RJ10434 (A0808-009) August 6, 2008
Other

IBM Research Report

A Conceptual Cortical Surface Atlas

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Abstract

Volumetric, slice-based, 3-D atlases are invaluable tools for understanding complex cortical convolutions. We present a simple scheme to convert a slice-based atlas to a conceptual surface atlas that is easier to visualize and understand. The key idea is to unfold each slice into a one-dimensional vector, and concatenate a succession of these vectors – while maintaining as much spatial contiguity as possible – into a 2-D matrix. We illustrate our methodology using a coronal slice-based atlas of the Rhesus Monkey cortex. The conceptual surface-based atlases provide a useful complement to slice-based atlases for the purposes of indexing and browsing.

Background

The cortical surface is folded into a number of gyri and sulci creating complex topology that often baffles the mind. Volumetric, slice-based, 3-D stereotaxic atlases are classical tools for completely capturing the cortical spatial complexity [1–3]. It is widely acknowledged that such atlases are difficult to visualize [4]. Hence, complementary computerized surface-based atlases have gained in popularity [5–8]. Precise surface-based atlases are invaluable in individual registration with respect to the atlas. However, for neuro-anatomically-challenged lay people or for experts seeking only a bird's eye view, the precision and details can become impediments to achieving a simpler, conceptual overview of the cortical organization. Here, by sacrificing some precision, we are seeking a surface-based atlas that is useful in providing a bird's eye view of the entire cortical surface while preserving as much information and details as possible.

While advocating "universal usability for information and communications technologies", [9] stressed a need for "advanced strategies for satisfying first-time as well as intermittent and expert users", and proposed encoding information in multiple layers where higher layers encode progressively more detailed information. Specifically, [9] put forth

> "the idea of multi-layer interface designs that enable first-time and novice users to begin with a limited set of features at layer 1. They can remain at layer 1, then move up to higher layers when needed or when they have time to learn further features".

In this context of multi-layer information presentation and visualization, we develop a simplified, conceptual cortical atlas that can be thought of as layer 1 that is suitable for novice and first-time users that are increasingly being drawn to neuroscience from a number of disciplines such as computer science, electrical engineering, mathematics, and so on. Further, our layer 1 atlas naturally links with the more detailed volumetric, slice-based atlas which can be subsequently consulted for more detailed information.

Results

To illustrate concrete application of our methodology, we chose a slice-based atlas of the Rhesus monkey cortex created by respected neuroanatomists George Paxinos, Xu-Feng Huang, and Arthur W. Toga [10]. This was the "first comprehensive delineation of cortical and subcortical structures of any primate species". The atlas depicts the entire brain, consists of 151 photographs, 400 μm apart, and was produced with input from some of the most senior cortical neuroanatomists (Deepak Pandya, Michael Petrides, and Lesley Ungerleider). To appreciate our results and methods, it will be helpful if the reader has ready access to [10].

Figure 1 shows a fragment of the conceptual surface-based atlas derived from [10] corresponding to a portion of the frontal lobe. Columns are indexed from 18 through 32 corresponding to figures 18 through 32 in [10].

Figure 2 shows a fragment of the conceptual surface-based atlas derived from [10] corresponding to portions of the parietal and temporal lobes. Columns are indexed from 63 through 78 corresponding to figures 63 through 78 in [10].

For the complete surface atlas including all 151 figures in [10], see Additional File 1: Complete Conceptual Surface Atlas of the Rhesus Monkey Cortex. Figures 1 and 2 are subsets of Additional File 1. In Additional File 1, the rostral-to-ventral extent of each cortical area can be clearly seen. For example, the area TPO extends from slice 47 through 98. Further, relative extents of two or more areas can be easily gleaned, for example, CA1 and CA2 are co-extensive from slice 62 through 95.

In Additional File 1, we have colored individual cortical areas. For a different perspective, see Additional File 2 which is identical to Additional File 1 except that we have colored larger groups (Frontal Lobe, Cingulate Cortex, Hippocampus + Parahippocampal Cortex, Insular Cortex, Temporal Lobe, Parietal Lobe, and Occipital Lobe).

Discussion

Assuming that slices are cut at a uniform distance, our conceptual atlas is accurate horizontally (across slices) in that relative extents of cortical areas are preserved. However, vertical (within a single slice) extents are not preserved. To emphasize, the vertical thickness of each cortical area along a slice is the only missing information in the conceptual atlas. By sacrificing this detail, a tremendous simplification in representation is achieved. Specifically, the whole atlas can now be represented as a 2-D matrix that can be easily communicated via simple spreadsheets without the need for any detailed co-ordinates. If a co-ordinate system is developed along the surface of each slice, then our conceptual atlas can also be made accurate vertically, and, hence, can be converted into a precise surface-based atlas. Appealing to the multi-layer information presentation principle in [9], such a more precise atlas can serve as layer 2 while the detailed volumetric atlas would then serve as layer 3. In other words, easily digestable overview is presented first followed by details on-demand.

The illustrative atlas [10] used in this paper is based on coronal slices through the brain. Such an atlas naturally gives more prominence to subdivisions related to gyri and sulci that run rostral (anterior) to caudal (posterior), for example, superior temporal gyrus and sulcus. However, our methodology can also be easily applied to atlases based upon transversal or sagittal slices whereupon different gyri and sulci may be highlighted.

Conclusions

The conceptual surface-based atlases provide an interesting and useful way to index, browse, visualize, and digest slice-based atlases and may prove to be a valuable complement to standard atlases such as [10]. Further, our scheme is easy and can be implemented in a matter of few days for any new slice-based atlas [11].

Finally, we have found that the conceptual atlas is very valuable in introducing neuro-anatomically-challenged lay people to the richness and beauty of the brain.

Methods

We now present a scheme to convert a slice-based atlas into a conceptual visualization that was used to produce the results in Figures 1-2 and Additional Files 1-2.

Algorithm Components

Before we describe the precise work flow, we discuss two conceptual steps that are repeatedly used.

Enumerate

The main idea is to think of the cortical surface along each slice as a one-dimensional vector, and traverse it while enumerating the cortical areas that are encountered. The key variables in enumeration are (a) the starting area for enumeration and (b) the order in which the areas are enumerated. For example, for slice 23 in [10], area 24a serves as a natural starting point. Then, slice 23 can be converted into the following one-dimensional column or vertical vector (enumerated from top to bottom): 24a, 24b, 24c, 8/32, 8B, 6DR(F7), 8B, 8AD, 9/46D, 46D, 46V, 9/46V, 45A, 47(12)L, 47(12)O, 13L, 13M, 13a, 25, 24a. Each entry in this vector corresponds to a box in the 23rd column in Figure 1. For a full index of abbreviations, please see [10].

Some slices are extremely easy to enumerate. In particular, slices 23-32 and 46-89 have an unique starting point and an innate natural order from start to end. We term these slices as *anchors*. Each anchor slice has an unambiguous, absolute representation as a column vector. Anchor slices have the topology of a line segment, and geometry of a horseshoe. The only ambiguity in anchor slices is which of the two end points to pick as the starting point. We have used the dorsal endpoint as the starting point.

The remaining slices have either no clearly defined start point or no clear order of enumeration. These non-anchor slices will be enumerated relative to the anchor slices.

Align

Let us suppose that we have enumerated two successive slices and created two column vectors. How should these column vectors be aligned with respect to each other? We would like to place them so that they visually appear maximally aligned. In other words, we would like to align the column vectors arising from successive slices so as to create minimal visual distortion by maintaining as much spatial contiguity between labeled cortical regions as possible. Less visual distortion leads to a surface-atlas that is easier to digest and study. As an example, in Figure 3, we show Columns 82 and 83. The first alignment shown on the left keeps 18 areas contiguous whereas the second alignment shown on the right keep 22 areas contiguous. Hence, we prefer the second alignment as it creates the smallest visual distortion via maximum alignment.

In addition to minimizing overall visual distortion, we will the above alignment process to help select starting points and/or order of enumeration for non-anchor slices by relating them to neighboring anchor slices.

Work Flow

We start by identifying anchor slices. Then, by using alignment with the anchor slices as a guide, we enumerate the remaining non-anchor slices.

Slices 23-32, 46-89

First, enumerate the anchor slices, namely, 23-32 and 46-89. Align anchor slices 23-32 so as to create minimal visual distortion, and ditto for slices 46-89. Figure 1 shows slices 23-32.

Slices 1-22

Slices 1 through 22 in frontal lobe have no logical beginning for enumeration step described above. They have the topology of a circle. For flatting them, a surgical cut is necessary.

By using slice 23 as a guide, for slice 22, we select a starting point, namely, area 32. Intuitively, this amounts to cutting through slice 22 at the boundary between areas 32 and 25 so as to endow the slice with a logical beginning for the purpose of enumerating. Our chosen cut is slightly dorsal to the rostral sulcus. Next, we enumerate the areas as: 32, 24a, 24b, 24c, 32/8, 8B, 8AD, 9/46D, 46D, 46V, 9/46V, 45A, 47(12)L, 47(12)O, 13L, 13M, 13a, and 25. Next, we align slice 22 to slice 23 so as to create minimal visual distortion. Now, slice 22 itself becomes an anchor, and we repeat the process for slice 21 by using slice 22 as a guide, and so on, until all slices 22-1 are cut, enumerated, and aligned. Figure 1 shows slices 18-32.

Slices 33-45

Slices 33 through 45 are interesting because both the temporal lobe and the frontal lobe exist but as disjoint regions. For each slice, the starting point is easy to determine. The issue is how to interleave the cortical areas from two different lobes into a single ordering while minimizing the overall visual distortion. We use slice 46 on the right as an anchor slice and enumerate and align slices 45 through 33 in that order so as to create minimal visual distortion. No cut is necessary for these slices. Figure 4 shows slices 33-46. Observe how frontal lobe and temporal lobes are shown as intertwined in slices 34-40.

Slices 97-151

Slices 97-151 in occipital lobe have no logical beginning for enumeration step described above. For flatting them, a surgical cut is necessary. We cut slice 97 slightly ventral to superior parietal sulcus at the boundary of areas PGM and 23. Thus endowing it with an unique starting point, namely, area PGM. We now enumerate slice 97 as: PGM, PECg, PEC, MIP, VIP, LIPI, LIPE, PG, PGOp, ReI, TPt TPO, MST, MT(V5), FST, TEOm, TEO, V4V, V3V, V2, ProSt, 23, 30, 29d, 29a-c, and S. Finally, by using slice 97 as an anchor, we cut, enumerate, and align slices 98 through 151 in that order.

Slices 90-96

Slices 90-96 where the cingulate cortex meets the hippocampus are interesting.

In slices 90-92, cingulate gyrus (areas 23, 30, 29/29a) exists as a disjoint area. Otherwise, they have a clear starting point and a clear order of enumeration. For these slices, the disjoint regions are shown as such, and the remaining areas are shown with respect to slice 89 as anchor.

In slices 93-96, neither a clear starting point nor a clear order for enumeration exits. In this case, by using slice 97 on the right as an anchor, we cut, enumerate, and align slices 96 through 93 in that order.

Figure 5 shows slices 89-97.

Color

The final step is to color code different areas so as to enhance visual discrimination. In the conceptual atlas, some areas are shown as spatially contiguous although they are not, and some areas that are spatially contiguous are not shown to be so. This distortion is a by-product of the fact that we have no co-ordinate system in the vertical direction, that is, along each column vector. The drawback can be alleviated by introducing color coding to indicate spatial contiguity. Color visually links same or grouped entities in successive columns.

Application of color theory to cartography, is a well-studied art [12]. Accordingly, the colors in the figures are judiciously chosen. Specifically, for Figure 1 and Additional File 1, we have used 12-class, qualitative Set3 from [12] and for Additional File 2, we have used 7-class, qualitative Set2 from [12].

Putting it Together

The entire conceptual cortical surface-based atlas is shown in Additional Files 1 and 2.

Acknowledgements

I am grateful to Dr. Anthony Sherbondy for a very careful reading of drafts of this manuscript, for his numerous constructive suggestions, and for suggesting references [9, 12].

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Figures

Figure 1 - Fragment of the Conceptual Surface-based Atlas (Frontal Lobe)

A fragment of the conceptual surface-based atlas derived from [10]. Columns are indexed from 18 through 32 corresponding to figures 18 through 32 in [10]. The fragment displays a portion of the frontal lobe. To enhance discrimination, different cortical areas are colored differently using 12-class, qualitative Set3 from [12].

Figure 2 - Fragment of the Conceptual Surface-based Atlas (Parietal and Temporal Lobes)

A fragment of the conceptual surface-based atlas derived from [10]. Columns are indexed from 63 through 78 corresponding to figures 63 through 78 in [10]. The fragment displays portions of the parietal and temporal lobes.

Figure 3 - Better Alignment Leads to Lesser Visual Distortion

Two possible alignments for Columns 82 and 83 are shown. The alignment on left keeps 18 areas contiguous whereas the alignment on right keep 22 areas contiguous. Hence, we prefer the second alignment as it creates smallest visual distortion.

Figure 4 - Columns 33-46 of the Conceptual Surface-based Atlas

A fragment of the conceptual surface-based atlas derived from [10]. Columns are indexed from 33 through 46 corresponding to figures 33 through 46 in [10]. Note the way in which temporal lobe and frontal lobe are shown as intertwined in columns 34-40.

Figure 5 - Columns 89-97 of the Conceptual Surface-based Atlas

A fragment of the conceptual surface-based atlas derived from [10]. Columns are indexed from 89 through 97 corresponding to figures 89 through 97 in [10]. The fragment displays slices where the cingulate cortex meets the hippocampus.

Additional Files

Additional file 1 — Complete Conceptual Surface-based Atlas

The figure shows the entire conceptual surface-based atlas derived from [10]. Figure 1 is a subset of this figure. Columns are indexed from 1 through 151 corresponding to figures 1 through 151 in [10]. To enhance discrimination, different cortical areas are colored differently using 12-class, qualitative Set3 from [12]. NOTE: The figure is meant to be printed as a poster.

Additional file 2 — Complete Conceptual Surface-based Atlas

This figure is identical to file 1, however, here we have colored larger regions such as the Frontal Lobe, Cingulate Cortex, Hippocampus + Para-Hippocampal Cortex, Insular Cortex, Temporal Lobe, Parietal Lobe, and Occipital Lobe in this file. To enhance discrimination, different cortical areas are colored differently using 7-class, qualitative Set2 from [12]. NOTE: The figure is meant to be printed as a poster.

18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
32					24a	24a	24a	24a	24a	24a	24a	24a	24a	24a
24a	32			32	24b	24b	24b	24b	24b	24b	24b	24b	24b	24b
24b	24a	32	32	24a	24c	24c	24c	24c	24c	24c	24c	24c	24c	24c
24c	24b	24a	24a	24b	32/8	32/8	32/6	32/6	32/6	32/6	32/6	32/6	32/6	32/6
32/9	24c	24b	24b	24c	8B	6M	6M	6M	6M	6M	6M	6M	6M	6M
9M	32/9	24c	24c	32/8	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)
9L	9M	32/8	32/8	8B	8B	8B	8B	8B	8B	8B	8B	8B	8B	8B
8B	8B	8B	8B	8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD
9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	9/46D	46/9	46/9	46/9	46/9
46D	46D	46D	46D	46D	46D	46D	46D	46D	46D	46D	8AV	8AV	8AV	8AV
46V	46V	46V	46V	46V	46V	46V	46V	46V	46V	46V	45B	45B	45B	45B
9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	9/46V	44	44	44	44
45A	45A	45A	45A	45A	45A	45A	45A	45A	45A	8AV	6VR(F5)	6VR(F5)	6VR(F5)	6VR(F5)
47(12)L	47(12)L	47(12)L	47(12)L	47(12)L	47(12)L	47(12)L	47(12)L	47(12)L	45B	45B	ProM	ProM	ProM	ProM
47(12)O	47(12)O	47(12)O	47(12)O	47(12)O	47(12)O	47(12)O	47(12)O	47(12)O	47(12)L	44	47(12)O	47(12)O	OPro	OPro
13L	13L	13L	13L	13L	13L	13L	13L	13L	47(12)O	ProM	13	13	OPAI	OPAI
13M	13M	13M	13M	13M	13M	13M	13M	13M	13L	47(12)O	OPAI	OPAI	25	25
13a	13a	13a	13a	13a	13a	13a	13a	13a	13M	13L	25	25	24a	24a
14O	14O	14O	14O	25	25	25	25	25	OPAI	13M	24a	24a	IG	IG
14M	14M	14M	14M		24a	24a	24a	24a	25	OPAI				
25	25	25	25						24a	25				
										24a				

63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
											IG				IG
					IG						SS	IG	IG	IG	SS
					SS	IG	IG	IG	IG	IG	29a-c	SS	SS	SS	29a-c
IG	IG	IG	IG	IG	29a-c	SS	SS	SS	SS	SS	29d	29a-c	29a-c	29a-c	29d
SS	SS	SS	SS	SS	29d	29a-c	29a-c	29a-c	29a-c	29a-c	30	29d	29d	29d	30
29a-c	29a-c	29a-c	29a-c	29a-c	30	29d	29d	29d	29d	29d	23a	30	30	30	23a
29d	29d	29d	29d	29d	23a	30	30	30	30	30	23b	23a	23a	23a	23b
30	30	30	30	30	23b	23a	23a	23a	23a	23a	23c	23b	23b	23b	31
23a	23a	23a	23a	23a	23c	23b	23b	23b	23b	23b	3a	23c	31	31	3a
23b	23b	23b	23b	23b	32/6	23c	23c	23c	23c	23c	1	3a	3b	3b	1
23c	23c	23c	23c	23c	4(F1)	32/6	3a	3a	3a	3a	4(F1)	1	1	1	3a
32/6	32/6	32/6	32/6	32/6	3a	4(F1)	4(F1)	4(F1)	4(F1)	1	3a	3a	3a	3a	3b
4(F1)	4(F1)	4(F1)	4(F1)	4(F1)	3b	3a	3a	3a	3a	4(F1)	3b	3b	3b	3b	1
3a	3a	3a	3a	3a	1	3b	3b	3b	3b	3a	1	1	1	1	2
3b	3b	3b	3b	3b	2	1	1	1	1	3b	2	2	2	2	PE
1	1	1	1	1	2Ve	2	2	2	2	1	PE	PE	PE	PE	MIP
2	2	2	2	2	2	2Ve	2Ve	2Ve	2Ve	2	MIP	MIP	MIP	MIP	VIP
S2E	S2E	S2E	S2E	S2E	S2E	2	2	2	2	2Ve	VIP	VIP	VIP	VIP	LIPI
S2I	S2I	S2I	S2I	S2I	S2I	S2E	S2E	S2E	S2E	PFCx	POa/LIP	POa/LIP	POa/LIP	POa/LIP	LIPE
GI	GI	GI	GI	GI	GI	S2I	S2I	S2I	S2I	PFOp	PFCx	PFCx	PFCx	PF	PF
DI	DI	DI	DI	DI	DI	GI	GI	GI	GI	S2	PFOp	PFOp	PFOp	PFOp	PFOp
IPro	IPro	IPro	IPro	IPro	IPro	IPro	IPro	IPro	IPro	GI	S2	S2	S2	S2	S2
ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	ProKM	GI	GI	GI	GI	GI
ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProKL	ProK	ProK	ProK	ProK	ProK
AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM	AKM
AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL	AKL
PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL	PaAL
ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3	ST3
TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa	TAa
TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO	TPO
PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa	PGa
IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa	IPa
TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa	TEa
TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm	TEm
TE2	TE2	TE2	TE2	TE2	TE2	TE2	TE2	TE2	TE3	TE3	TE3	TE3	TE3	TE3	TE3
TE1	TE1	TE1	TE1	TE1	TE1	TE1	TE1	TF	TE2	TE2	TE2	TE2	TE2	TE2	TE2
TLR	TLR	TLR	TLR	TLR	TF	TF	TF	TLR	TF	TF	TF	TF	TF	TF	TF
35	35	35	35	35	TLR	TLR	TLR	35	TLR	TLR	TLR	TLR	TLR	TLR	TLR
ELC	ELC	EC	EC	EC	35	35	35	EC	35	35	35	ECL	ECL	ECL	ECL
EI	EC	ECL	ECL	ECL	EC	EC	EC	ECL	ECL	ECL	ECL	PaS	PaS	PaS	PaS
PaS	PaS	PaS	PaS	PaS	ECL	ECL	ECL	PaS	PaS	PaS	PaS	PrS	PrS	PrS	PrS
PrS	PrS	PrS	PrS	PrS	PaS	PaS	PaS	PrS	PrS	PrS	PrS	S	S	S	S
S	S	S	S	S	PrS	PrS	PrS	S	S	S	S	ProS	ProS	ProS	ProS
ProS	ProS	ProS	ProS	ProS	S	S	S	ProS	ProS	ProS	ProS	CA1	CA1	CA1	CA1
CA1	CA1	CA1	CA1	CA1	ProS	ProS	ProS	CA1	CA1	CA1	CA1	CA2	CA2	CA2	CA2
CA2	CA2	CA2	CA2	CA2	CA1	CA1	CA1	CA2	CA2	CA2	CA2	CA3	CA3	CA3	CA3
CA3	CA3	CA3	CA3	CA3	CA2	CA2	CA2	CA3	CA3	CA3	CA3	CA4	CA4	CA4	CA4
CA2	CA2	CA1'	CA4	CA4	CA3	CA3	CA3	CA4	CA4	CA4	CA4				
CA1'	CA1'	AHi	CA1'	CA1'	CA4	CA4	CA4								

82	83
IG	IG
SS	SS
29a-c	29a-c
29d	29d
30	30
23a	23a
23b	23b
31	31
PECg	PECg
1	1
2	2
PE	PE
MIP	MIP
VIP	VIP
LIPI	LIPI
LIPE	LIPE
PF	PF
PGOp	PGOp
S2	ReIP
ReIP	ReIT
ReIT	PaAC
PaAC	TPt
TPt	TAa
TAa	TPO
TPO	PGa
PGa	FST
FST	TEm
TEm	TE3
TE3	TFL
TFL	TFM
TFM	TL(36)
TL(36)	TH
TH	PaS
PaS	PrS
PrS	S
S	ProS
ProS	CA1
CA1	CA2
CA2	CA3
CA3	CA4
CA4	

18 areas aligned

82	83
IG	
SS	IG
29a-c	SS
29d	29a-c
30	29d
23a	30
23b	23a
31	23b
PECg	31
1	PECg
2	1
PE	2
MIP	PE
VIP	MIP
LIPI	VIP
LIPE	LIPI
PF	LIPE
PGOp	PF
S2	PGOp
ReIP	ReIP
ReIT	ReIT
PaAC	PaAC
TPt	TPt
TAa	TAa
TPO	TPO
PGa	PGa
FST	FST
TEm	TEm
TE3	TE3
TFL	TFL
TFM	TFM
TL(36)	TL(36)
TH	TH
PaS	PaS
PrS	PrS
S	S
ProS	ProS
CA1	CA1
CA2	CA2
CA3	CA3
CA4	CA4

22 areas aligned

33	34	35	36	37	38	39	40	41	42	43	44	45	46
	IG	IG	IG	IG	IG	IG	IG						
24a	24a	24a	24a	24a	24a	24a	24a	IG					
24b	24b	24b	24b	24b	24b	24b	24b	24a	IG	IG			IG
24c	24c	24c	24c	24c	24c	24c	24c	24b	24a	24a	IG	IG	24a
32/6	32/6	32/6	32/6	32/6	32/6	32/6	32/6	24c	24b	24b	24a	24a	24b
6M	6M	6M	6M	6M	6M	6M	6M	32/6	24c	24c	24b	24b	24c
6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6DR(F7)	6M	32/6	32/6	24c	24c	24d
8B	8B	8B	8B	8B	8B	8B	8B	6DC(F2)	6M	6M	32/6	32/6	32/6
8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD	8AD	6DC(F2)	6DC(F2)	6M	6M	6M
46/9	46/9	46/9	8AV	8AV	8AV	8AV	8AV	8AV	8A	8A	6DC(F2)	6DC(F2)	6DC(F2)
8AV	8AV	8AV	45B	45B	45B	45B	45B	44	6VR(F5)	6VC(F4)	8A	8A	8A
45B	45B	45B	44	44	44	44	44	6VR(F5)	ProM	ProM	6VC(F4)	6VC(F4)	6VC(F4)
44	44	44	6VR(F5)	6VR(F5)	6VR(F5)	6VR(F5)	6VR(F5)	ProM	area 2/1	area 2/1	3a	3a	3a
6VR(F5)	6VR(F5)	6VR(F5)	ProM	ProM	ProM	ProM	ProM	area 2/1	ProM	ProM	area 2/1	area 2/1	area 2/1
ProM	ProM	ProM	Gu	Gu	Gu	Gu	Gu	ProM	Gu	S2	S2	S2	S2
Gu	Gu	Gu	AI	AI	AI	AI	AI	Gu	S2	AI	AI	DI	DI
OPro	AI	AI	OPro	OPro	OPro	OPro	IPro	AI	AI	IPro	IPro	AI	AI
OPAI	OPro	OPro	OPAI	TPPro	OPAI	OPAI	OPAI	IPro	IPro	TPPro	TPPro	IPro	IPro
TPPro	OPAI	OPAI	TPPro	TLR	TPPro	TPPAI	TPPAI	TPPAI	TPPAI	ST2S	ST2S	TPPro	TPPro
OPAI	TPPro	TPPro	TLR	Pir	TLR	TPPro	TPPro	TPPro	TPPro	ST2G	ST2G	ST2S	ST2S
25	OPAI	OPAI	Pir	OPAI	Pir	ST2S	ST2S	ST2S	ST2S	ST1	ST1	ST2G	ST2G
24a	25	25	OPAI	25	OPAI	ST2G	ST2G	ST2G	ST2G	TPPro	TPPro	ST1	ST1
IG	24a	IG	25		25	ST1	ST1	ST1	ST1	TLR	TLR	TPPro	TPPro
	IG					TPPro	TPPro	TPPro	TPPro	35	35	TE1	TE1
						TLR	TLR	TLR	TLR	EOI	ELR	TLR	TLR
						Pir	Pir	EOI	35	APir	EOI	35	35
						OPAI	OPAI	Pir	EOI	Pir	APir	ELR	ELR
						25	25		APir		Pir	ER	ER
									Pir			EOI	EOI
												APir	APir
												Pir	

COLOR CODES

- Frontal Lobe
- Cingulate Cortex
- Hippocampus + ParaHip
- Insular Cortex
- Temporal Lobe
- Parietal Lobe

89	90	91	92	93	94	95	96	97
	IG	IG						
IG	SS	SS	IG	IG				
SS	29a-c	29a-c	SS	SS				
29a-c	29d	29d	29a-c	29a-c				
29d	30	30	29d	29d				
30	23a	23a	30	30				
23a	23b	23b	23a	23a	23a			
23b	PGM.31	PGM	23b	23b	23b			
31	PECg	PECg	PGM	PGM	PGM	PGM	PGM	
PECg	2	2	PECg	PECg	PECg	PECg	PECg	PGM
2	PEC	PEC	PEC	PEC	PEC	PEC	PEC	PECg
PE	PE	PE	PE	PE	PE	PE	PE	PEC
MIP	MIP	MIP	MIP	MIP	MIP	MIP	MIP	MIP
VIP	VIP	VIP	VIP	VIP	VIP	VIP	VIP	VIP
LIPI	LIPI	LIPI	LIPI	LIPI	LIPI	LIPI	LIPI	LIPI
LIPE	LIPE	LIPE	LIPE	LIPE	LIPE	LIPE	LIPE	LIPE
PG	PG	PG	PG	PG	PG	PG	PG	PG
PGOp	PGOp	PGOp	PGOp	PGOp	PGOp	PGOp	PGOp	PGOp
RelP	RelP	Rel	Rel	Rel	Rel	Rel	Rel	Rel
RelT	RelT	PaAC	PaAC	PaAC	PaAC	TPt	TPt	TPt
PaAC	PaAC	TPt	TPt	TPt	TPt	TPO	TPO	TPO
TPt	TPt	TPO	TPO	TPO	TPO	MST	MST	MST
TPO	TPO	MT(V5)	MST	MST	MST	MT(V5)	MT(V5)	MT(V5)
PGa	PGa	PGa	MT(V5)	MT(V5)	MT(V5)	FST	FST	FST
FST	FST	FST	FST	FST	FST	TEOm	TEOm	TEOm
TEm	TEOm	TEOm	TEOm	TEOm	TEOm	TEO	TEO	TEO
TE3	TE3	TE3	TEO	TEO	TEO	V4V	V4V	V4V
TFO	TEO	TEO	TFO	TFO	V4V	V3V	V3V	V3V
TLO	TFO	TFO	36O	36O	V3V	V2	V2	V2
THO	TLO	TLO	V4V	V4V	V2	ProSt	ProSt	ProSt
V2	THO	V4	V2	V3V	ProSt	23	23	23
ProSt	V2	V2	ProSt	V2	23b	30	30	30
PaS	ProSt	ProSt	PaS	ProSt	23	SS	SS	29d
PrS	PaS	PaS	PrS			IG	IG	29a-c
S	PrS	PrS	S			29d	29d	S
ProS	S	S	ProS			29a-c	29a-c	
CA1	ProS	ProS	CA1			PrS	PrS	
CA2	CA1	CA1	CA2		IG	S	S	
CA3	CA2	CA2	CA3		SS	ProS	CA3	
CA4	CA3	CA3	CA4		29a-c	CA1		
	CA4	CA4		23	29d	CA2		
				30	30	CA3		
	23	23	23	29d	29d			
	30	30	30	29a-c	29a-c			
	29	29a	29a	PrS	PrS			
				S	S			
				ProS	ProS			
				CA1	CA1			
				CA2	CA2			
				CA3	CA3			
					DG			

COLOR CODES

- Frontal Lobe
- Cingulate Cortex
- Hippocampus + ParaHip
- Insular Cortex
- Temporal Lobe
- Parietal Lobe
- Occipital Lobe