A Reduced-Dimension fMRI Shared Response Model

Po-Hsuan (Cameron) Chen[1], Janice Chen[2], Yaara Yeshurun[2], Uri Hasson[2], James V. Haxby[3], Peter J. Ramadge[1]

[1]Department of Electrical Engineering, Princeton University, [2] Princeton Neuroscience Institute and Department of Psychology, Princeton University,

[3]Center for Cognitive Neuroscience, Dartmouth College

email : pohsuan@princeton.edu

Oral Presentation
Dec 9 (Wed)
2:50pm-3:30pm

Introduction

Motivation:

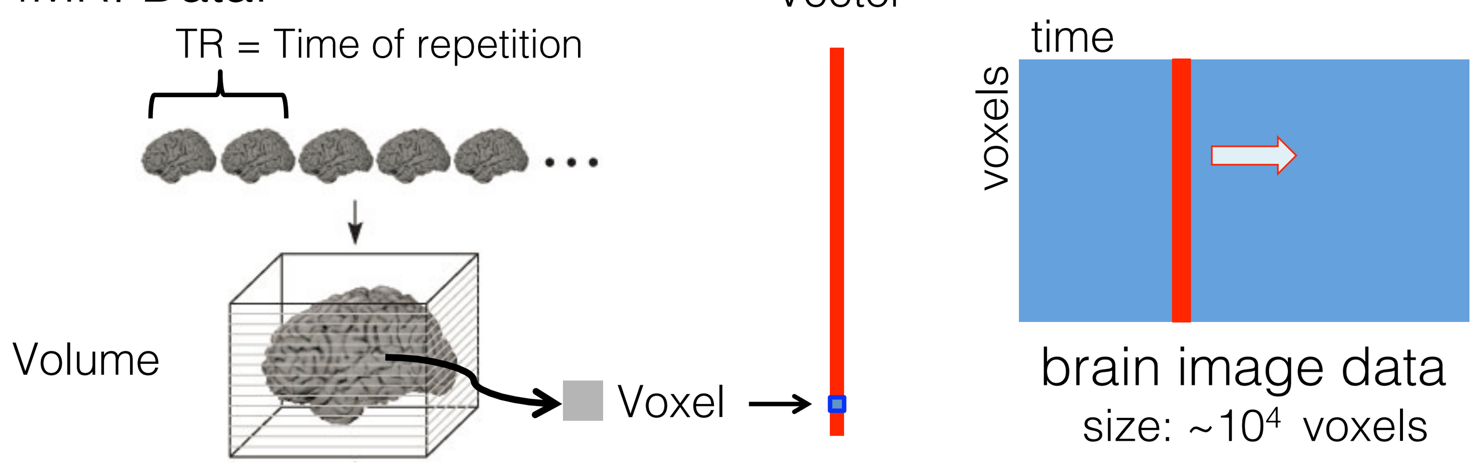
- Modern fMRI studies of human cognition use data from multiple subjects.
- Why? Scientific reasons, and to increase the power of multivariate statistical analysis.

Challenge :

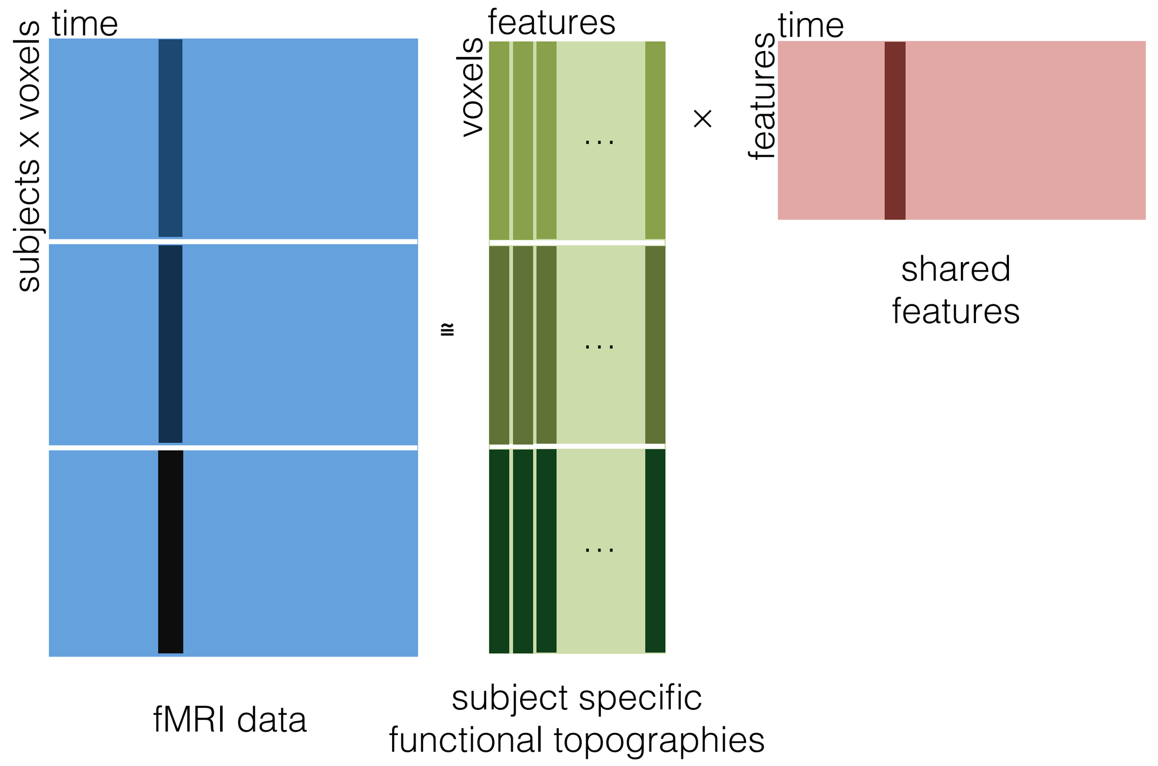
- Inter-subject variability in anatomical structure and functional topographies.
- So how can we aggregate multi-subject fMRI data?

Evaluation :

- Form this as a machine learning question.
- Given test subject's fMRI response, can we successfully classify the stimulus using other subjects' data.



Factor Model



Shared Response Model (SRM)

What are we looking for?

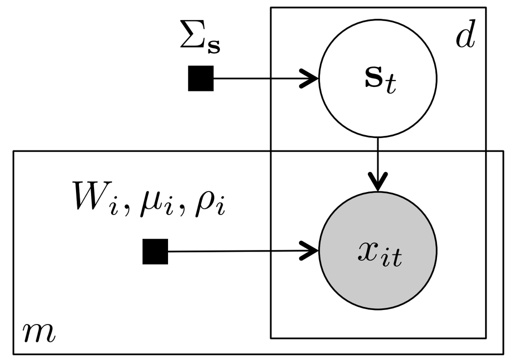
- dimensionality reduction
- better identify the feature space

Approach: generative probabilistic model

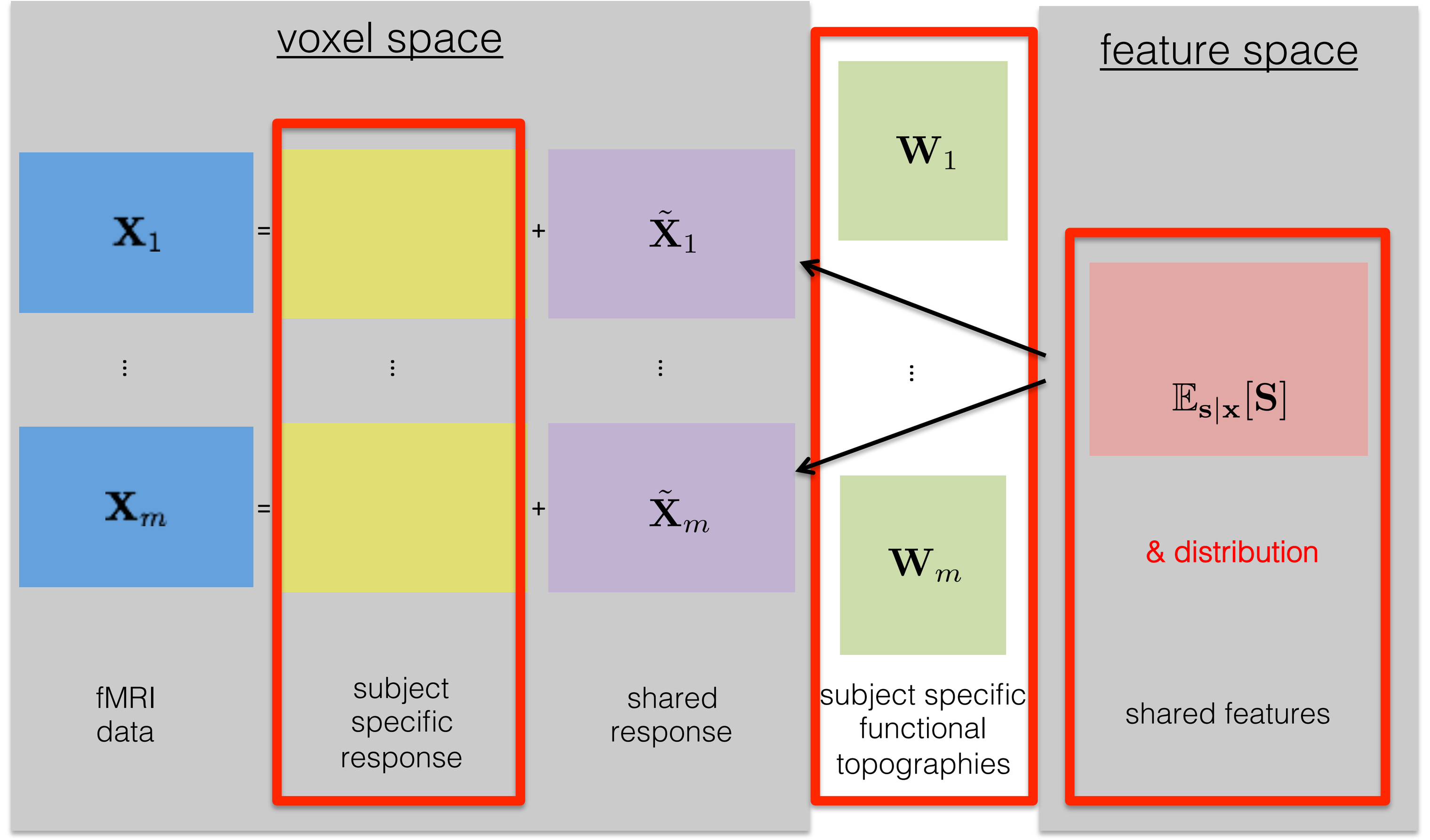
- apply existing statistical tools
- natural incorporation of prior knowledge

$$s_t \sim \mathcal{N}(0, \Sigma_s)$$
$$x_{it}|s_t \sim \mathcal{N}(W_i s_t + \mu_i, \rho_i^2 I)$$
$$W_i^T W_i = I$$

W_i not square



- Closed-form constrained EM algorithm derived.
- Feature identification with dimensionality reduction.



Constrained EM algorithm

E-step :

$$\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t] = (W\Sigma_s)^T(W\Sigma_s W^T + \Psi)^{-1}(x_t - \mu)$$
$$\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t\mathbf{s}_t^T] = \mathrm{Var}_{\mathbf{s}|x}[\mathbf{s}_t] + \mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t]\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t]^T$$
$$= \Sigma_s - \Sigma_s^T W^T(W\Sigma_s W^T + \Psi)^{-1}W\Sigma_s + \mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t]\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t]^T$$

M-step :

$$\mu_i^{\mathrm{new}} = \frac{1}{d}\sum_t x_{it}$$
$$W_i^{\mathrm{new}} = A_i(A_i^T A_i)^{-1/2}, \quad A_i = \frac{1}{2}\left(\sum_t (x_{it} - \mu_i^{\mathrm{new}})\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t]^T\right)$$
$$\rho_i^{2\,\mathrm{new}} = \frac{1}{dv}\sum_t \left(\|x_{it} - \mu_i^{\mathrm{new}}\|^2 - 2(x_{ix} - \mu_i^{\mathrm{new}})^T W_i^{\mathrm{new}}\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t] + \mathrm{tr}(\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t\mathbf{s}_t^T])\right)$$
$$\Sigma_s^{\mathrm{new}} = \frac{1}{d}\sum_t (\mathbb{E}_{\mathbf{s}|x}[\mathbf{s}_t\mathbf{s}_t^T])$$

Datasets

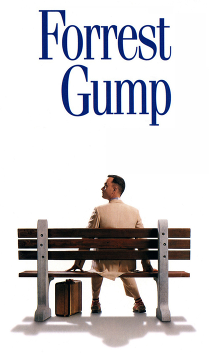
sherlock

- movie watching
- 16 subjects
- 1976 TRs
- 813 voxels
- Posterior Medial Cortex

audiobook

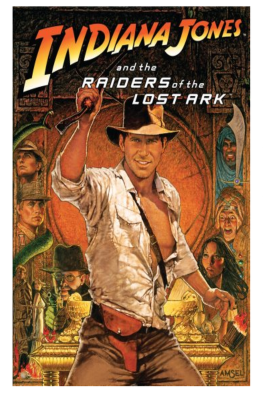
- audiobook listening
- 40 subjects
- 449 TRs
- 5000 voxels
- Default Mode Network

forrest



- auditory feature film listening
- 18 subjects
- 3599 TRs
- 2600 voxels
- Planum Temporale

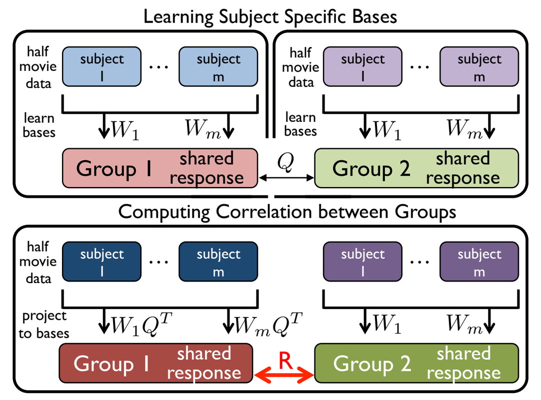
raider

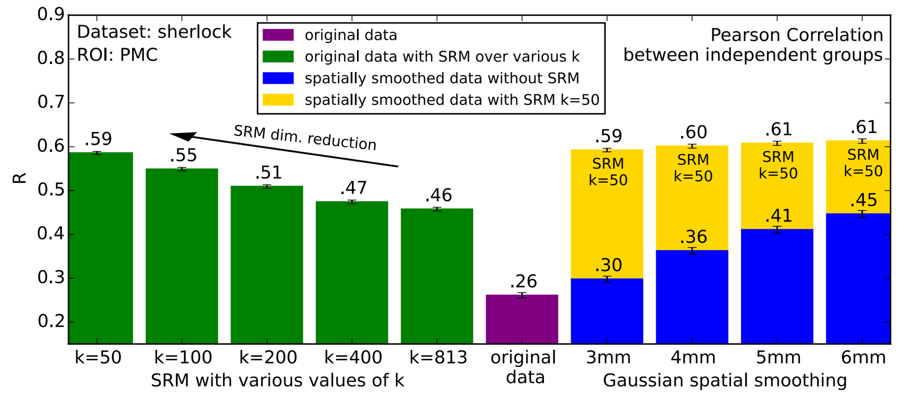


- movie and images watching
- 10 subjects
- 2203 TRs
- 1000 voxels
- Ventral Temporal Cortex

SRM and spatial smoothing

Robustness: Consistent across groups, high correlation between groups, better than anatomical alignment, comparable to 6mm spatial smoothing.



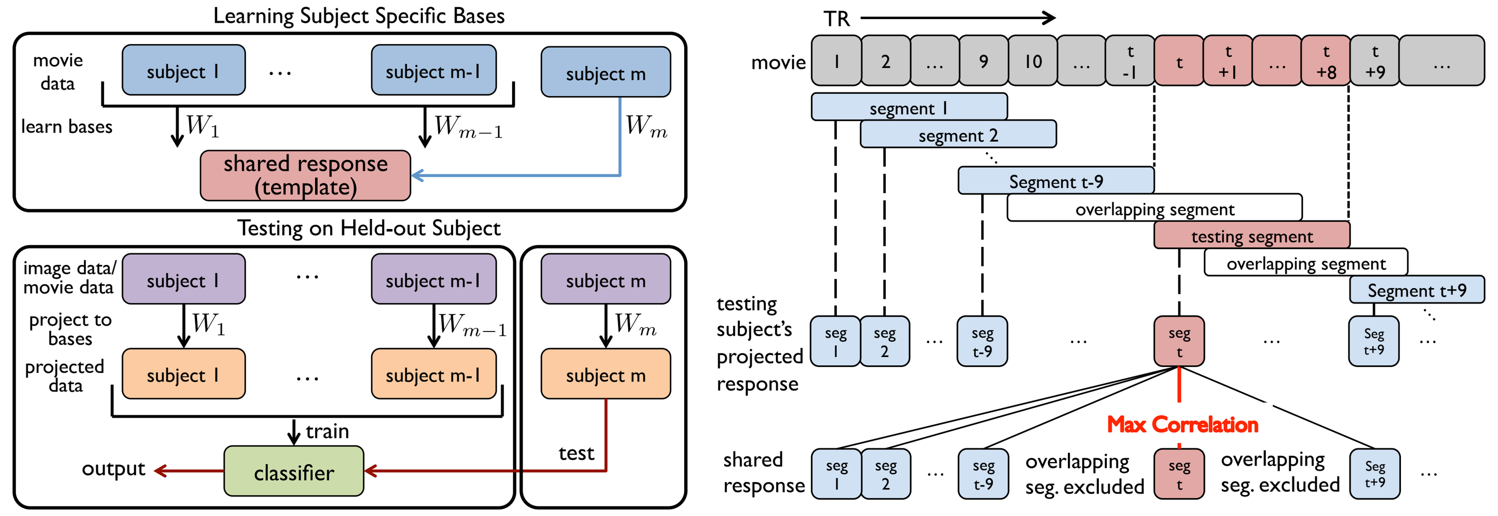


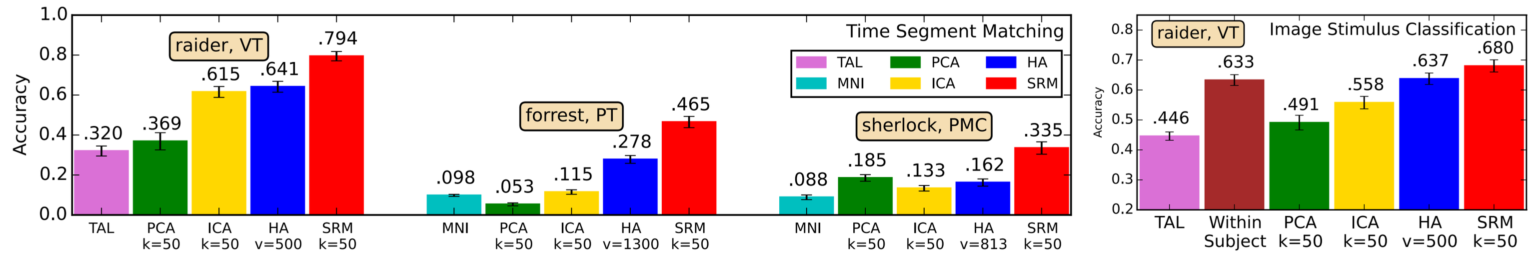
- Identify correlated response between independent groups.
- Increased correlation without dimensionality reduction.

Time segment matching and Image classification

Generalization to new subject and new stimulus:

1. Given a segment of movie watching response from a test subject, predict the time point of the segment while using other subjects' data for training.
2. Given an image watching response from a test subject, predict the image category while using other subjects' data for training.

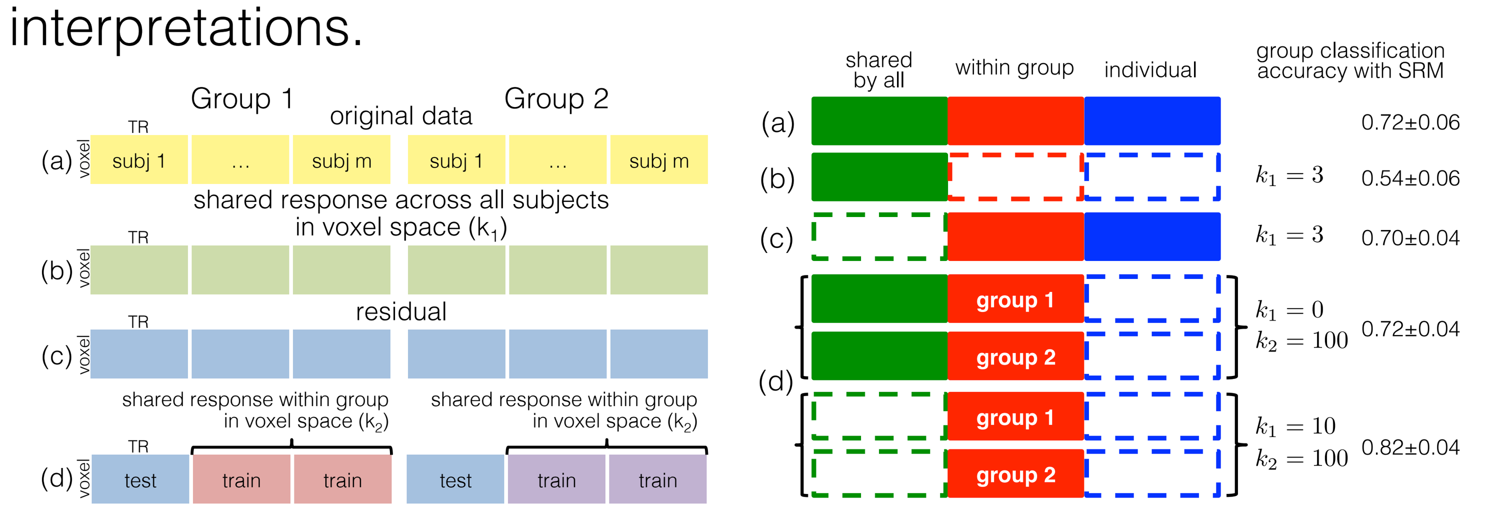


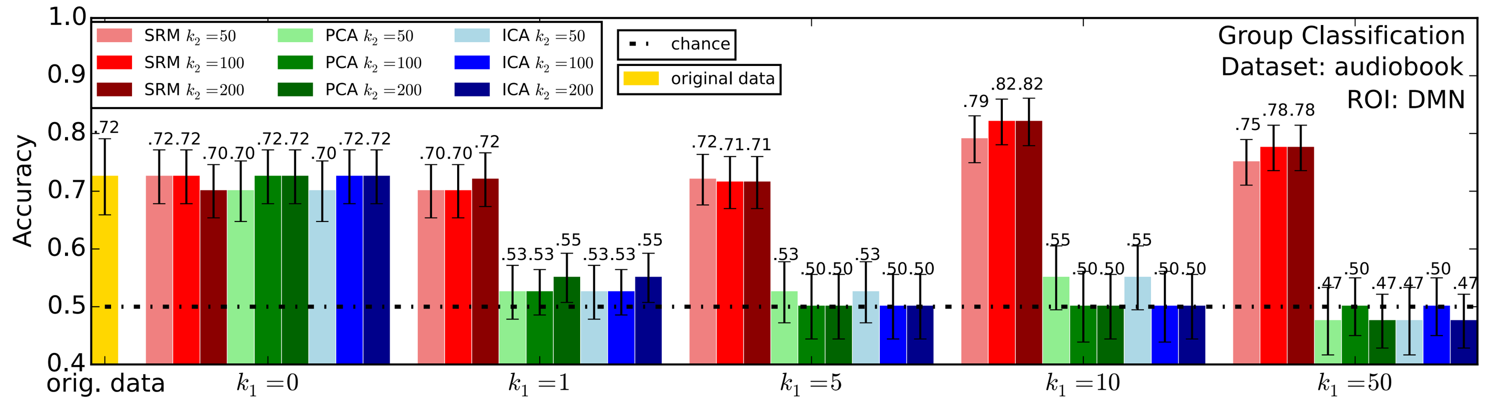


- State-of-the-art performance in time segment matching and image prediction, suggesting identifying informative shared response.
- Outperforms within subject prediction.

Differentiating between groups

Differentiating two cognitive states : Subjects listen to identical story but different prior context leads to different interpretations.





- Identification of shared and individual responses.
- Ability to detect group specific responses opens up wide range of situations where group differences are the key experimental variable.