Interpreting Neural Activity Through Linear and Nonlinear Models for Brain-Machine Interfaces

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Brain-Machine Interface Project
Motivation for Modeling and Analysis

- **Help Individuals with Disabilities**
  - Of the 43 million Americans with disabilities, approximately 38 per cent have mobility limitations (NIH 1997).
  - Can we extract information about voluntary movement from the brain?
  - Can we restore movement to individuals with neurological disorders?

- **Augment Performance**
  - The nervous system is slow!
    - Complete limb action (~100-900 msec)
  - Muscle strength is limited

- **Learn about neurophysiology!**
Modeling for Brain Machine Interfaces

Posterior Parietal (PP) – Visual to motor transformation

Premotor (PM) – Preparation and guidance (visual inputs)

Primary Motor (M1) – Initiates muscle contraction

We invoke the principles of:

Broadman – Cytoarchitectonic Analysis, Penfield – Topographic Representation

Adrian – Rate Coding, Georgopoulos – Population Coding
BMIs Present an Input/Output Modeling Problem

- We must create a representation space which can map neuronal firing patterns to hand position
- Adaptive systems are tools for modeling
- What is the complexity of the system being modeled?
- Data: nonstationary, sparse, many-to-one mapping
Model Topologies

Linear Feedforward
“Wiener Filter”

Nonlinear Dynamic
“Recurrent Multilayer Perceptron” (RMLP)

\[ y(t) = Wx(t) \]

\[ y_1(t) = f(W_1 x(t) + W_f y_1(t-1) + b_1) \]

\[ y_2(t) = W_2 y_1(t) + b_2 \]
Motor Task & Simultaneous Recording of Neural Activity

Task 1

- Monkey cued to make a 3-D reaching movement to a food reward.
Model Building Techniques

- Train the adaptive system with neuronal firing patterns as the input and hand position as the desired signal.
- Training - 20,000 samples (~33 minutes of neuronal firing)
- Preserve model generalization
- Freeze weights and present novel neuronal data.
- Testing - 3,000 samples – (5 minutes of neuronal firing)
3-D Trajectory I/O Modeling Movie (Fixed Parameters)

Red - Actual
Blue - Predicted
How does each cortical area contribute to the reconstruction of this movement?
Train 15 separate Wiener filters with every combination of cortical input.
Cortical Contributions **Nonlinear**

Train 15 separate RMLPs with every combination of cortical input.

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Computing Sensitivities Through the Models

Identify the neurons that affect the output the most.

**Feedforward Linear Eq.**

\[ y(t) = Wx(t) \]

**Feedforward RMLP Eqs.**

\[ y_1(t) = f(W_1 x(t) + W_f y_1(t-1) + b_1) \]

\[ y_2(t) = W_2 y_1(t) + b_2 \]

**General form of Linear Sensitivity**

\[ \frac{\partial y(t)}{\partial x(t)} = W \]

**General form of RMLP Sensitivity**

\[ \frac{\partial y_2(t)}{\partial x(t-\Delta)} = W_2^T D_t \left( \prod_{i=1}^{\Delta} W_f^T D_{t-i} \right) W_1^T \]
Select Neurons Based on Sensitivity

Firing Counts of Entire Ensemble of Neurons (104)

Sensitivity = \frac{\text{Change in Position}}{\text{Change in Neural Activity}}

Select Neurons with Largest Sensitivity
Ordered Lists of Important Neurons for each Topology

7/10 most sensitive neurons are identical for both topologies
The Effect of Sensitive Neurons on RMLP Performance
Conclusions

- Interpretation of the neuronal activity is independent of the model topology.
- From a BMI design Perspective:
  - Identified cortical regions contributing to the reaching motor task.
  - Developed methods for selecting neurons related to a reaching motor task.
- Spatially sample the cortex as many neurons as technically feasible.
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For references see www.cnel.ufl.edu > Research > BMI