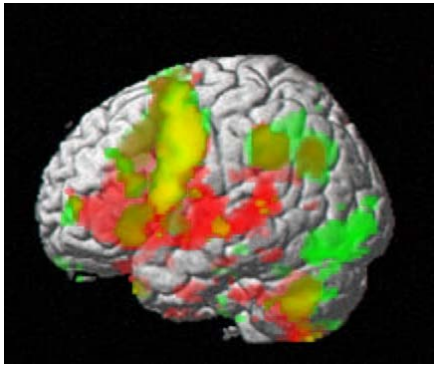


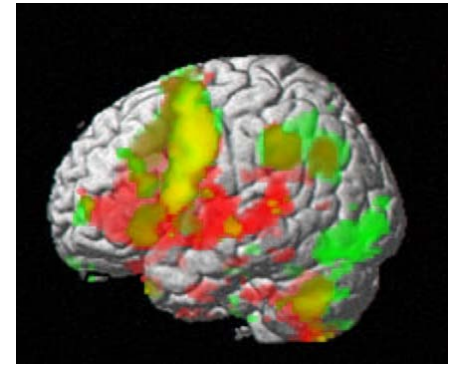
A Similarity Retrieval System for Multimodal Functional Brain Images



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

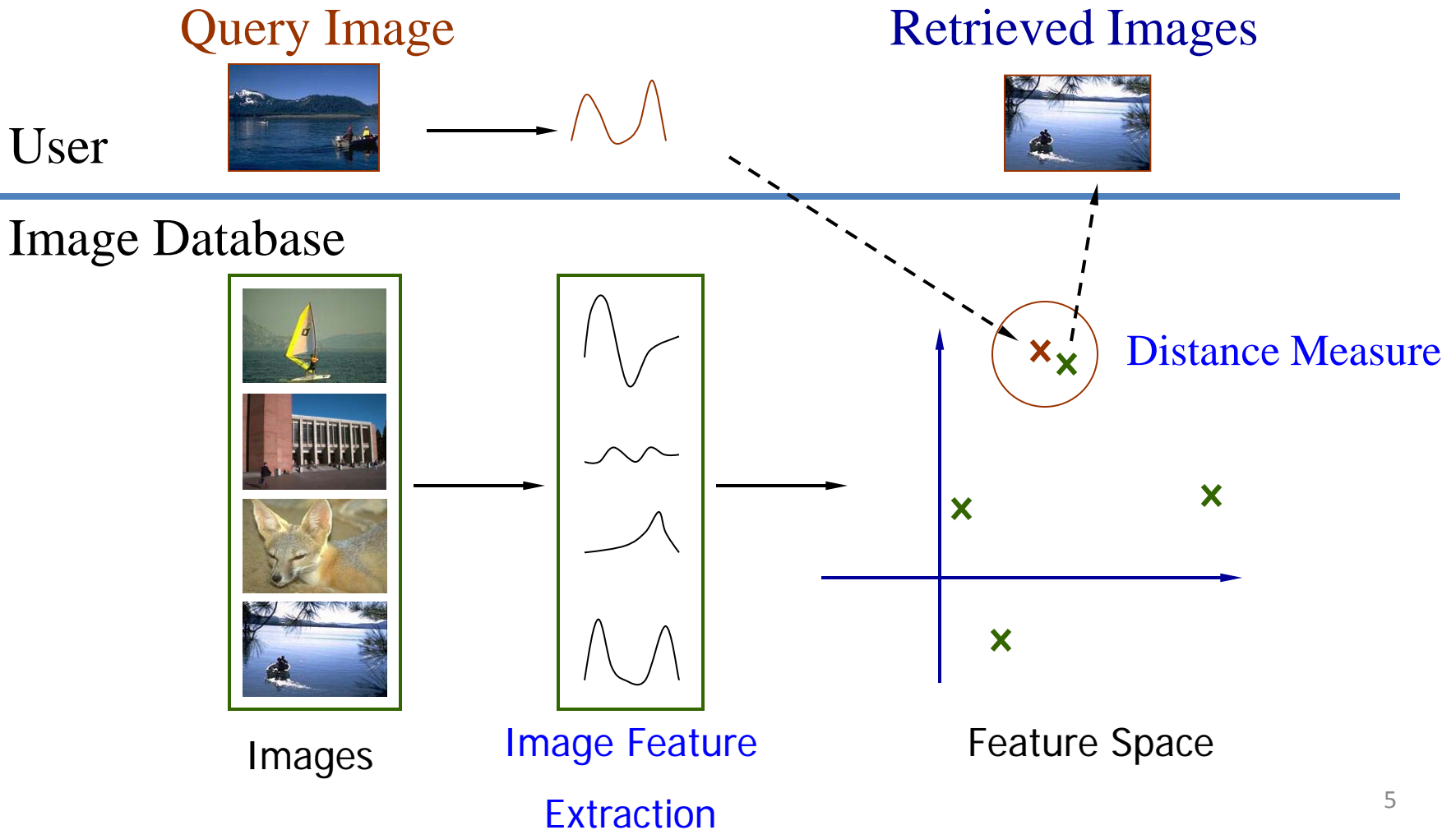
Motivation

- 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

Content-Based Image Retrieval

- Given a query image and an image database, retrieve the images that are most similar to the query in order of similarity.
- Example system for photographic images:
Andy Berman's FIDS system; Yi Li's Demo
<http://www.cs.washington.edu/research/imagedatabase/demo>

Image Features / Distance Measures



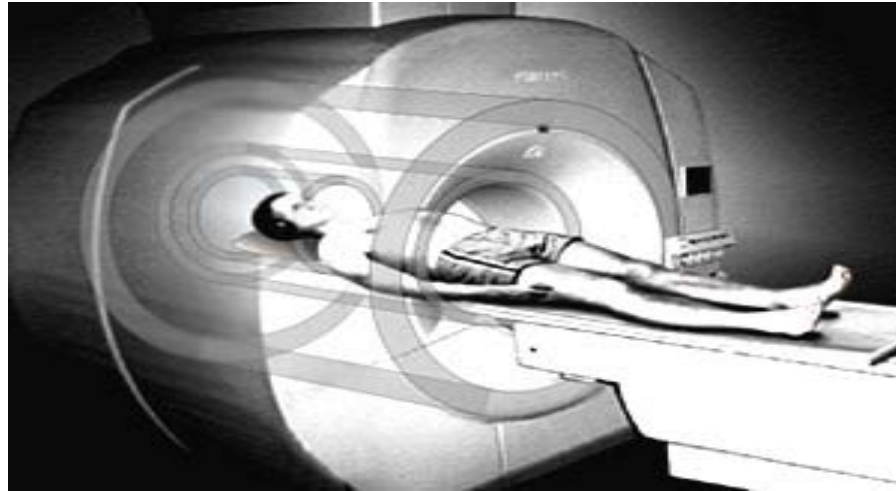
Contributions

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

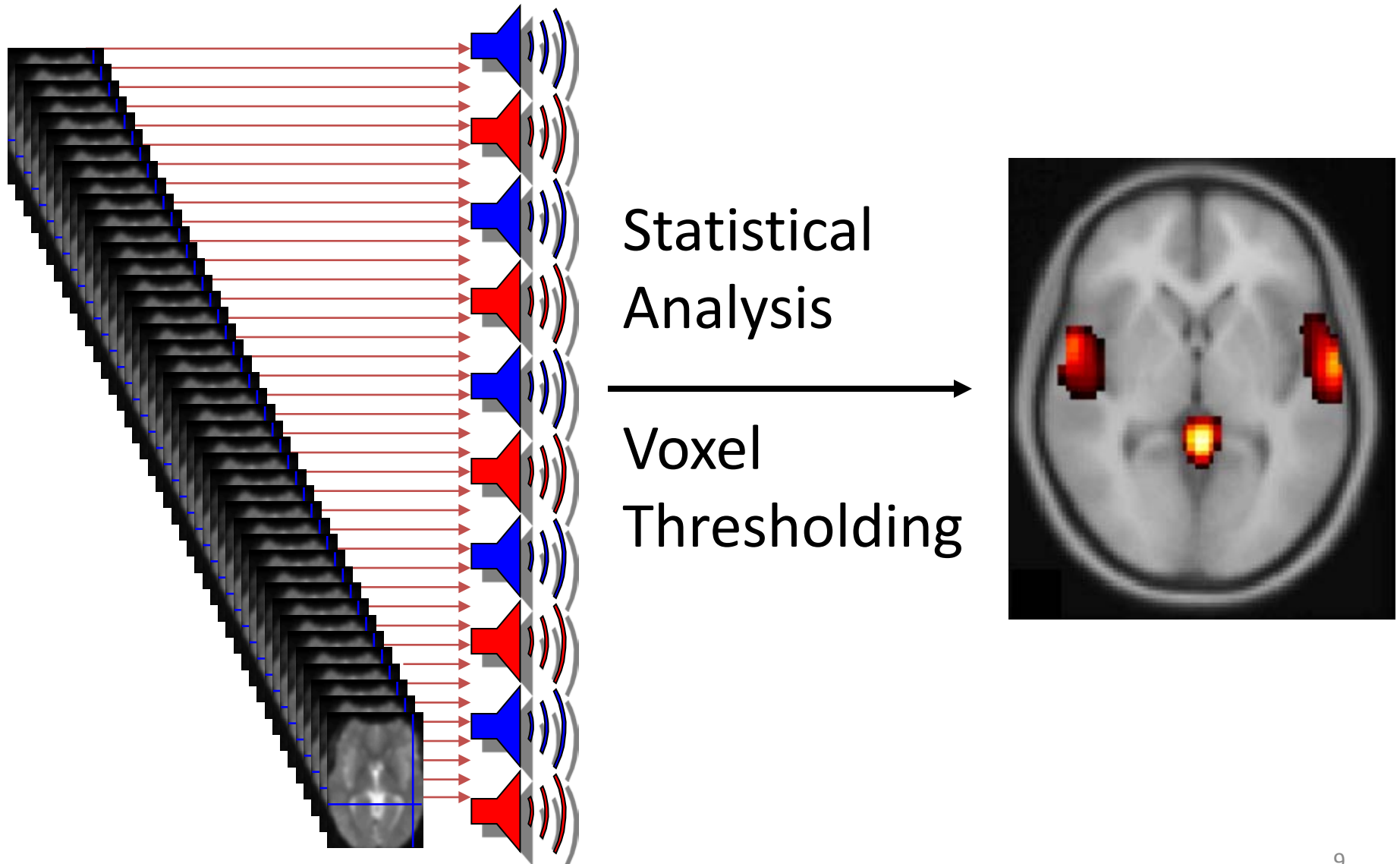
- **Background**
 - **fMRI**
 - **ERP**
 - **Existing Similarity Retrieval Systems for these modalities**
- **Feature Extraction Process**
- **Similarity Metric**
- **User Interface**
- **Retrieval Performance**
- **Simulate Human Expert**

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



Event-Related Potentials (ERP)

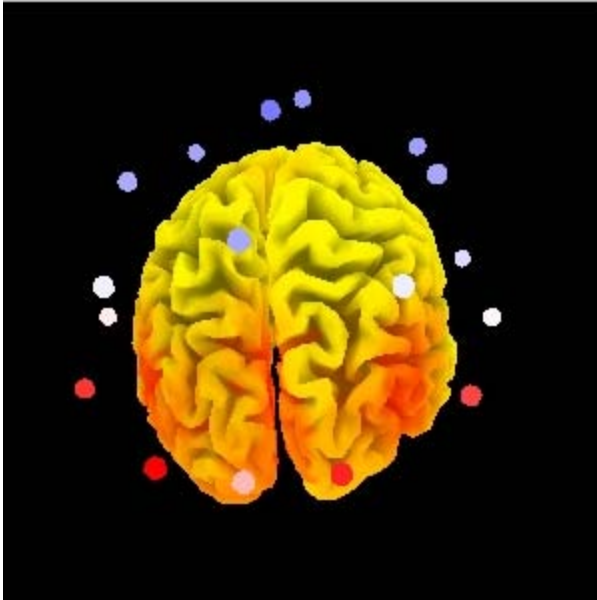


@ 2004 by Nucleus Communications, Inc.

- 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

Retain "Most Important" Voxels

Whole Brain Similarity

Region of Interest Similarity

Feature Selection

Similarity Retrieval Systems for ERP Images

No relevant literature found

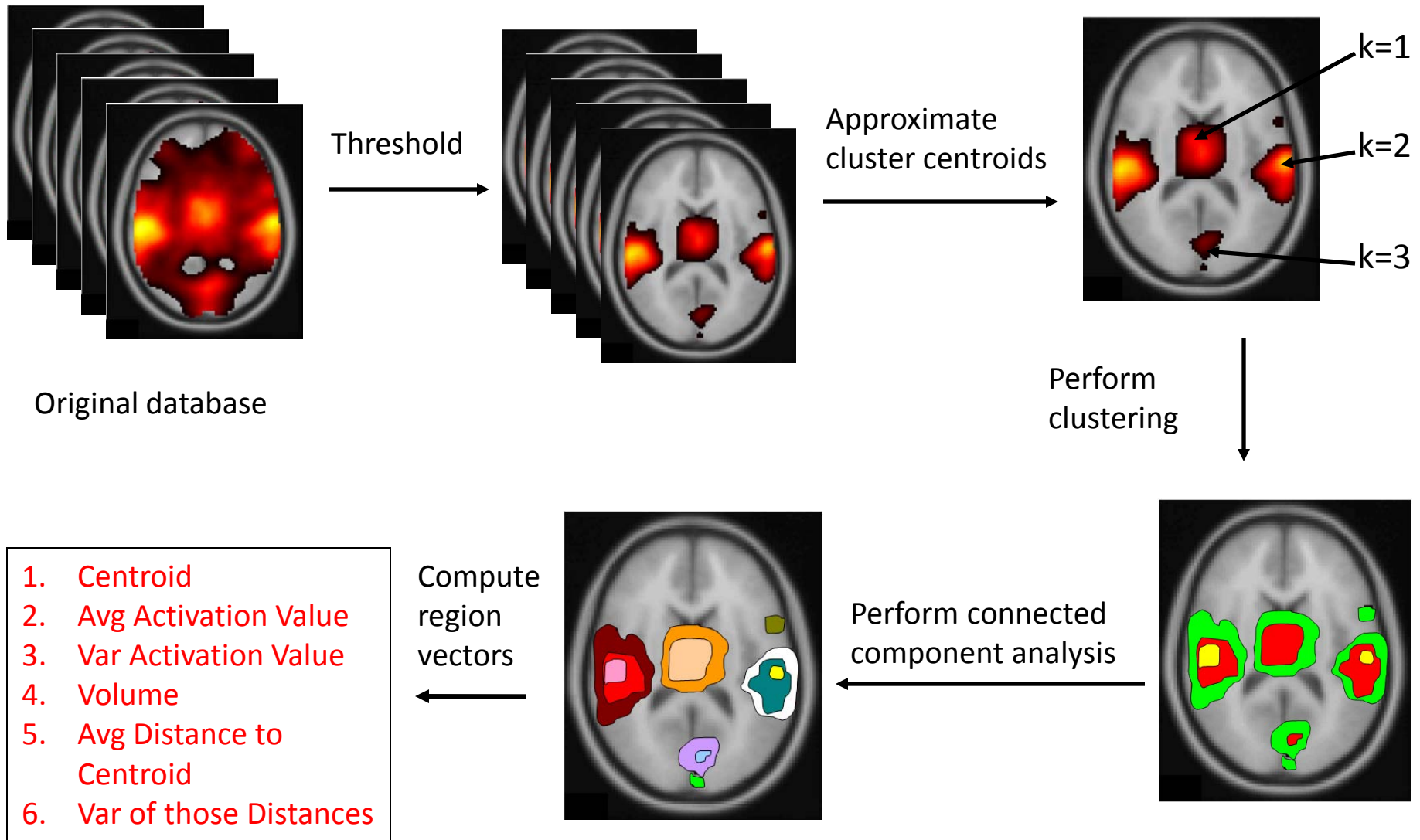
Similarity Retrieval Systems for Combined fMRI-ERP Images

No relevant literature found

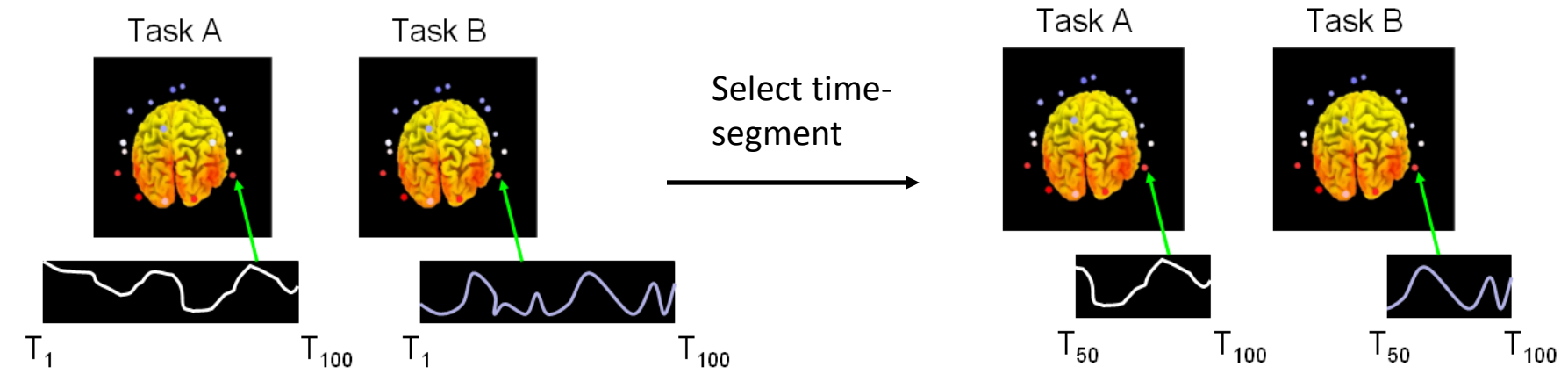
Outline

- Background
- **Feature Extraction Process**
 - **fMRI features**
 - **ERP features**
- Similarity Metric
- User Interface
- Retrieval Performance
- Simulate Human Expert

fMRI Feature Extraction



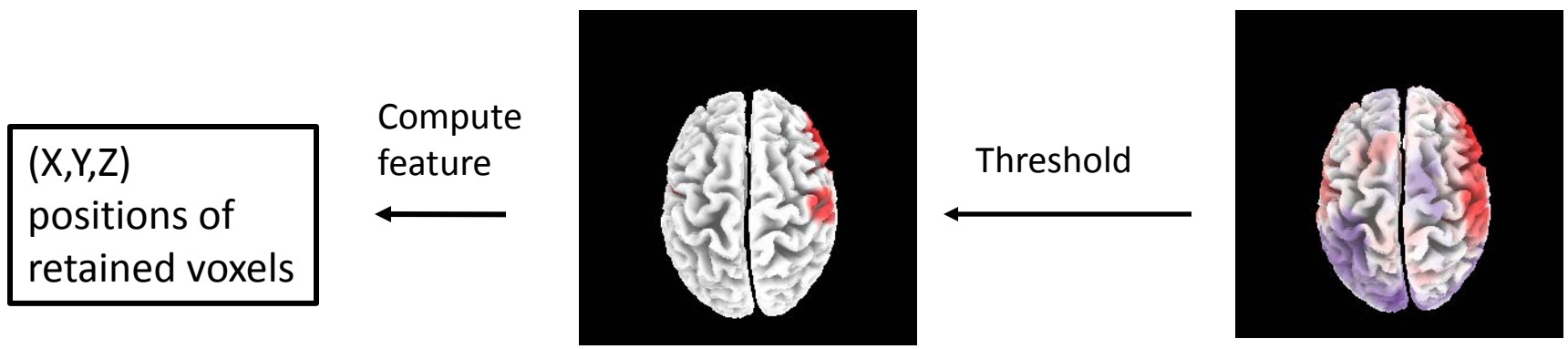
ERP Feature Extraction



Signals at each point incorporate information from that voxel and neighbors.

The retained voxels have significant activation meaning activities A and B are very different.

Compute voxel-wise statistically significant difference between means

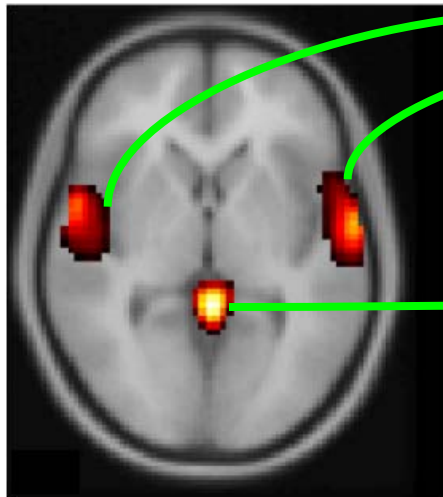


Outline

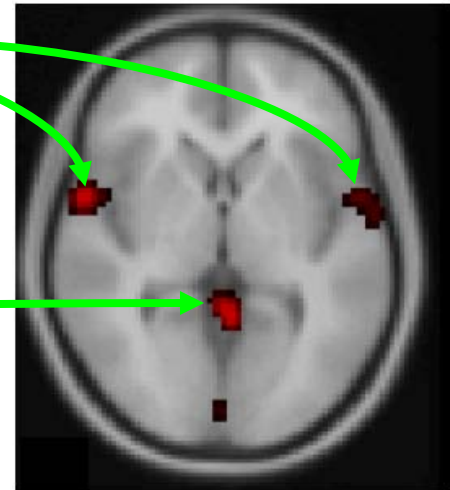
- Background
- Feature Extraction Process
- **Similarity Metric**
 - **Summed Minimum Distance**
 - **Similarity Score for Combined fMRI-ERP Images**
- User Interface
- Retrieval Performance
- Simulate Human Expert

Summed Minimum Distance (SMD) for fMRI and ERP Images

Subject Q



Subject T



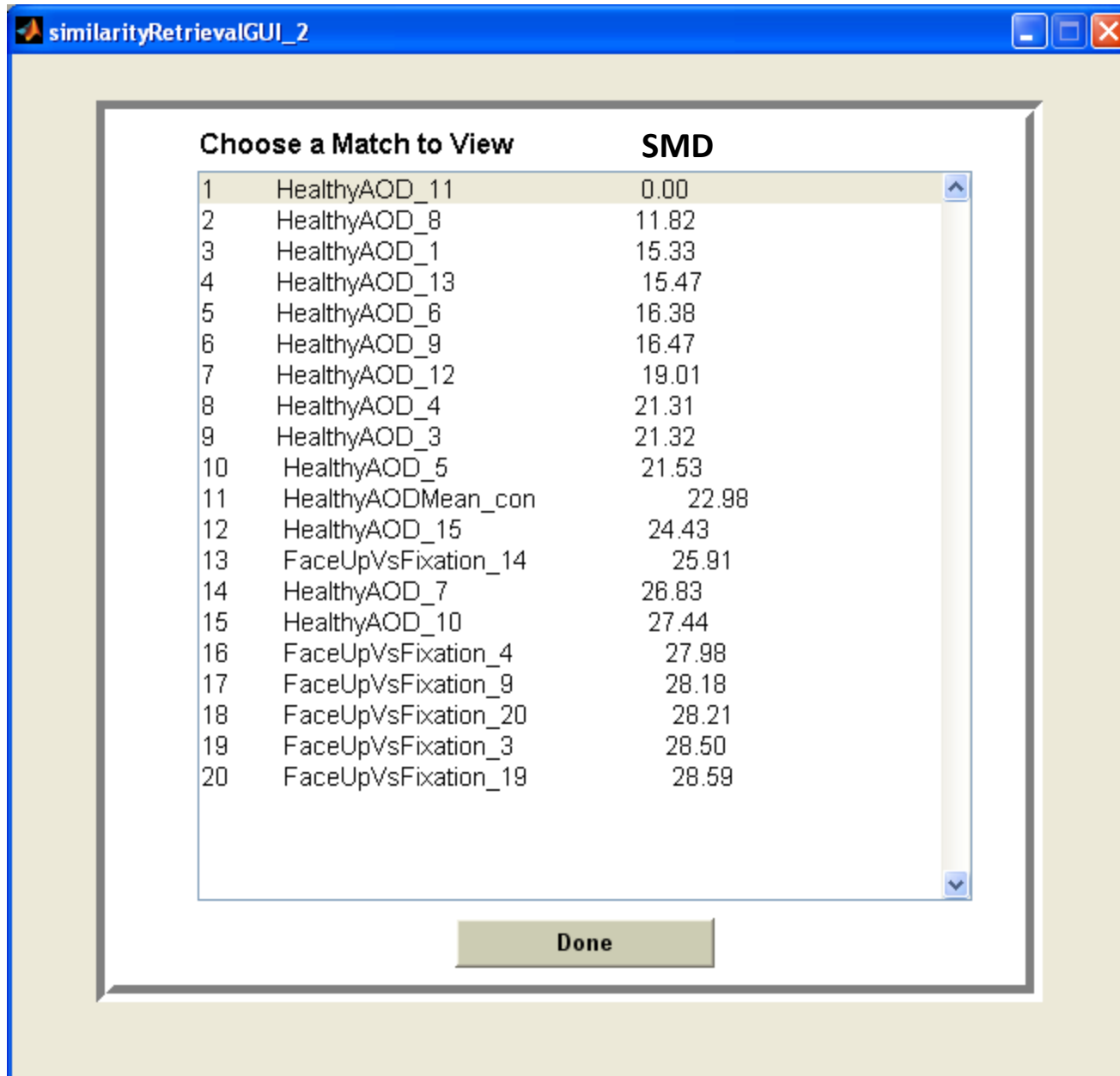
$$Q2T = \frac{\sum_{r \in Q} \min_{s \in T} d_E(r, s)}{N_Q}$$

Euclidean distance between feature vectors*

$$\text{SMD} = (Q2T + T2Q) / 2$$

*We also used normalized Euclidean distance.

Sample SMD Scores



Choose a Match to View	SMD
1 HealthyAOD_11	0.00
2 HealthyAOD_8	11.82
3 HealthyAOD_1	15.33
4 HealthyAOD_13	15.47
5 HealthyAOD_6	16.38
6 HealthyAOD_9	16.47
7 HealthyAOD_12	19.01
8 HealthyAOD_4	21.31
9 HealthyAOD_3	21.32
10 HealthyAOD_5	21.53
11 HealthyAODMean_con	22.98
12 HealthyAOD_15	24.43
13 FaceUpVsFixation_14	25.91
14 HealthyAOD_7	26.83
15 HealthyAOD_10	27.44
16 FaceUpVsFixation_4	27.98
17 FaceUpVsFixation_9	28.18
18 FaceUpVsFixation_20	28.21
19 FaceUpVsFixation_3	28.50
20 FaceUpVsFixation_19	28.59

Done

Similarity Score for Combined fMRI-ERP Images

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

Outline

- Background
- Feature Extraction Process
- Similarity Metric
- **User Interface**
- Retrieval Performance
- Simulate Human Expert

GUI: Front Page

Similarity Retrieval Tool for Multimodal Brain Images

Choose Modality

fMRI

ERP

Both

fMRI Threshold

0.01

ERP Threshold

10

Scope

Global

ROI

ERP Timeframe

TF1

101

TF2

121

Alpha

0

Upload Database

fMRI Feature Weights

Cluster Centroid

100

Cluster Area

0

Voxel Mean Distance to Centroid

0

Voxel Mean Activation Value

0

Variance of Voxel Activation Values

0

Variance of Voxel Distances to Centroid

0

Query Brain

HealthyAODMean_con

Query Brain Viewer

Slices

-26:6:26

or

All Slices

Axial

Coronal

Sagittal

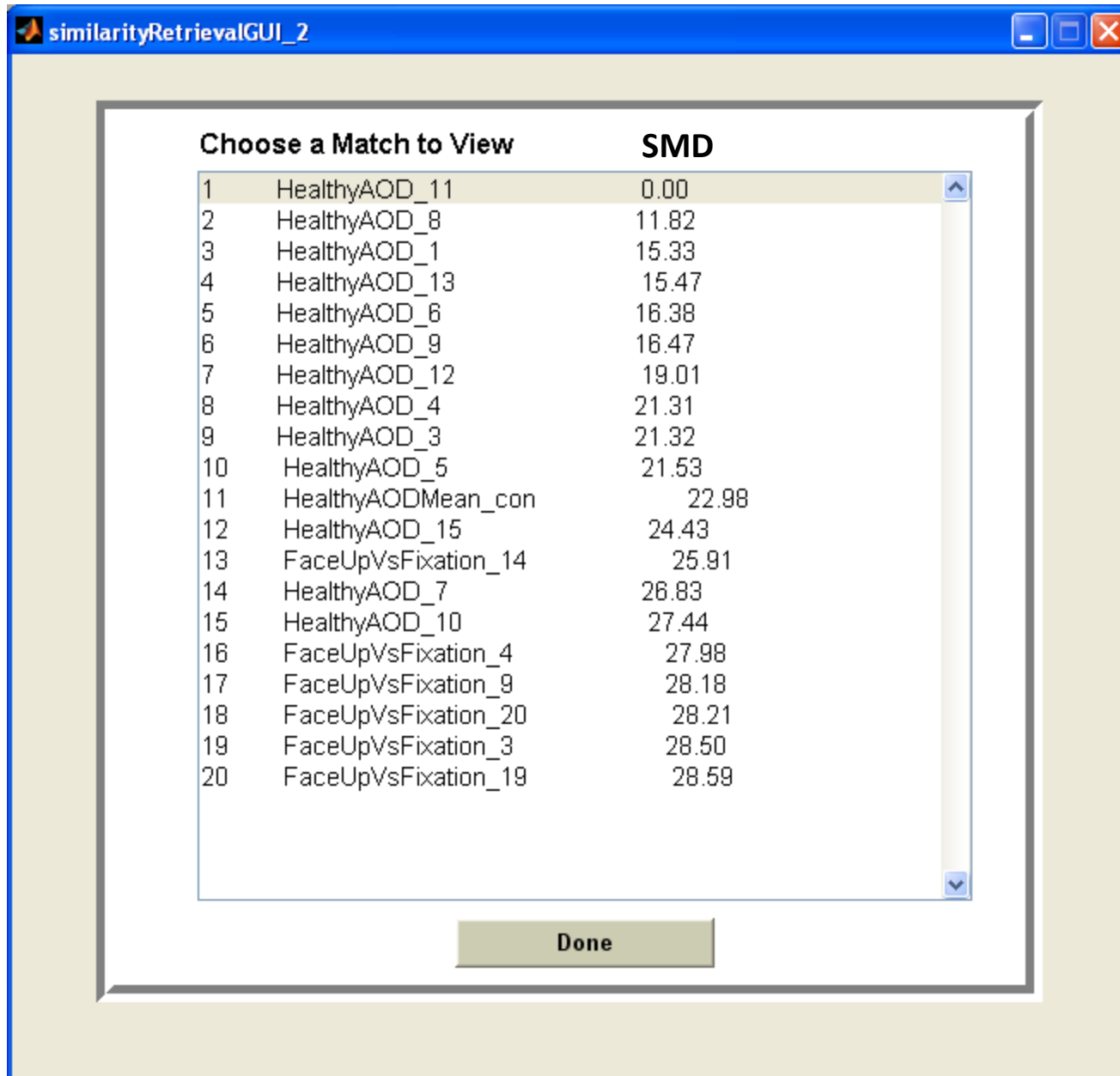
Return Top

15

Matches

Get Matches

GUI: Retrievals with SMD Scores



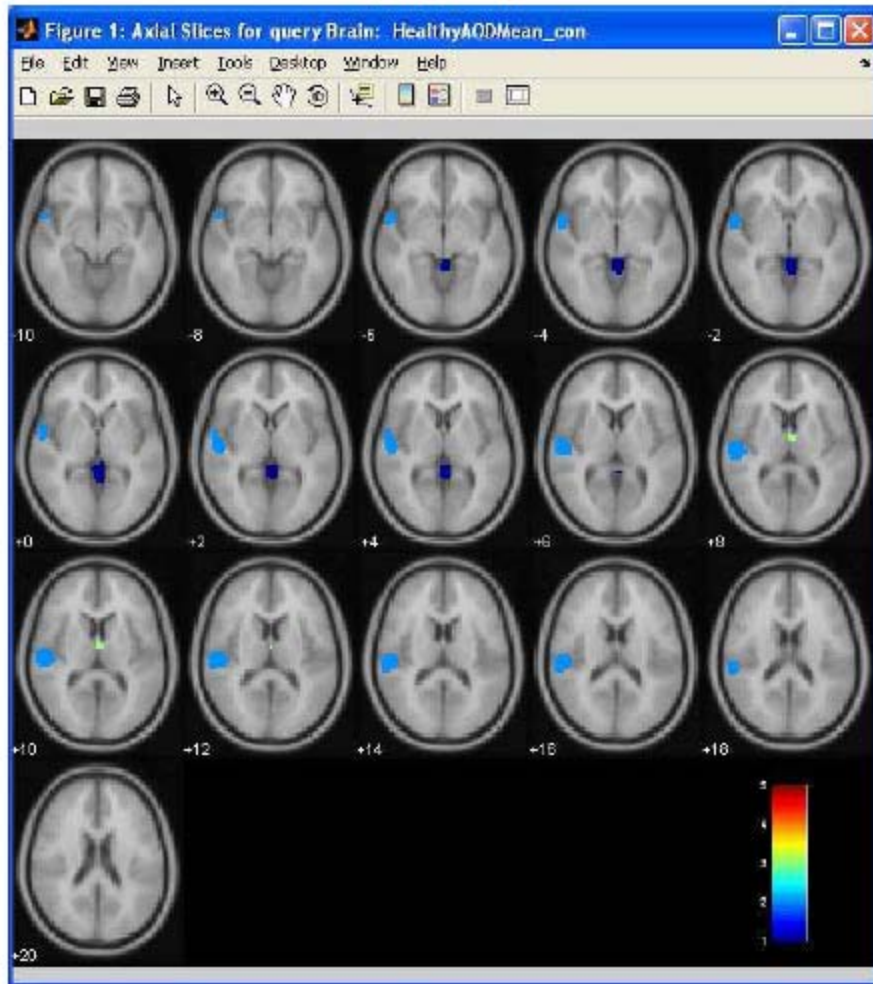
The screenshot shows a window titled "similarityRetrievalGUI_2" with a list of 20 items. Each item consists of a rank number, a match name, and an SMD score. The items are sorted by SMD score from lowest to highest. A "Done" button is positioned at the bottom center of the window.

	Choose a Match to View	SMD
1	HealthyAOD_11	0.00
2	HealthyAOD_8	11.82
3	HealthyAOD_1	15.33
4	HealthyAOD_13	15.47
5	HealthyAOD_6	16.38
6	HealthyAOD_9	16.47
7	HealthyAOD_12	19.01
8	HealthyAOD_4	21.31
9	HealthyAOD_3	21.32
10	HealthyAOD_5	21.53
11	HealthyAODMean_con	22.98
12	HealthyAOD_15	24.43
13	FaceUpVsFixation_14	25.91
14	HealthyAOD_7	26.83
15	HealthyAOD_10	27.44
16	FaceUpVsFixation_4	27.98
17	FaceUpVsFixation_9	28.18
18	FaceUpVsFixation_20	28.21
19	FaceUpVsFixation_3	28.50
20	FaceUpVsFixation_19	28.59

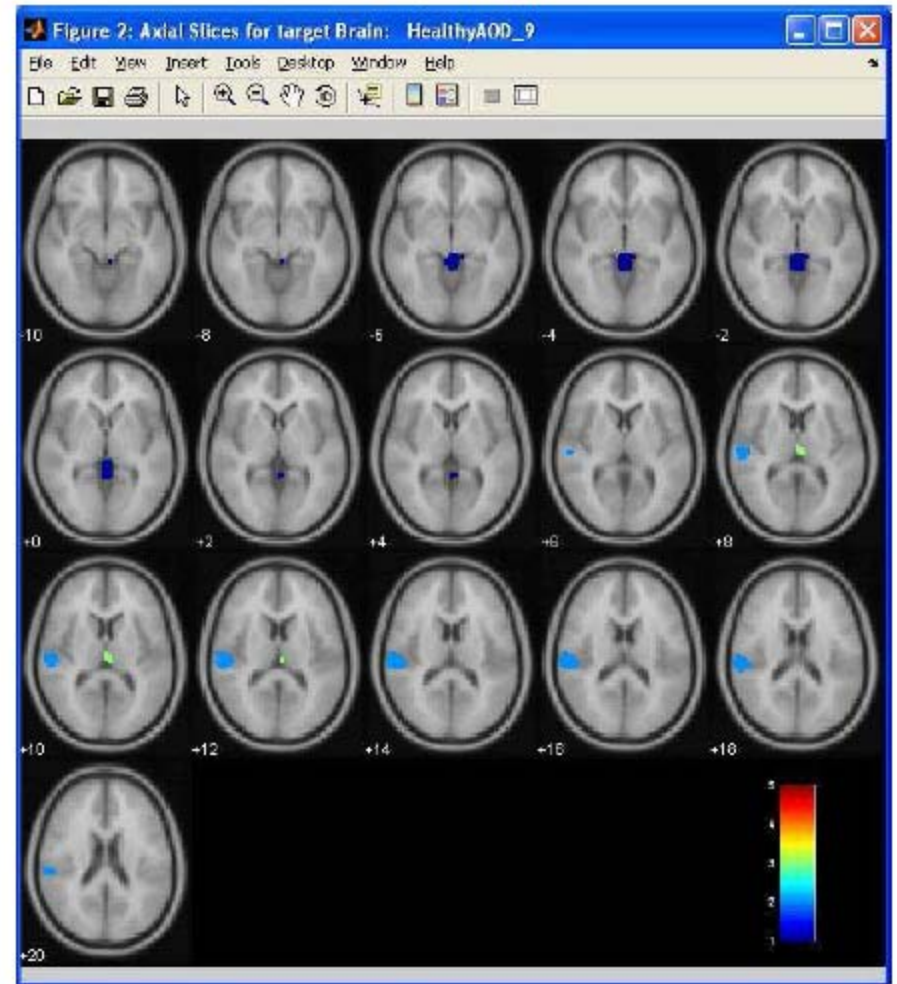
Done

GUI: Query-Target Activations (fMRI)

Query Image

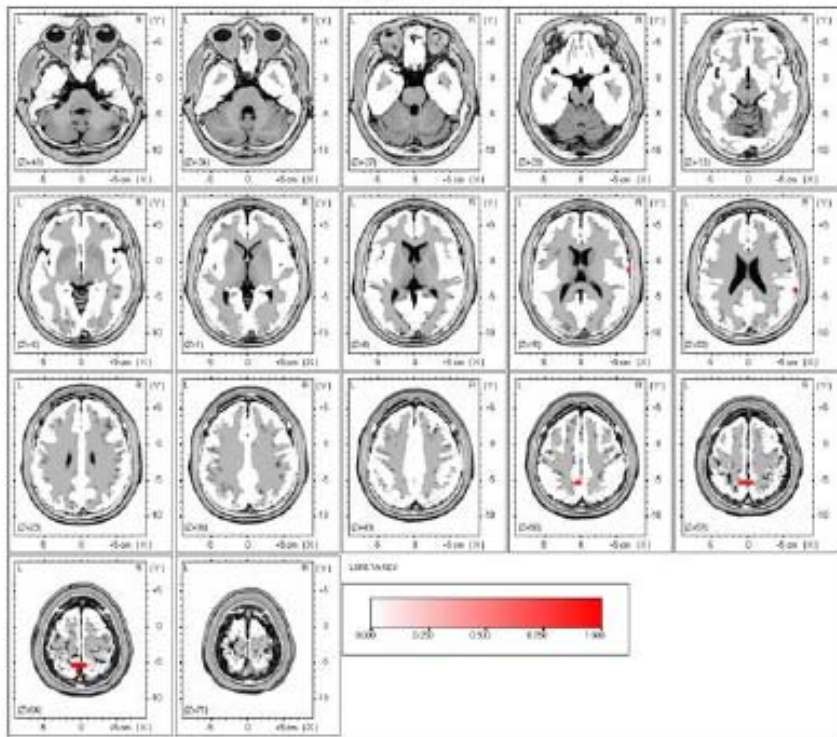


Target Image

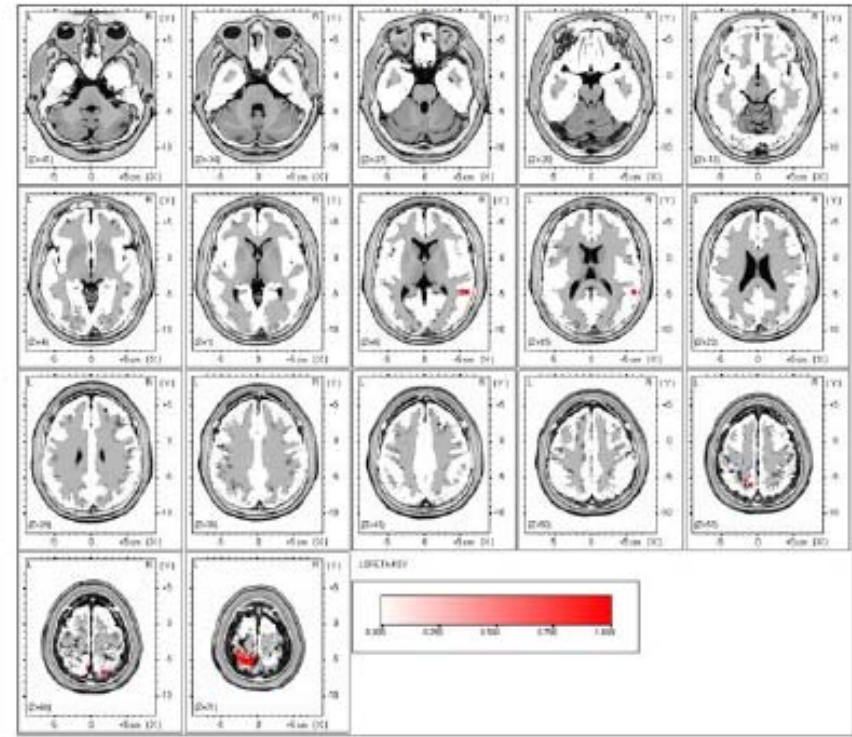


GUI: Query-Target Activations (ERP)

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



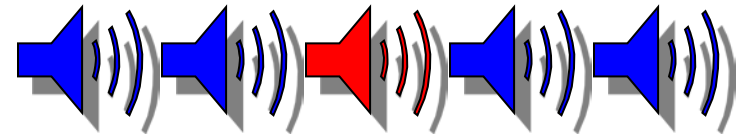
Checkerboard -- 12 subjects
(Face Recognition)



Central-Cross -- 24 subjects
(Face Recognition)



SB -- 15 subjects
(Memorization)

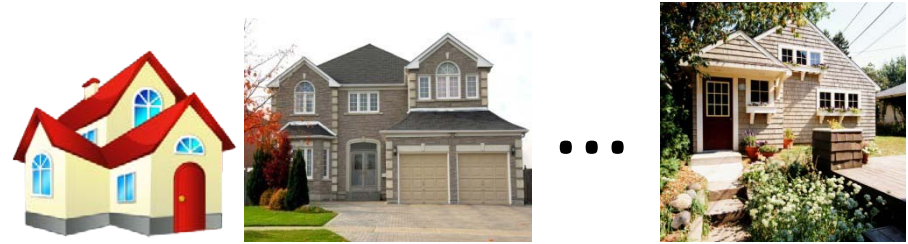


AOD -- 15 subjects
(Sound Recognition)

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 Random effects models are very conservative average activation models from a group, which contain only activated voxels present in all members.
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**

Example Scores

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

- Let $N = 100$ and $N_{rel} = 3$
- Sample Case 1 $R_i = i, i = 1$ to 3
 $1 + 2 + 3 - 6 = 0/300$
- Sample Case 2 $R_1 = 3, R_2 = 2, R_3 = 1$
 $3 + 2 + 1 - 6 = 0/300$
- Sample Case 3: $R_1 = 10, R_2 = 20, R_3 = 30$
 $10 + 20 + 30 - 6 = 54/300$

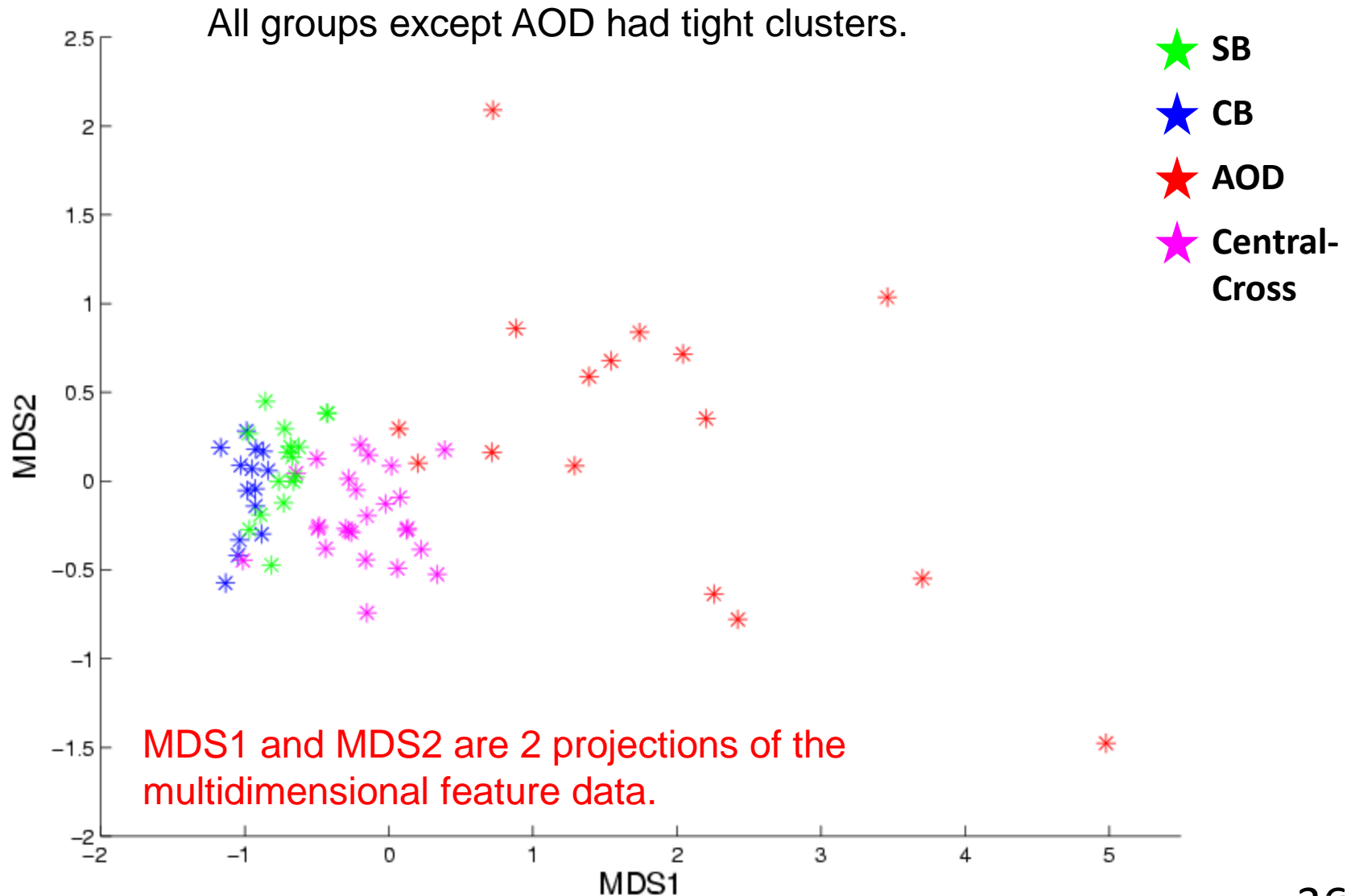
fMRI Individual Brain Retrievals

- Use individual brain as query

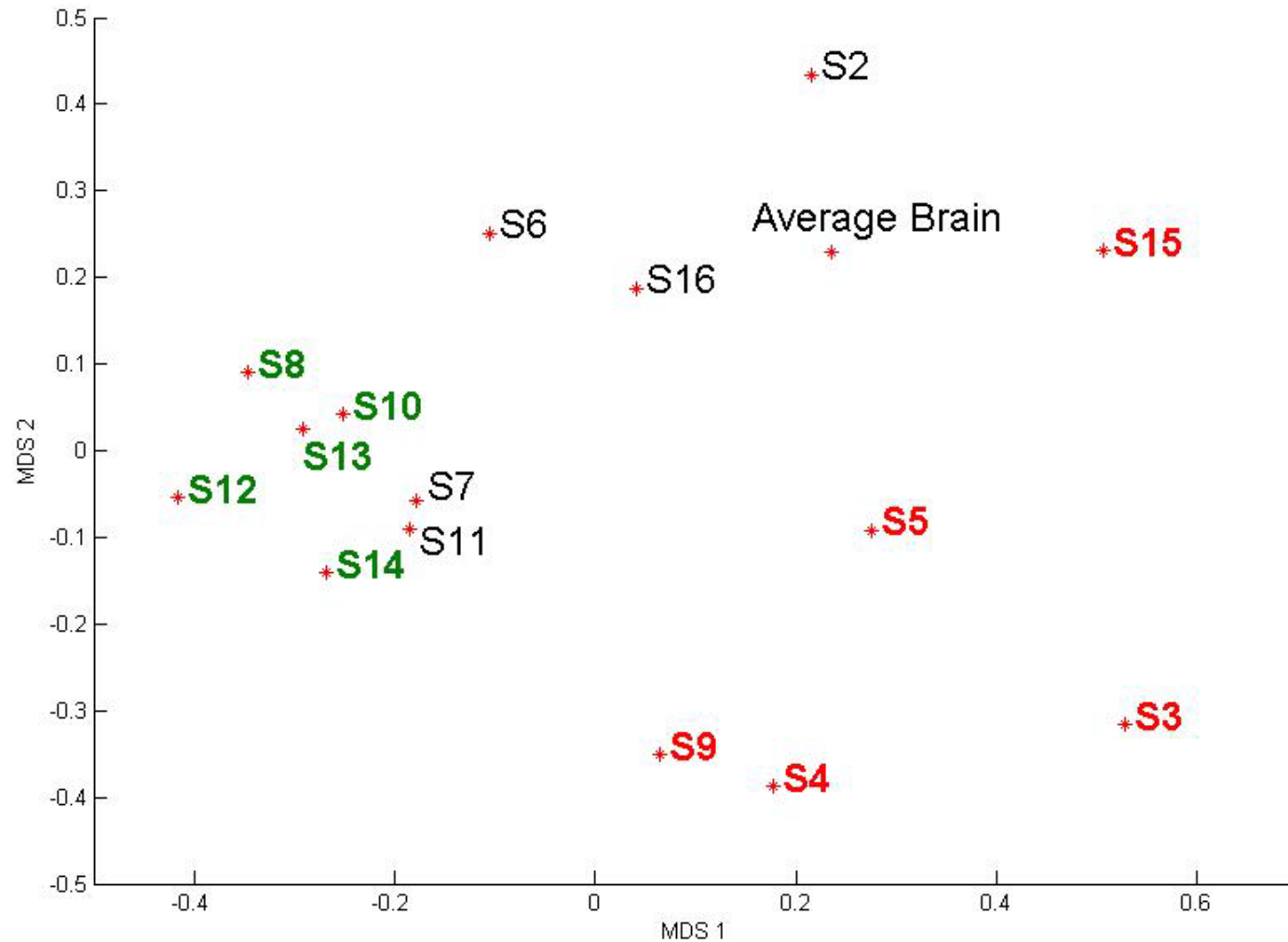
Mean Retrieval Scores
(Top 6% activated voxels)

Checkerboard	0.09
SB	0.16
Central-Cross	0.21
AOD	0.26

Testing Group Homogeneity for fMRI

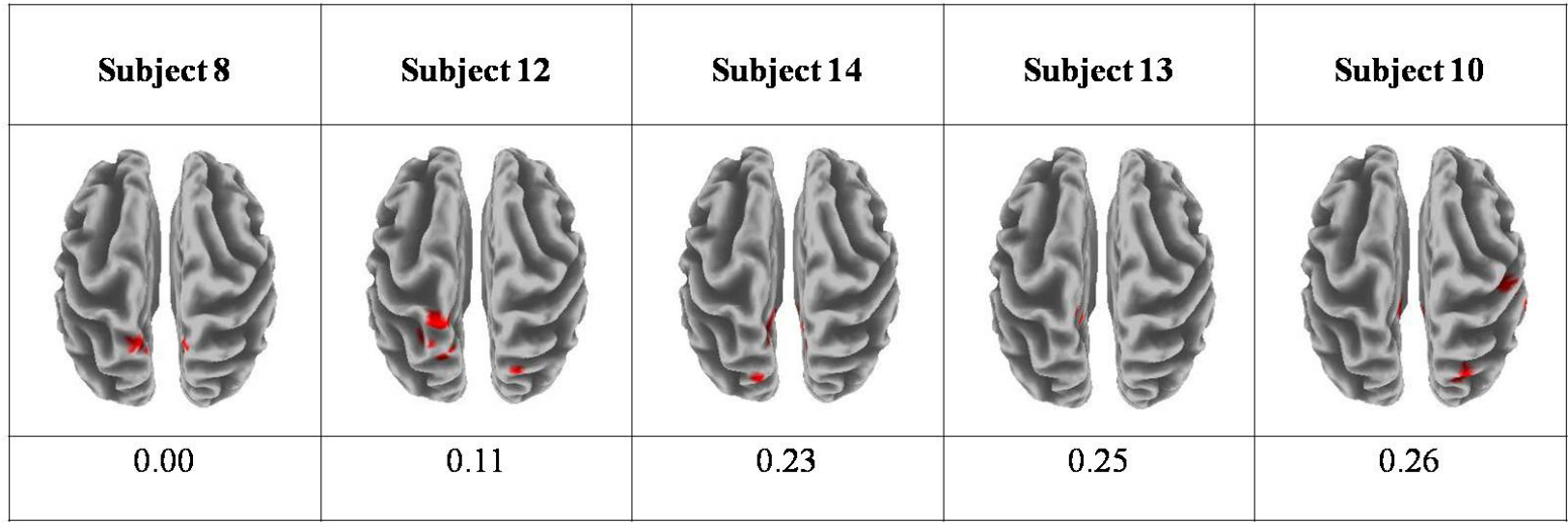


ERP Retrieval Performance

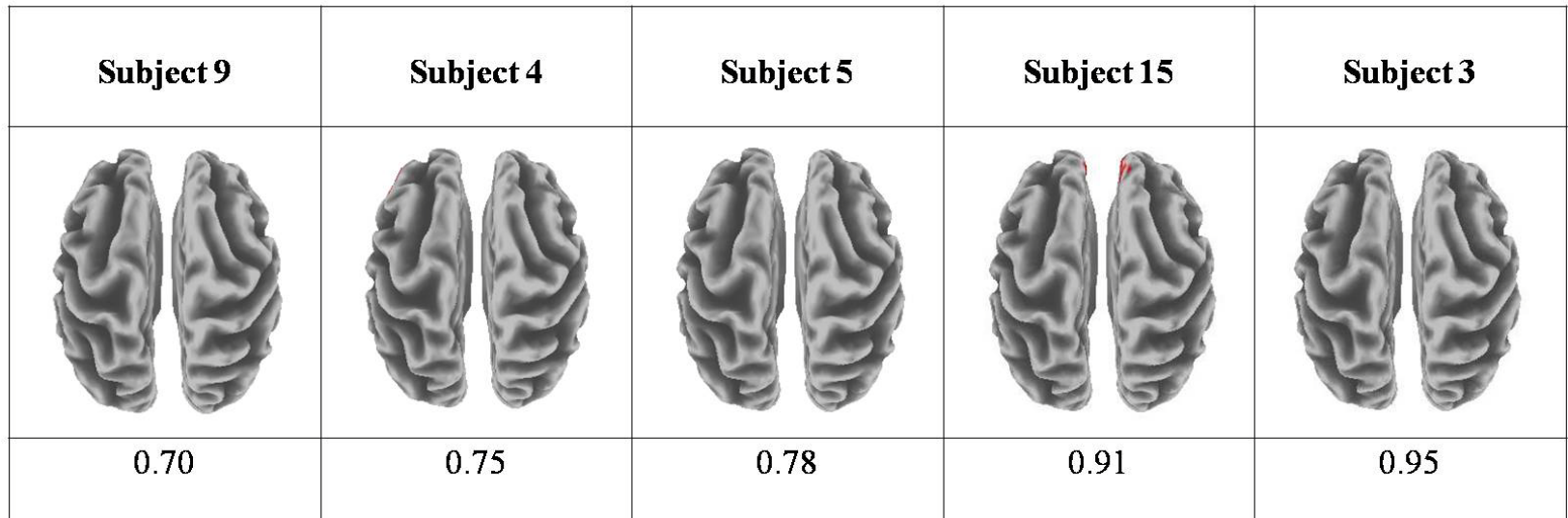


Subject #8 Retrievals

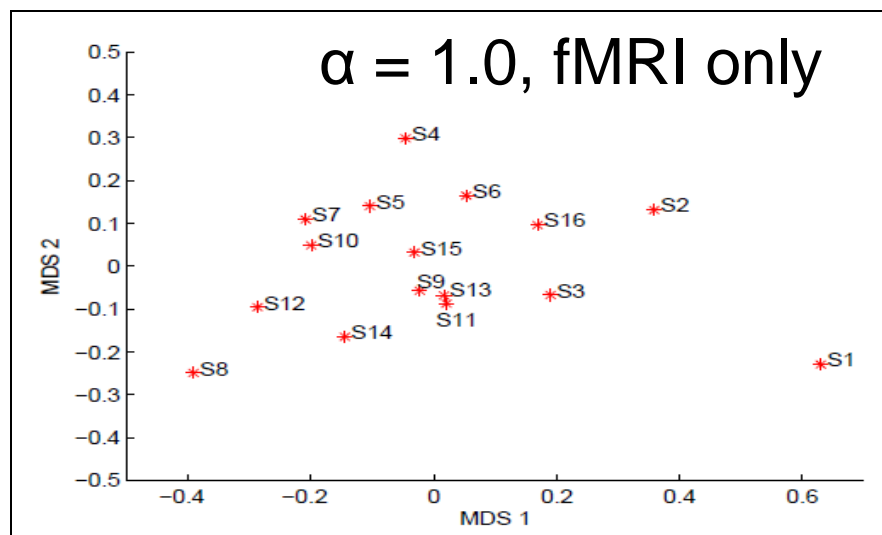
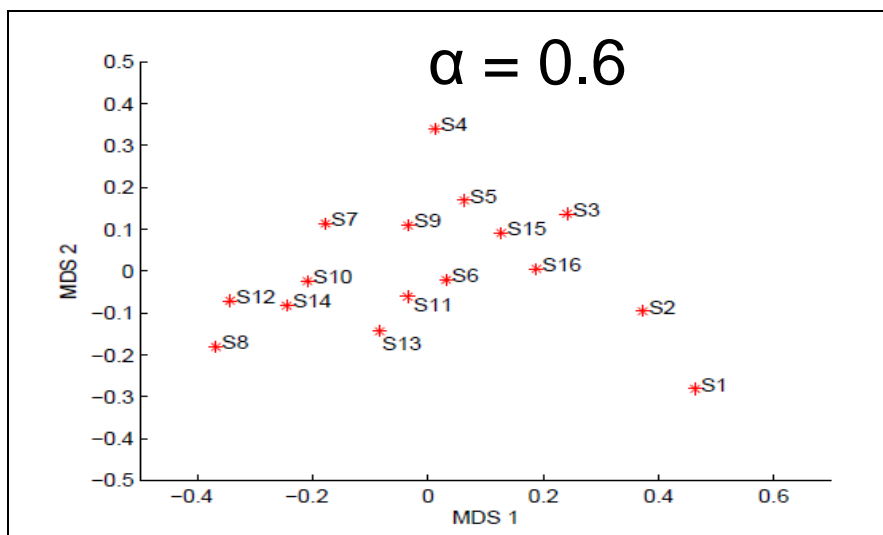
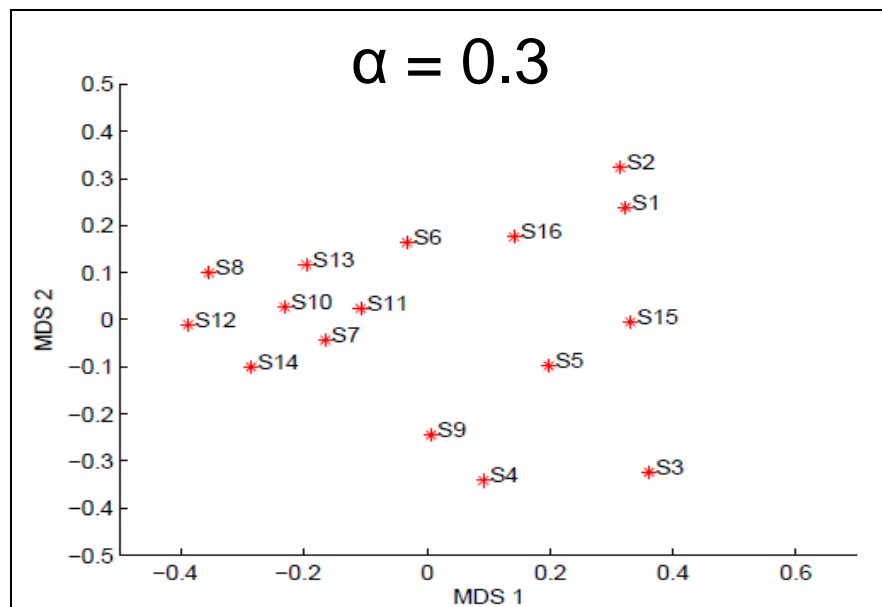
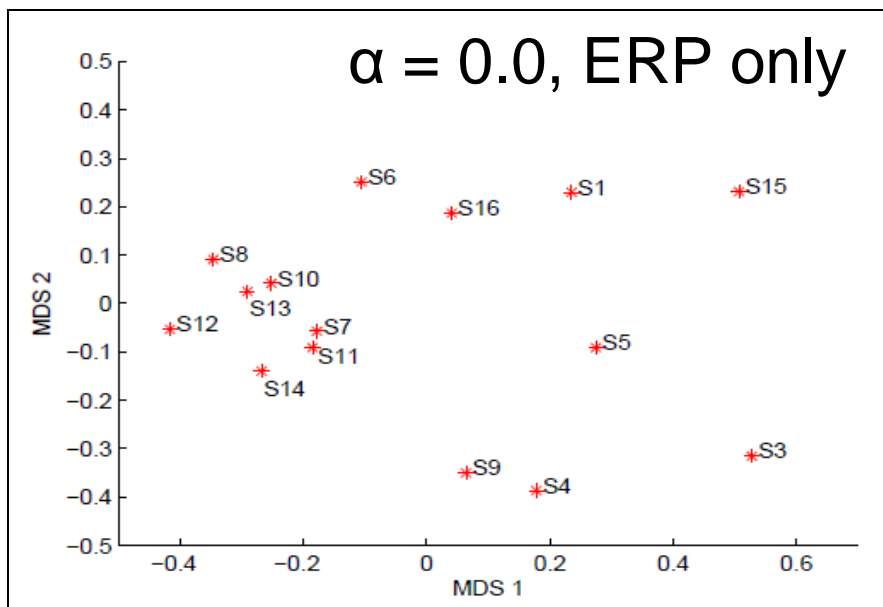
Top
Retrievals



Bottom
Retrievals



Combined fMRI-ERP Retrieval



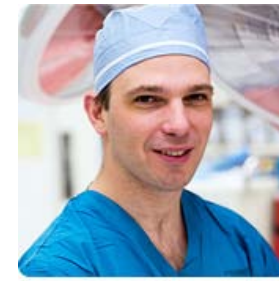
$$\text{SIM}(i,j) = \alpha \text{SMD}_{\text{fMRI}}(i,j) + (1-\alpha) \text{SMD}_{\text{ERP}}(i,j)$$

Outline

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

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

Simulate Human Expert



Dr. Jeff
Ojemann

- 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

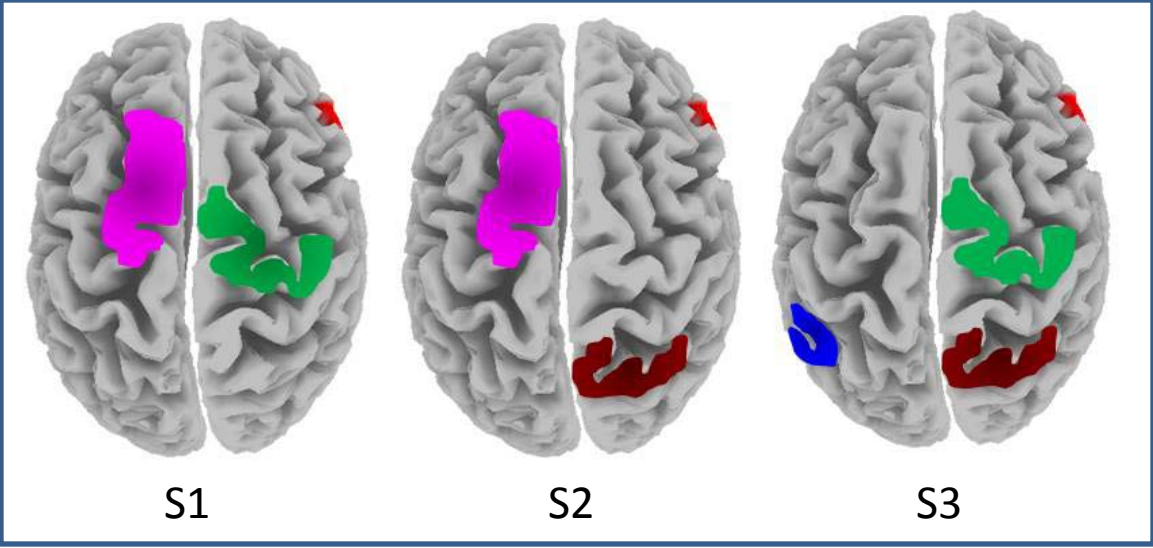
Simulation Method

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

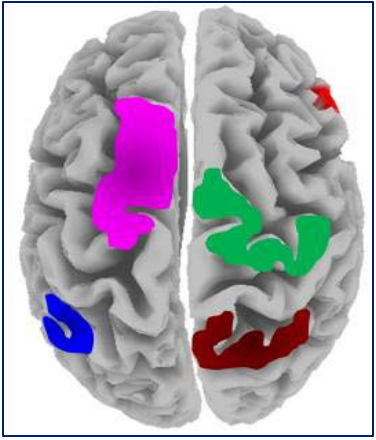
The Codebook

- Out of all the clusters found in all N brains, create **a single brain that has a representation of each unique cluster**. This is the codebook.
- Then for each of the N brains use the codebook to create a subject-specific vector representing each of those clusters.
- In the case where the codebook has a given cluster, but that particular subject misses it, that whole portion of this subject's codebook will be empty.
- Otherwise, the other parts of this subject's codebook will be filled with the properties of this subject's clusters.

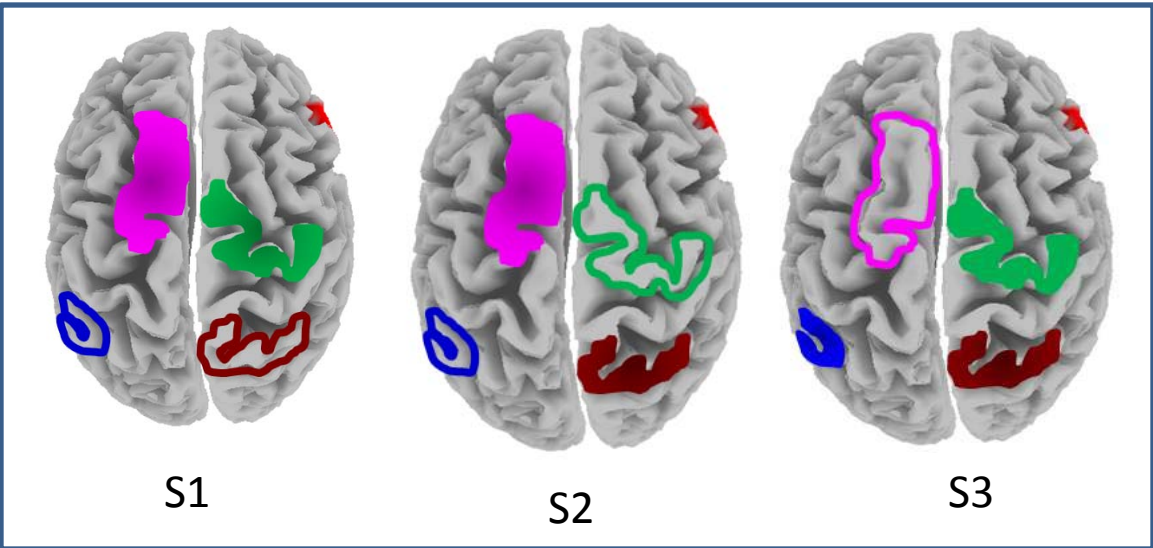
1. Uniform Feature Representation



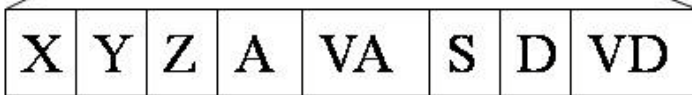
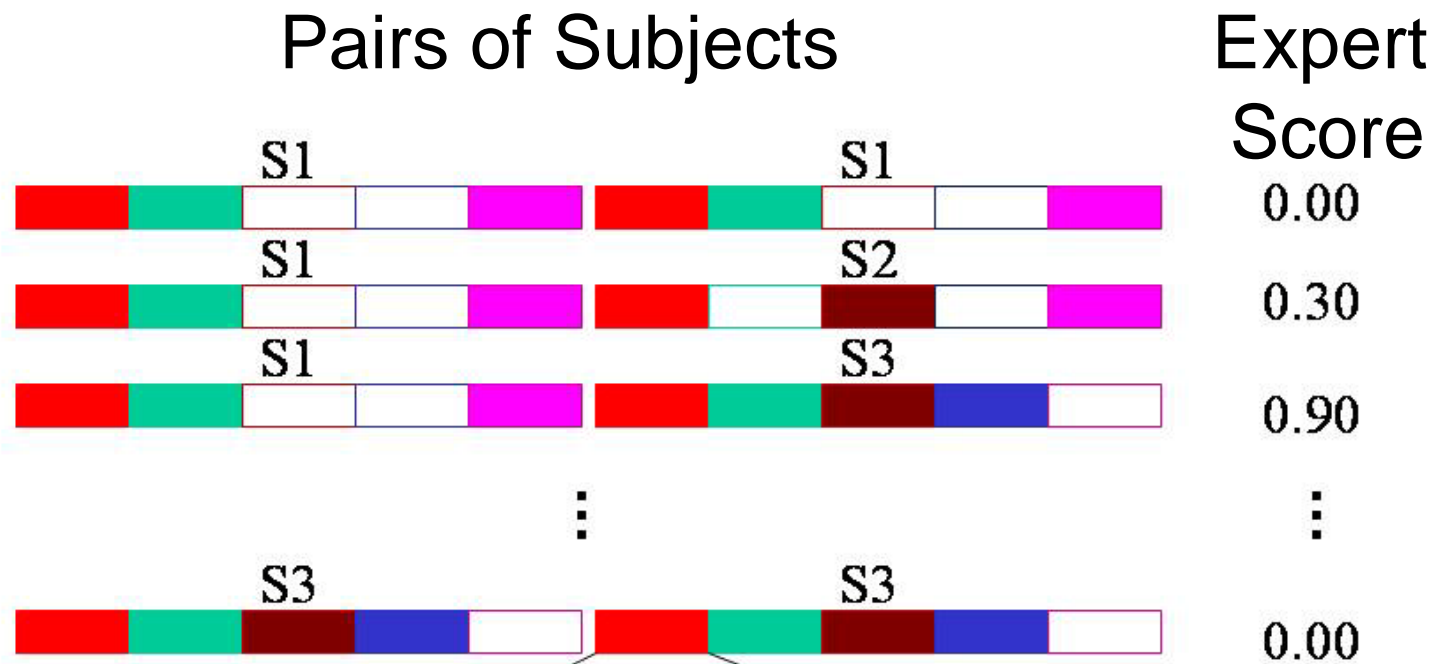
Create the reference brain (codebook)



Encode Images



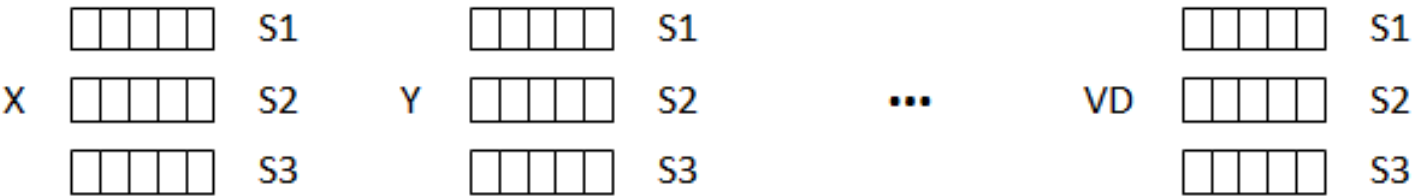
2. Concatenate Codebook Features



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

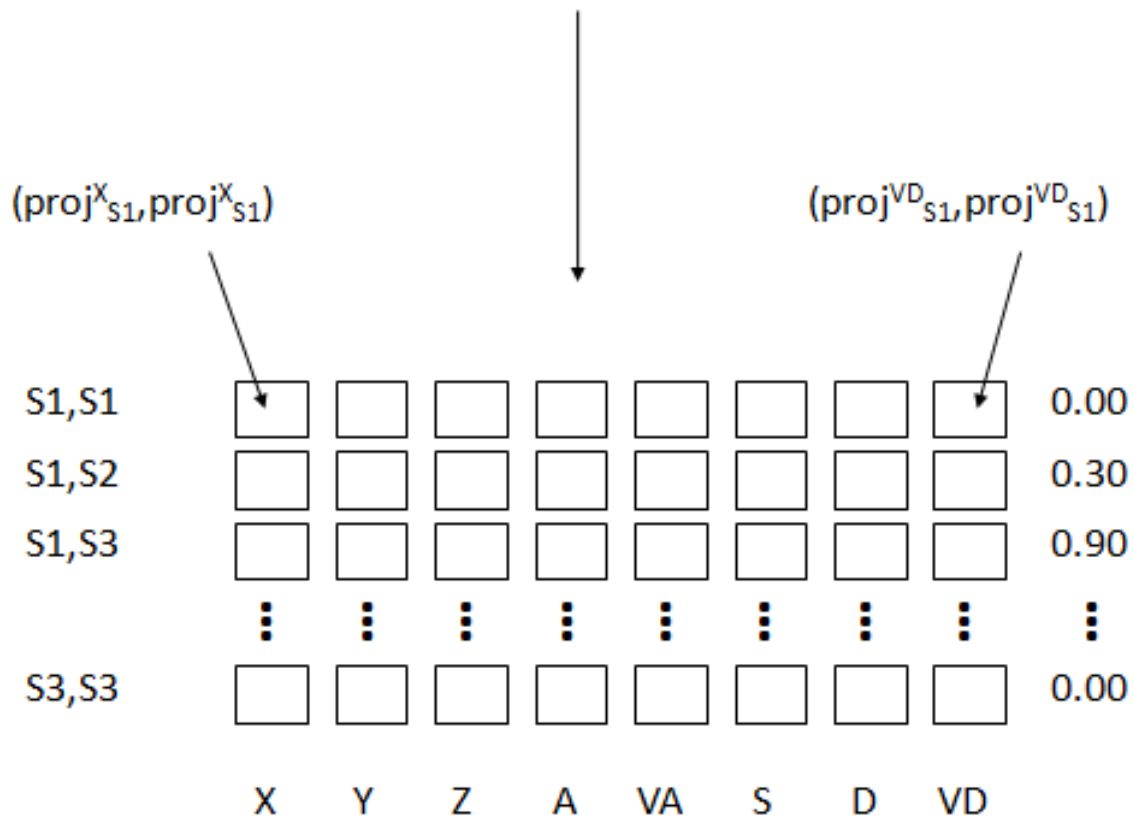
3. Create Eigenfeatures

original feature space



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

eigenfeature space



4. Estimate a Function

We want to estimate a function that takes a pair of region vectors from two subjects and computes their similarity score.

S1,S1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.00
S1,S2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.30
S1,S3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.90
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
S3,S3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.00

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

5. Test Function Performance

- The Pearson Correlation Coefficient (CC)

$$\frac{\sum_{i=1}^n (\hat{y}_i - \mu_{\hat{y}}) (y_i - \mu_y)}{(n-1) s_{\hat{y}} s_y}$$

- The Average Absolute Error (A-ABSE)

$$\frac{\sum_{i=1}^n [y_i - \hat{y}_i]}{n}$$

- The Root Mean Square Error (RMSE)

$$\sqrt{\frac{\sum_{i=1}^n [y_i - \hat{y}_i]^2}{n}}$$

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

overfitting!

Contributions

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