Mapping Atlas ROIs to Individual Anatomical Volumes
using CBA

by Jorie van Haren

March 22, 2024

Contents

0.1 Short word

A good grasp on what brain regions do, and a good fit between these regions is important for robust group-level statistical analyses. However, moving to standard spaces (MNI or Talairach) poses problems because group maps often involve extensive spatial smoothing. While functional areas are not precisely predictable from the macro-curvature of the brain, it has been shown that cortical matching approach substantially improves statistical group results by reducing anatomical variability.

Here I describe my implementation of a technique called Curvature Based Alignment (CBA) for mapping the ROIs defined in an atlas (Glasser et al., 2016) back to individual anatomical volumes. BrainVoyager implementation of CBA offers a high-resolution approach to align brains using the macro-anatomical curvature of the brain.

CBA operates in several stages and can be used in several different manners, but for our purposes, the approach is as follows. We generate surface curvature 'spheres' per subject – indicating the macro-anatomical curvature of that subject's brain. We consequently align all our participants into a dynamic group average. Next, we align this group average to our atlas of interest. Given we know the transformations we did to align to the Glasser atlas, we can now simply map the regions within this atlas back to the group average – and from the group average to the individual's surfaces. What we end up with is regions of interest (POIs) within each subject's cortex.

- BrainVoyager download page:
- BrainVoyager Python Plugins:
- Glasser et al., 2016:
- BrainVoyager CBA Guide and Resources:
- Sublement to Glasser et al., 2016 - including atlas labelling and region grouping:

0.2 The Glasser Atlas

The Glasser atlas parcellates the human cerebral cortex into its major (and sometimes minor) subdivisions. This atlas uses multi-model magnetic resonance imaging from the Human Connectome Project and an objective semi-automated neuroanatomical approach to delineate 180 areas per hemisphere by changes in architecture, function, connectivity, and/or topography. These 180 patches of interest are available as *POI* file in BrainVoyager, linked to the associated surface map. In most cases a 180-area parcellation is just too many, luckily Glasser et al. (2016) extensively cover a subsequent 22 region-by-region grouping. Section 22-Region and section 180-Parcellation of this document describe functions and labelling for each of these 22 main sections represents as well as the complete 180 area parcellation.

0.3 CBA - Guide

Morphing Cortex into Sphere

First things first, we need to prepare our cortex hemisphere mesh for CBA, and morph it to a sphere. The CBA algorithm uses these spheres with the original curvature superimposed to align between participants and standard spaces.

This guide assumes you've done the steps of creating mid-grey matter volumes and have smoothed and simplified these meshes sufficiently. If you have not done this as of yet, please follow the steps described in my *'Cortical Layer Sampling and Mapping'* guide.

Do the following steps for all participants and both hemispheres.

1. Open the *'WMGM_LH_Mid-GM_Mid-GM_RECO_D300k.srf'* surface mesh.
2. Go to **Meshes** / **Cortex-Based Alignment**.
   - Set **Resolution**: **High resolution**, press **Curvature** and **Smooth**.
   - Go to **Make Sphere**: press **Morph** and **Correct**. Inspect whether the spherical curvature maps seem *ok*, and adjust parameters if needed. Save the *'_SPHERE.srf'*.
   - Go to **Sample Sphere**: press **Map Std Sphere**.
     - Save the HIRES sphere-to-sphere vertex mapping file. (*'_D300k_SPHERE_HIRES.ssm'*)
     - Load the **Folded mesh**. (*'_RECO_D300k.srf'*)
     - Press **Set Std Sphere Vertices**.
     - Set the curvature smoothing levels (depending on the number of subjects). Increasing smoothing for a few participants, and decreasing for many participants. Roughly I've used the following; 20 subjects: [*5, 15, 35, 70*] - 10 subjects: [*15-30-45-75*] - 5 subjects: [*35, 50, 65, 85*].
     - Press **Source Curvature**, and save the curvature map. (*'_RECO_D300k_HIRES_SPH_CURVATURE.smp'*)

The resulting *'_SPH'* you will obtain from this first step are needed for a better alignment procedure, as the created spherical meshes are now sampled on a standard sphere with 40962 vertices (163842 for high-resolution).

Align Group Average

Next, we align the surfaces of our subjects to a *'dynamic group average'*. From this group average, we create a curvature surface map. Recognise that in all these steps we internally take notes of the transformation we have performed so we can eventually project our areas of interest back to the individual participants.

Additionally - since we have obtained curvature maps and cross-subject mapping of curvature maps - we can generate a group average mesh file. This mesh should look similar to a 'smoothed' group average brain as obtained from commonly used atlases.

1. Go to **Meshes** / **Cortex-Based Alignment** / **Align Group**.
    - Press **Add...**, and add all *'_D300k_HIRES _SPH_CURVATURE.smp'* of a hemisphere.
    - Save .gal file (*'group_av_lh.gal'*).
    - Set **Alignment mode** to **Align to dynamic group average**.
    - *Optional: if you feel that your subject curvature maps may align to the target sphere directly (possible for similar smoothness), you may use the '**Align each entry to target sphere**' instead.*
    - Press **GO**. Note that if subject-subject spheres look wildly different you may need to run a *'Align Rigid...'* first to align spheres. To use *Align Rigid...* you must first assign a target sphere (in the target sphere tab), this target sphere can be one of the subject spheres (*'_D300k_HIRES _SPH_CURVATURE.smp'*).
2. Go to **Meshes** / **Cortex-Based Alignment** / **Options**.
    - Tick the checkbox for **'Shape'** at the lower right of the box.
    - **Add** group aligned SRF files (*'_D300k_HIRES_SPH.srf'*) and associated ssm files (*'_D300k_HIRES_SPH_GROUPALIGNED.ssm'*).
    - Press **Average** to generate average surface.
    - *(Optionally: you may want to save a* ***'.sal'*** *file indicating folded spheres and sphere-to-sphere mapping files - for later reuse.)*
    - Next smooth the group average using **Meshes** / **Advanced Mesh Smoothing**, set iterations to around 200-600.
    - Lastly save the smoothed group averaged mesh.

Align to Atlas

Taking this group average (which is in standard sphere coordinates), we can now start alignment to the **Glasser** atlas.

We load in our Glasser curvatures, and delineate this curvature map from Euclidean coordinates (xyz) to a polar coordinate system (2-values). This *'.pmp'* is subsequently used for aligning our group average curvature map.

1. Before alignment, we quickly do a visual inspection of whether our group averages and the Glasser surface have a similar level of smoothness. This similar level of smoothness is important for effective alignment, having a too-rough group average might induce fitting to local minima, whereas having a too-smooth group average might reduce the precision of fit.
2. Open the *'GroupAlignedAverageFoldedCortex_LH_N-X_smooth.srf'* surface mesh.

3. Go to **Meshes** / **Cortex-Based Alignment**.
   - Set **Resolution**: **High resolution**, press **Curvature** and **Smooth**.
   - Go to **Make Sphere**: press **Morph** and **Correct**. Reduce the **NrOfSteps** of **Correct** to 10.
   - Go to **Sample Sphere**: press **Map Std Sphere**.
     - Save the HIRES sphere-to-sphere vertex mapping file. (*'_N-X_smooth_SPHERE_HIRES.ssm'*)
     - Load the **Folded mesh**. (*'_N-X_smooth.srf'*)
     - Press **Set Std Sphere Vertices**.
     - Press **Source Curvature**, and save the curvature map. (*'_N-X_smooth_HIRES_SPH_CURVATURE.smp'*)
4. Go to **Meshes** / **Cortex-Based Alignment** / **Target Sphere**
   - Load **Curvature SMP** - select the atlas curvature for the current hemisphere. (*'HCP-Glasser2016_resampled_LH_HIRES_SPH_CURVATURE.smp'*)
   - Press **Create PMP**
5. Go to **Meshes** / **Cortex-Based Alignment** / **Align Group**
   - Add your group-aligned curvature map. (*'...dedCortex_LH_N-X_smooth_HIRES_SPH_CURVATURE.smp'*)
   - Set **Alignment mode** to **Align each entry to target sphere**.
   - Run **Align Rigid...**
   - Press **GO** to run non-linear alignment.

Mapping Regions of Interest from Glasser to Individual Subjects

Now that we have done our forward alignment from **subject** to **group average** to **Altas**, we can - using the saved transformation information - do a back projection of the regions of interest (*POI*) from **Atlas** to **Group average** to **subject**.

This step uses my **'Map_POI.py'** BrainVoyager tool, which requests *'ssm'*(s) and *'poi'* files to map vertices from one reference frame to another. We can do this mapping because our surfaces are in *'_SPH'* space and we saved *'_INV'* mapping files during the CBA procedure.

1. Go to **Python** / **Python Development...** (*ctrl+p*) / **Map_POI.py** / **Run**.
   - Directory Path: *'/path/to/parent/directory'*.
   - SSM transformation file name(s): *'GroupAlignedAverageFoldedCortex_LH_N-X_HIRES_SPH_ALIGNED_TO_HPC-Glasser2016_INV.ssm'* - make sure to use **'_INV'** .ssm file.
   - POI Document: *'Glasser/HCP-Glasser2016_LH_22grouping.poi'*.
   - Press **Map POI using SSM(s)**.
2. With **Python** / **Python Development...** (*ctrl+p*) / **Map_POI.py** still open.
   - Directory Path: */path/to/parent/directory*.

- SSM transformation file name(s):
  - /S01_SES1/..._D300k_HIRES_SPH_GROUPALIGNED_INV.ssm
  - /S02_SES1/..._D300k_HIRES_SPH_GROUPALIGNED_INV.ssm
  - /S03_SES1/..._D300k_HIRES_SPH_GROUPALIGNED_INV.ssm
  - ...
- POI Document:
  'GroupAlignedAveragedFoldedCortex_LH_N-X_HIRES_SPH_ALIGNED_TO_HCP-Glasser2016_INV_HCP-Glasser2016_LH_22grouping.poi'
- Press **Map POI using SSM(s)**.

0.4 22-Regions grouping

Below you will find a spreadsheet with the main 22 region-by-region sections describing the boundary between each pair of cortical areas. If you like to know which of the 180 areas belong to what of the 22 groupings, please take a look at the 180-parcellation description.

Table 0.1: 22-Region Grouping

Group-Index	Group Label	Main Domain
1	V1	Visual
2	Early Visual Cortex	Visual
3	Dorsal Stream	Visual
4	Ventral Stream	Visual
5	MT-Complex	Visual
6	Early Somatosensory and Motor	Somatosensory/Motor
7	Sensory-motor associated paracentral lobular & mid cingulate cortex	Somatosensory/Motor
8	Premotor Cortex	Somatosensory/Motor
9	Posterior Opercular Cortex	Somatosensory/Motor
10	Early Auditory	Auditory
11	Association Auditory Cortex	Auditory
12	Insular and Frontal Opercular Cortex	Auditory
13	Medial Temporal Cortex	Remaining: Temporal-Cortex
14	Lateral Temporal Cortex	Remaining: Temporal-Cortex
15	Sensory Bridge of temporal-parietal-occipital junction	Remaining: Posterior-Cortex
16	Superior Parietal and IPS Cortex	Remaining: Posterior-Cortex
17	Inferior Parietal Cortex	Remaining: Posterior-Cortex
18	Posterior Cingulate Cortex	Remaining: Posterior-Cortex
19	Anterior Cingulate and Medial Prefrontal Cortex	Remaining: Anterior-Cortex
20	Orbital and Polar Frontal Cortex	Remaining: Anterior-Cortex
21	Inferior Frontal Cortex	Remaining: Anterior-Cortex
22	Dorsolateral Prefrontal Cortex	Remaining: Anterior-Cortex

0.5 180-Parcellation Description

Finally a comprehensive spreadsheet on the 180-area parcellation, including area name and description, but also to which of the 22-region grouping each parcellation belongs to.

Table 0.2: 180-Group Parcellation

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
1	V1	Primary Visual Cortex	1	2	17, hOC1, OC, BA17
2	MST	Medial Superior Temporal Area	5	15	MSTv, hOC5, hOC5v
3	V6	Sixth Visual Area	3	2,18	112
4	V2	Second Visual Area	2	1	18, hOC2, OB, BA18
5	V3	Third Visual Area	2		V3d, V3v, VP, hOC3d, hOC3v
6	V4	Fourth Visual Area	2	3,4,5	V4d, V4v, hV4, hOC4v, hOC4lp, LO1
7	V8	Eighth Visual Area	4	2,5	VO1
8	4	Primary Motor Cortex	6	7,8,9	BA4, 4a, 4p, M1, PMC, F1
9	3b	Primary Sensory Cortex	6	7,9	S1, 3
10	FEF	Frontal Eye Fields	8	6,22	
11	PEF	Premotor Eye Field	8	6,21,22	6v2
12	55b	Area 55b	8	6,22	
13	V3A	Area V3A	3	2	V3D, hOC4d
14	RSC	RetroSplenial Complex	18	13	29,30
15	POS2	Parieto-Occipital Sulcus Area 2	18	16	
16	V7	Seventh Visual Area	3		IPS0
17	IPS1	IntraParietal Sulcus Area 1	3	16,17	
18	FFC	Fusiform Face Complex	4	5,14	FFA, FG2
19	V3B	Area V3B	3	5,17	V3C
20	LO1	Area Lateral Occipital 1	5	2	LO2, hOC4la
21	LO2	Area Lateral Occipital 2	5	2,4	LO1, hOC4la
22	PIT	Posterior InferoTemporal Complex	4	2,5	phPITv, phPITd, OFA, hOC4la
23	MT	Middle Temporal Area	5	15	hOC5, hOC5d

Table 0.2 – continued from previous page

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
24	A1	Primary Auditory Cortex	10		Core, R1, TC, TE1.0, TE1.1, 41
25	PSL	PeriSylvian Language Area	15	9,10,11,17	
26	SFL	Superior Frontal Language Area	22	7,19	
27	PCV	PreCuneus Visual Area	18	7,16	PrCu
28	STV	Superior Temporal Visual Area	15	11,17	
29	7Pm	Medial Area 7P	16	18	7P
30	7m	Area 7m	18	16	
31	POS1	Parieto-Occipital Sulcus Area 1	18		”Retrosplenial Cortex”
32	23d	Area 23d	18	19	
33	v23ab	Area ventral 23 a+b	18		23a, 23b, v23
34	d23ab	Area dorsal 23 a+b	18		23a, 23b, d23
35	31pv	Area 31p ventral	18		31, 31d, 31v
36	5m	Area 5m	7	6	
37	5mv	Area 5m ventral	7	16,18	5ci
38	23c	Area 23c	7	18,19	
39	5L	Area 5L	7	6,16	
40	24dd	Dorsal Area 24d	7	6,18	24d
41	24dv	Ventral Area 24d	7	19	24d
42	7AL	Lateral Area 7A	16	6,7	
43	SCEF	Supplementary and Cingulate Eye Field	7	19,22	SEF, CEF, 6, SMA, SMAr
44	6ma	Area 6m anterior	7	8,22	SMAr, 6, SMA
45	7Am	Medial Area 7A	16	7,18	
46	7Pl	Lateral Area 7P	16	18	
47	7PC	Area 7PC	16	6	
48	LIPv	Area Lateral IntraParietal ventral	16		hIP3
49	VIP	Ventral IntraParietal Complex	16		
50	MIP	Medial IntraParietal Area	16	3,17	
51	1	Area 1	6	7,9,17	

Table 0.2 – continued from previous page

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
52	2	Area 2	6	7,16,17	
53	3a	Area 3a	6	7,9,17	
54	6d	Dorsal area 6	8	6,7	6, 6aα
55	6mp	Area 6mp	7	6,8	SMAc, 6, SMA
56	6v	Ventral Area 6	8	6,9	6, 6v1
57	p24pr	Area Posterior 24 prime	19	7,18	p24'
58	33pr	Area 33 prime	19	18	33', 16
59	a24pr	Anterior 24 prime	19		a24'
60	p32pr	Area p32 prime	19	7	32'
61	a24	Area a24	19		24, s24
62	d32	Area dorsal 32	19		32
63	8BM	Area 8BM	19	7,22	8B
64	p32	Area p32	19	20	32ac, 32
65	10r	Area 10r	19	20	
66	47m	Area 47m	20	21	
67	8Av	Area 8Av	22	8	
68	8Ad	Area 8Ad	22		
69	9m	Area 9 Middle	19	20,22	9
70	8BL	Area 8B Lateral	22	19	8B
71	9p	Area 9 Posterior	22	19	9
72	10d	Area 10d	20	19,22	10, Fp1, Fp2
73	8C	Area 8C	22	8,21	8Av
74	44	Area 44	21	8,12	44d, 44v
75	45	Area 45	21	12	45a, 45p
76	47l	Area 47l (47 lateral)	21	12,20	
77	a47r	Area anterior 47r	21	20,22	47r
78	6r	Rostral Area 6	8	9,12,21	
79	IFJa	Area IFJa	21	8,22	
80	IFJp	Area IFJp	21	8,22	
81	IFSp	Area IFSp	21	22	
82	IFSa	Area IFSa	21	22	
83	p9-46v	Area posterior 9-46v	22	21	9-46v
84	46	Area 46	22	21	
85	a9-46v	Area anterior 9-46v	22	20,21	9-46v

Table 0.2 – continued from previous page

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
86	9-46d	Area 9-46d	22	20	
87	9a	Area 9 anterior	22	19,20	9
88	10v	Area 10v	19	20	10, Fp2
89	a10p	Area anterior 10p	20	22	10p, 10, Fp1
90	10pp	Polar 10p	20	19	10p, 10, Fp1
91	11l	Area 11l	20		Fo3
92	13l	Area 13l	20		Fo3
93	OFC	Orbital Frontal Complex	20	19	11m, 13b, 13m, 14r, Fo1
94	47s	Area 47s	20	12	
95	LIPd	Area Lateral IntraParietal dorsal	16	17	
96	6a	Area 6 anterior	8	7,22	6, 6aβ
97	i6-8	Inferior 6-8 Transitional Area	22	8	FC(B)
98	s6-8	Superior 6-8 Transitional Area	22	7,8	FC(B)
99	43	Area 43	9	6,8,12	41
100	OP4	Area OP4/PV	9	6,17	68
101	OP1	Area OP1/SII	9	10	
102	OP2-3	Area OP2-3/VS	9	10,12	OP2,OP3
103	52	Area 52	10	12	IBT
104	RI	RetroInsular Cortex	10	9,12,15	reI, reIt, RetroInsular, Belt, TD
105	PFcm	Area PFcm	10	9,15,17	
106	PoI2	Posterior Insular Area 2	12		Id1, Id2, Id3
107	TA2	Area TA2	11	10,12	TE1.2
108	FOP4	Frontal OPercular Area 4	12	9,21	
109	MI	Middle Insular Area	12		Ial
110	Pir	Pirform Cortex	12	14,20	Poc
111	AVI	Anterior Ventral Insular Area	12	20,21	Iai
112	AAIC	Anterior Agranular Insula Complex	12	20	Iai, Ial
113	FOP1	Frontal OPercular Area 1	9	8,12	

Table 0.2 – continued from previous page

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
114	FOP3	Frontal OPercular Area 3	12		
115	FOP2	Frontal OPercular Area 2	12	9	
116	PFt	Area PFt	17	6,16	
117	AIP	Anterior IntraParietal Area	16	6,17	
118	EC	Entorhinal Cortex	13		28
119	PreS	PreSubiculum	13	2,18	Sub, Subicular
120	H	Hippocampus	13		
121	ProS	ProStriate Area	18	1,2,13	
122	PeEc	Perirhinal Ectorhinal Cortex	13	14	ATFP, AFP1, Ectorhinal, Perirhinal, 35, 36
123	STGa	Area STGa	11	12,14	
124	PBelt	ParaBelt Complex	10	11	ParaBelt, TA1
125	A5	Auditory 5 Complex	11	15	
126	PHA1	ParaHippocampal Area 1	13	2,4	
127	PHA3	ParaHippocampal Area 3	13	4,14	
128	STSda	Area STSd anterior	11	14	
129	STSdp	Area STSd posterior	11	15	
130	STSvp	Area STSv posterior	11	14,15	
131	TGd	Area TG dorsal	14	11,12,13	TG
132	TE1a	Area TE1 anterior	14	11	
133	TE1p	Area TE1 posterior	14	5,11	
134	TE2a	Area TE2 anterior	14		
135	TF	Area TF	13	4,14	
136	TE2p	Area TE2 posterior	14	4,5	
137	PHT	Area PHT	14	5,11,15	
138	PH	Area PH	5	4,14	
139	TPOJ1	Area TemporoParietoOccipital Junction 1	15	11,14,17	
140	TPOJ2	Area TemporoParietoOccipital Junction 2	15	5,14,17	
141	TPOJ3	Area TemporoParietoOccipital Junction 3	15	5,17	

Table 0.2 – continued from previous page

Parcel Index	Area Name	Area Description	Primary Section	Tangent Sections	Other Names
142	DVT	Dorsal Transitional Visual Area	18	2,3,16	
143	PGp	Area PGp	17	5,15	39,PG
144	IP2	Area IntraParietal 2	17	16	
145	IP1	Area IntraParietal 1	17	16	
146	IP0	Area IntraParietal 0	17	3,5,16	
147	PFop	Area PF opercular	17	6,9	40, 72
148	PF	Area PF Complex	17	9,15	40, 88
149	PFm	Area PFm Complex	17	15	40, 89
150	PGi	Area PGi	17	15	PGa, 39, PG, 90
151	PGs	Area PGs	17	15	PGa, 39, PG, 90
152	V6A	Area V6A	3	18	112
153	VMV1	VentroMedial Visual Area 1	4	2,13	PHC2, PHC-2
154	VMV3	VentroMedial Visual Area 3	4	2,13	VO2
155	PHA2	ParaHippocampal Area 2	13	4	
156	V4t	Area V4t	5		LO2
157	FST	Area FST	5	14,15	
158	V3CD	Area V3CD	5	2,3,17	V3A,V3B, hOC4la
159	LO3	Area Lateral Occipital 3	5	15,17	hOC4la
160	VMV2	VentroMedial Visual Area 2	4	2,13	PHC1, PHC-1
161	31pd	Area 31pd	18		31, 31d, 31v
162	31a	Area 31a	18		31, 31d, 31v
163	VVC	Ventral Visual Complex	4	13,14	VO1, VO2, PHC1, PHC2, PHC-1, PHC2, FG1
164	25	Area 25	19	20	
165	s32	Area s32	19		32pl, 32
166	pOFC	posterior OFC Complex	19	12,20	13a, 14c, Fo2
167	PoI1	Area Posterior Insular 1	12		Id1, Id2, Id3
168	Ig	Insular Granular Complex	12	9	Ig1, Ig2
169	FOP5	Area Frontal Opercular 5	12	21	PrCO
170	p10p	Area posterior 10p	20	22	10p, 10, Fp1
171	p47r	Area posterior 47r	21	20,22	47r
172	TGv	Area TG Ventral	14	13	

Table 0.2 – continued from previous page

Parcel Index	**Area Name**	**Area Description**	**Primary Section**	**Tangent Sections**	**Other Names**
173	MBelt	Medial Belt Complex	10	12	Belt, TB
174	LBelt	Lateral Belt Complex	10		Belt, TB
175	A4	Auditory 4 Complex	11	15	TE3
176	STSva	Area STSv anterior	11	14	
177	TE1m	Area TE1 Middle	14	11	
178	PI	Para-Insular Area	12	11,14	IBT
179	a32pr	Area anterior 32 prime	19		32’
180	p24	Area posterior 24	19		24