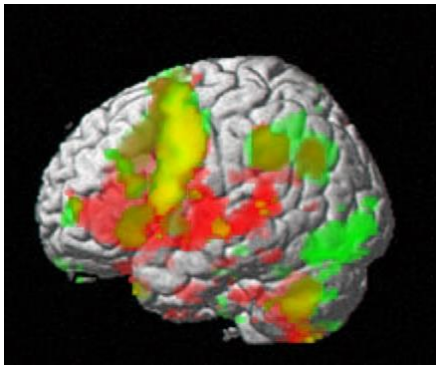
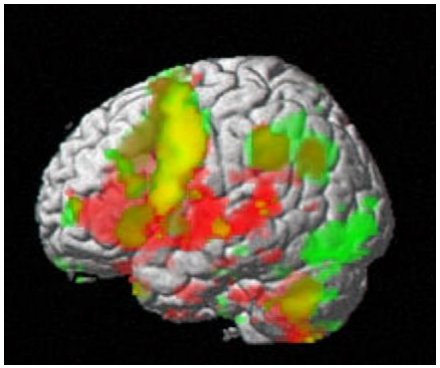
A Similarity Retrieval System for Multimodal Functional Brain Images

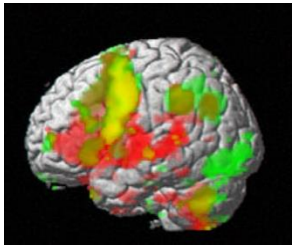


Rosalia F. Tungaraza
Advisor: Prof. Linda G. Shapiro

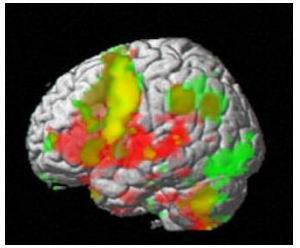
Ph.D. Defense

Computer Science & Engineering
University of Washington





Functional Brain Imaging



- Study how the brain works
- Imaging while subject performs a task
- Image represents some aspect of the brain e.g.
  - **fMRI**: brain blood oxygen level
  - **ERP**: scalp electric activity

Motivation

- Given a database of functional brain images from various subjects, cognitive tasks, and image modality.

- Database users need to retrieve similar images

- A system that can automatically perform this retrieval will reduce amount of time and effort users spend during this task

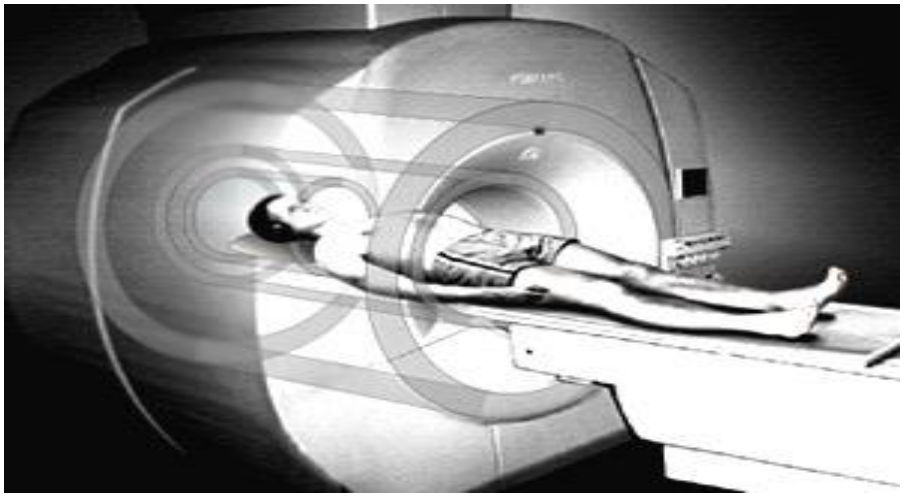
Contributions

1. Created a similarity retrieval system for multimodal brain images
    I. fMRI, ERP, and combined fMRI-ERP
    II. User interface
2. Developed feature extraction methods for fMRI and ERP data
3. Developed pair-wise similarity metrics
4. Simulated human expert similarity scores

Outline

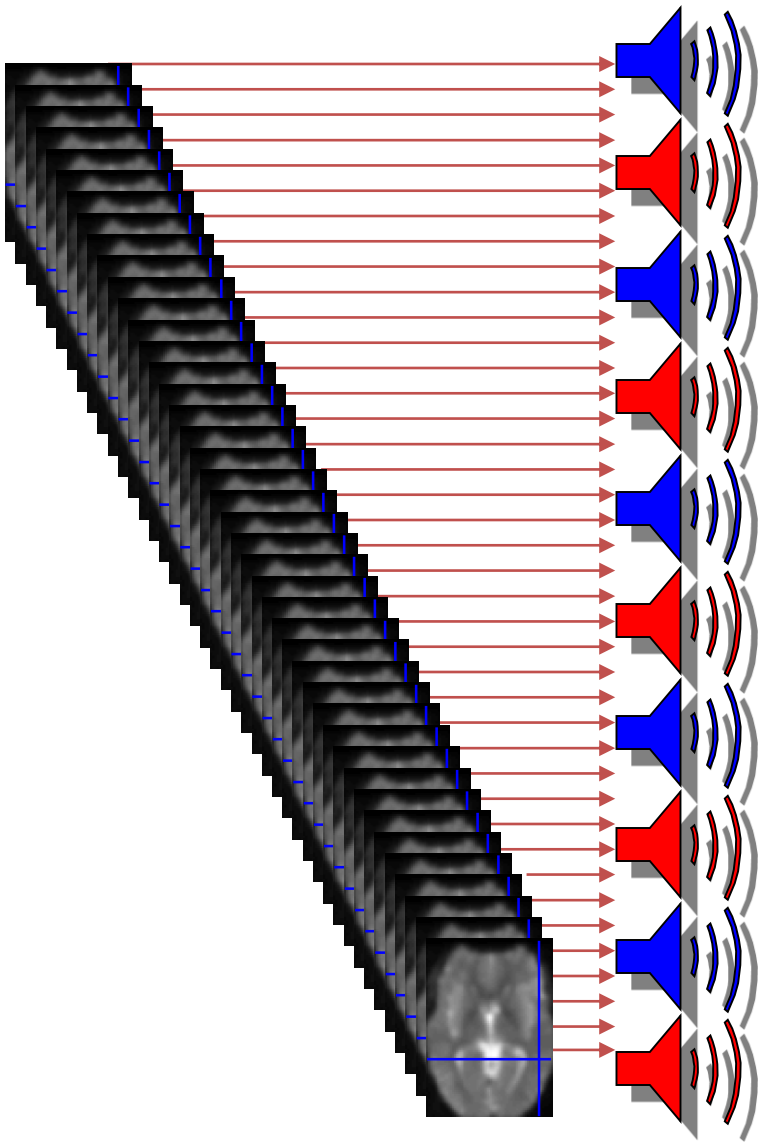
- **Background**
  - **fMRI**
  - **ERP**
  - **Existing Similarity Retrieval Systems for these modalities**
- Feature Extraction Process
- Similarity Metric
- User Interface
- Retrieval Performance
- Simulate Human Expert

Functional Magnetic Resonance Imaging (fMRI)



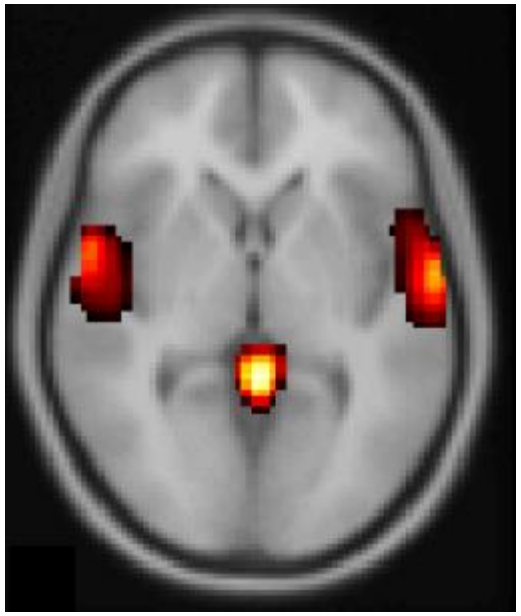
- A non-invasive brain imaging technique
- Records blood oxygen level in brain
- While imaging, subject performs a task

fMRI Statistical Images



Statistical Analysis

Voxel Thresholding

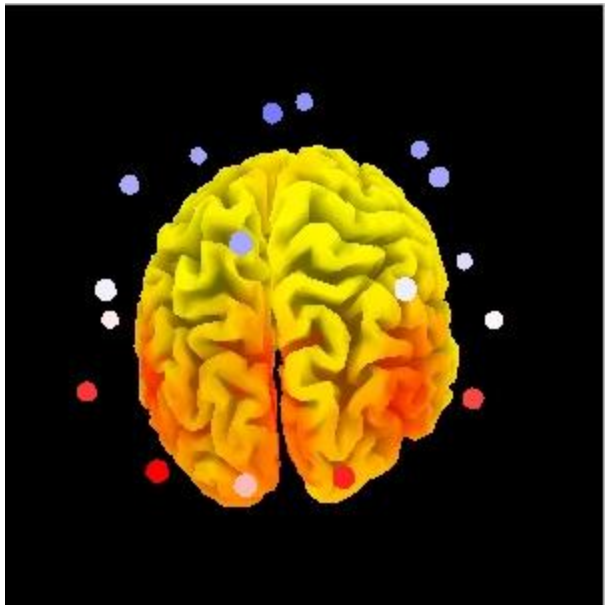


Event-Related Potentials (ERP)

- A non-invasive brain imaging technique
- Records electric activity along scalp
- While imaging, subject performs a task

ERP Source Localization

- Researchers want to identify the **electric activity** and **its source** for each electrode
- But, **multiple sources** for each electrode



- **LORETA** approximates anatomic locations of sources

Comparison of fMRI and ERP Data

	fMRI	ERP
Spatial resolution	Good (in mm)	undefined/poor
Temporal resolution	Poor (in sec)	Excellent (in msec)

Similarity Retrieval Systems for fMRI Images

	Our System	Codebook	Wavelet	Bipartite	RV-Coefficient	Correspondence
Retain "Most Important" Voxels	Yes	No	No	Yes	No	Yes
Whole Brain Similarity	Yes	Yes	Yes	Yes	Yes	No
Region of Interest Similarity	Yes	No	No	No	No	Yes
Feature Selection	Yes	No	No	No	No	No

Similarity Retrieval Systems for ERP Images

No relevant literature found

Similarity Retrieval Systems for Combined fMRI-ERP Images

No relevant literature found

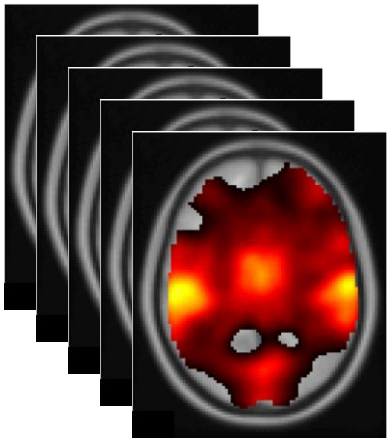
Outline

- Background

- **Feature Extraction Process**
  - **fMRI features**
  - **ERP features**

- Similarity Metric
- User Interface
- Retrieval Performance
- Simulate Human Expert

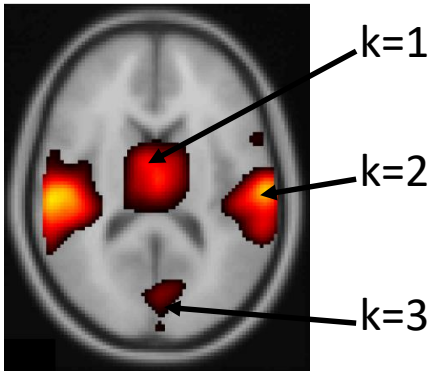
fMRI Feature Extraction



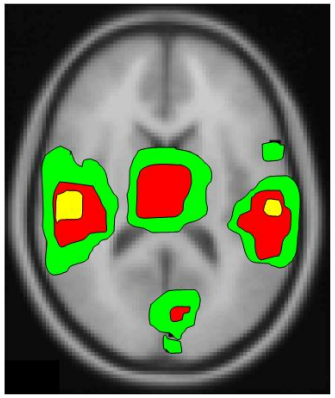
Original database

Threshold

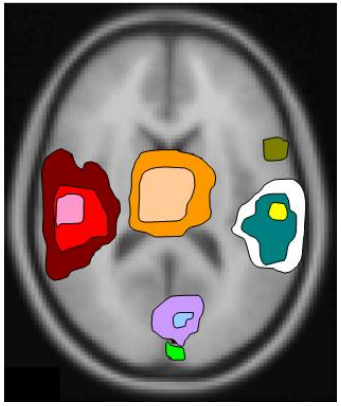
Approximate cluster centroids



Perform clustering



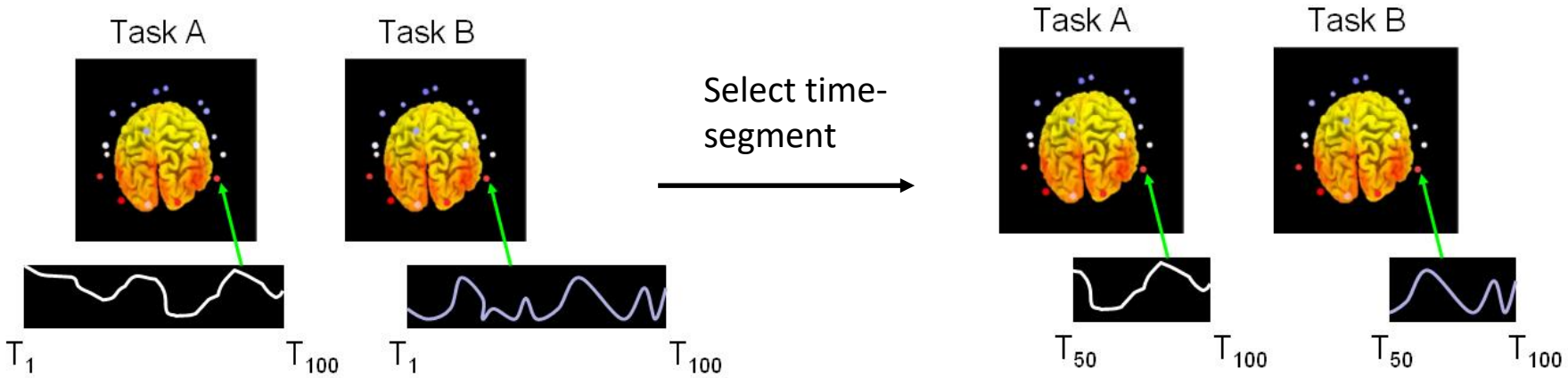
Perform connected component analysis



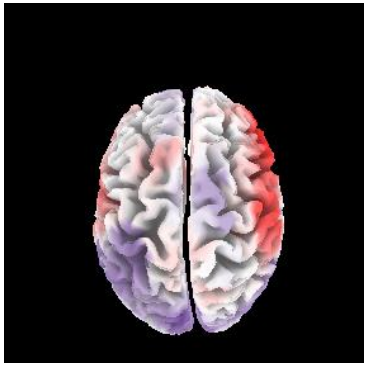
Compute region vectors

1. Centroid
2. Avg Activation Value
3. Var Activation Value
4. Volume
5. Avg Distance to Centroid
6. Var of those Distances

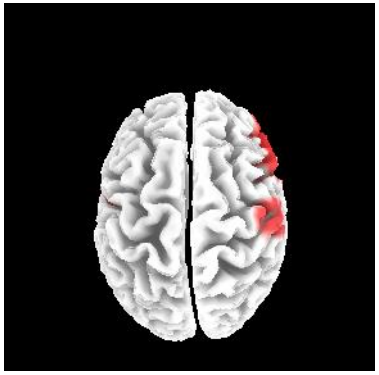
ERP Feature Extraction



Compute voxel-wise statistically significant difference between means



Threshold



Compute feature

(X,Y,Z) positions of retained voxels

Outline

- Background
- Feature Extraction Process

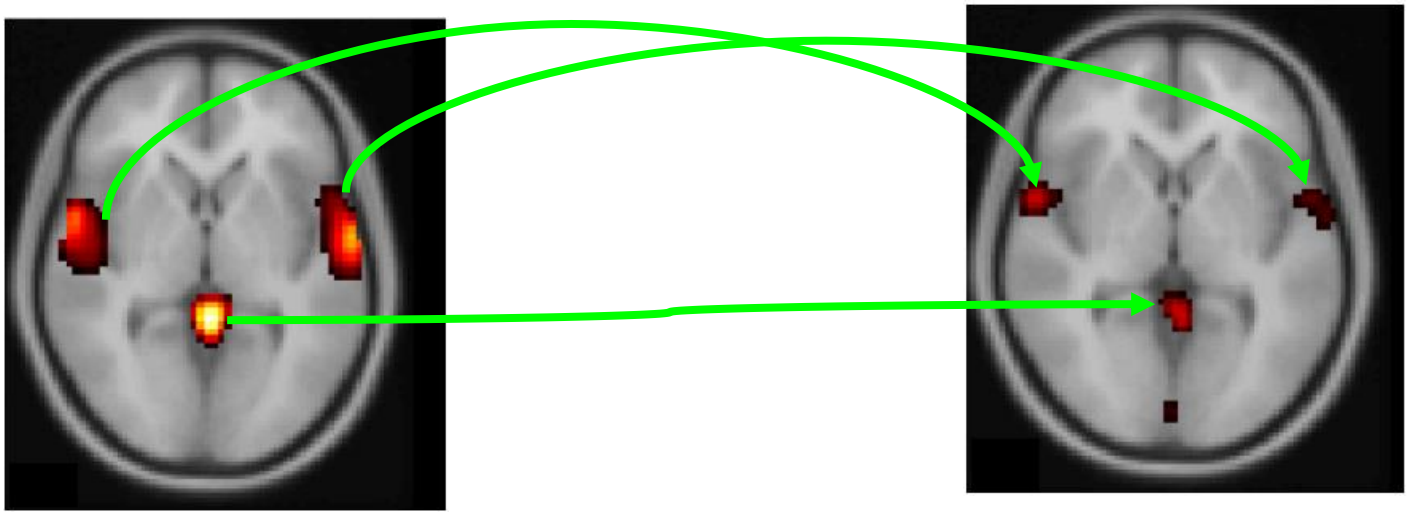
- **Similarity Metric**
  - **Summed Minimum Distance**
  - **Similarity Score for Combined fMRI-ERP Images**

- User Interface
- Retrieval Performance
- Simulate Human Expert

Summed Minimum Distance (SMD) for fMRI and ERP Images

Subject Q

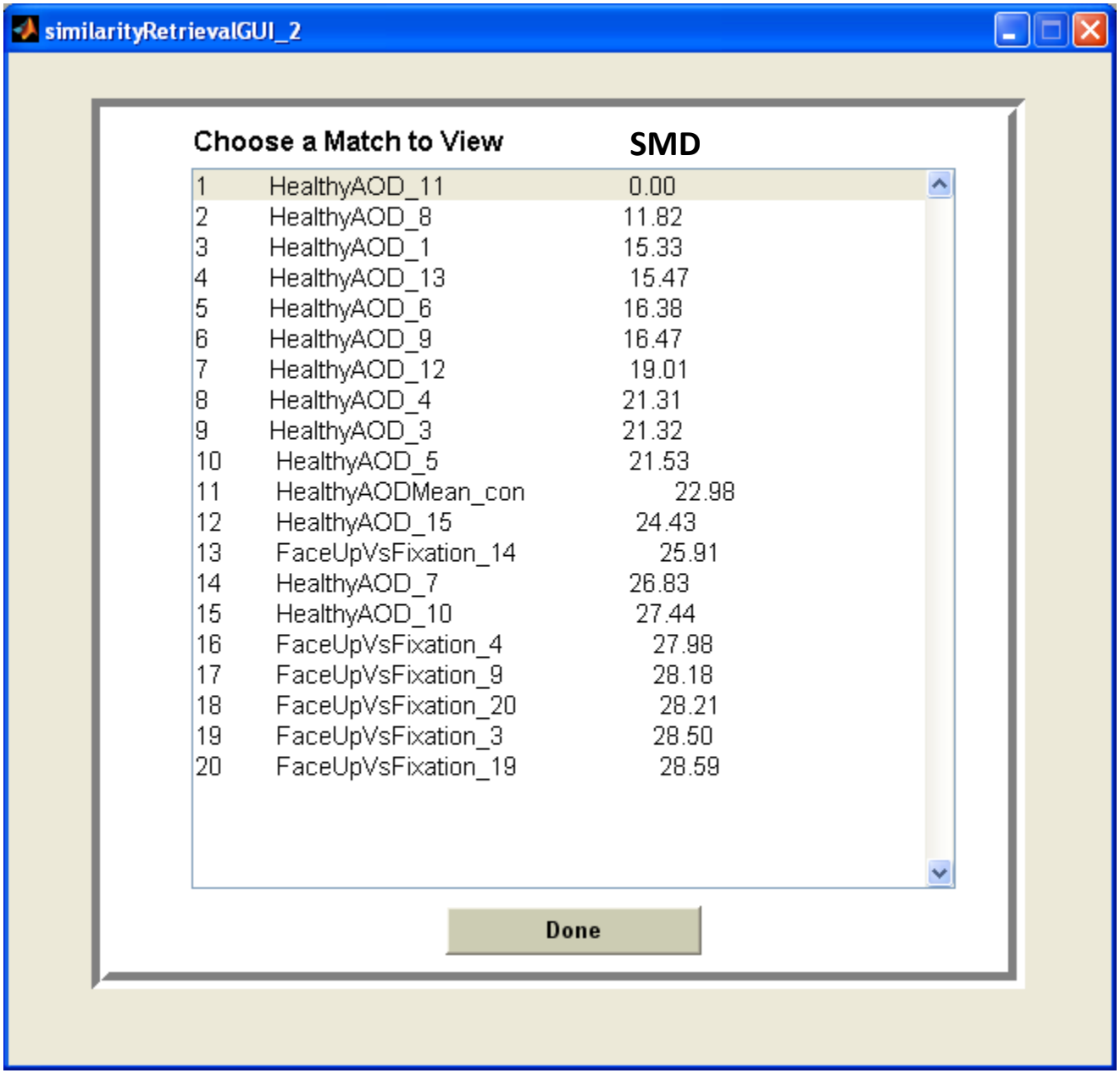
Subject T



$$\textbf{Q2T} = \frac{\sum_{r \in Q} \min_{s \in T} \; d_E(r, s)}{N_Q}$$

SMD = (Q2T+T2Q) / 2

Sample SMD Scores



Similarity Score for Combined fMRI-ERP Images

$$SIM(i,j) = \alpha SMD_{fMRI}(i,j) + (1-\alpha)SMD_{ERP}(i,j)$$

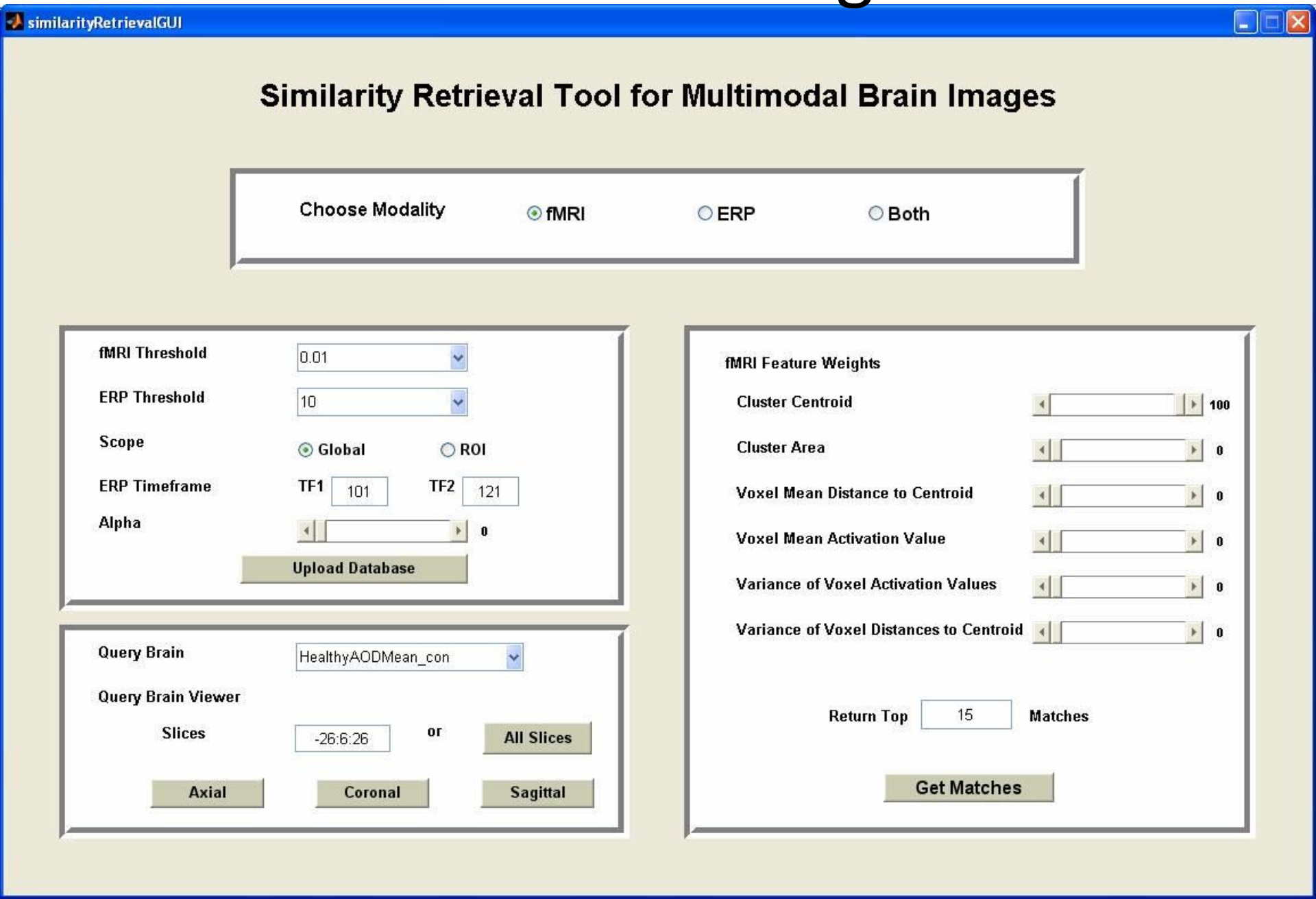
Outline

- Background
- Feature Extraction Process
- Similarity Metric

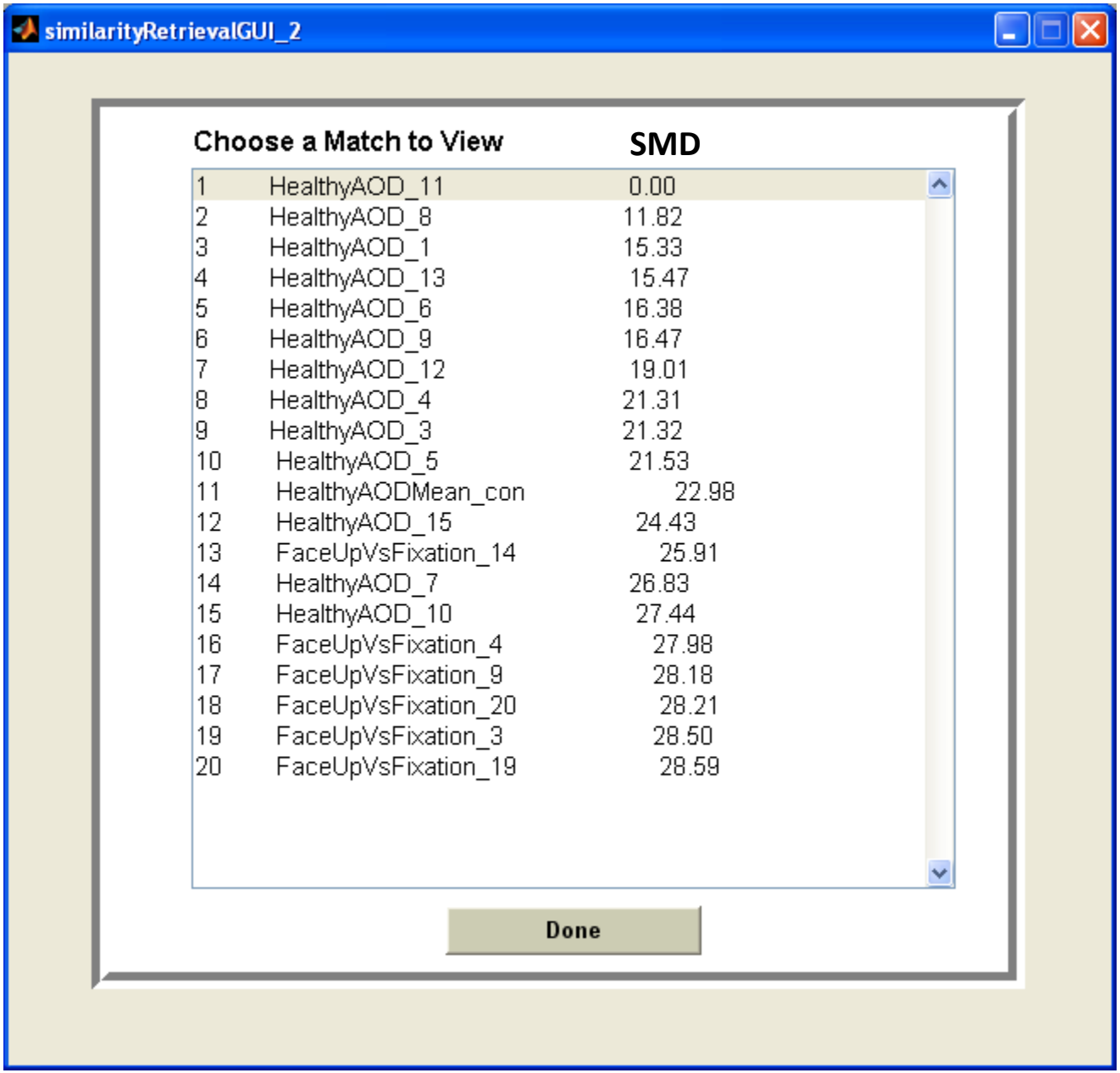
- **User Interface**

- Retrieval Performance
- Simulate Human Expert

GUI: Front Page

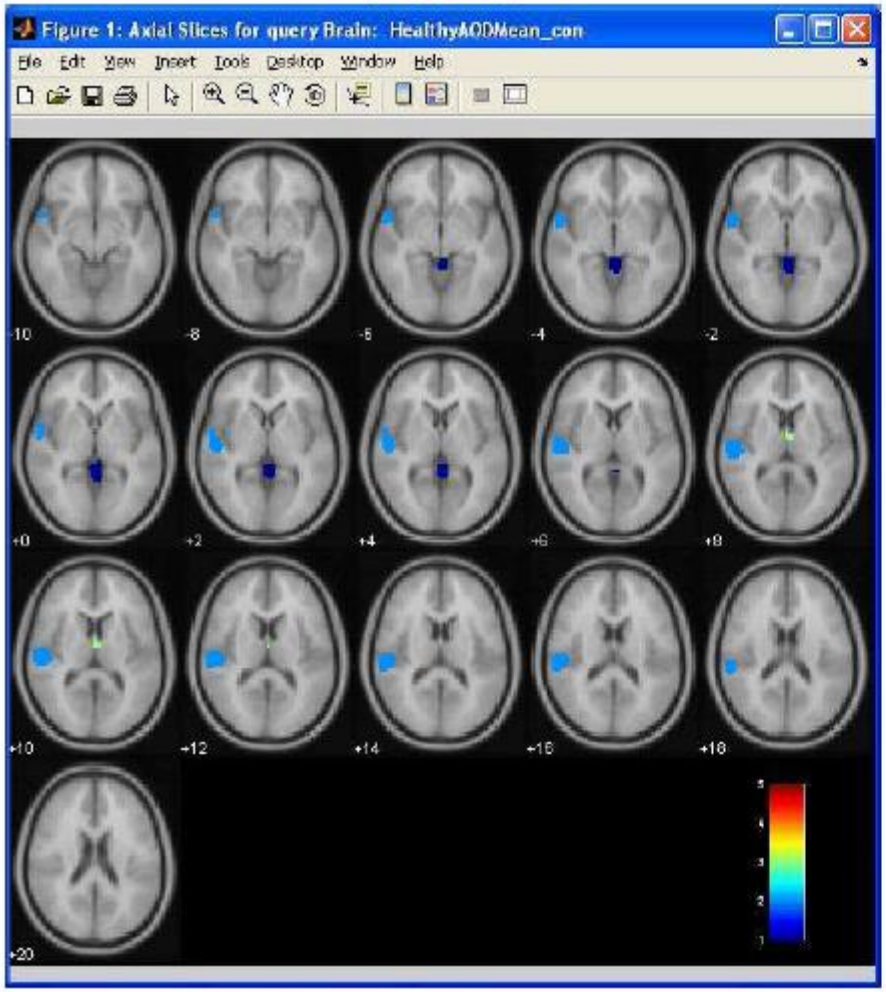


GUI: Retrievals with SMD Scores

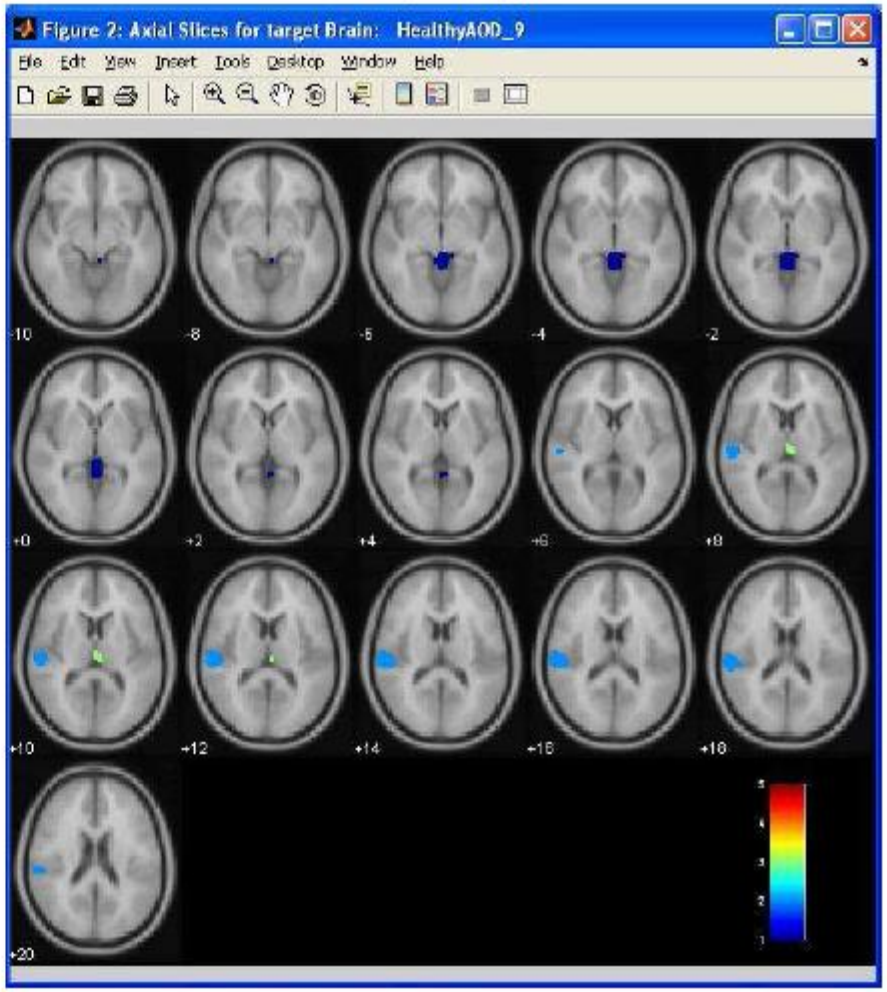


GUI: Query-Target Activations (fMRI)

Query Image

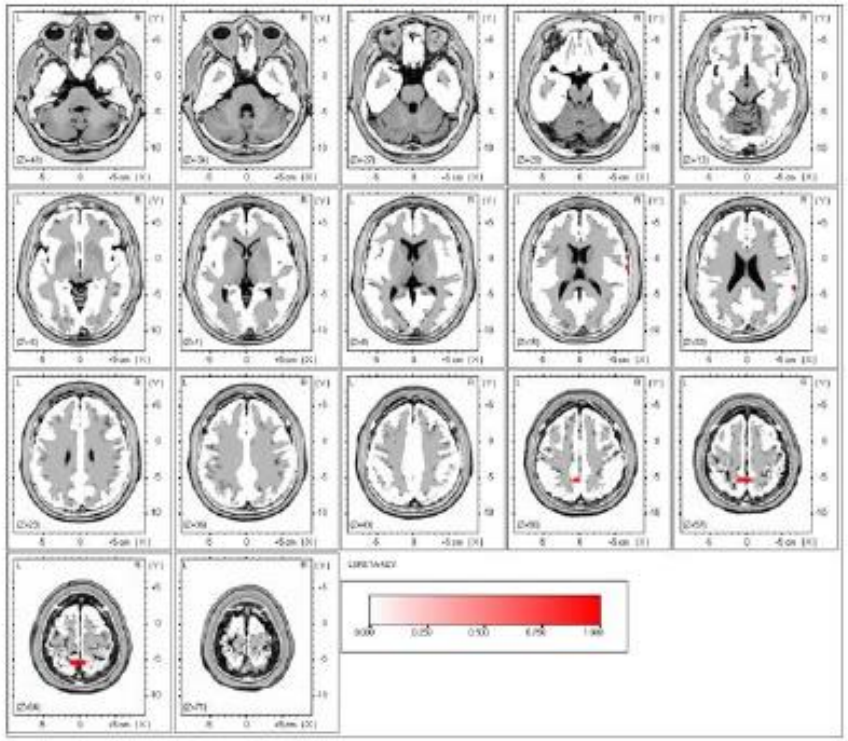


Target Image

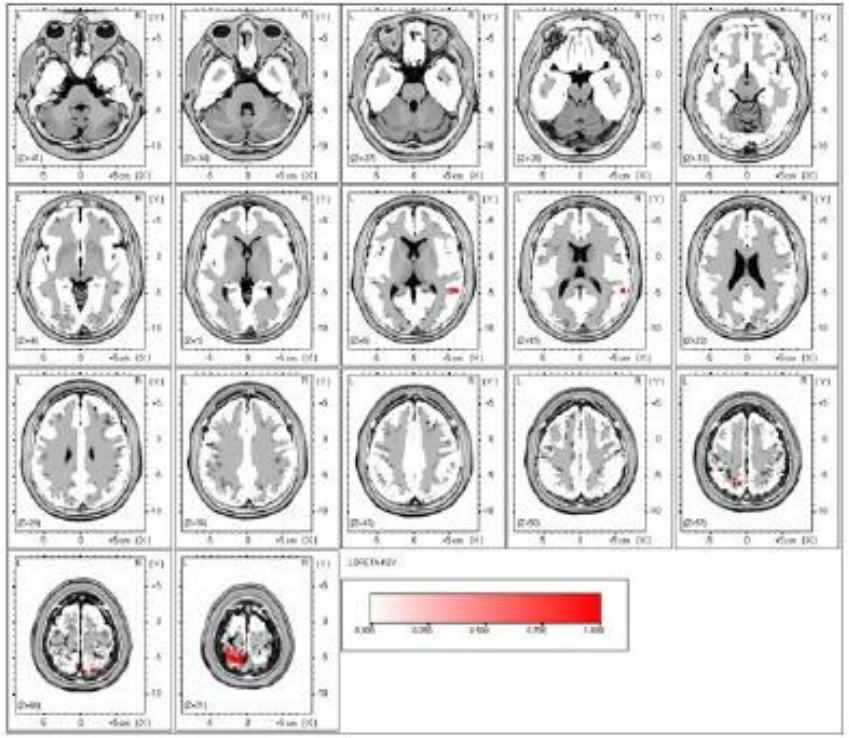


GUI: Query-Target Activations (ERP)

Query Image



Target Image



Outline

- Background
- Feature Extraction Process
- Similarity Metric
- User Interface

- **Retrieval Performance**
  - **Data Sets**
  - **fMRI Retrieval Performance**
  - **ERP Retrieval Performance**
  - **Combined fMRI-ERP Retrieval Performance**

- Simulate Human Expert

Data Sets for fMRI Retrievals

Checkerboard -- 12 subjects
(Face Recognition)

Central-Cross -- 24 subjects
(Face Recognition)

SB -- 15 subjects
(Memorization)

AOD -- 15 subjects
(Sound Recognition)

Data Set for ERP Retrievals

View Human Faces
(Face Up)
-- 15 subjects

View Houses
(House Up)
-- 15 subjects

Data Set for Combined fMRI-ERP Retrievals

- ERP: same data set as used in ERP retrieval

- fMRI:
  - Task: Face recognition using a house up background

  - Same subjects and images as data set for ERP retrieval

fMRI Retrieval Performance

1. RFX Retrievals

2. Individual Brain Retrieval

3. Testing Group Homogeneity

4. Feature Selection

fMRI Retrieval Score

$$\text{Retrieval Score} = \frac{1}{N \times N_{rel}} \left(\sum_{i=1}^{N_{rel}} R_i - \frac{N_{rel}(N_{rel}+1)}{2} \right)$$

Perfect score : **Retrieval Score = 0**

Random score: **Retrieval Score ~ 0.5**

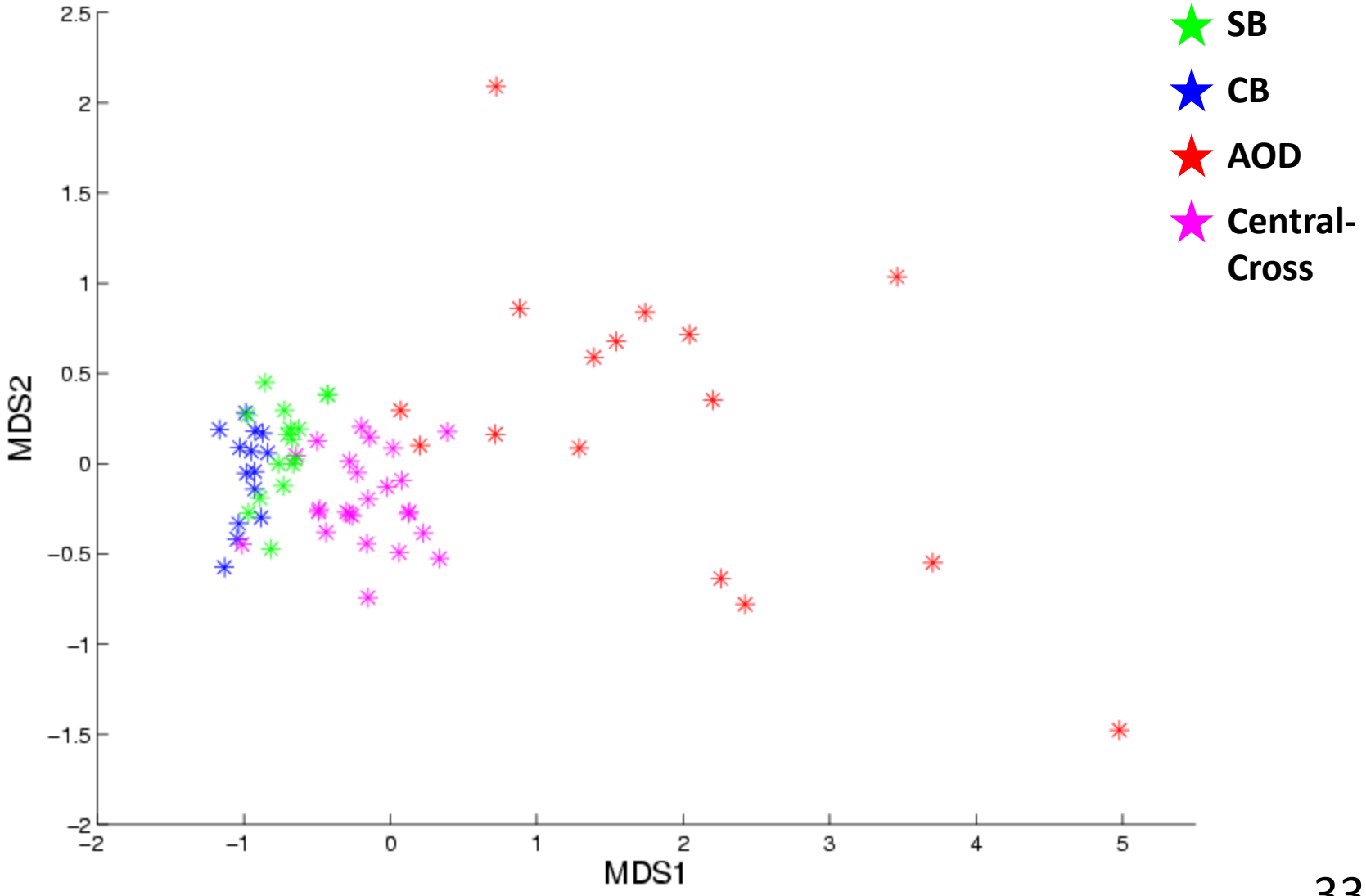
Worst score: **Retrieval Score = 1**

fMRI Individual Brain Retrievals

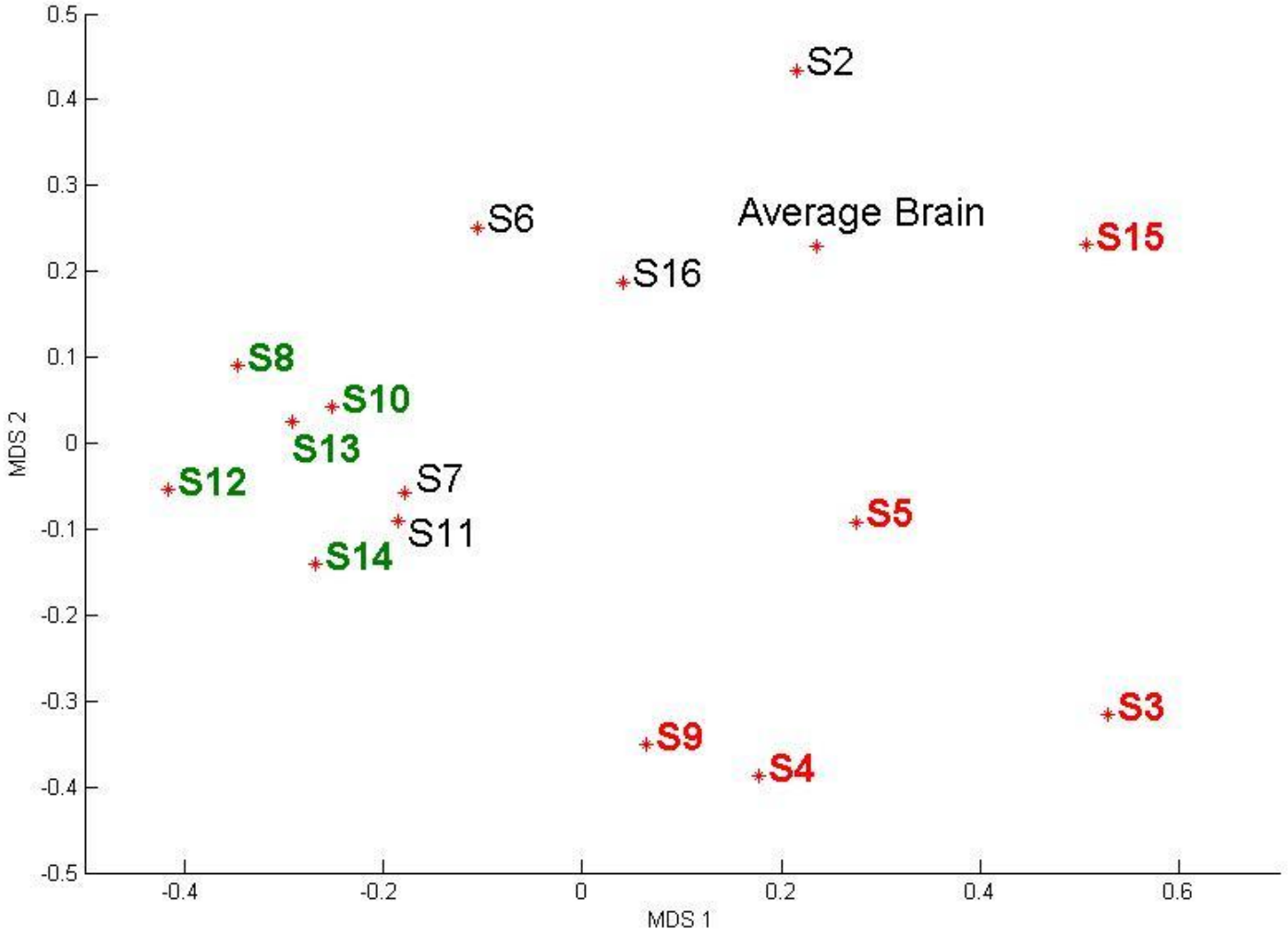
- Use individual brain as query

	Mean Retrieval Scores (Top 6% activated voxels)
Checkerboard	0.09
SB	0.16
Central-Cross	0.21
AOD	0.26

Testing Group Homogeneity for fMRI

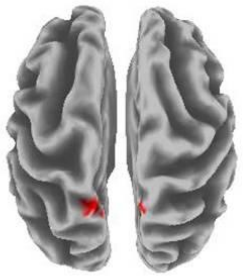
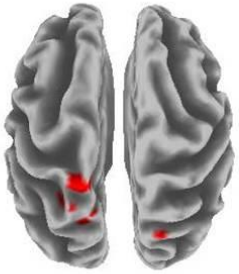


ERP Retrieval Performance



Subject #8 Retrievals

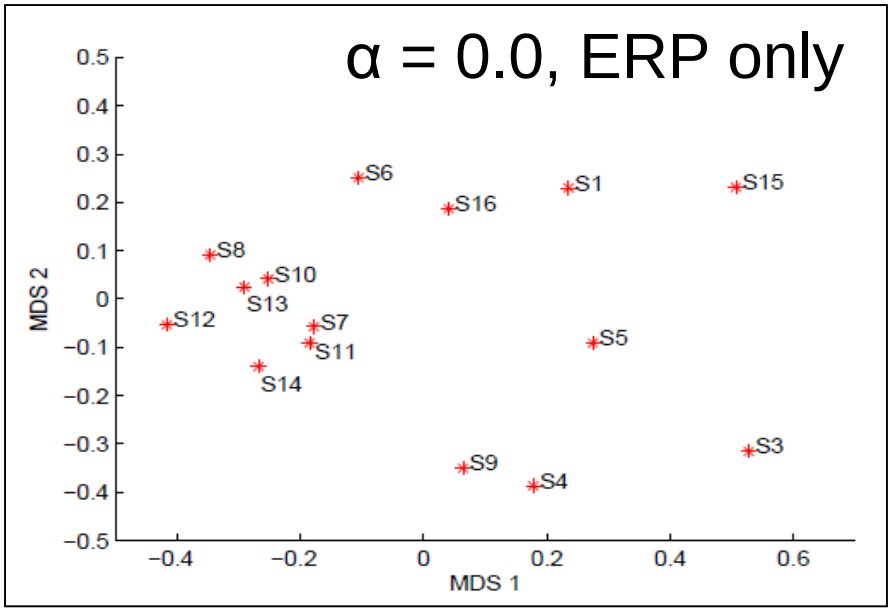
Top Retrievals

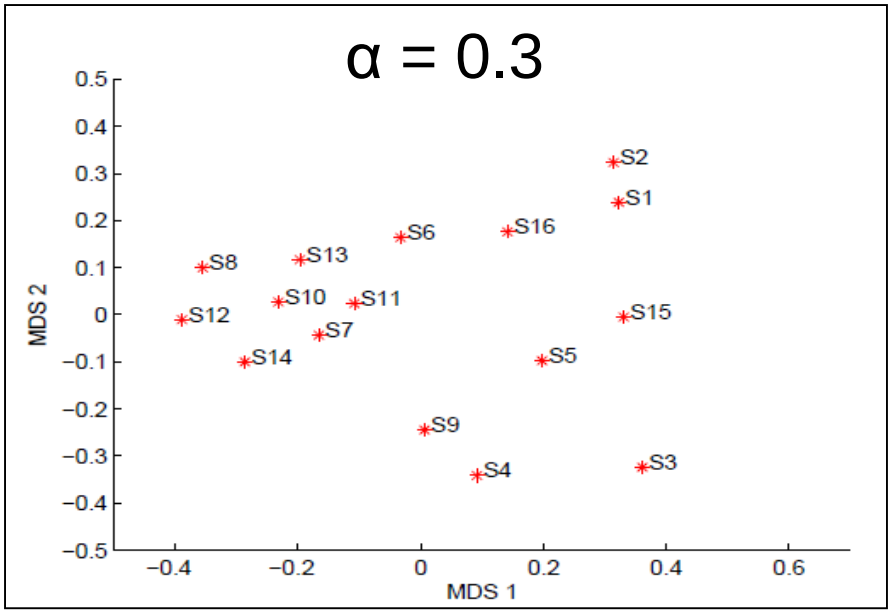
Subject 8	Subject 12	Subject 14	Subject 13	Subject 10
				
0.00	0.11	0.23	0.25	0.26

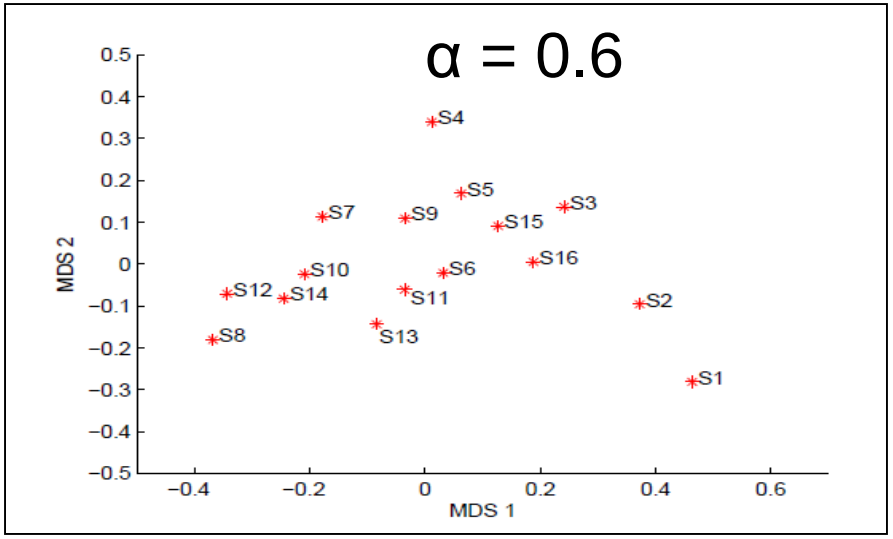
Bottom Retrievals

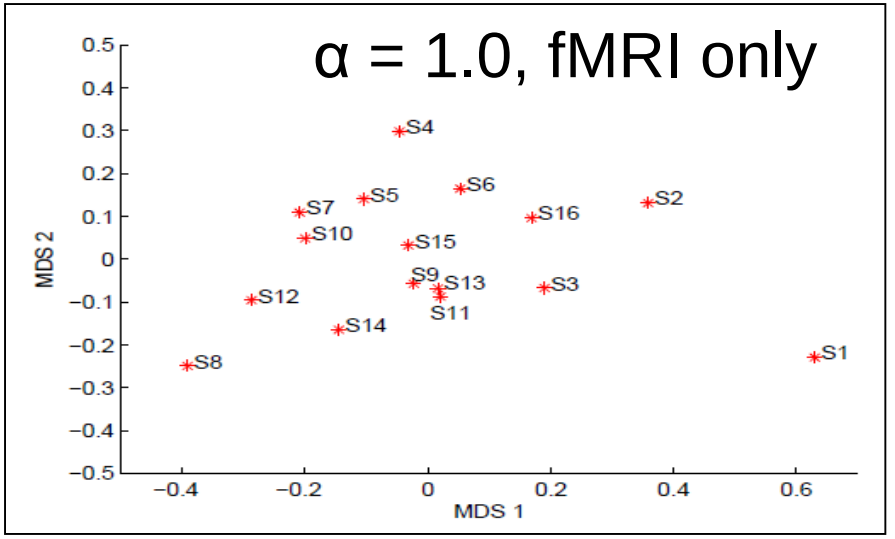
Subject 9	Subject 4	Subject 5	Subject 15	Subject 3
				
0.70	0.75	0.78	0.91	0.95

Combined fMRI-ERP Retrieval









$$SIM(i,j) = \alpha SMD_{fMRI}(i,j) + (1-\alpha)SMD_{ERP}(i,j)$$

Outline

- Background
- Feature Extraction Process
- Similarity Metric
- User Interface
- Retrieval Performance

- **Simulate Human Expert**
  - **Simulation Method**
  - **Data Set**
  - **Testing Function Performance**

Simulate Human Expert

- Current retrieval system requires some expert knowledge

	Centroid Only	Centroid and Average Activation Value Only	Average Activation Value Only
Correlation Coefficients	0.60	0.64	0.52

- Estimate a function to generate similarity scores with high correlation to expert scores

Simulation Method

1. Uniform feature representation: create codebook and encode each subject

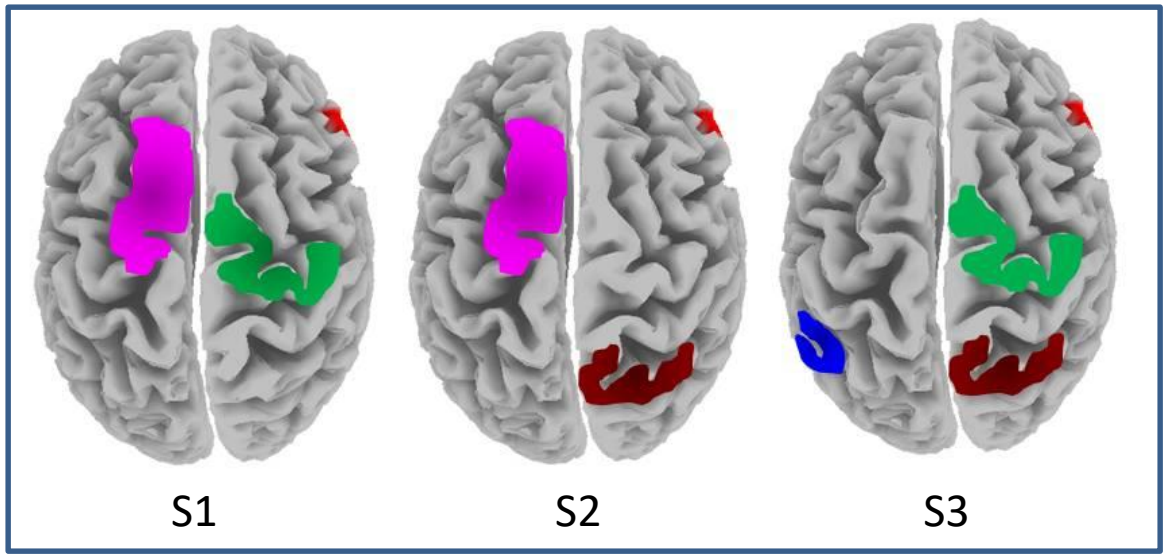
2. Concatenate the codebook features for each pair of subjects

3. Create eigenfeatures

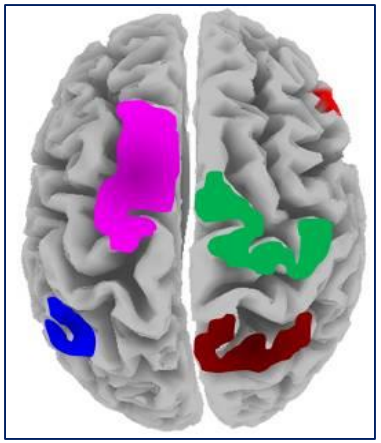
4. Estimate a function

5. Test function performance

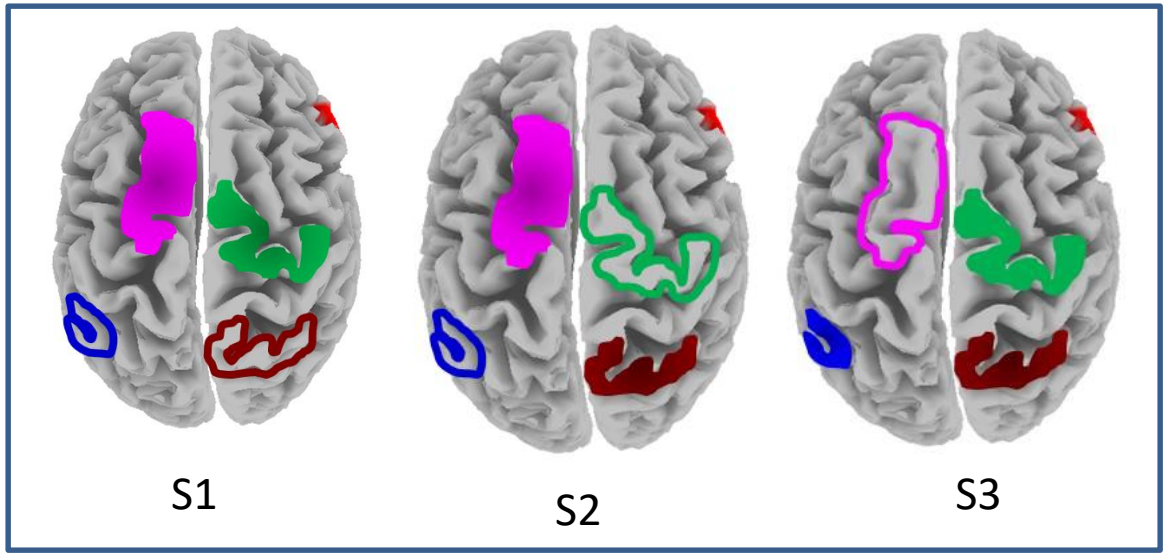
1. Uniform Feature Representation



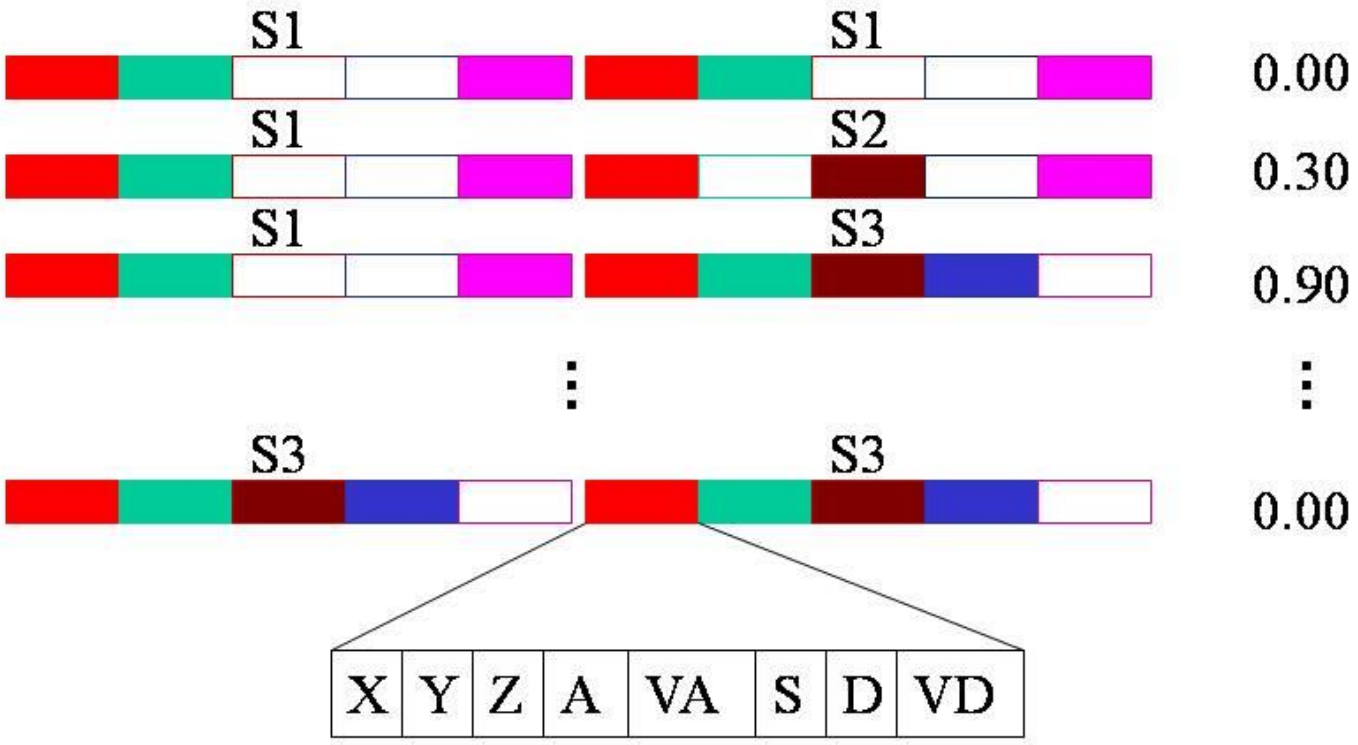
Create the reference brain (codebook)



Encode Images

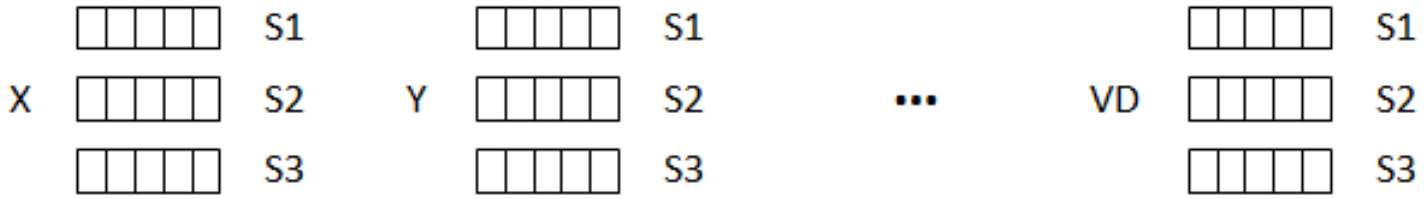


2. Concatenate Codebook Features

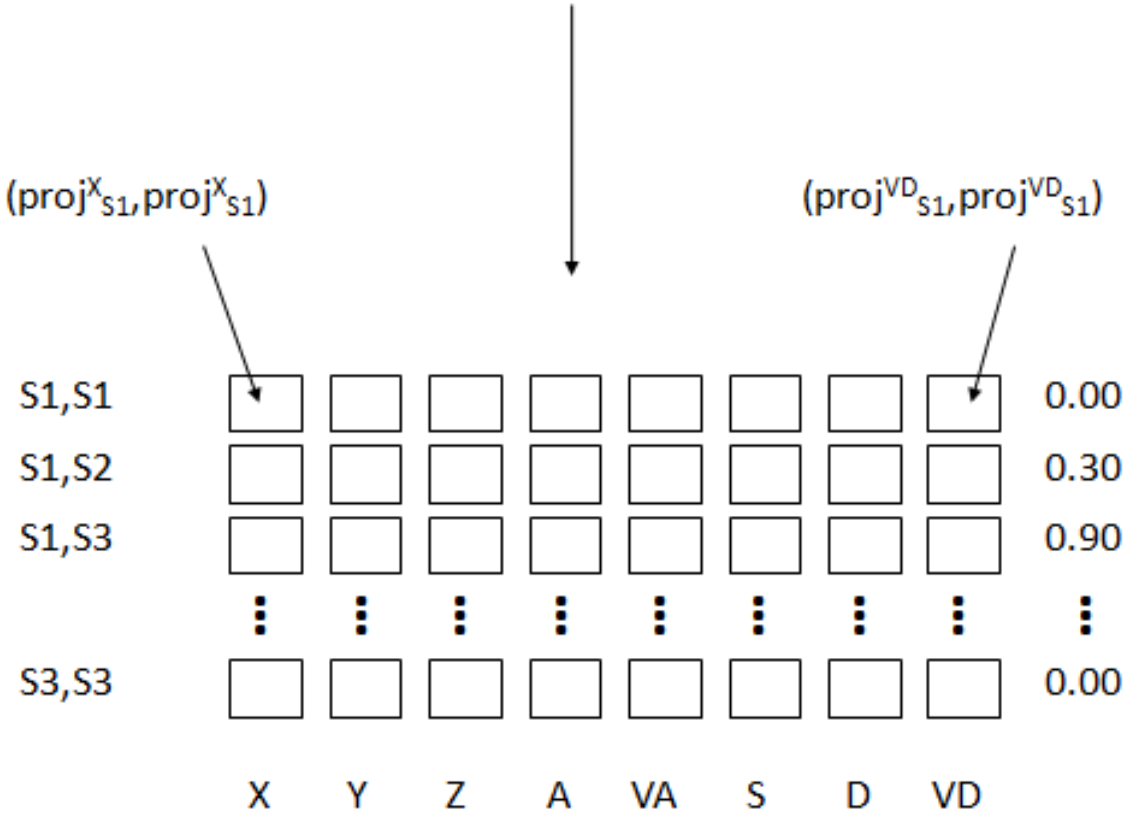


XYZ → Centroid
A → Avg Activation Value
VA → Var Activation Value
S → Size (Volume)
D → Avg Distance to Centroid
VD → Var of those Distances

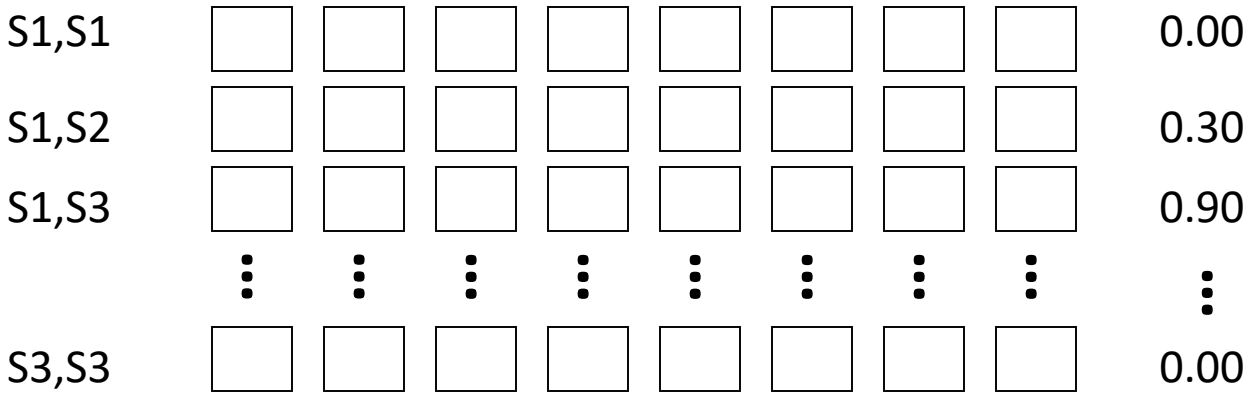
3. Create Eigenfeatures



Use PCA to project each feature onto N principal components. Here N=1.



4. Estimate a Function



- Linear function using linear regression
- Non-linear function using generalized regression neural networks (GRNN)

5. Test Function Performance

- The Pearson Correlation Coefficient (CC)

$$\frac{\sum_{i=1}^{n}\left(\widehat{y_i}-\mu_{\widehat{y}}\right)\left(y_i-\mu_y\right)}{(n-1)\,s_{\widehat{y}}s_y}$$

- The Average Absolute Error (A-ABSE)

$$\frac{\sum_{i=1}^{n}\left[y_i-\widehat{y_i}\right]}{n}$$

- The Root Mean Square Error (RMSE)

$$\sqrt{\frac{\sum_{i=1}^{n}\left[y_i-\widehat{y_i}\right]^2}{n}}$$

Data Set

+

Human Expert Generated Pair-wise Similarity Matrix

fMRI data (Central-Cross)

-- 23 subjects

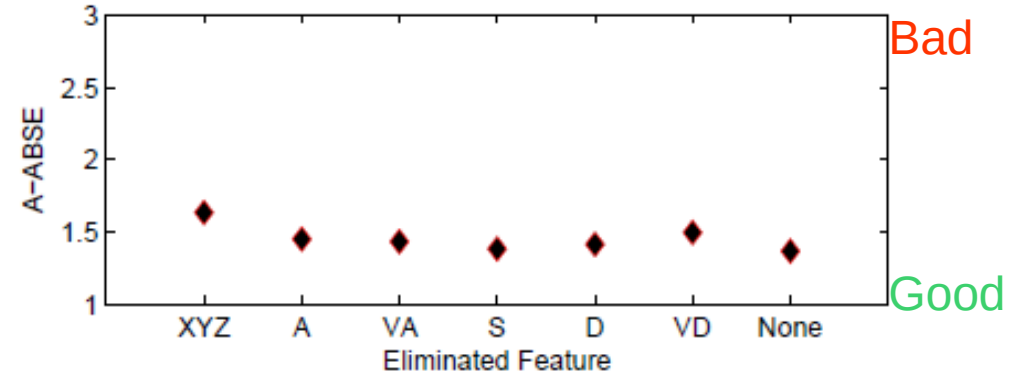
-- Face Recognition task

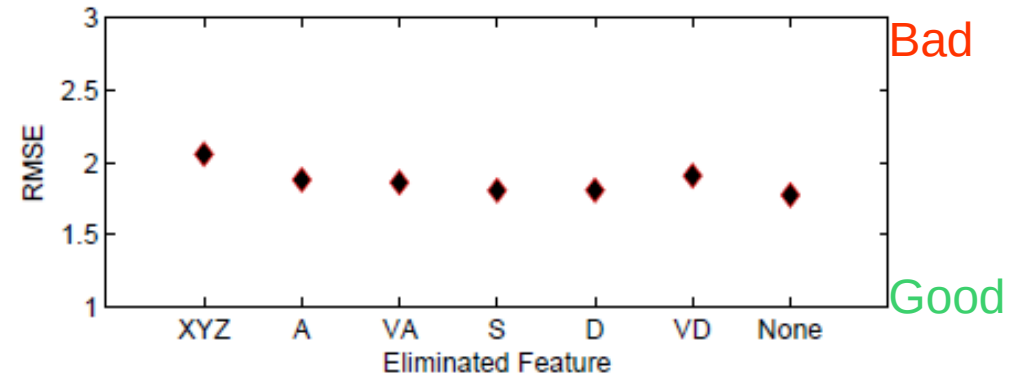
Overall Function Performance

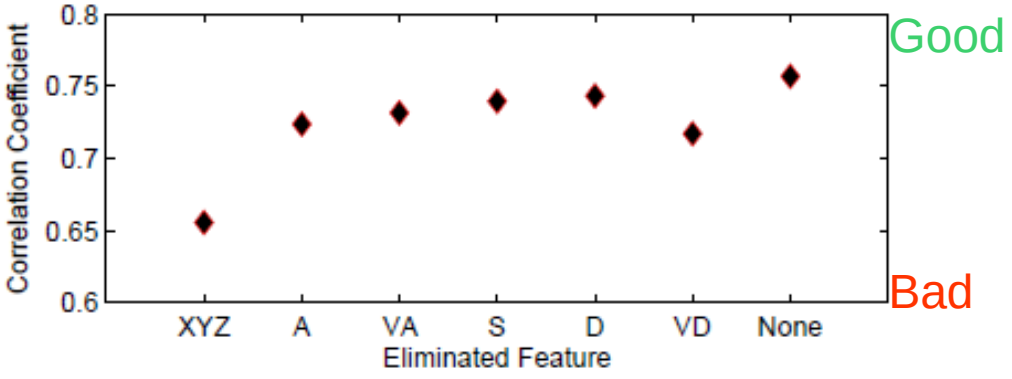
		Original Codebook Features		Eigenfeatures	
		Linear Function	Non-Linear Function	Linear Function	Non-Linear Function
Training	A-ABSE	1.82	**0**	2.11	**0.58**
	RMSE	2.25	**0**	2.57	**0.82**
	CC	0.52	**1**	0.35	**0.96**
Testing	A-ABSE	2.26	**1.74**	2.18	**1.36**
	RMSE	2.83	**2.32**	2.67	**1.77**
	CC	0.23	**0.59**	0.25	**0.76**

Feature Selection

XYZ → Centroid
A → Avg Activation Value
VA → Var Activation Value
S → Size (Volume)
D → Avg Distance to Centroid
VD → Var of those Distances







Contributions

1. Created a similarity retrieval system for multimodal brain images
    I. fMRI, ERP, and combined fMRI-ERP
    II. User interface
2. Developed feature extraction methods for fMRI and ERP data
3. Developed pair-wise similarity metrics
4. Simulated human expert similarity scores

Future Direction

- Add more modalities to the system
- Obtain more expert scores for function estimation
- Obtain more data
- Develop similarity metrics other than SMD

Acknowledgements

Prof. Linda Shapiro

Prof. James Brinkley

Prof. Jeffrey Ojemann

Prof. John Kramlich

NSF grant number DBI-0543631

Computer Vision Lab

Collaborators in Radiology department

Practice-talk participants