MULTIVARIATE ANALYSES WITH fMRI DATA

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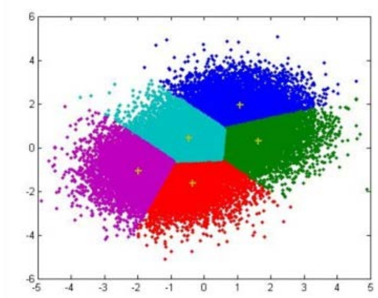
Motivation

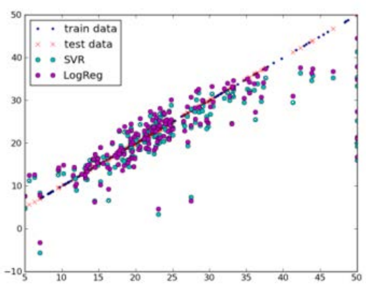
Modelling Concepts

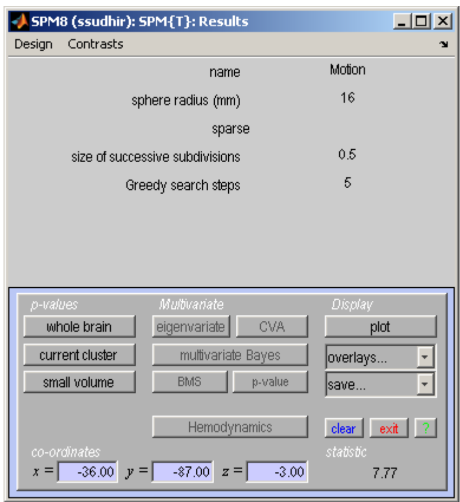
Learning From Data

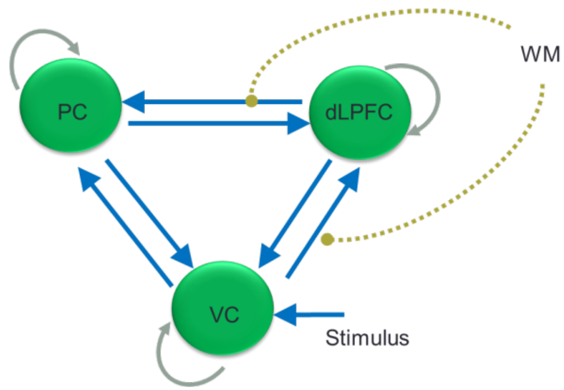
Multivariate Bayes in SPM

Generative Embedding



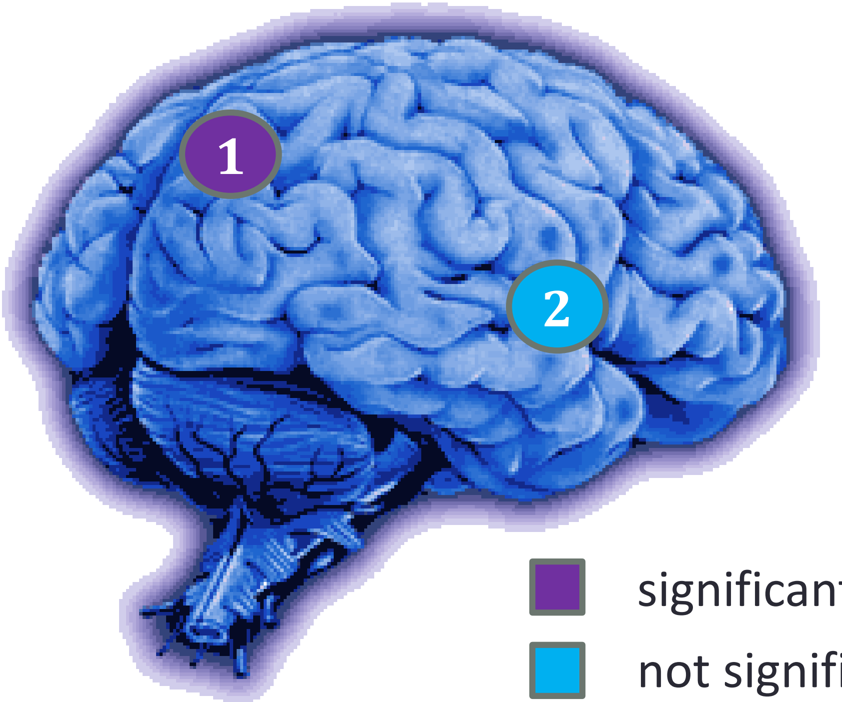


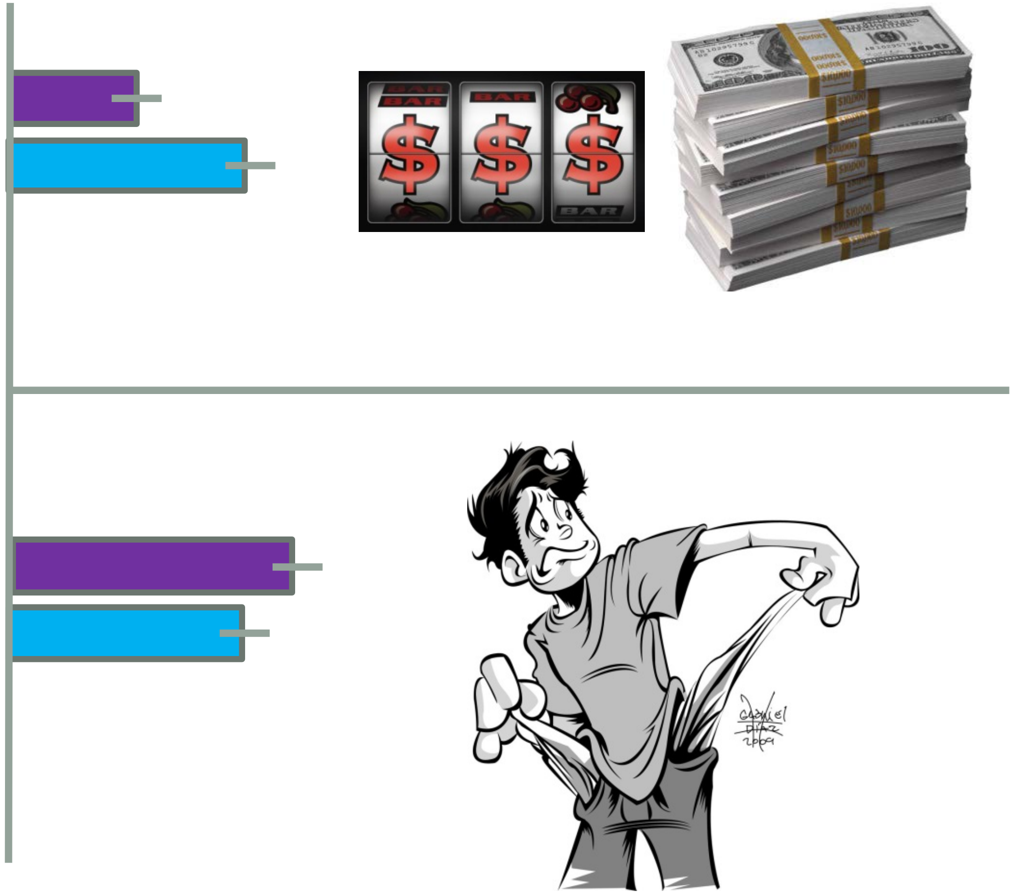




Motivation

- Local activations – Univariate approach

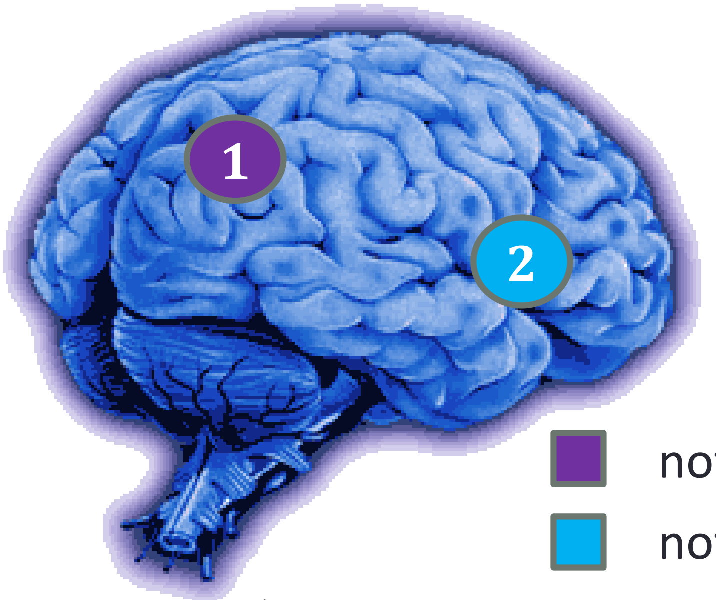




significant

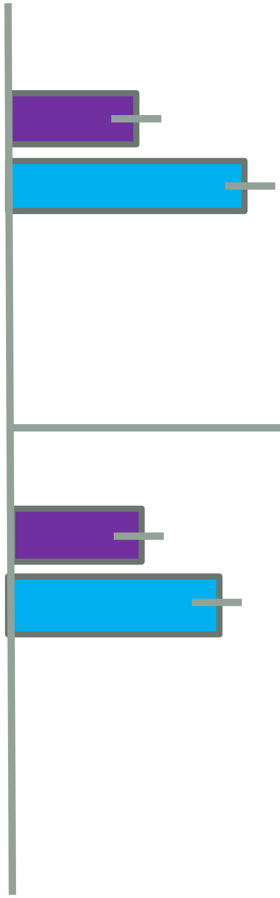
not significant

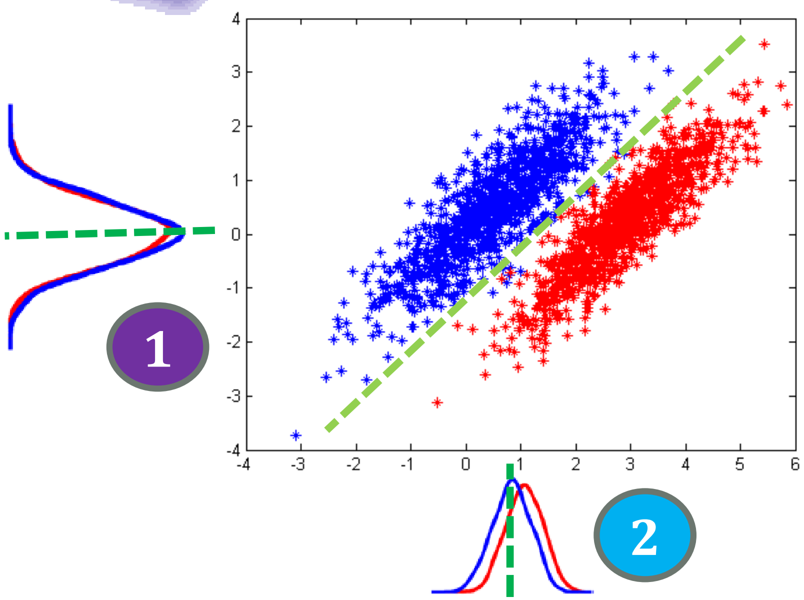
Univariate to Multivariate



not significant

not significant





Motivation

Modelling Terminology

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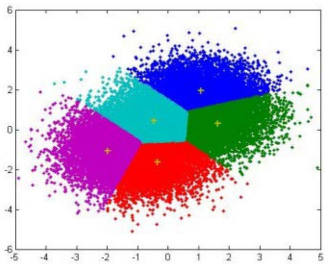
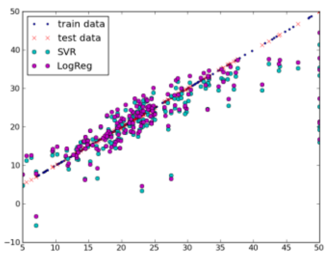
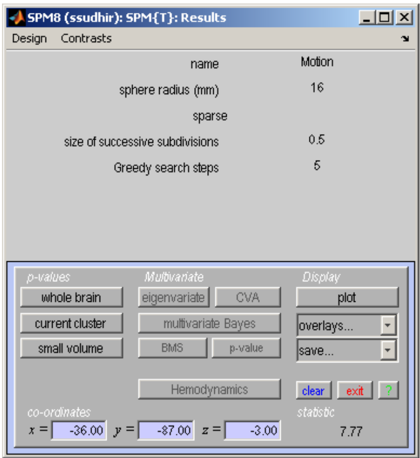
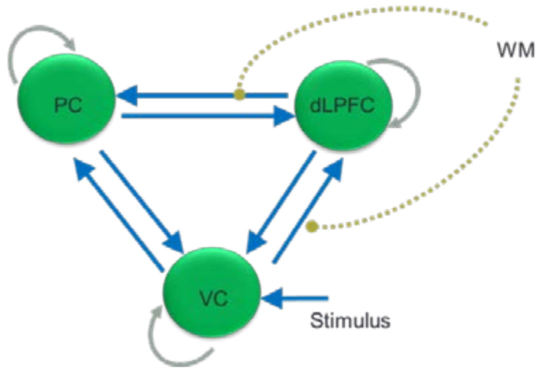
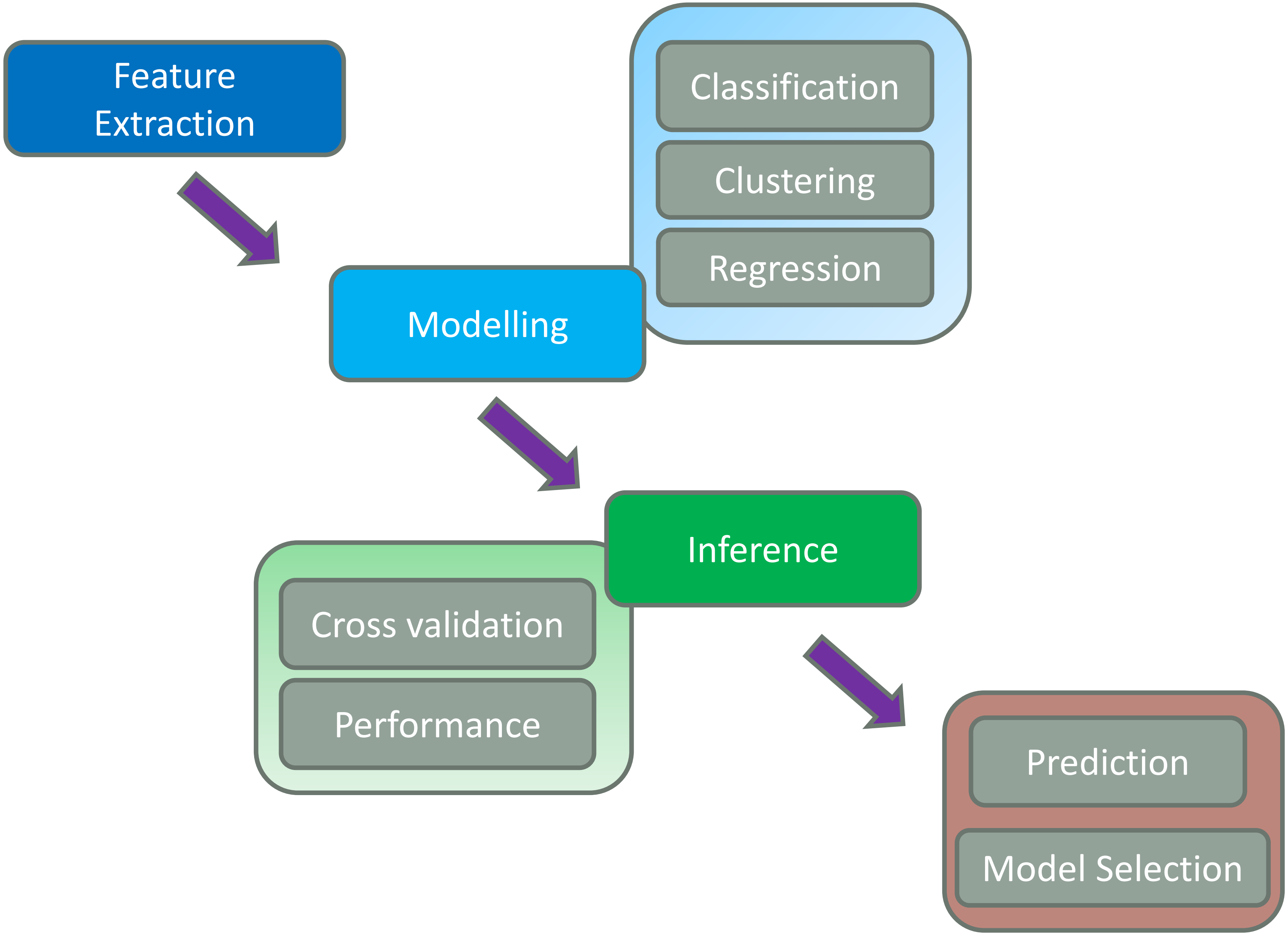








Steps for analysis

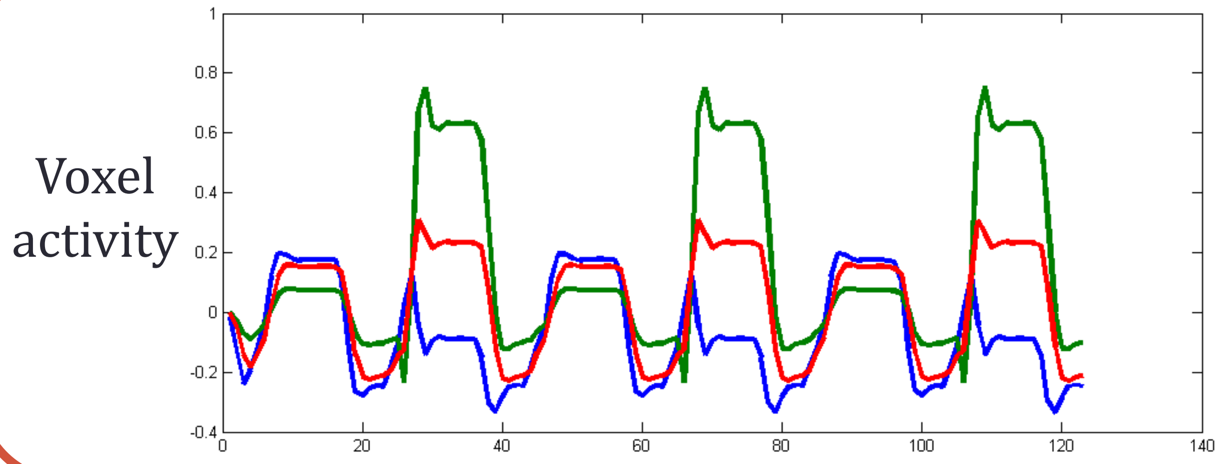


Feature Spaces

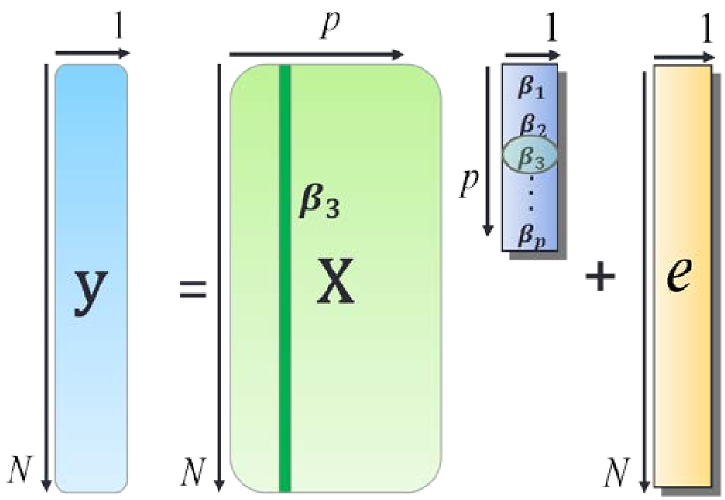
	F_1	F_2	. . .	F_P
S_1				
S_2	Data Point or Feature Vector			
.				
.				
S_N				

- High dimensionality
- Class/Cluster distributions
- Interpretation

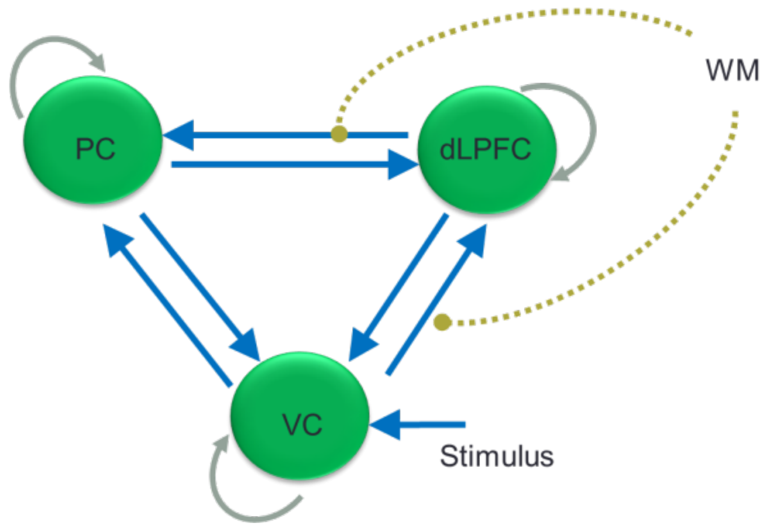
Raw data



Model parameters



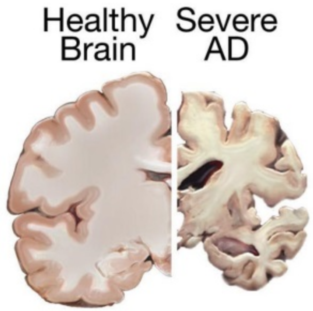
GLM – regression coefficients



DCM – connection parameters

Modelling goals

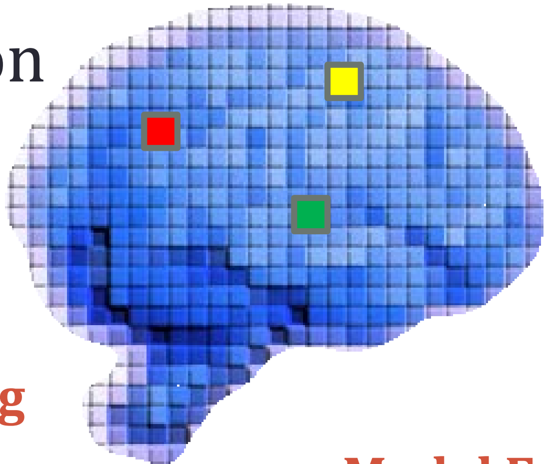
- Prediction



Predictive Density

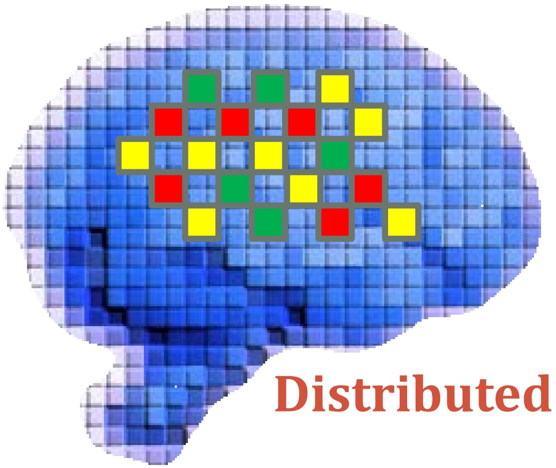
$$p(X_{\text{new}}|Y_{\text{new}}, X, Y) = \int p(X_{\text{new}}|\theta, Y_{\text{new}})q(\theta)d\theta$$

- Model Selection



Sparse Coding

VS

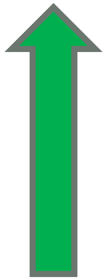


Distributed Coding

Model Evidence

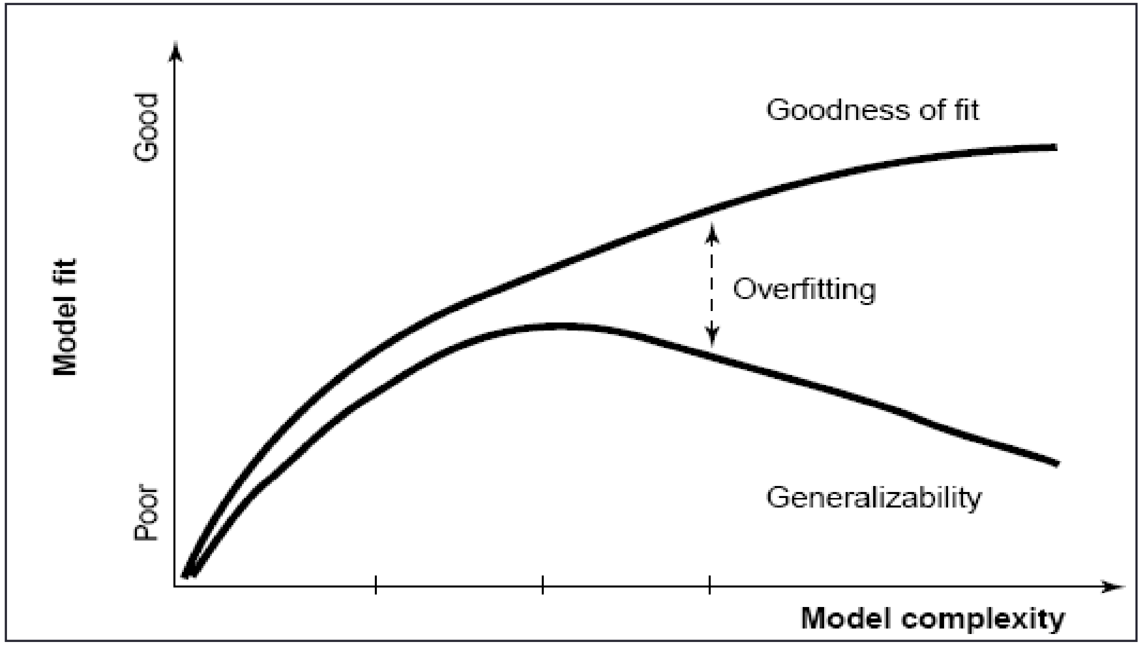
$$p(Y|X) = \int p(Y, \theta|X)d\theta$$

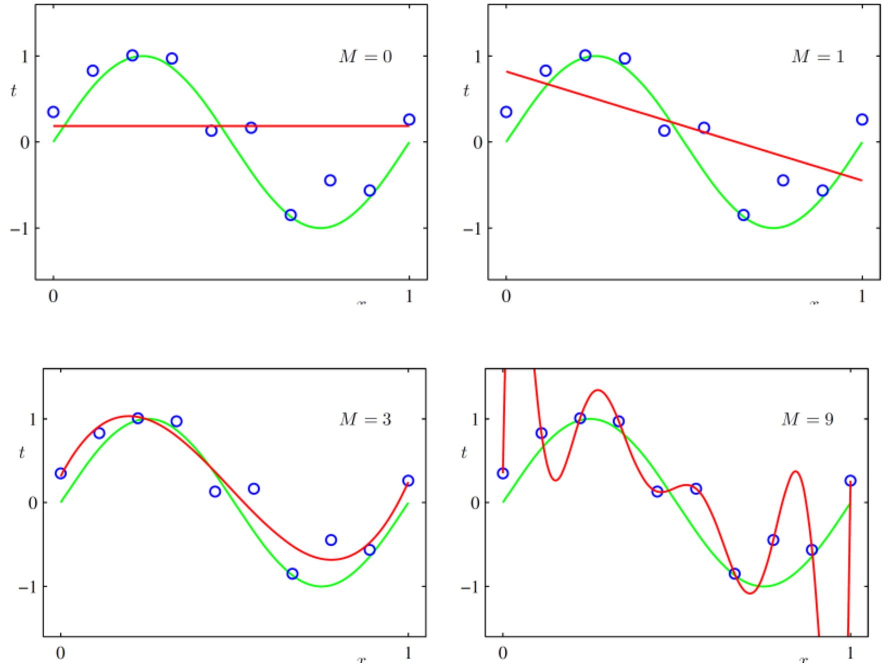
Model Selection - Generalizability



Model
Fit

Model
Complexity





Bishop (2006), Pitt & Miyung (2002), *TICS*

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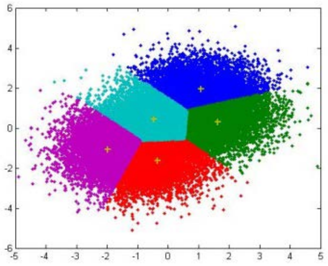
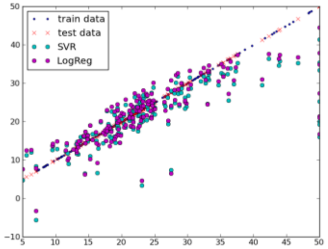
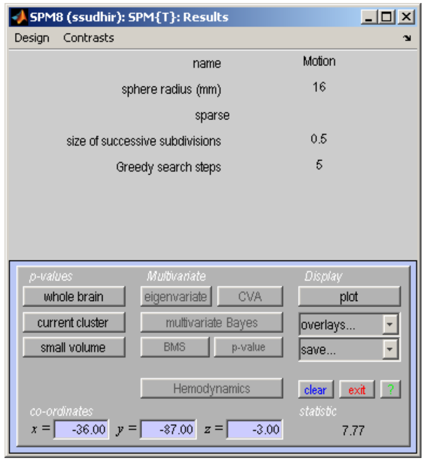
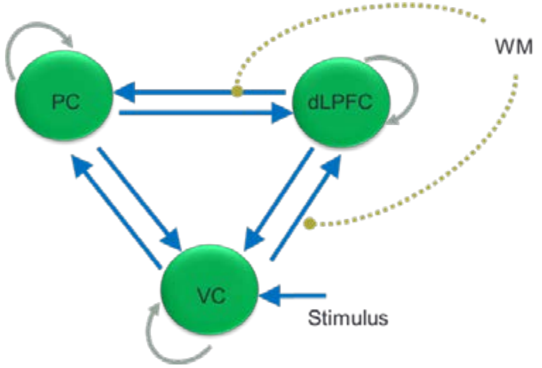


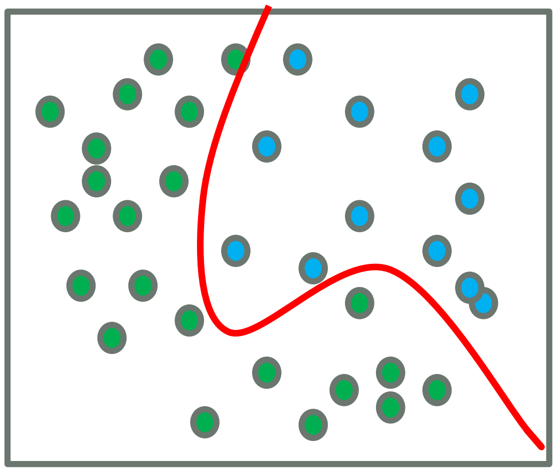


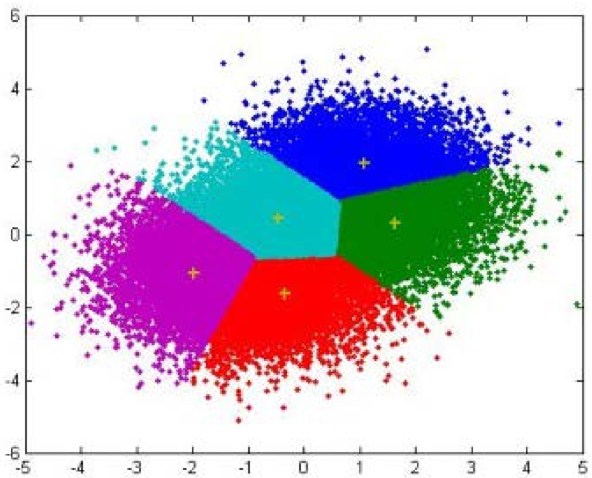




Learning from Data

- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning
  - Semi-supervised Learning





Supervised Learning

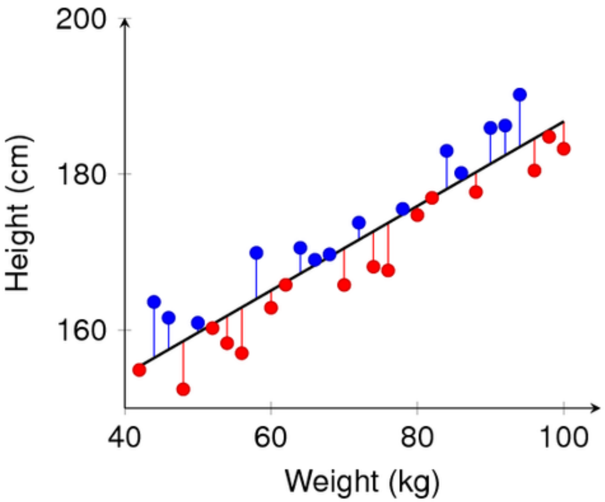
Independent variables
X

Function - f

dependent variable
Y

Regression

Continuous

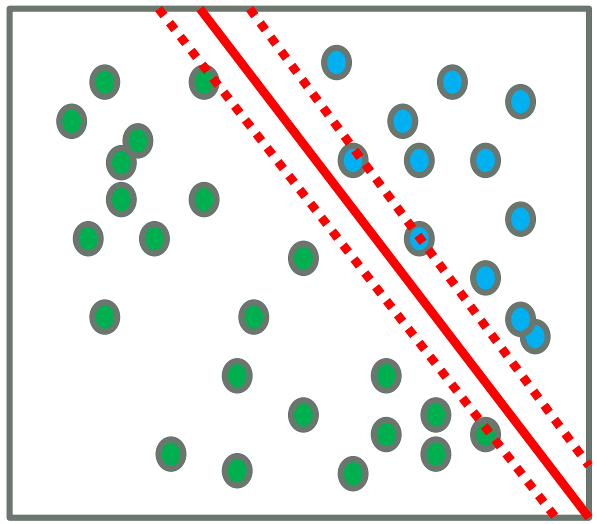


Classification

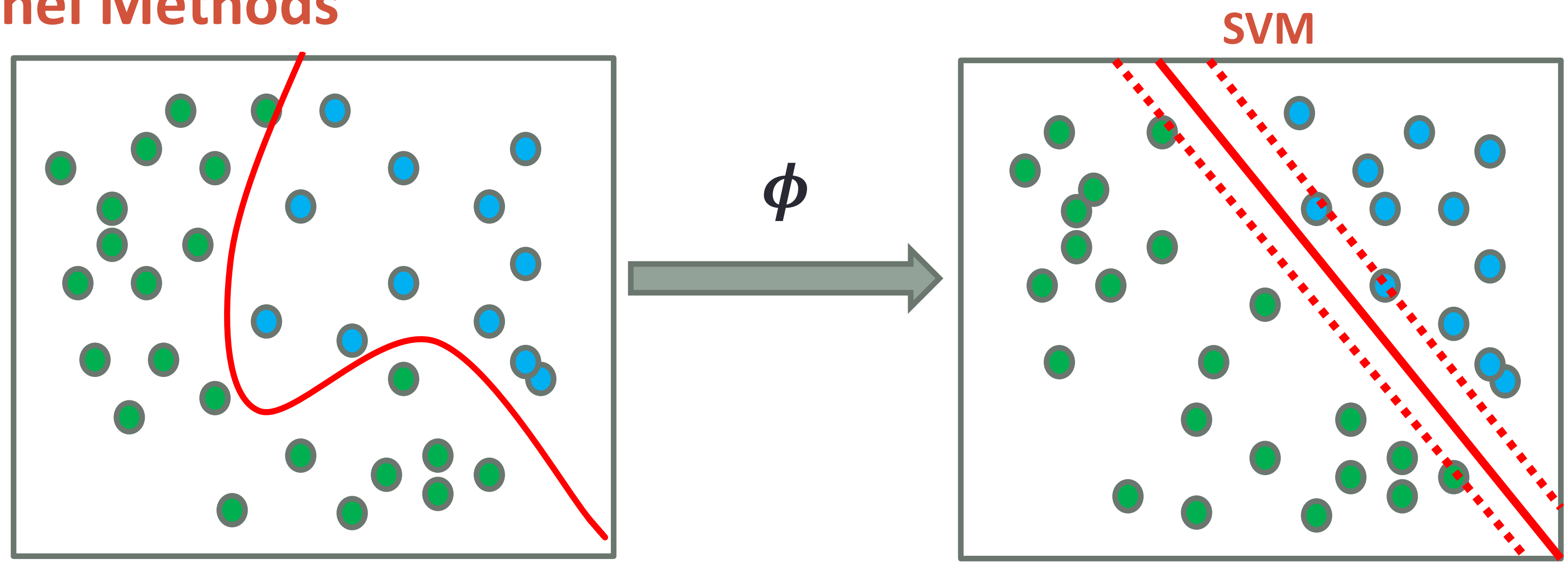
Categorical

Classification

- Generative classifier
- Discriminative classifier



Kernel Methods

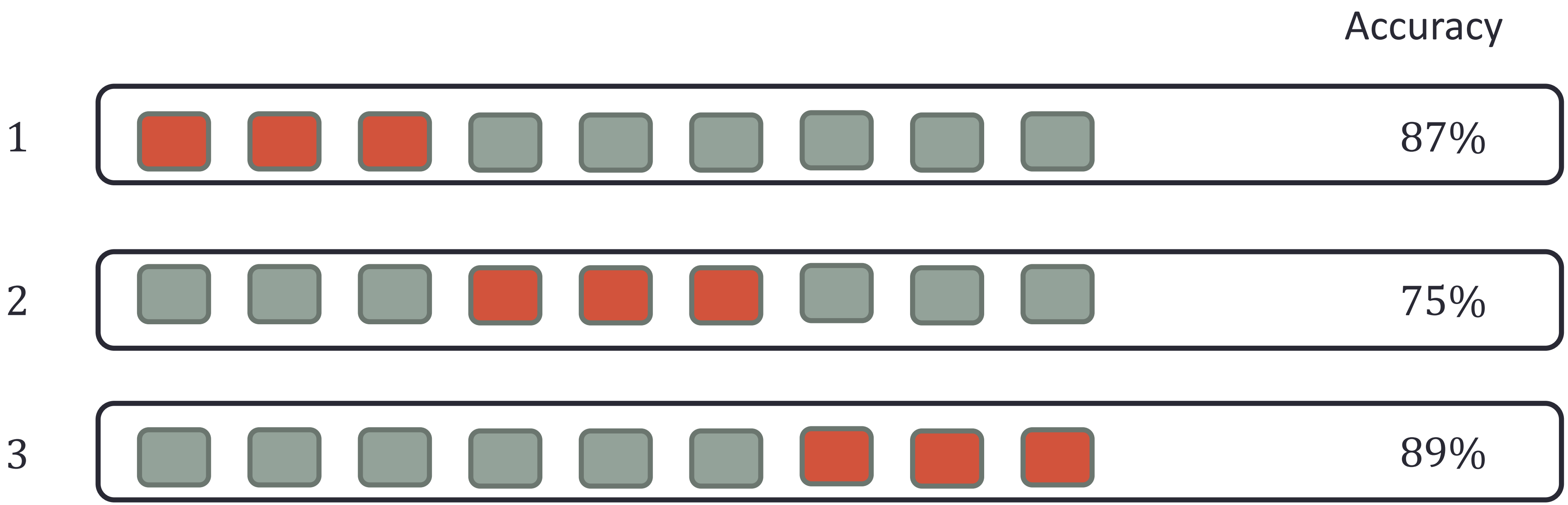


- Kernel Function – $\mathrm{K}(\boldsymbol{x_i}, \boldsymbol{x_j}) = \boldsymbol{\phi}(\boldsymbol{x_i}).\boldsymbol{\phi}(\boldsymbol{x_j})$

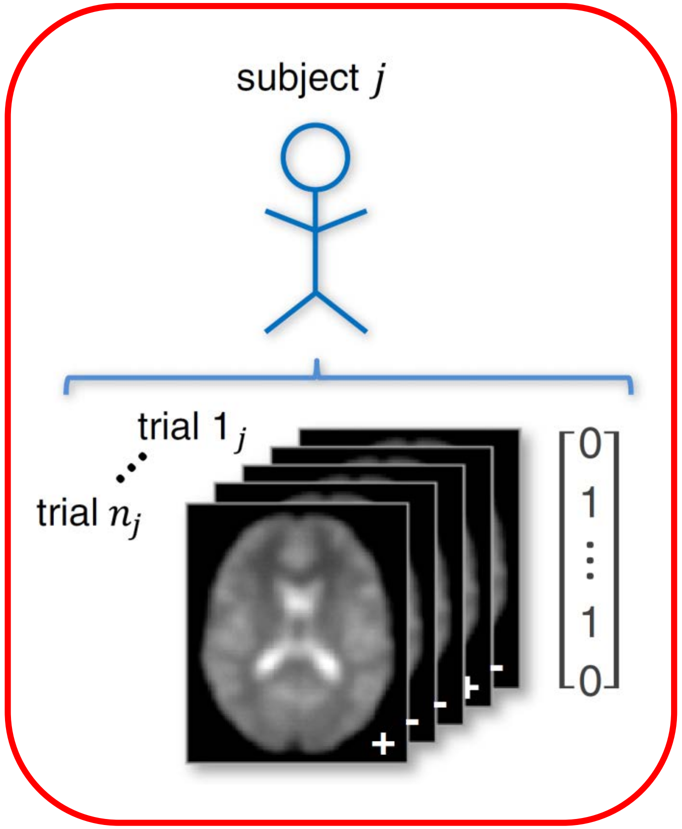
Kernel methods for pattern analysis, Taylor , Cristianini, 2004

K-fold Cross Validation

- Model Selection
- Performance evaluation



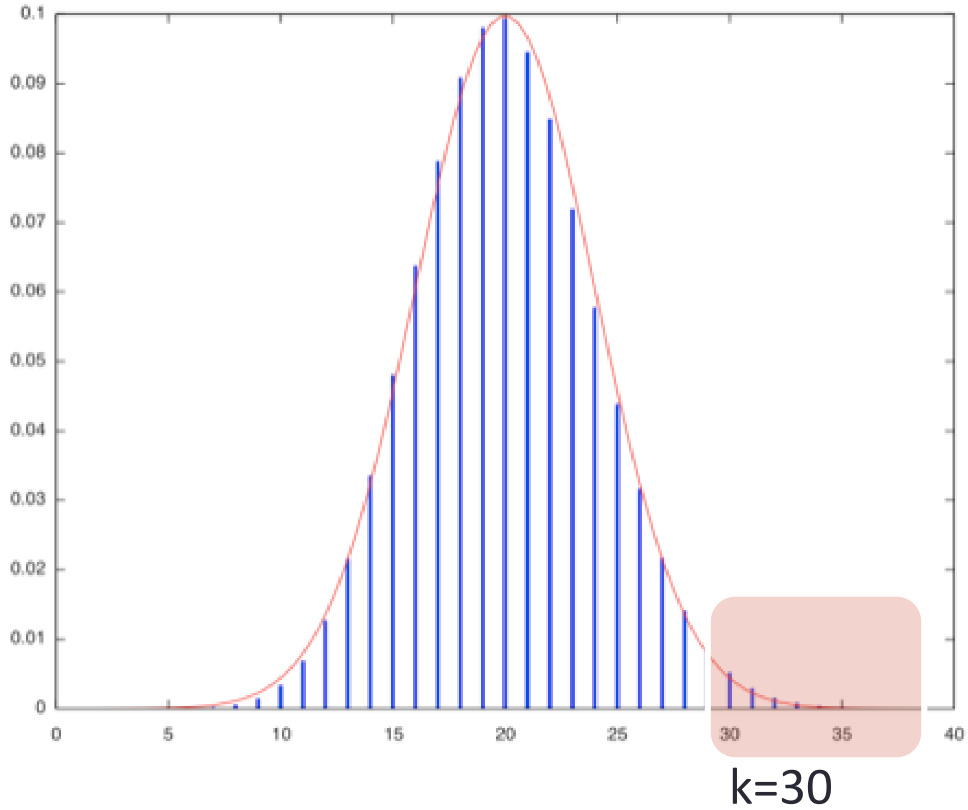
Performance – Single Subject



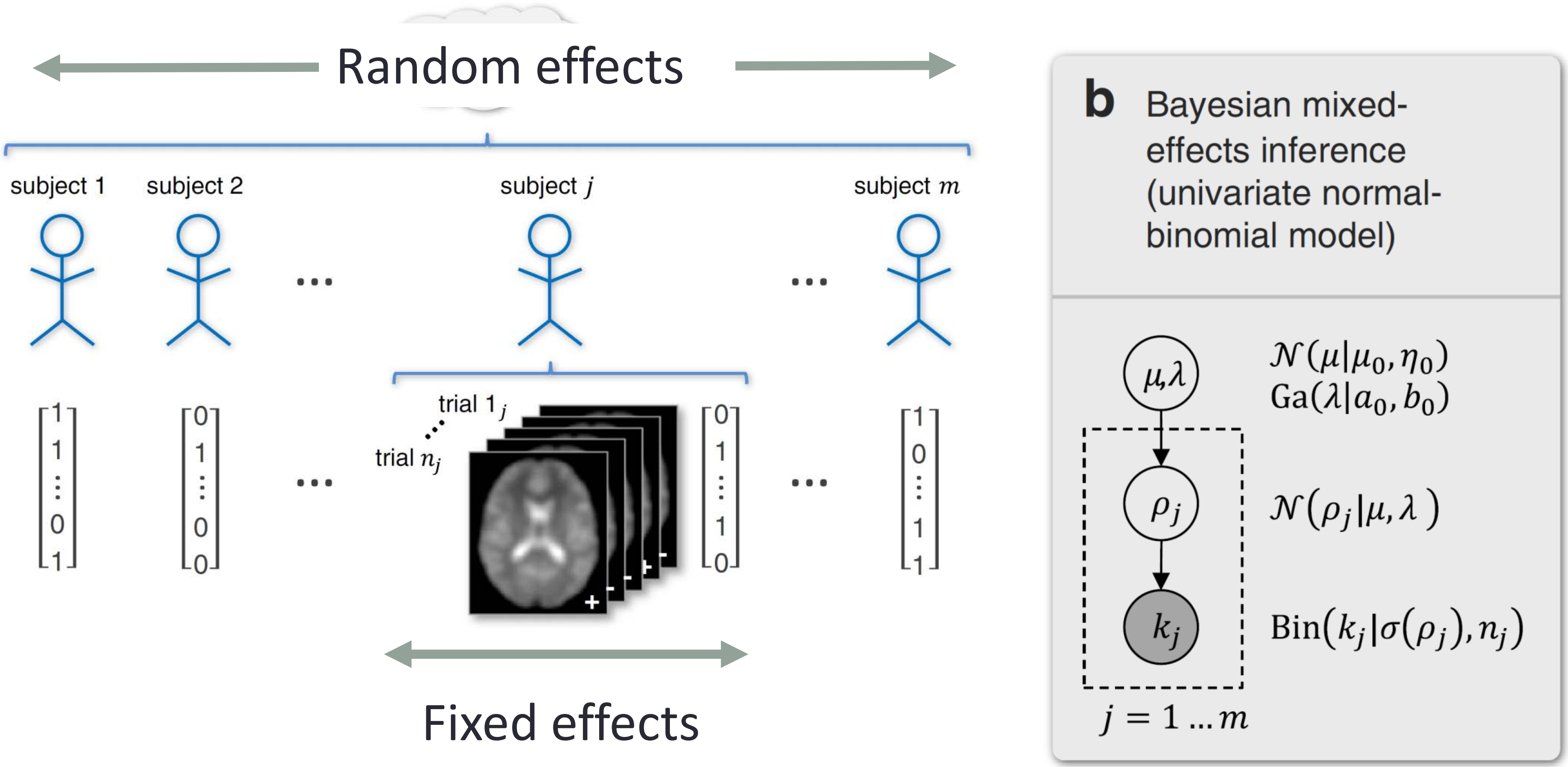
Brodersen et al. 2013, *NeuroImage*

Binomial Test

$$p = P(X \geq k|H_0) = 1 - B(k|n, \pi_0)$$



Performance – Multiple Subjects

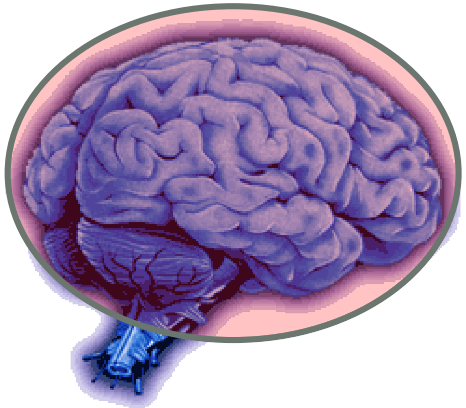


http://www.translationalneuromodeling.org/tapas/

Brodersen et al. 2013, *NeuroImage*

Using classification for fMRI data

Whole brain

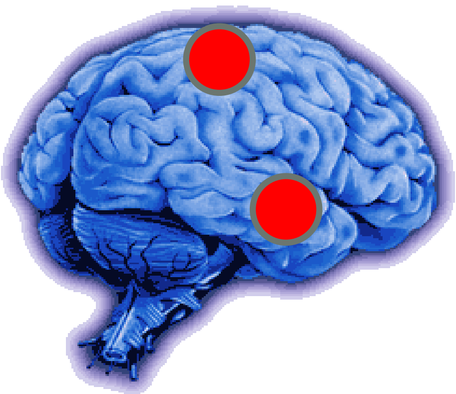


Mourao-Miranda et al. *(2005) NeuroImage,*
Marquand et al. *(2010) NeuroImage*

Searchlight classifier

Kriegeskorte et al. (2006) *PNAS*

Pattern localization

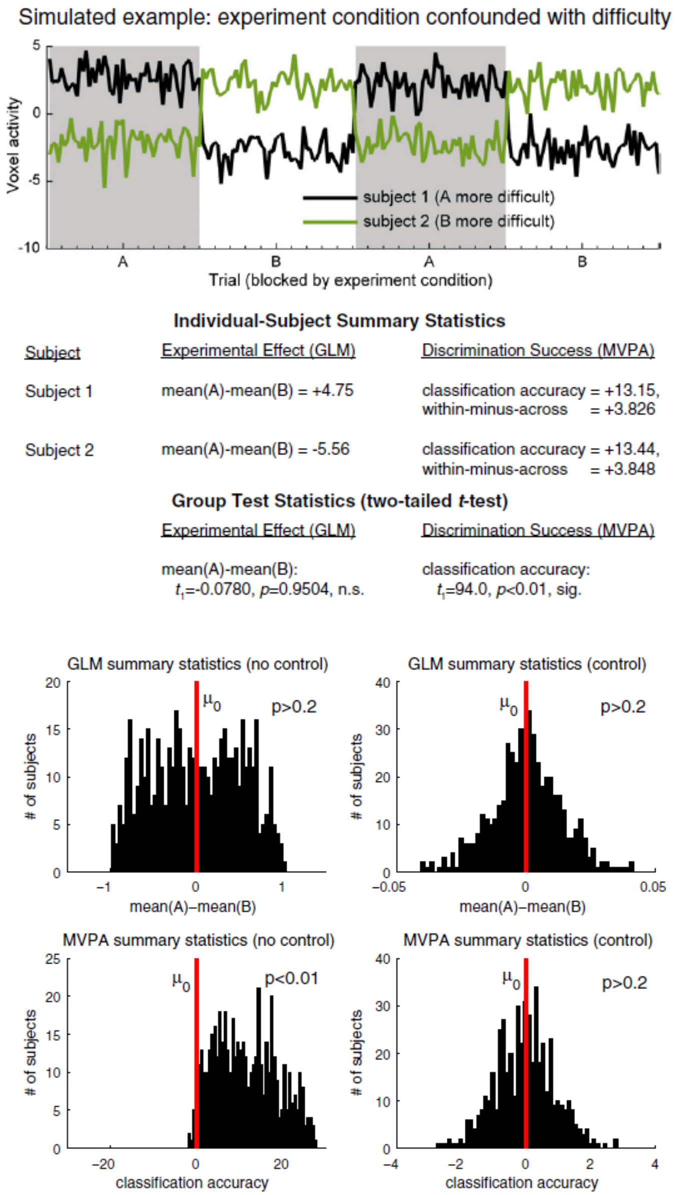


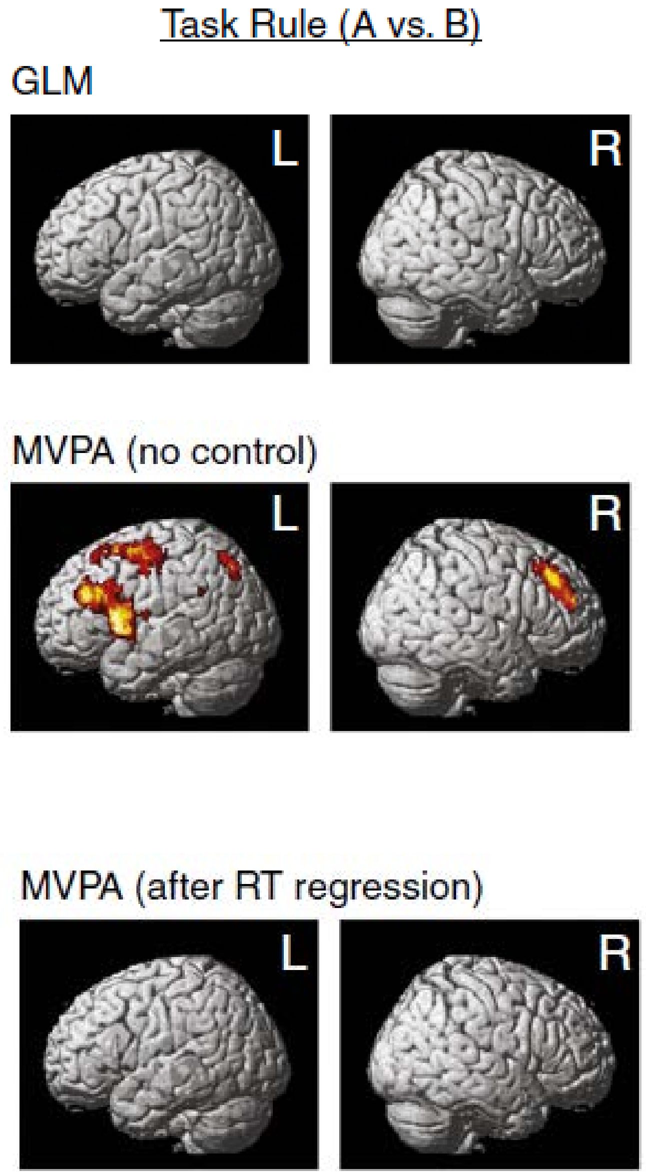
Word Category

Food
Building
People

Pereira et al. (2009) *NeuroImage*, Mitchell et al. (2004) *Machine Learning*

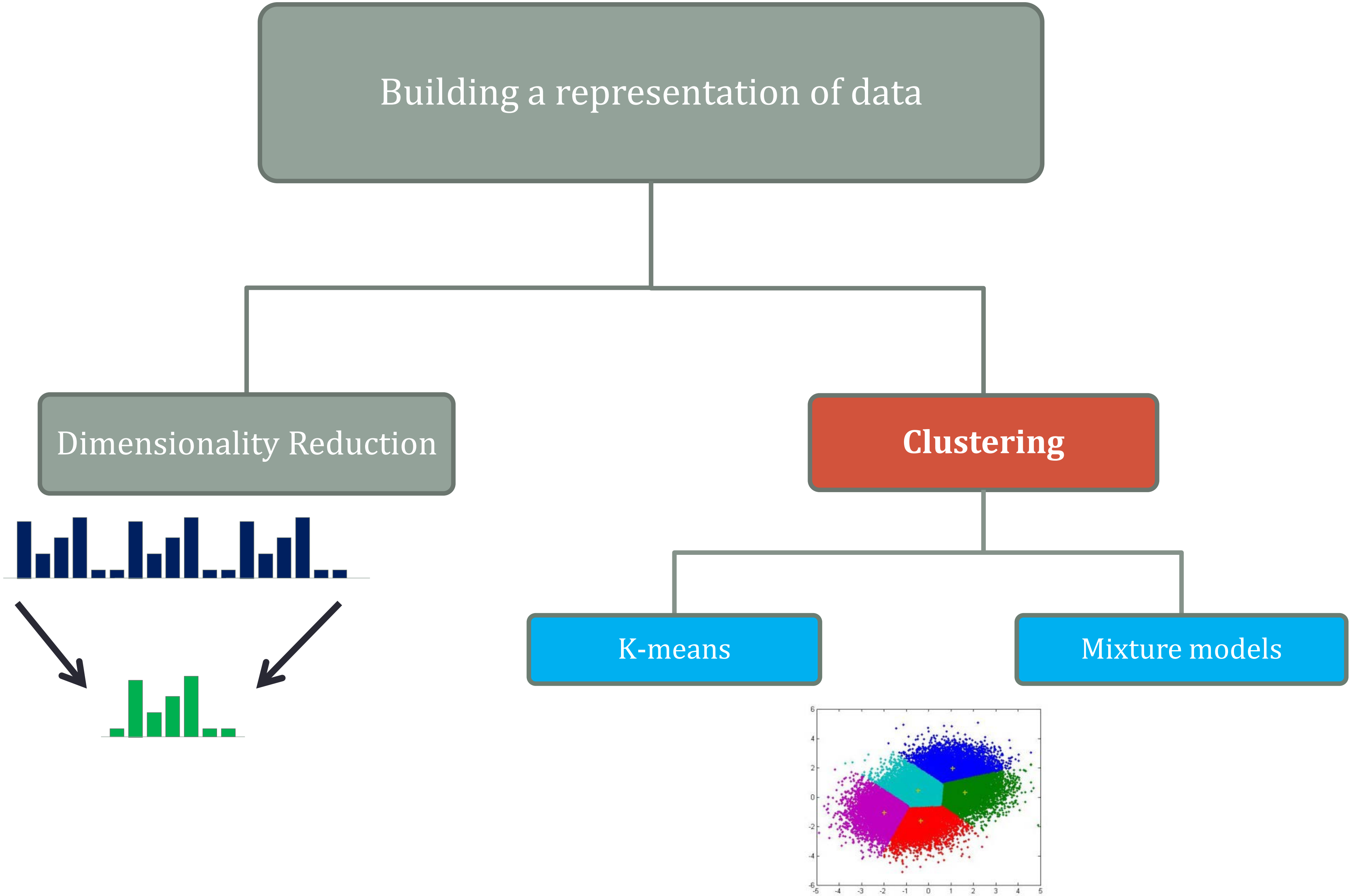
Confounds – GLM vs MVPA





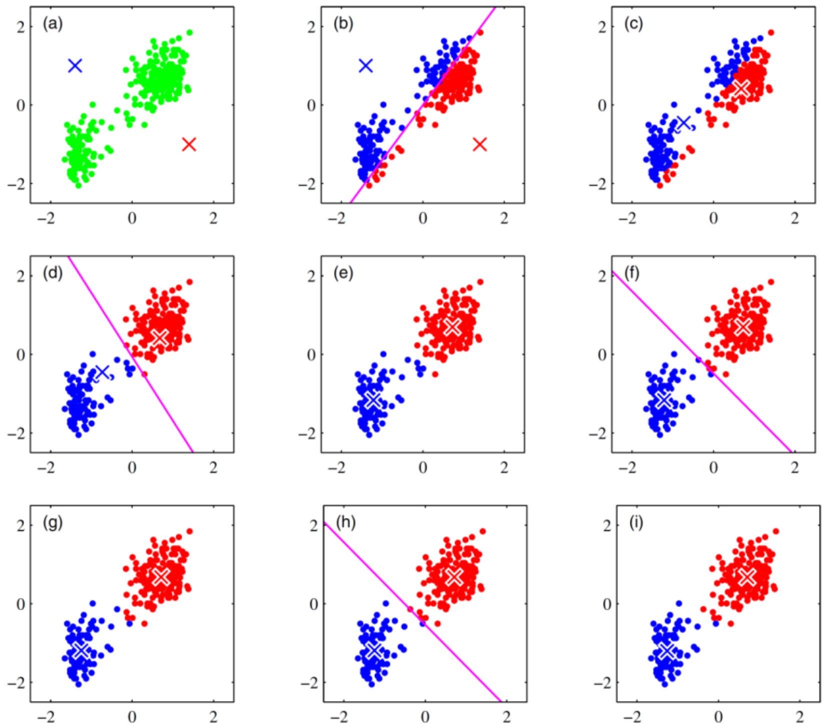
Todd et al. 2013, *NeuroImage*

Unsupervised Learning

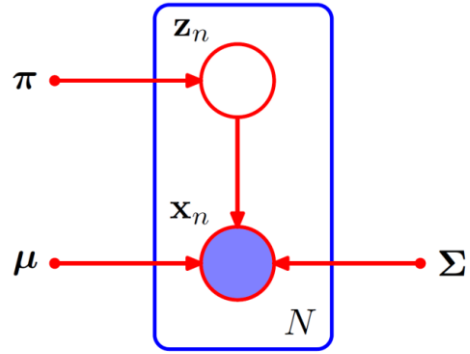


K-means

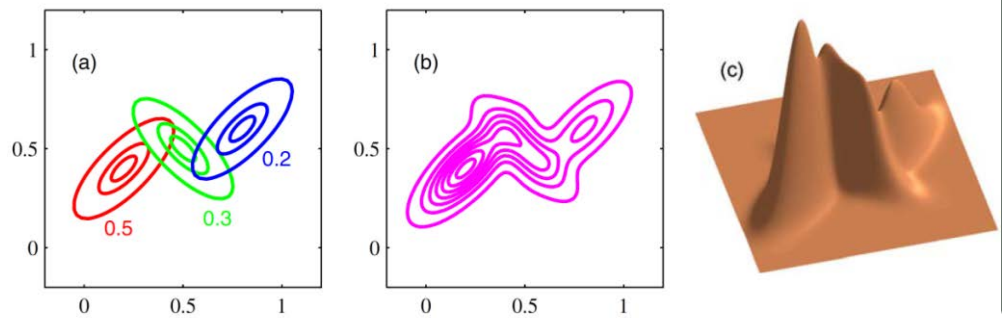
$$\widetilde{J} = \sum_{n=1}^{N} \sum_{k=1}^{K} r_{nk} \mathcal{V}(\mathbf{x}_n, \boldsymbol{\mu}_k)$$



Mixture of Gaussians



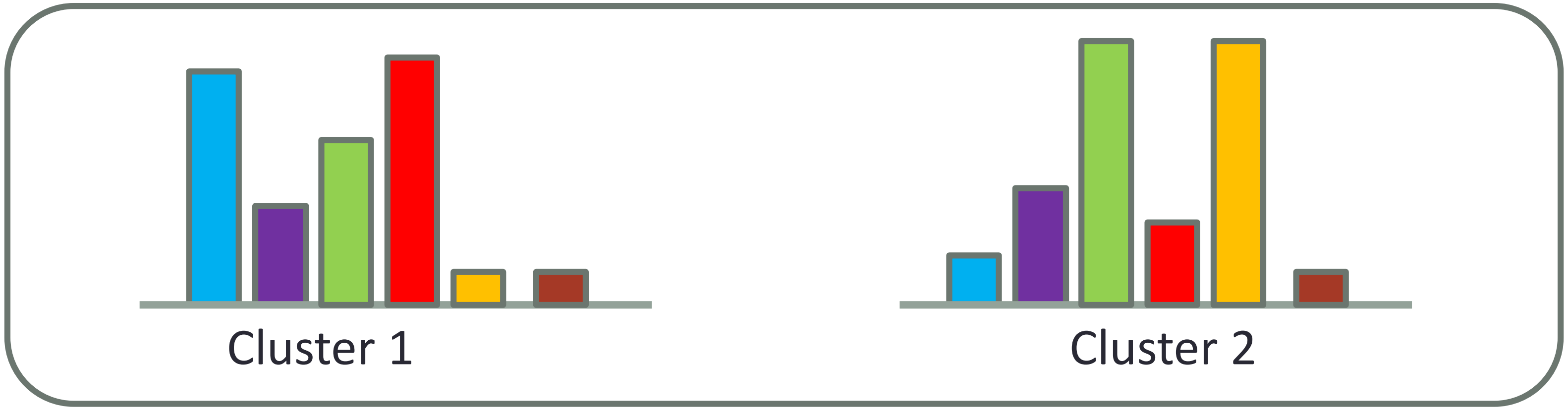
$$p(\mathbf{x}) = \sum_{k=1}^{K} \pi_k \mathcal{N}(\mathbf{x}|\boldsymbol{\mu}_k, \boldsymbol{\Sigma}_k)$$



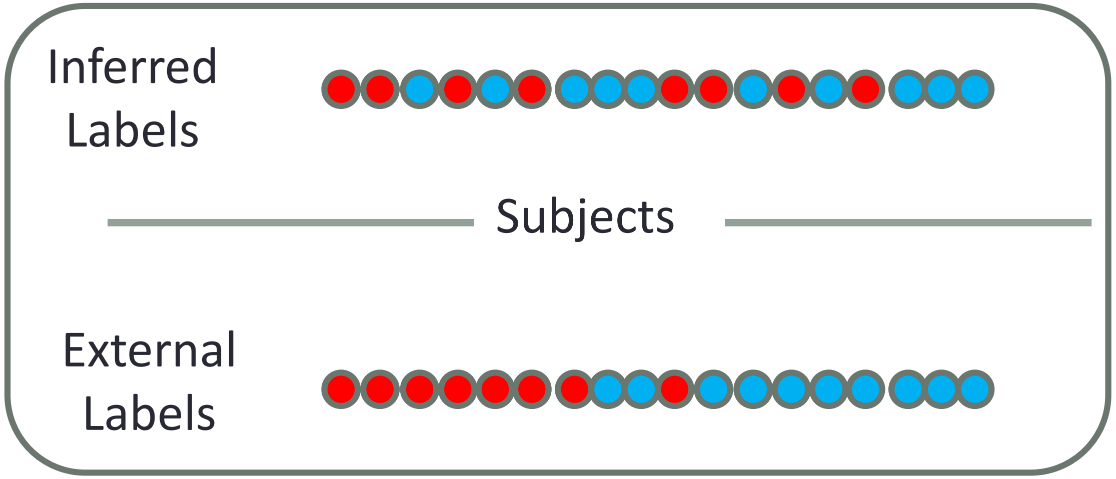
Bishop (2006)

Interpretation

- Cluster parameters



- Internal Criterion – Model Evidence
- External Criterion - Purity



Normalized Mutual Information (NMI)

Balanced purity

Rand Index

Motivation

- Modelling
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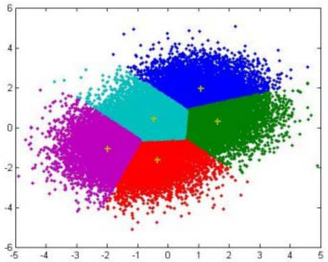
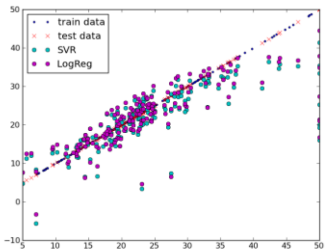
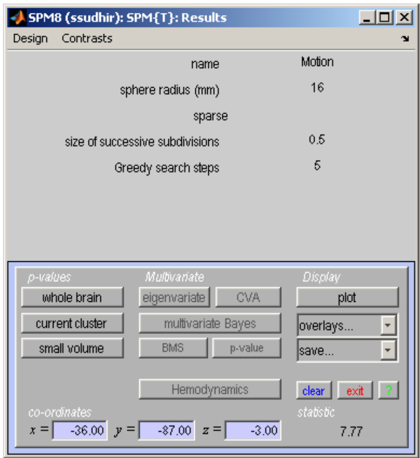
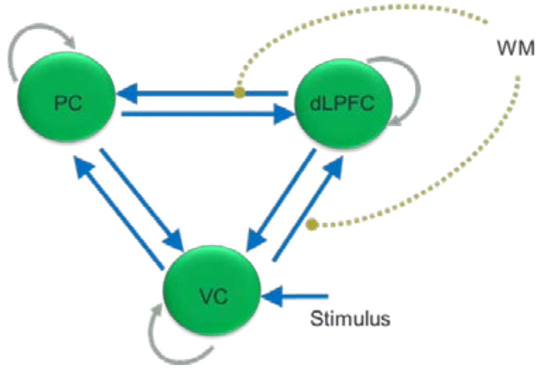
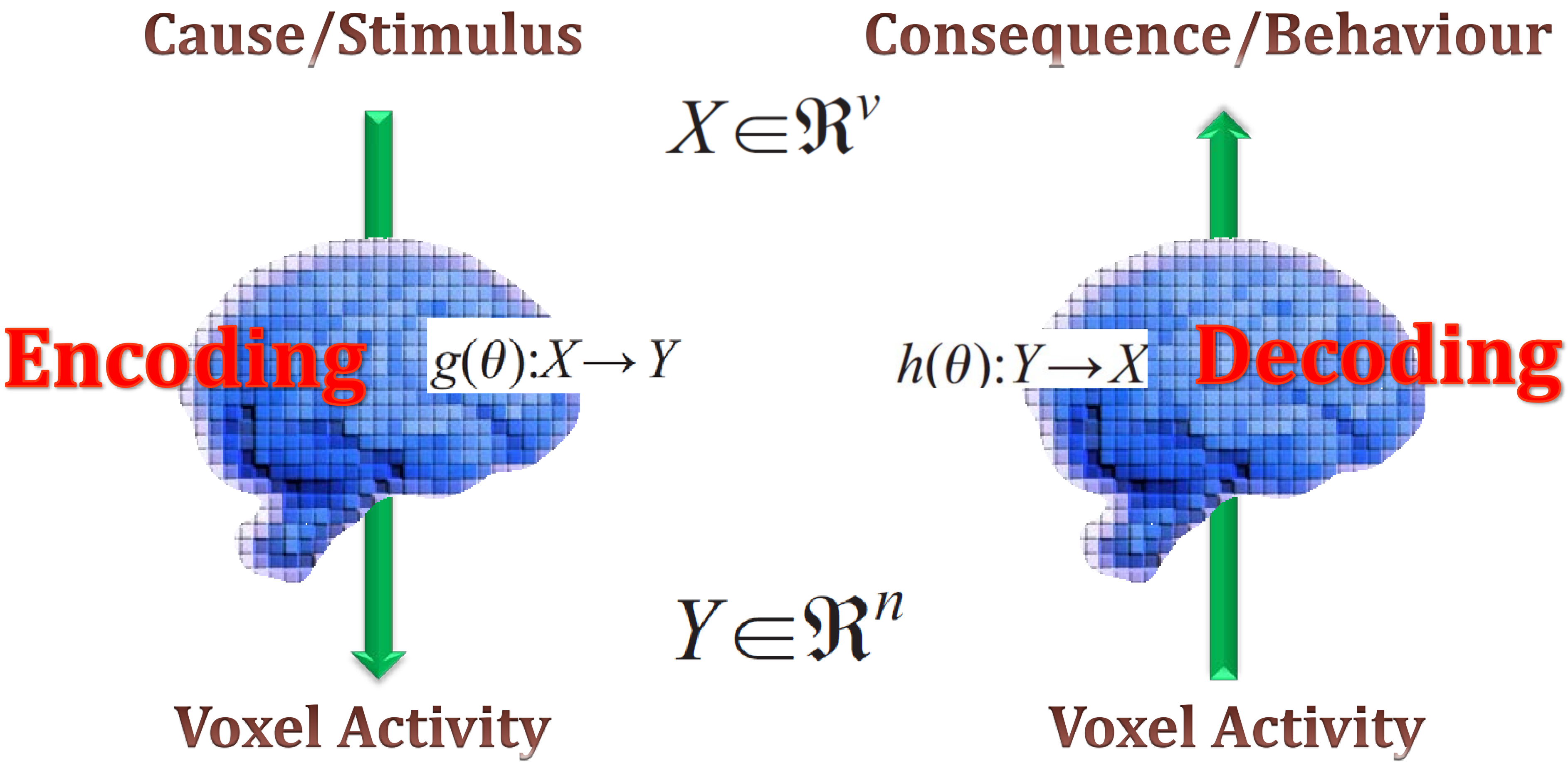




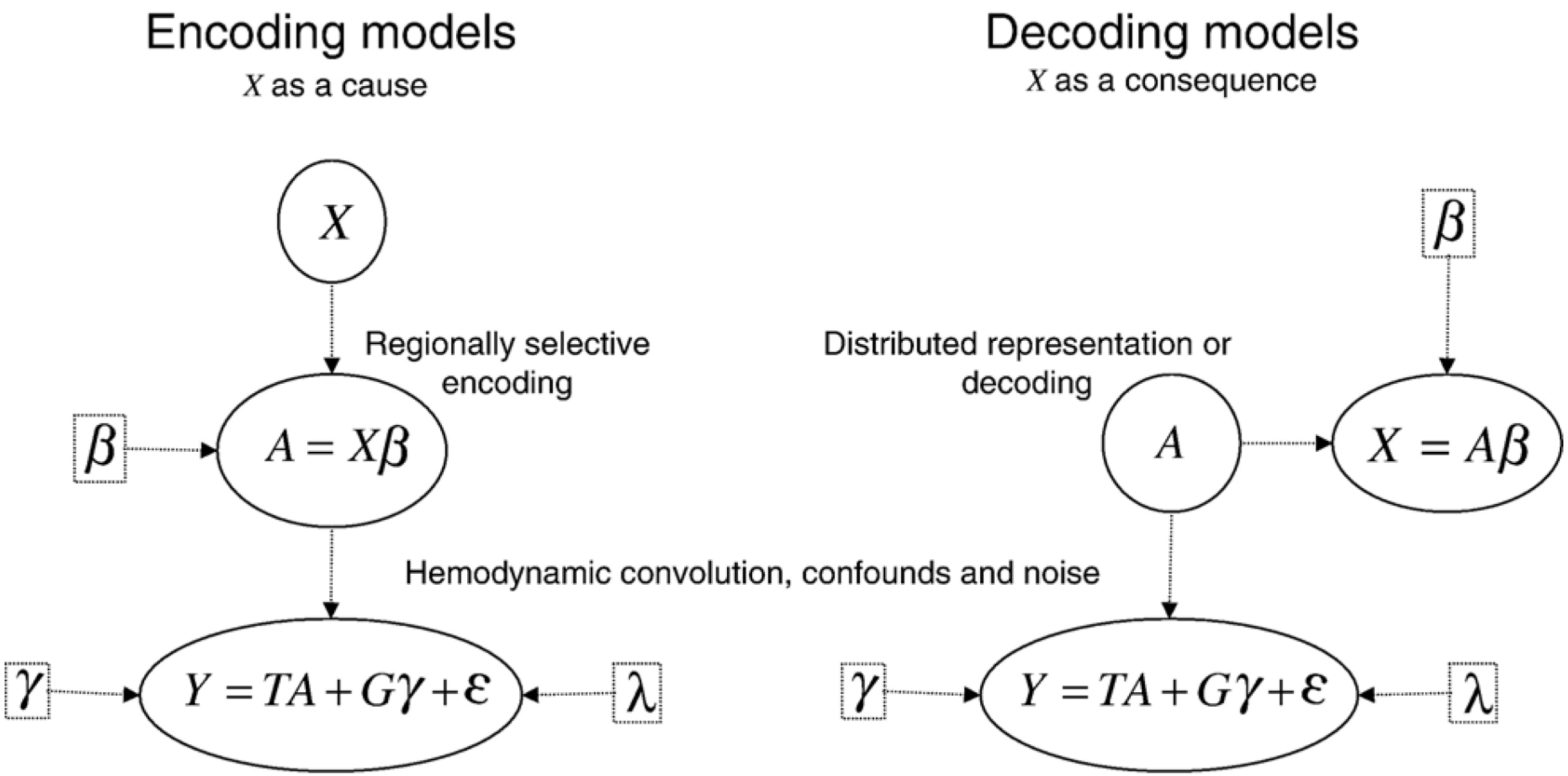




Encoding Vs Decoding Models



Encoding Vs Decoding



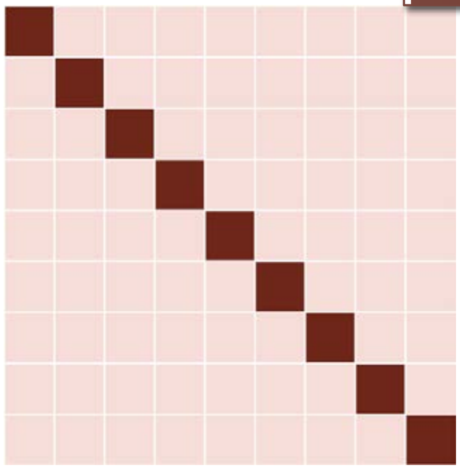
$$g(\theta): X \rightarrow Y$$
$$Y = TX\beta + G\gamma + \varepsilon$$

$$g(\theta): Y \rightarrow X$$
$$TX = Y\beta - G\gamma\beta - \varepsilon\beta$$

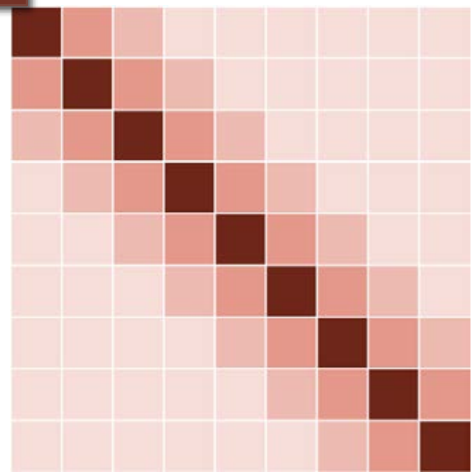
Friston et al. 2008 NeuroImage

Coding hypotheses

Sparse vectors



Spatial vectors

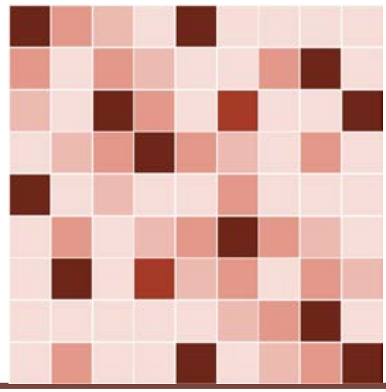


Smooth vectors

Distributed vectors

Singular vectors
of data

$$UDV^T = RY^T$$



Support vectors

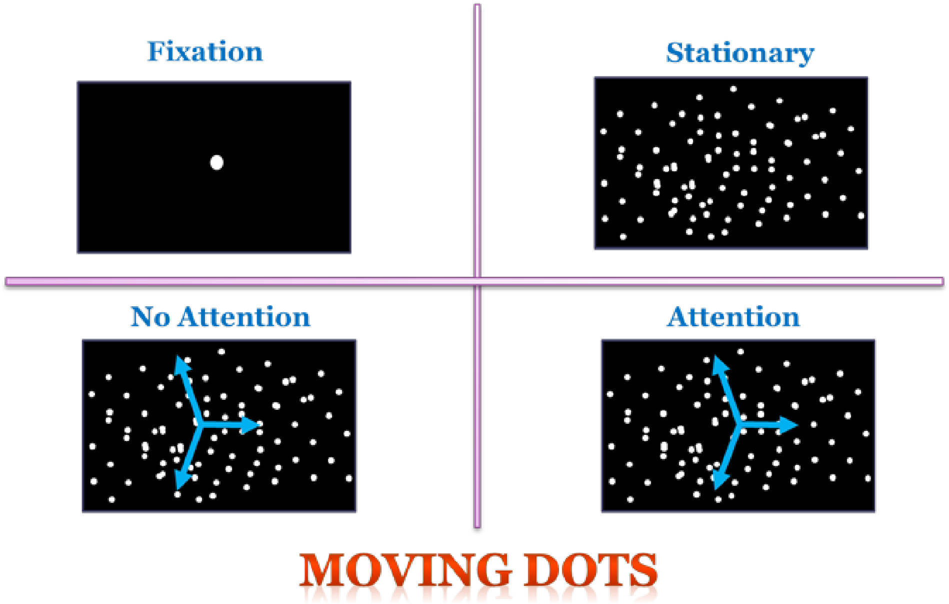
$$U = RY^T$$

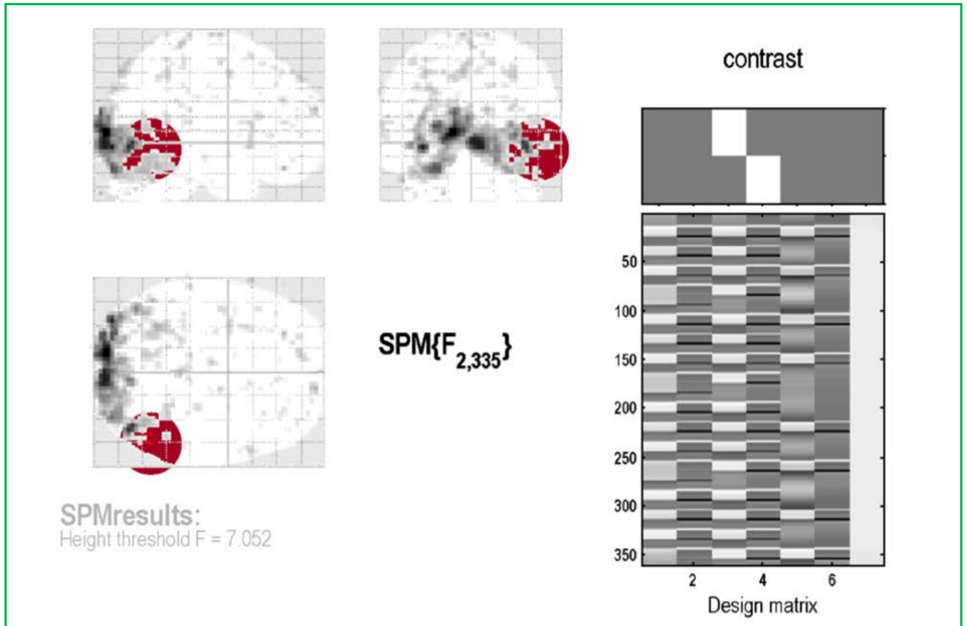
Bayesian decoding of motion

Attention to motion dataset - Büchel & Friston 1999 Cerebral Cortex

Experimental factors:

1. Photic
2. Motion
3. Attention





Statistics: *search volume: 16.0mm sphere at [48,-63,0]*

set-level		cluster-level			voxel-level					mm mm mm
p	c	$p_{corrected}$	k_E	$p_{uncorrected}$	$p_{FWE-corr}$	$p_{FDR-corr}$	F	$(Z_\equiv)$	$p_{uncorrected}$	
0.006	4		39		0.000	0.000	40.66	Inf	0.000	39 -72 0
					0.000	0.000	40.09	Inf	0.000	42 -75 -3
			3		0.002	0.000	13.35	4.55	0.000	39 -63 -12
			1		0.124	0.003	8.67	3.52	0.000	51 -66 -3
			1		0.436	0.010	7.36	3.18	0.001	48 -63 0

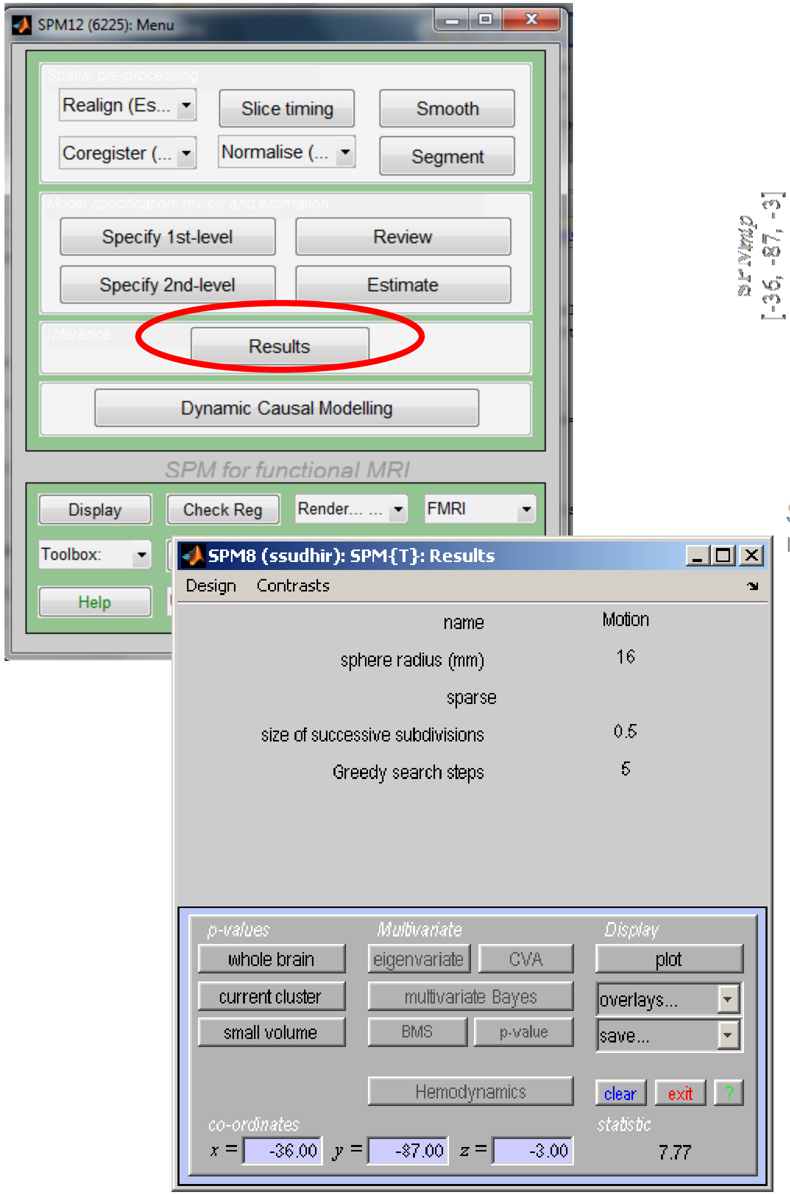
table shows 16 local maxima more than 4.0mm apart

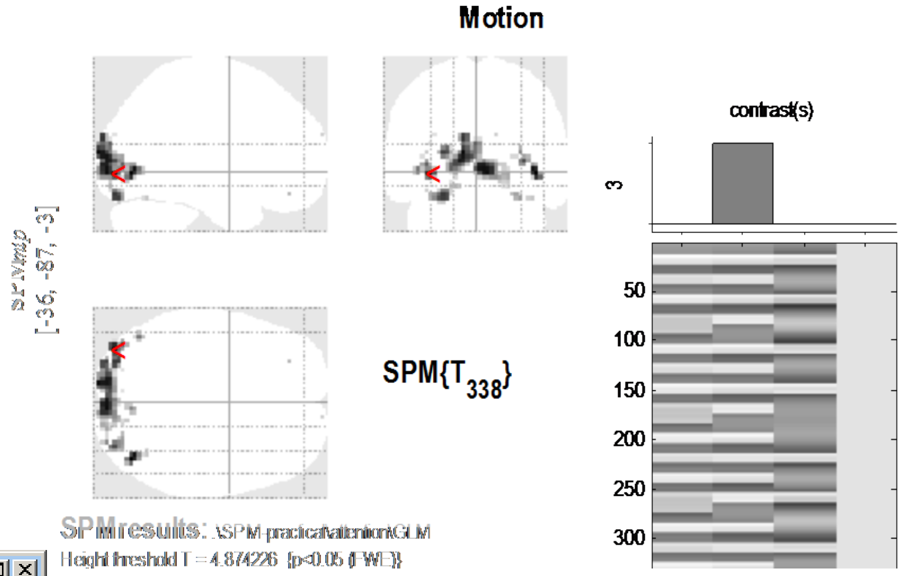
Height threshold: F = 7.05, p = 0.001 (0.513) {p<0.001 (unc.)}
Extent threshold: k = 0 voxels, p = 1.000 (0.513)
Expected voxels per cluster, <k> = 1.212
Expected number of clusters, <c> = 0.72
Expected false discovery rate, <= 0.01

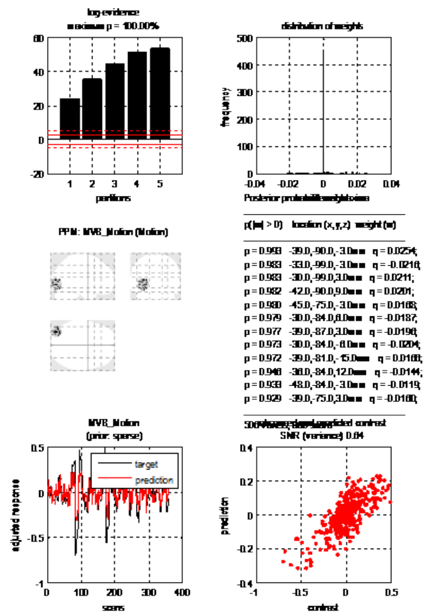
Degrees of freedom = [2.0, 335.0]
FWHM = 7.5 7.4 7.1 mm mm mm; 2.5 2.5 2.4 {voxels};
Volume: 15741; 583 voxels; 43.3 resels
Voxel size: 3.0 3.0 3.0 mm mm mm; (resel = 14.69 voxels)

Friston et al. 2008 NeuroImage

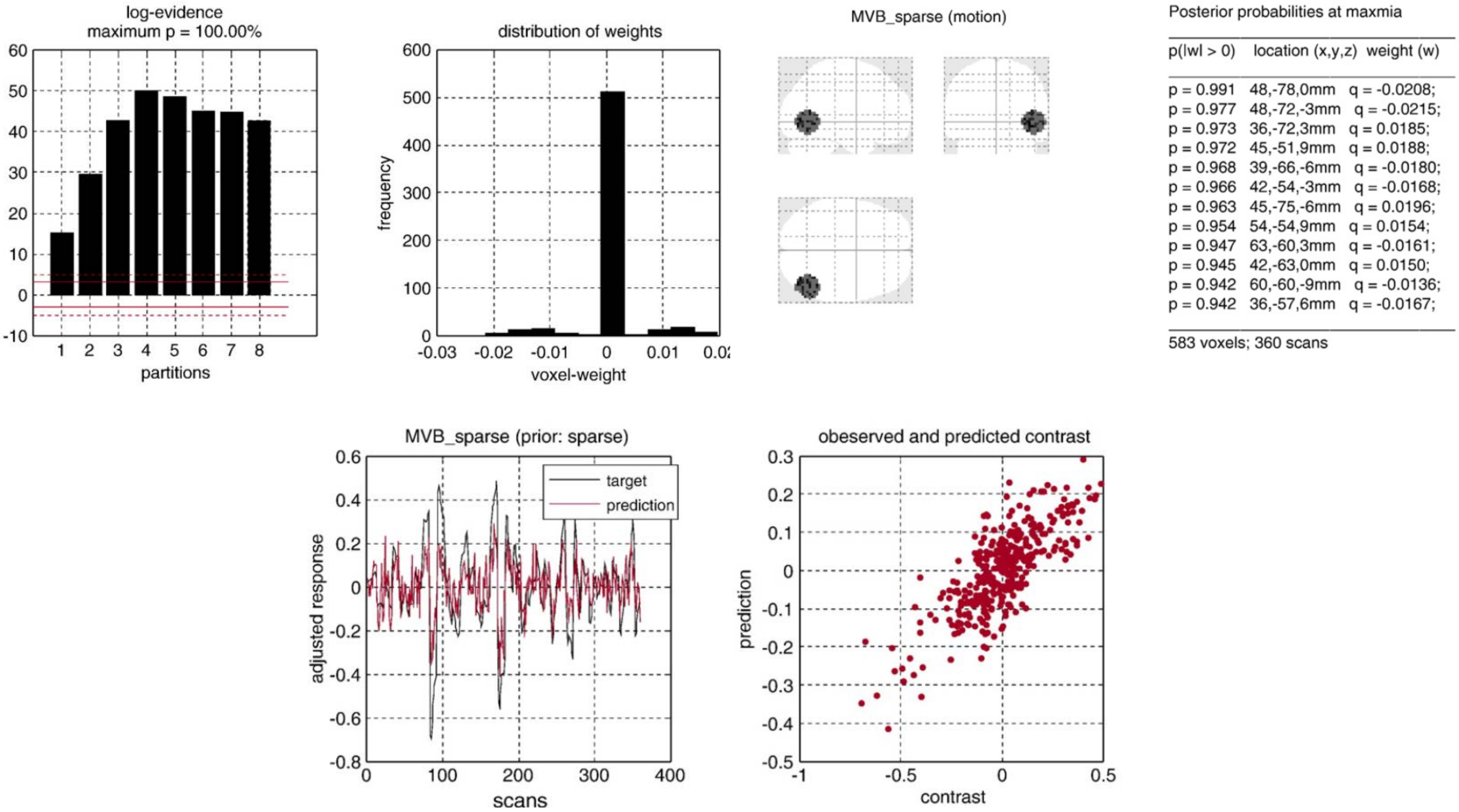
Multivariate Bayes in SPM





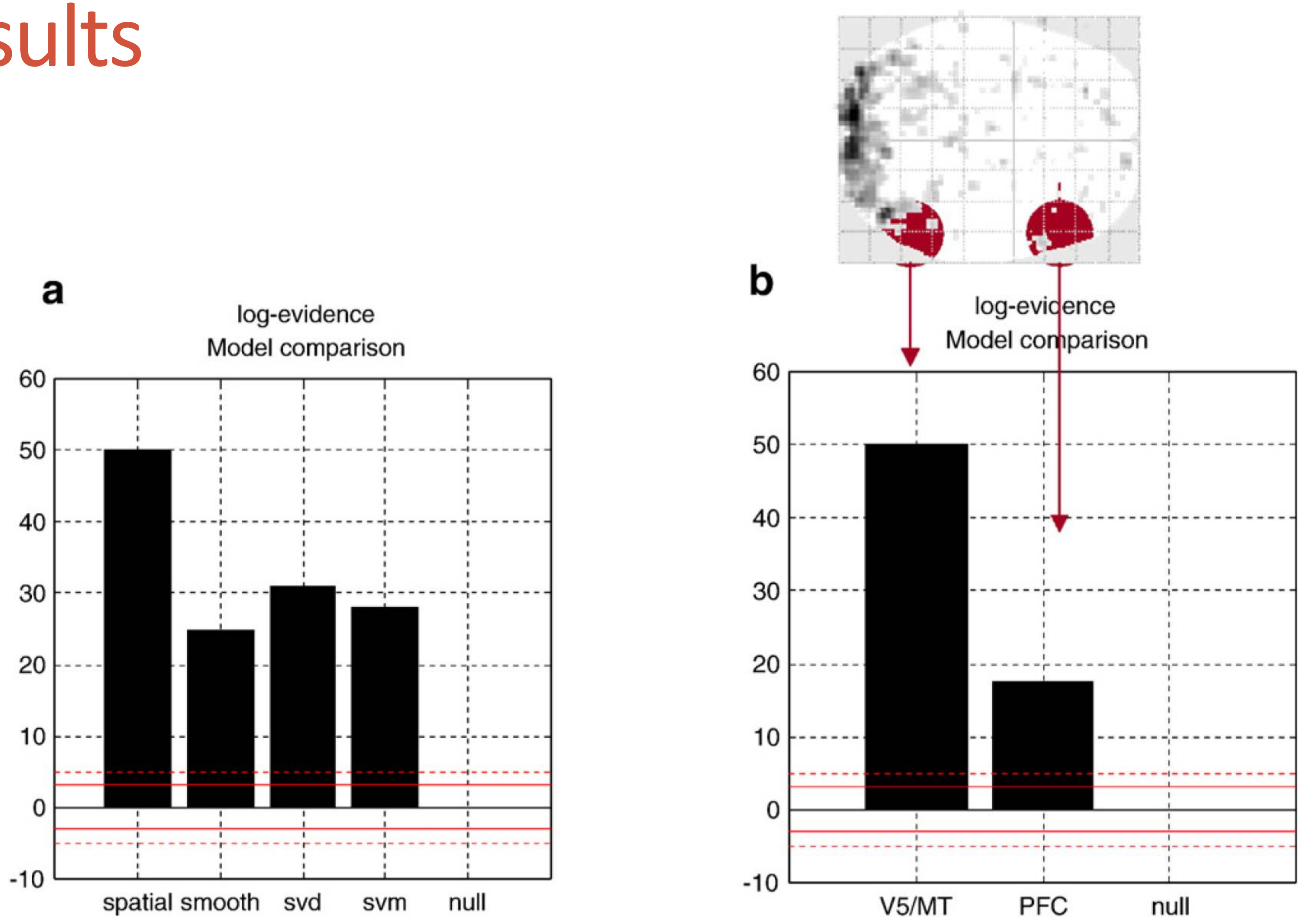


Results



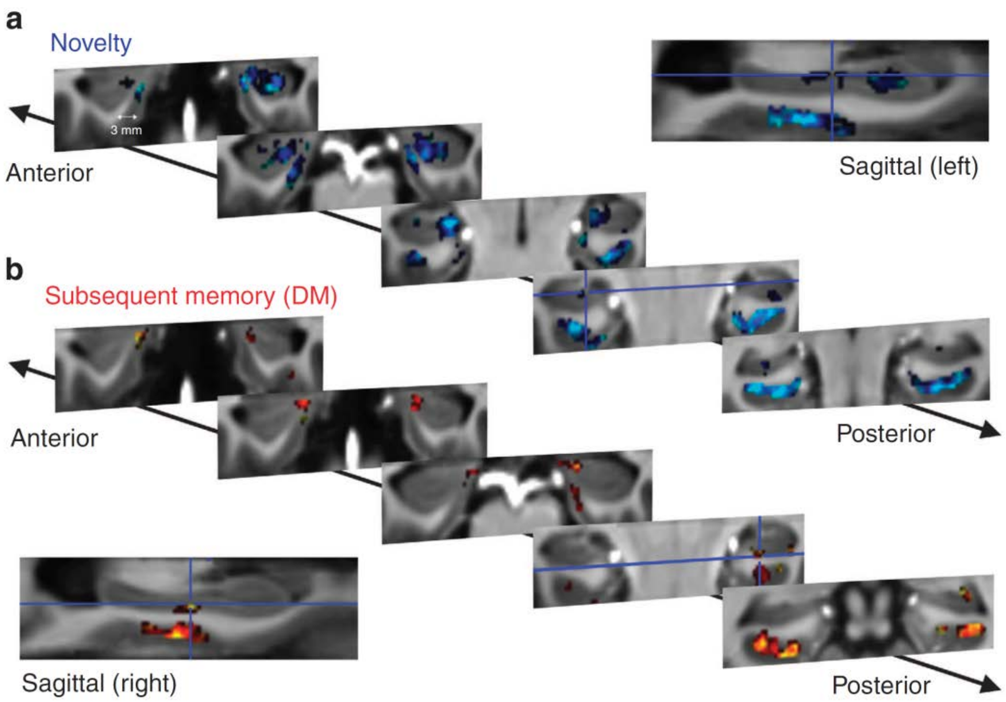
Friston et al. 2008 NeuroImage

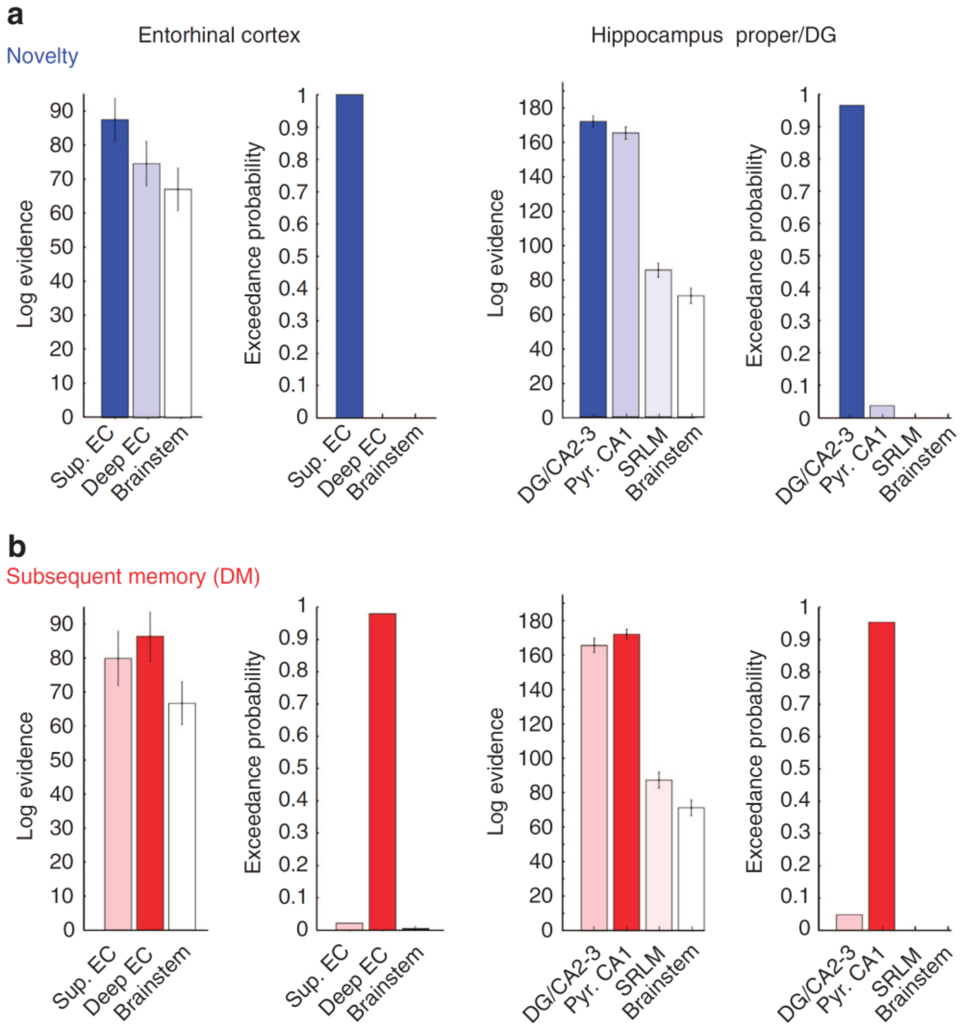
Results



a
log-evidence
Model comparison
60
50
40
30
20
10
0
-10
spatial smooth
svd
svm
null
b
log-evidence
Model comparison
60
50
40
30
20
10
0
-10
V5/MT
PFC
null

Laminar activity related to novelty and episodic encoding





Maas et al. 2014 Nature Communications

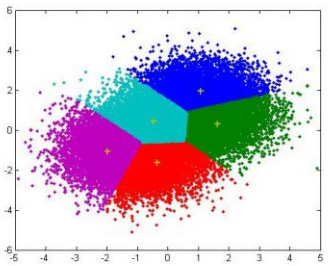
Motivation

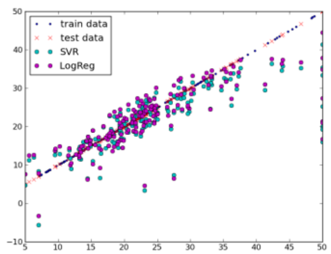
Modelling Principles

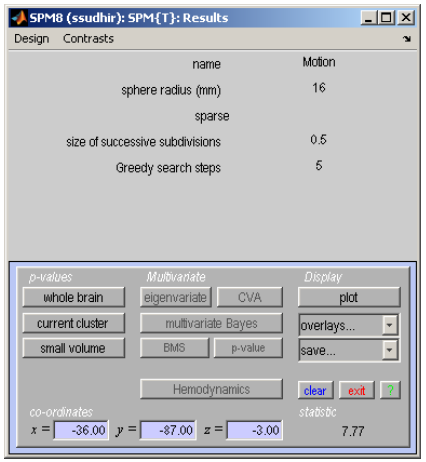
Learning from Data

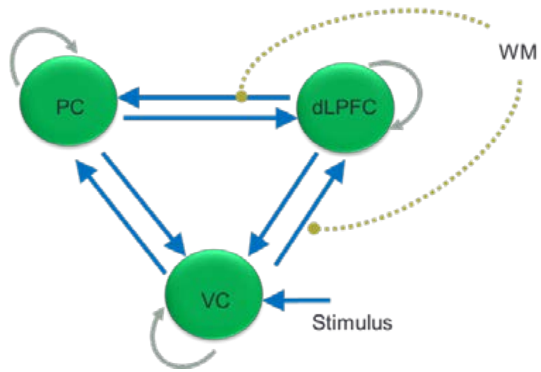
Multivariate Bayes in SPM

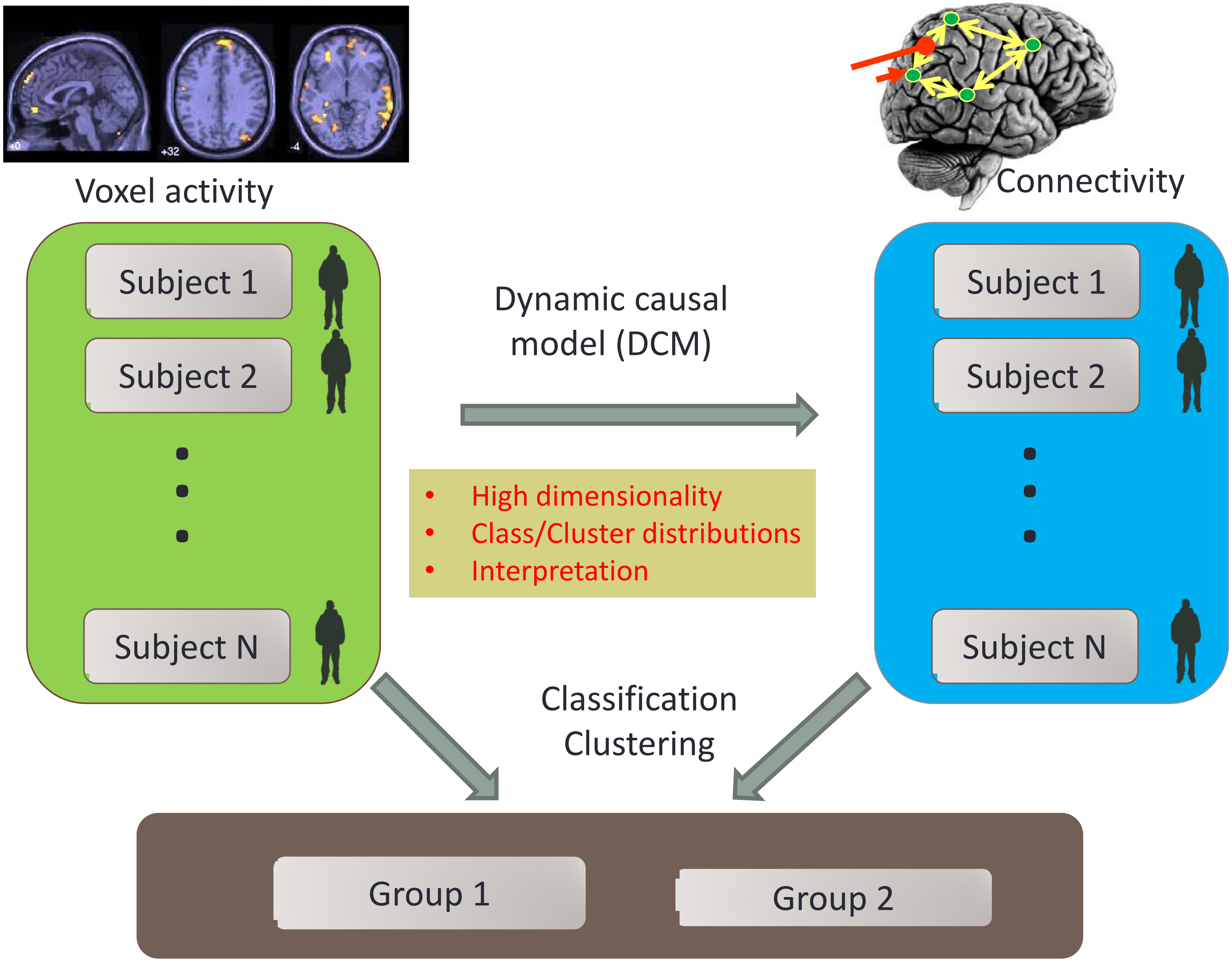
Generative Embedding



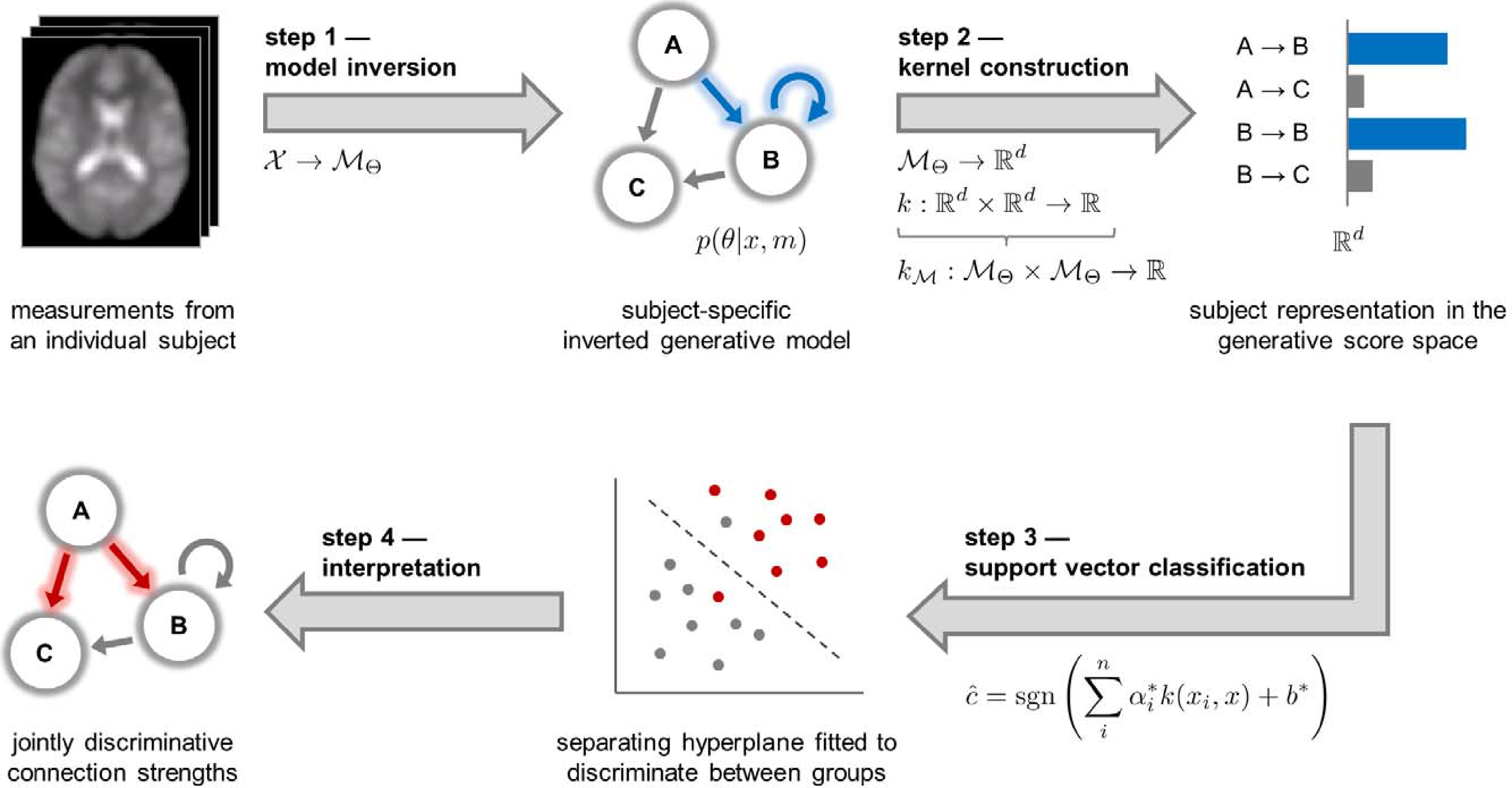






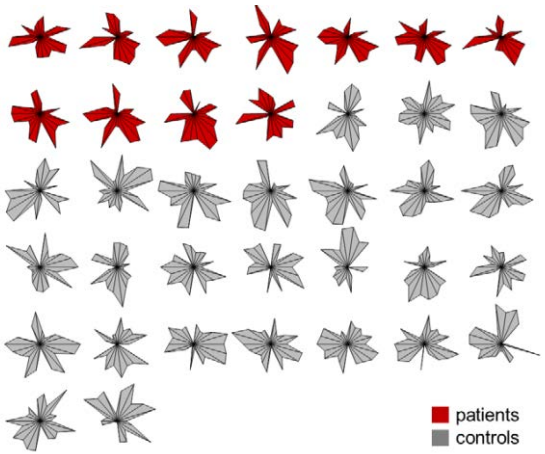

Voxel activity
Connectivity
Subject 1
Subject 2
Subject N
Subject 1
Subject 2
Subject N
Dynamic causal model (DCM)
High dimensionality
Class/Cluster distributions
Interpretation
Classification
Clustering
Group 1
Group 2

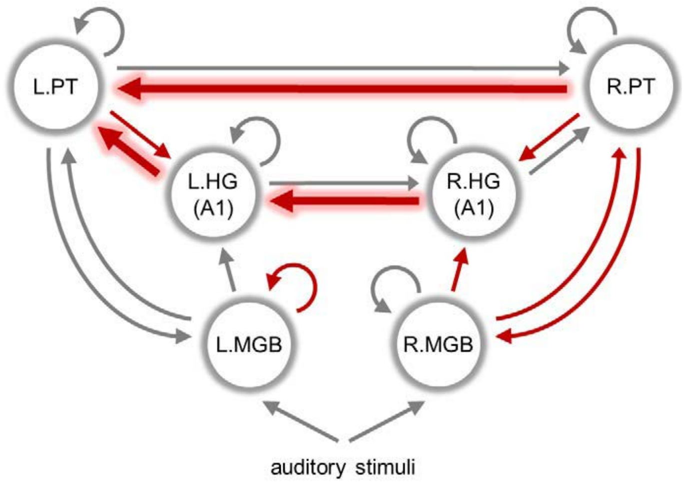
Generative Embedding - Classification

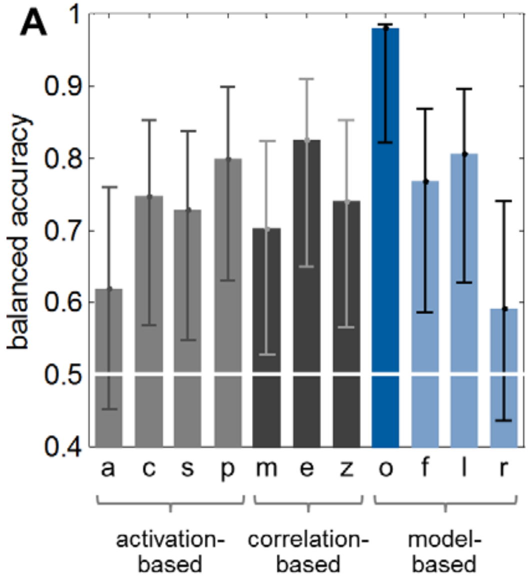


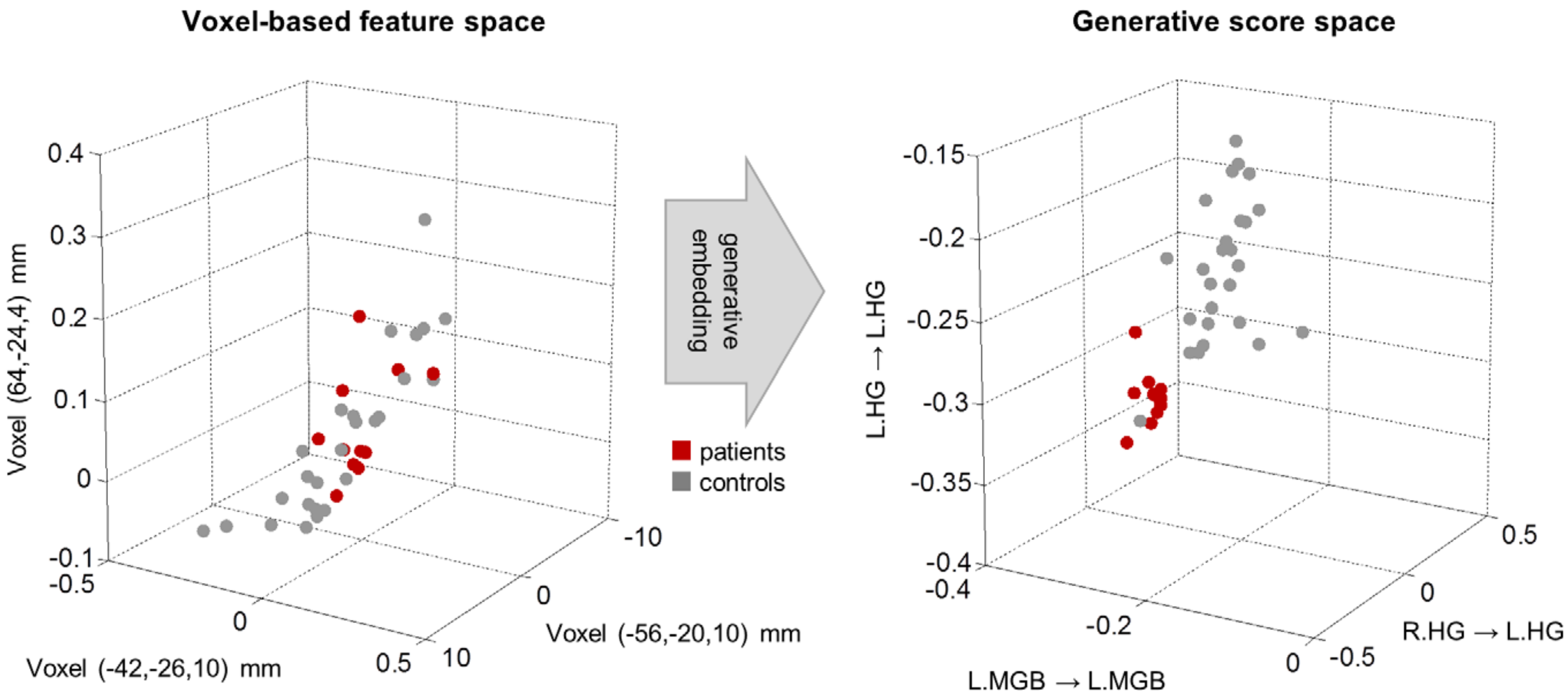
Brodersen et al. pLOS computation biology 2011.

DCM - Speech processing





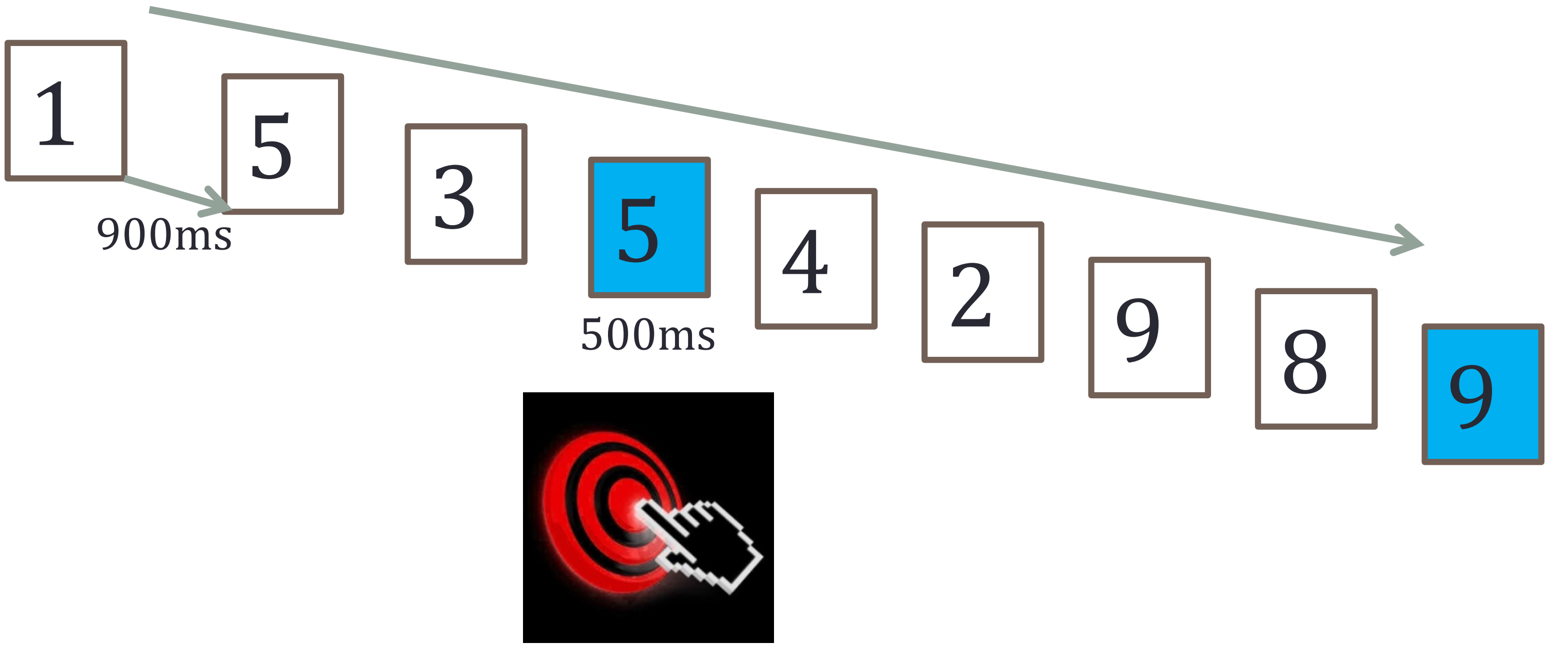




Brodersen et al. pLOS computation biology 2011.

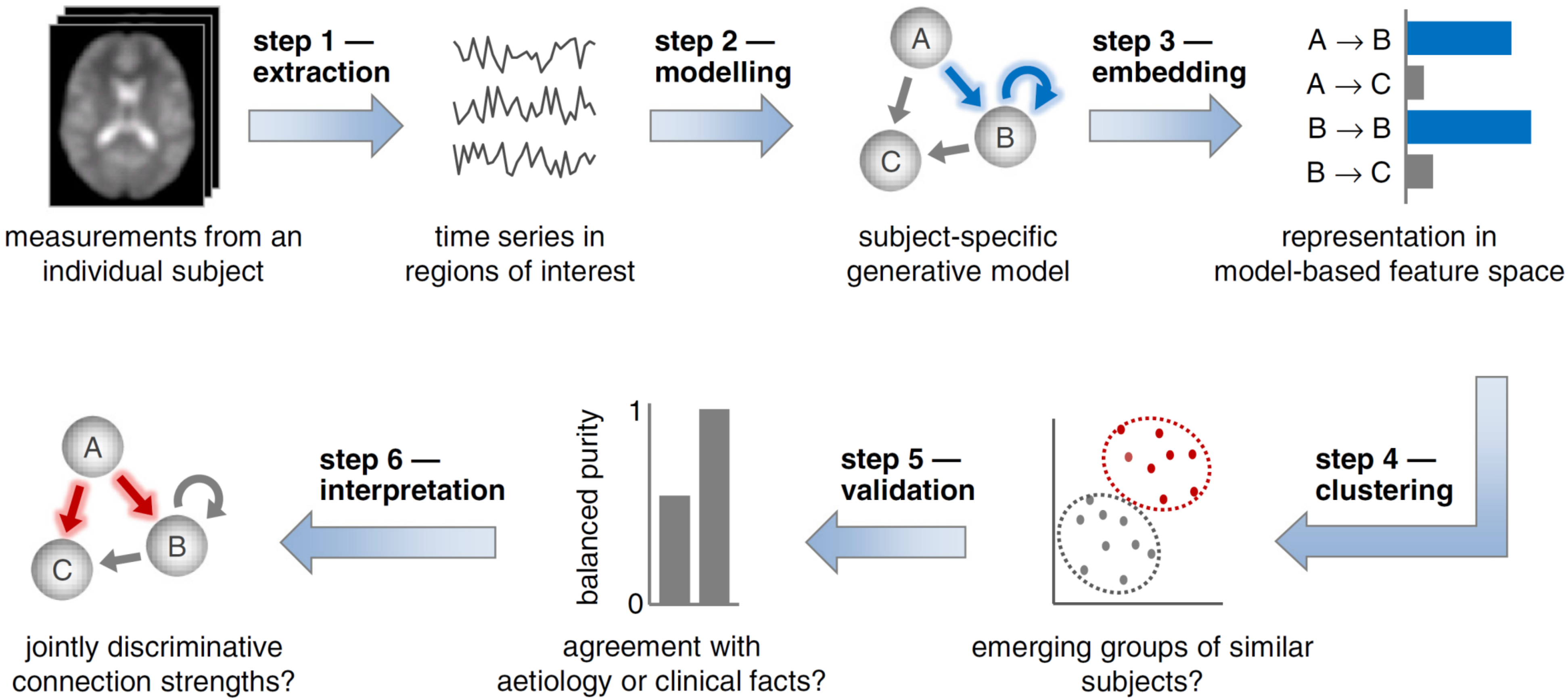
Working memory - fMRI

- 41 Schizophrenia patients (DSM IV,ICD 10), 42 controls
- Visual numeric n-back working memory task



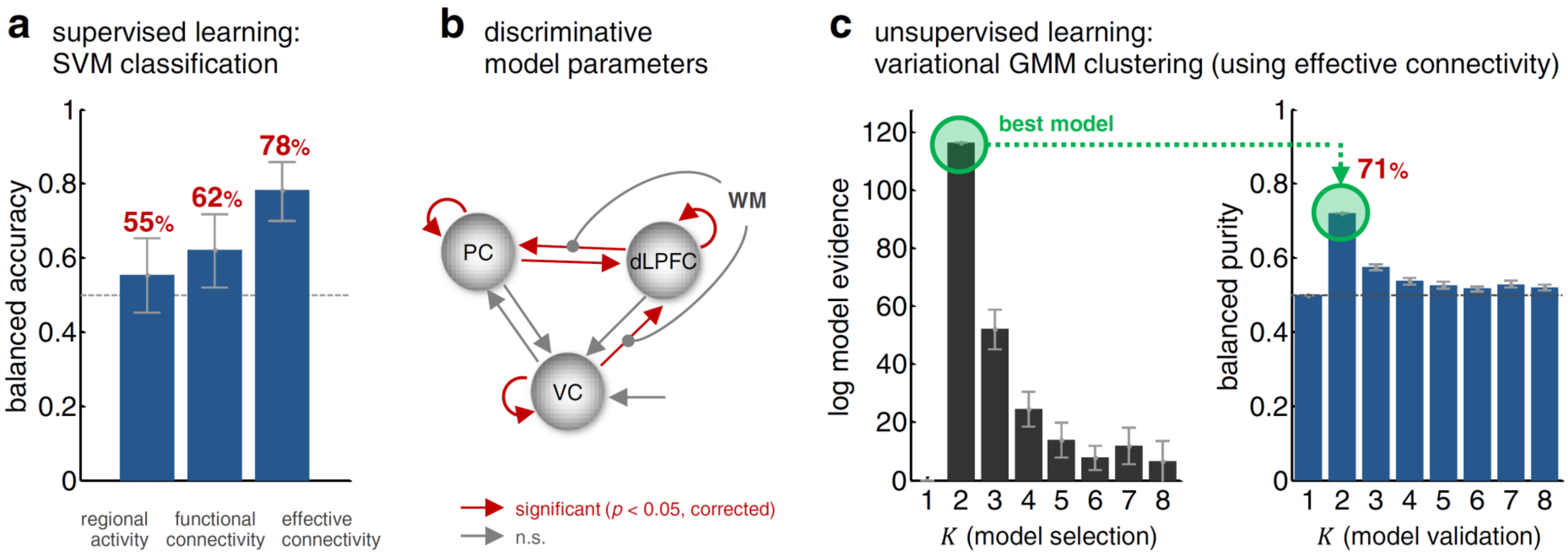
Deserno, Lorenz et al 2012. *The Journal of Neuroscience* 32 (1). Society for Neuroscience: 12–20.

Model based clustering



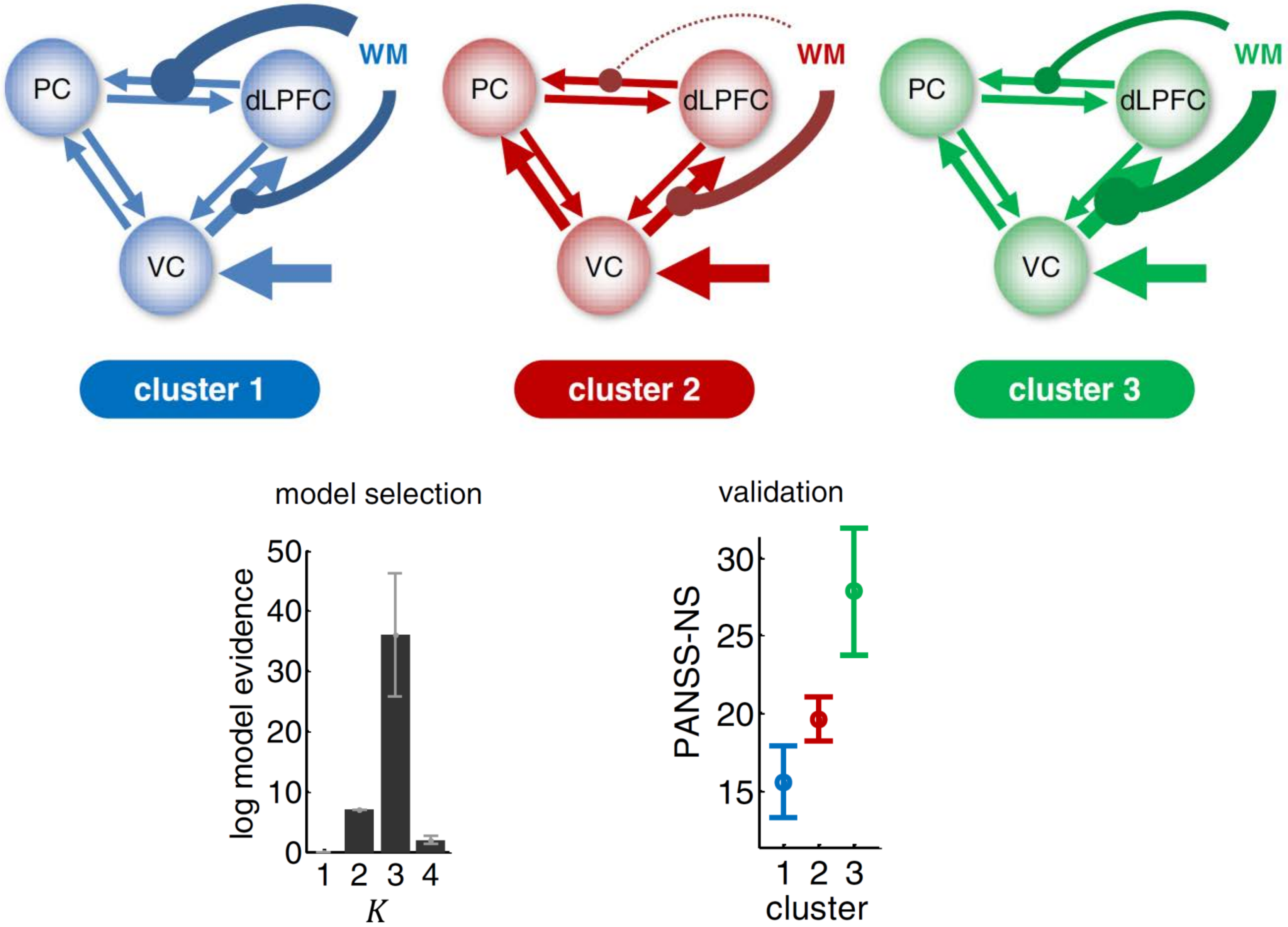
Brodersen et al 2014 Neuroimage

Results – Healthy vs Schizophrenic



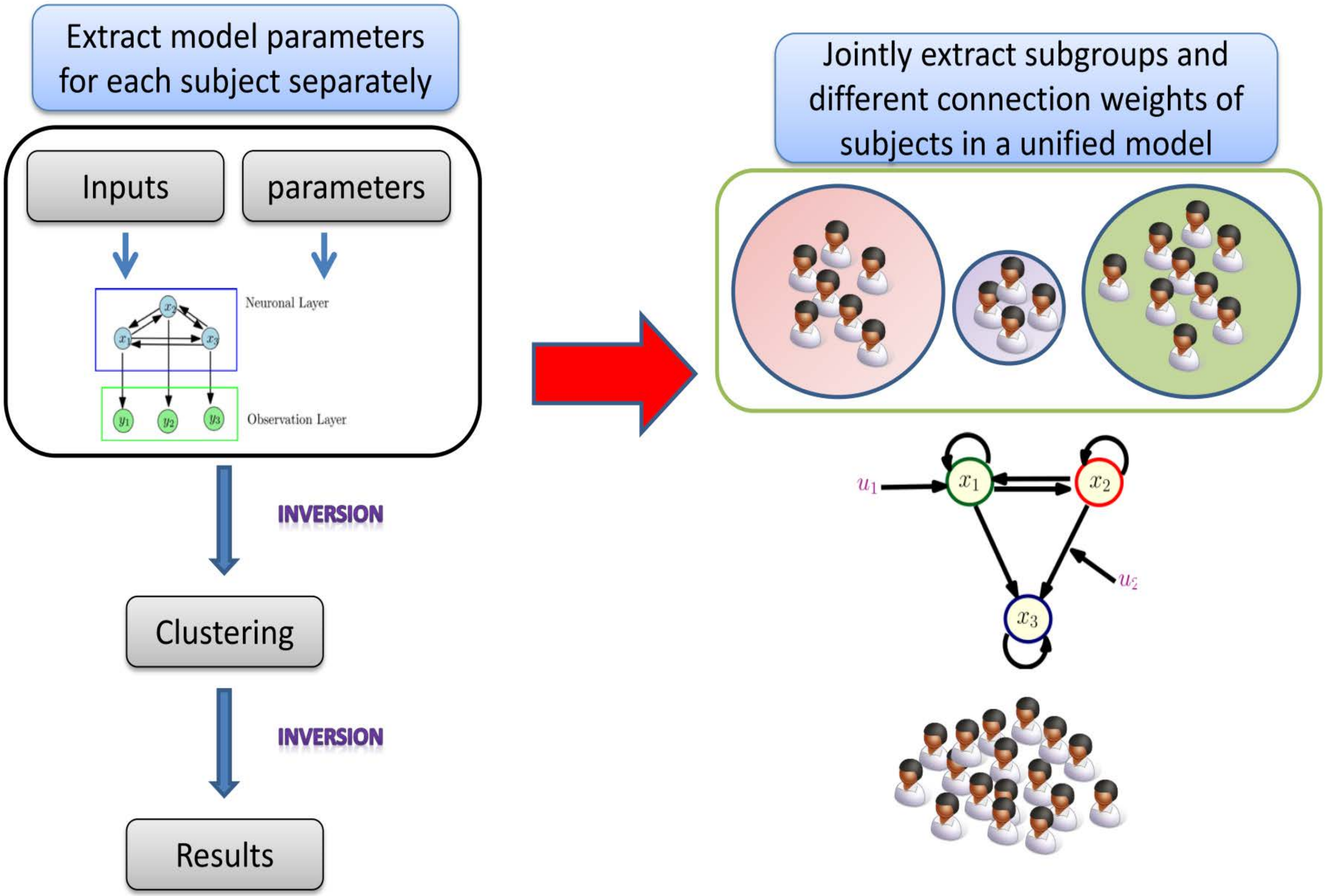
Brodersen et al 2014 Neuroimage

Results – Schizophrenia patients



Brodersen et al 2014 Neuroimage

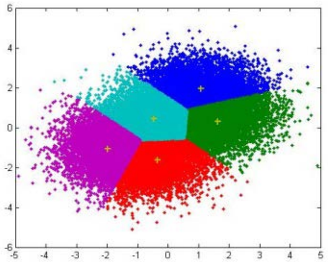
Unified model for identifying subgroups



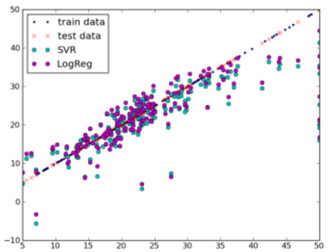
Raman, S et al A hierarchical model for unifying unsupervised generative embedding and empirical Bayes *Under Revision*

Summary

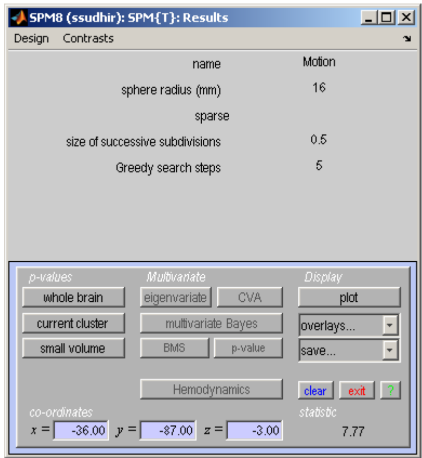
Modelling Principles



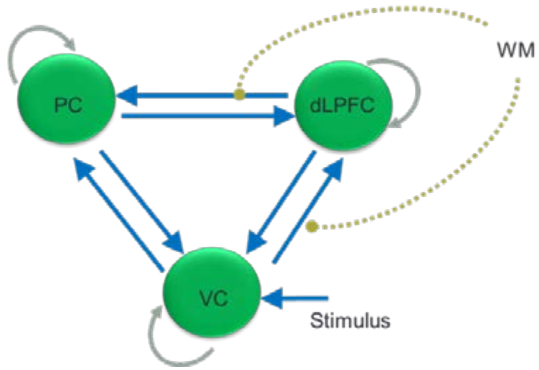
Learning from Data



Multivariate Bayes in SPM

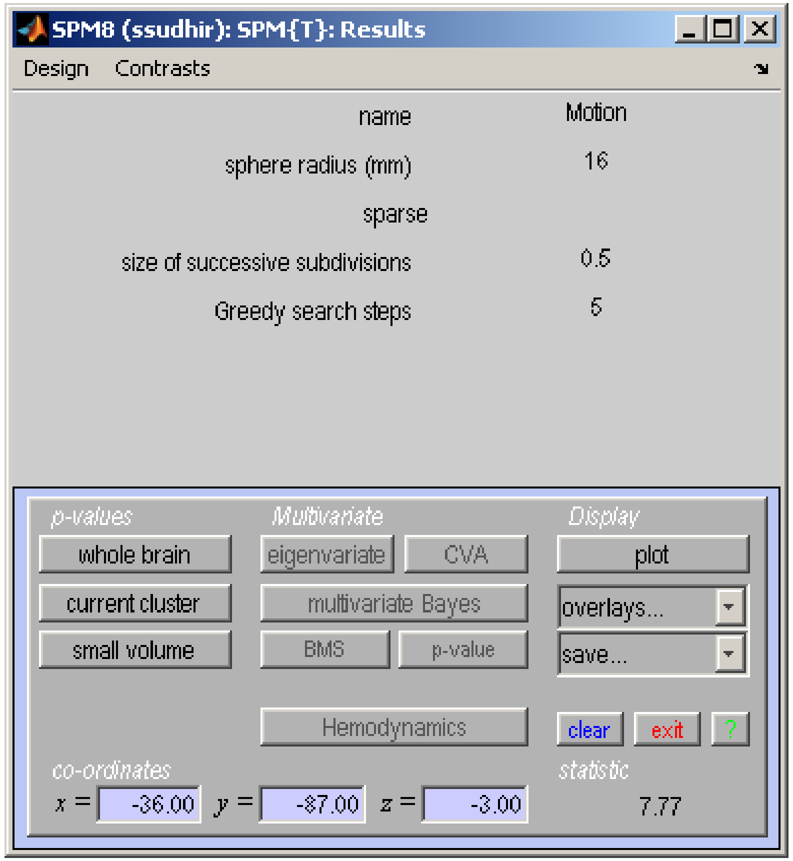


Generative Embedding

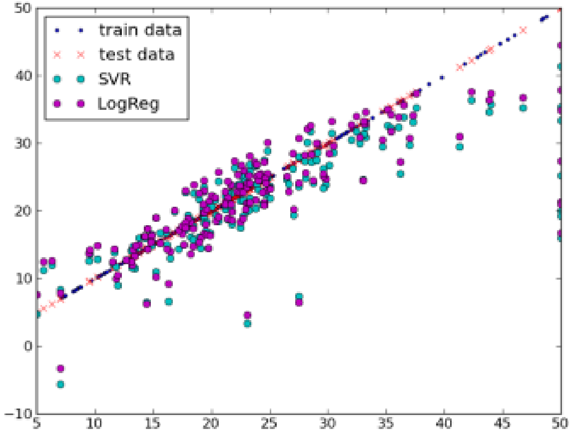


Practicals

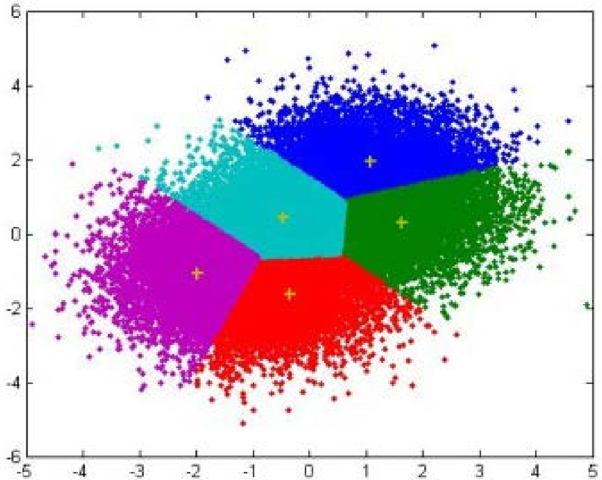
- Multivariate Bayes in SPM



- Classification



- Clustering



Thank you