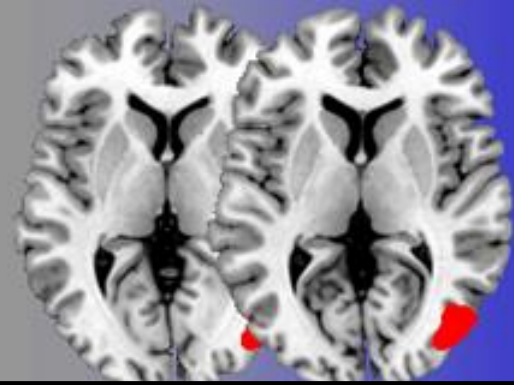




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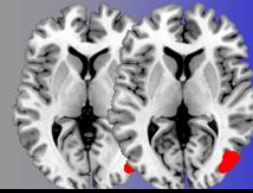
JIVE Integration of Behavioral and FMRI Data

Qunqun Yu*, **Benjamin Risk**[#], Kai Zhang*, J. S. Marron*

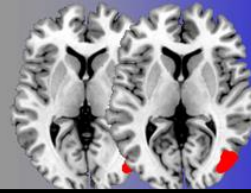
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of North Carolina, Chapel Hill



- *Scientific question:* how does behavior relate to brain activity?
- *Statistical problem:* decompose two or more datasets into
 - joint + individual + noise
- Pressing problem in big data:
 - Genomics and cancer research: Gene expression, copy number, mutations
 - Neuroimaging: Combine imaging modalities, behavior, genetics

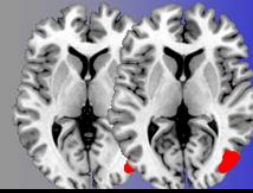


- Canonical correlation analysis: issues when $d_1 > n$ or $d_2 > n$

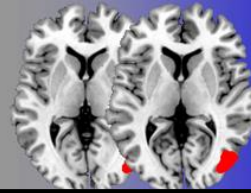
- Partial least squares:

$$\operatorname{argmax}_{a_1, a_2} \sqrt{\operatorname{Var}(a_1' X_1) \operatorname{Var}(a_2' X_2) \operatorname{Corr}(a_1' X_1, a_2' X_2)}$$

- Challenges when $d_1 \gg d_2$
 1. Unit variance: X_1 dominates
 2. Standardize by energy: X_2 dominates
- **Joint & Individual Variation Explained**



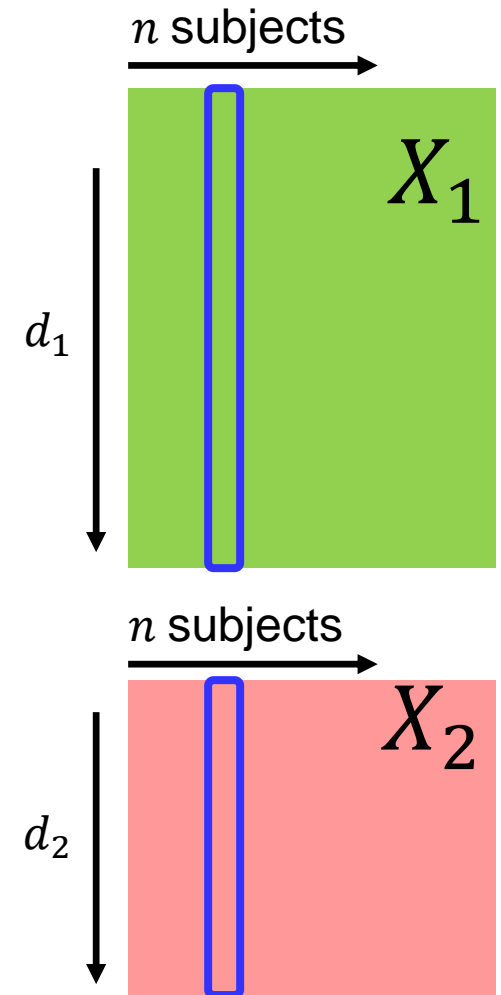
1. Eric Lock, Katherine Hoadley, Steve Marron, Andrew Nobel. Joint and Individual Variation Explained (JIVE) for integrated analysis of multiple data types. *Annals of Applied Statistics*. 2013.
2. Qing Feng, Jan Hannig, Meilei Jiang, and Steve Marron. Angle-Based Joint and Individual Variation Explained. In review.
3. Qunqun Yu, Ben Risk, Kai Zhang, and Steve Marron. JIVE integration of imaging and behavioral data. *NeuroImage*. 2017.

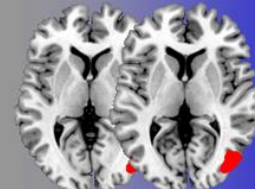


- Multiple Matrices
- Here, we focus on $K = 2$

d_1, d_2 = number of variables
(i.e. features)

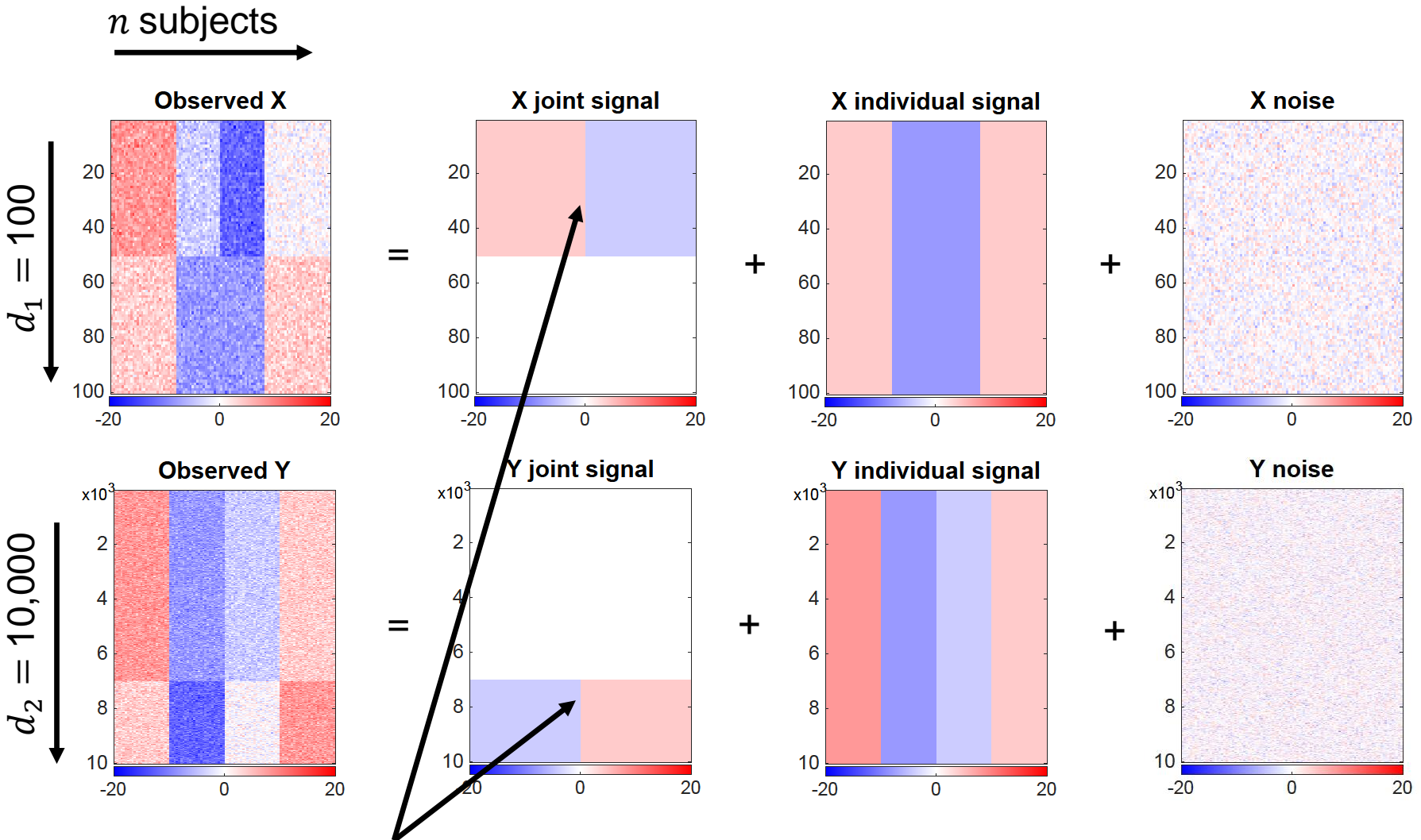
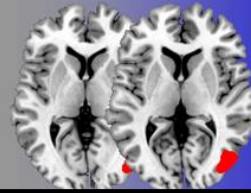
n = number of cases
(i.e. subjects or samples)





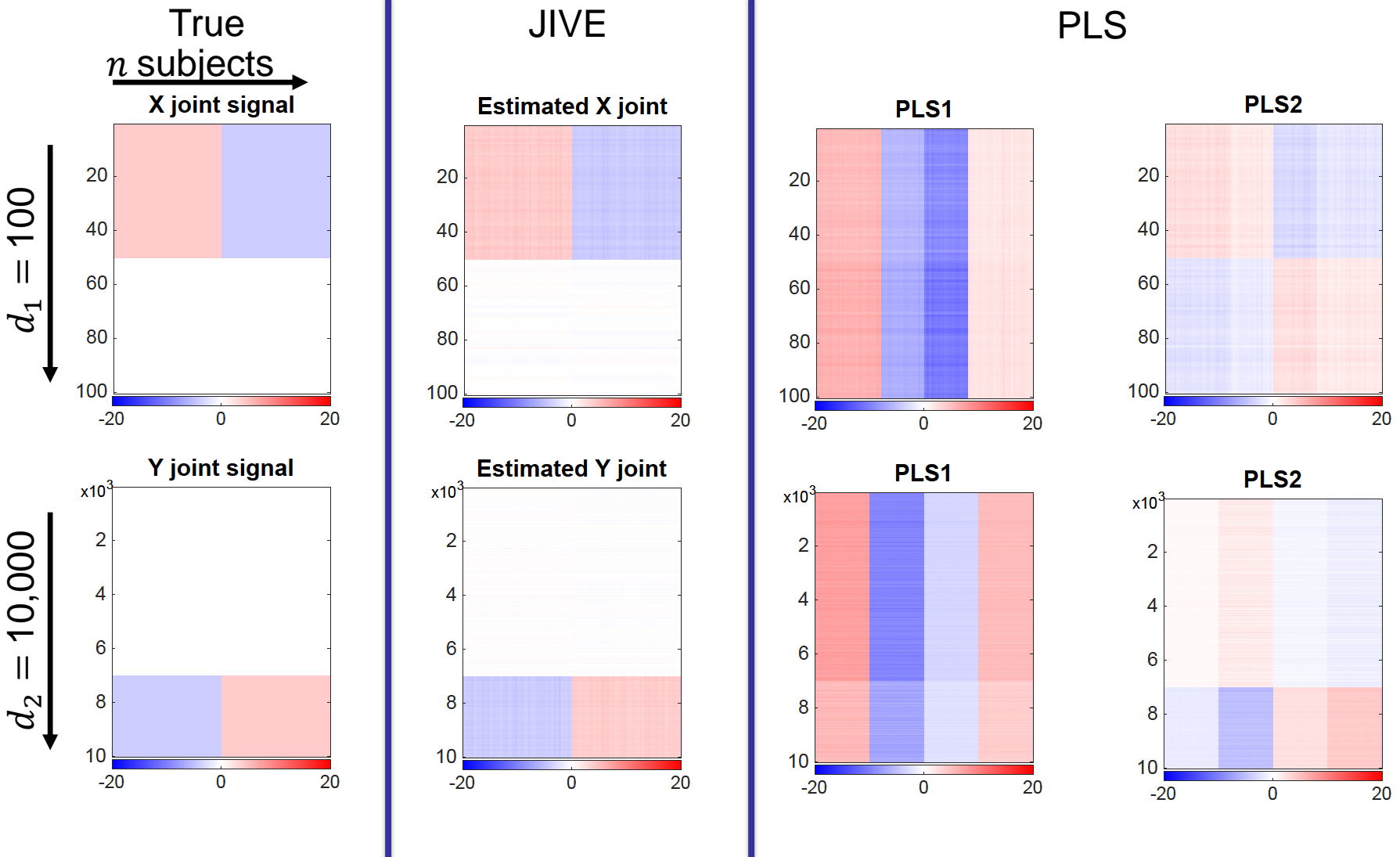
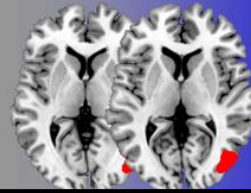
- $X_1 = A_1 + E_1 = J_1 + I_1 + E_1$
- $X_2 = A_2 + E_2 = J_2 + I_2 + E_2$
- Focus on score subspaces of \mathbb{R}^n :
 1. $\text{row}(J_k) = \text{row}(J) \subset \text{row}(A_k), k = 1, 2$
 2. $\text{row}(J) \perp \text{row}(I_k), k = 1, 2$
 3. $I_1 \cap I_2 = 0$
- E_k is isotropic

Toy example

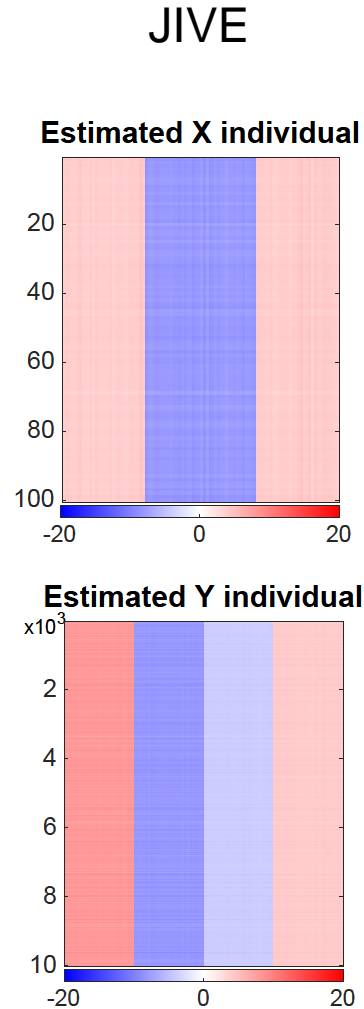
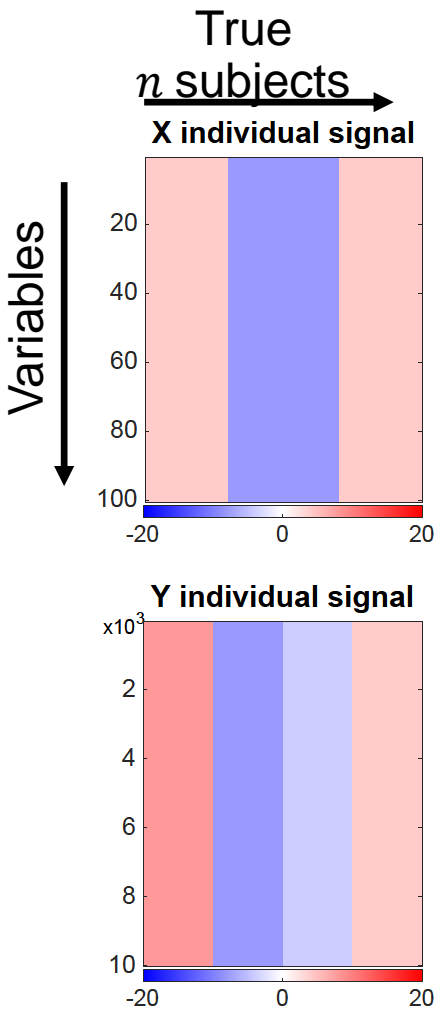
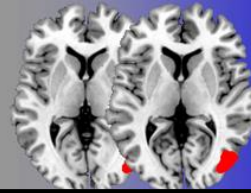


Same rank-1 row space

Toy example, cont.

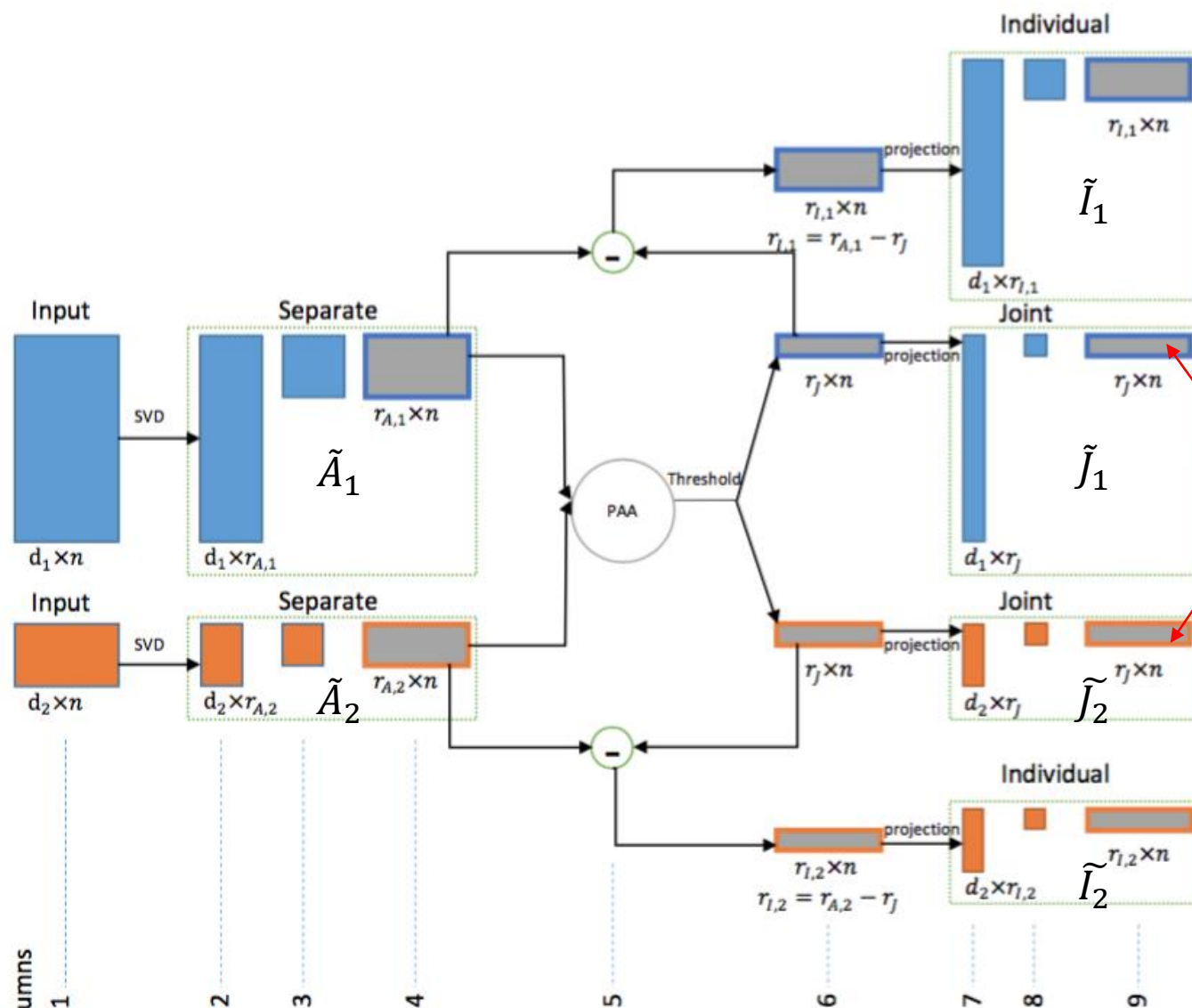
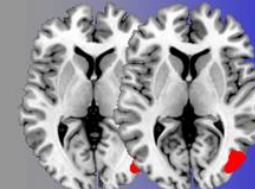


Toy example

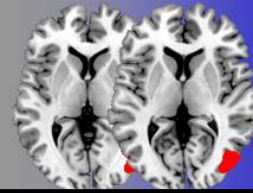


- JIVE accurate
- Not estimated in PLS

JIVE Schematic



Same
subspace

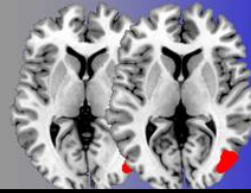


- Principal Angle Analysis developed for JIVE by Feng et al
- Theoretical Version:

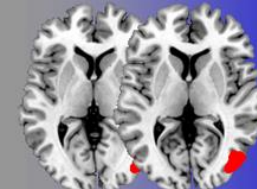
$$\text{In } \mathbb{R}^n, \quad \text{Row}(V_{J_1}) = \text{Row}(V_{J_2})$$

- Empirical Version:

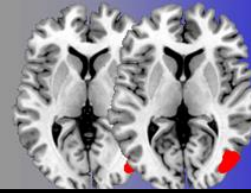
$$\text{In } \mathbb{R}^n, \quad \text{Row}(\hat{V}_{J_1}) \approx \text{Row}(\hat{V}_{J_2})$$



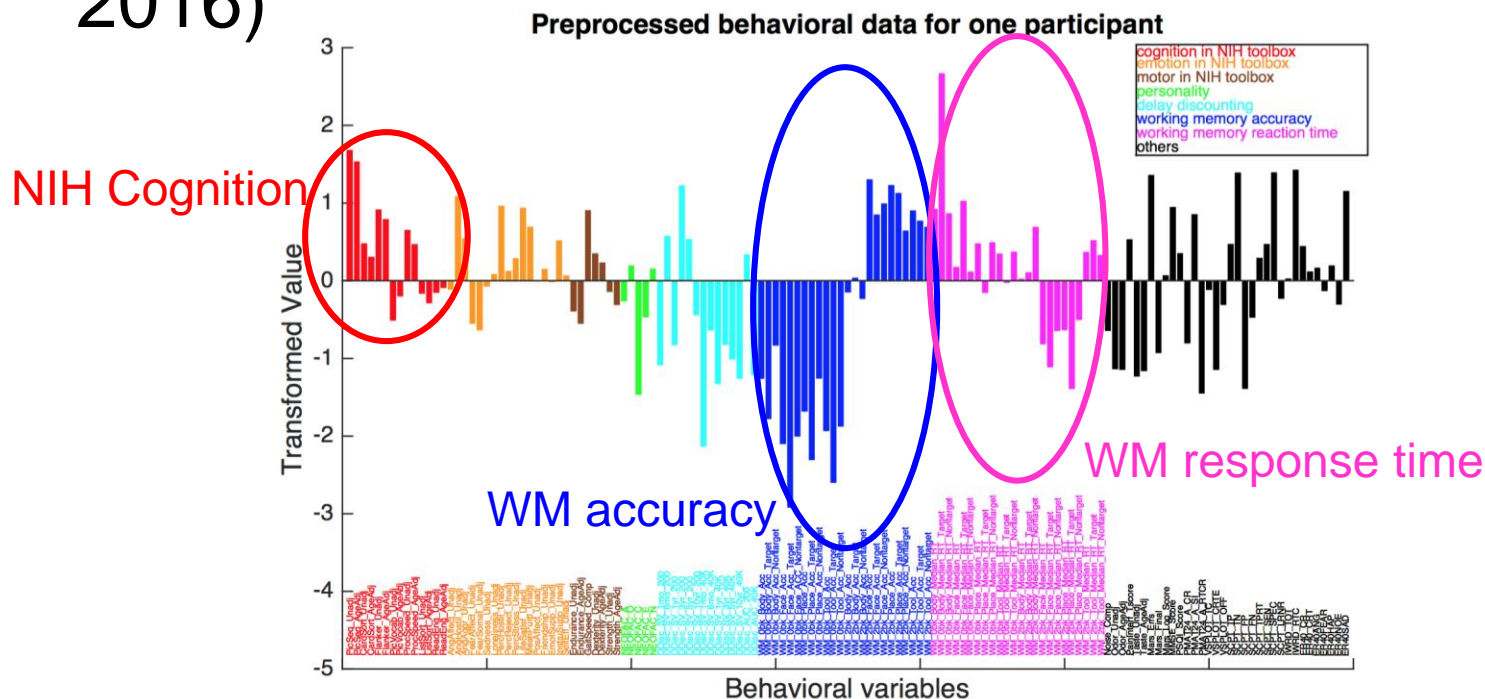
- Stack RSV of SVDs of A_1 and A_2
- Take another SVD, those RSVs are the averages of matched noisy directions
- Largest σ_m correspond to smallest PA:
$$\theta_m = \arccos(\sigma_m^2 - 1)$$
- Threshold with bounds determined from:
 1. Wedin's *sin* thm bounds PA for $J_k + E_k$,
 2. Assumption of isotropy,
 3. Sample noise directions to get thresh for θ_m .

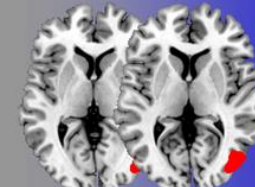


- Analyzed 487 subjects from the Human Connectome Project
- Three analyses differing in imaging:
 1. *Case 1:* Large WM signal in imaging
 2. *Case 2:* Weak WM signal
 3. *Case 3:* No WM signal
- Same behavior dataset in 3 cases
 - Large WM signal in behavior



- Behavior: 139 x 487 subjects
- NIH toolbox, in-task working memory, others
- Normalized with shifted log transform (Feng 2016)

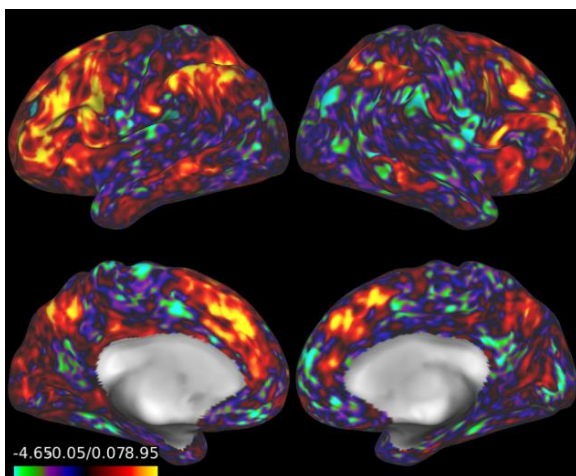




- HCP estimated activation from two runs of same task for variety of tasks
- Z-stat subject images: 91,282 x 487

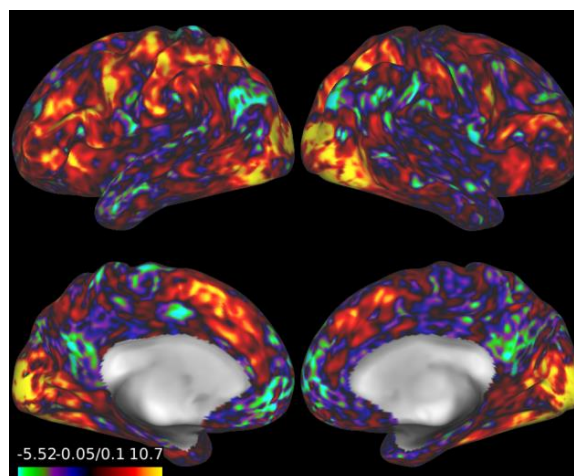
Case 1: strong working
memory signal

*2 bk – 0 bk contrast (faces,
places, tools, body parts)*



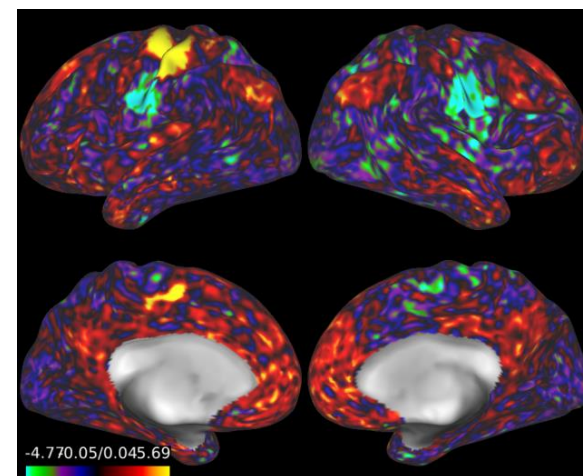
Case 2: weak working
memory signal

2 bk tool main effect

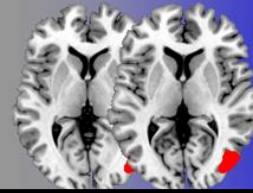


Case 3: no working
memory signal

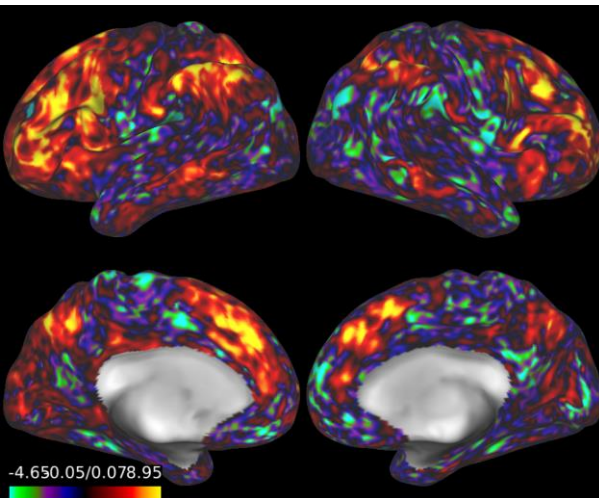
right hand motor task



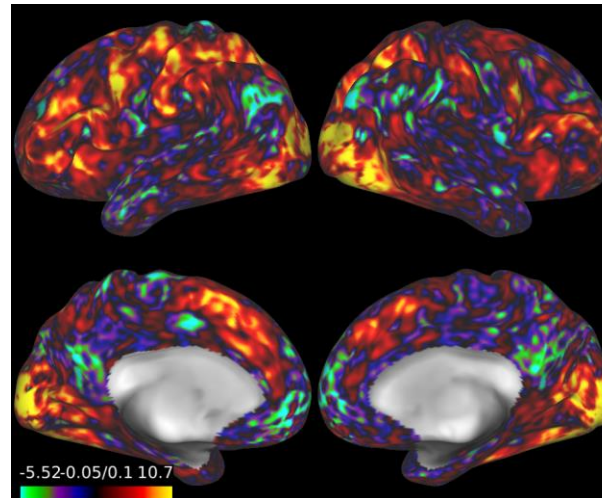
Application: HCP



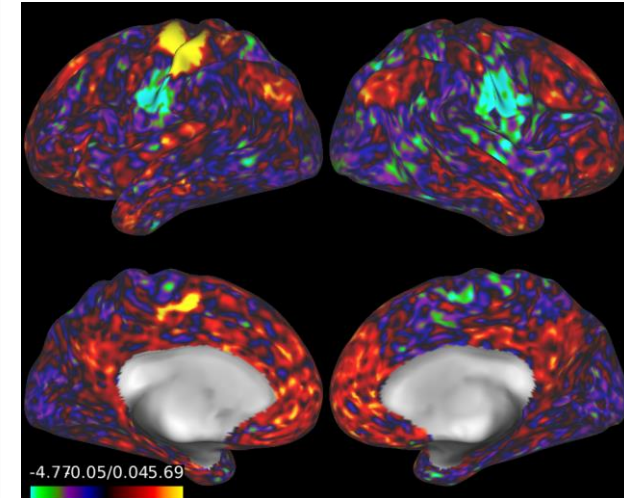
Case 1: strong working
memory signal
2 bk – 0 bk contrast



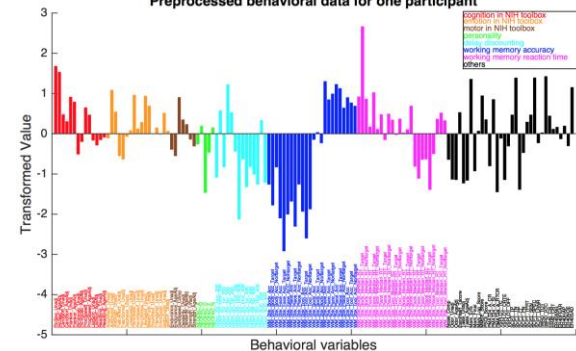
Case 2: weak working
memory signal
2 bk tool main effect



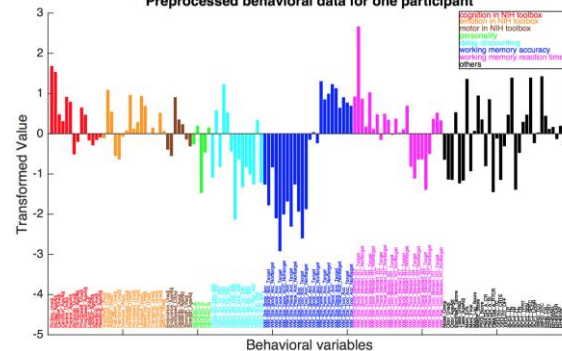
Case 3: no working
memory signal
right hand motor task



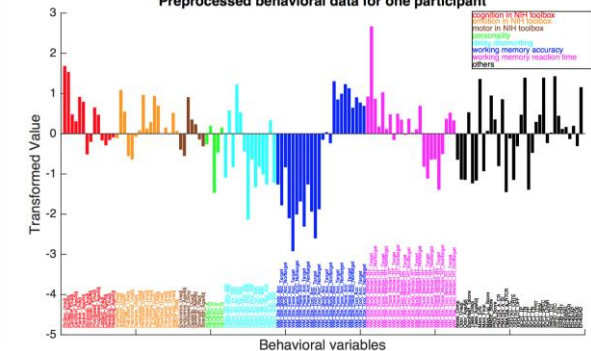
Preprocessed behavioral data for one participant



Preprocessed behavioral data for one participant



Preprocessed behavioral data for one participant



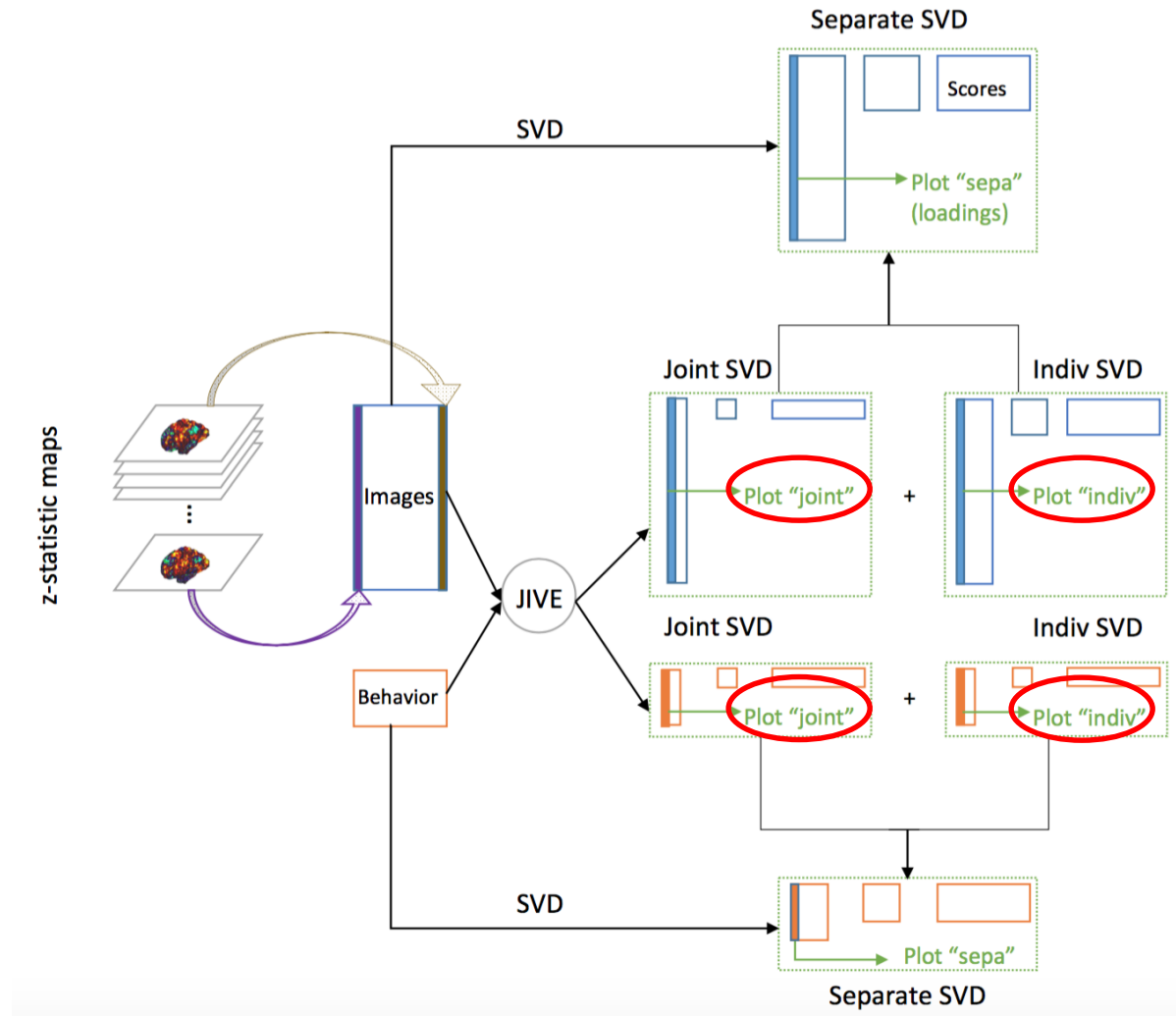
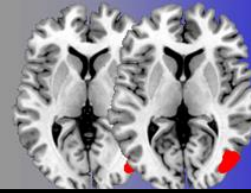
Imaging & behavior

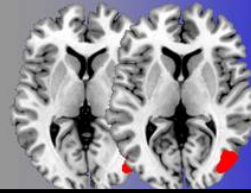


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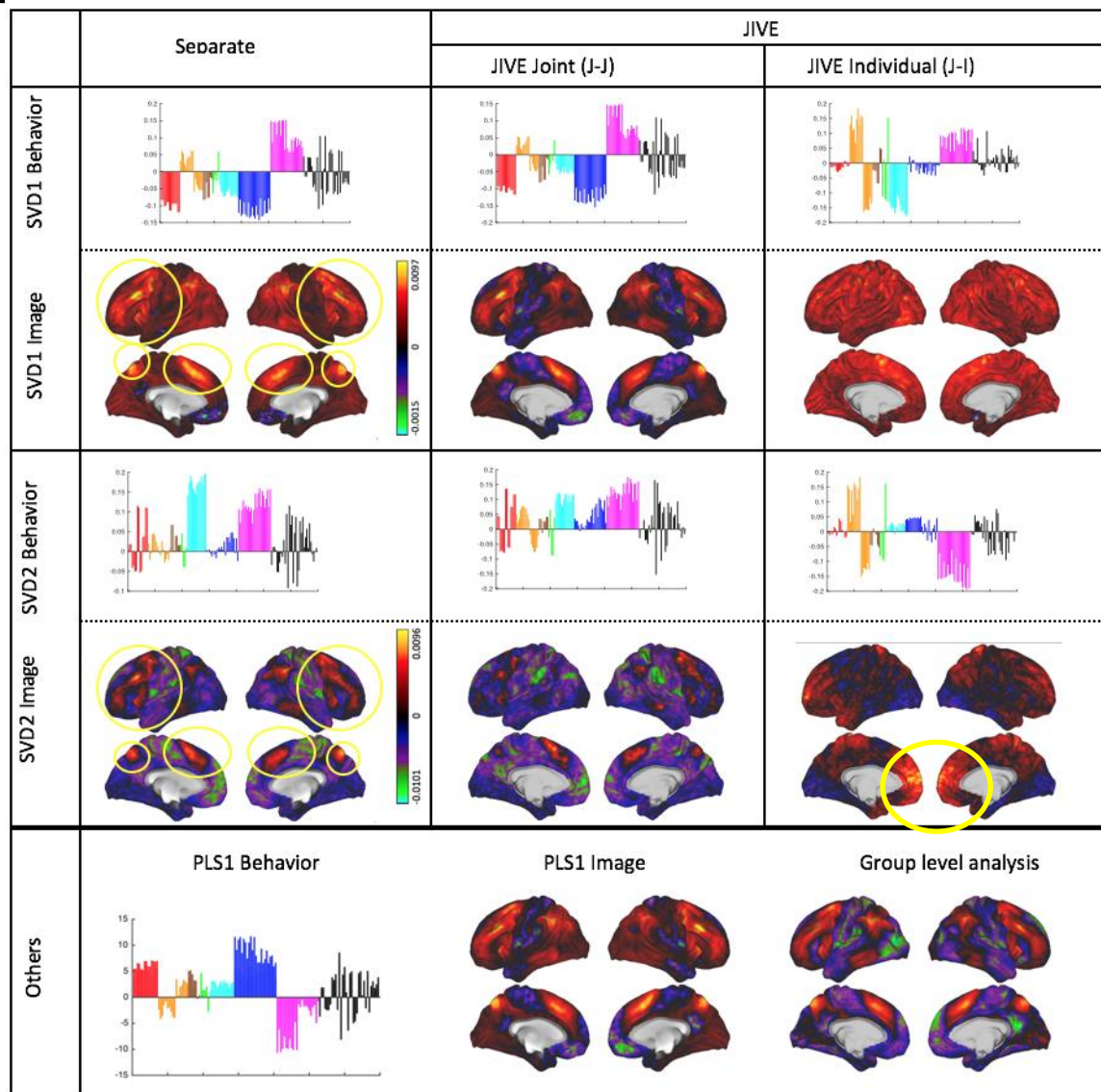
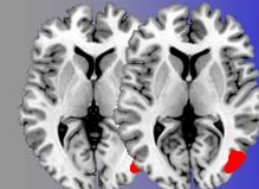
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- PAA: joint rank based on bounds
- Is joint subspace significant?
- We define a permutation test:
 - Permute subject in behavior data
 - Perform JIVE on imaging and permuted behavior to generate new estimate, $\tilde{j}_1^{(t)}$
 - Calculate energy of $\tilde{j}_1^{(t)}$

Case 1: strong WM

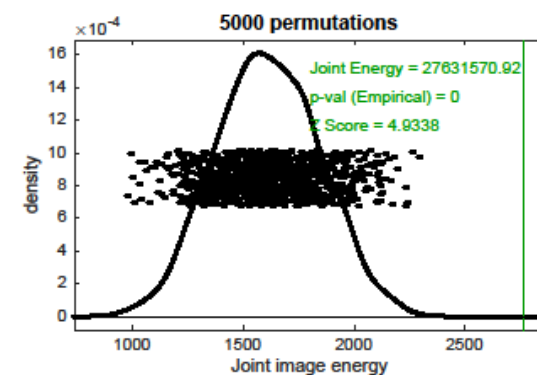


Case 1: strong working
memory signal
2 bk – 0 bk contrast

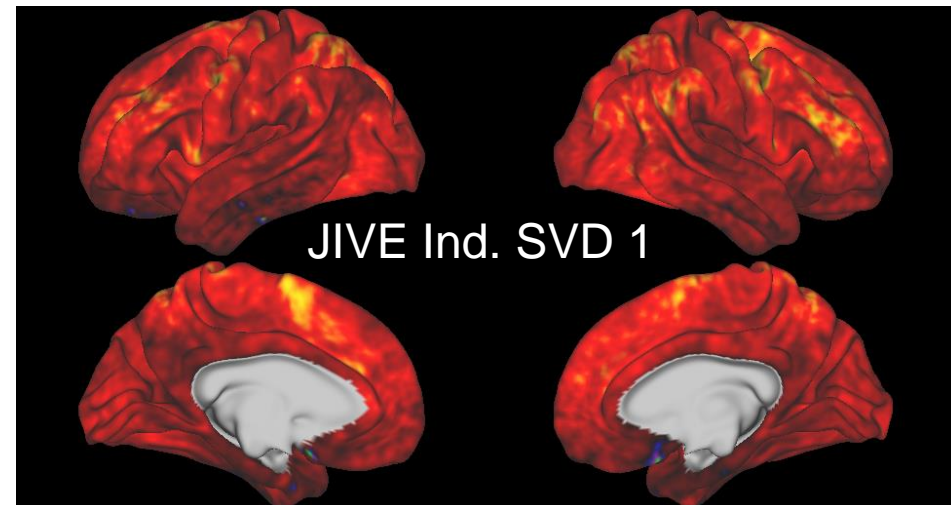
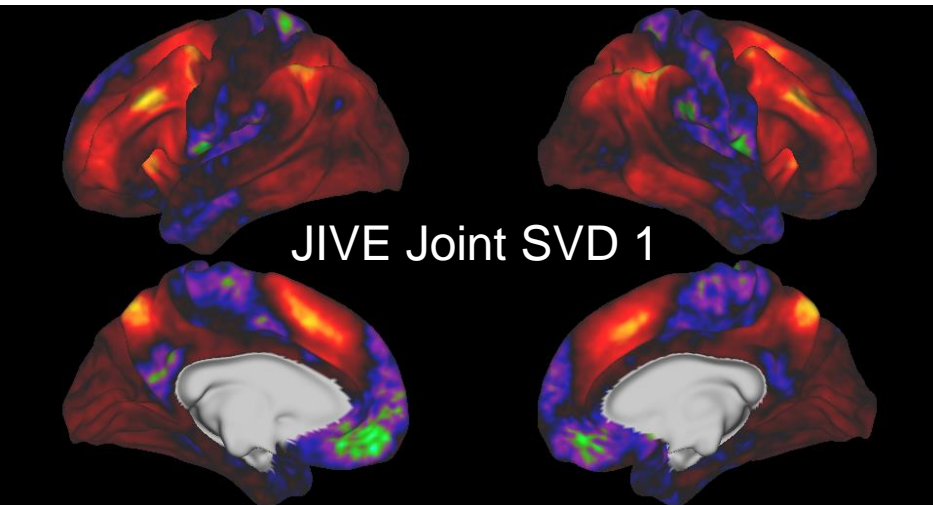
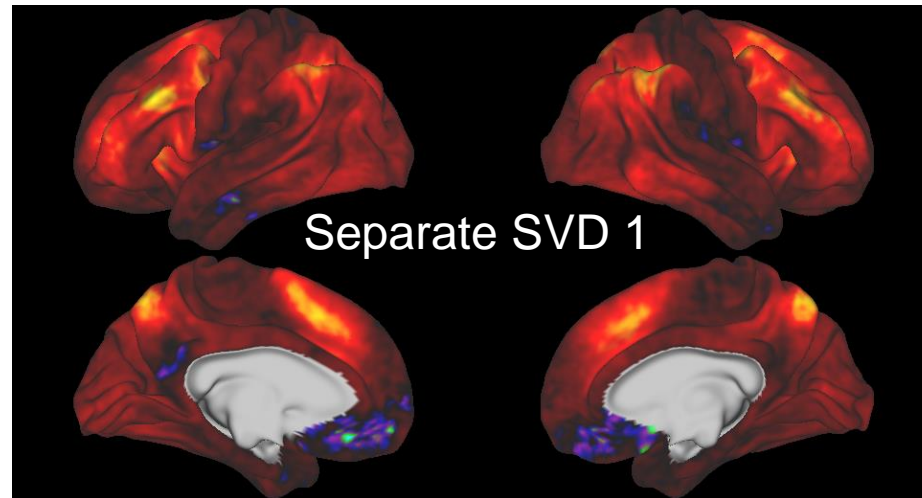
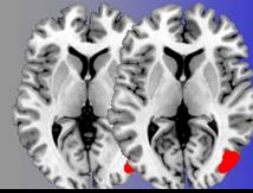
NIH Cognition

WM accuracy

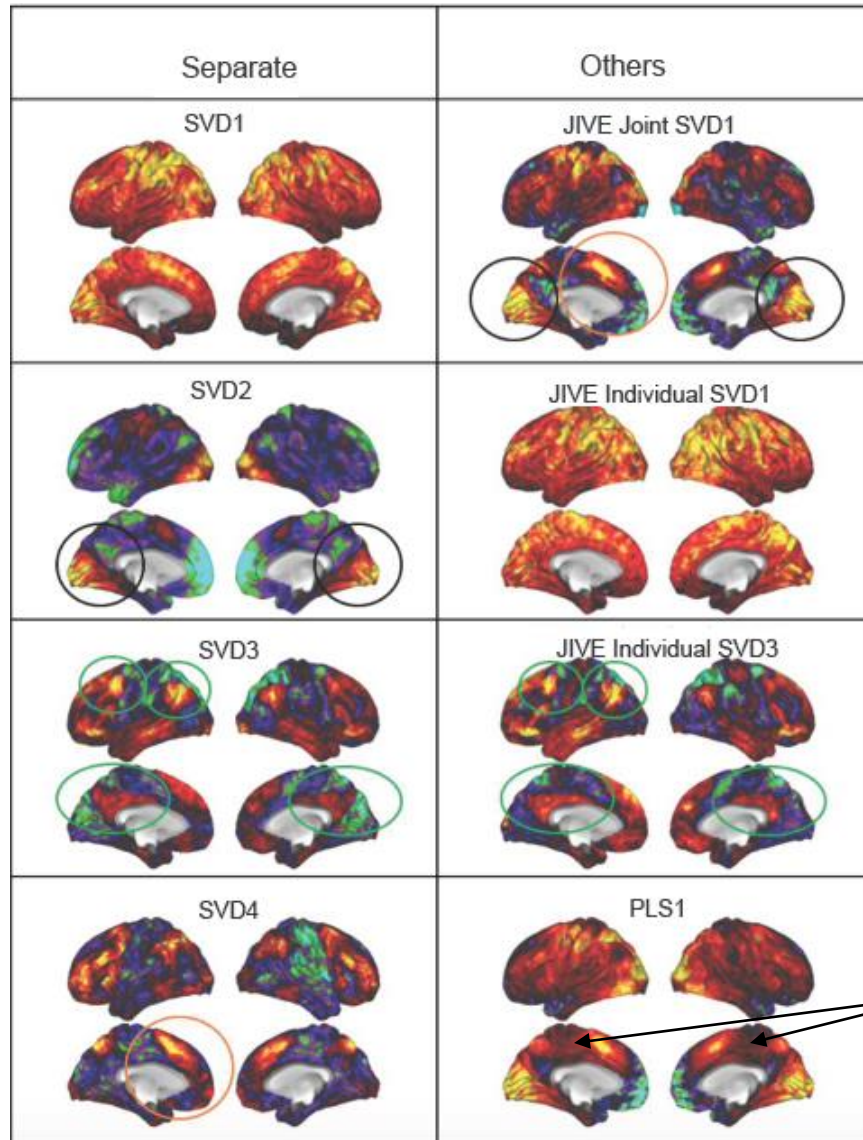
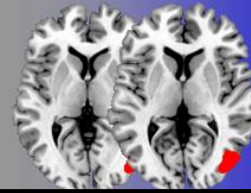
WM response time



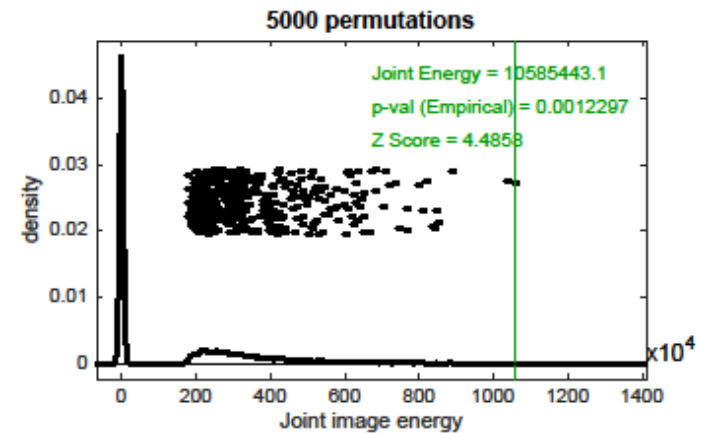
Case 1: Zoomed in



Case 2: weak WM

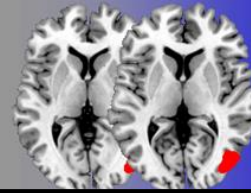


Case 2: weak working
memory signal
2 back tool main effect

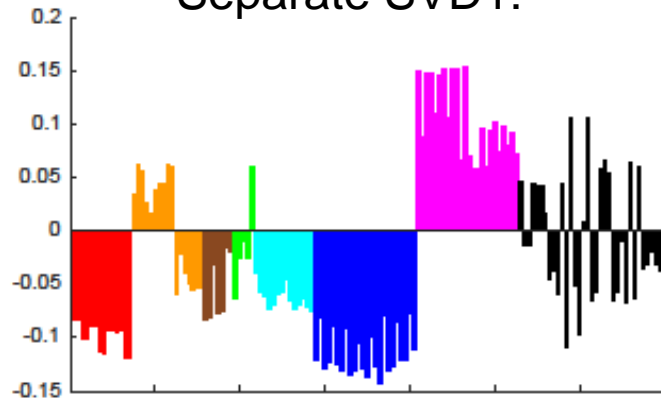


Less contrast

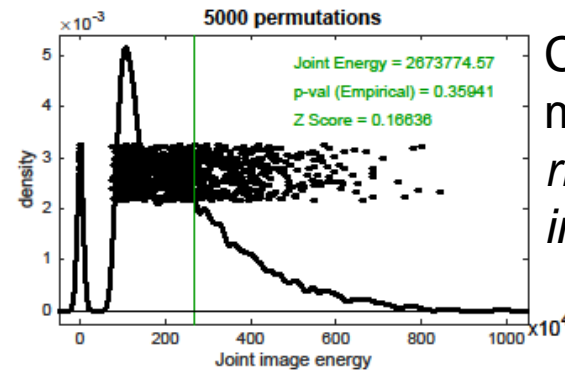
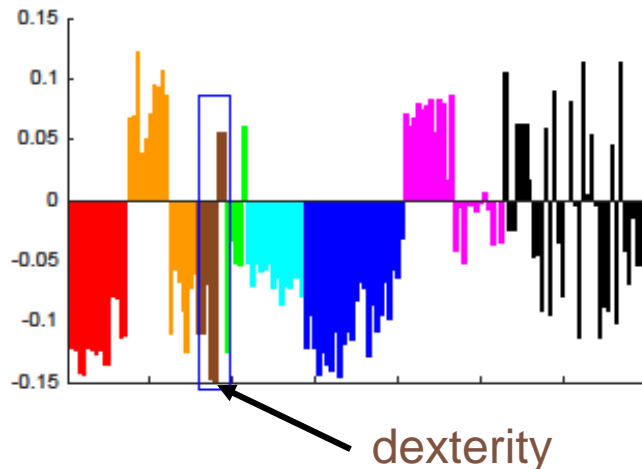
Case 3: Unrelated



Separate SVD1:

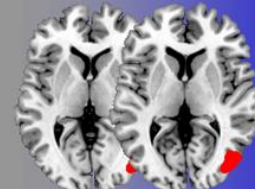


JIVE Joint SVD1:

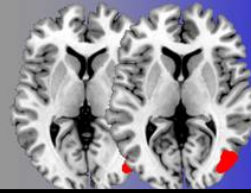


Case 3: no working
memory signal
*right hand – other contrast
in motor task*

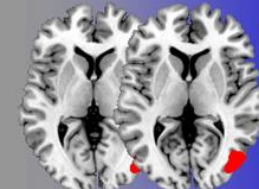
| Motor rh task | Separate | JIVE | |
|---------------|----------|-------|------------|
| | | Joint | Individual |
| SVD1 Image | | | |
| SVD2 Image | | | |
| SVD3 Image | | | |



- Illustrated JIVE using 3 scenarios varying in joint variation
- Cognition and in-task performance reveal working memory activation
- JIVE provides new insights: reveals variation unique to a dataset
- Focus on row subspace – great when $d_1 \gg d_2$



- We focused on joint and individual loadings
- Did not discuss subject scores
- Analyzed population of healthy young adults
- Subject scores interesting in heterogeneous populations:
 - cancer studies: clustering as in PCA
- Future research:
 - As alternative to contrasts, JIVE with 2-bk and 0-bk, look if working memory in *individual*
 - Alternatives to variance: NGCA for multiple blocks



- Tim Johnson, Martin Lindquist, and the Big Data working group at SAMSI.
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- B. Risk partly supported by NSF grant DMS-1127914 to SAMSI.
- HCP WU-Minn Consortium (Principal Investigators: David Van Essen and Kamil Ugurbil; 1U54MH091657).