Gravity Transform for Input Conditioning in Brain Machine Interfaces

António R. C. Paiva, José C. Príncipe and Justin C. Sanchez

Computational NeuroEngineering Laboratory and Neuroprosthetics Research Group

University of Florida

presented by John DiGiovanna

EMBC 2006 - September 2, 2006

Outline

1. Motivation
2. Methods
   i. Gravity Transform
   ii. Modeling and output sensitivity analysis
3. Data Analysis

Outline

1. Motivation
2. Methods
   i. Gravity Transform
   ii. Modeling and output sensitivity analysis
3. Data Analysis

Motivation: Input Conditioning?

- Brain Machine Interfaces (BMIs) use recordings from many neurons.
  - Problems: modeling complexity increases dramatically!
  - Solution: input dimensionality reduction.
- Previous solutions for input conditioning reduction are *supervised*!
  - Not good in practice.
- **Goal:** Select/process inputs relevance in a *unsupervised* manner.

Motivation: Why Gravity Transform?

- Allows search of neural assemblies of synchronous neurons.
- Unsupervised.
- Smaller computational requirements.
- Easier to interpret than other methods.
  - Such as:
    - Cross-correlation,
    - Joint peri-stimulus time histogram,
    - Partial directed coherence.

Outline

1. Motivation
2. Methods
   i. Gravity Transform
   ii. Modeling and output sensitivity analysis
3. Data Analysis

Gravity Transform: concepts

- Interactions between neurons are described as forces in a *hypothetical* hyperspace.
- Neurons firing synchronously will attract each other.
  - Look at distance between all neuron pairs
  - Neuron attracking to a point in space are said to be a neural assembly

Gravity Transform: algorithm

1. Place the “neurons” on the corners of a hypercube, so there are *equidistant*.
2. Define the “charge” of each neuron as:

$$q_i(t) = \frac{1}{\lambda_i} \sum_{t_k < t} \exp\left[-\frac{t - t_k}{\tau} \right] - \tau$$

In words:

- Whenever a neuron fires the charge is incremented by $1/\lambda_i$,
- The charge decays exponentially,
- Subtract τ for zero mean charge.

Gravity Transform: algorithm (cont.)

3. In this space, the velocity of the *i*-th neuron is:

$$\frac{dx_i(t)}{dt} = \eta q_i(t) \sum_{j \neq i} q_j(t) \frac{(x_j - x_i)}{\|x_j - x_i\|}$$

4. Using Euler integration with step *dt*, the particle position update equation is:

$$x_i(t+dt) = x_i(t) + \eta q_i(t) \sum_{j \neq i} q_j(t) \frac{(x_j - x_i)}{\|x_j - x_i\|} dt$$

5. For each time step, compute the distance between all pairs of neurons.

System Modeling

- Inputs are binned spike trains in non-overlapping 100ms windows
- Output is prediction of lever position
- Multiple input linear filter, followed by hard threshold
- Memory embedding: 10-tap delay line
- Trained with Wiener-Hopf solution:

$$\boldsymbol{W} = \boldsymbol{R}^{-1}\boldsymbol{P}$$

Output Sensitivity Analysis

- Advantage of multiple input linear filter, *filter weights measure modeling relevance* of neurons and taps.
- Input variance σ_i^2 must also be accounted for.
- In this work, the average “sensitivity” (over the taps) of the desired response to the *i*-th neuron was defined as

$$S_i = \frac{1}{10}\sum_{i=0}^{9}\left|W_{\mathbf{10}(i-\mathbf{1})+j}\right|\sigma_i$$

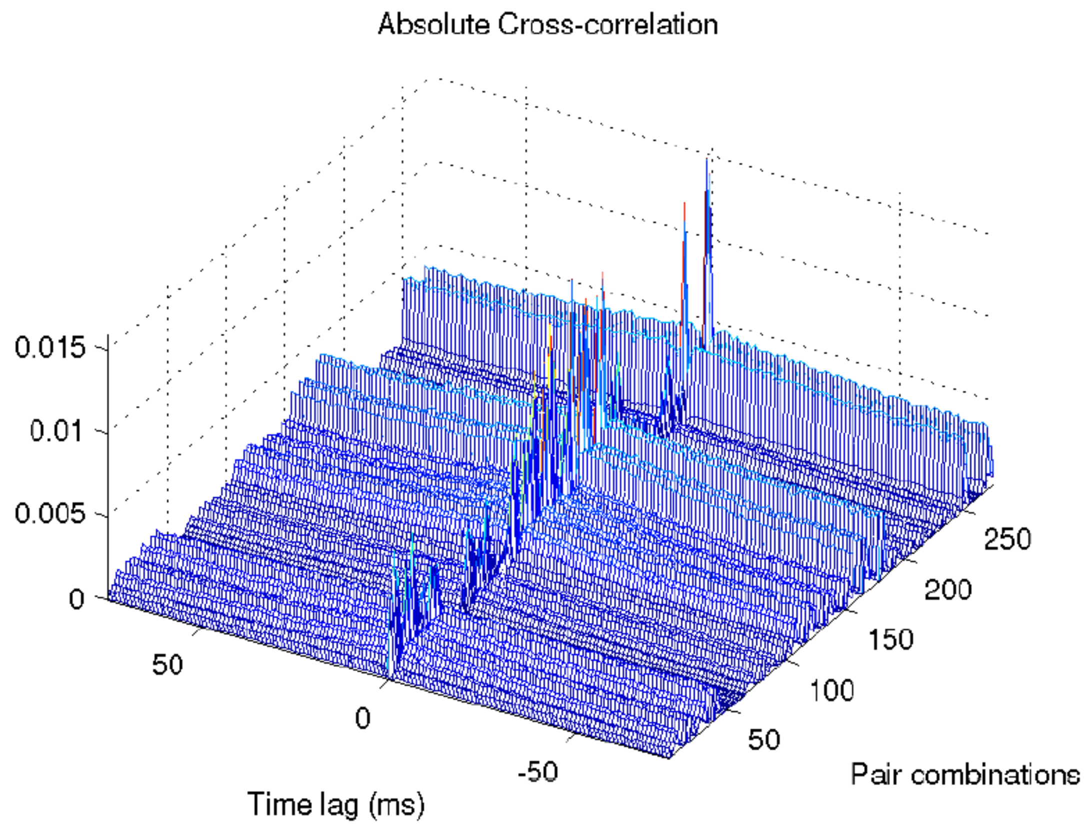
Outline

1. Motivation
2. Methods
   i. Gravity Transform
   ii. Modeling and output sensitivity analysis
3. Data Analysis

Data Analysis: data description

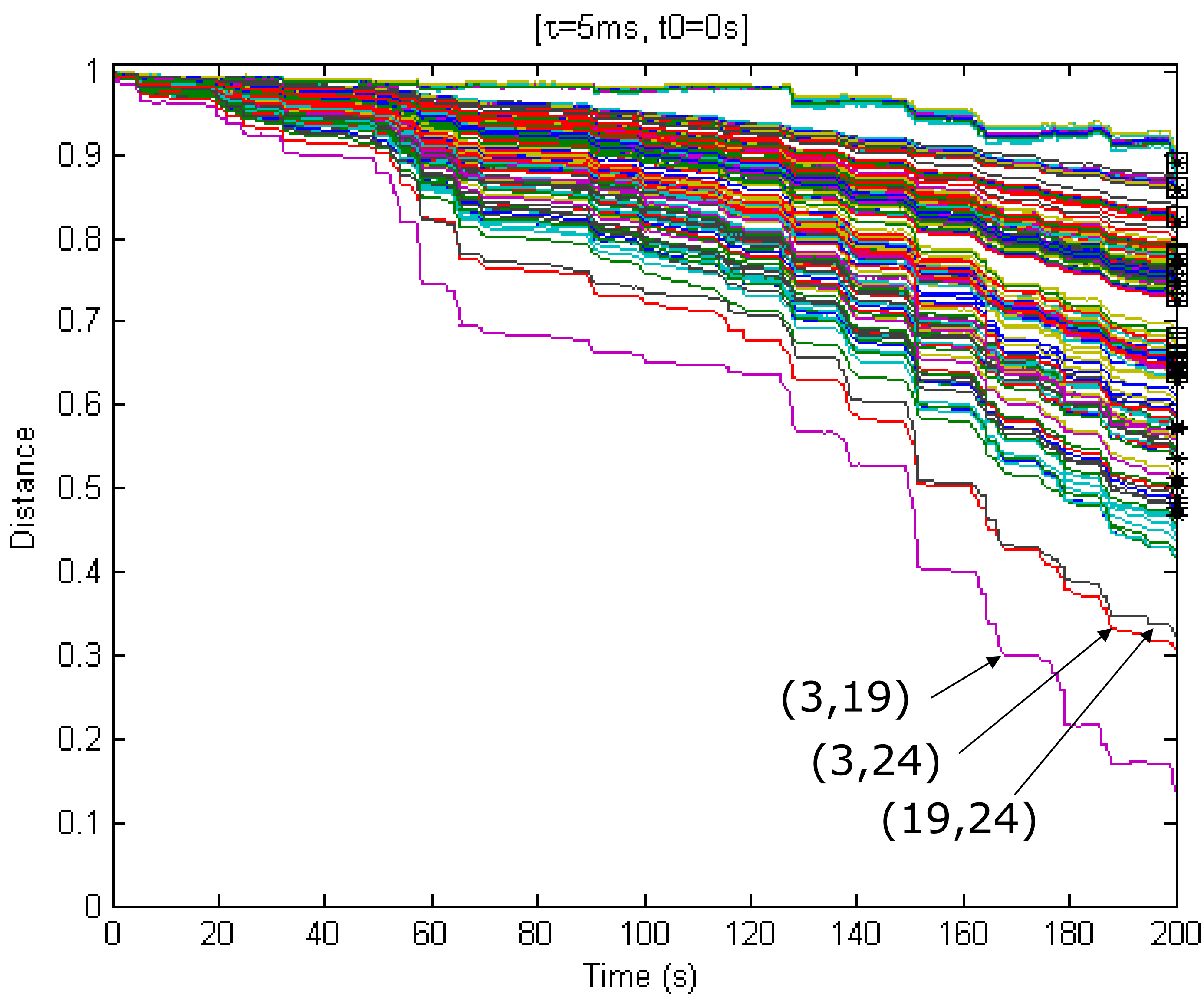
- Used multielectrode array recordings collected from male Sprague-Dauley rats performing a go-no go lever pressing task.
- 2x8 electrode array configurations, chronically implanted in the forelimb region of M1.
- Considered for analysis only the 24 neurons (after sorting) from the left hemisphere.

Data Analysis: neuron cross-correlations



- Are there synchrony delays that can affect our analysis?
- Cross-correlation peak of all pairs occurs at zero lag.

Data Analysis: gravity transform

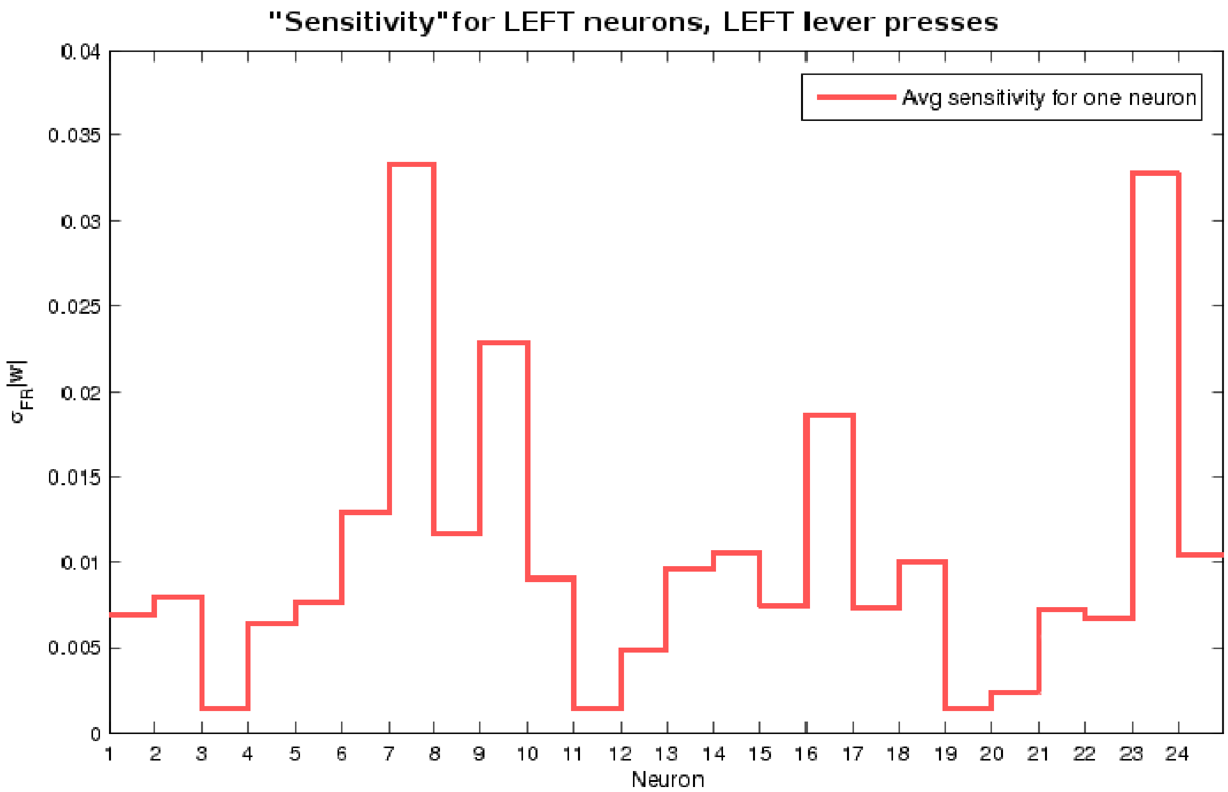


- □ pairs with neuron 7
- * pairs with neuron 23

Data Analysis: gravity transform

- Results seem to not depend on the value of τ, or segment of data used in analysis.
- Almost uniform distribution of pairwise distances among neuron pairs makes difficult to define what is a neural assembly!
- Faster attracting neuron pairs are (3,19), (3,24) and (19,24).
- Yet,...

Data Analysis: sensitivity analysis

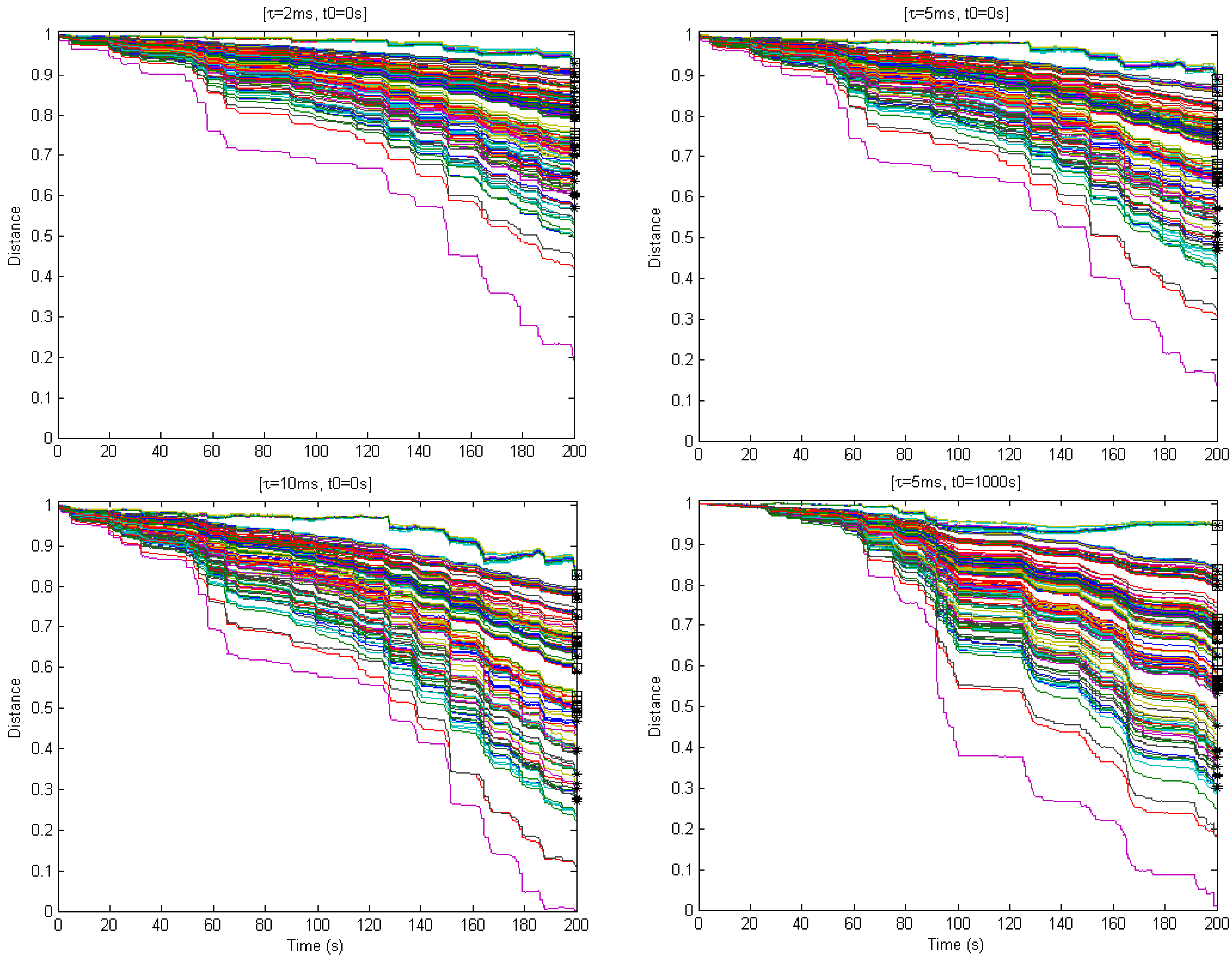


- Most relevant neurons are 7 and 23.
- Modeling relevance does not match gravity transform selection.

Conclusions

- Studied gravity transform an *unsupervised* analysis tool with the intention of performing input dimensionality reduction.
- Results reveal the strong interconnectivity in neurons of the motor cortex (MI) area.
- Results support that neuron ensembles are not easily defined.
- Gravity transform, and its underlying metric, seem inappropriate for the task.

Data Analysis: gravity transform



- □ pairs with neuron 7
- * pairs with neuron 23