Dimensionality reduction of large-scale neural recordings

Byron Yu

Associate Professor

Electrical & Computer Engineering and Biomedical Engineering

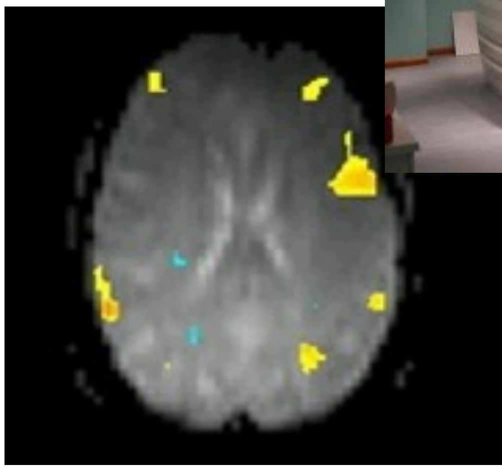
Carnegie Mellon

Multi-dimensional neural recordings

Electroencephalography (EEG)

http://people.brandeis.edu/~sekuler

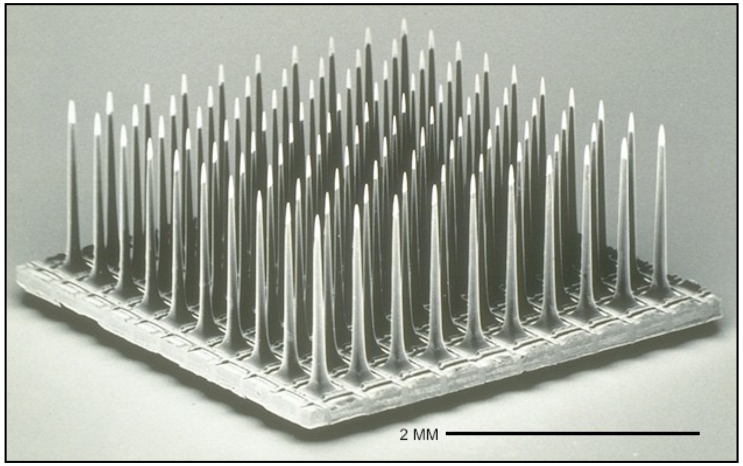
Functional magnetic resonance imaging (fMRI)



http://neurophilosophy.files.wordpress.com/

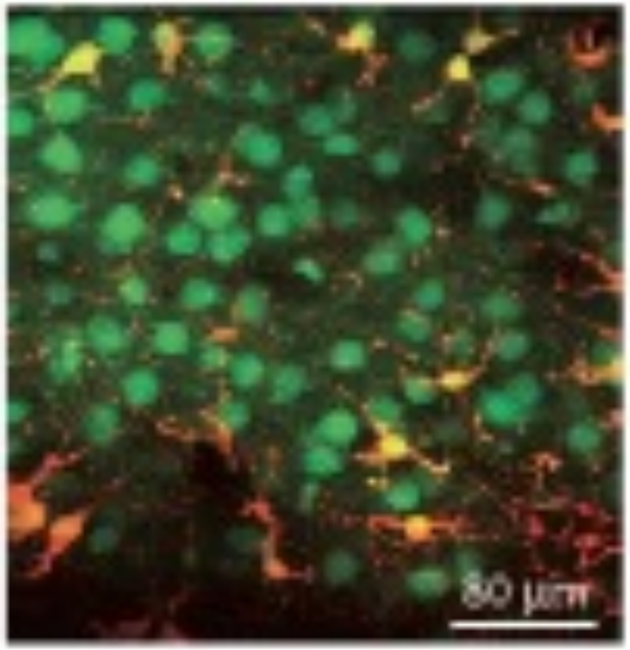
Multi-dimensional neural recordings

Multi-electrode arrays

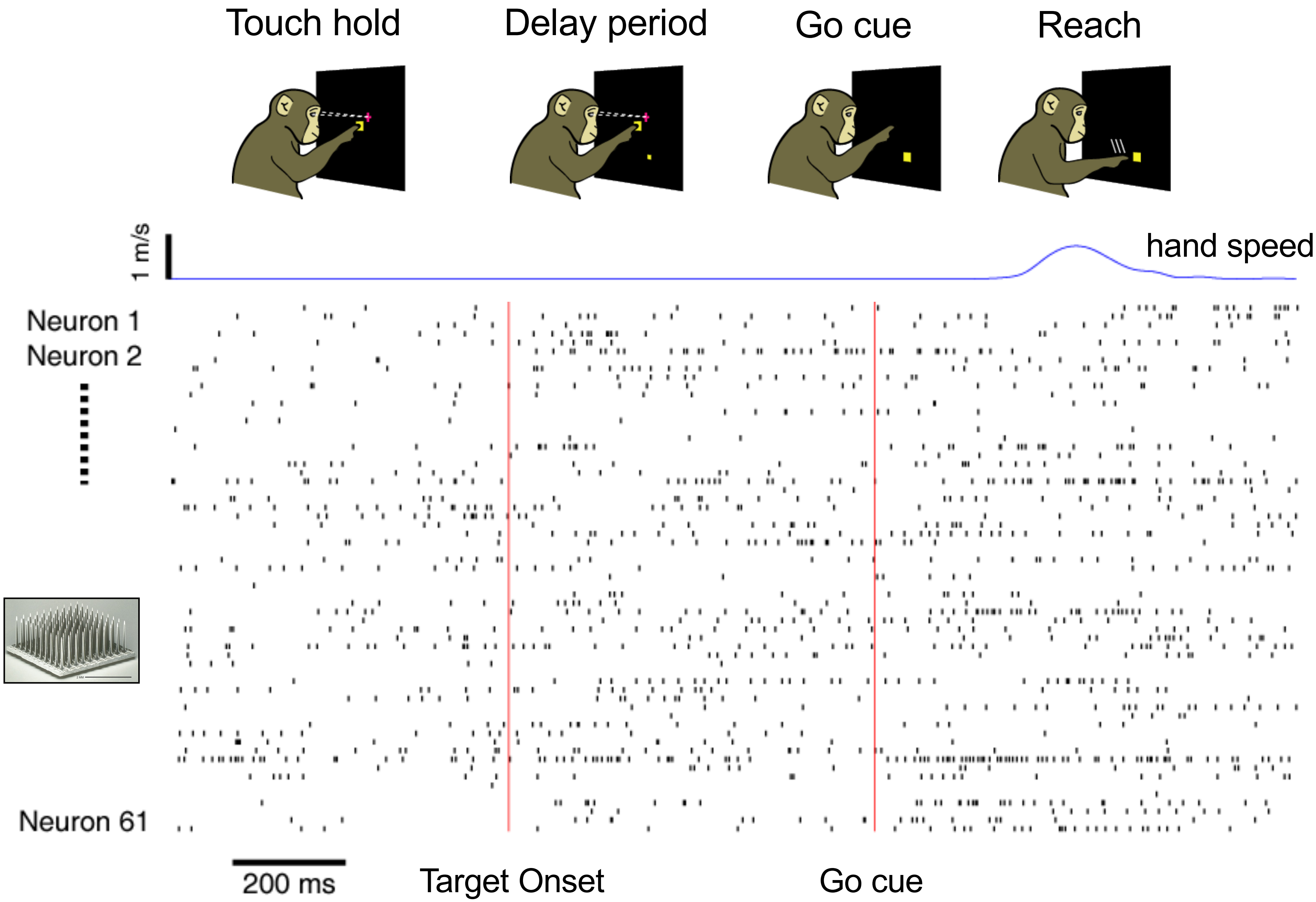


Cyberkinetics, Inc

Optical imaging



Kerr and Denk, 2008.



Trial G20040123.430

Rationale for dimensionality reduction

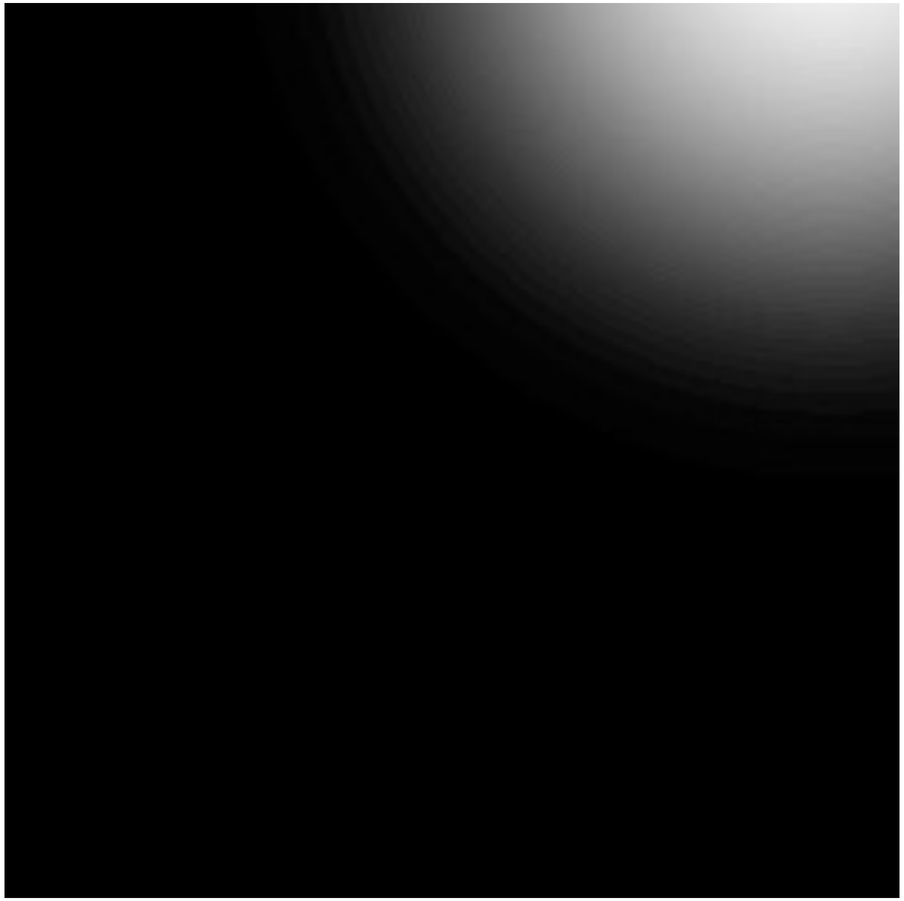
- Because neurons form networks, each neuron cannot act independently

- The brain has fewer degrees of freedom at its disposal than the number of neurons at play

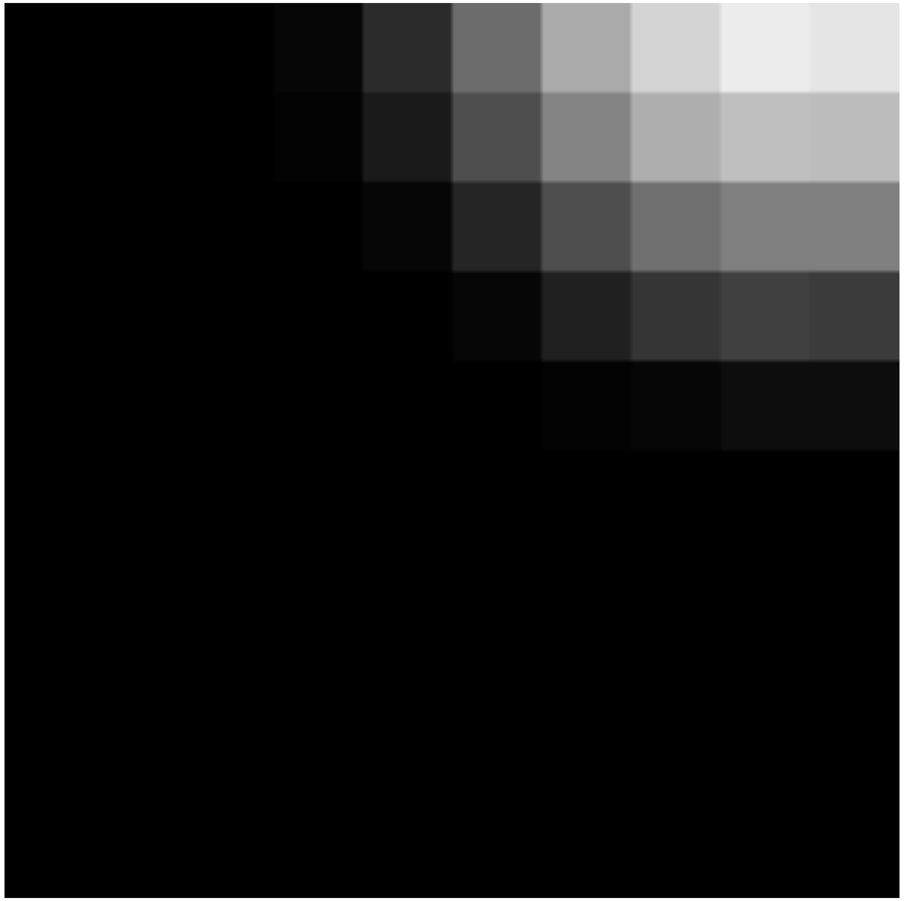
Video analogy

- Each pixel is a neuron
- Pixel intensity is activity level of neuron

Video analogy



Video analogy



Video analogy

Video analogy

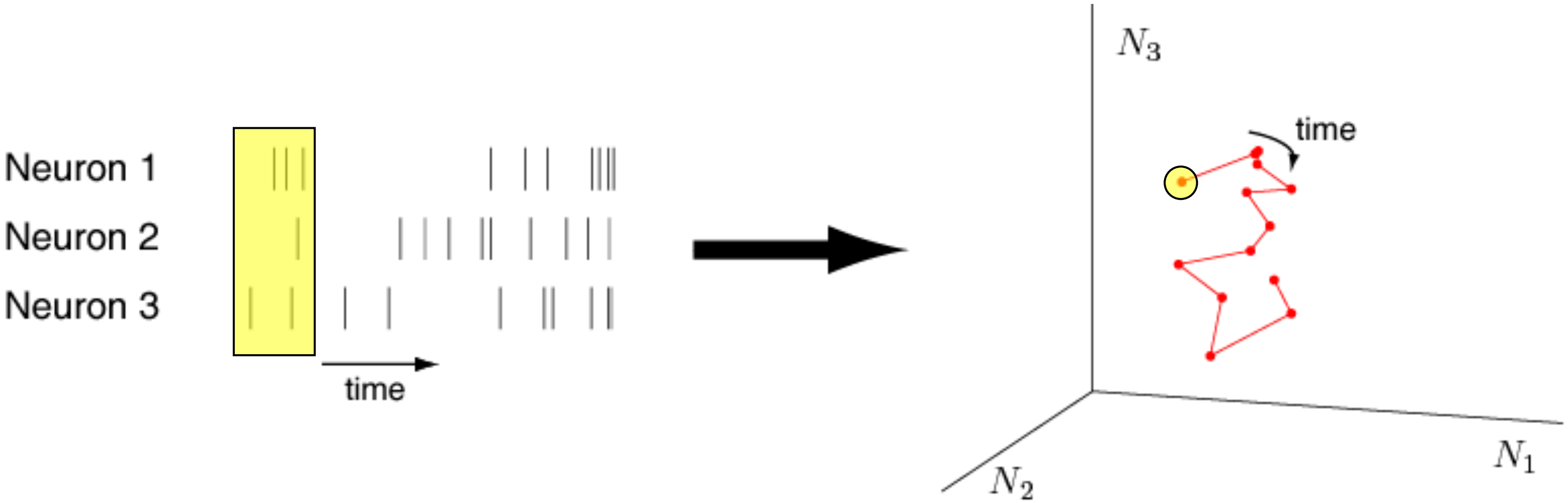
- To fully describe this video, don’t need to model each pixel’s intensity (high-D)

- Each frame fully specified by location of ball (2D)

- Sequence of frames fully specified by Newton’s laws

- Challenge: can we identify low-D state from noisy high-D observations (“**dimensionality reduction**”)?

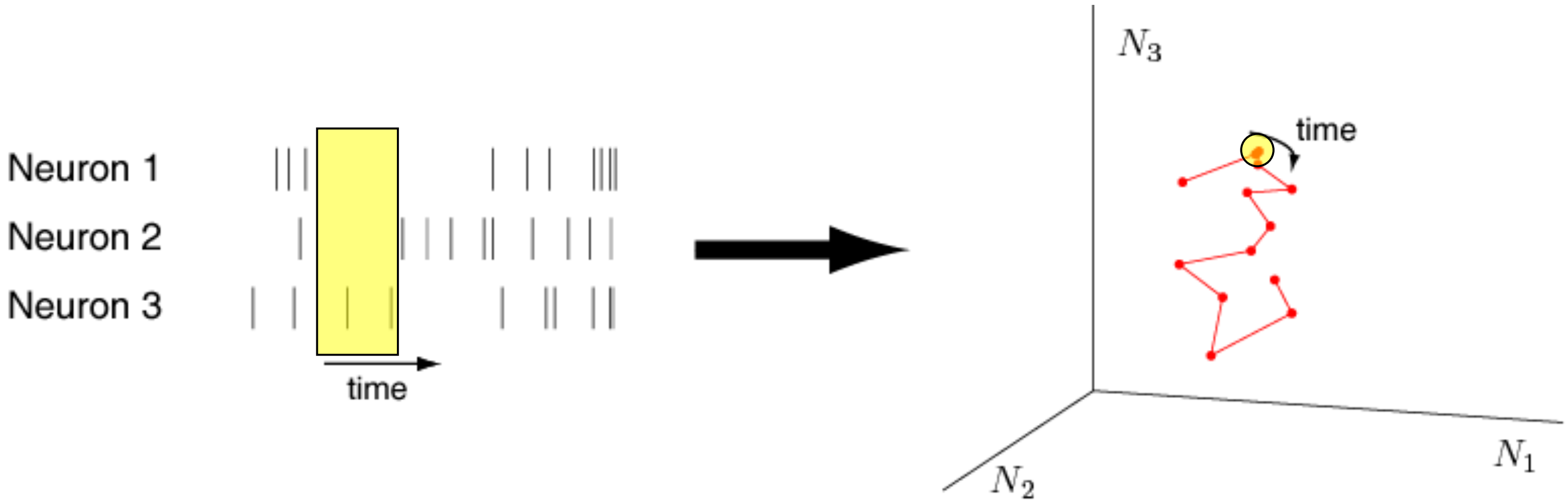
Dimensionality reduction of population activity



Spike trains

Noisy time series

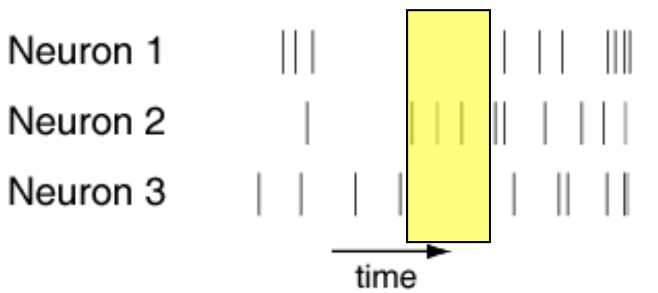
Dimensionality reduction of population activity

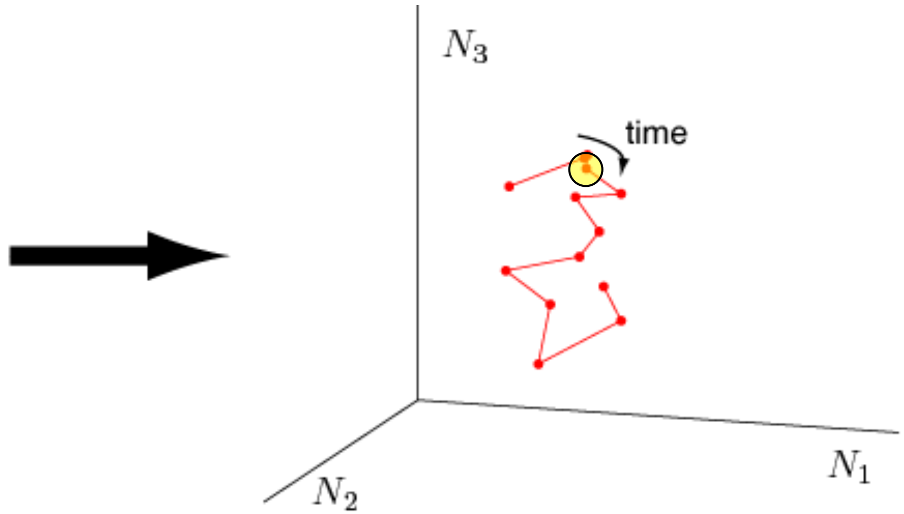


Spike trains

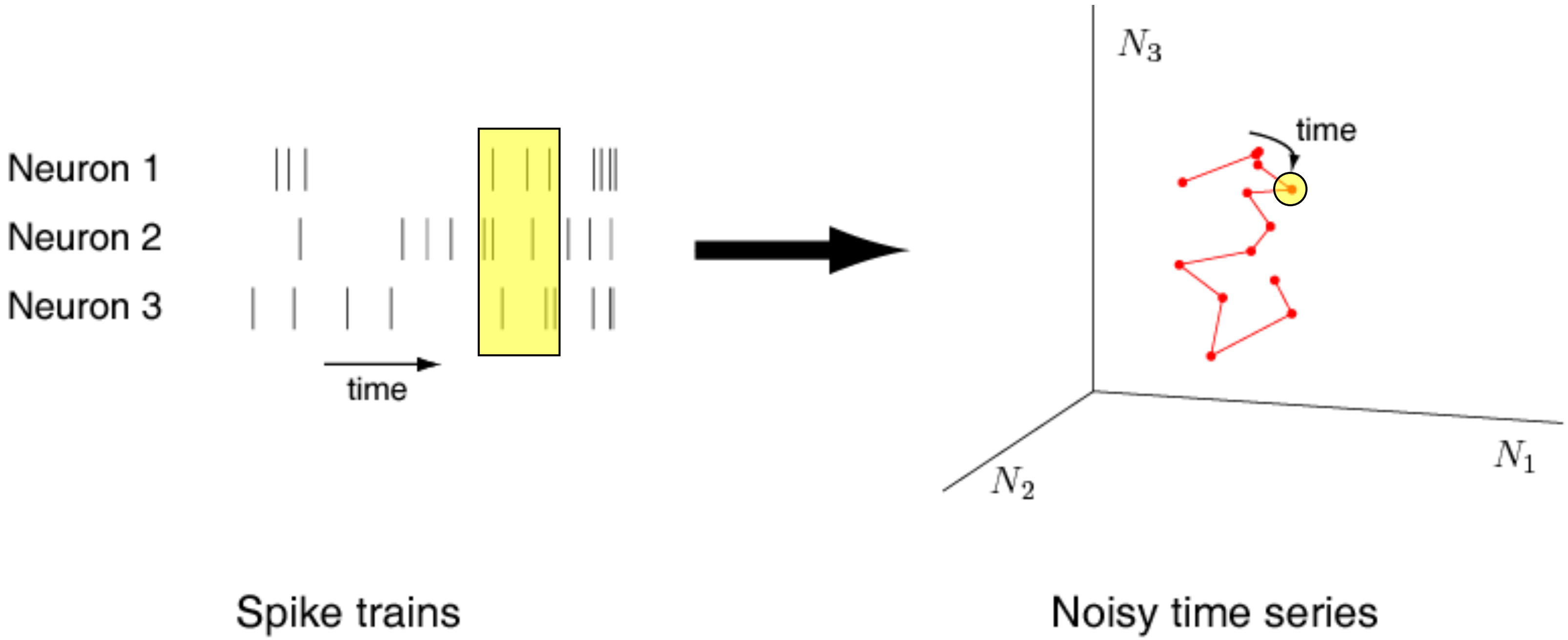
Noisy time series

Dimensionality reduction of population activity

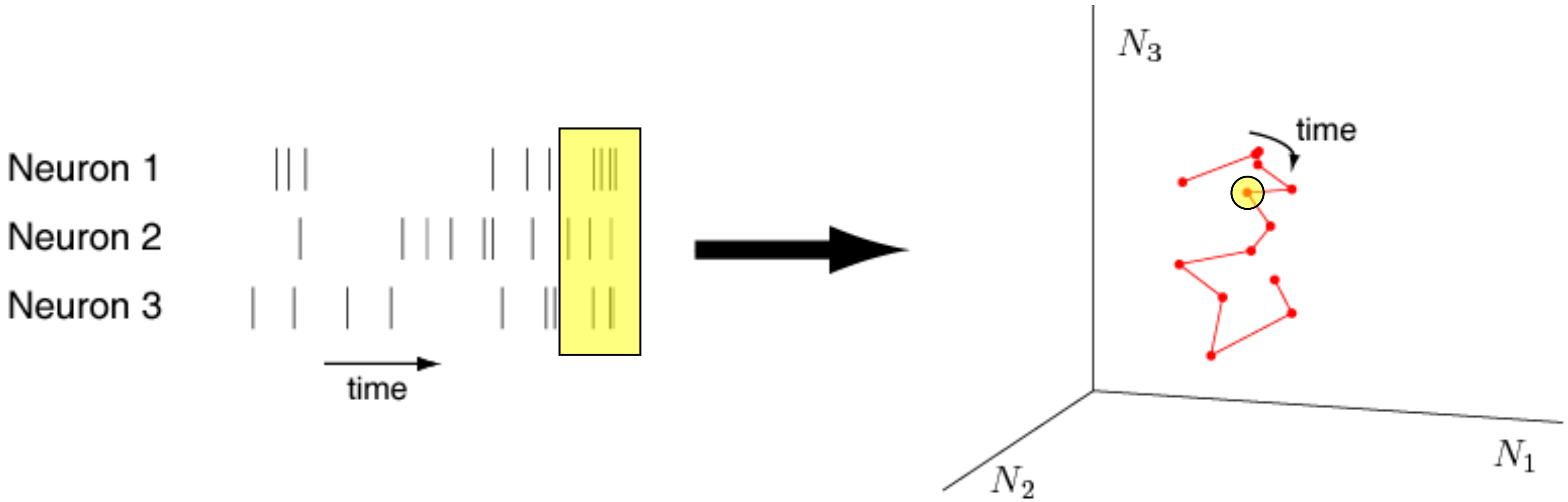




Dimensionality reduction of population activity



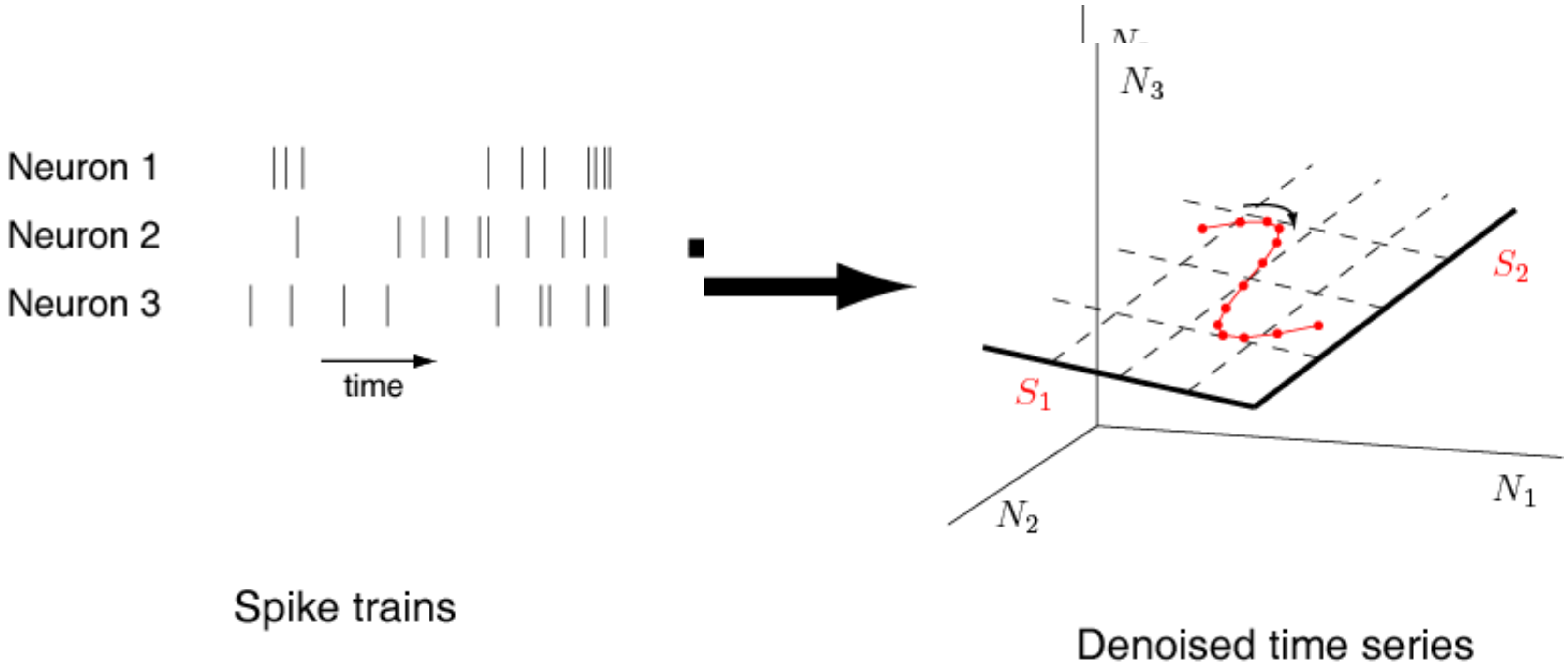
Dimensionality reduction of population activity



Spike trains

Noisy time series

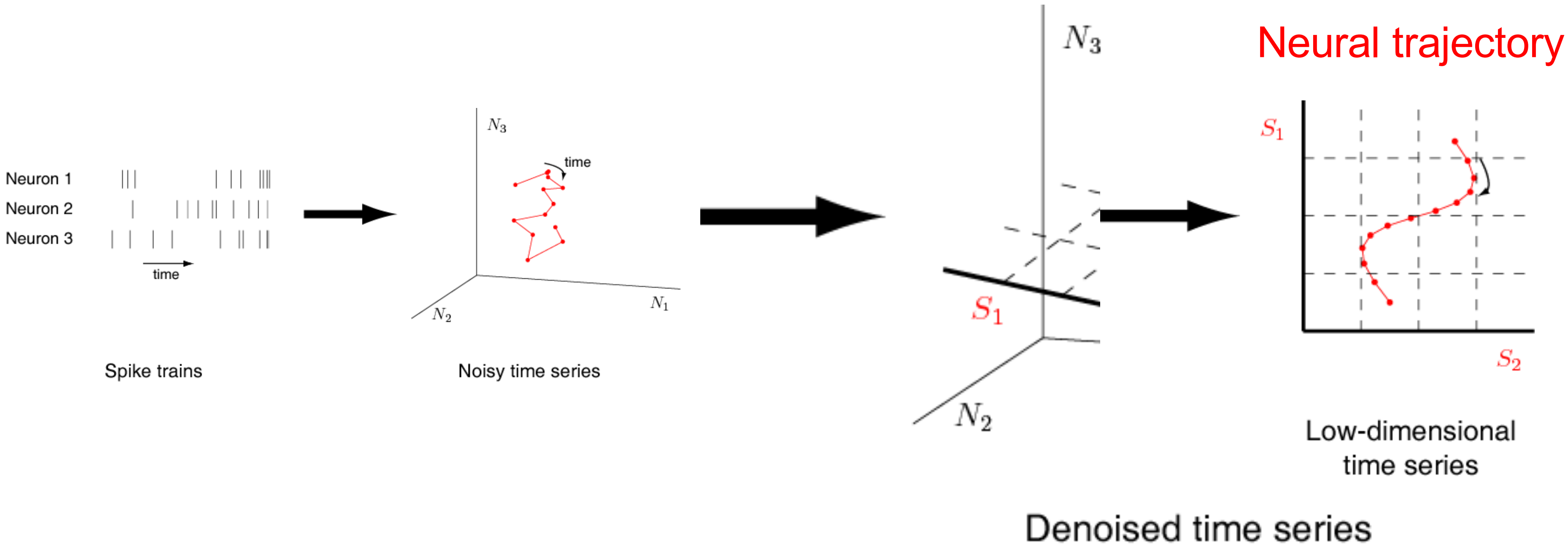
Dimensionality reduction of population activity



Key operations:

- Temporal smoothing
- Dimensionality reduction

Dimensionality reduction of population activity



Example studies using dimensionality reduction

Decision making: Harvey et al., *Nature* 2013; Mante et al., *Nature* 2013

Learning: Durstewitz et al., *Neuron*, 2010; Sadtler et al., *Nature* 2014

Motor control: Churchland et al., *Nature* 2012; Kaufman et al., *Nat Neurosci* 2014

Olfaction: Mazor & Laurent, *Neuron* 2005

Working memory: Machens et al., *J Neurosci* 2010; Rigotti et al., *Nature* 2013

Visual attention: Cohen & Maunsell, *J Neurosci* 2010

Audition: Luczak et al., *Neuron* 2009

Cunningham & Yu, *Nat Neurosci*, 2014.

Reasons to use dimensionality reduction

1) Single-trial analyses of neural population activity

(e.g., Afshar et al., *Neuron* 2011; Harvey et al., *Nature*, 2012;
Kiani et al., *Curr Biol* 2014; Kaufman et al., *eLife* 2015)

2) Hypotheses about population activity structure

(e.g., Mante et al., *Nature* 2013; Sadtler et al., *Nature* 2014;
Kaufman et al., *Nat Neurosci* 2014)

3) Exploratory analyses of large datasets

(e.g., Ahrens et al., *Nature*, 2012)

Cunningham & Yu, *Nat Neurosci*, 2014.

Dimensionality reduction methods available

- Principal components analysis (PCA):

  Good for trial-averaged analyses; no concept of "noise"

- Factor analysis (FA):

  Good for single-trial analyses; no temporal smoothing

- Gaussian-process factor analysis (GPFA):

  Good for single-trial analyses; has temporal smoothing

Cunningham & Yu, *Nat Neurosci*, 2014.

Dimensionality reduction methods available

- Latent dynamical systems:

  Use if know the form of dynamical rules governing time-evolution of neural activity

- Non-linear methods (e.g., Isomap, LLE):

  Generally not recommended; typically don't deal well with noisy data

Cunningham & Yu, *Nat Neurosci*, 2014.