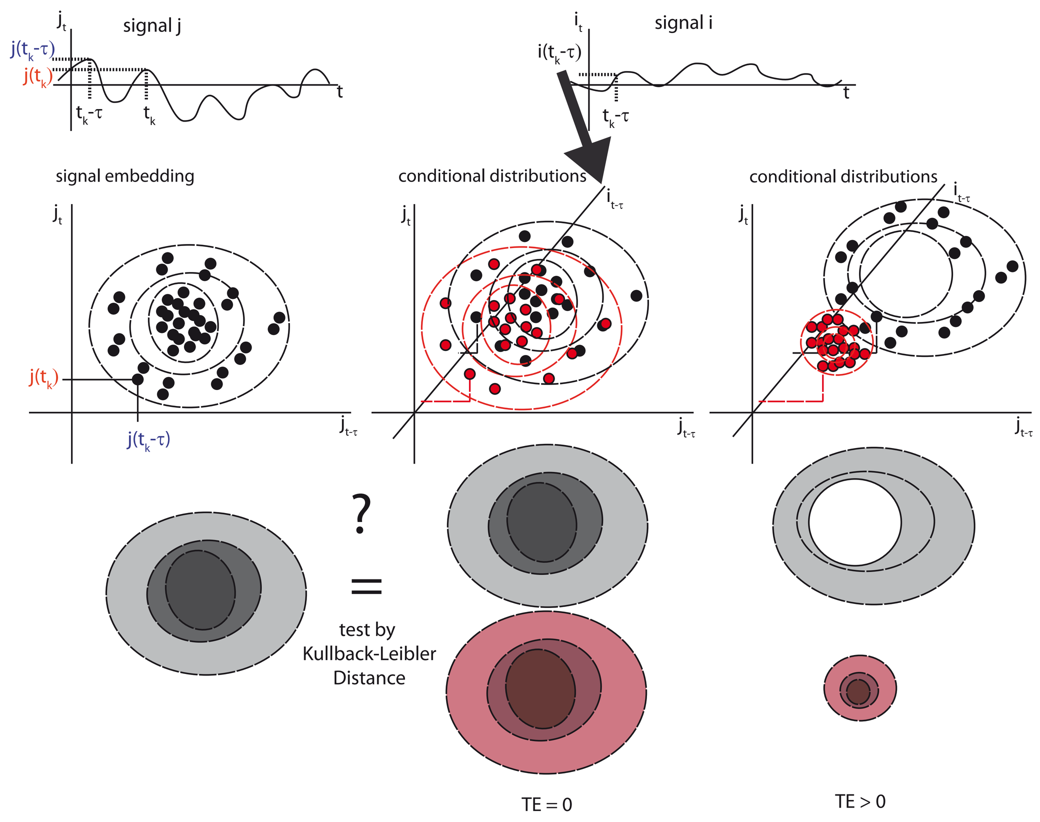
$$TE(X \rightarrow Y) = \sum_{y_{t+u},\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x}} p(y_{t+u},\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x}) \log \frac{p(y_{t+u}|\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x})}{p(y_{t+u}|\mathbf{y}_t^{d_y})}$$

Transfer entropy can be seen as the most natural implementation of Wiener's principle !

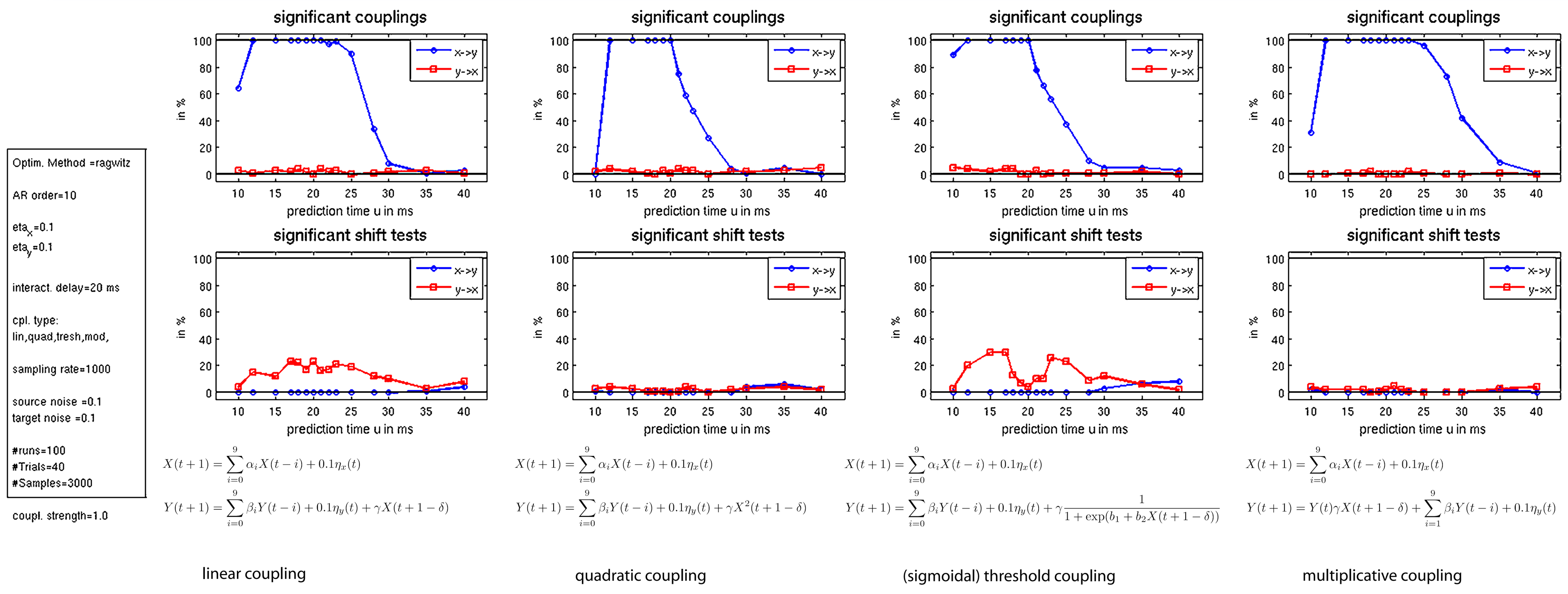
Dynamical systems point of view

Transfer entropy also results naturally from a model-free aproach to the prediction of time series based on transition probabilities in dynamical systems theory.

$$T_{I\rightarrow J} = \sum p(j_{n+1}, j_n^{(k)}, i_n^{(l)}) \log \frac{p(j_{n+1}|j_n^{(k)}, i_n^{(l)})}{p(j_{n+1}|j_n^{(k)})}$$



4 Transfer entropy detects 'arbitrary' types of directed interactions



5 Estimating transfer entropy can be a complex task, unfortunately

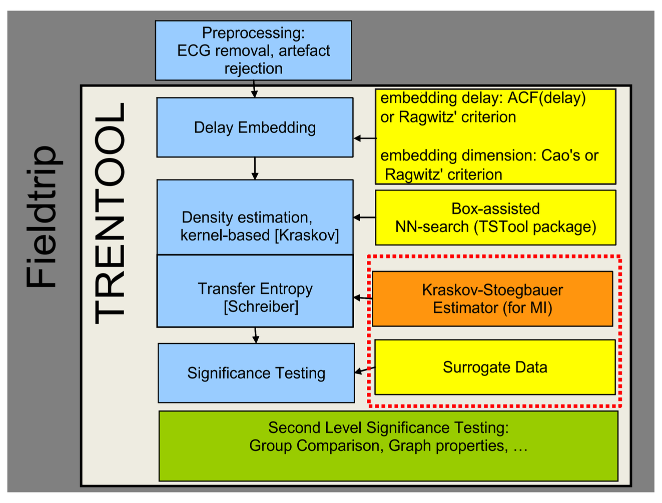
Several parameters (embedding dimensions and lags, prediction times) have to be estimated from the data for the method to work well on finite noisy data.

$$I(Y_{t+u};\mathbf{X}_t^{d_x}|\mathbf{Y}_t^{d_y}) =$$

$$TE(X \rightarrow Y) = \sum_{y_{t+u},\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x}} p(y_{t+u},\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x}) \log \frac{p(y_{t+u}|\mathbf{y}_t^{d_y},\mathbf{x}_t^{d_x})}{p(y_{t+u}|\mathbf{y}_t^{d_y})}$$

Data efficient parameter estimators and probability density estimators were only developed recently [Ragwitz, Kraskov]. Moreover, when analysing directed interactions in noisy neural data, TE is only a *biased metric* to be used in the usual statistical tests -this places an additional burden on the user.

6 TRENTOOL - The Transfer Entropy Toolbox (download: www.trentool.de)



(**Left**) TRENTOOL [Lindner] in a Nutshell: TRENTOOL uses the data format of the open source MATLAB toolbox Filedtrip, that is popular for electrophysiology data (EEG/MEG/LFP). Parameters for delay embedding are automatically obtained from the data. TE values are estimated by the Kraskov-Stögbauer-Grassberger estimator [Kraskov] and subjected to a statistical test against suitable surrogate data. Experimental effects can then be tested on a second level. Results can be plotted using Fieldtrip layout formats.

(**Right**) Detailed flow chart of TRENTOOL's architecture, indicating the flow of data.

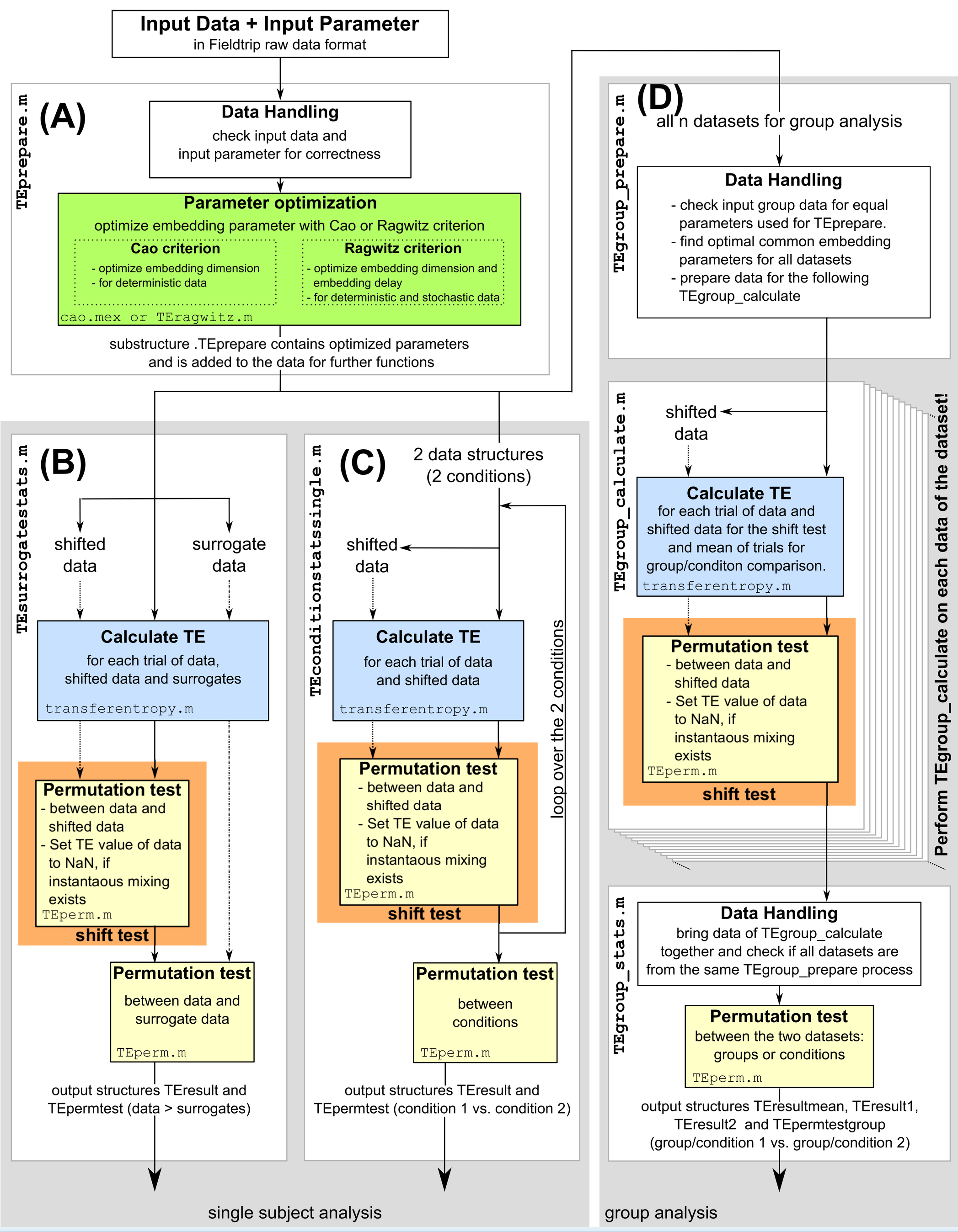
(A) All data have to pass through **TEprepare.m** for parameter estimation.

(B) For the detection of significant directed interactions data are then passed to **TEsurogatestats.m** , where they are statistically compared by permutation testing against suitable surrogate data, cerated by trial shuffling of block resampling.

(C) For the statistical comparison of interaction strength within units of observation (e.g. subjects) **TEconditionstatssingle.m** can be used, again relying on permutation testing.

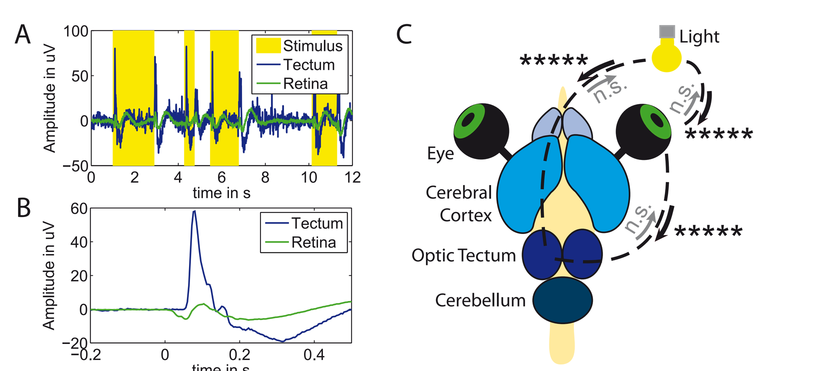
(D) For the statistical comparison of interaction strength between groups of units of observation (independent sample tests) the suite of functions: **TEgroup_prepare.m**, **TEgroup-calculate.m** and **TEgroup_stats.m** takes care of bias equalization, trivially parallel TE computation and statistical testing.

In all usage scenarios results can be corrcetd for EEG/MEG volume conduction (linear crosstalk)!

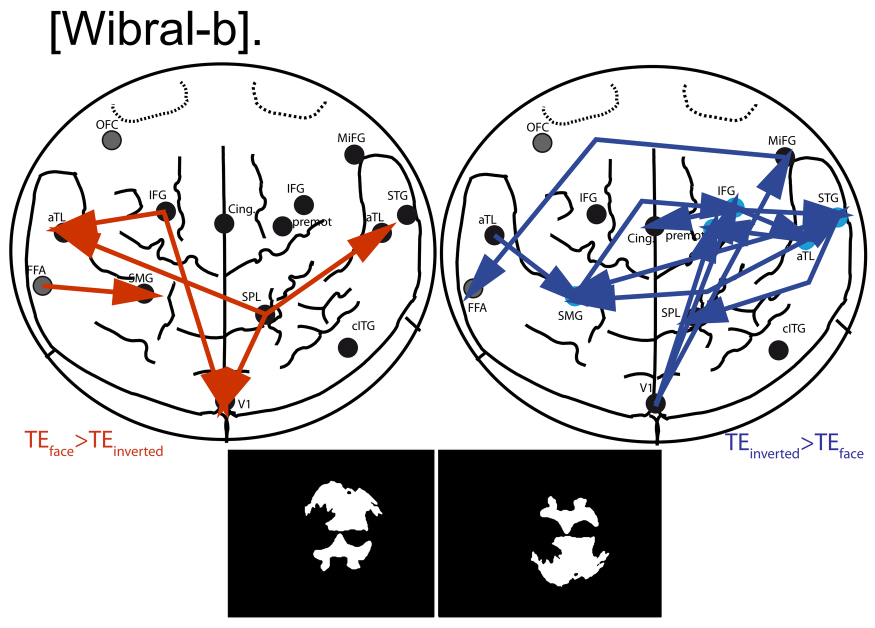


7 Application examples

Proof of principle:
Detection of unidirectional directed interactions between retina and optic tectum in freshwater turtle.



Application to cognitive neuroscience:
MEG source connectivity [Wibral-a] for succesful detection of a face (red) and for an unsuccesful attempt (blue) [Wibral-b].



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