Analysis of Functional Magnetic Resonance Imaging (fMRI)

Brain Decoding – Multivariate Pattern Analysis (MVPA)

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Teaching Materials

- http://www.ym.edu.tw/~cflu/CFLu_course_fMRIana.html

- ***Week 15: Brain Decoding – Multivariate Pattern Analysis (MVPA)***
- **＜*Handout*＞***Lesson15_slides.pdf*
  ＜*Materials*＞*fMRIana15_materials.zip*

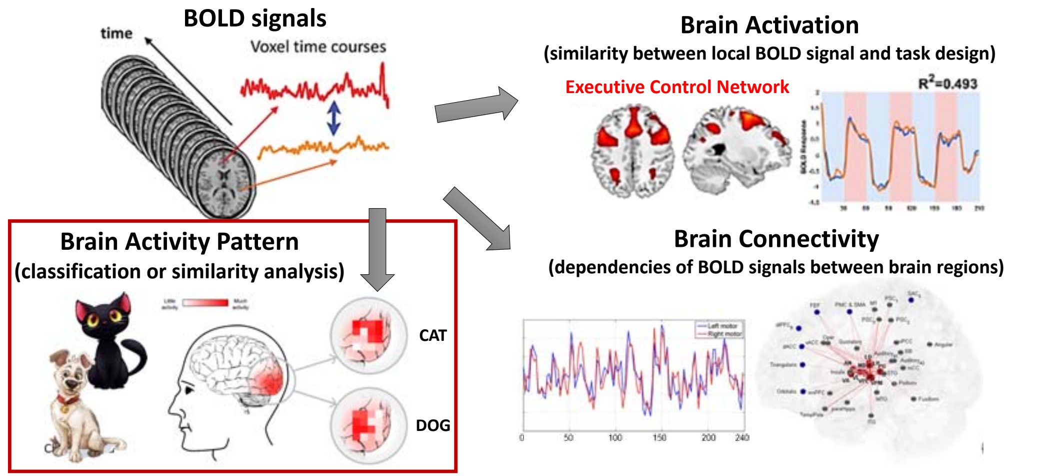
Original Dataset (Haxby_dataset) from
http://www.mlnl.cs.ucl.ac.uk/pronto/prtdata.html

Employed Software

- **MRIcro**
  - https://people.cas.sc.edu/rorden/mricro/mricro.html#Installation
- **Statistical Parametric Mapping (SPM 12)**
  - http://www.fil.ion.ucl.ac.uk/spm/
- **PRoNTo Software**
  - http://www.mlnl.cs.ucl.ac.uk/pronto/

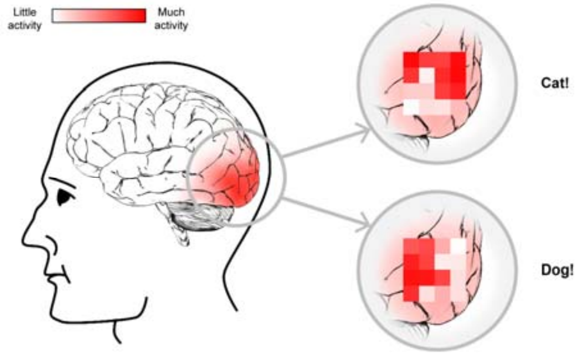
[Caution] File name\path contains Chinese character or space may cause error!

fMRI Analysis



Multivariate Pattern Analysis (MVPA)

Decoding Activity Pattern of Brain



Looking at the pattern of activation within a brain area allows us to answer what the person is seeing.

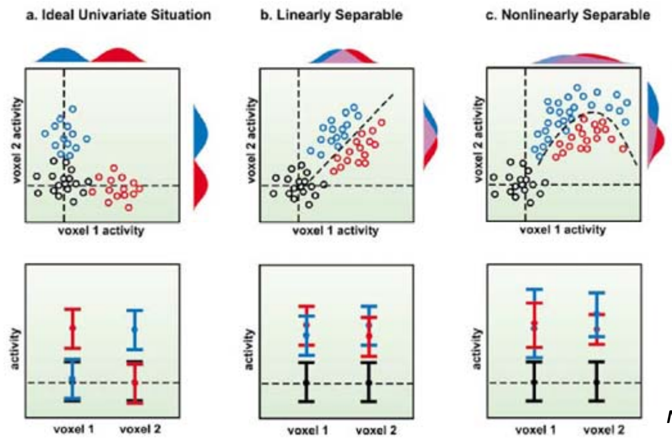
Illustration by Pim Mostert http://blog.donders.ru.nl/?p=4361&lang=en

Brain Activation → Brain Decoding

- **Mass-univariate model-based analysis**
  - Analyze every voxel (~50,000) one at a time
  - General Linear Model, GLM (since 1995)

- **Multivoxel Pattern Analysis, MVPA**
  Multivariate Pattern Analysis, MVPA
  - Original version: correlation analysis
  - Machine learning: Support Vector Machine, SVM

Why we need multivariate analysis?



A: Human face

B: Chair

Neuroimage, *19*(2), pp.261-270, 2003.

Major limitations of GLM

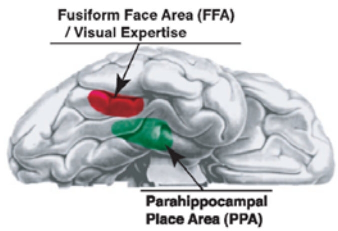
- The basic assumption that the covariance across neighboring voxels is not informative about the cognitive function under examination.
- Such covariance is considered as uncorrelated noise and normally reduced using spatial filters that smooth BOLD signals across neighboring voxels.
- Additionally, the GLM approach is inevitably limited by the model used for statistical inference.

➔ Fail to capture "distributed" neural codes.

Origin of MVPA

Three hypothesis made by **James V. Haxby**, 2001.

- Each object category would evoke a distinct pattern of response in ventral temporal cortex.
- These distinctive patterns would not be restricted to category-selective regions, such as the FFA (face) and PPA (other objects).
- Neural activity patterns within category-selective regions would carry information that discriminates between categories.

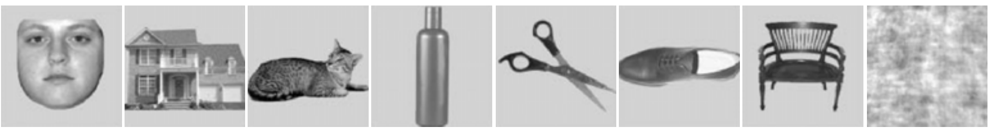


Science, *293*(5539), 2425-2430, 2001.

Origin of MVPA

Object form topography

- The ventral temporal cortex has a topographically organized representation of attributes of form that underlie face and object recognition.
  - Can produce unique representations for a virtually unlimited number of categories.



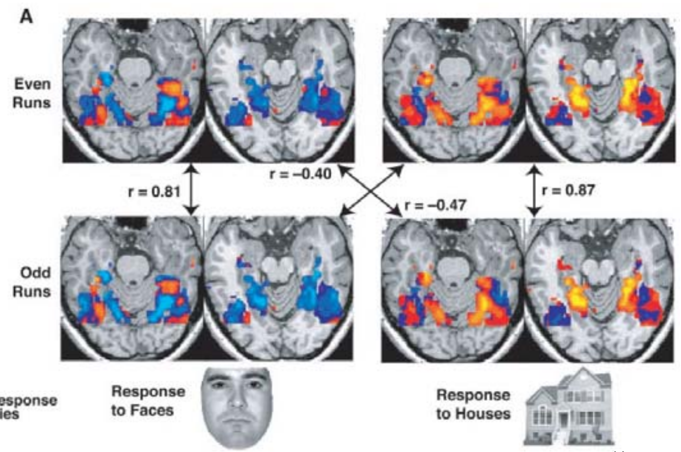
Science, *293*(5539), 2425-2430, 2001.

Origin of MVPA

Science, *293*(5539), 2425-2430, 2001.

Split-sample cross-correlation (odd vs. even runs)

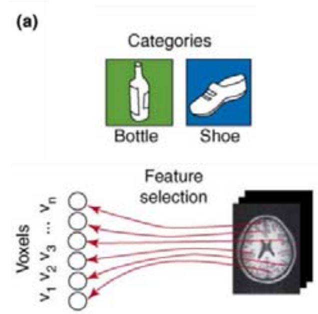
- The response to that category should be more similar to each other than to responses to different categories.

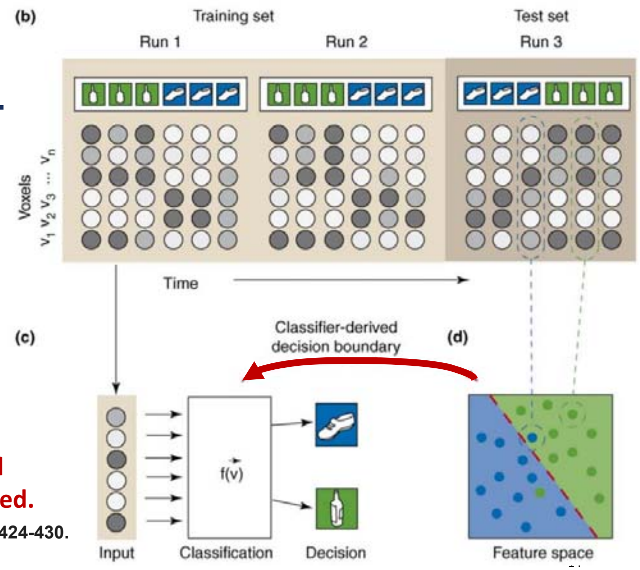


MVPA: A Classification Problem

- Classification consists in determining a decision function f that takes the values of various "features" in a data "example" x and predicts the class of that "example."
- An "**example**" may represent a given trial in the experimental run.
- The "**features**" may represent the corresponding fMRI signals in a cluster of voxels.
- The experimental conditions may represent the different "**classes**".

MVPA Diagram





No explicit temporal or spatial smoothing should be performed.

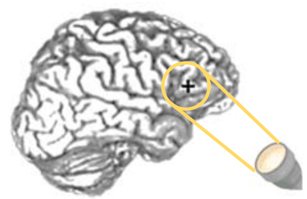
***Trends in cognitive sciences*, *10*(9), pp.424-430.**

Support Vector Machine (SVM)

Alice Zhao, https://youtu.be/N1vOgolbjSc

Searchlight Approach

- Kriegeskorte, N., Goebel, R. and Bandettini, P., 2006. Information-based functional brain mapping. ***Proceedings of the National Academy of Sciences***, *103*(10), pp.3863-3868.
- **Where in the brain does the activity pattern contain information about the experimental condition?**
  - Rather than asking where in the brain does the average activity changes across experimental condition.



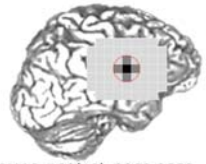
Searchlight Approach

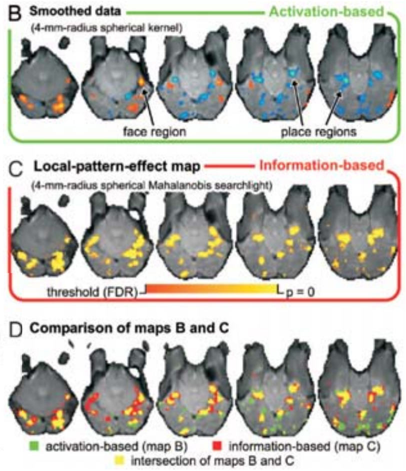
When the **target** is to find…

When the target is to find…	Assumption	Combination of local signals
Activated Regions →	**Activate a region as a whole** →	**Local averaging** (spatial smoothing)
V.S.		
Informative Regions →	**Activity patterns as distributed representations** →	**Multivariate statistics** (compare activity patterns among conditions)
	Salt-and-pepper fine structure	

Searchlight Approach

- Scan the brain with a **spherical multivariate "searchlight"** centered on each voxel in turn.
  - An optimal radius of 4mm contains 33 2-mm-isotropic voxels.
- The resulting map shows **how well the multivariate signal in the local spherical neighborhood differentiates the experimental conditions.**
  - Average absolute t value
  - Mahalanobis distance

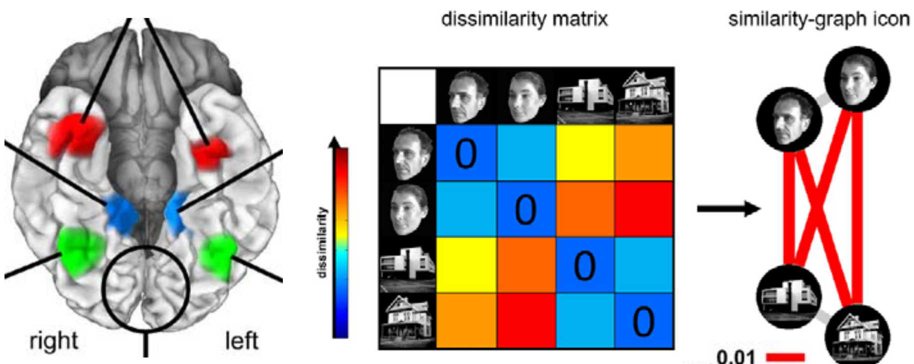




PNAS, 103(10), 3863-3868.

Pattern Similarity Analysis

Compared between regions, species, mental states, and diseases.



Frontiers in systems neuroscience, *2*, p.4, 2008

Toolbox of MVPA

- Hanke, M., Halchenko, Y.O., Sederberg, P.B., Hanson, S.J., Haxby, J.V., Pollman, S., 2009. **PyMVPA**: a Python toolbox for multivariate pattern analysis of fMRI data. ***Neuroinformatics*** 7, 37–53.
- An MVPA toolbox using Matlab (the **Princeton MVPA toolbox**) (http://code.google.com/p/princeton-mvpa-toolbox/).
- Schrouff J, Rosa MJ, Rondina JM, Marquand AF, Chu C, Ashburner J, Phillips C, Richiardi J, Mourão-Miranda J. **PRoNTo**: pattern recognition for neuroimaging toolbox. **Neuroinformatics**. 2013 Jul 1;11(3):319-37.
- Oosterhof, N.N., Connolly, A.C. and Haxby, J.V., 2016. **CoSMoMVPA**: multi-modal multivariate pattern analysis of neuroimaging data in Matlab/GNU Octave. ***Frontiers in neuroinformatics***, *10*, p.27.

PRoNTo Software

Relevant Publications

PRoNTo Software:

- Schrouff J, Rosa MJ, Rondina JM, Marquand AF, Chu C, Ashburner J, Phillips C, Richiardi J, Mourão-Miranda J. **PRoNTo**: pattern recognition for neuroimaging toolbox. **Neuroinformatics**. 2013 Jul 1;11(3):319-37.

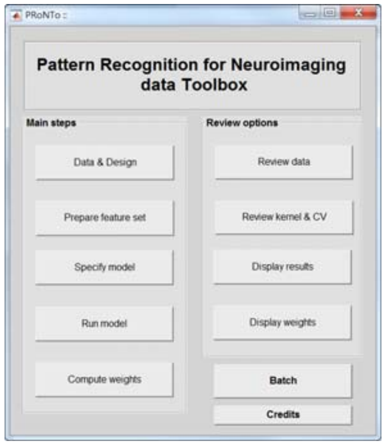
Dataset:

- **Haxby JV**, Gobbini MI, Furey ML, Ishai A, Schouten JL, Pietrini P. Distributed and overlapping representations of faces and objects in ventral temporal cortex. **Science**. 2001 Sep 28;293(5539):2425-30.

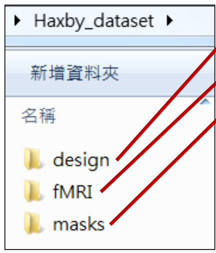
PRoNTo Software

Include PRoNTo_v2.1.1 path and key in **pronto** in MATLAB command window

- **PRoNTo (Pattern Recognition for Neuroimaging Toolbox)**
  - Brain scans are treated as spatial patterns and statistical learning models are used to identify statistical properties of the data that can be used to **discriminate between experimental conditions or groups of subjects (classification models)** or to **predict a continuous measure (regression models).**



Step 1: Data Preparation



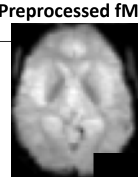
Specified SPM.mat for imaging parameters and block/condition onset setup.

Preprocessed fMRI data without spatial smoothing.

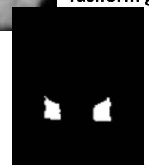
Mask images to identify the region of interests (ROIs).

1. TR = 2.5 sec
2. Units = 'scans'
3. Durations = 9 scans
4. Onsets:
   a. Faces: 21 127 334 426 533 640 732 853 974 1095 1302 1394
   b. Houses: 63 213 348 384 490 611 804 953 1017 1138 1288 1352
   c. Cats: 35 142 248 412 576 683 818 925 1003 1110 1216 1423
   d. Shoes: 49 156 320 369 562 654 775 896 1046 1181 1273 1409
   e. Bottles: 92 199 305 455 519 697 832 910 1060 1195 1259 1337
   f. Chairs: 106 170 291 398 547 668 747 939 989 1167 1245 1366
   g. Scissors: 6 184 277 469 505 711 761 882 1074 1152 1316 1437
   h. Scrampix: 78 227 263 441 590 626 789 868 1031 1124 1231 1380

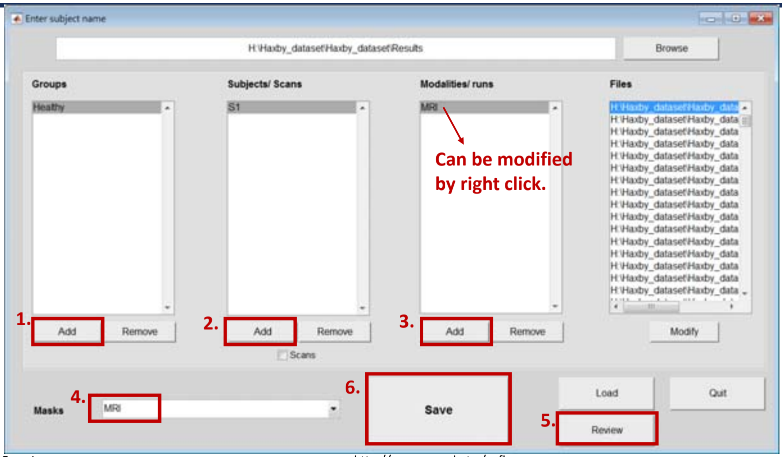
Preprocessed fMRI.



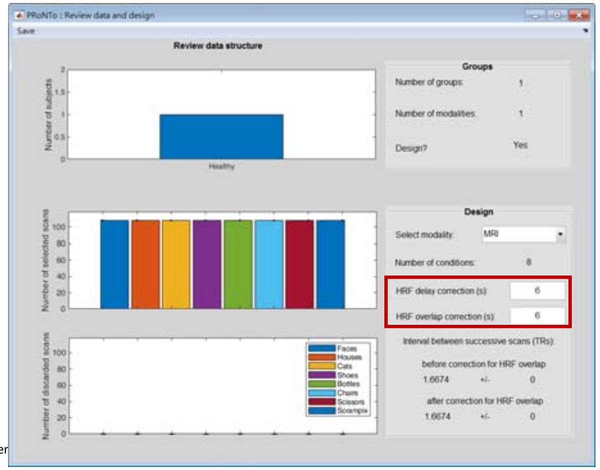
Mask of fusiform gyrus

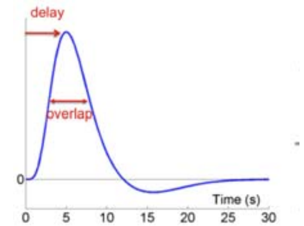


Step 2-1: Data & Design



Step 2-2: HRF Corrections

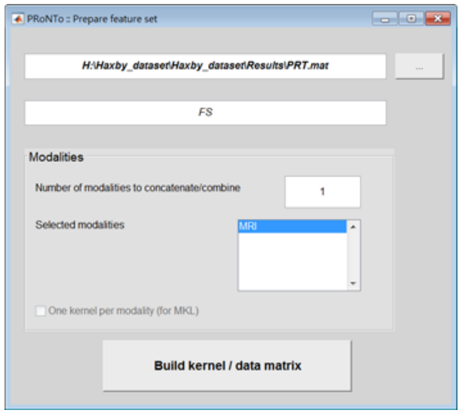


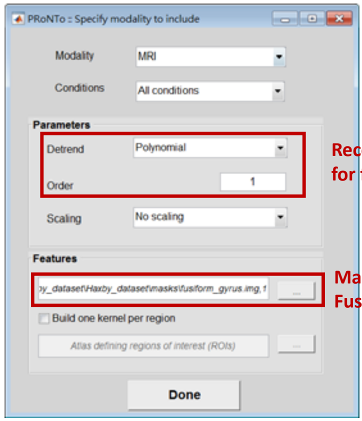


The HRF delay: time it takes for the hemodynamic response to peak after the stimulus, which will shift the onsets in time.

The HRF overlap: the dispersion of the HRF.

Step 3: Prepare feature set



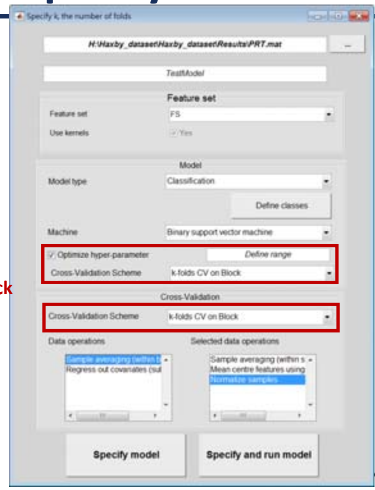


Recommended for fMRI

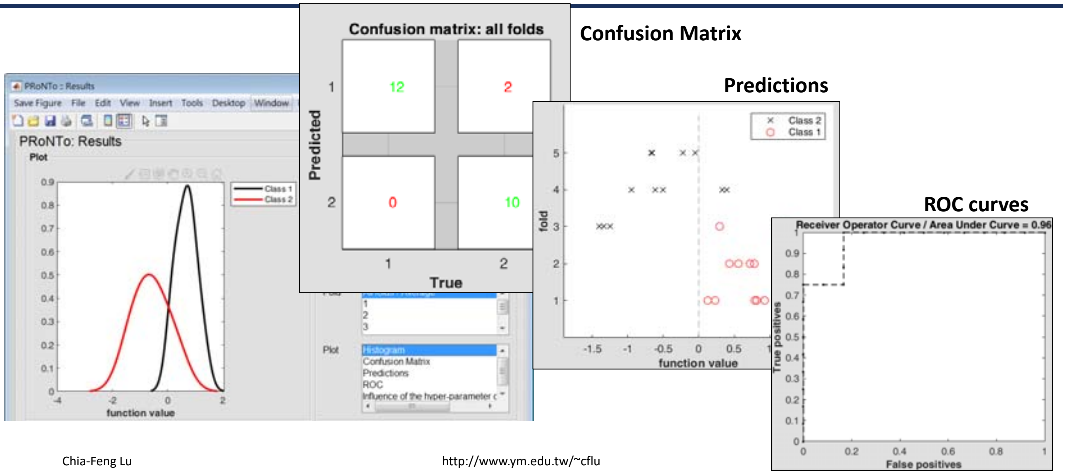
Mask of Fusiform gyrus

Step 3: Specify model

5-fold CV on Block

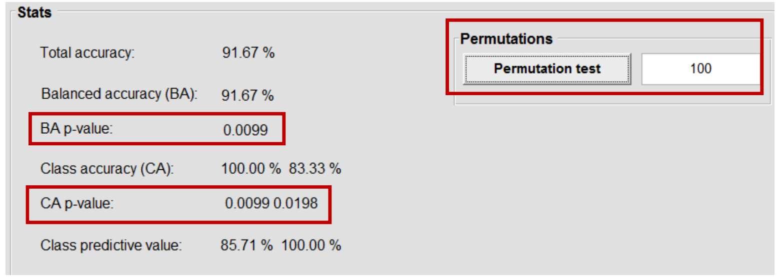


Step 4: Review results

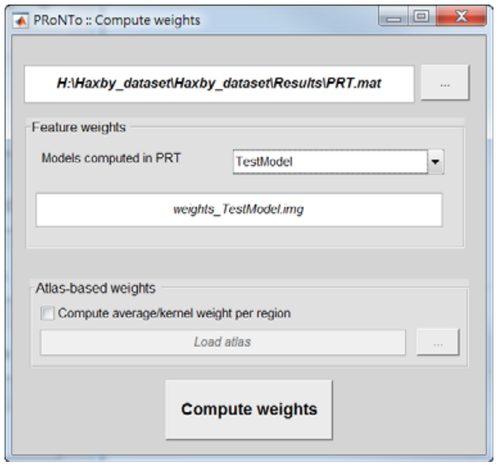


Step 4: Review results

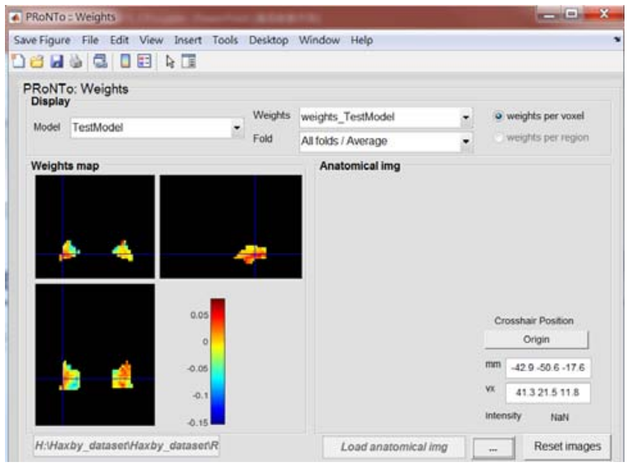
Usually, computing several hundreds to a thousand permutations is recommended to obtain meaningful confidence intervals and p-values for performance statistics.



Step 5: Compute weights



Step 6: Review weights



THE END

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