Analyzing time-series data in neuroscience

All the most important stuff I’ve learned

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This mini-course

Comprehensive guide to analyzing time-series data in neuroscience

For:

Anyone interested in working with modern neuroscience data

Whether you want to:

Analyze data collected to address a specific question

Extracting new scientific results from existing data

Note:

Intended to be comprehensive yet concise, dense but useful.

Why is analyzing time-series data important?

The bread and butter of modern neuroscience

Output of most modern measurement devices

<img EEG signal> <img neuropixel raster> <img behavior video>

Crucial to understand how to work rigorously with such data

Requires both technical and domain knowledge

Goals of this course

Fast-track your way to expertise in time-series analysis in neuroscience

* Gain familiarity with fundamental concepts in time-series analysis

* Gain familiarity with canonical and many state-of-the-art analysis approaches

* Learn to efficiently quantify meaningful phenomena in neural and behavioral data

* Learn to design new analyses to ask new questions

Not included:

How to write code.
Software for managing big data and big compute.
Extensive technical details for specific models.
But see resources at end for this.

The complete outline: everything you need to hit the ground running

Fundamental concepts

- Common data types in neuroscience
  - Intracellular voltage
  - Spike trains
  - LFP/ECoG
  - Calcium imaging
  - fMRI/EEG/MEG
  - Fiber photometry?
  - Video/tracked behavior
  - Stimuli/other sensors
  - Simulation data
- Challenges of time-series analysis
- Modeling as analysis
- Model fitting
  - Parameters
  - Loss functions
  - Training/test data
  - Overfitting/bias-variance tradeoff
  - Model comparison
- Random processes perspective
- Dynamical systems perspective

Philosophy

- What you see depends on how you look
- Frameworks/theories/models
- Descriptive/mechanistic/normative levels
- Measurable vs important quantities
- Importance of making predictions
- Transforming data into scientific results

Methods survey I: Canonical methods

- Common pre-processing steps
  - Spike sorting
  - Image processing/ROI extraction
  - Estimating firing rates
  - Tracking
  - Smoothing
  - Detrending
  - Creating artificial trials
- Classical signal processing
  - Correlation functions
  - Fourier transforms/power spectra
  - Linear filters/impulse response
- Canonical neural data analyses
  - Raster plots and ISIs
  - PSTHs and tuning curves
  - LNP/spike-triggered average

Methods survey II: Modern methods

- Dimensionality reduction
- Clustering/segmentation
- Statistical models
- Latent variable models
- Dynamics/state-space models
- Mechanistic models
- Spatiotemporal analyses
- Neural networks/VAEs/ELBO
- Learning/inference techniques
- Information theoretic methods

Common issues

- Multicollinearity
- Controlled vs naturalistic data
- Nonstationarity and long timescales
- Trials/Sessions/Animals/Conditions
- Binning
- Missing data
- Too much data
- Gotchas: normalization, correlated training/test data, what is N? etc.
- Interpreting data-driven analyses

Practical tips

- Approaching/vetting a new dataset
- Data pre-processing
- Statistics
- Data munging/storage
- Null/control datasets
- Deconstructing fit models
- How to not make mistakes
- Leveraging AI
- Designing custom analyses
- Coding strategies
- Reproducibility/data sharing

Miscellaneous

- Other methods
- Common software
- Other resources