Localized Cluster Enhancement: TFCE revisited with valid error control

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Overview

1. TFCE recap

2. What error rate (if any) does TFCE control?

3. Discuss why TFCE very strongly depends a threshold h_0

4. Introduce a Localized TFCE: to provide precise inference and valid error control

TFCE recap

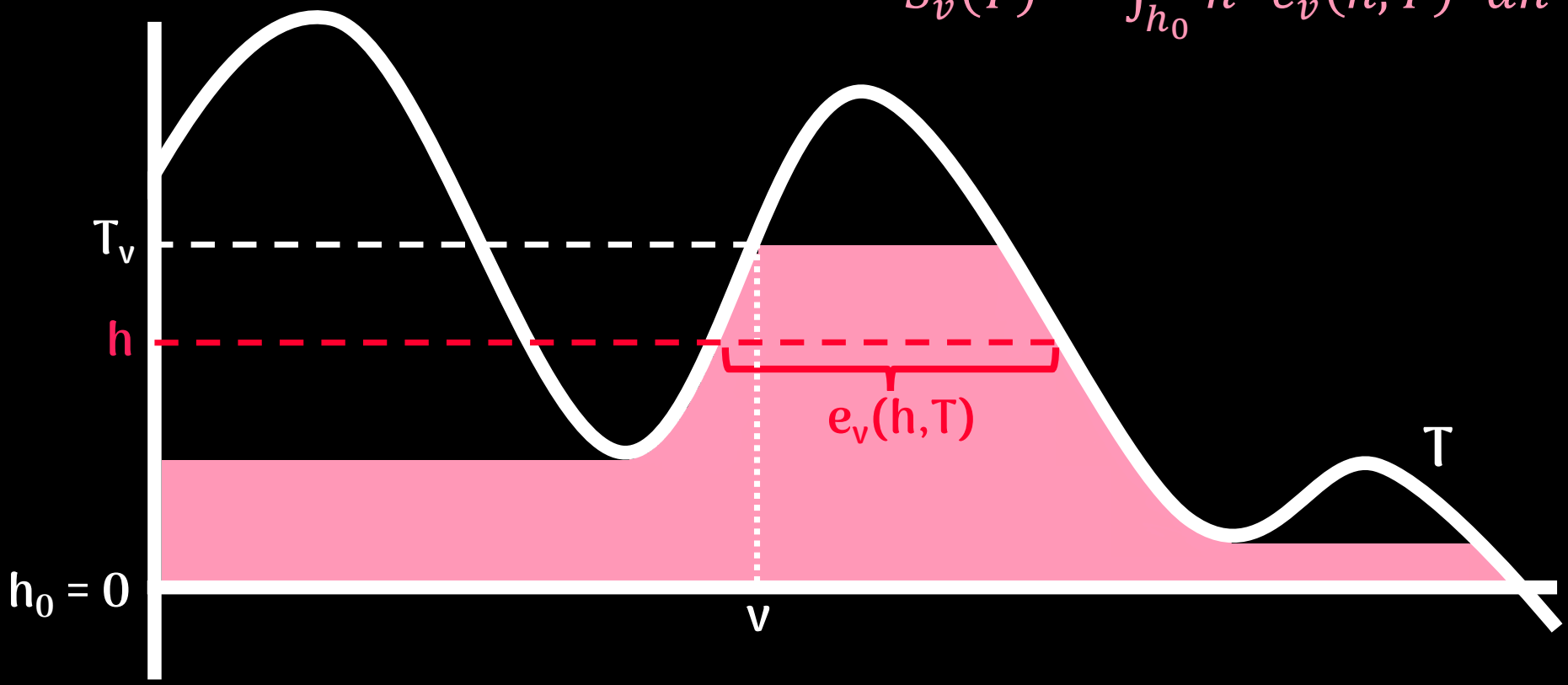
Suppose that we have a test-statistic $T : \mathcal{V} \to \mathbb{R}$ at each voxel in the brain. The the TFCE transformation is defined as:

$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h, T)^E \mathrm{d}h.$$

- Here h is the height and $e_v(h, T)$ is the extent of the test statistic at the level h for the voxel v.
- In practice - $H = 2$, $E = 0$ and $h_0 = 0$ are the default parameters typically chosen.
- S_v thresholded at a level based on permutation thresholding.
- Permuted TFCE test-statistics: $S^*_{v,1}, \ldots, S^*_{v,P}$ are calculated.
- level t^* chosen based on the α quantile of the permutation distribution of $\max_{1 \leq p \leq P} S^*_{v,p}$.

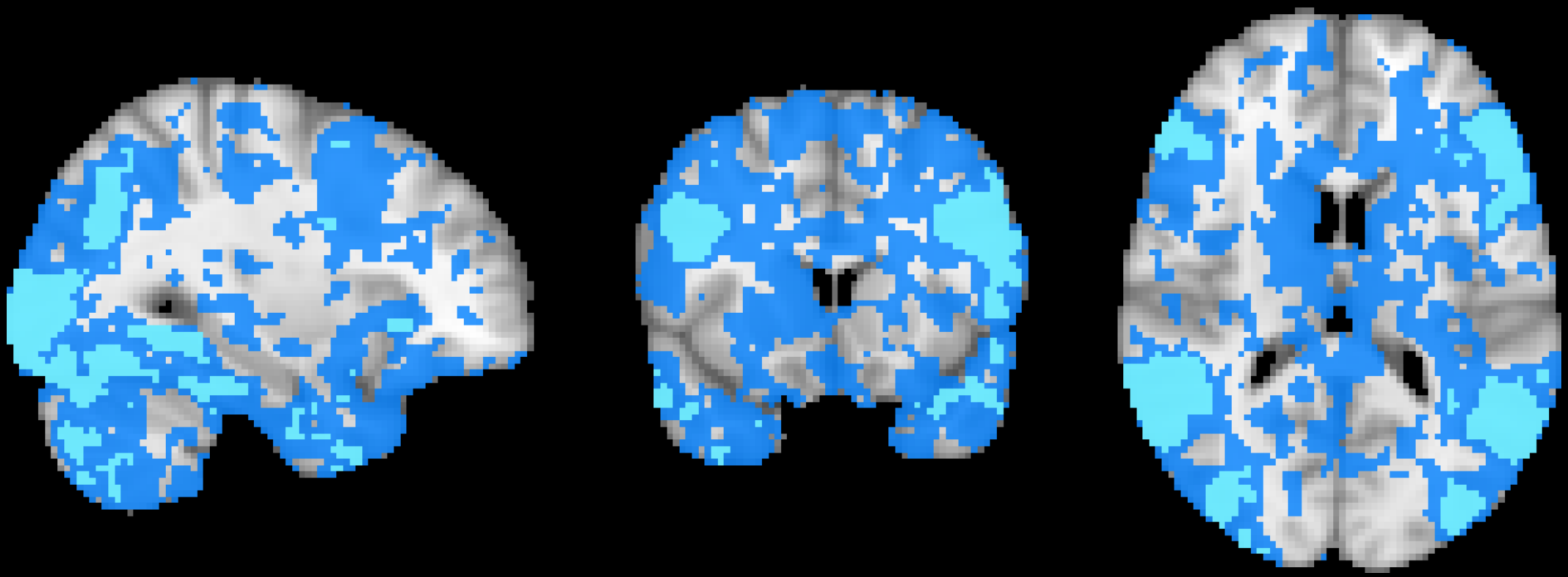
Understanding the TFCE integral

$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h,T)^E \, dh$$

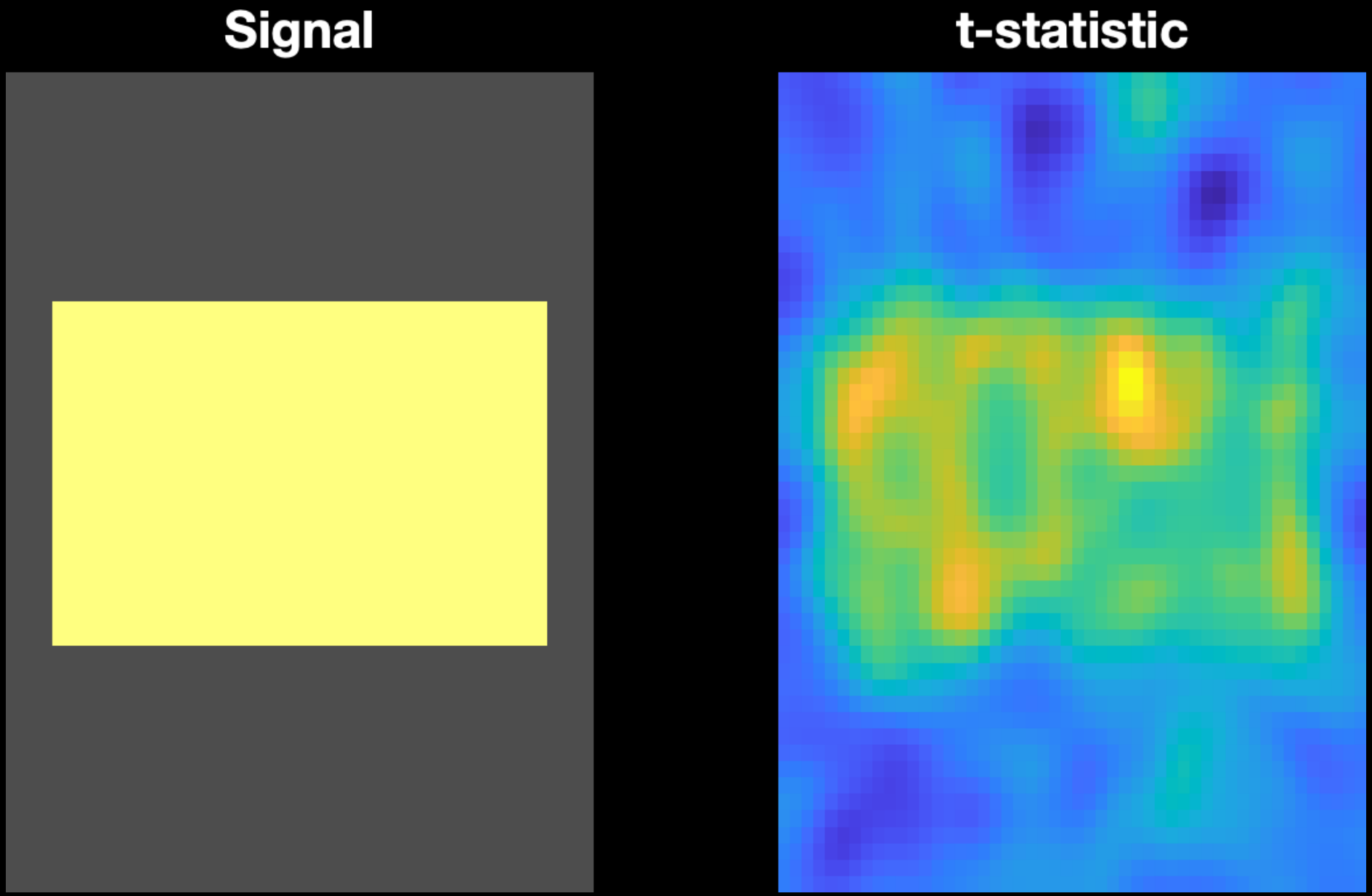


TFCE illustration

We apply TFCE to 20 subjects from the HCP to the primary social contrast.



Simulation example (based on $n = 50$)



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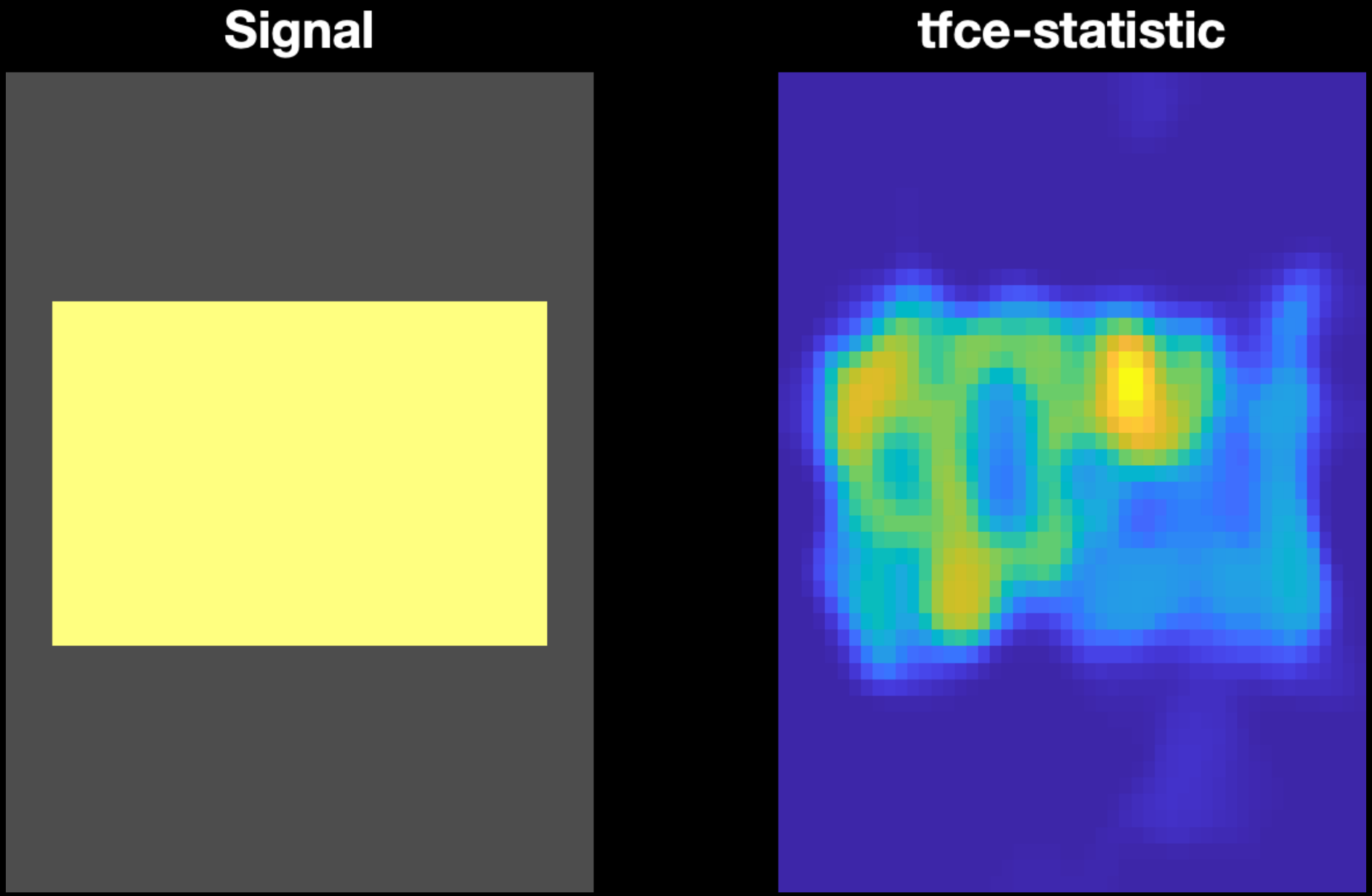

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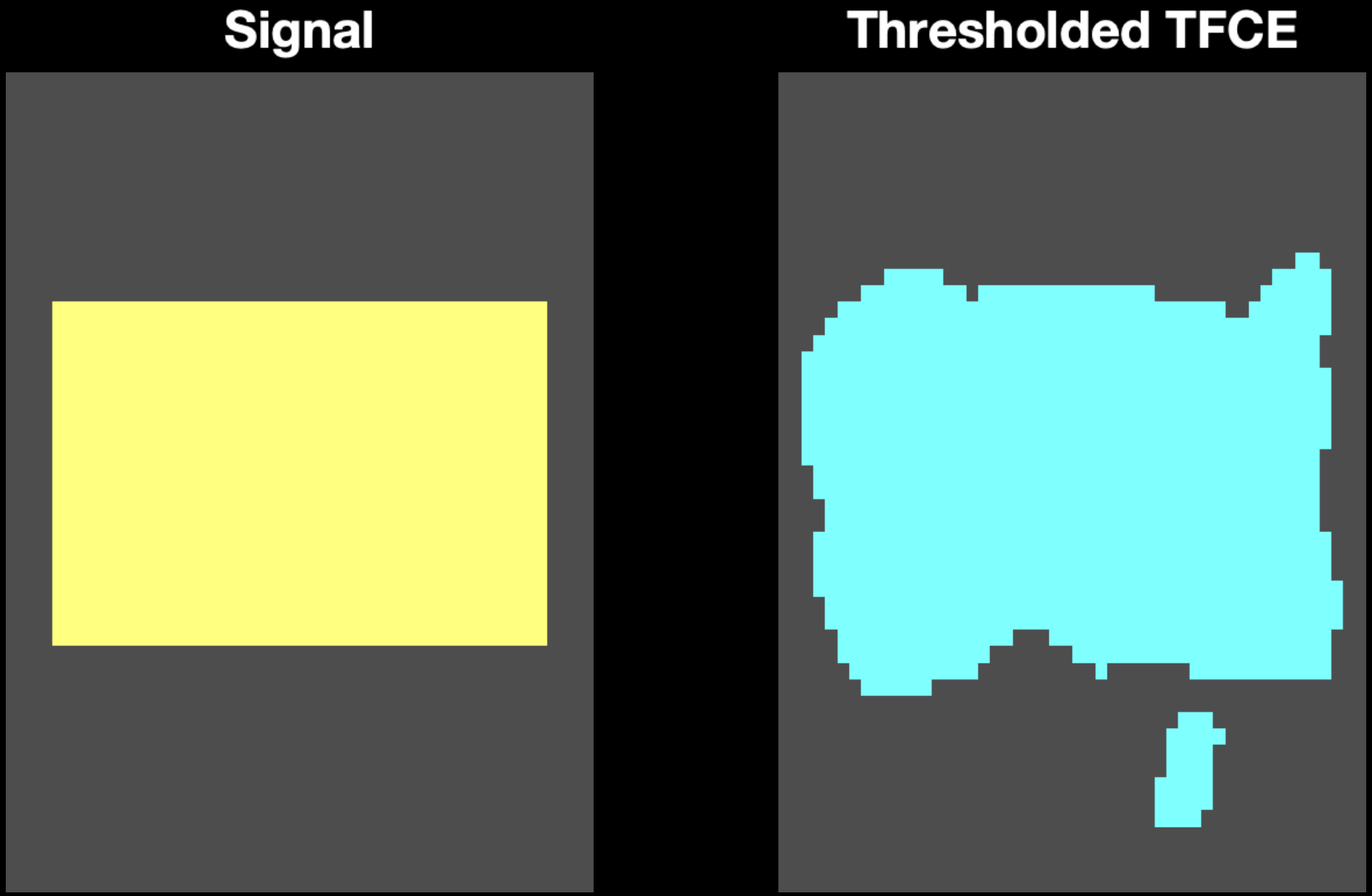

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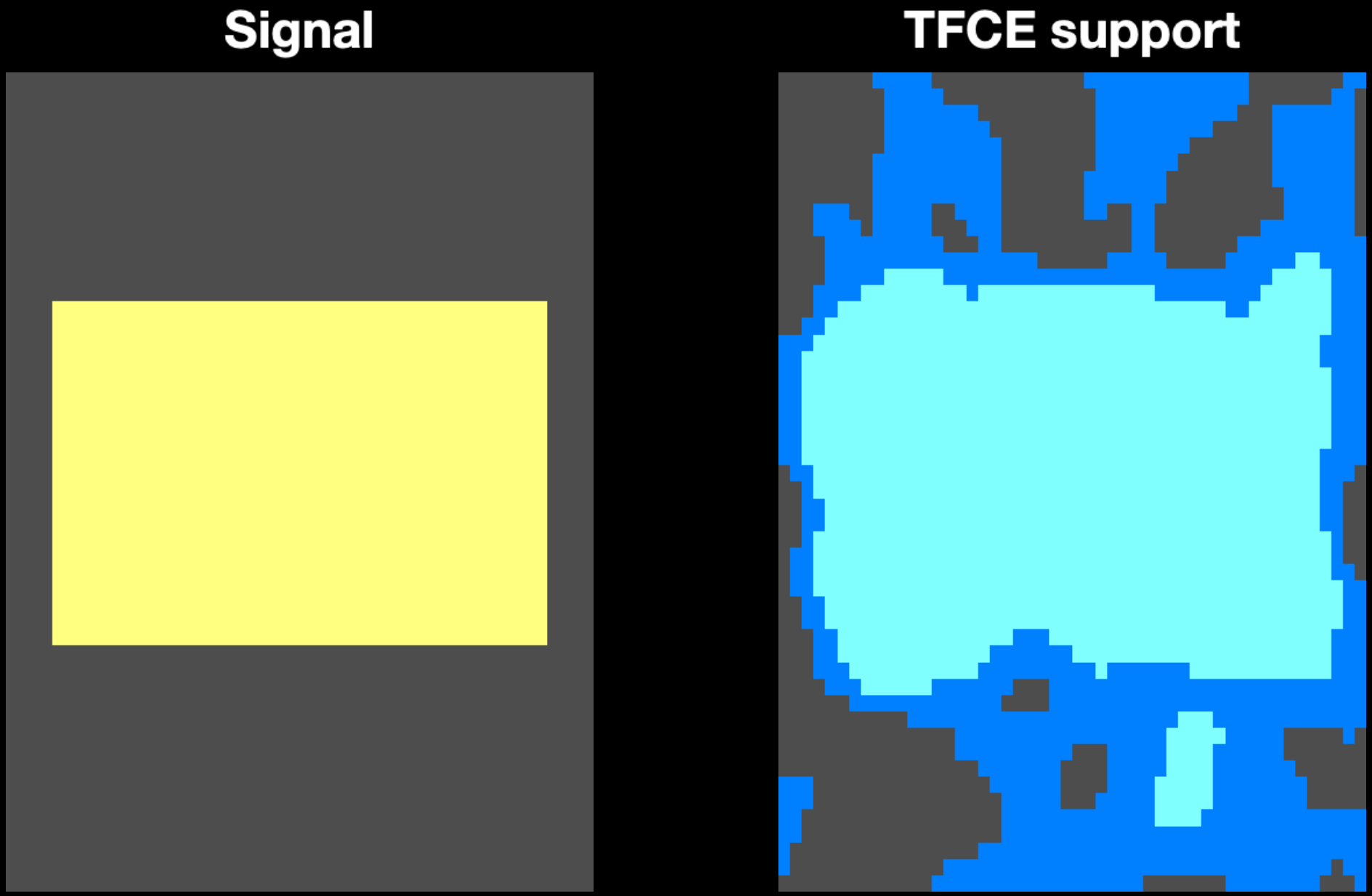

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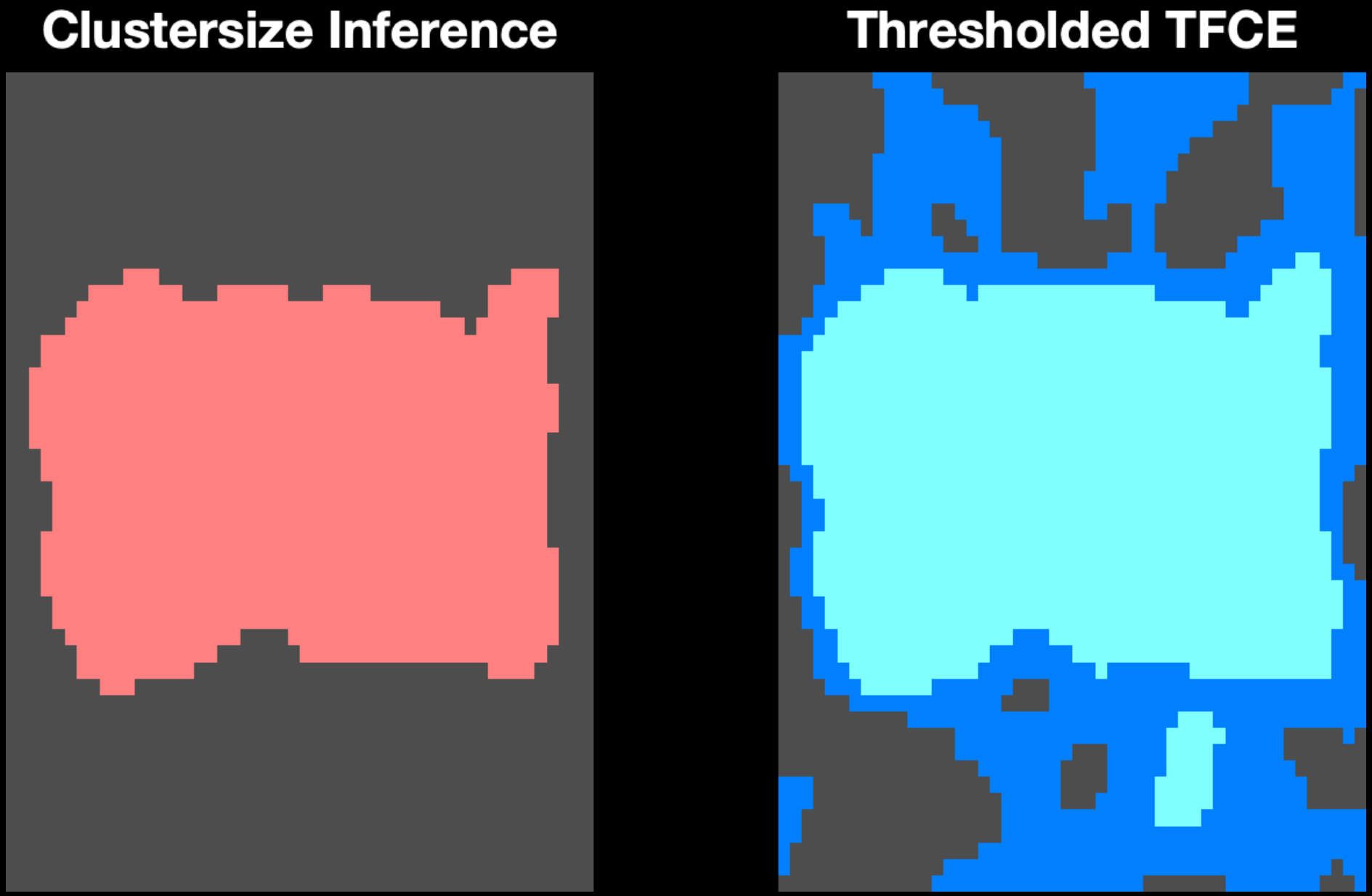
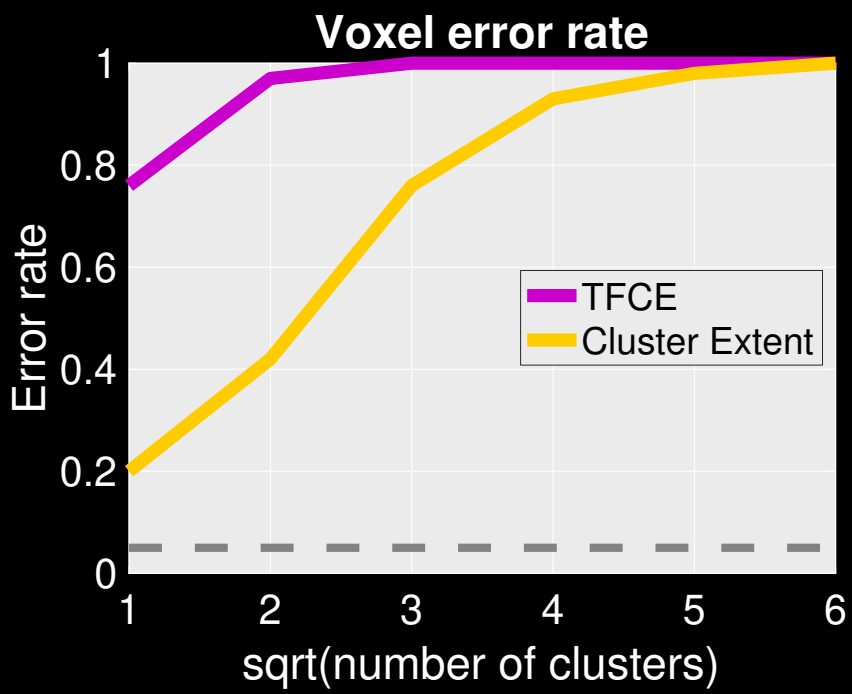
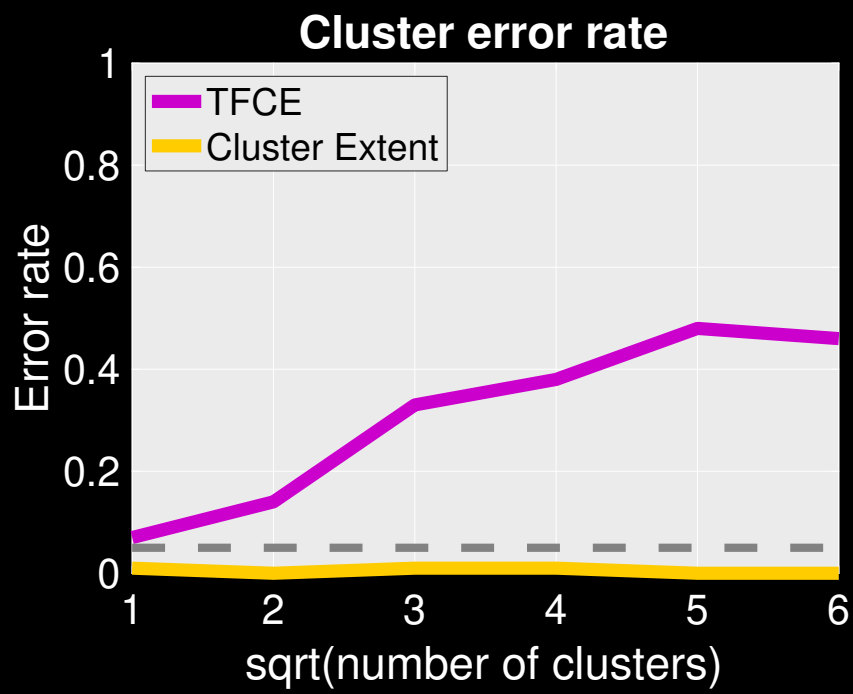


TFCE false positives





TFCE increases the number of free paramters

One of the main motativations for TFCE was to reduce researcher degrees of freedom, to make it "threshold free". However the TFCE transformation is defined as:

$$S_v = \int_{h_0}^{T_v} h^H e_v(h)^E \mathrm{d}h. \tag{1}$$

- Unlike Clustersize inference TFCE thus actually has 3 free parameters.
- In particular h_0 acts as a threshold.

Localized Cluster Enhancement

Recall the TFCE statistic is:

$$S_v(T) = \int_{h_0}^{T_v} h^H e_v(h, T)^E \mathrm{d}h.$$

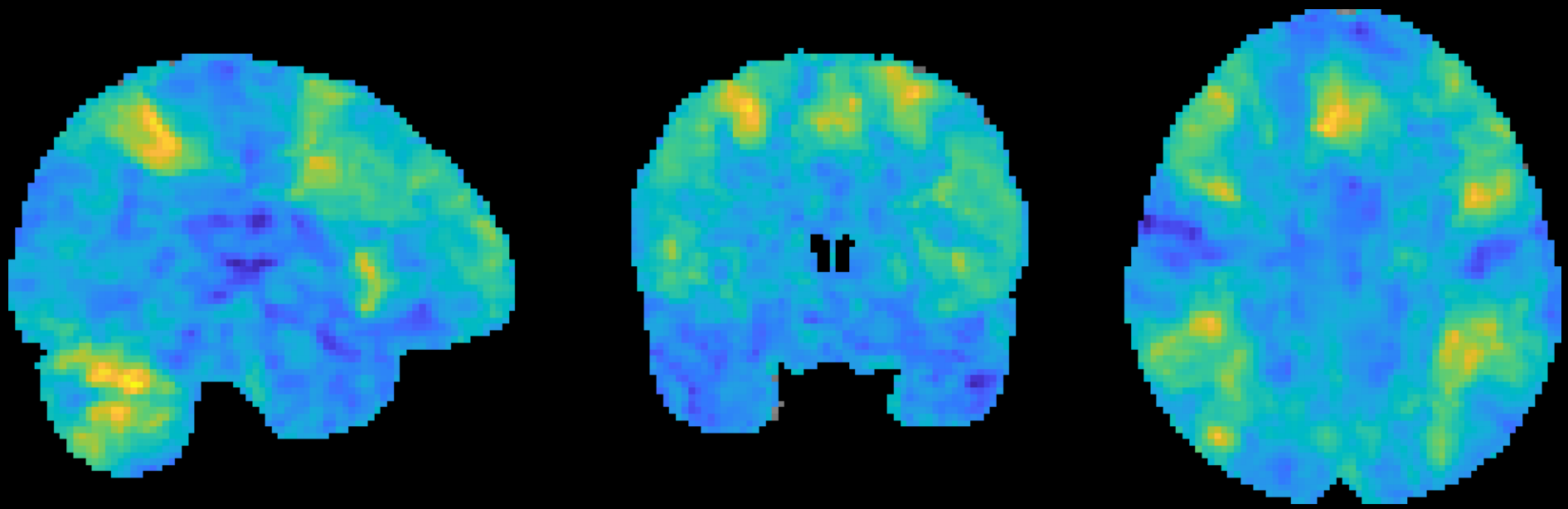
To localize this statistic, for a region $R \subset \mathcal{V}$ let

$$S_{v,R}(T) = S_v(T \times 1[R]) = \int_{h_0}^{T_v} h^H e_v(h, T \times 1[R])^E \mathrm{d}h.$$

Let t^* be the $(1-\alpha)$ quantile of the permutation distribution of $\max_{v \in \mathcal{V}} S_v(T)$. Then we can say R contains at least one active voxel if $S_{v,R}(T) > t^*$.

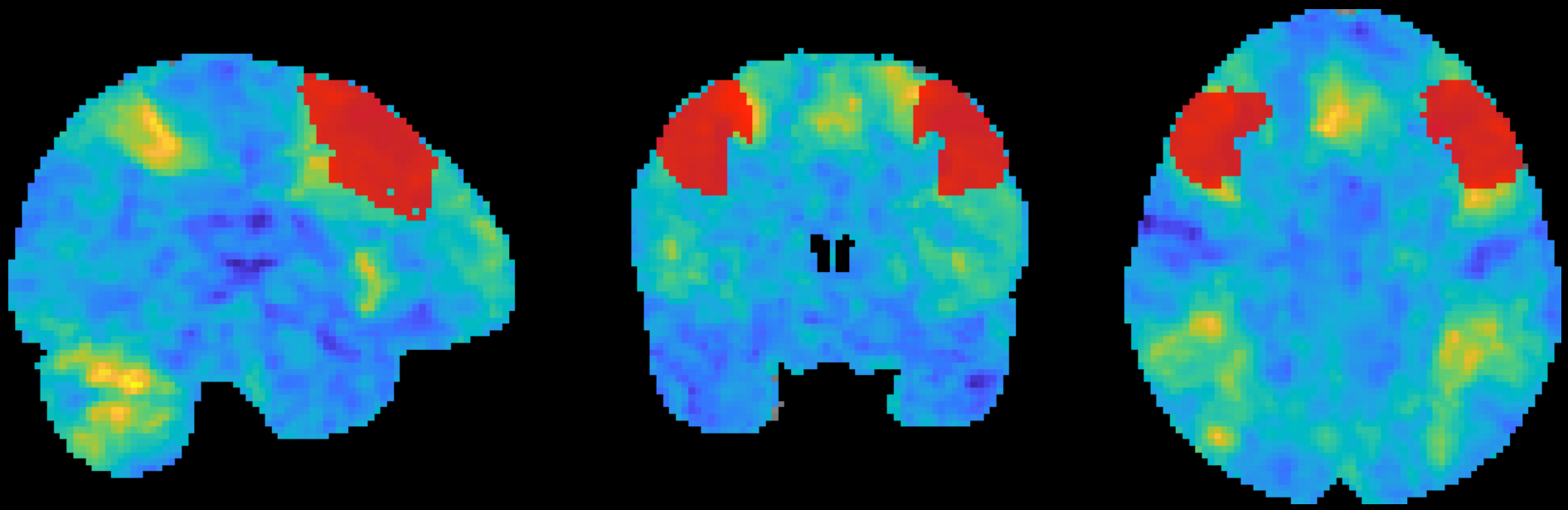
Localized Cluster Enhancement illustration

The t-statistic based on 20 subjects (for the HCP Gambling task)



Localized Cluster Enhancement illustration

Apply a mask of the Middle Frontal Gyrus



Localized Cluster Enhancement illustration

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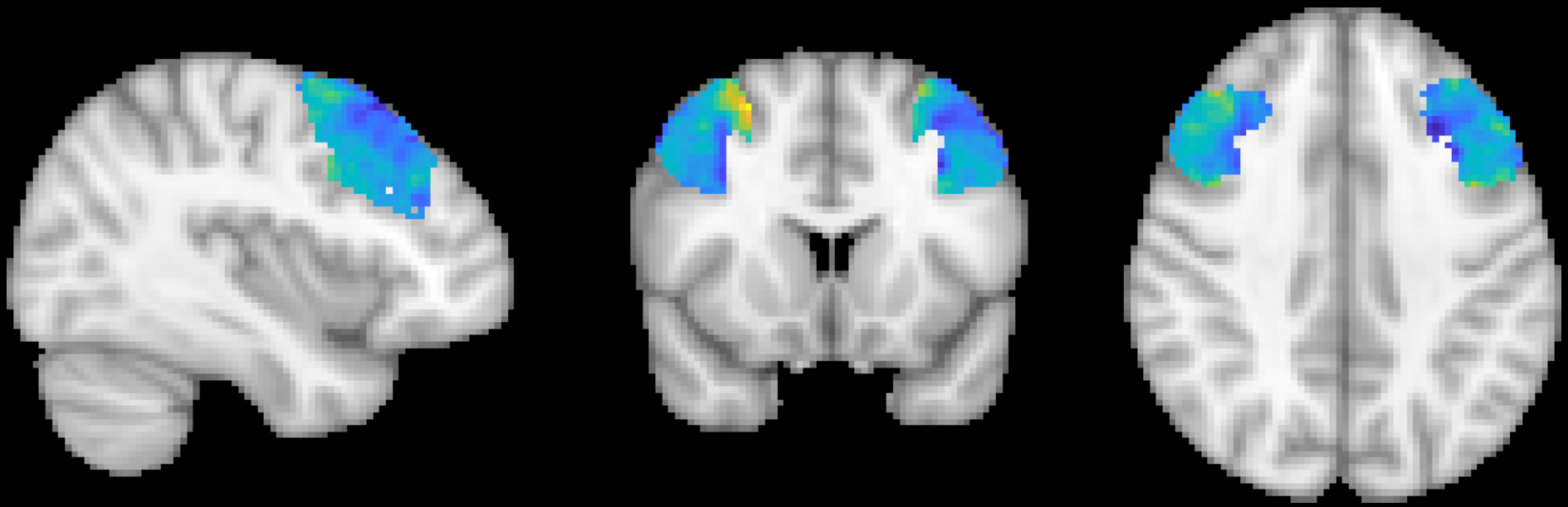
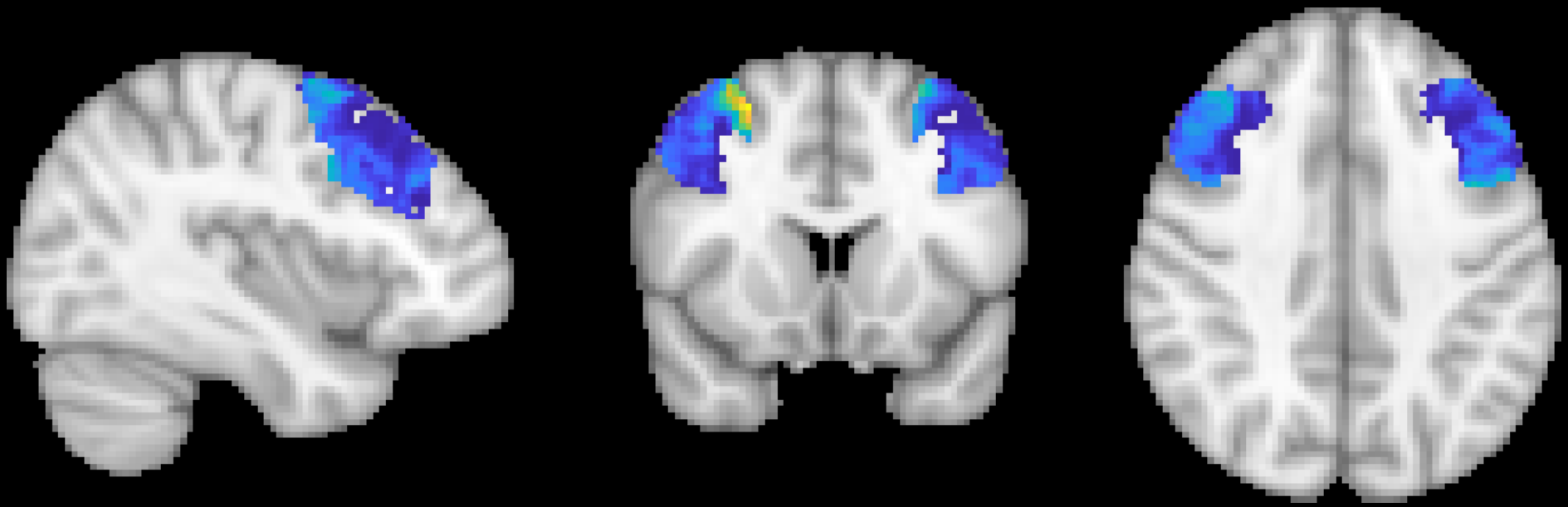


Localized Cluster Enhancement illustration

Apply TFCE on that mask

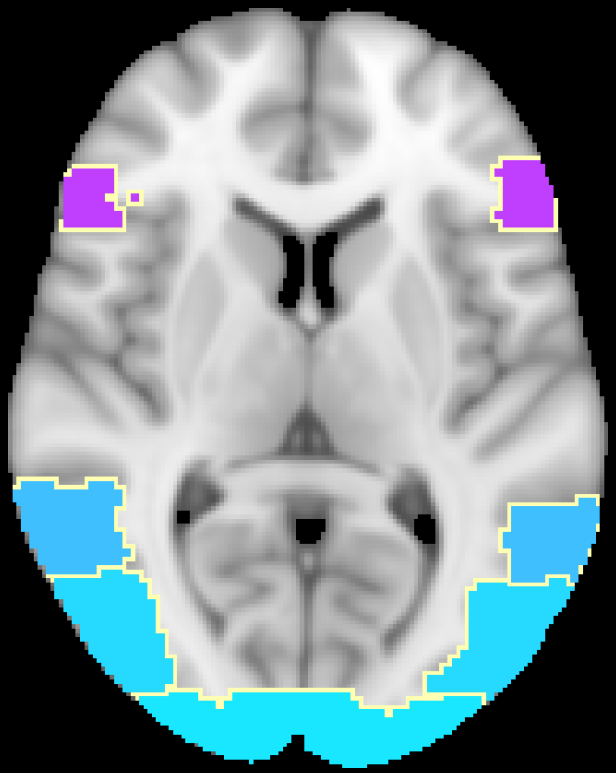


Theory

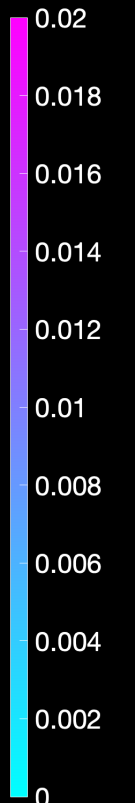
Suppose that the data satisfies an exchangeability assumption. Then

Theorem: $\mathbb{P}\left(S_{v,R}(T) < t^* \text{ for all inactive } R\right) \geq 1 - \alpha.$

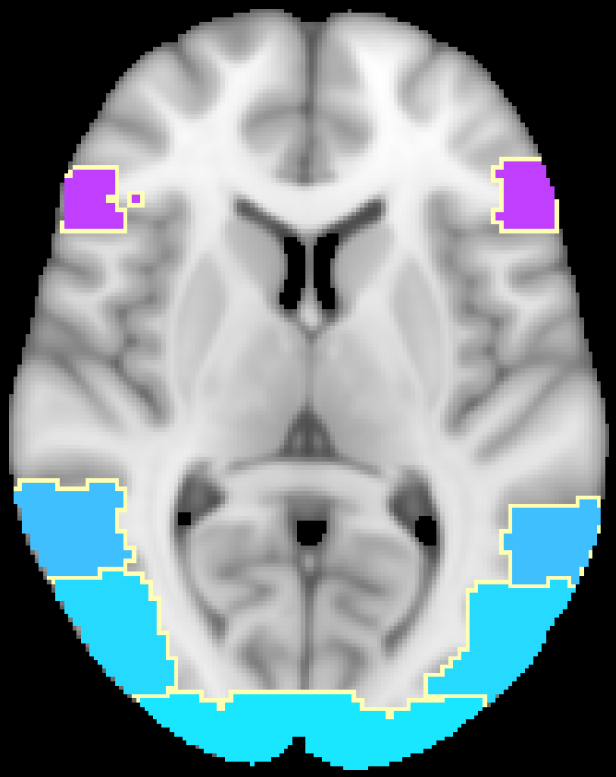
Regional activation (HCP - Social)



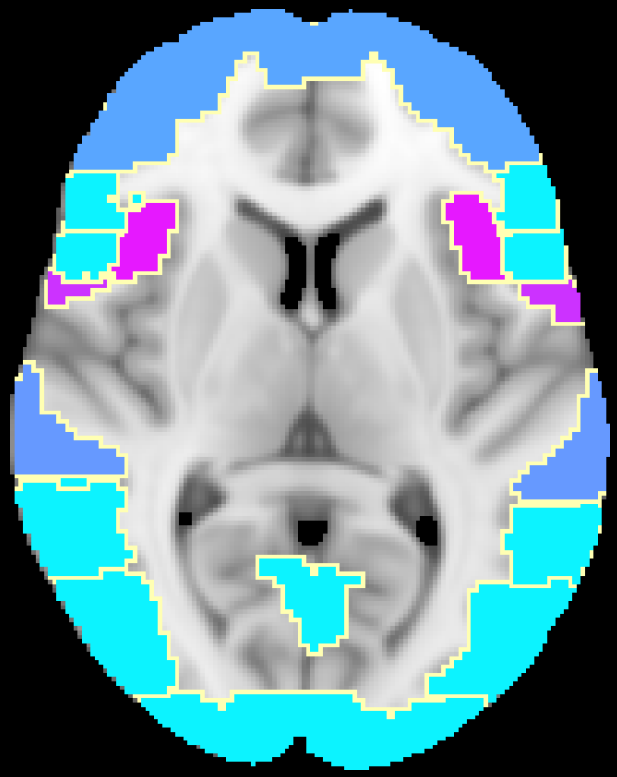
(a) Localized TFCE, $h_0 = 0$



Regional activation (HCP - Social)

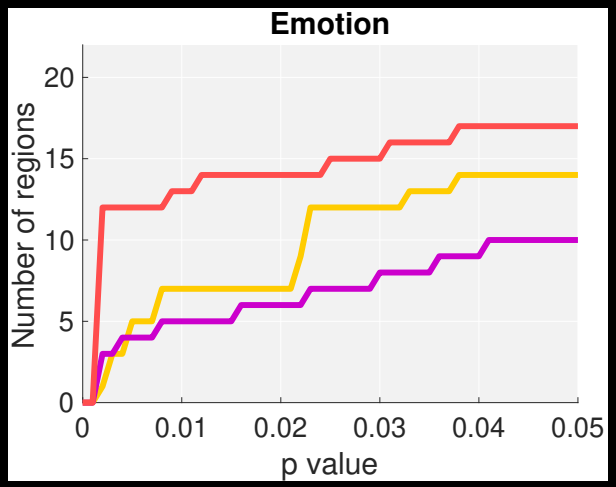


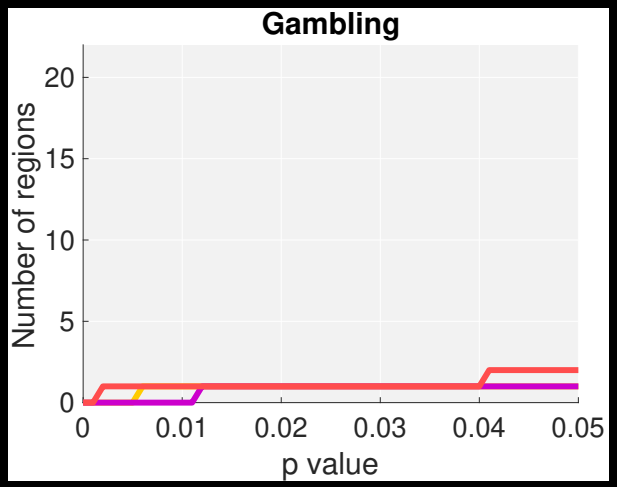
(a) Localized TFCE, $h_0 = 0$

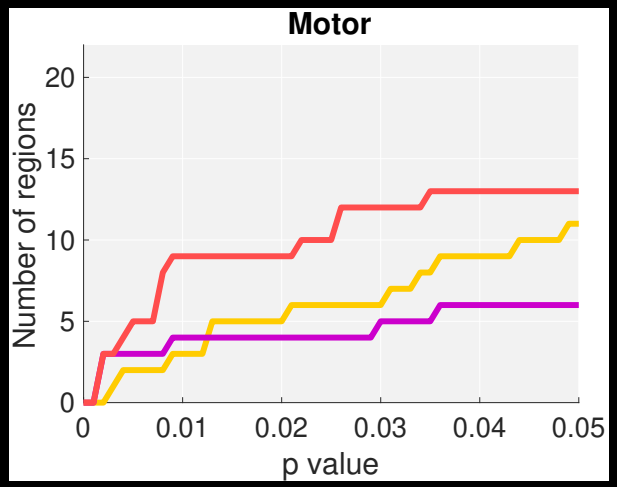


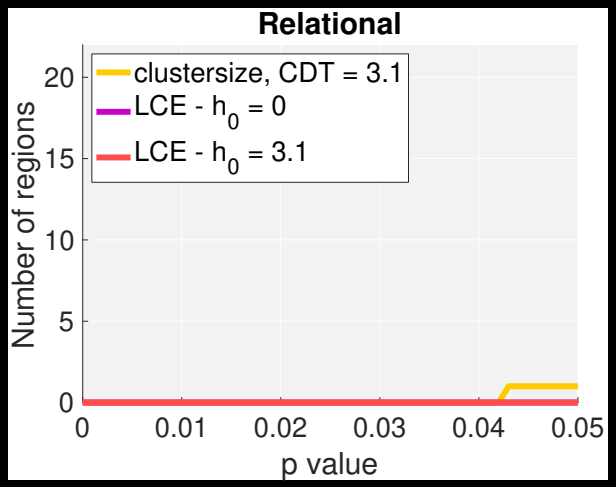
(b) Localized TFCE, $h_0 = 3.1$

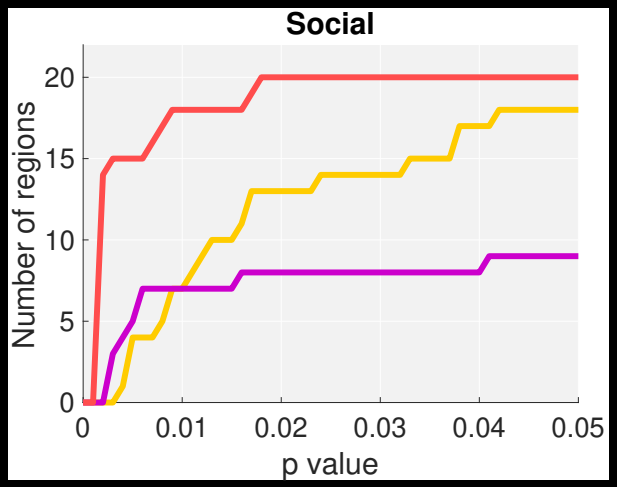
Power comparison for a regional analysis

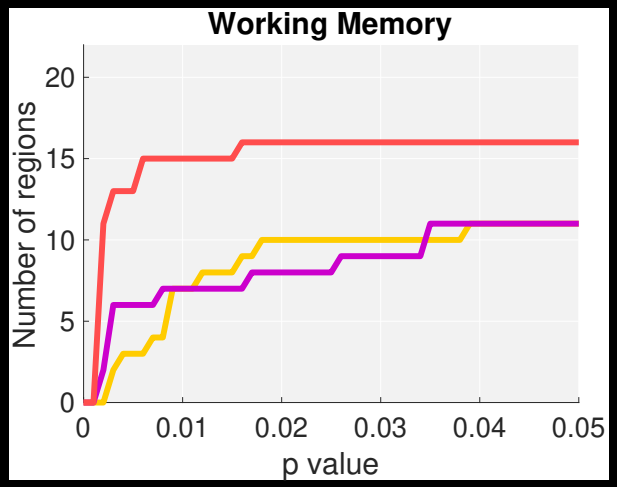












Conclusions

- TFCE as classically used can have inflated voxel and clusterwise error rates.

- **Localized Cluster Enhancement** provably controls clusterwise and regional error rates and allows for increases in power and localization.

- TFCE is not threshold free as it (strongly) depends on a threshold h_0. The default choice of $h_0 = 0$ means that TFCE typically can only make the weak global statement in practice.

- For localized cluster enchancement we recommend a threshold of $h_0 = 3.1$ in line with the default for clustersize inference.

Thanks

- Slides for this talk are available on my website: `sjdavenport.github.io/talks`

- Code to implement LCE and a tutorial on TFCE are available in the StatBrainz MATLAB package available at: `sjdavenport.github.io/software`

- Further details available at my poster: 1871

Global vs voxel vs cluster level inference

There are 3 types of inference statements typically used.

1. Voxel: Every highlighted voxel is active
2. Cluster: Every cluster contains at least one active voxel
3. Global: There is some voxel active somewhere in the brain.

Classifying fMRI inference methods

There are 3 types of inference statements typically used.

1. Voxel: Every highlighted voxel is active
Voxelwise inference

2. Cluster: Every cluster contains at least one active voxel
Clustersize inference

3. Global: There is some voxel active somewhere in the brain.
TFCE