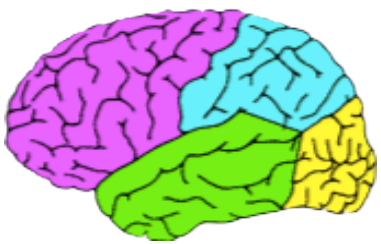
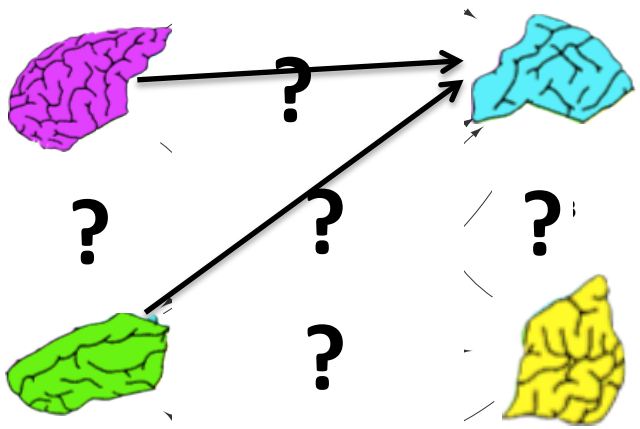
Roadmap

- ➢ Introduction
- The Good Enough Brain Model (GeBM)
- Proposed Algorithm
- Discoveries
- Conclusions

What?

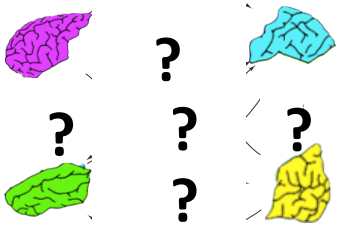
- You see a word ("***apple***")
- You try to answer a question ("***Is it edible?***")
- How do different parts of your brain communicate in the meanwhile?
- Functional Connectivity



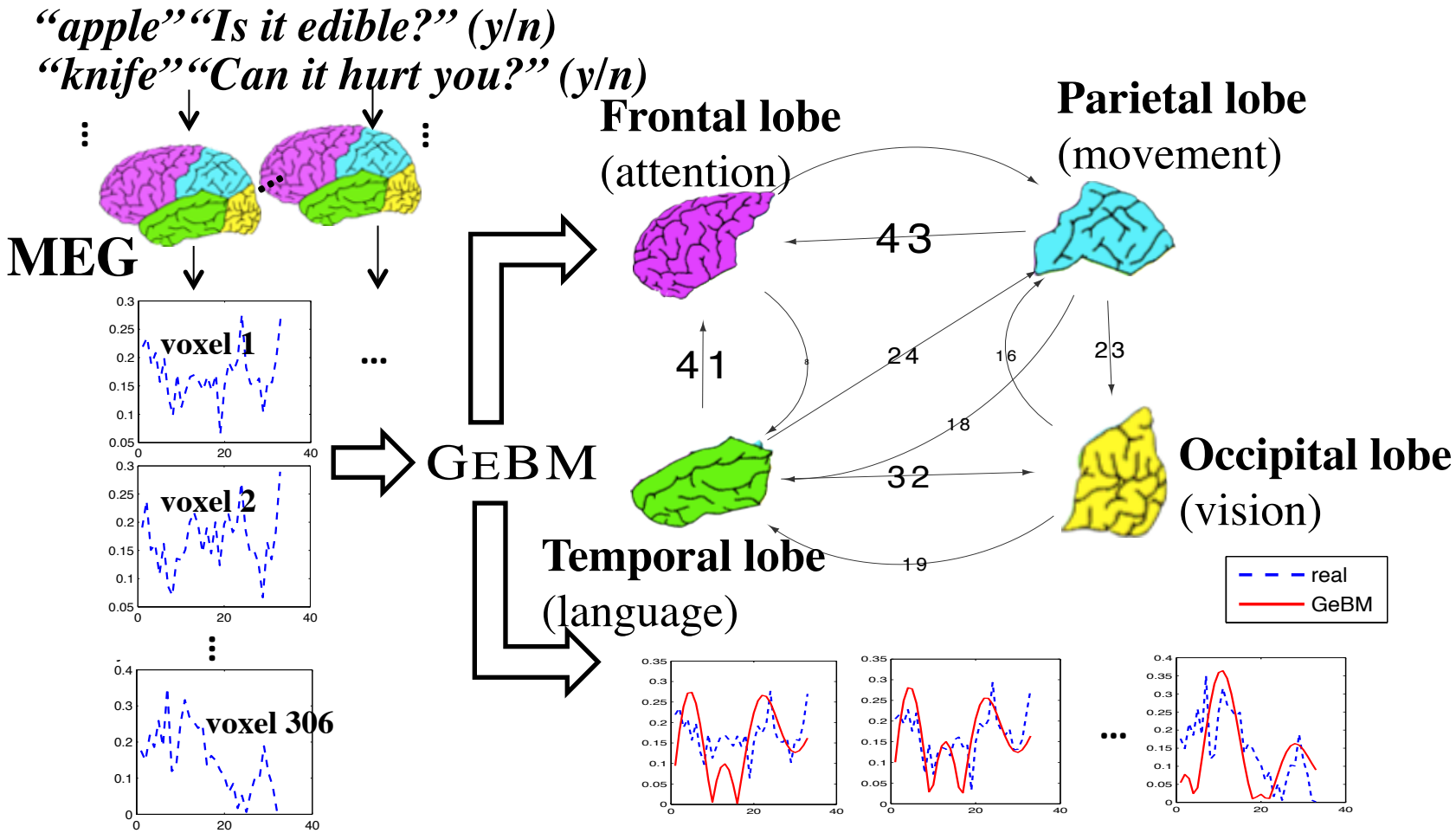


Why?

- Understand the human brain
  - How do different parts communicate?
  - How is information processed?
- Build better robots
- Detect learning disorders at an early age
- …



Bird's Eye (Over)View



Related Work

On the same setting/problem:

- G. Sudre et al., *Tracking neural coding of perceptual and semantic features of concrete nouns*, NeuroImage 2012
- A. Fyshe et al. *Hierarchical latent dictionaries for models of brain activation*, AISTATS 2012

On functional connectivity

- L. Sun et al., *Mining brain region connectivity for alzheimer's disease study via sparse inverse covariance estimation*, KDD 2009
- P. Valdes-Sosa et al., *Estimating brain functional connectivity with sparse multivariate autoregression*, Philosophical Transactions of the Royal Society 2005
- …

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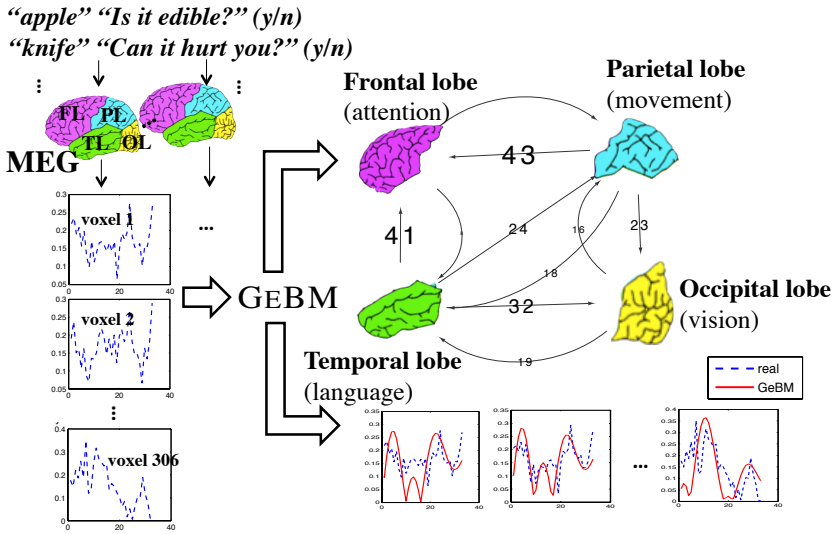
Problem Definition

- **Given:** MEG measurements (*m* sensors) for *T* time intervals, when subject is shown a set of stimuli and asked yes/no questions.
- **Find:** A Graph/Connectivity Matrix between different brain regions



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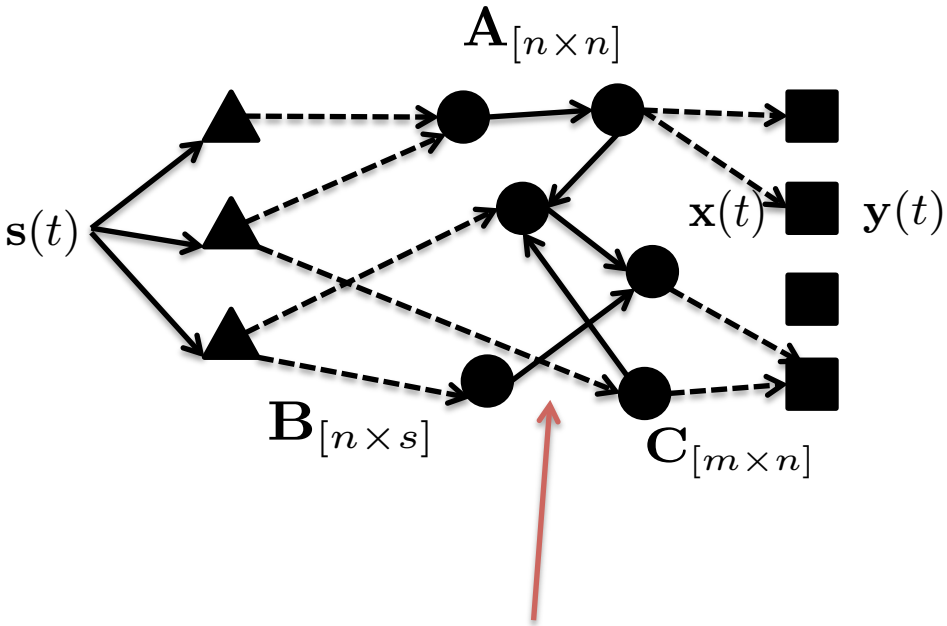
GeBM: Good-Enough Brain Model

$$\mathbf{x}(t+1) = \mathbf{A}_{[n\times n]} \times \mathbf{x}(t) \; + \; \mathbf{B}_{[n\times s]} \times \mathbf{s}(t)$$
$$\mathbf{y}(t) = \mathbf{C}_{[m\times n]} \times \mathbf{x}(t)$$

$\mathbf{A}_{[n\times n]}$	Latent Connectivity Matrix
$\mathbf{B}_{[n\times s]}$	Perception Matrix
$\mathbf{C}_{[m\times n]}$	Measurement Matrix
$\mathbf{x}(t)$	Latent Brain Activity
$\mathbf{y}(t)$	Observed Brain Activity



Latent Neuron Regions

GeBM key points

- Latent states/~neurons
- "Good enough" approach
  - Linear model
  - Ideal: model trillions of neurons (intractable!)
  - We use K (~25) latent "neurons"
- Sparsity
  - Each sensor records few neural regions
  - Regions don't form full clique
  - Stimulus activates only few regions

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Solving for GeBM

DETAILS

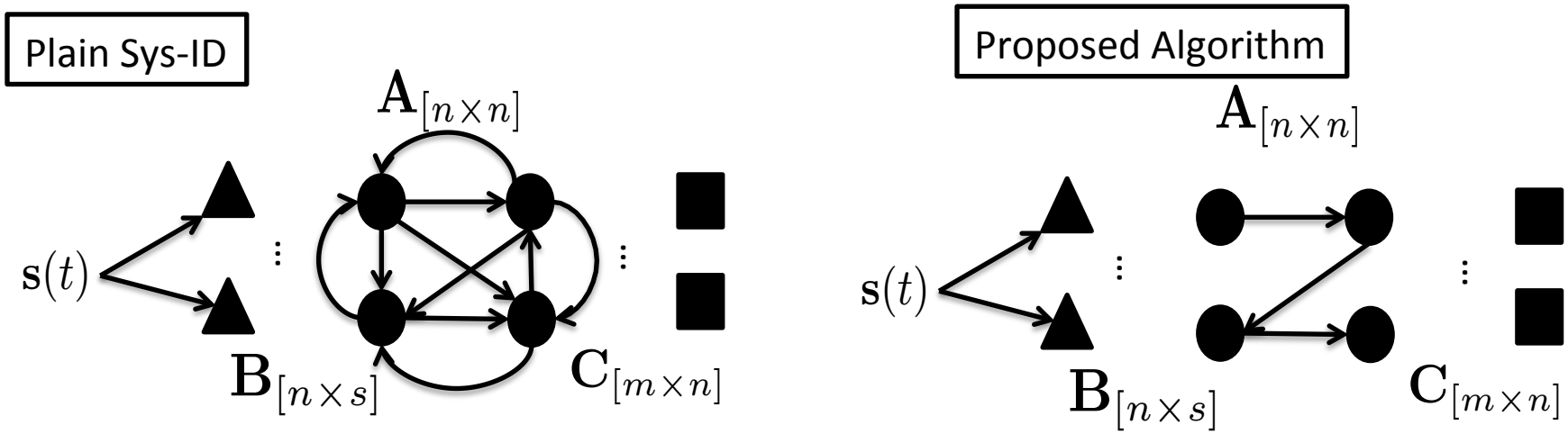
$$\mathbf{x}(t+1) = \mathbf{A}_{[n\times n]} \times \mathbf{x}(t) \; + \; \mathbf{B}_{[n\times s]} \times \mathbf{s}(t)$$
$$\mathbf{y}(t) = \mathbf{C}_{[m\times n]} \times \mathbf{x}(t)$$

- Linear Control System
- Control Theory to the rescue:
  - *System Identification*

Proposed Algorithm

DETAILS

- BUT, Plain sys-ID gives **full clique (A, B, C** dense)

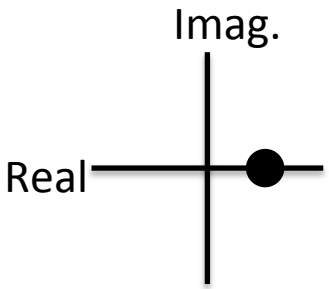


- Q: How to sparsify (maintaining behavior)?
- Hint: Preserve the **Eigenvalues**

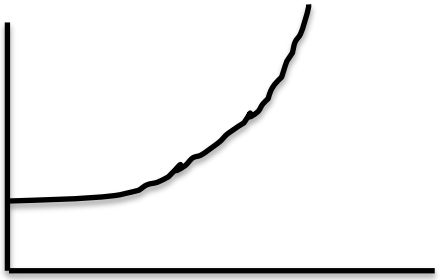
Eigenvalues → Behavior

Background

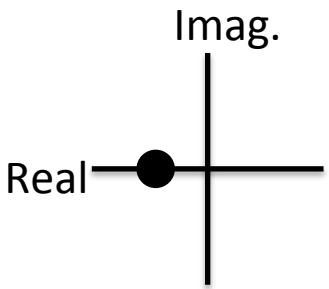
System's response



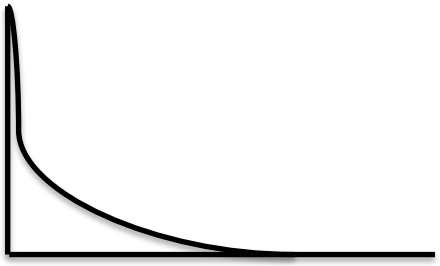
Real & positive eigenvalue



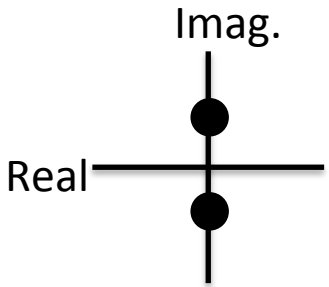
Exponential increase



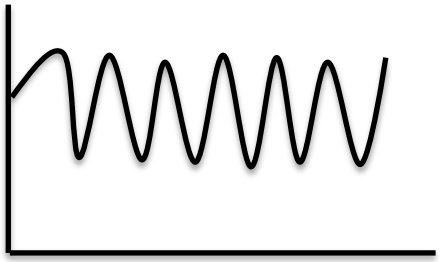
Real & negative eigenvalue



Exponential decay



Complex



Oscillation

Roadmap

- Introduction
- The Good Enough Brain Model (GeBM)
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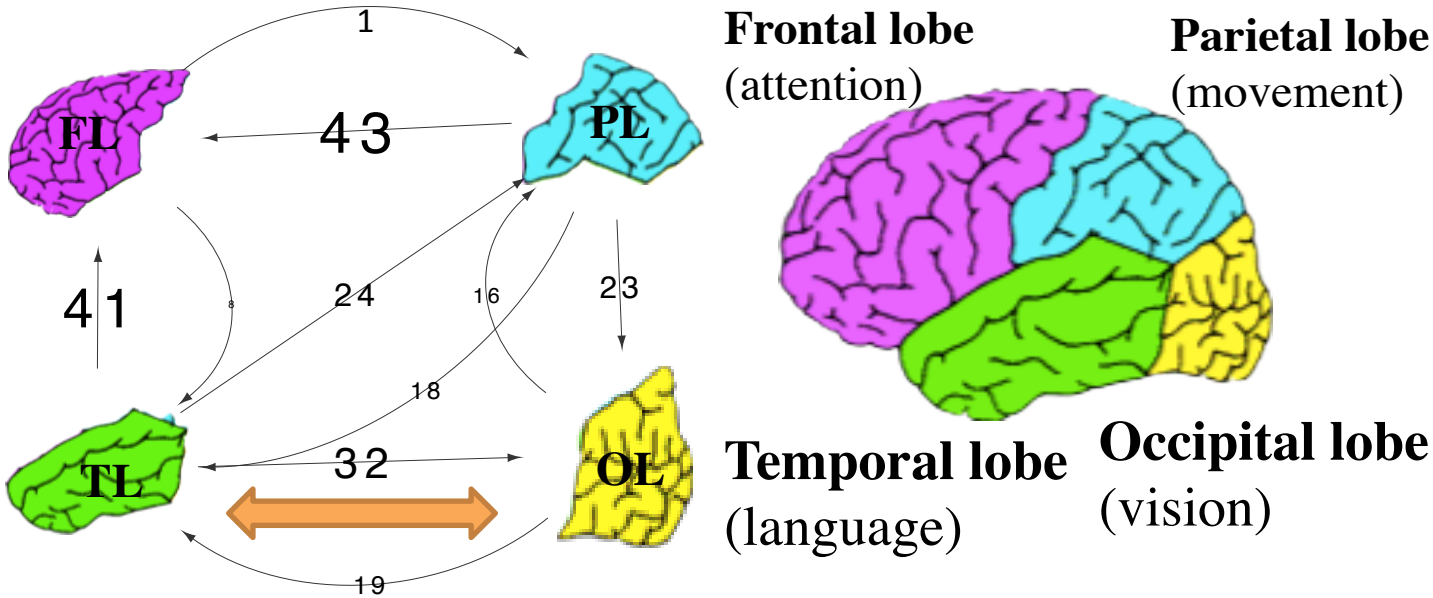
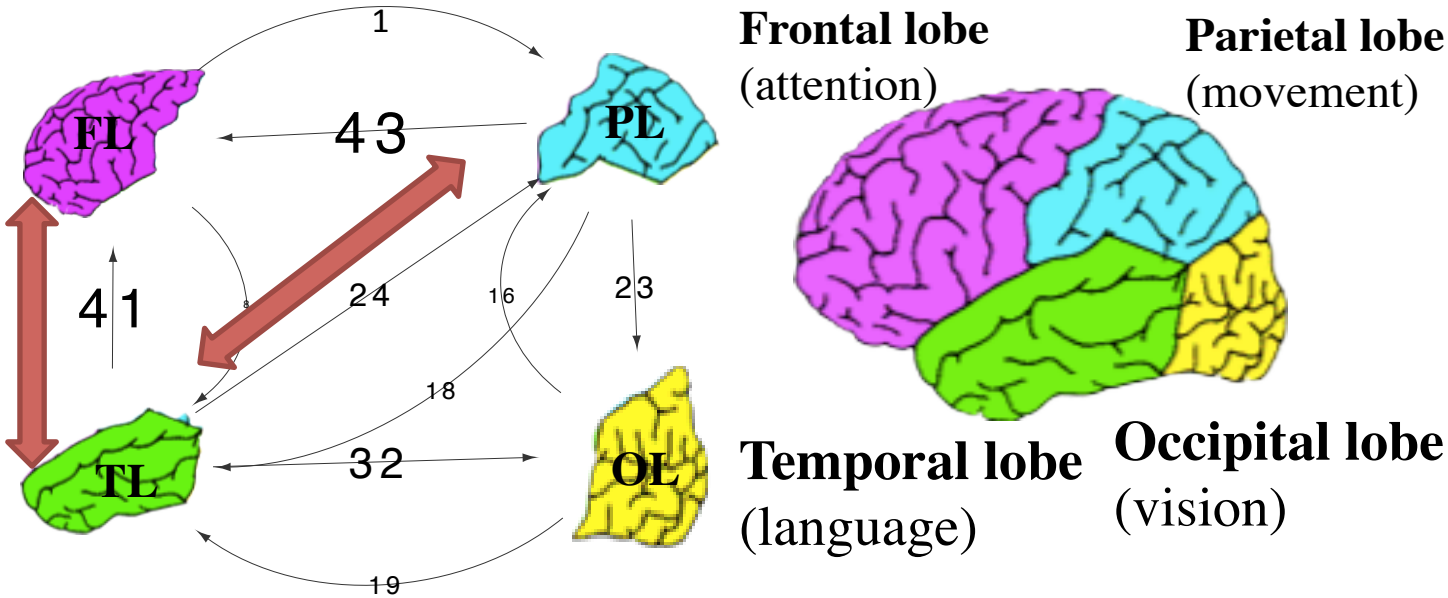
- Discoveries
  - D1: Functional Connectivity Graphs
  - D2: Cross-subject Analysis
  - D3: Brain Activity Simulation
  - D4: Simulation of Psychological Phenomena
- Conclusions

D1: Functional Connectivity Graphs



- *Ventral & Dorsal* pathways [Hickock & Poeppel '04]
- ***Ventral***: From Occipital Lobe (Vision) to Temporal Lobe (Language) ⟷

D1: Functional Connectivity Graphs

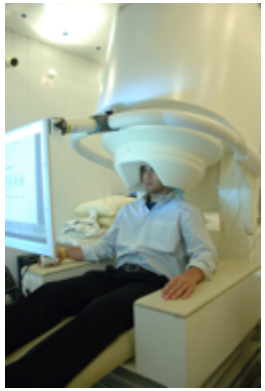


- ***Dorsal*** pathway: From Temporal Lobe (Language) to Parietal & Frontal Lobes (for planning and acting)

D2: Cross-subject Analysis

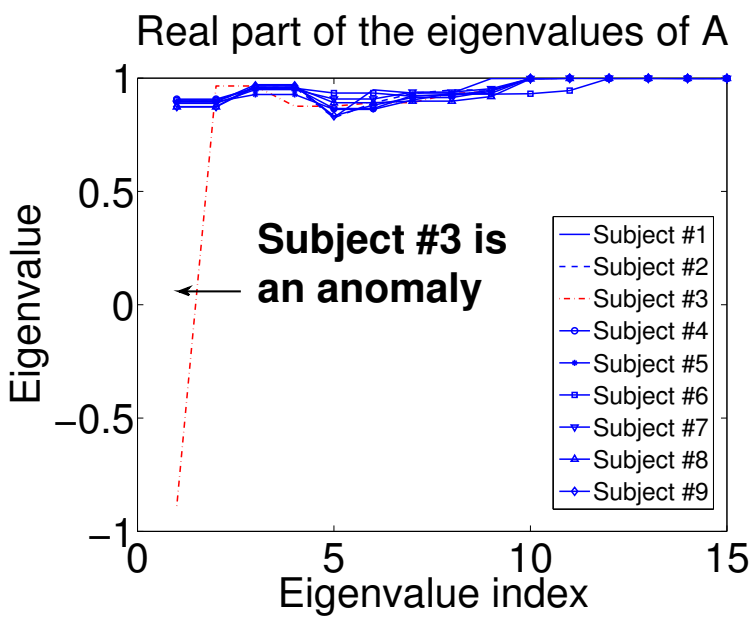
Setup

- Nine human subjects (balanced male/female)
- All did same experiment (same noun/question pairs)

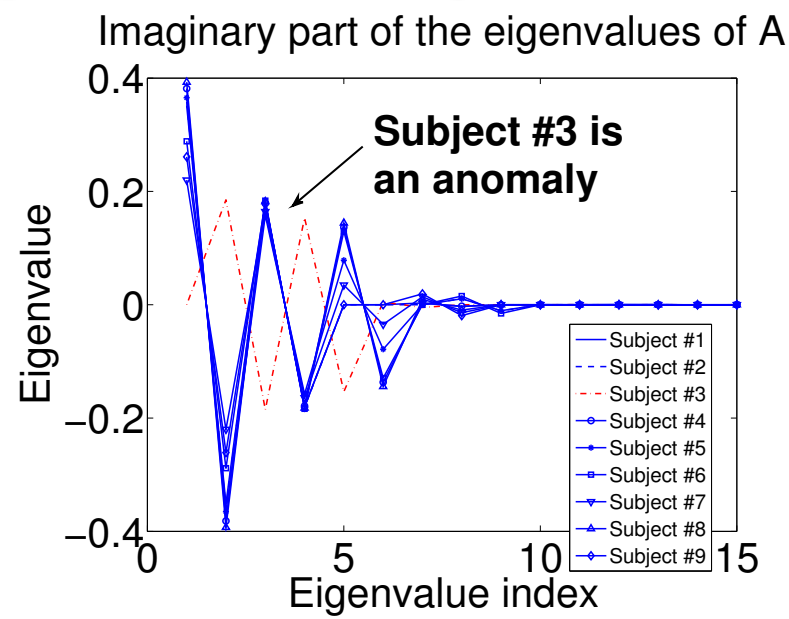


"apple" "Is it edible?" (y/n)
"knife" "Can it hurt you?" (y/n)

D2: Cross-subject Analysis



(a) Real part of eigenvalues

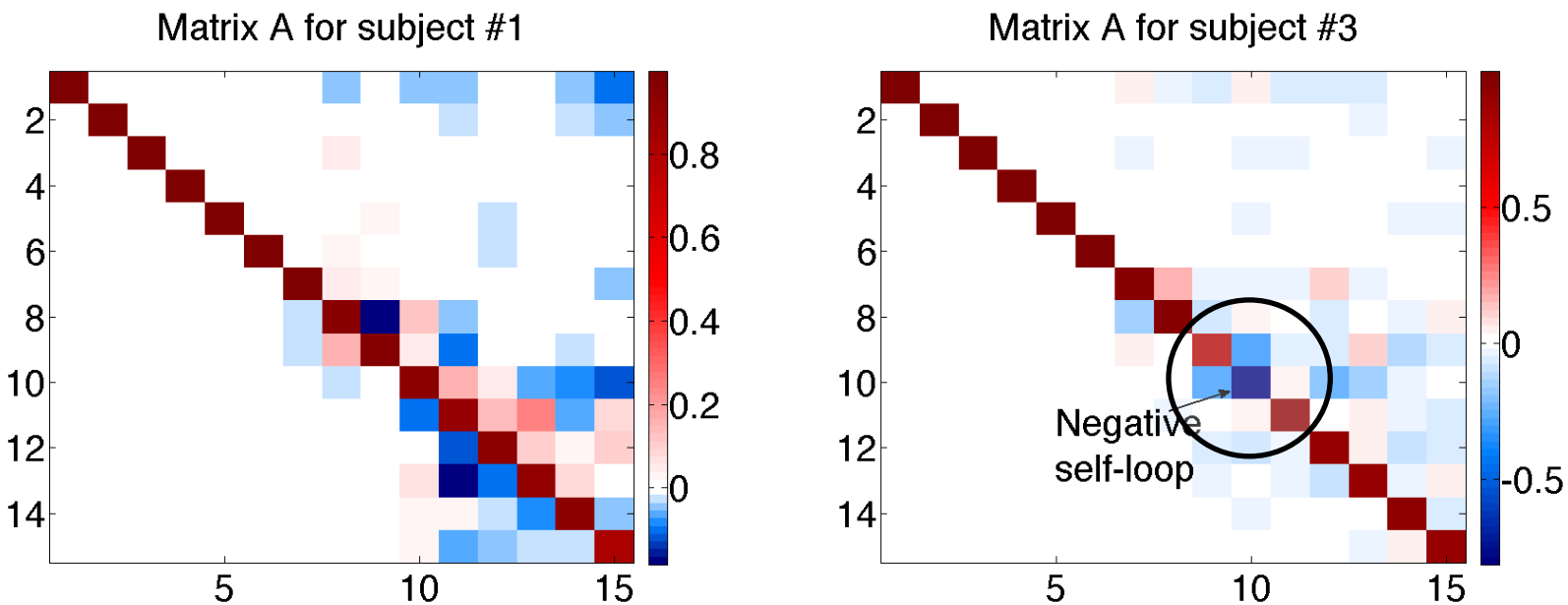


(b) Imaginary part of eigenvalues

- **Observations**

1. GeBM produced almost same model for 8/9 human subjects
2. All subject but #3 have same eigenvalues

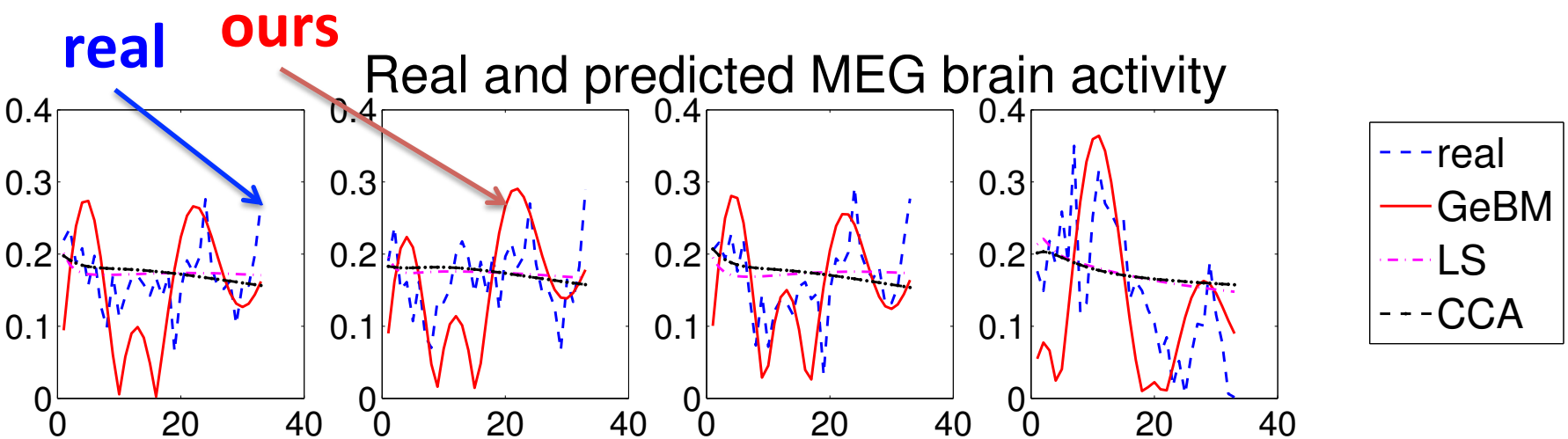
D2: Cross-subject Analysis



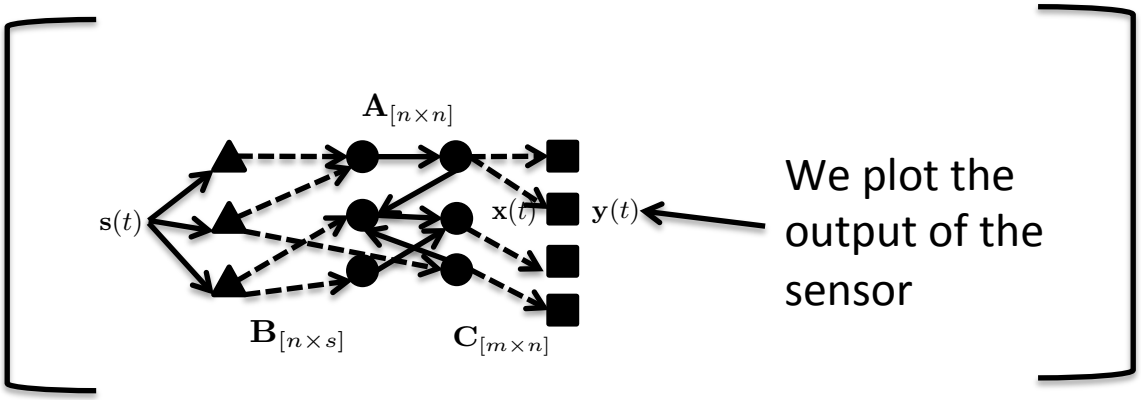
(c) Subject #1 (d) Subject #3

- Explanation: Connectivity matrix for Subj. #3 has negative self loop
- (Road noise during experiment)

D3: Brain Activity Simulation



GeBM is produces realistic brain activity time-series



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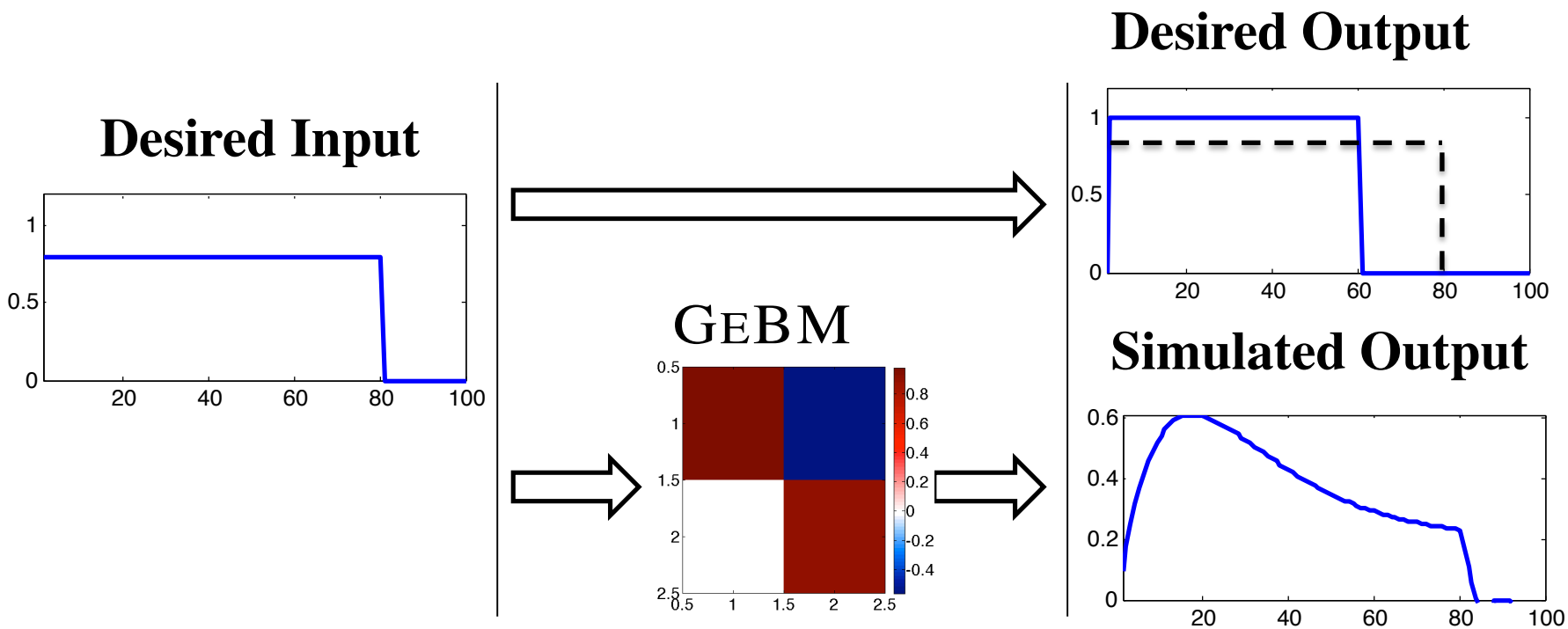
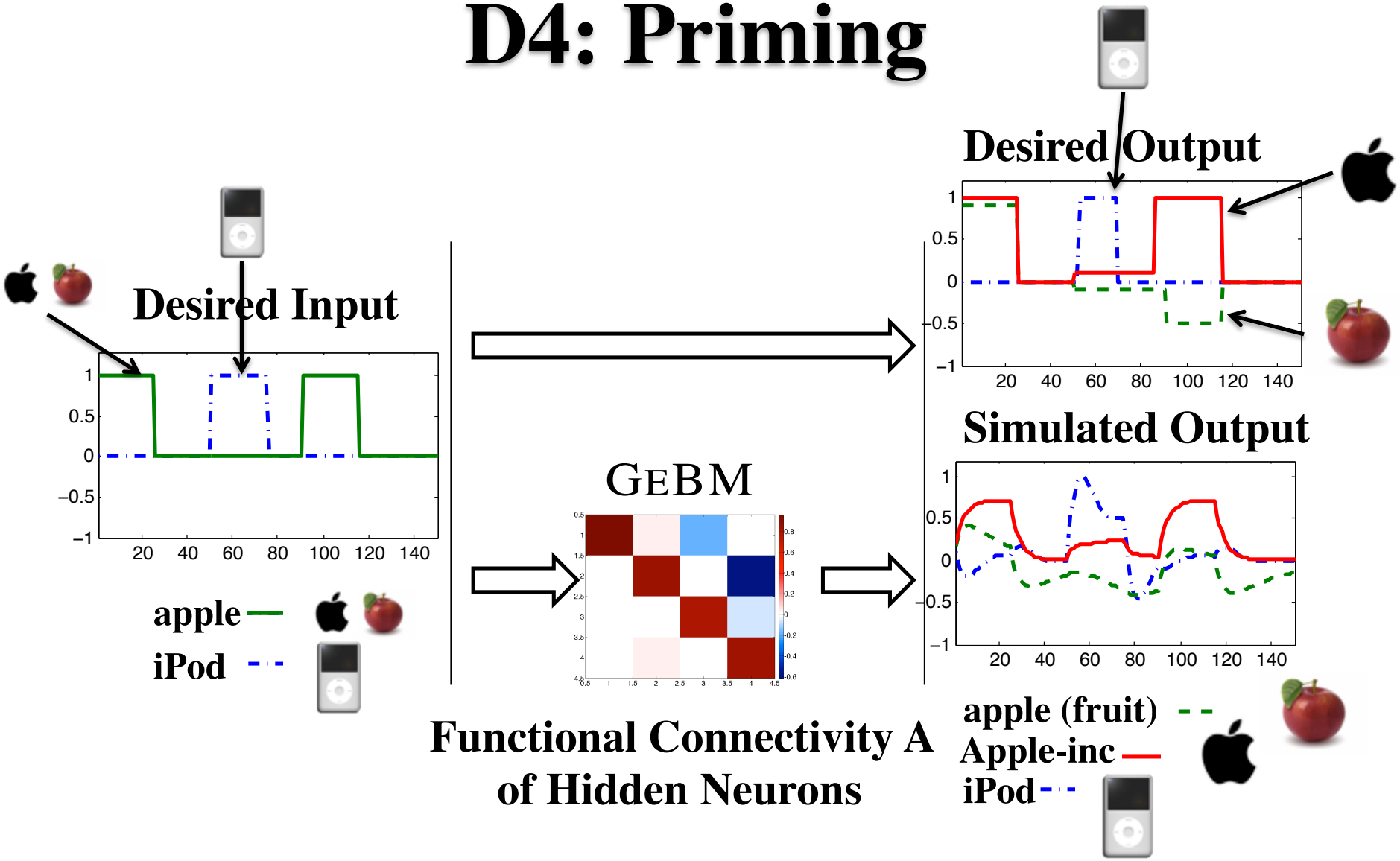
D4: Simulation of Psychological Phenomena

- Habituation
  - Repeated stimulus causes neural activity to attenuate
- Priming
  - Power of context
  - E.g. iPod/ Apple vs. Orange/ Apple

D4: Habituation



D4: Priming


Desired Input
apple
iPod
GEBM
Functional Connectivity A of Hidden Neurons
Desired Output
Simulated Output
apple (fruit)
Apple-inc
iPod

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Conclusions

- We introduce GeBM, a **simple** and **effective** brain model
- Introduce novel Sparse System Identification Algorithm
- Discoveries correspond to Neuroscientific ground truth

Thanks

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Grants no. FA87501320005, FA865013C7360

UPMC Brain Mapping Center

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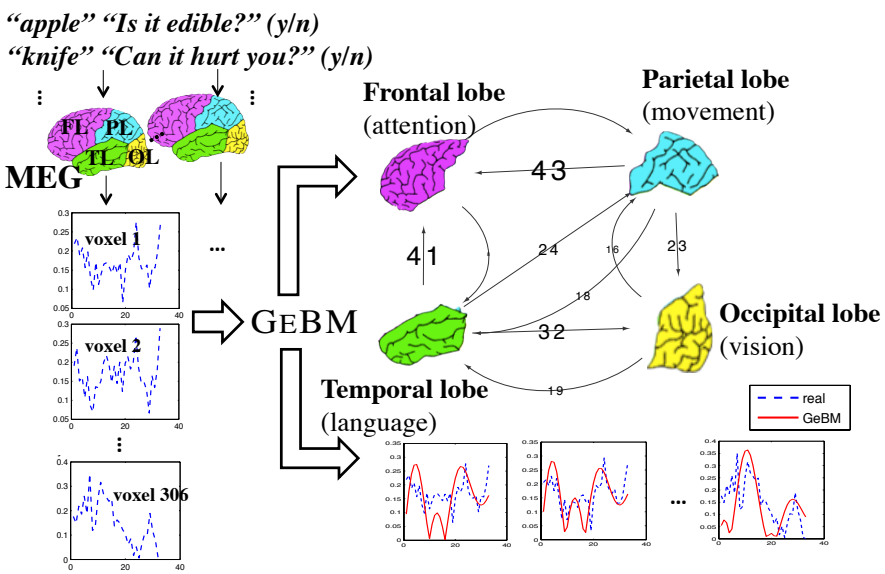
Questions?

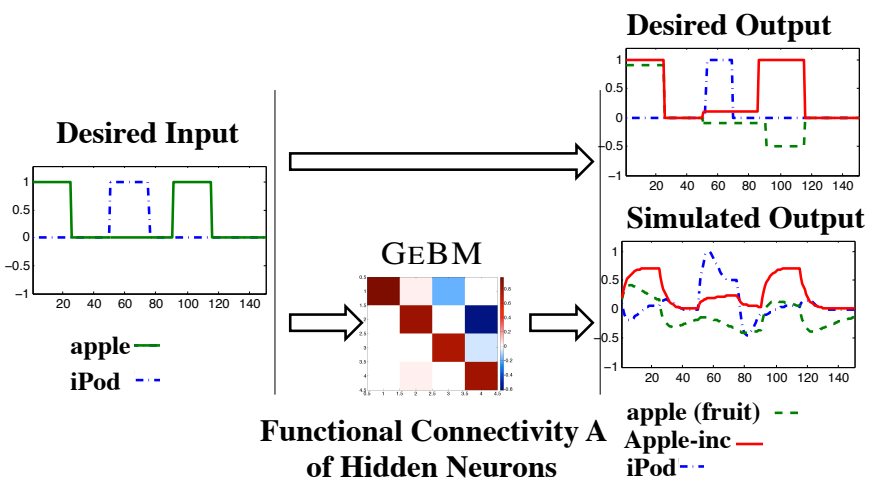
Download **code** at: www.cs.cmu.edu/~epapalex/src/GeBM.zip

More **code** at: www.cs.cmu.edu/~epapalex/code.html

Model



Effectiveness



Model$_0$: First modeling attempt

DETAILS

- Linear autoregressive model with input stimulus

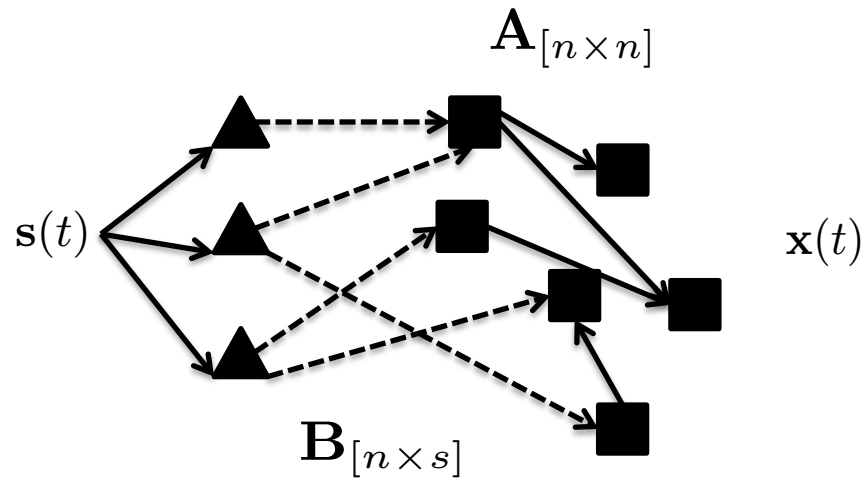
$$\mathbf{x}(t+1) = \mathbf{A}_{[n\times n]} \times \mathbf{x}(t) \; + \; \mathbf{B}_{[n\times s]} \times \mathbf{s}(t)$$

$\mathbf{A}_{[n\times n]}$ Sensor to sensor connectivity

$\mathbf{x}(t)$ MEG sensor activity at time *t*

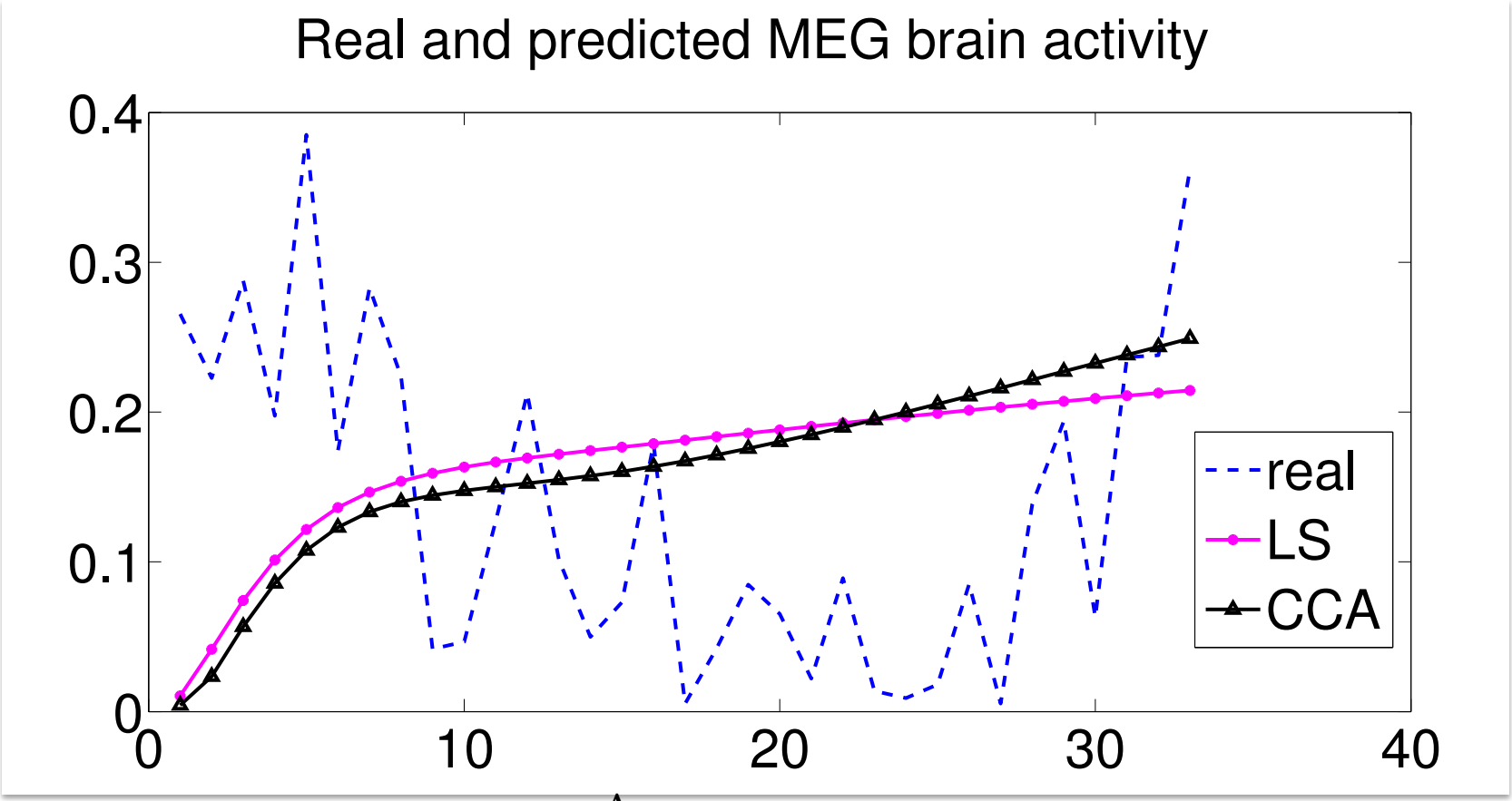
$\mathbf{s}(t)$ stimulus at time *t*

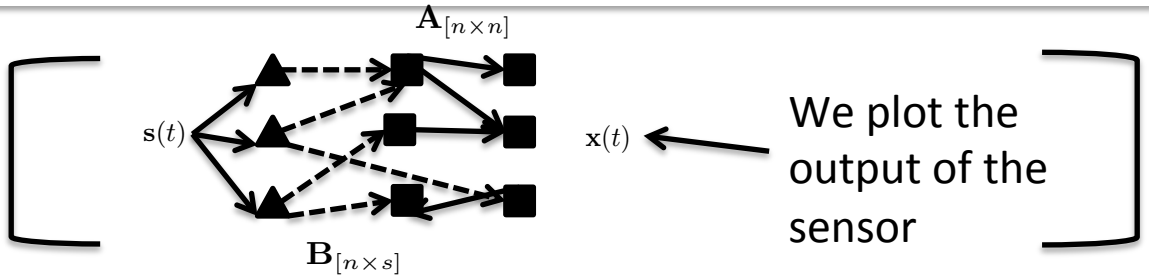
$\mathbf{B}_{[n\times s]}$ Stimulus to sensor matrix



s(t) contains feature representation of the noun and the question asked

Model$_0$ is Unsuccessful





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Introducing GeBM

- Model_0 ignores an important aspect:
  - MEG measures indirectly the brain activity
- Brain has latent/unobserved states
- We need a model that captures that