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# Nonlinear kernel-based fMRI activation detection

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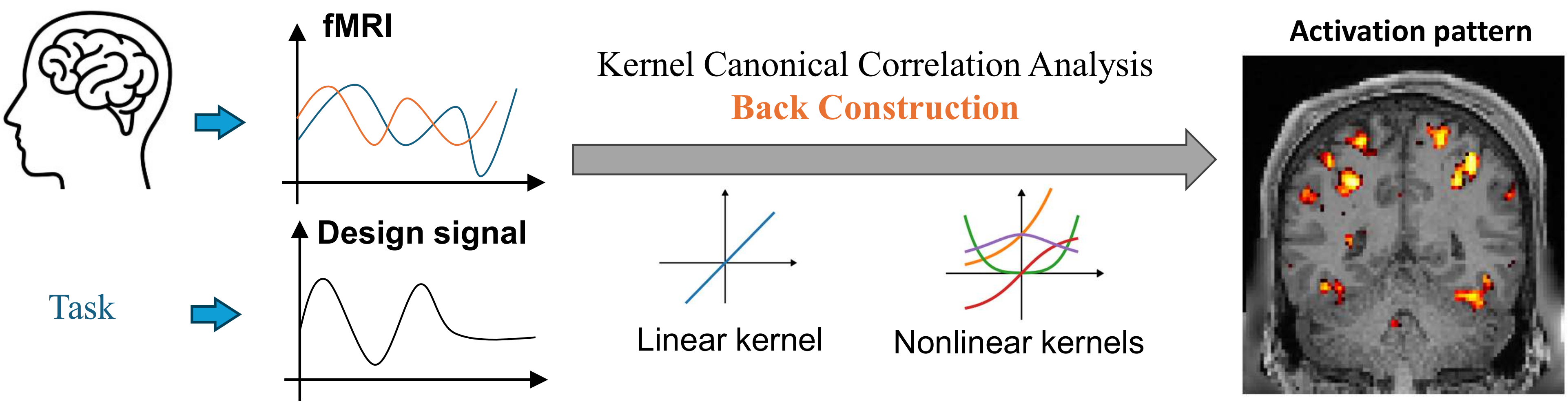

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# Statement

- We declare that there is no conflict of interest.
- The data used in this paper comes from Human Connectome Project projects (HCP) [1]. All the data are publicly accessible, and patients' information is protected.
- This work was funded by NIH-R01AG071566-02 and NIH-P20GM109025-08

1. Barch, D., et al. Neuroimage, 80, 169-189. (2013)

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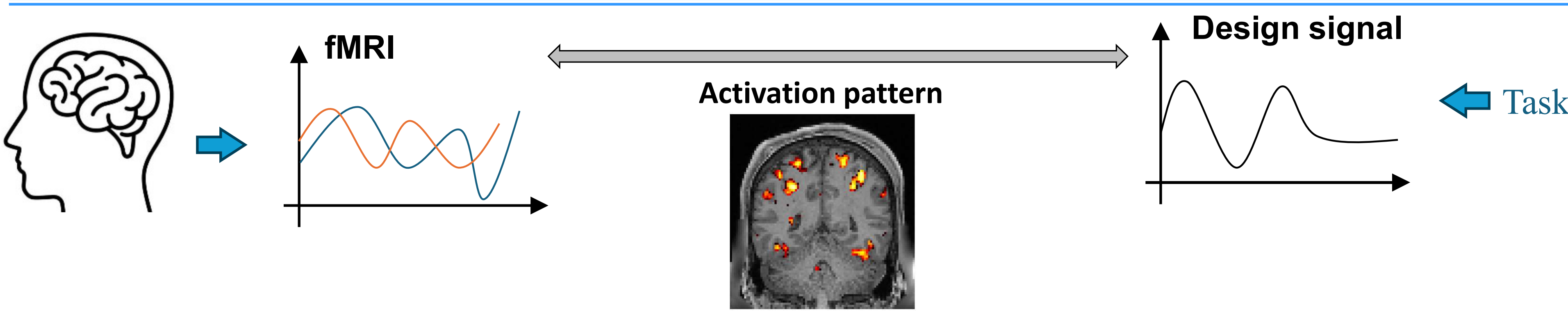
# Background




| | Multi variable | Global method | Nonlinear relationship |
|---|---|---|---|
| Single voxel smoothing [2] | No | No | No |
| Canonical Correlation Analysis (CCA) [3] | Yes | No | Nonlinear constraints [4] |
| Linear Kernel Canonical Correlation Analysis (KCCA) [5] | Yes | Yes | No |
| **Nonlinear KCCA** | **Yes** | **Yes** | **Nonlinear kernels** |

2. Friman, O., et al. NeuroImage, 19(3), 837-845. (2003)
3. Friman, O., et al. Magnetic Resonance in Medicine: An Official Journal of the International Society for Magnetic Resoance in Medicine, 45(2) 323-330. (2001)
4. Xiaowei, Z., et al. NeuroImage, 149, 63-84. (2017)
5. Hardoon, D., et al. Neural computation, 16(12), 2639-2664. (2004)

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# Step 1: Back construction Algorithm

$$\mathbf{Y} \in \Re^{T\times Q} \longrightarrow \tilde{\mathbf{Y}} = \mathbf{Y}\mathbf{A} \longrightarrow K_{\mathbf{Y}} \longrightarrow K_{\mathbf{Y}}\mathbf{v}_{\mathbf{Y}}$$

**fMRI data**

$$\max_{\mathbf{v}_{\mathbf{Y}},\mathbf{v}_{\mathbf{X}}} \frac{\mathbf{v}_{\mathbf{Y}}^T K_{\mathbf{Y}} K_{\mathbf{X}} \mathbf{v}_{\mathbf{X}}}{\sqrt{\mathbf{v}_{\mathbf{Y}}^T (K_{\mathbf{Y}}^2 + \gamma K_{\mathbf{Y}})\mathbf{v}_{\mathbf{Y}}}\sqrt{\mathbf{v}_{\mathbf{X}}^T (K_{\mathbf{X}}^2 + \gamma K_{\mathbf{X}})\mathbf{v}_{\mathbf{X}}}}$$

$$s = \operatorname{sign}\left[\operatorname{corr}(\mathbf{X}_{\text{eff}}, K_{\mathbf{Y}}\mathbf{v}_{\mathbf{Y}})\right]$$

$$\mathbf{X} \in \Re^{T\times D} \longrightarrow \mathbf{X}_{\text{eff}} \longrightarrow K_{\mathbf{X}} = \mathbf{X}_{\text{eff}}\mathbf{X}_{\text{eff}}^T$$

**Design signal** [6]

Voxel specific activation

$$\boldsymbol{\alpha} \in \Re^{Q\times 1}$$

**A**: spatial filter
Q: number of voxels
T: number of time points
D: number of design signals

- Assumption

$$\boxed{\mathbf{Y}\boldsymbol{\alpha} \equiv K_{\mathbf{Y}}\mathbf{v}_{\mathbf{Y}}}$$

*Back construction 1:* $\boldsymbol{\alpha} = s\sum_t \frac{\partial\left(K_{\mathbf{Y}}\mathbf{v}_{\mathbf{Y}}\right)_t}{\partial \mathbf{Y}_t}$

*Back construction 2:* $\boldsymbol{\alpha} = s\mathbf{A}\tilde{\mathbf{Y}}^T\left(\tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T\right)^{\dagger} K_{\mathbf{Y}}\mathbf{v}_{\mathbf{Y}}$

6. Cordes, D., et al. **33**: p. 2611-2626. (2012)

# Step 2: Nonlinear kernels

| Name | Expression | Number of hyperparameters |
|---|---|---|
| Linear | $K_{\mathbf{Y}} = \tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T$ | 1 |
| Parabolic | $K_{\mathbf{Y}} = (\tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T + b^2)^2$ | 2 |
| Gaussian | $K_{\mathbf{Y}} = \exp\left(-\Vert\tilde{\mathbf{Y}} - \tilde{\mathbf{Y}}^T\Vert/\sigma^2\right)$ | 2 |
| Inverse square | $K_{\mathbf{Y}} = 1/\sqrt{\Vert\tilde{\mathbf{Y}} - \tilde{\mathbf{Y}}^T\Vert + b^2}$ | 2 |
| Bounded Linear | $K_{\mathbf{Y}} = \min\left(C, \tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T\right)$ | 2 |
| Square | $K_{\mathbf{Y}} = \Vert\tilde{\mathbf{Y}} - \tilde{\mathbf{Y}}^T\Vert$ | 1 |
| Tanh | $K_{\mathbf{Y}} = \tanh\left(b\tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T + c\right)$ | 3 |
| Mixed Tanh | $K_{\mathbf{Y}} = \tanh\left(b_1\tilde{\mathbf{Y}}\tilde{\mathbf{Y}}^T + b_2\Vert\tilde{\mathbf{Y}} - \tilde{\mathbf{Y}}^T\Vert + c\right)$ | 4 |

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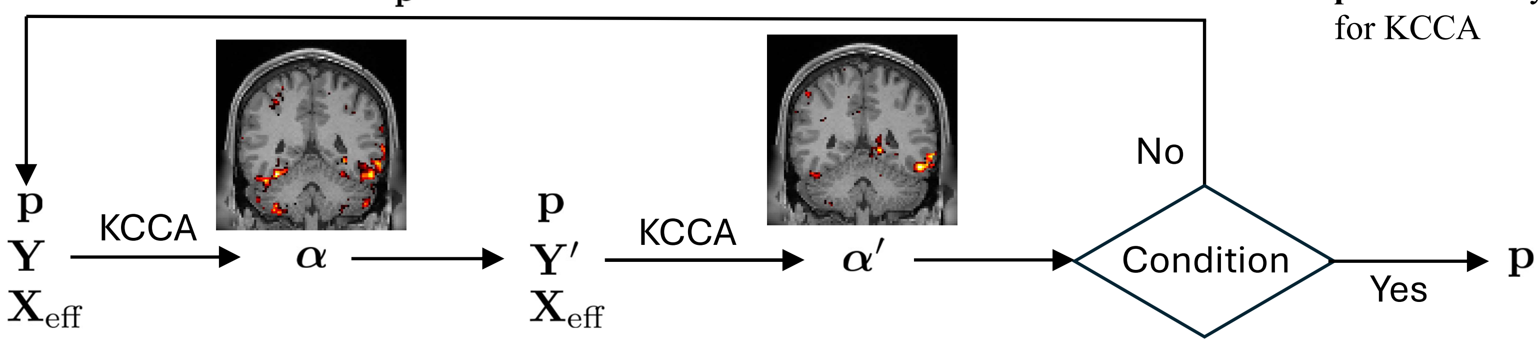
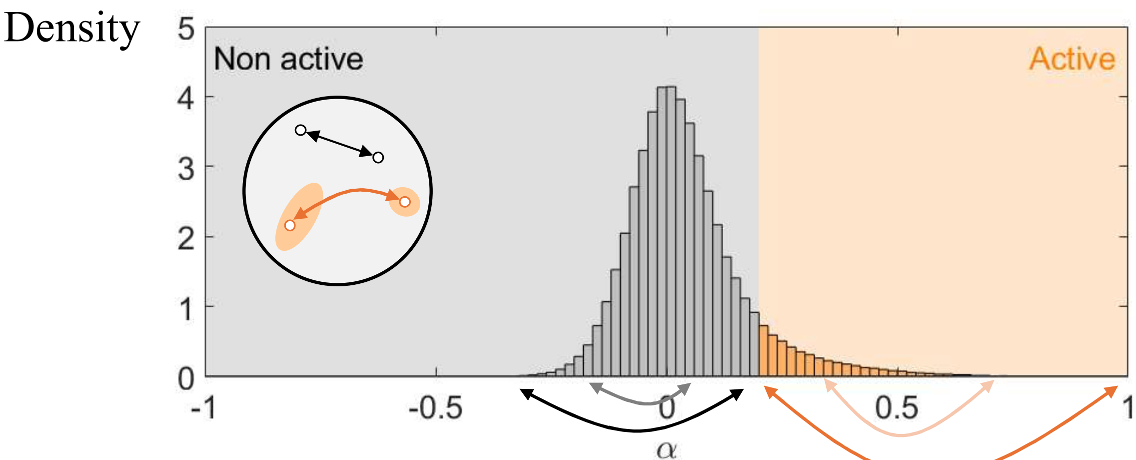
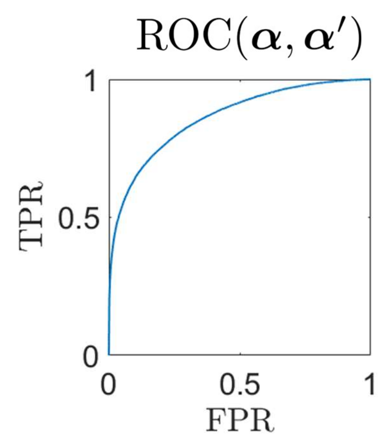
# Step 3: Hyperparameters optimization

$$\max_{\mathbf{p}} \mathrm{AUC}_{\mathrm{FPR}<0.1}(\boldsymbol{\alpha}, \boldsymbol{\alpha}')$$

**p**: unknown hyperparameters for KCCA




**True positive**: Both $\alpha$ and $\alpha'$ are activated.
**False positive**: Only $\alpha'$ is activated.

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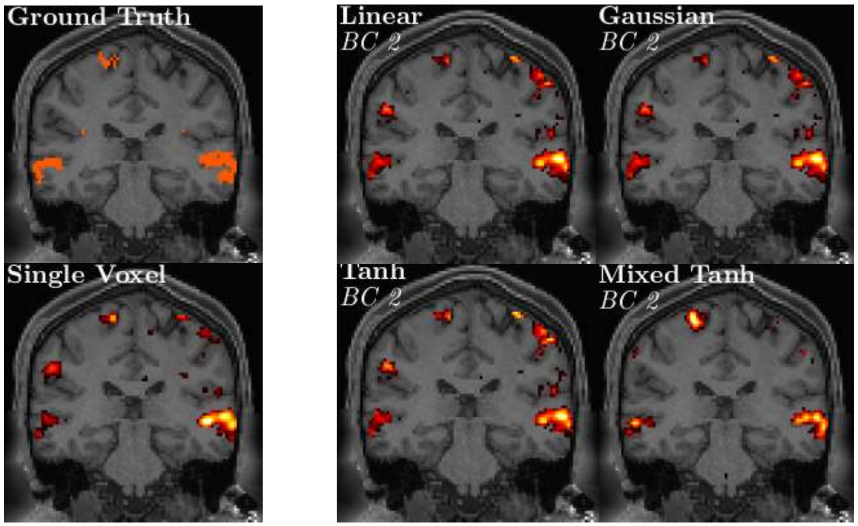
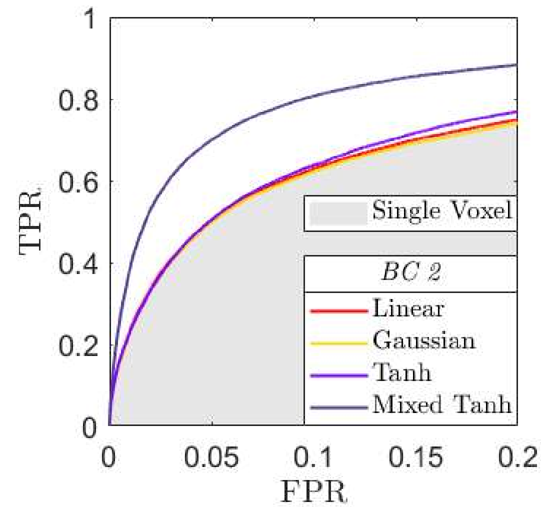
# Simulated fMRI [7]




- Group level study for *BC2*

$$r = \frac{\mathrm{AUC}_{\mathrm{FPR}<0.1}(\mathrm{KCCA})}{\mathrm{AUC}_{\mathrm{FPR}<0.1}(\text{Single Voxel Smoothing})}$$

Mean and standard deviation for 87 subjects

| | | | |
|---|---|---|---|
| Linear | $1.12 \pm 0.27$ | Bounded Linear | $1.39 \pm 0.37$ |
| Parabolic | $1.09 \pm 0.31$ | Square | $0.99 \pm 0.40$ |
| Gaussian | $1.21 \pm 0.27$ | Tanh | $1.39 \pm 0.37$ |
| Inverse | $1.14 \pm 0.30$ | Mixed Tanh | $\mathbf{1.42 \pm 0.36}$ |

[7] Yang, Z., et al. Medical Image Analysis, **60**, 101622. (2020)

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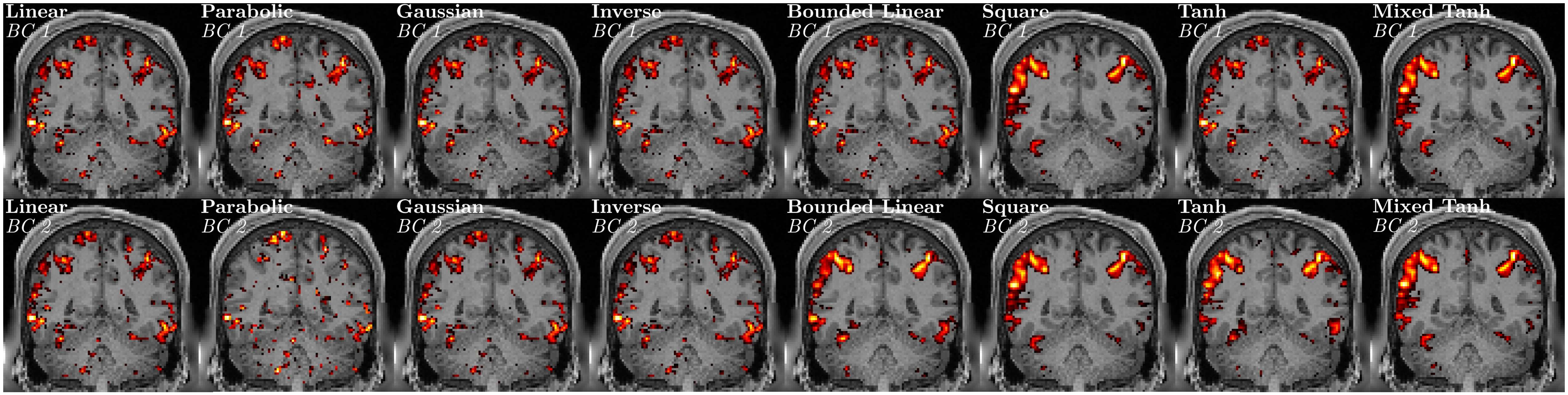
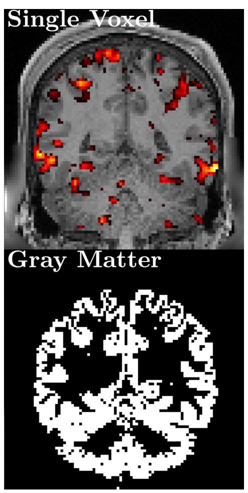
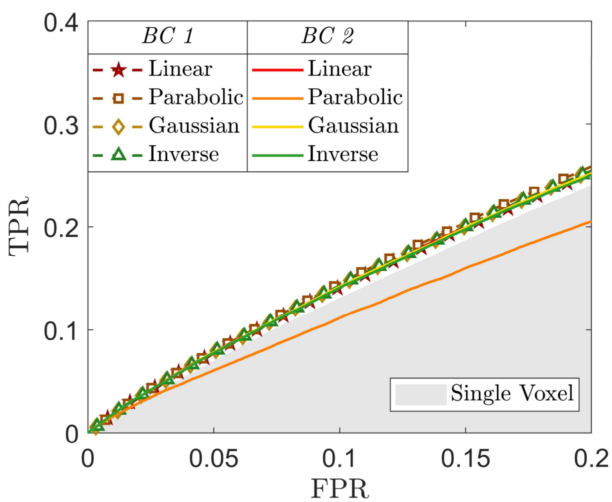
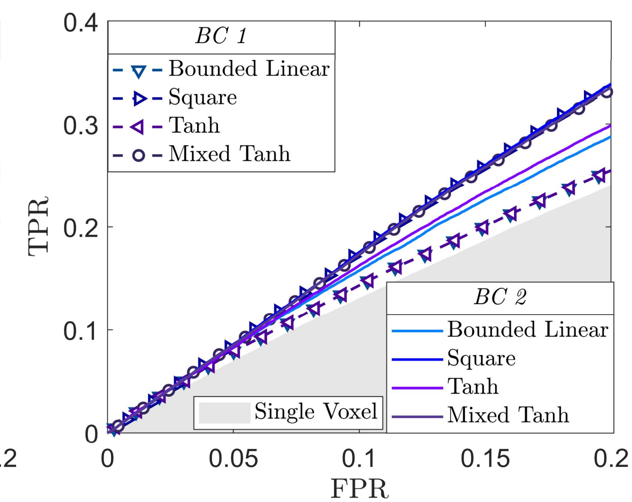
# Result from one selected subject



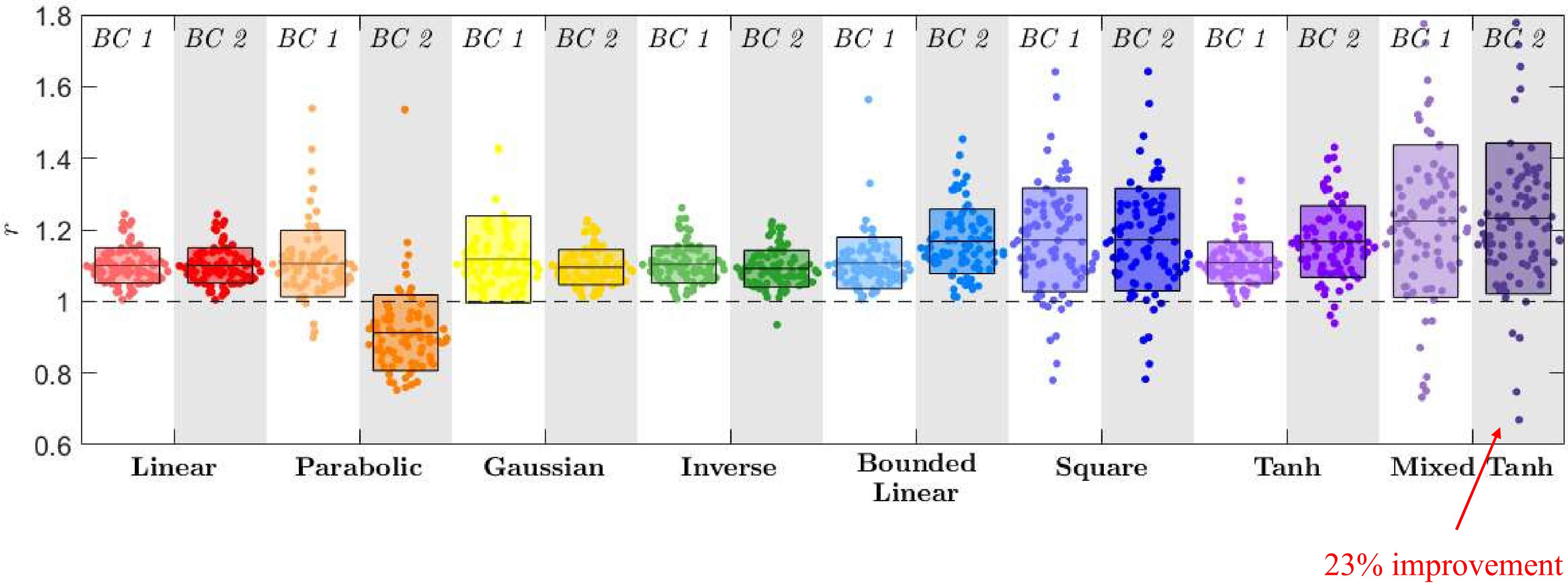




**True positive**: Activation appears on the Gray matter.
**False positive**: Activation not on the Gray matter.

## Group level gray matter overlapping comparison

$$r = \frac{\mathrm{AUC}_{\mathrm{FPR}<0.1}(\mathrm{KCCA})}{\mathrm{AUC}_{\mathrm{FPR}<0.1}(\text{Single Voxel Smoothing})}$$

Mean and standard deviation for 87 subjects



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# Summary

## Previously results

- Linear kernel based KCCA for fMRI activation detection.

## Our results

- New proposed back construction algorithm work for general type of nonlinear kernels.
- Mixed Tanh under BC2 gives the best performance.

**Thanks for your attention !**