Detecting overlapped functional clusters in resting state fMRI with Connected Iterative Scan: A graph theory based clustering algorithm

Xiaodan Yana,b, Stephen Kelleyc, Mark Goldbergc, Bharat B. Biswal

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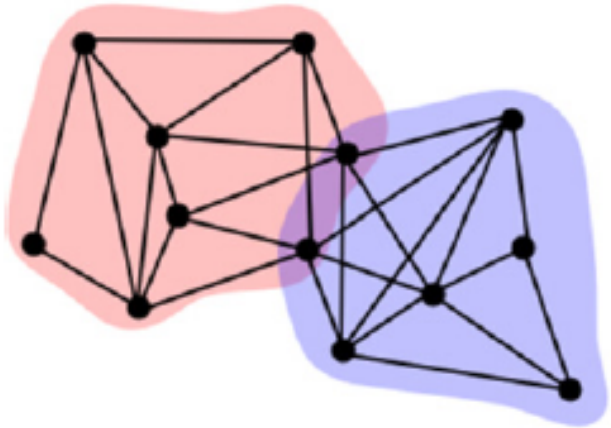
Introduccion

- RSN: resting state network.
- Functional connectivity.
- Select an appropriate seed voxel or seed region based on a research interest, correlate the average signal from the seed with all other voxels in the brain, and determine the statistical significance of the correlation. (research bias)
- Data-driven methos like (separate regions):
  - Clustering
  - ICA
  - PCA
- Connected Iterative Scan (CIS) using graph theory clustering (previously applied to social networks).

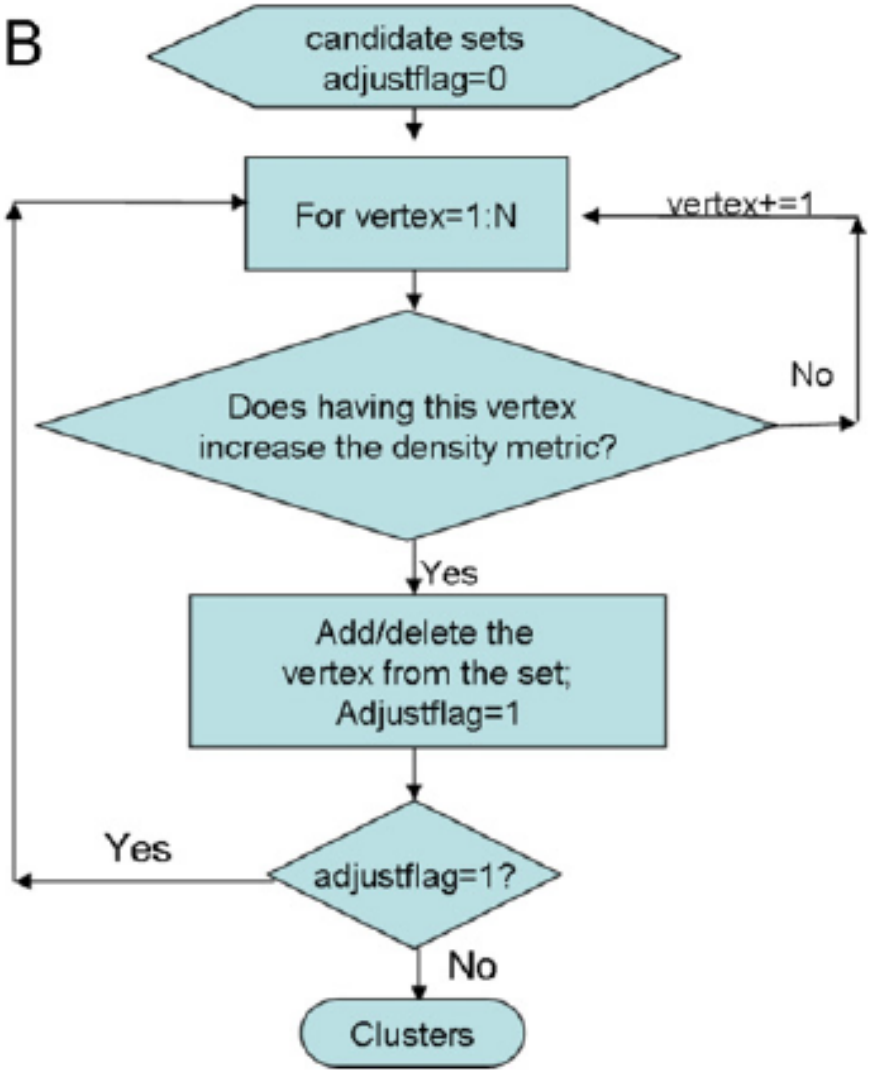
Connected Iterative Scan

A



Connected Iterative Scan

B



Method

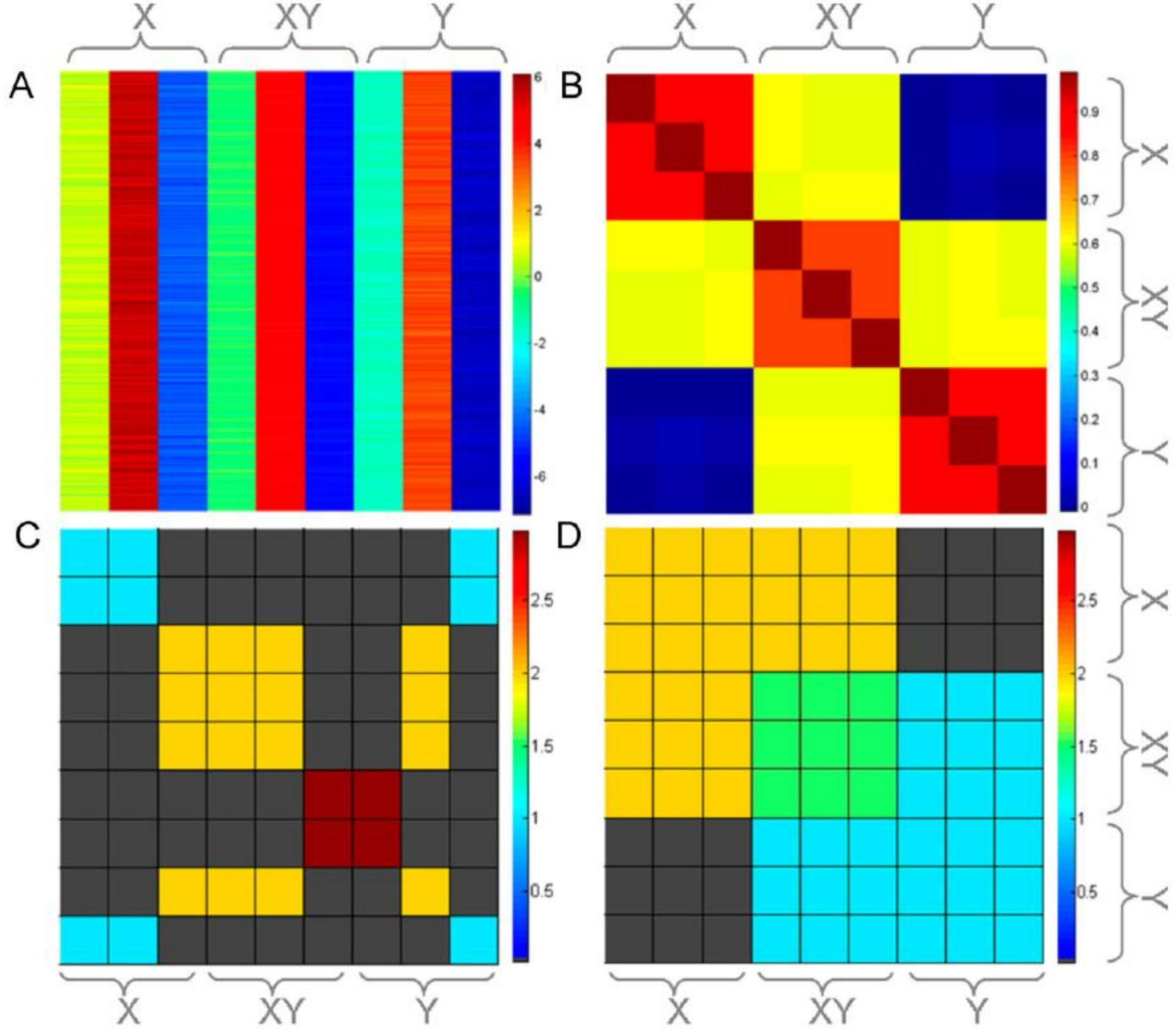
- Simulating data sets
  - Data set generation

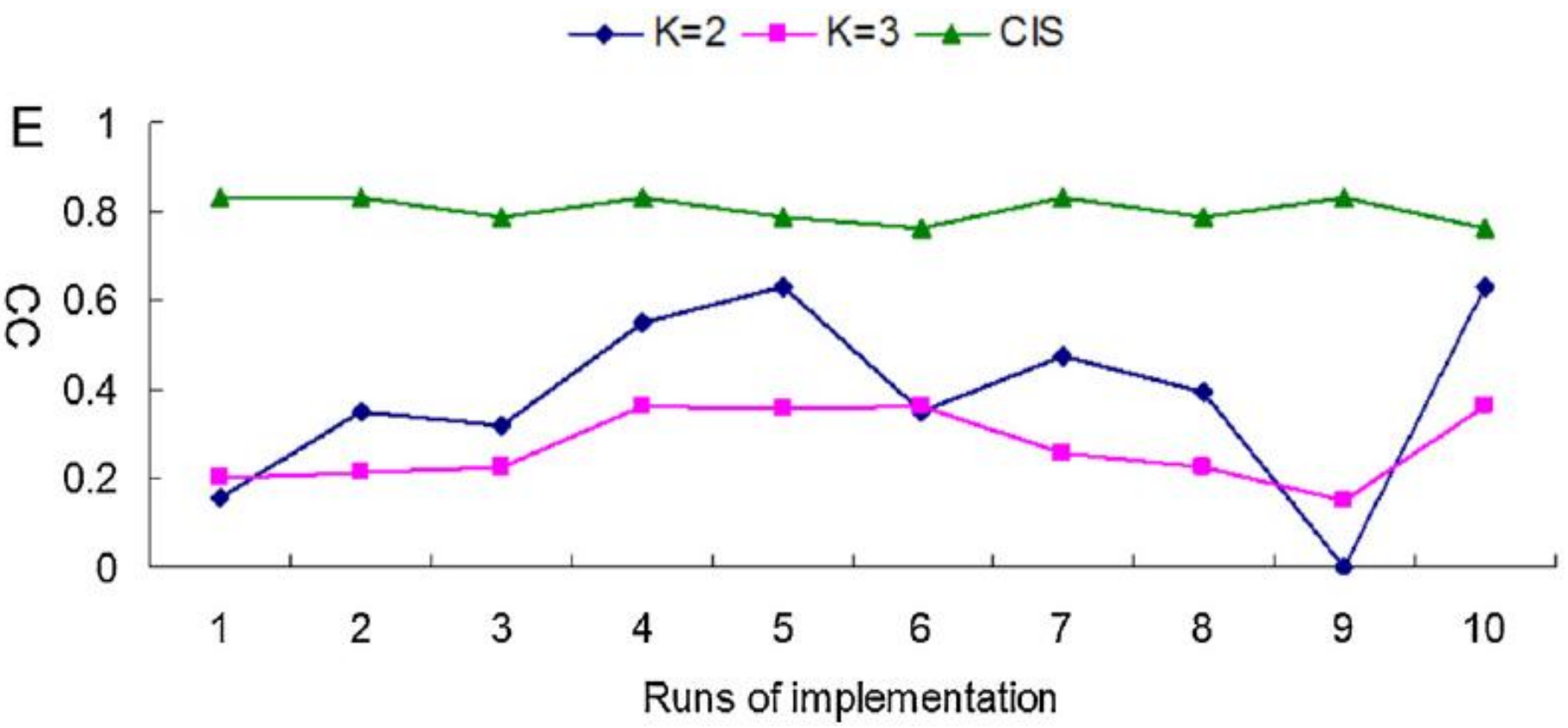
$$x = rand_1; y = rand_2;$$
$$delay = ceil(abs(rand_3) * 5)$$
$$X = [x, x + delay, x - delay];$$
$$XY = [w_1 x + w_2 y, w_1 x + w_2 y + delay, w_1 x + w_2 y - delay];$$
$$Y = [y, y + delay, y - delay];$$
$$w_1 = rand_4 * 0.001 + 0.5; w_2 = rand_5 * 0.001 + 0.5.$$

And the final dataset was constructed as

$$M = [X, XY, Y];$$

  - Clustering with CIS
  - Clustering with K-means


A
B
C
D
X
XY
Y
6
4
2
0
-2
-4
-6
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2.5
2
1.5
1
0.5


K=2
K=3
CIS
E
CC
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
Runs of implementation

Biological data set

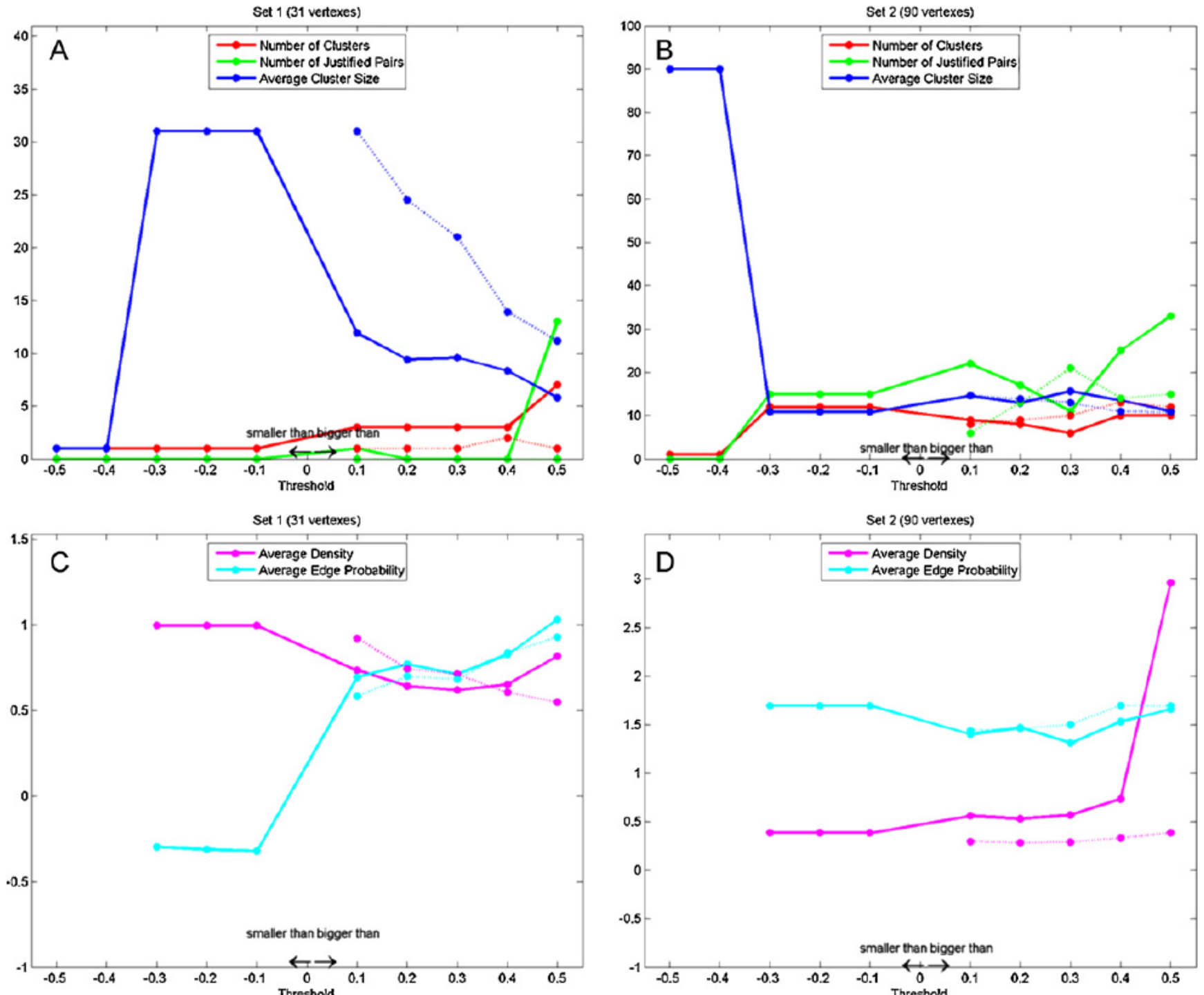
- Data acquisition
  - fMRI Resting State
- Data preprocessing
  - normalized to Talairach and Tournoux space.
  - discarding the first 10 volumes for scanner calibration.
  - Slice timing, motion correction, removal of linear drift, smoothing with a Gaussian filter of 6 mm FWHM.
  - Regression analisys.
- Graph generation: negative, positive and absolute regions
- Clustering with CIS (Justified Pairs JPs)

$$Index_{Hub} = \left(\sum_{|T|}^{K} freq(JP_T) * \left| \frac{T}{10} \right| \right) * \left(\bigcap_{|T|}^{K} freq(JP_T) \right)$$

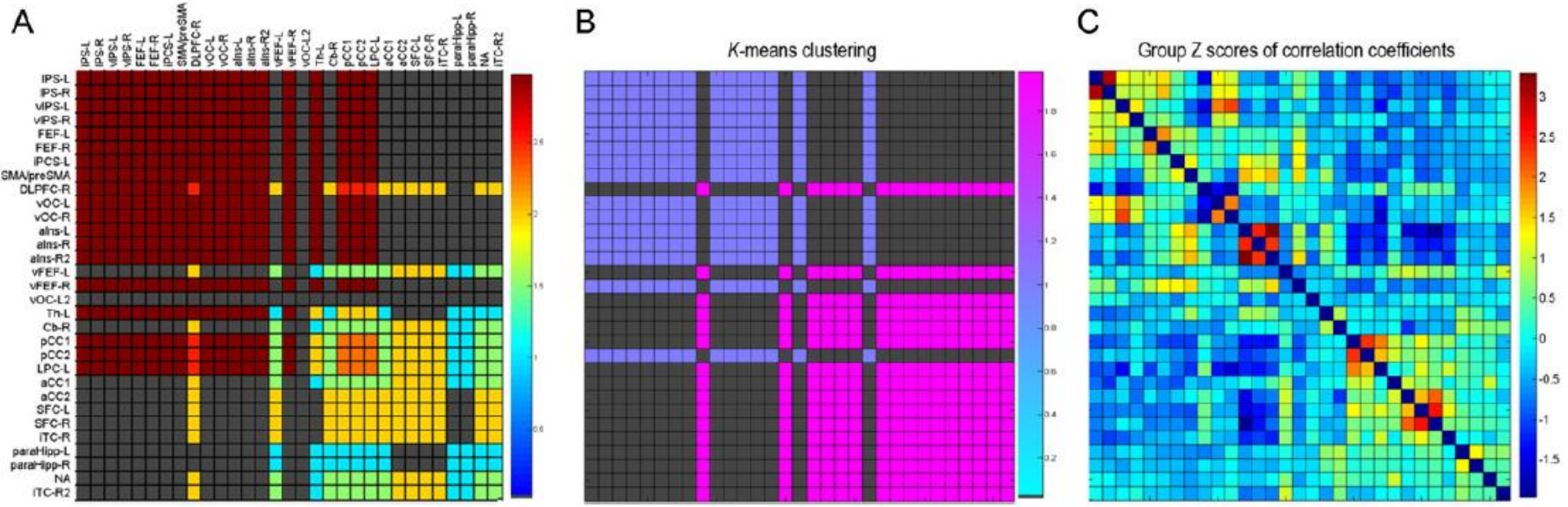
- Clustering with k-means

Table 1
The clustering results and ROI membership in dataset 1. $K = 2$: output from the K-means clustering method with cluster number specified as 2. CIS: output from the Connected Iterative Scan method.

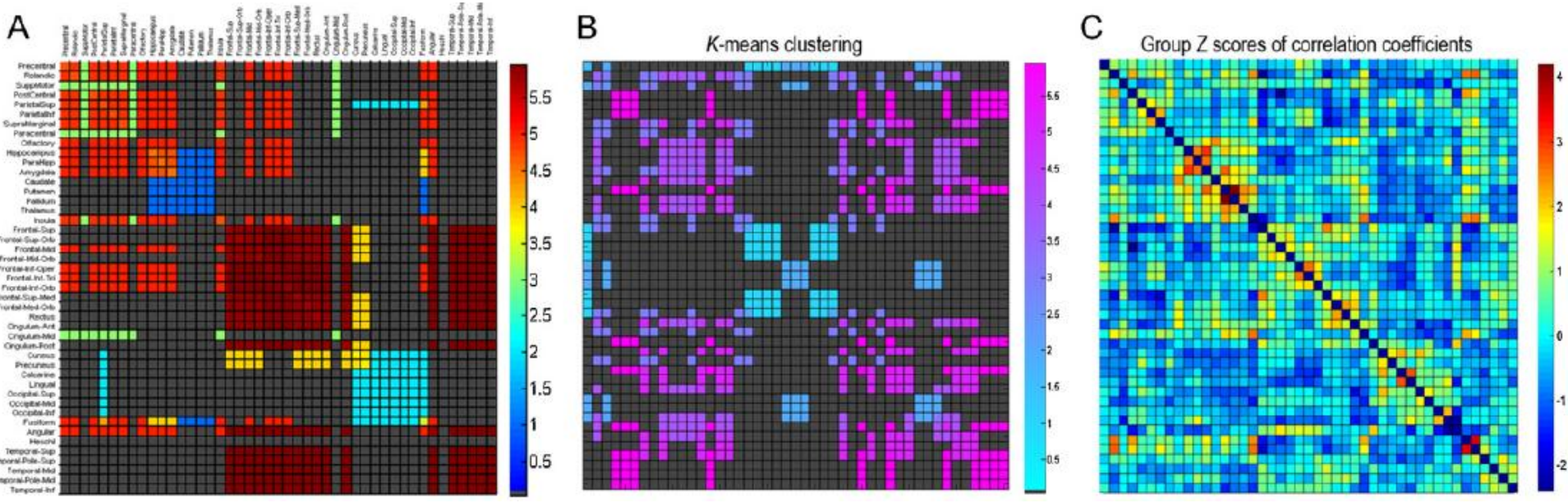
ROI	Ref*	$K = 2$	CIS
IPS-L	p	C1	C3
IPS-R	p	C1	C3
vIPS-L	p	C1	C3
vIPS-R	p	C1	C3
FEF-L	p	C1	C3
FEF-R	p	C1	C3
iPCS-L	p	C1	C3
SMA/preSMA	p	C1	C3
DLPFC-R	p	C2	C2,C3
vOC-L	p	C1	C3
vOC-R	p	C1	C3
aIns-L	p	C1	C3
aIns-R	p	C1	C3
aIns-R2	p	C1	C3
vFEF-L	p	C2	C1,C2
vFEF-R	p	C1	C3
vOC-L2	p	C2	
Th-L	p	C2	C1,C3
Cb-R	p	C2	C1,C2
pCC1	d	C2	C1,C2,C3
pCC2	d	C1	C1,C2,C3
LPC-L	d	C2	C1,C2,C3
aCC1	d	C2	C1,C2,
aCC2	d	C2	C2
SFC-L	d	C2	C2
SFC-R	d	C2	C2
iTC-R	d	C2	C2
paraHipp-L	d	C2	C1
paraHipp-R	d	C2	C1
NA	d	C2	C1,C2
iTC-R2	d	C2	C1,C2


Set 1 (31 vertexes)
A
Number of Clusters
Number of Justified Pairs
Average Cluster Size
smaller than bigger than
Threshold
Set 2 (90 vertexes)
B
Number of Clusters
Number of Justified Pairs
Average Cluster Size
smaller than bigger than
Threshold
Set 1 (31 vertexes)
C
Average Density
Average Edge Probability
smaller than bigger than
Set 2 (90 vertexes)
D
Average Density
Average Edge Probability
smaller than bigger than

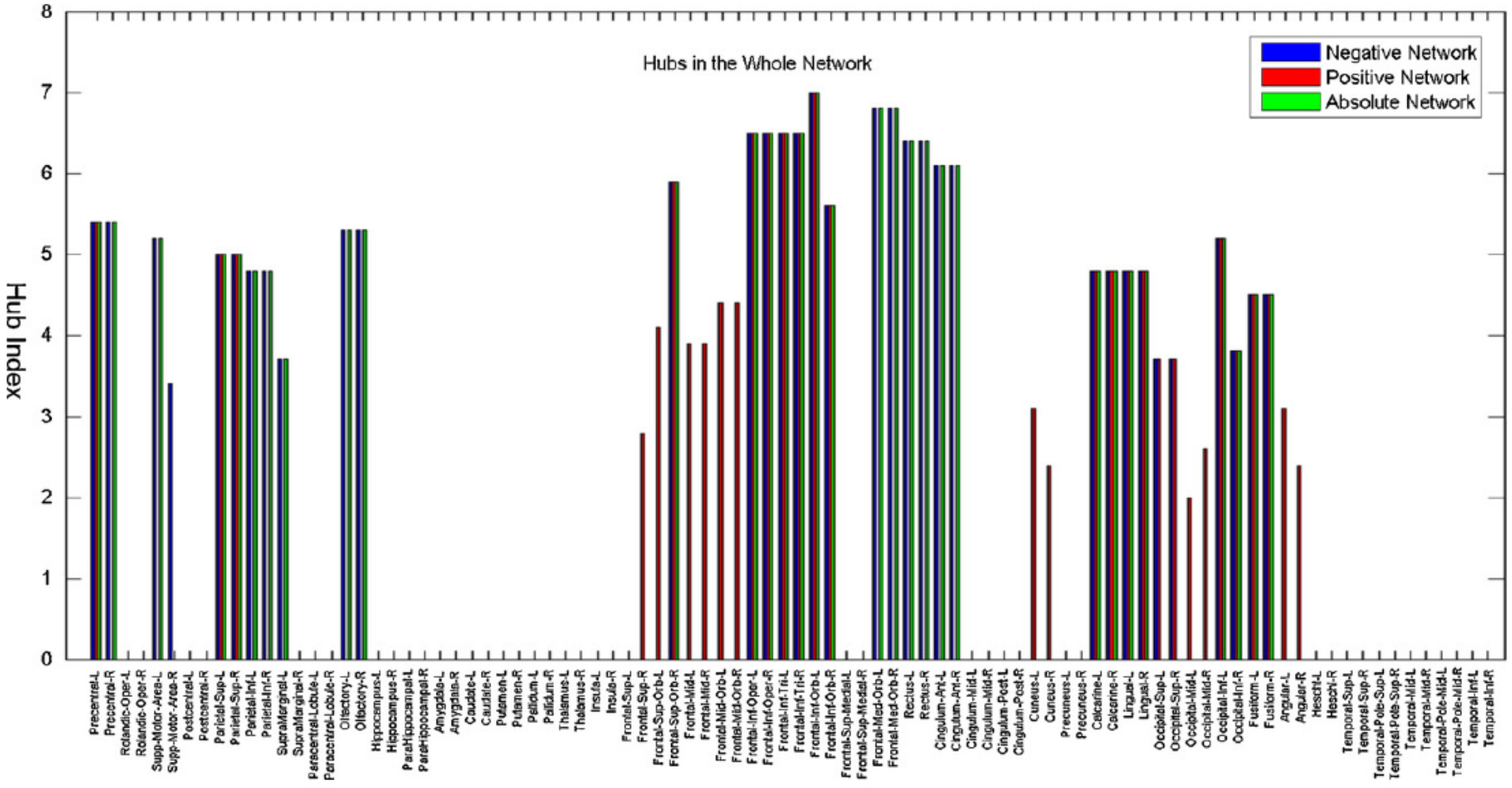
(A) Cluster results of Set 1 (31 vertexes). Colors labeled the cluster IDs in Table 1. If an element is the overlap between two or more clusters, it will be set to an intermediate color. Refer to Table 1 for detailed clustering results and explanation of the abbreviations. (B) Cluster results of K-means clustering algorithm. Colors are labeled in the same way as in (A). (C) The matrix of group average correlation coefficients, in the form of Z scores, which is the matrix based on which graphs were generated for CIS. We can see blurry clusters in such raw data.



(A) Cluster results of the whole brain dataset. Colors labeled the cluster IDs in Table 2. If an element is the overlap between two or more clusters, it will be set to an intermediate color. Refer to Table 2 for detailed clustering results. (B) Cluster results of K-means clustering algorithm. Colors are labeled in the same way as in (A). (C) The matrix of group average correlation coefficients, in the form of Z scores, which is the matrix based on which graphs were generated for CIS. We can see blurry clusters in such raw data. Note: To facilitate illustration, the left and right sides of corresponding anatomical region were merged into one element in each of the three figures.



Hub regions were identified in three kinds of networks via hub index as defined in formula (6). A region is considered as a hub region if and only if it appears in justified pairs (with 10–90% overlap) among the clustering results of graphs from all thresholds under investigation.



Locations of the hub regions in the brain. Regions were labeled in different colors to indicate in which brain network they served as hubs

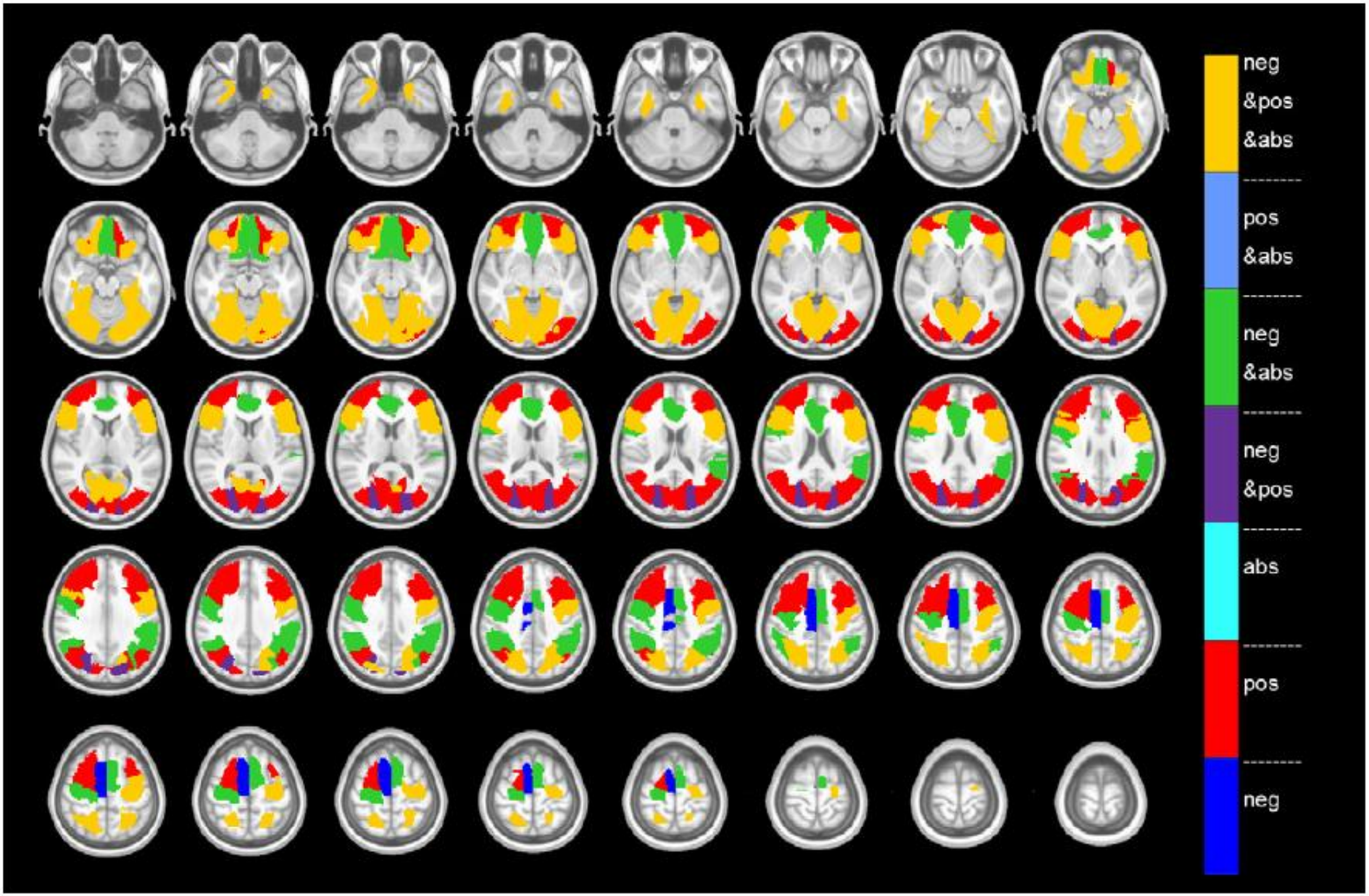


Table 2
The clustering results and ROI membership in dataset 2. $K = 6$: in the K-means clustering method, the number of clusters was set to 6. CIS: the Connected Iterative Scan method.

ROI	Ref	$K = 6$	CIS
Precentral	Motor-Somatosensory	C1	C3,C6
Rolandic	Motor-Somatosensory	C2	C3,C6
SuppMotor	Motor-Somatosensory	C3	C3,C5
PostCentral	Motor-Somatosensory	C1	C3,C6
ParietalSup	Motor-Somatosensory	C1	C2,C3,C6
ParietalInf	Motor-Somatosensory	C1	C3,C6
SupraMarginal	Motor-Somatosensory	C1	C3,C6
Paracentral	Motor-Somatosensory	C1	C3
Olfactory		C1	C5,C6
Hippocampus	Emotion-memory	C1	C1,C6
ParaHipp	Emotion-memory	C2	C1,C6
Amygdala	Emotion-memory	C2	C1,C6
Caudate		C2	C1
Putamen		C2	C1
Pallidum		C2	C1
Thalamus		C2	C1
Insula		C4	C3,C6
Frontal-Sup	Frontal	C3	C4,C5
Frontal-Sup-Orb	Frontal	C2	C4,C5
Frontal-Mid	Frontal	C3	C4,C5,C6
Frontal-Mid-Orb	Frontal	C5	C4,C5
Frontal-Inf-Oper	Frontal	C4	C4,C5,C6
Frontal-Inf-Tri	Frontal	C1	C5,C6
Frontal-Inf-Orb	Frontal	C1	C5,C6
Frontal-Sup-Med	Frontal	C1	C4,C5
Frontal-Med-Orb	Frontal	C1	C4,C5
Rectus	Frontal	C1	C4,C5
Cingulum-Ant	Cingulate	C3	C4,C5
Cingulum-Mid	Cingulate	C3	C3
Cingulum-Post	Cingulate	C3	C4,C5
Cuneus	Cingulate	C4	C2,C4
Precuneus	Cingulate	C5	C2,C4

Table 3
Hub regions shown in Figs. 6 and 7.

Regions	$Index_{Hub}$		Networks	functional systems	Previous report
	L	R			
Cingulum_Ant	6.1	6.1	Neg&Abs	C	1,3,4
Cuneus	3.1	2.4	Pos	C	1,3
Frontal_Inf_Oper	6.5	6.5	Pos&Neg&Abs	F	
Frontal_Inf_Orb	7	5.6	Pos&Neg&Abs	F	1,4
Frontal_Inf_Tri	6.5	6.5	Pos&Neg&Abs	F	
Frontal_Med_Orb	6.8	6.8	Neg&Abs	F	4
Frontal_Mid	3.9	3.9	Pos	F	1,2,3,4
Frontal_Mid_Orb	4.4	4.4	Pos	F	1,2,4
Frontal_Sup_Orb_L	4.1	–	Pos	F	1,2,4
Frontal_Sup_Orb_R	–	5.9	Pos&Neg&Abs	F	1,2,4
Frontal_Sup_R	–	2.8	Pos	F	1,4
Olfactory	5.3	5.3	Neg&Abs	F	
Rectus	6.4	6.4	Neg&Abs	F	
Precentral_L	5.4	–	Pos&Neg&Abs	M	1,2
Precentral_R	–	5.4	Neg&Abs	M	1
Supp_Motor_Area	5.2	3.4	Neg&Abs	M	1
Parietal_Inf	4.8	4.8	Neg&Abs	P	1,3,4
Parietal_Sup	5	5	Pos&Neg&Abs	P	1,3,4
SupraMarginal	3.7	–	Neg&Abs	P	2,3,4
Angular	3.1	2.4	Pos	V	2
Calcarine	4.8	4.8	Pos&Neg&Abs	V	1,3
Fusiform	4.5	4.5	Pos&Neg&Abs	V	1
Lingual	4.8	4.8	Pos&Neg&Abs	V	1,2
Occipital_Inf	5.2	3.8	Pos&Neg&Abs	V	
Occipital_Mid	2	2.6	Pos	V	1
Occipital_Supp	3.7	3.7	Pos&Neg	V	1

Abbreviations: Pos: positive network, Neg: negative network, Abs: absolute network, C: cingulum, F: frontal, M: motor, P: parietal, and V: visual; 1: Achard et al. (2006), 2: He et al. (2008), 3: Hagmann et al. (2008), and 4: Buckner et al. (2009).