Visualizing and understanding complex neural time series

Advanced Statistical Methods and Dynamic Data Visualizations for Mental Health Studies, June 2021

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- EEG, MEG, fMRI, calcium imaging, ...
- ECG, accelerometer, self-reports, ...
- Common scientific questions:
 - Is there interesting structure in the dataset?
 - What time-series properties distinguish different classes of data (e.g., schizophrenia/control)?
 - How accurately can I classify conditions ('biomarkers')?

Setting

Modern datasets often contain a large number of time series:

Interactive visualizations can help to understand complex time-series datasets.







- Feature-based time-series analysis (representing time-series using properties) is powerful
 - We have developed a range of tools for doing this systematically.
- I'll give an overview of the tools available, focusing on two key analyses:
 - Finding structure in a dataset through a low-dimensional projection.
 - Classifying a dataset (and understanding why).
- I'll give a quick demo of an interactive low-dimensional projection of a timeseries dataset (we'll try it together in the interactive session).

Today













Time-series analysis is a very interdisciplinary field

We should learn from each other...

How can we reduce the barriers to meaningful interdisciplinary exchange? (rapid knowledge transfer across fields)









Characterizing time series using features

How can I reduce complex time-varying patterns to informative summary statistics?



- We consider *features*, which map a time series onto a single real number
- These numbers are often ulletinterpretable:
 - 'periodic', 'unpredictable', 'nonlinear', 'stationary', 'intermittent', 'bursty', ...
- Feature-based time series analysis involves representing time series as a set of features.





What feature(s) should I use?

Methods for time-series analysis have been developed across diverse scientific literature for decades The *hctsa* feature set contains a sample of >7000 features

Static Distribution

Trimmed means Quantiles Fits to standard distributions **Outliers** Moments Entropy Rank-orderings Standard deviation

Stationarity

StatAv Sliding window measures Step detection Distribution comparisons

Correlation

Linear autocorrelation Decay properties Additive noise titration Nonlinear autocorrelations Time reversal asymmetry Generalized self-correlation Recurrence structure Autocorrelation robustness Scaling and fluctuation analysis Permutation robustness Local extrema Seasonality tests Zero crossing rates

Basis Functions

Wavelet transform

Peaks of power spectrum

Spectral measures

Power in frequency bands

Information Theory

Sample Entropy Lempel-Ziv Complexity Automutual information Information Approximate dynamics Entropy **Tsallis entropies**

Model Fitting

Local prediction GARCH models Fourier fits **Exponential** smoothing State space models Hidden Markov models Piecewise splines ARMA models Gaussian Processes

(Phys) Nonlinear

2D embedding structure Taken's estimator Fractal dimension Correlation dimension Surrogate data Poincaré sections Nonlinear prediction error Lyapunov exponent estimate False nearest neighbors

Others

Transition matrices Local motifs Dynamical system coupling Visibility graph Stick angle distribution **Extreme events** Singular spectrum analysis Domain-specific techniques





The highly comparative approach

Compare the performance of a comprehensive library of scientific time-series methods: pick those that best suit your problem



Fulcher & Jones (2017). hctsa: A Computational Framework for Automated Time-Series Phenotyping Using Massive Feature Extraction. Cell Systems, 5, 527–531.

Our Feature Sets and Tools







Others have done work in this space also:

https://github.com/benfulcher/hctsa/wiki/Related-time-series-resources





Low-Dimensional Feature-Space Projections

How are my time-series data structured?

Represent each time series as a set of features (interpretable structural properties), and look for patterns in the low-dimensional feature space: *time series with similar properties are close in the space.*

Major Depressive Disorder

Healthy Control

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- few spectral bands)
- Small feature set (e.g., *catch22*)
- Large feature set (e.g., *hctsa*)

Feature

extraction



> 7700 features

- 3 hand-picked features (e.g., power in a

Dimensionality Reduction





Low-dimensional feature-space projections



Fulcher et al. A self-organizing, living library of time-series data. Scientific Data 7, 213 (2020).











Classification

Feature

extraction

Major Depressive Disorder

Healthy Control

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What types of features distinguish classes in my dataset?

(straightforward extension to real-valued labels: regression)

- 3 hand-picked features (e.g., power in a few spectral bands) - Small feature set (e.g., *catch22*) - Large feature set (e.g., *hctsa*)

Chemogenetic manipulations for mouse fMRI

Structure-function coupling in mouse

https://github.com/benfulcher/hctsa/wiki/Publications-using-hctsa

Assess stress-induced changes in astrocyte calcium dynamics

Liu et al. (2019). A hybrid model for appliance classification based on time series features. Energy and Buildings, 196, 112-123.

AC CFL Fan

Hairdryer

Miller, C. (2019). What's in the box?! Towards explainable machine learning applied to non-residential building smart meter classification. *Energy and* Buildings, 199, 523-536.

Fridge

Heater ILB

Laptop

Microwave

Vacuum

Daviu et al. CRH neurons encode stress controllability and regulate defensive behavior selection. *Nat Neurosci* **23**, 398–410 (2020).

Fig. 7. Confusion matrix of the proposed model.

Distinguish multiple sclerosis MEPs

Yperman et al. Deciphering the Morphology of Motor Evoked Potentials. Front. Neuroinform. 14:28 (2020).

Hand-gesture recognition

Siddiqui et al. Multimodal hand gesture recognition using single IMU and acoustic measurements at wrist. PLoS ONE, 15, e0227039 (2020).

Finding Connections

Are other scientists studying similar data to me?

www.comp-engine.org

- CompEngine Time Series is a self-organizing database of interdisciplinary time-series data
- Connects diverse scientists through the structure of their data
- Bulk download functionality, and API for custom time-series data download: facilitates comprehensive empirical phenotyping of time-series analysis algorithms

Step 1: Drag on your data

Name MUS_Gobbledigook_444s_F0.05_b8

Description

Unit N/A

Contributor N/A

Sampling rate N/A

Highcharts.com

Interesting Information 🕑

If you don't have data on-hand, you can still explore

Browse the full time-series library

Browse by source

Browse by category

Browse by tag

Visualize their inter-connections

And keep exploring...!

Download any/all data you find:

Browsing by all time series within the "Birdsong" category

CSV (zipped)

 \sim

DOWNLOAD ALL ON PAGE

100 examples of each of 5 classes of EEG

(301) MD_EEG_UniBonn_F001_LP40Hz.dat [epileptogenic] (4097)
(312) MD_EEG_UniBonn_F012_LP40Hz.dat [epileptogenic] (4097)
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{356} MD_EEG_UniBonn_F056_LP40Hz.dat [epileptogenic] (4097)
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hctsa + catch22

https://github.com/benfulcher/hctsa https://github.com/chlubba/catch22

Demo

Interactive visualization

Time

https://github.com/benfulcher/hctsaTutorial_BonnEEG

Demo

Compute time-series features

Interact with your lowdimensional data visualization

TS_LowDimInspect

TS_Compute

catch22 (22 features) for speed *hctsa* (>7k) for comprehensiveness

TS_Normalize

Put all features on a similar scale

1500

1 Prepare Dataset: INP_Bonn_EEG.mat

2 Initialize (default hctsa feature set): TS_Init('INP_Bonn_EEG.mat') **Initialize (catch22 feature set):** TS_Init('INP_Bonn_EEG.mat','INP_mops_catch22.txt','INP_ops_catch22.txt',true,'HCTSA_catch22.mat') HCTSA.mat TS_DataMat 500 (time series) x 22 (features) matrix [empty] Generates: **TimeSeries** 500-row table with information about time series **Operations** 22-row table with information about operations/features

3 Compute all features (without parallelization): TS_Compute(false);

4 Normalize features to a similar scale (and filter poor performers): TS_Normalize();

5 Visualize! Analyze! E.g., Play with a low-dimensional representation!: TS_LowDimInspect();

(Many other visualizations: see <u>https://github.com/benfulcher/hctsaTutorial_BonnEEG</u>

labels 500 x 1 cell strings uniquely identify each time series timeSeriesData 500 x 1 cell vectors of time-series data keywords 500 x 1 cell class labels

(very fast for *catch22*)

Going Further

Comprehensive documentation on GitBook + wiki

Introduction It is manual outlines the steps required to set up and implement highly comparative timeseries analysis using the hotsa package, as described in our papers. 1. B.D. Fulcher and N.S. Jones. *hotsa*: A computational framework for automated timeseries phenotyping using massive feature extraction. *Cell Systems* 5, 527 (2017). B.D. Fulcher, M.A. Little, N.S. Jones. Highly comparative time-series analysis: the empirical structure of time series and their methods. *J. Roy. Soc. Interface* 10, 2130048 (2013). A updated list of papers related to *hotsa*, or using *hotsa* is maintained on the *hotsa* awakare. M to verview tutorial on applying *hotsa* to a 5-class EEG dataset is here. Xet

WAS THIS PAGE HELPFUL? 🔀

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https://hctsa-users.gitbook.io/hctsa-manual/

https://github.com/benfulcher/hctsa/wiki

Work through the full suite of *hctsa* functionality for this dataset:

https://github.com/benfulcher/hctsaTutorial_BonnEEG)

Work through other *hctsa* analyses for fly and worm phenotyping (open code and pre-computed data):

https://github.com/benfulcher/hctsa_phenotypingFly

https://github.com/benfulcher/hctsa_phenotypingWorm

FYI: Using reduced feature sets (like catch22), there is similar functionality in **theft** or through a drag-and-drop online interface

LOW DIMENSION VISUALISATION

FEATURE CALCULATION QUALITY

ADDITIONAL VISU

CLASSIFICATION PERFORMANCE ABOUT

Low Dimension Visualisation

Page Information

This page visualises the time series features in a low-dimensional representation

Plotting Controls

Select a rescaling function to apply prior to performing dimension reduction	
RobustSigmoid	▼
Select a low dimens	sion method to use
● PCA ○ t-SNE	
If using t-SNE, sele	ct a perplexity hyperparameter value
2	30
2 12 22	2 32 42 52 62 72 82 92 100
Select a unique time	e-series ID to explore further
MD_EEG_UniBonr	n_F001_LP40Hz.dat
Do you want to high	hlight this specific ID on the low dimension plot?
⊙ No O Yes	

Download Controls

The button below downloads the calculated features as a tidy formatted .csv file.

La Download Calculated Feature File

Acknowledgements

Sarab Sethi

Carl Lubba

Imperial College London

Nick Jones

Selected References:

- methods. J. Roy. Soc. Interface.
- Data Eng.
- brain. Chaos.

- Network Neuroscience.

ben.fulcher@sydney.edu.au **2** @bendfulcher CompTimeSeries **O** benfulcher www.benfulcher.com www.comp-engine.org/ github.com/benfulcher/hctsa github.com/chlubba/catch22

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