Bibliography on Neuroinformatics

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Abstract

Neuroinformatics references are collected, especially in the area of functional neuroimaging of the human brain. The emphasis is on tools for analysis of neuroscience data, particularly programs for functional neuroimaging. The original URL to this document is

- PDF: http://www.imm.dtu.dk/˜fn/bib/Nielsen2001BibNeuroinformatics.pdf
- PostScript: http://www.imm.dtu.dk/˜fn/bib/Nielsen2001BibNeuroinformatics.ps
- HTML: http://www.imm.dtu.dk/˜fn/bib/Nielsen2001BibNeuroinformatics/.

This bibliography is part of a larger collection of bibliographies that was begun in 2001 see http://www.imm.dtu.dk/˜fn/bib/Nielsen2001Bib/. The bibliography is written in LaTeX and BIBTeX and should be available both as HTML and PostScript.

The bibliography is probably far from complete, but new references are added whenever the author finds new material and has the time to add them. You can email the author if corrections are required or you have found some references that you feel ought to be included: fn@imm.dtu.dk.

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Contents

List of Tables

1 Neuroinformatics — definitions

Neuroinformatics is:

$$\text{neuroinformatics} = \text{neuroscience} + \text{informatics}.$$

A more detailed definition appears in (Beltrame and Koslow, 1999):

> ... combining neuroscience and informatics research to develop and apply advanced tools and approaches essential for a major advancement in understanding the structure and function of the brain. Neuroinformatics research is uniquely placed at the intersections of medical and behavioral sciences, biology, physical and mathematical sciences, computer science, and engineering. The synergy from combining these approaches will accelerate scientific and technological progress, resulting in major medical, social, and economic benefits.

In (Luscombe et al., 2001, page 347) a definition of bioinformatics was proposed. A parallel definition of neuroinformatics is:

> **Neuro-informatics:** neuroinformatics is conceptualizing neuroscientific data and applying **"informatics techniques"** (derived from disciplines such as applied mathematics, computer science and statistics) to **understand** and **organise** the **information** associated with the data on a *large scale*.

2 General reference for neuroinformatics

Dedicated books about neuroinformatics are (Arbib and Grethe, 2001; Koslow and Huerta, 1997). (Rashidi and Buehler, 2000, section 5.1) contains a small section on neuroinformatics.

General review and discussion articles are (Shepherd et al., 1998; Fox and Lancaster, 1994; Cohen et al., 2001; Chicurel, 2000; Beaulieu, 2001; Brinkley and Rosse, 2002; Nielsen et al., 2006) and the most recent (French and Pavlidis, 2007).

Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, 2001 August is a theme issue on neuroscience databases and contains articles describing some of the existing and planned databases (Kötter, 2001): LGICdb (Le Novère and Changeux, 2001), L-Neuron (Ascoli et al., 2001), XANAT (Press et al., 2001b), CoCoMac (Stephan et al., 2001), NeuroScholar (Burns, 2001), NeuroML (Goddard et al., 2001), SuMS (Dickson et al., 2001), fMRIDC (Van Horn et al., 2001a). Abstracts from "Neuroinformatics Workshop: Computing the Chromaffin Cell", September 7, 2001, San Diego, California are available on http://www.nimh.nih.gov/neuroinformatics/compchroabstracts.cfm. *Journal of the American Medical Informatics Association*, volume 8, issue 1; Jan/Feb, 2001 has a short focus on neuroinformatics: (Wong and Koslow, 2001; Miller et al., 2001; Gardner et al., 2001b). Neuroinformatics. Proceedings of a workshop. Arlington, Virginia, USA, September 19-20, 1995 is published as NeuroImage, 1996 Dec, 4(3 Pt 2):S1-61. More recent is *Nature Neuroscience*, 2004 May, volume 7, number 5, with a focus on "scaling up neuroscience".

A group under OECD has issued a report on neuroinformatics (Global Science Forum, 2002) listing formal neuroinformatics projects throughout the world, see also (Working Group on Biological Informatics, 1999). This work has resulted in the formation of the "International Neuroinformatics Coordinating Facility" (INCF) (Eckersley et al., 2003; Working Group on Neuroinformatics, 2003; Butler, 2004). The homepage of this organization is http://incf.org/.

Journals with neuroinformatics content are *Neuroinformatics*, *NeuroImage*, *Human Brain Mapping* and many more.

A web-site with links are available from Berlin http://www.neuroinf.de/.

3 Levels of the nervous system

Table 1 shows a way to subdivide neuroscience that focuses on the scale: Macroscopic neuroscience focuses on a system level description with, e.g., brain areas. Microscopic neuroscience focus on, e.g., molecular biology.

A	Behavior	Psychological descriptions, ...
B	Distributed systems	Brain mapping on a macroscopic level as obtainable with PET, SPECT, fMRI, EEG
C	Local Circuits	Cortex layers, ...
D	Neuron	
E	Microcircuit	The pattern of synaptic connections
F	Synapse	
G	Macromolecules	Membranes, molecules, ions
H	Genes	

Table 1: Levels of the nervous system. Based on (Shepherd, 1994, figure 1.1).

4 Data sources

Table 2: Specific data sources. A star "*" indicates that the data source has public data easily available, e.g., through the Internet. The second column refer to Shepherd's levels listed in table 1. See also the *The SfN Neuroscience Database Gateway* at http://big.sfn.org/ndg/site/ (Gardner and Shepherd, 2004), Neuroguide web-page on databases: http://www.neuroguide.com/neuroresac_4.html.

Name		Description	Reference
Allen Brain Atlas *	AH	Mouse brain atlas of gene transcriptions. *In situ* hybridization stained 3D images	http://www.brain-map.org/, http://www.brainatlas.org/, (Dong, 2006; Lein et al., 2007; Markram, 2007)
(Old) BrainMap™ *	AB	Neuroimaging location data. Contains Bibliographic information, experimental descriptors and 3D Talairach coordinates. This "old" and closed database is continued as "BrainMap DBJ" (which now is referred to as "BrainMap")	(Fox and Lancaster, 1994; Fox et al., 1994; Fox et al., 1995; Lancaster et al., 1994; Lancaster et al., 1997a; Fox and Lancaster, 2002)
(New) BrainMap™/ BrainMap DBJ®*	AB	Neuroimaging location data. Continuation of (original) BrainMap. As of 2005 referred to as "BrainMap"	(Fox et al., 2002; Fox and Lancaster, 2002; Fox et al., 2005a; Laird et al., 2005b), http://www.brainmap.org
Brede Database *	AB	Neuroimaging location data, brain region taxonomy, brain function taxonomy.	(Nielsen, 2003), http://hendrix.imm.dtu.dk-/services/jerne/brede/, http://hendrix.imm.dtu.dk/software-/brede/
fMRIDC *	(A)B	fMRI scanning data, summary images	(Van Horn et al., 2001a; Van Horn and Gazzaniga, 2002; Grethe et al., 2001; Van Horn et al., 2003; Van Horn, 2003) http://www.fmridc.org
Neuro-Generator	AB	Database for human brain imaging.	(Roland et al., 2001; Svensson and Forsberg, 2002; Halldorsson and Fredriksson, 2002; Svensson et al., 2003; Forsberg, 2003; Forsberg, 2004) http://www.neurogenerator.org

Name		Description	Reference
BrainWeb *	B	Simulated MRIs of the human brain	(Cocosco et al., 1997; Kwan et al., 1996; Kwan et al., 1999; Collins et al., 1998) http://www.bic.mni.mcgill.ca/brainweb/
IBSR *	B	MGH CMA Internet Brain Segmentation Repository (IBSR). Repository with raw and segmented (GM/WM/CSF) MRI volumes	http://neuro-www.mgh.harvard.edu-/cma/ibsr/
IBVD *	B	MGH CMA Internet Brain Volume Database (IBVD). "Neuroanatomic volumetric observations", e.g., from MRI morphological studies.	(Kennedy et al., 2003; Haselgrove and Kennedy, 2003), http://www.cma.mgh.harvard.edu/ibvd/
CoCoMac *	B	Neural connectivity database for the Macaque brain	(Stephan et al., 2001; Stephan et al., 2000b; Stephan and Kötter, 1999; Kötter and Wanke, 2005) http://cocomac.org/
"Cat connectivity" *	B	Cortico-cortical, thalamo-cortical, and cortico-thalamic connectivity of the cat. Distributed as ASCII and Excel files.	(Scannell et al., 1995) http://www.ncl.ac.uk/biol/research-/psychology/nsg/neuroinformatics.htm
MC-ET *	B	Simulation data sets for emission tomography	http://www.ibfm.cnr.it/mcet-/index.html
NeSys *	B	Database of pontine projections to SI cortex in rat	(Bjaalie, 2002), http://www.nesys.uio.no/Database/
OASIS	B	Open Access Series of Imaging Studies. Structural MR from 416 subjects.	http://www.oasis-brains.org
Thalamic Connectivity Atlas *	B	Probabilistic mapping of thalamo-cortical connections based on probabilistic diffusion tractography	(Behrens et al., 2003a; Behrens et al., 2003b), http://www.fmrib.ox.ac.uk-/connect/
XANAT	B	Neural connectivity	(Press et al., 2001b; Olshausen and Press, 1994), http://redwood.ucdavis.edu/xanat/
SumsDB	B	"Surface Management Systems DataBase"	(Van Essen et al., 2001; Van Essen, 2002; Van Essen et al., 2005; Dickson et al., 2001), http://sumsdb.wustl.edu:8081/sums-/index.jsp
CoCoDat	C	Database "Collation of Cortical Data" — for "organization of single cell and microcircuitry data"	(Dyhrfjeld-Johnsen et al., 2001)
WormAtlas	CD	Complete neuronal connectivity for the small worm *C. elegans*	(Chen et al., 2006), http://www.wormatlas.org
L-NEURON	CD	Database with dendritic trees. L-Neuron and ArborVitae are programs.	(Ascoli et al., 2001), http://www.krasnow.gmu.edu/L-Neuro/
Duke-Southampton archive of neuronal morphology	D	Database with rat hippocampal neurons.	(Cannon et al., 1998) http://www.cns.soton.ac.uk-/~jchad/cellArchive/index-/topindex.html

Name		Description	Reference
Neurodatabase.org *	D	Neurophysiology database with time-series and histogram data. Java program as entrance and with the data structure used termed “common data model” (CDM). Previously called “Cortical Neuron Net Database”. Associated with BrainML	(Gardner et al., 2001b; Gardner et al., 2001a), http://neurodatabase.org/, http://brainml.org/
Neocortical microcircuit database *	DE(H)	Neuron type (anatomical, electrophysiological), neuron connections	http://microcircuit.epfl.ch/
WebQTL *	H		(Wang et al., 2003; Chesler et al., 2004), http://www.webqtl.org/
SenseLab *	DG	Organization of neurons, neurotransmitters, receptors, cellular ionic currents, computation neuroscientific models (GENESIS, NEURON). Separate database for olfactory receptors.	(Mirsky et al., 1998; Marenco et al., 1999; Skoufos et al., 1990; Skoufos et al., 2000; Crasto et al., 2003; Marenco et al., 2003; Crasto et al., 2007), http://senselab.med.yale.edu/senselab/
GPCRDB *	G	A database of G protein-coupled receptors. Ligand dissociation constants, 3D models	(Horn et al., 1998; Horn et al., 2001), http://www.gpcr.org/
LGICdb *	G	“The Ligand Gated Ion Channel Database”.	(Le Novère and Changeux, 1999; Le Novère and Changeux, 2001; Le Novère and Changeux, 2001), http://www.pasteur.fr/recherche-/banques/LGIC/
HPMR *	G	“Human Plasma Membrane Receptome”. A database of plasma membrane receptors	(Ben-Shlomo et al., 2003), http://receptome.stanford.edu-/HPMR/
WormBase	GH	Gene expression in *Caenorhabditis elegans* and other worms	(Harris et al., 2004; Bieri et al., 2007), http://www.wormbase.org/
PubMed *	—	Bibliographic data within biomedical sciences	http://www.ncbi.nlm.nih.gov/entrez/ (Wilbur and Yang, 1996)
CiteSeer *	—	Also called ResearchIndex. Index of research articles in PostScript on the Internet	(Lawrence et al., 1999) http://citeseer.ist.psu.edu/
Publisher’s website *	—		E.g., http://www.sciencedirect.com/, http://www.interscience.wiley.com/
Bibliographic databases *	—	Special subject databases, e.g., MuSICA (previously “Music & Brain Information Database” — MBI) and “Copenhagen Neuropsychology Database”	E.g., http://www.musica.uci.edu/, http://www.open-rehab.com/ris/risweb.isa

Researchers in functional neuroimaging typically both acquired (from original experiments) and analyze the data. However, a number of Internet services store data (raw or analyzed), enabling other researchers to reanalyze, meta-analyze: Table 2 lists Internet databases with available neuroscientific data.

Biological pathways may be protein-protein interactions, metabolic pathways, signaling pathways or gene regulatory networks. Biological pathways databases are listed at http://www.pathguide.org/. Some of the databases are aMAZE http://www.amaze.ulb.ac.be/, KEGG http://www.genome.ad.jp/kegg/pathway.html and "Signal Transduction Knowledge Environment" (STCK, not public) http://stke.sciencemag.org/. WikiPathways is a wiki-oriented pathway database with graphical display of the pathways (Pico et al., 2008).

APLYSIA ("APLYSIA Proficienty Lets You Scan Indentifying Attributes") once available from http://mollusc.med.cornell.edu/ seems to have been superseded http://neurodatabase.org/.

Neuroscientific data can be voluminous, e.g., A fMRI study can have a size of a gigabyte and a few minutes of a single EEG multi-electrode recordings can generate hundreds of megabyte. Table 3 is an overview of the different types and sizes of data from experimental measurements and associated sources that are collected in neuroscientific databases.

Table 3: Size of data. Table parallel to (Luscombe et al., 2001, table 1).

Name	Description	Reference
Data source	Data size	Neuroinformatics topic
Neuroimaging scanning data	Gigabytes / study	Reanalyses Meta-analyses
Neuroimaging summary images	Megabyte / study	Meta-analyses Volume searches
Neuroimaging location data	Kilobytes / study	Meta-analyses volumes searches
Neural connectivity	Kilobytes / study	Neural network analysis
Literature	11 million	Bibliographic searches

4.1 Brain images

Table 4 shows some to the web-sites with brain images and programs. These are usually not in any reference (stereotaxic) space. The images are often more applicable for educational purposes rather than research purposes.

A dead link is "David" (Online Atlas of Human Anatomy for Clinical Imaging Diagnosis developed by J.-C. Oberson. CT and MRI (T1, T2, PD) labeled sections) http://www.cid.ch/DAVID/head.html

Some of the many books with brain images are (Mai et al., 1997; Talairach and Tournoux, 1988; Heimer, 1994; Moos and Møller, 2001; Damasio, 1995).

Table 4: Brain images — either on the web, as program or digitized. More brain images listed in (Toga, 2002a, table 1) and at http://www.msu.edu/~brains/atlases/.

Name	Description	Reference
BrainInfo	'The Template Atlas' 62 drawings from the longtailed macaque (Macaca fascicularis), nissl, myelin, photographs (unstained), MRI of Macaca fascicularis. Integrated with NeuroNames	http://www.elsevier.com-/homepage/sah/pbm/, http://rprcsgi.rprc.washington.edu-/~atlas/, http://braininfo.rprc.washington.edu/; (Martin and Bowden, 1996; Rauschning, 1983)
GENSAT	Gene expression atlas of the mouse brain	(Heintz, 2004), http://www.gensat.org
Brain stem (MSU)	"Atlas of the Human Brain Stem" with axial images	http://www.msu.edu/~brains-/brains/human/brainstem/
Brain stem (Swenson)	"Atlas of the Brain Stem" with axial images	http://www.dartmouth.edu-/~rswenson/Atlas/
The Whole Brain Atlas	Extensive site with human brain transversal sections images (and movies) of normal as well as pathological brains in multiple modalities (T1, T2, PD, PET, CT). Navigation and often labeled images	http://www.med.harvard.edu-/AANLIB/, (Johnson and Becker, 1999).
SPL/NSL Anatomy Browser	3D views of segmented human brain	(Golland et al., 1998; Anderson et al., 1998; Umans et al., 1997; Kikinis et al., 1996; Shenton et al., 1995) http://splweb.bwh.harvard.edu:8000-/pages/papers/AnatomyBrowser-/current/index.html
Atlas of the Sheep Brain	Cell and fiber stained sections with optional labeling. Labeled external surface images.	http://www.msu.edu-/user/brains/sheepatlas/
Columbia Brain Atlas	MRI and In vivo (PET) and in vitro (autoradiography) molecular neuroimages	http://cba.cpmc.columbia.edu/
Flybrain	Images and illustration of Drosophila	(Armstrong et al., 1995), http://www.flybrain.org/
Digital Anatomist	Human brain image in sections, surface and 3D views with interactive labels from Seattle	(Brinkley and Rosse, 1997), http://www9.biostr.-washington.edu/da.html
Neur@nat	Human brain images with interactive labels	http://www.chups.jussieu.fr/ext-/neuranat/
MBL C57BL/6J Atlas	Mouse brain pictures in coronal and horizontal sections with/out grid. C57BL/6J is a specific strain. DBA/2J atlas is also available.	http://www.mbl.org/atlas232-/atlas232_frame.html, http://www.mbl.org/atlas170-/atlas170_frame.html
PET Brain Atlas (PBA)	PET images of the normal and diseased human brain. Labeled and unlabel illustrations.	http://oracle.crump.ucla.edu:8001-/pet/pba/. http://laxmi.nuc.ucla.edu:8000-/PBA/HTML/

Name	Description	Reference
Neuroanatomy	Neuroanatomy, A Photografic Study of the Central Nervous System	http://www.neuroanatomy.hpg.-ig.com.br/
The NPAC Visible Human Viewer	Java applet for viewing the Visible Human data set in coronal, transversal and sagittal sections	(Chang et al., 1998) http://www.npac.syr.edu/projects-/vishuman/VisibleHuman.html
Comparative Mammalian Brain Collections	Photographs of external surfaces of 175 mammalian species, some (stained?) section images	http://brainmuseum.org/
The Human Brain. Dissection of the Real Brain	Photographs and labeled drawings of the human brain from the *Virtual Hospital*	http://www.vh.org/Providers-/Textbooks/BrainAnatomy-/BrainAnatomy.html
Brain stem of Rhesus	Label sections in stereotaxic coordinates with links to BrainInfo	(Smith et al., 1972) http://braininfo.rprc.-washington.edu-/otheratlas/Brainstem/index.html
The HCIL Visible Human Explorer	Not a web application but a SUN computer program to display images from the visible human data set	(North and Korn, 1996; North et al., 1996) http://www.cs.umd.edu/hcil-/visible-human/
	(*Items below do not seem (or has not seemed) to work on a Linux system*)	
LONI Human atlas	Cryosection images from two normal female cadavers. Possible the termed "Human cryotome data" and "LADY" before.	(Toga et al., 1994) (?), http://www.loni.ucla.edu/Research-/Atlases/HumanAtlas.html
LONI Monkey Atlas	Sections and images of 3D models	(Cannestra et al., 1997) (?), http://www.loni.ucla.edu/Research-/Atlases/MonkeyAtlas.html
LONI Rat Atlas	Labeled Coronal, sagittal and transversal cryosections with coordinates	(Toga et al., 1995) (?) http://www.loni.ucla.edu/Research-/Atlases/RatAtlas.html
DTI Atlas	Labeled images of analyzed diffusion tensor images	http://www.DTIatlas.org

4.2 Genetics

Table 5: Genetics association databases

Name	Description	Reference
AlzGene	Limited to Alzeimer's disease. Numerical results from published studies are entered and results of meta-analysis are displayed in tables and plots	http://www.alzforum.org/res/com-/gen/alzgene/ (Bertram et al., 2007)
CGEMS	*Cancer Genetic Markers of Susceptibility*	http://cgems.cancer.gov/
dbGaP	Genome-wide association studies	http://www.ncbi.nlm.nih.gov/gap
GAD	*Genetics Association Database* from NIH	http://geneticassociationdb.nih.gov/, (Becker et al., 2004)

Name	Description	Reference
HuGE Pub Lit	Human Genome Epidemiology (HuGE) Published Literature database	http://hugenavigator.net/, (Lin et al., 2006)
OMIM	The text-oriented web-site *Online Mendelian Inheritance in Man* links gene and genetic disorders	http://www.ncbi.nlm.nih.gov-/entrez/query.fcgi?db=OMIM, (McKusick, 1998)
PADB	*Published Association Database* automatically extracts text from published association study abstracts. For the studies were this is possible the database can sort them according to risk measure.	http://www.medclue.com/padb (Rhee and Lee, 2007)
PDGene	Limited to Parkinson's disease.	http://www.pdgene.org/
PharmGKB	The Pharmacogenetics and Pharmacogenomics Knowledge Base	http://www.pharmgkb.org/
SzGene	Limited to schizophrenia	(Allen et al., 2008)
T1DBase	Limited to type 1 diabetes	http://www.t1dbase.org/

5 Experimental design

Type	Subtype	Description	Reference
Subtraction			(Lassen et al., 1978)
Double subtraction	fMRI	Subtraction of the form $(A-B)-(C-B)$	(Poldrack et al., 1998; Poldrack et al., 1999)
Parametric	PET		(Grafton et al., 1992)
Parametric		Presentation rate of heard words is varied	(Price et al., 1992)
Parametric	Nonlinear		(Büchel et al., 1996)
Parametric			(Büchel et al., 1998)
Block		Block-design in fMRI presents the paradigm	
Event-related		fMRI design where the paradigm is presented as short stimuli.	
Mixed		fMRI design Mixed between block design and event-related.	e.g., (Visscher et al., 2003; Donaldson, 2004)
Stochastic event-related		Event-related design where the periods between the stimuli are varied.	
2×2 factorial	PET	Motor activation and time	(Friston et al., 1992a)
2×2 factorial	PET	Memory and drug (apomorphine and buspirone) interaction	(Friston et al., 1992b)
2×2 factorial	efMRI	Maintenance and manipulation	(Honey et al., 2001)
PPI		Pycho-physiological interaction where the change in interaction between one area and another is analyzed	(Friston et al., 1997), Example analysis: http://www.fil.ion.ucl.ac.uk-/˜wpenny/datasets/attention-/README_GLM_PPI.txt
Conjunction		$(A-B) \wedge (C-D)$	(Price and Friston, 1997; Friston et al., 1999a; Nichols et al., 2005; Brett et al., 2004; Friston et al., 2005)
Conjunction	Multimodal		(Hayasaka et al., 2006)

Table 6: Experimental designs in functional neuroimaging.

Table 6 shows some of the experimental designs in (cognitive) functional neuroimaging.

In pycho-physiological interaction (PPI) experiments (Friston et al., 1997) the change in interaction strength between one area and another are investigated. The change appears when the experimental paradigm is changed.

Cognitive conjunction (Price and Friston, 1997) includes a series of subtraction designs that differ in the cognitive component they elicit. The resulting statistical maps are "and'ed" to form a statistical map for (usually) a single cognitive component. The exact interpretation of the "and" can vary depending on the statistics used (Brett et al., 2004).

(Hemodynamic) response modeling in fMRI can model shape and amplitude of hemodynamic response function (HRF), e.g., (Boynton et al., 1996) where the function between the contrast of a visual stimuli (flickering checkerboard pattern) and the BOLD response is described.

In fMRI and especially in event-related fMRI (efMRI) the paradigm is either a "Dirac" impulse or a short block of stimulus/response. Common for efMRI is that the measured signal is not regarded as being in a steady state. In these kind of experiments the paradigm pattern can be varied in many ways, e.g., the interstimulus interval (ISI) can be varied. *Jittering* is when the presentation of the paradigm is deliberately varied so that it is not correlated in phase with the acquisition rate of the scanner. In *stochastic designs* the paradigm is presented aperiodically (Heid et al., 1997).

A program for optimizing experiment design with genetic algorithms has been constructed by Tor Wagner and Tom E. Nichols (Wager and Nichols, 2002): http://www.lsa.umich.edu/psych-/research&labs/jjonides/download.html.

5.1 Statistical approach to optimize experimental design

(Liu et al., 2001a) distinguishes between estimation efficiency and detection power, where the former is the ability to estimate the shape of the hemodynamic response function (HRF) and the latter is the ability to estimated the brain activation. In connection with the general linear model the measure for the *efficiency* is (Dale, 1999, equation 12), (Friston et al., 1999b, page 608 and equation A.3), (Liu et al., 2001a, equation 4), (Birn et al., 2002, equation 12)

$$E = \frac{1}{\text{trace}\left[(\mathbf{X}^\mathsf{T}\mathbf{X})^{-1}\right]} \tag{1}$$

where $\mathbf{X}$ is the design matrix and σ^2 is the covariance of the Gaussian distributed noise. This is called the inverse *A-optimality* criterion (Montgomery, 2001, page 468).

The direct optimization of experimental design for BOLD fMRI should take into account the nonlinear effect occurring when a stimulus is presented rapidly and the 1/f-noise which prevents the stimulus to be presented to long. (Aguirre et al., 2002) find that BOLD fMRI are contaminated by autocorrelated noise contrary to perfusion arterial spin labeling (ASL) fMRI in which the autocorrelated noise is absent.

Other discussions of functional neuroimaging experimental design are found in (Birn et al., 2002).

5.1.1 Unclassified

J. E. Desmond, G. H. Glover, Estimating sample size in functional MRI (fMRI) neuroimaging studies: statistical power analyses. J Neurosci Methods 2002 Aug 30;118(2):115-28 PMID: 12204303

Mapping Voxel-Based Statistical Power on Parametric Images" by JD Van Horn et al. Neuroimage 7, 97-107 (1998)

Jason Steffener SPM-mailing list

5.2 Neuropsychological tests

Table 7 shows a number of tests that are particularly used in clinical neuropsychology. Description of many neuropsychological tests are available in (Crawford et al., 1992; Lezak, 1995).

Table 7: Neuropsychological tests.

Abbrev.	Name	Description	Reference
ADIS	Adult Diagnostic Interview Schedule		
BPRS	Brief Psychiatric Rating Scale		Southwick et al., 1993
CRAS	Clinician Rated Anxiety Scale		
EPQ	Eysenck Personality Questionnaire		
HAMA	Hamilton Anxiety Rating Scale	"Hamilton Anxiety scale"	(Hamilton, 1959)
HAMD	Hamilton depression scale		
MAS	Manifest Anxiety Scale		(Taylor, 1953)

Abbrev.	Name	Description	Reference
MMPI	Minnesota Multiphasic Personality Inventory		Wikipedia
MMSE	Mini-Mental State Examination	A brief test for dementia	(Folstein et al., 1975), (Morris and Kopelman, 1992, page 304)
NEO PI-R	Revised NEO Personality Inventory		(Costa and McCrae, 1992)
PANAS	Positive Affect Negatve Affect Schedule		(Watson et al., 1988)
PASS	Panic Attack Symptom Scale	A panic attack is defined in DSMIV as a PASS score of higher than 8	
POMS	Profile of Mood States. Originally "Psychiatric Outpatient Mood Scale"		(McNair et al., 1981; McNair and Lorr, 1964)
SAM	Self-Assessment Manikin	A quick non-verbal pictorial assessment of emotional reaction split in pleasure, arousal, and dominance components	(Bradley and Lang, 1994)
SCID	Structured Clinical Interview for DSM-IV		(Spitzer et al., 1987)
SCL-90-R	Symptom Check List 90 Revised		Hopkins(?)
SHSS	Stanford Hypnotic Susceptibility Scale	"Form A" "Form C", "Form I" and Form II" seem to exist	(Hilgard et al., 1963)
SDS	Self-rating Depression Scale. Also "Zung's depression scale".	20 questions answered by the patient. < 50 is normal, > 70 is severe depression	(Zung et al., 1965)
STAIS-s	Spielberger's State Anxiety Inventory		
SUB	Subjective Units of Distress		
UPDRS	Unified Parkinson's Disease Rating Scale		(Fahn et al., 1987)
WAIS	Wechsler Adult Intellingence Scale		(Wechsler, 1955; Crawford, 1992)
WAIS-R	Wechsler Adult Intellingence Scale — Revised		(Wechsler, 1981; Crawford, 1992)
Y-BOCS	Yale-Brown obsessive-compulsive scale		(Goodman et al., 1989)
YGTSS	Yale Global Tic Severity Scale	Used for Tourette Syndrome	

5.3 Psychological test software tools

Table 8 displays a list of psychological experiment generator software. Some of these only incorporate presentation of visual stimulus, while others also allow for collection of responses from a number of different devices as well as synchronization with an fMRI scanner. Psychology Software Distribution, http://www.psychologysoftwaredistribution.com/, maintains a short list of experiments written for a number of these software packages. It is based on data collected by CTI from University of York, http://www.york.ac.uk/inst/ctipsych/expgen/entry.html. (Hammond and Trapp, 1996) is a 1996 review of ten experiment software packages. Journal of Neurobehavioral Experiments and Stimuli (JONES, http://www.neuroexpts.com) also lists a experiments.

Table 8: Psychological software and hardware.

Name		Description	Reference
BrainLogics	A(B)	Commercial fMRI system with response buttons, experimental development and analysis	http://www.pstnet.com/brainlogics/
Cogent	A	Windows Matlab-based presentation program with possibility for manipulating output (sound and graphics) and input (mouse, keyboard, joystick, serial and parallel port plus fMRI scanner triggering)	(Hutton et al., 2002) http://www.fil.ion.ucl.ac.uk-cogent2000/
DMDX	A		(Forster and Forster, 2003)
Eloquence	A(B)	Commercial paradigm presentation hardware and software for fMRI	http://www.mridevices.com/-products/-fMRIProductDetail.aspx?ID=100
E-Prime	A	Commercial Windows-based presentation program with graphical and Visual Basic like scripting language and response collection. From *Psychology Software Tools*.	http://www.pstnet.com/E-Prime/e-prime.htm
ERTS	A	PC-based presentation program. Features fMRI triggering with a TTL-signal	http://www.erts.de/
FEST	A	"FMRIB Enhanced Stimulation Tool": Stimulation tool for presenting pictures, sounds and text and record button press.	http://www.fmrib.ox.ac.uk/˜dave-/festman/
fLEXI	A		http://www.psy.uva.nl/Service/SG-/Software/fLexi.html
IFIS	A(B)	Integrated Functional Imaging System. Commercial software and hardware system. Software is a variation of E-Prime suitable for presentation in an functional neuroimaging experiment. Features MRI RF-pulse triggering (via antenna), graphical and Visual Basic like scripting language, non-magnetic finger buttons and dual screens (control and presentation). fMRI analysis via BrainVoyager.	IFIS-SA: http://www.mridevices.com/-products/-fMRIProductDetail.aspx?ID=101
LabVIEW	A	Commercial program from National Instruments. Signal aquisition program and stimulus control	http://www.ni.com/labview/, SPM mailing list: labview
MacStim	A	68k Mac based program by David Darby	http://www.brainmapping.org-/WhiteAnt/
MEL	A	DOS-based experiment generation program.	http://www.pstnet.com-/melproducts/mel_product_line.htm
Presentation	A	PC-based stimulus generator with input devices (e.g., mouse and joystick) and MRI-scanner synchronization with built-in programming language	http://www.neurobs.com/
Psychophysics Toolbox	A	Matlab-based (Windows and MacIntosh) toolbox for vision research.	http://psychtoolbox.org/, (Brainard, 1997; Pelli, 1997)

Name		Description	Reference
PsyScope	A	Macintosh-based (OS7-OS9) "interactive graphic system for experimental design and control". Development has ceased.	(Cohen et al., 1993; MacWhinney et al., 1997), http://psyscope.psy.cmu.edu/ (original site), http://cnts.uia.ac.be-/psyscope/index.html (Belgian mirror)
PyEPL	A	"The Python Experiment-Programming Library": Python-based with playback and recording of sound, displaying text, images and 3 dimensional environments with input from keyboard and synchronization with external recorded events	(Geller, 2006; Geller et al., 2006), http://pyepl.sourceforge.net/
Stim[2]	A	Commerical Windows-based stimulus presentation from Neuroscan.	http://www.neuro.com-/product.sstg?id=58
Rings	A	Mac-based program for generation of simple visual stimuli	http://porkpie.loni.ucla.edu-/BMD_HTML/SharedCode-/SharedSoftware.html#Stimuli
SuperLab	A	Commercial Macintosh/Windows-based experiment generator supporting a number of input devices (keyboard, mouse, microphone, Cedrus and PST response boxes, I/O cards). From *Cedrus Corporation.*	http://www.superlab.com/
Vision Egg	A	2D and 3D visual stimulus creation and control open source software based on python and OpenGL for Windows, Mac OS X, Linux, SGI	http://www.visionegg.org

5.4 MRI compatible hardware

Table 9 shows publicly available MRI compatible hardware. A fiber optic joystick is used in (Van Horn et al., 2001b). The Altra Felix pointing device is not made for use in MRI, but it has been used in a 1.5T scanner (Balslev et al., 2004).

Name	Items	Reference
ADInstruments	Finger electrodes, galvanic skin response, respiratory transducer, laser Doppler probe, termocouple probe	http://www.adinstruments.com-/products/MR_list/research/
ASL 504LRO	fMRI compatible eyetracker	http://www.a-s-l.com-/504lro.htm
Avotec	LCD projection system with eye tracking, e.g., "Silent Vision" system.	http://www.avotec.org-/silentvision.htm
Cambridge Research Systems	"Lumina" response pads and "MR-Eyetracker"	E.g., http://www.crsltd.com-/catalog/lumina/
Coldswitch	*LUMItouch™* response pad and *LUMItouch Joystick*	http://www.coldswitch.com-/medical.asp
Current Designs	Fiber Optic Response Pad system (fORP): Buttons, joystick, trackball	http://www.curdes.com/
Imagelys	fMRI response pads and fMRI synchronization interface	http://www.imagilys.com/fmri-dti-neurosurgery-products/
Invivo Research	Patient monitoring, Pulse Oximetry, and e.g., "monitors ECG, Respiration, HR, SpO2, NIBP, with optional EtCO2"	http://invivoresearch.com-/prod_mpm.html
Mag Design and Engineering	Response box, head constraints, tactile stimuli, eye tracking, joystick. Commercial products by Ben Krasnow	http://www.magconcept.com-/mri.html
Measurand	"ShapeHand MRI" data glove	http://www.measurand.com-/products/ShapeHand.html
MRI Devices Corporation	IFIS, response pad, earphones, visual display, control room console	http://www.mridevices.com-/products/ifis/
NeuroScan	*STIM* stereoscopic visual (*Silent Vision™*) and stereo auditory (*Silent Scan™*) stimulation, *MagLink* EEG recording	http://www.neuro.com-/neuroscan/stimfmri.htm
Nonin	Portable Pulse Oximeter	http://www.nonin.com
Resonance Technology	*Commander XG* earphones, *MRIVision 2000* and *VisuaStim XGA* stereoscopic head-mounted displays	http://www.mrivideo.com-/temp/functionalmri/
Rowland Institute	Response box by Chris Stokes(?)	http://hill-server.rowland.org-/rurb/
Sven Haller	Pneumatic MR compatible response box available "at a reasonable price"	SPM Mailing list, 2002-9-11

Table 9: MRI compatible hardware: Response pads, joysticks, displays, earphones and EEG recording.

6 Analysis and processing

6.1 Methods in neuroimaging

The literature presents (exceedingly) many methods for analysis of neuroscience data. Table 10 lists only few for use within functional and molecular neuroimaging.

Table 10: Analysis methods.

Domain	Name/topic	Description	Reference
Dynamic PET	"Logan plot", the classic Logan plot		(Logan et al., 1996)
Dynamic PET	Logan's Reference Tissue Model	Logan's plot with a reference region used with k_2' Implemented in PMOD.	http://pmod.com-/technologies/doc/pkin-/2322.htm
Dynamic PET	MRTM0	Ichise's (original) multi-linear reference tissue model	(Ichise et al., 1996), http://www.pmod.com-/technologies/doc/pxmod-/3250.htm
Dynamic PET	MRTM	Ichise's (modified) multi-linear reference tissue model, a three-parameter model	(Ichise et al., 2003; Ichise et al., 2002), http://www.pmod.com-/technologies/doc/pkin-/2316.htm
Dynamic PET	MRTM2	Ichise's multi-linear reference tissue model, a two-parameter model with fixed k_2'	(Ichise et al., 2003), http://www.pmod.com-/technologies/doc/pxmod-/3251.htm
fMRI BOLD response modeling	Convolution with FIR-filter	Linear modeling of the response from paradigm to fMRI signal with a finite impulse response (FIR) filter.	(Nielsen et al., 1997; Goutte et al., 2000; Lange et al., 1999)
fMRI response modeling	Convolution with Bayesian estimated FIR	Modeling the fMRI response with a finite impulse response (FIR) filter, Bayesian estimation, a Gaussian process prior, and Markov chain Monte Carlo (MCMC)	(Goutte et al., 2000; Andersen et al., 2002),
fMRI BOLD response modeling	Convolution, Gamma	A gamma probability density function modeling the hemodynamic response, estimation in the frequency domain, and modeling of the noise in the frequency domain. Partly implemented in Lyngby	(Lange and Zeger, 1997)
fMRI BOLD response modeling	Bayesian balloons	Balloon models, extended balloon models with Bayesian Markov chain Monte Carlo and split-half resampling.	(Jacobsen et al., 2008)

Domain	Name/topic	Description	Reference
fMRI unsupervised multivariate	K-means clustering	K-means clustering of voxels with use of cross-correlation function between paradigm and fMRI signal. Estimation of the number of clusters.	(Goutte et al., 1999b)
fMRI unsupervized multivariate	K-means clustering	Clustering of voxel based on features from, e.g., and FIR-filter modeling of the hemodynamic response	(Goutte et al., 2001; Goutte et al., 1999a)
fMRI unsupervised multivariate	Independent component analysis (ICA)	There are many studies in this domain	See Bibliography on Independent Component Analysis in Functional Neuroimaging
fMRI semi-supervized	Univariate correlation across subjects	Showing the same stimulus to several subjects and analysis the intersubject correlation, inter-participant correlation (IPC)	(Hasson et al., 2004; Hejnar et al., 2007)
Analysis	Image-based covariates	(Biological parametric mapping)	(Casanova et al., 2007; Oakes et al., 2007; Mehta et al., 2006)
Prediction	PCA and neural network classifier	Principal component analysis and an artificial neural network	(Lautrup et al., 1995; Hansen et al., 1994)
Prediction	Neural network classifier	SPECT predicting Alzheimer and controls	(Halkjær et al., 1997a; Halkjær et al., 1997b)
Prediction	PET and fMRI, neural network, principal component analysis		(Mørch et al., 1997; Mørch et al., 1995; Mørch et al., 1996)
Prediction	fMRI, neural network and principal component analysis with saliency maps		(Nielsen, 1996)
Prediction and reproducibility	Learning curves	Demonstrated on four different PET data sets. Prediction error expressed in terms of mutual information and sensitivity map shown.	(Kjems et al., 2002)
Prediction	fMRI, evolutionary algorithm feature selection, linear classifier, neural network, support vector machine with relevance maps	Prediction	(Åberg et al., 2006)
Connectivity modeling	Structural equation modeling, etc.		See the Bibliography on Path Analysis
Imaging	Location identification		(Reimold et al., 2005)

Domain	Name/topic	Description	Reference
Multiple comparisons	Permutation test on the maximum in the statistical summery image		(Holmes et al., 1996; Nichols and Holmes, 2001)
Multiple comparisons	False discovery rate (FDR)	Introduction of FDR into neuroimaging	(Genovese et al., 2002)
Multiple comparisons	Two-step FDR		(Jiang and Doerge, 2006)

6.2 Tools

There exists a large number of programs for processing and analysis of brain signals, particularly within the functional neuroimaging field.

6.2.1 Neuroimaging

A review of some of the programs for fMRI analysis is available in (Gold et al., 1998): AFNI 2.01, SPM96, Stimulate 5.0, MEDIMAX 2.01, and FIT were tested; FIASCO, Yale, and MEDx 2.0. FIT (functional imaging toolkit) does not seem to be available any longer. More recent comments on tools for fMRI appear in (Nielsen et al., 2006).

For lists of image registration software see the Image Registration bibliography: http://www.imm.dtu.dk/~fn/bib/Nielsen2001BibImage/. And for lists of brain segmentation software see the "Bibliography of Segmentation in Neuroimaging" http://www.imm.dtu.dk/~fn/bib/Nielsen2001BibSegmentation/.

Most programs work with volumes. The programs that allow for analysis or visualization of the 2D cortical surface are BrainVoyager, CirclePack, FreeSurfer, SureFit/Caret, SUMA, SurfRelax and McGray

Apart from the listed programs there is also, e.g., CliniViewer, a program for display of multiple MRIs (Uttecht and Thulborn, 2002).

Table 11: Neuroinformatics tools for functional neuroimaging (PET and fMRI). The entries are alphabetically ordered. See also *The SfN Neuroscience Database Gateway* at http://big.sfn.org/ndg/site/ (Gardner and Shepherd, 2004), *Internet Analysis Tools Registry* at http://www.cma.mgh.harvard.edu-/tools/, Andrew Crabb's *I do Imaging* at http://idoimaging.com/ and NIH's list of visualization software http://www.cc.nih.gov/cip-/visualization/vis_packages.html.

Name	Impl.	Description	Reference
3D slicer		Visualization, segmentation, registration	(Gering et al., 1999; Gering, 1999) http://www.slicer.org/
3DVIEWNIX	X	Commercial program for preprocessing, visualization and analysis of 3D imaging data. From the Medical Image Processing Group and University of Pennsylvania.	http://www.mipg.upenn.edu/~Vnews/
ABLe	Solaris, Linux, SGI IRIX	Commercial program part of MEDx for "Analysis of Brain Lesions"	http://medx.sensor.com/products-/medx/able.html

Name	Impl.	Description	Reference
Activ2000	Delphi5	Windows-based program for fMRI processing and analysis.	http://www.multimania.com-/dducreux/activ2000.htm
AFNI	C	Functional neuroimaging analysis program	(Cox, 1996; Cox and Hyde, 1997; Cox and Ward, 1997; Ward and Cox, 1997), http://afni.nimh.nih.gov/afni/
AIR	C	Image registration program	(Woods et al., 1998a; Woods et al., 1998b) http://bishopw.loni.ucla.edu/AIR3/
AMIDE	Unix, Mac, Windows	Volume viewing	(Loening and Gambhir, 2003), http://amide.sourceforge.net/
Anatomist	Unix	Structural morphometry analysis, e.g., sulci identification. Part of BrainVISA	(Riviére et al., 2003), http://anatomist.info
Atamai	Linux, Mac OS X, windows	"Atamai Viewer" with 3D visualization. Image registration (comericial)	http://www.atamai.com/
BAMM		"[S]oftware library for statistical analysis of structural and functional magnetic resonance (MR) images"	http://www-bmu.psychiatry.cam.ac.uk/BAMM/
BET		Brain Extraction Tool by Stephen Smith et al. Included in MRIcro	http://www.fmrib.ox.ac.uk/fsl/bet/
BPM	Matlab	"Biological Parametric Mapping Toolbox" matlab toolbox with image-based regressors	(Casanova et al., 2007), http://www.fmri.wfubmc.edu
BrainMap™	Internet, Java	Database with functional neuroimaging results	(Fox and Lancaster, 1994; Fox et al., 1994; Fox et al., 1995; Lancaster et al., 1994; Lancaster et al., 1997a; Fox and Lancaster, 2002; Fox et al., 2005a) http://www.brainmap.org
BRAINS2	X11, OpenGL, TCL/TK	"Brain Research: Analysis of Images Networks and Systems". Manual and automated tools for structural analysis, tissue classification and cortical surface extraction.	(Magnotta et al., 2002; Magnotta and Andreasen, 2001), http://moniz.psychiatry.uiowa.edu-/local/brains2/brains2.html
Brain Tools		Software by Krish Singh for the Analysis of Structural and Functional Brain images. Consists of mri3dX and mriWorkshopX.	http://www-users.aston.ac.uk-/~singhkd/software.html
BrainVoyager	C++/-OpenGL/Qt	Commercial program for fMRI analysis and visualization	http://www.brainvoyager.de/
BrainWeb	Internet service	Database with simulated MRI of the human brain	(Cocosco et al., 1997; Kwan et al., 1996; Kwan et al., 1999; Collins et al., 1998) http://www.bic.mni.mcgill.ca/brainweb/
BRIAN	C, C++, Unix	Perhaps continued as LIPSIA?	(Kruggel and Lohmann, 1996)
BSE		Automated Brain Surface Extraction	http://www.loni.ucla.edu/NCRR-/Software/BSE.html

Name	Impl.	Description	Reference
CamBA	Windows, POSIX	Cambridge Brain Activation. fMRI analysis.	(Suckling et al., 2006b; Bullmore et al., 1999; Bullmore et al., 2001; Suckling and Bullmore, 2004; Suckling et al., 2006a), http://www-bmu.psychiatry.cam.ac.uk/software/
Caret	SGI/Linux-/Sun/Mac	'Computerized Anatomical Reconstruction and Editing Toolkit' from Van Essen Laboratory. for 'visualizing, editing, analyzing, and flattening cortical surface reconstructions'.	(Drury et al., 1996; Van Essen et al., 2001; Harwell et al., 2001), http://brainmap.wustl.edu/caret/
CCHIPS©	IDL	"Cincinnati Children's Hospital Image Processing Software" Preprocessing and analysis software for fMRI, dMRI, spectroscopy, and pMRI.	http://www.irc.chmcc.org/chips.htm
CirclePack	X-windows	Software for flatmapping	http://www.math.utk.edu/~kens/, http://neurovia.umn.edu/incweb-/flatmap_info.html
CLEAVE	C	"C Language Exploratory Analysis of Variance with Enhancements" that is "designed for the analysis of very large data sets of the sort obtained in experiments using EEG and fMRI"	http://www.ebire.org/hcnlab-/software/cleave.html
Corner Cube	IDL or Web	Visualization environment	(Rehm et al., 1998; Schaper et al., 1996; Rehm et al., 1997), http://www.neurovia.umn.edu/-incweb/ccinfo.html Web demo: http://neurovia.umn.edu/incweb/-ccweb/
DP Tools	Delphi5	Windows-based diffusion and perfusion MRI analysis program by *Denis Ducreux*	(Smith et al., 2000; Ducreux et al., 2001) http://www.multimania.com-/dducreux/DPTools.htm
Display	Unix, OpenGL	A program to view MINC files	ftp://ftp.bic.mni.mcgill.ca-/pub/register+Display/, http://www.bic.mni.mcgill.ca-/software/Display/Display.html, http://sourceforge.net/projects/mni-minc-win32/
EMMA	Matlab	"Extensible MATLAB Medical image Analysis" from BIC, MNI, McGill Reading and writing of MINC files. Visualization, ROI and dynamic PET analyses	http://www.bic.mni.mcgill.ca-/software/emma/
EvIdent		(Fuzzy) cluster analysis for neuroimaging	(Pizzi et al., 2001), http://www.ibd.nrc-cnrc.gc.ca/english/info_e_evident.htm
FIASCO	Shell, C	Collection of programs (C and shell scripts) for processing of fMRI.	http://lib.stat.cmu.edu/~fiasco/ (Eddy et al., 1996)

Name	Impl.	Description	Reference
fMRI Analysis Package (Yale)	Matlab	Analysis	http://mri.med.yale.edu/individual/-pawel/fMRIpackage.html
FMRISTAT	Matlab	fMRI analysis program. Also called BICstat and multistat	(Worsley et al., 2002; Worsley et al., 2000) http://www.bic.mni.mcgill.ca/~keith/
FMRLAB	Matlab	Independent component analysis for fMRI	http://sccn.ucsd.edu/fmrlab/
FreeSurfer	Linux, Darwin, Solaris, IRIX	Program for reconstruction of the cortical surface.	(Dale et al., 1999; Fischl et al., 1999a; Fischl et al., 1999b; Fischl and Dale, 2000; Fischl et al., 2001; Busa, 2002) http://surfer.nmr.mgh.harvard.edu/
FSL	C	Preprocessing and analysis in structural and functional neuroimaging by Stephen Smith et al.	(Smith et al., 2001; Smith et al., 2004), http://www.fmrib.ox.ac.uk-/fsl/index.html
GIFT	Matlab	Group ICA of fMRI Toolbox	http://icatb.sourceforge.net/
GpetView	C, Gtk+	Simple neuroimaging visualization of ANALYZE files	http://homepage2.nifty.com-/peco/gpetview/gpetview.html, Hiroshi Watabe
HAMMER (*)		"Hierarchical Attribute Matching Mechanism for Elastic Registration". Skull-stripping and elastic warping	(Shen and Davatzikos, 2002; Shen and Davatzikos, 2003), http://www.rad.upenn.edu/sbia-/rsoftware.html
iBrain			(Abbott and Jackson, 2001)
LIMA	C++/-OpenGL	Software package for segmentation and visualization of MRIs.	(Busch et al., 2001)
Lipsia	C	fMRI analysis program	(Lohmann et al., 2001b; Lohmann et al., 2001a; Lohmann et al., 2000)
LOFA			(Gokcay et al., 1999)
Lyngby	Matlab	Neuroimaging analysis (fMRI and PET) with a number of multivariate (and univariate) analysis tools	(Hansen et al., 1999; Hansen et al., 2000; Hansen et al., 2001) http://hendrix.imm.dtu.dk/software-/lyngby/
MARINA	Windows, Linux with Wine	"MAsks for Region of INterest Analysis" enables to "create, smooth, threshold, edit, and save masks in an SPM-ANALYZE format"	(Walter et al., 2003), http://www.bion.de/Marina.htm
Martinez Flat-Mapper	Web	Flatmap and orthogonal plane visualizations of, e.g., specified Talairach coordinates	(Kang et al., 2004), http://www.ebire.org/hcnlab/cortical-mapping/
MEDx	Solaris, Linux, IRIX, Tru64	Commercial multimodality brain imaging processing and analysis software by *Sensor Systems*. MEDx 3.4 contains, e.g., SPM99, FSL, ABLe and "Functional Data Simulator".	http://medx.sensor.com/

Name	Impl.	Description	Reference
MIDAS (Tsui)	Solaris	"Multimodal Image Data Analysis System". Region-of interest analysis for multimodal 3D data	(Tsui et al., 2001)
MINC	Unix, Windows	Tools for processing MINC files	http://sourceforge.net-/projects/mni-minc-win32/, http://www.bic.mni.mcgill.ca/˜rotor-/distro/deb/
MIPAV	Java	Medical Image Processing, Analysis, and Visualization. Extensions are available for more specific neuroimaging applications.	http://mipav.cit.nih.gov/, (Bazin et al., 2007)
MPITool	Unix	"Multi Purpose Imaging Tool" from *Advanced Tomo Vision*. Reading and displaying of ECAT files. Reslicing, region of interest, filter.	http://www.atv-gmbh.de/mpitoolh/, (Advanced Tomo Vision, 1999)
MRIcro	Windows, Linux, Solaris	A program for conversion and viewing of 3D medical images by *Chris Rorden*. Features also region of interest (ROI) drawing and volume rendering	(Rorden and Brett, 2000), http://www.psychology.nottingham.-ac.uk/staff/cr1/mricro.html
MRIcron	Linux, OSX and Windows (via GTK)	A program somewhat similar to MRIcro	http://www.sph.sc.edu/comd/rorden-/mricron/
mri3dX	Unix/OpenGL	Program by Krish Singh "for visualization and analysis of structural and functional magnetic resonance images". Part of Brain Tools	http://www-users.aston.ac.uk-/˜singhkd/mri3dX/
MRIVIEW	IDL	Visualization and segmentation of 2D and 3D brain images	(Ranken and George, 1997), http://www.biophysics.lanl.gov/brain-_imaging/mriview/mriview.html
MRIWarp	C	Image registration program for MRI	(Kjems et al., 1999b; Kjems et al., 1999a), http://hendrix.imm.dtu.dk-/software/mriwarp/
MRVision	Unix/Linux	Commercial program for visualization and simple fMRI analysis	http://www.mrvision.com/
N3		Correction of intensity non-uniformity in MRI	(Sled et al., 1998; Sled et al., 1997; Sled, 1997) http://www.bic.mni.mcgill.ca-/software/N3/
Neuro-Modeller	Windows	3D Visualization, 3D model generation from contours	http://users.infohouse.com/amiller/
NIPY	Python	Neuroimaging tools for Python	http://neuroimaging.scipy.org/

Name	Impl.	Description	Reference
NPAIRS	Unix, IDL	"Nonparametric, Prediction, Activation, Influence, Reproducibility, re-Sampling". Package with resampling for comparing preprocessing and analysis choices and returning reproducibility and prediction indices.	(Strother et al., 2002), http://www.neurovia.umn.edu-/incweb/npairs_info.html
PI-WAVE	Matlab	Wavelet modeling for positron emission tomography	(Turkheimer et al., 1999; Turkheimer et al., 2000a; Turkheimer et al., 2000b), http://www.irsl.org/˜fet-/piwave/piwave.html
PLS toolbox			http://www.rotman-baycrest.on.ca:8080/index.html
PMOD	Java	Kinetic modeling, viewing	(Mikolajczyk et al., 1998), http://www.pmod.com/,
RPM			(Aston et al., 2001)
RView8	Windows-/Unix	General purpose multimodality image registration program with display and ROI-drawing facilities	http://noodle.med.yale.edu/˜cs-/software/software.html
scanSTAT	Mac	Conversion, analysis of fMRI	http://www.brainmapping.org-/scanSTAT/
SPAMALIZE	IDL	"Spect, Pet, And Mri analysis" by Terry Oakes includes ROI drawing and analysis, interactive volume display coregistration and dynamic PET tools.	http://tezpur.keck.waisman.wisc.edu-/˜oakes/spam/spam_frames.htm
SPM	Matlab, (C mex)	Functional neuroimaging analysis program includes slice time correction, image realignment (motion, coregistration, spatial normalization), spatial filtering, analysis with the general linear model and random field theory. SPM2 features dynamic causal modeling and false discovery rate inference.	(Friston et al., 1995; Frackowiak et al., 1997; Frackowiak et al., 2003; Pernet, 2005), http://www.fil.ion.ucl.ac.uk/spm/.
Stimulate	C, X	Analysis and display program for fMRI	http://www.cmrr.umn.edu/stimulate/, (Strupp, 1996)
SUMA	Motif, OpenGL	"SUrface MApping with AFNI". Program for cortical-based analysis and visualization.	See AFNI
SuMS	?	'Surface Management System' from Van Essen Laboratory. A software system for storing and accessing surface based data.	(Dickson et al., 2001; Van Essen et al., 2001; Harwell et al., 2001) http://stp.wustl.edu/resources-/sumsnew.html

Name	Impl.	Description	Reference
SureFit	Python, C	'Surface Reconstruction by Filters and Intensity Transformations' from Van Essen Laboratory. A program for segmentation, surface reconstruction and visualization of the cerebral cortex.	(Van Essen et al., 2001; Harwell et al., 2001; Van Essen et al., 2002), http://stp.wustl.edu/
Talairach Daemon	Internet, Java	Talairach coordinate to anatomical label tool	(Lancaster et al., 1997b; Lancaster et al., 1997c; Freitas et al., 1996; Lancaster et al., 2000b; Lancaster et al., 2000a), http://ric.uthscsa.edu/TDapplet/, http://ric.uthscsa.edu/resources-/body.html
Tina	xview		http://www.niac.man.ac.uk/Tina/
TSU	'Talairach Space utility'. Matlab SPM plugin	Neuroimaging visualization	http://www.ihb.spb.ru-/~pet_lab/TSU/TSUMain.html
UCLA BMD		fMRI analysis programs containing CC_gr, T_gr, Cproto, Overlay	http://porkpie.loni.ucla.edu-/BMD_HTML/SharedCode-/SharedSoftware.html
VINCI		Volume Imaging in Neurological Research, Co-Registration and ROIs Included	http://www.nf.mpg.de/vinci/
VoxBo	UNIX	'Software package for processing voxel-based functional brain imaging data' made at the University of Pennsylvania	http://www.voxbo.org
WFU Pick-Atlas		ROI-based analysis based on the Talairach Daemon and SPM	(Maldjian et al., 2003; Maldjian et al., 2004), http://www.fmri.wfubmc.edu-/download.htm
(X)MedCon	C, Gtk+	Simple neuroimaging visualization and conversion	http://xmedcon.sourceforge.net, Erik Nolf

Table 12 lists a number of execution environments (or *wrappers* or pipelines) which can encapsulate other programs. An execution environment typically offers a graphical user interface where program variables can be setup and the programs can be executed in arbitrary order. They will typically also allow for the storage of the parameters or the script so the setup and execution can be separated.

A few programs, e.g., SPM and AFNI, offer the possibility of *plugins*. SPM plugins are listed in table 13. These plugins are usually written by researchers that are not (directly) associated with the SPM developers. Note that some of the plugins are now outdated since their functionality is directly implemented in the standard distribution of later version of SPM, i.e., SPM2 and SPM5..

Name	Description	Reference
BrainFX+GenericFX	Execution environment	http://www-staff.psychiatry.cam.ac.uk/˜co224-/projects/brainfx/
BrainVISA	Execution environment in Python. Includes Anatomist	(Cointepas et al., 2001), http://brainvisa.free.fr/
FisWidgets	Execution environment in Java (with Swing)	(Fissell et al., 2003; Strother, 2003), http://neurocog.lrdc.pitt.edu-/fiswidgets/
RUMBA	Execution environment with visualization and visual data flow written in python	(Bly et al., 2004; Bly et al., 2001a), http://www.rumba.rutgers.edu/-projects.php
LONI Pipeline Processing Environment	Execution environment implemented with visualization and visual data flow in XML and Java	(Rex et al., 2003; Toga et al., 2001), http://www.loni.ucla.edu/-Software/Installing_Detail.jsp?-software_id=2
PVElab	(PVEOut) Execution environment and data processing environment in Matlab for, e.g., partial volume effect correction	(Quarantelli et al., 2004), http://nru.dk/software/pveout/
SPM5	(spm_jobman) Execution environment for SPM5 functions with XML derived from work of Philippe Ciuciu and Guillaume Flandin	http://www.fil.ion.ucl.ac.uk/spm/-software/spm5/

Table 12: “Meta”-software.

Table 13: SPM plugins. See also Thomas Nichols’ collection of *SPM extensions* http://www.fil.ion.ucl.ac.uk/spm/ext/ (where some of this information is taken from) as well as his collection of John Ashburner’s code snippets http://www.sph.umich.edu/˜nichols/JohnsGems.html: ‘John Gems’. A multivariate toolbox has been announced on http://www.fil.ion.ucl.ac.uk/spm/spm99.html but is presently (2002-10-24) not available.

Name	Description	Reference
ArtRepair	fMRI artifact detection and repairing by Paul Mazaika	http://cibsr.stanford.edu/tools-/ArtRepair.htm
autospm2	Batch scripts for SPM2	http://www.md.ucl.ac.be/rdgn-/autospm2.html
batch_general	Front end to SPM batch analysis by Russ Poldrack	http://sourceforge.net/projects/spm-toolbox
batch_subject	Toolbox by Russ Poldrack	http://sourceforge.net/projects/spm-toolbox
CBMG-Tools	A few function for visualization and extraction of fMRI time series	http://www.brain.northwestern.edu-/cbmg/cbmg-tools/
CCA-fMRI	Canonical correlation analysis for fMRI	(Borga, 1998; Friman et al., 2003), http://cca-fmri.sourceforge.net

Name	Description	Reference
Conjunction	SPM2 (1spm2_conj) and SPM99 (spm99_conj) modifications for "conjunction null" conjunction inference	(Brett et al., 2004), http://www.sph.umich.edu/˜nichols-/Conj/
Deformations	Toolbox by John Ashburner with spatial normalization utilities, e.g., extraction of information from SPM99 spatial normalization file (_sn3d.mat) for deformation-based morphometry (DBM) or tensor-based morphometry (TBM)	ftp://ftp.fil.ion.ucl.ac.uk/spm-/toolbox/Deformations/
diffusion	Toolbox by Russ Poldrack	http://sourceforge.net/projects/spm-toolbox
Diffusion	Toolbox by Volkmar Glauche for diffusion weighted MRI	http://www.uke.uni-hamburg.de-/kliniken/neurologie/spm/downloads/
DISTANCE	Specialized permutation test.	(Mériaux et al., 2006a; Mériaux et al., 2006b), http://www.madic.org/download-/DISTTBx/DISTTBx_main.html
Dynamic PET	Toolbox by Florian Wilke and Ralph Buchert from Hamburg includes realignment, spatial normalization, modeling of dynamic PET and SPECT and VOI analysis.	Available via email (SPM mailing list, 2000-04-04)
ezSPM2	GUI for batch construction in SPM2	http://www.izkf.rwth-aachen.de/downloads/ezspm2.htm
FDR	False discovery rate extension and patch for SPM by Thomas Nichols. This plugin has been included in SPM2.	http://www.sph.umich.edu-/˜nichols/FDR/
IBASPM	"Individual Brain Atlases using Statistical Parametric Mapping software". SPM2 plugin that combines the AAL atlas and tissue segmentation for construction of segmentation of individuals.	http://www.thomaskoenig.ch/Lester/-ibaspm.htm
KUL	Also called KUL_SPM, kulSPM and KULeuven. Batch script for SPM99	http://www.kuleuven.ac.be/radiology-/Research/fMRI/kulSPM/
LI-Tool	SPM2/5 toolbox for computation of lateralization indices	Marko Wilke, Tübingen
LOR2SPM	Converts output from LORETA into SPM compatible format. Program by Sergey Pakhomov.	http://www.ihb.spb.ru/˜pet_lab/L2S-/L2SMain.htm
MarsBar	Region of interest toolbox by Matthew Brett	(Brett et al., 2002), http://www.mrc-cbu.cam.ac.uk/Imaging/marsbar.html
mascoi	"MASked COntrast Images". A toolbox/function to combine a contrast image with z-score image	(Reimold et al., 2005), http://homepages.uni-tuebingen.de-/matthias.reimold/mci/mascoi.m
mfBox	Model-free toolbox	http://mips.gsf.de/proj/cmb-/researchmfbox.html

Name	Description	Reference
MM Toolbox	Multivariate analysis (principal component analysis and multivariate linear models, partial least squares) by CEA-SHFJ	http://www.madic.org/download-/MMTBx/
MNI Space utility	Anatomical label tool	http://www.ihb.spb.ru/~pet_lab-/MSU/MSUMain.html
PCT	'Percent Change Threshold' toolbox by Thomas Nichols	http://www.sph.umich.edu/fni-stat-/PCT/ (Nichols, 2002)
PSPM	Parallel implementation of SPM image processing and analysis procedures using LAM/MPI and MPICH	http://sourceforge.net/projects-/parallelspm/
RobustWLS	A toolbox that performs weighted least squares estimation to account for artifacts, e.g., head motion.	(Diedrichsen and Shadmehr, 2005), http://www.bangor.ac.uk/~pss412-/imaging/robustWLS.html
roi	Definition of ROI and extraction of signal by Russ Poldrack	http://sourceforge.net/projects/spm-toolbox
SEM	Structural equation modeling by Christian Büchel	In beta test.
slice_overlay	2D visualization by Matthew Brett capable of merging an anatomical and functional image. Also called "Slice display"	http://www.mrc-cbu.cam.ac.uk-/Imaging/display_slices.html
SLT	Region of interest analysis, batch scripting, semiautomated ROI identification, Contains RAT2, ASAP, SurfTools, FSTools.	(Nieto-Castanon et al., 2003; SpeechLab, 2003), http://speechlab.bu.edu/SLT.php
SnPM	Nonparametric permutation tests. SnPM99 is for SPM99 and SnPM2 is for SPM2	(Nichols and Holmes, 2001; Holmes et al., 1996; Holmes, 1998), http://www.fil.ion.ucl.ac.uk/spm-/snpm
spm2_batch (Ashburner)	Batch program for SPM2 programmed by John Ashburner	ftp://ftp.fil.ion.ucl.ac.uk/spm/toolbox-/spm2_batch_031210.tar.gz (preview version)
spm2_batch	Batch program from SPM programmed in Cambridge	ftp://ftp.mrc-cbu.cam.ac.uk/pub-/imaging/SPM2_batch
SPM Anatomy toolbox	Region of interest tools with probabilistic Brodmann areas atlas	(Eickhoff et al., 2005; Eickhoff, 2005), http://www.fz-juelich.de/ime/spm_anatomy_toolbox
spm_batch	Batch preprocessing by Sebastian Thees	http://www.charite.de/ch/neuro-/forschung/teams/klinisch/people-/thees/index.html
SPMd	'Statistical Parametric Mapping Diagnosis' by Wen-Lin Luo and Thomas Nichols for residual analysis	(Luo and Nichols, 2003), http://www.sph.umich.edu/~nichols-/SPMd/
spmjob	Batch processing toolbox for SPM2 with GUI.	http://spmjob.ffii.org/
spm_loop	Batch processing for display multiple result images (SPMs).	http://www.mrc-cbu.cam.ac.uk-/Imaging/Common/spm_loop.shtml
spm_orthoviews	ROI and movie tools by Volkmar Glauche.	http://www.uke.uni-hamburg.de-/kliniken/neurologie/spm/downloads/

Name	Description	Reference
SPM_Script	Front-end tool for automatic fMRI analysis	http://www.nfil.rwth-aachen.de
spm_xbrain	Visualization extension by Tom Sieger	http://www.neuro.lf1.cuni.cz/spm-/spm_xbrain_3d.html
SPM XML Toolbox	A toolbox for storing point activation from SPM in the XML file format.	(Keator et al., 2005; Keator, 2005), http://www.nbirn.net-/Resources/Users/Applications-/xcede/SPM_XMLTools.htm
Talairach Space utility	Neuroimaging visualization	http://www.ihb.spb.ru/˜pet_lab/TSU-/TSUMain.html
Volumes	Toolbox by Volkmar Glauche for volume operations, e.g., extraction of subvolumes.	http://www.uke.uni-hamburg.de-/kliniken/neurologie/spm/downloads/
Unwarp	'Toolbox for estimation and removal of movement-by-susceptibility induced variance in fMRI time series'	(Andersson, 2001), http://www.fil.ion.ucl.ac.uk/spm-/toolbox/unwarp.html
xjView	SPM2 visualization	http://people.hnl.bcm.tmc.edu/cuixu-/xjView/
Zephyr	SPM2 batch for preprocessing	http://diddy.dartmouth.edu/zephyr/

6.2.2 Computational neuroscience and simulators

Table 14 shows software in connection with neuronal modeling. (De Schutter, 1992) is an early review of seven neuronal modeling software: AXONTREE, GENESIS, NEURON, NEMOSYS, NODUS, SABER and SPICE. GENESIS and NEURON are probably the most widely used. See also the sort review of (Jeong, 2005).

Table 14: Computational neuronal models. See also list at http://www.emsl.pnl.gov:2080/proj/neuron/neuro/systems-/shareware.html

Name	Description	Reference
GENESIS		http://www.bbb.caltech.edu-/GENESIS/
NEST	The "NEural Simulation Technology Initiative". A program suitable for many simple neurons.	(Diesmann and Gewaltig, 2003), http://www.nest-initiative.org/
NeuGen	"Generation of dendritic and axonal morphology"	(Eberhard et al., 2006), http://neugen.uni-hd.de/
neuroConstruct	"Biophysical neural network modeling software"	(Gleeson et al., 2007), http://www.neuroconstruct.org/
Neurolator		http://www.brainvoyager.com-/Neurolator.htm
NEURON		http://www.neuron.yale.edu/
NEUSIM		http://www.neosim.org/
NODUS		http://bbf-www.uia.ac.be/SOFT/

Name	Description	Reference
NSL	"Neural Simulation Language". Neural network simulator language	(Weitzenfeld et al., 1999; Weitzenfeld et al., 2002), http://www-hbp.usc.edu-/Projects/nsl.htm
Surf-Hippo		http://www.cnrs-gif.fr/iaf/iaf9/surf-hippo.html
XNBC		(Vibert et al., 1997) http://www.u444.jussieu.fr/xnbc/
BMW	"Brain Models on the Web" is a database of neuronal models	http://www-hbp.usc.edu/Projects-/bmw.htm
SenseLab ModelDB	Database with "compartmental neuron models". Contained 15 models 2001-10-25	(Peterson et al., 1996), http://senselab.med.yale.edu-/senselab/ModelDB/

6.2.3 Other areas

Table 15: Neuroinformatics tools — other tools. E.g., MEG, EEG and electrophysiology.

Name	Impl.	Description	Reference
4D Toolbox	Matlab	Analysis and visualization of (Neuromag) MEG data	http://boojum.hut.fi/~ojensen-/4Dtools/
ASA	Windows(?)	"Advanced source analysis". EEG or MEG analysis with source analysis from ANT.	http://www.ant-software.nl/asa/
BESA	Windows	"Brain Electrical Source Analysis". Commercial EEG and MEG source localization.	http://www.besa.de/
Brain project (bp)	Windows, Linux	"a Delphi Library for EEG data Analysis and Display"	http://www.irisa.fr/siames/GENS-/mcongedo/MC_Projects.html
BrainStorm	Matlab	MEG and EEG data processing, visualization and source localization	http://neuroimage.usc.edu/brainstorm/
CogniTrace	Linux	"EEG/ERP data acquisition for 32 to 128 channels" from ANT.	http://www.ant-software.nl/erp/
Curry	PC, HP, Sun, SGI	Commercial program from Neuroscan with electromagnetic source localization and visualization	http://www.neuro.com-/product.sstg?id=39
cvapp	Java	Neuronal morphology editor	http://www.cns.soton.ac.uk-/~jchad/cellArchive/cellArchive.html
EEGLAB	Matlab	Analysis (independent component analysis) and visualization for EEG and MEG by Arnaud Delorme and Scott Makeig from Swartz Center for Computational Neuroscience et al.	http://sccn.ucsd.edu/eeglab/

Name	Impl.	Description	Reference
EEG toolbox	Matlab	EEG toolbox for visualization	http://eeg.sourceforge.net/
ERPWAVELAB	Matlab	Analysis of event related EEG and MEG data in the time-frequency domain.	(Mørup et al., 2007), http://www.erpwavelab.org/
G-clamp	LabView		http://hornlab.neurobio.pitt.edu/
ILAB©	Matlab	Eye movement analysis software for data generated by ISCAN©and ASL©	(Gitelman et al., 2001), http://www.brain.northwestern.edu-/ilab/
Klusters	Linux	"A graphical interface for spike sorting of extracellular neuronal recordings"	http://klusters.sourceforge.net
LOFA			(Gokcay et al., 1999)
LORETA		"Low Resolution Brain Electromagnetic Tomography". Program for inversion reconstruction of the 3D electromagnetic distribution from surface EEG and MEG recordings.	(Pascual-Marqui, 1999), http://www.unizh.ch/keyinst-/NewLORETA/LORETA01.htm
NeuroBench	Java	Program to analyze and view electrophysiological recordings	http://www-hbp.usc.edu/Projects-/neuronBench.htm
Neurolucida™		Commercial software from *MicroBrightField* for neuroanatomical analysis, e.g., 3D neuron reconstruction.	(Glaser and Glaser, 1990) http://www.microbrightfield.com-/prod-nl.htm
Neuro-Modeller	Windows	3D Visualization, 3D model generation from contours	http://users.infohouse.com/amiller/
NeuroScholar	Java	MySQL Database frontend with management of bibliography, histological and tracing data.	(Burns, 2001; Burns, 1998; Shahabi et al., 1999; Burns et al., 2002; Burns et al., 2003), http://www.neuroscholar.org, http://chasseur.usc.edu/ns/
NeuroScope	C++, Linux/KDE	"Viewer for electrophysiological and behavioral data with limited editing capabilities"	http://neuroscope.sourceforge.net
NeuroSim	Matlab	"Neurosim is a MATLAB program that implements a conductance-based model sympathetic neuron and can also can create synaptic template files for driving G-clamp"	http://hornlab.neurobio.pitt.edu/
SOURCE		Commercial EEG dipole source localization from Neuroscan	http://www.neuro.com/-product.sstg?id=40
Spike2	Windows	Commercial software for data capture and analysis of, e.g., electroneurophysiological data made by *Cambridge Electronic Design*.	http://www.ced.co.uk/spk4wglu.htm
TEMPO	OpenGL	3D EEG scalp data plotting	http://tempo.sourceforge.net/

Name	Impl.	Description	Reference
XANAT	X Windows	Analysis and storage of neural connectivity data	(Press et al., 2001b; Olshausen and Press, 1994), http://redwood.ucdavis.edu/bruno-/xanat/xanat.html

6.3 Unclassified

(Stiber et al., 1997)

http://www.compneuro.org/ includes CD-ROM that is included in connect ion with the book *Computational Neuroscience: Realistic Modeling for Experimentalists* (Schutter, 2000).

7 Computer, computational data modeling issues

Name	Description	Reference
Computer Cluster	fMRI preprocessing with a computer cluster	(Erberich et al., 2000)
Peer-to-peer database	Napster like service for brain imaging data	(Bly et al., 2001b)
QBISM	Database for 3D spatial data especially brain mapping data. Built around Starburst DBMS.	(Arya et al., 1996a; Arya et al., 1994; Arya et al., 1993; Arya et al., 1996b)
BRAID	Object-oriented database augmented with image processing and statistical operations based on *Illustra*™	(Herskovits, 2000a; Letovsky et al., 1998) http://braid.uphs.upenn.edu-/websbia/braid/
B-SPID	Object-relational database for neuroimaging data based on *Illustra*™	(Diallo et al., 1999a; Diallo et al., 1997a)
BIRN	"Biomedical Informatics Resource Network": American project to closely link universities for collaboration in neuroimaging by application of SDSC's *Storage Resource Broker* (SRB).	http://birn.ncrr.nih.gov/ http://www.npaci.edu/DICE/SRB/
NeuroCore	Database framework used in, e.g., fMRIDC	http://www-hbp.usc.edu/Projects-/neurocore.htm
NeuroML	XML for neuroscience, more specifically neuronal modeling	(Goddard et al., 2001; Crook et al., 2005) http://www.neuroml.org/
XNAT	Software platform to store MR neuroimaging and related data. The technologies used are Java, DICOM and XML.	(Marcus et al., 2007), http://www.xnat.org/
—	3-dimensional database of deep brain functional anatomy for image-guided neurosurgery (IGNS). Coding structure according to Tasker	(Finnis et al., 2000; Tasker et al., 1978)

Table 16: Computer/database issues.

7.1 Image Compression

There exist a number of general purpose lossless compression programs, e.g., *gzip* and *compress*. These programs seldom make a very efficient compression of neuroimaging data. *SmallTime* (Cohen, 2000), (http://www.brainmapping.org/SmallTime/) is a program specifically designed for MRI sequences and works with differences of 16 bit images. Other algorithms have been described (Thiran et al., 1996; Adamson, 2002; Wu and Forchhammer, 2004), some based on wavelets.

The DICOM standard specifies lossless compression via the JPEG-LS (ISO 14495-1) and JPEG 2000 (15444-1) standards.

7.2 Databases

Most databases management systems (DBMS) are *relational*. These consist of tables and links between tables. A wide-spread query language is *SQL*. Early relation database management systems (RDBMS) had very simple types: integer, floats, string, etc. and would not represent 3D neuroimaging data well. Extensible DBMS such as so-called object-relation DBMS (ORDBMS) augment the ordinary relation DBMS with (complex) user-defined types (objects). One of the first ORDBMS was POSTGRES, see, e.g., (Stonebraker and Kemnitz, 1991). This database was commercialized by *Illustra*, which in December 1995 was bought by *Informix*. Informix was in turn bought by IBM in April 2001. Another extensible DBMS is/was the *Starburst* DBMS, see, e.g., (Lohman et al., 1991). It's query language "hydrogen" is based on SQL. Open source ORDBMS version exists with PostgreSQL (http://www.postgresql.org/). EXODUS is yet another extensible database system (Carey et al, 1991).

7.2.1 Image databases

Content-based image retrieval (CBRI) uses image feature, e.g., for finding similar images in a database.

One finds descriptions of general systems (not necessarily for neuroscience images) with Photobook (Pentland et al., 1993), http://vismod.media.mit.edu/vismod/demos/photobook/, QBIC (Flickner et al., 1995) and Virage (Bach et al., 1996).

7.2.2 Medical image databases

(Tagare et al., 1997) discusses some of the issues in content-based retrieval approaches in medical database.

Clinical medical image databases are often refered to as "picture archiving and communication systems" PACS (Huang and Taira, 1992). There are probably many commercial systems in this area. One such is EasyViz by Medical Insight.

7.2.3 Neuroimaging image databases

(Bjaalie, 2002) discusses neuroscientific databases, particularly the NeSys database, and (Kötter, 2002) is an edited book about neuroscience databases. Other methods of image retrieval are presented in (Liu and Dellaert, 1998a; Liu and Dellaert, 1998b; Liu et al., 1998; Liu et al., 2001b; Liu et al., 2002).

A review of databases for neuroimaging appears in (Diallo et al., 1999b; Diallo et al., 1997b).

Image archives and data sharing in research oriented brain mapping have been discussed in a number of articles (Chicurel, 2000; Aldhous, 2000; Marshall, 2000; Nature editorial, 2000; Cohen et al., 2001; Barinaga, 2003; Toga, 2002b). This discussion was initiated after suggestion for required submission to the fMRI Data center (Van Horn et al., 2001a; Van Horn and Gazzaniga, 2002). A review of neuroscience atlas/databases is (Van Essen, 2002).

(Wang et al., 2006) implemented content-based image retrieval on fMRI contrast maps with a combination of wavelets and image feature extraction. (Cho, 2005) discusses a retrieval system with fMRI and single unit recordings. The CCVT tool also enables query-by-example (Cornea, 2005). NeuroServ and NIRV are software tools mentioned by (Carley-Spencer et al., 2006). Table 17 lists other content-based image retrieval systems in the neuroimaging context.

Table 17: Medical image retrieval systems

Name	Area	Features and description	Reference
—	Lympho-proliferative disorders	Shape (Fourier descriptors), texture (MRSAR), color. Image-based queries, trained classifier	(Comaniciu et al., 1999; Comaniciu et al., 1998).
—	(Synthetic) MRI	Topographical relations, size, roundness, orientation. Images represented as "attributed relational graphs"	(Petrakis and Faloutsos, 1997; Petrakis, 2002)
Brede Database	Functional neuroimaging	Finding nearest Talairach coordinate to a given location. "Grey-level" volume from voxelized locations. Determination of related volumes in the Brede Database.	(Nielsen and Hansen, 2004b; Nielsen, 2003; Nielsen and Hansen, 2002b), http://hendrix.imm.dtu.dk-/services/jerne/brede/
Dermatlas	Clinical dermatological images (photographs, histological, biopsy)	Text-based (keywords, diagnosis, body site, pigmentation, ...). Internet-based with collaboration (users are able to submit new images).	http://www.dermatlas.org

Name	Area	Features and description	Reference
I^2Cnet	MRI, ...	ROI (location, shape, size: roundness, compactness, area, orientation), texture (maximum probability, angular second moment, contrast, inverse difference moment, entropy, correlation, variance, cluster shade, diagonal moment, k statistics, fractal signature). Internet-based.	(Orphanoudakis et al., 1996)
(Jerne, "Related volumes")	Functional neuroimaging	"Grey-level" volume: Voxelized locations. Determination of related volumes in the BrainMap™ database by voxelization	(Nielsen and Hansen, 2004b; Nielsen and Hansen, 2002b), http://hendrix.imm.dtu.dk/services/jerne/ninf/relvol.html
(KMeD)	MRI, x-ray, ...	Shape, size, texture, topological relations. Spatial temporal query language: (KSTL). Features in a hierarchical structure	(Chu et al., 1998)
MIMS		Image descriptors: file type (JPEG, GIF), device (MRI, radio), domain (radiology), ... Topographical relations. Java Internet-based. Stores images voice reports and general (text) data. Thesaurus on descriptors	(Chbeir et al., 1999; Chbeir et al., 2000)
WebMIRS	X-rays		http://archive.nlm.nih.gov/proj/webmirs/
xBrain	Functional neuroimaging	Search for nearest Talairach coordinates.	http://www.xbrain.org/

7.2.4 Neuroinformatics database

In neuroimaging contexts the neuroimages themselves do not only have to be databased but all the associated data as well. These associated data might be subject information such as demographic, clinical and genetic. Complications for the construction of databases for such data might be extensibility and the secure transportation of data across multiple sites. Thoughts on the problems for such systems appear, e.g., in (Bockholt et al., 2006) ("The MIND Institute") and (Keator et al., 2006) ("XCEDE", "BIRN"). Some form of relational database for neuroscience data is described by (Rudowsky et al., 2004).

Unique identifiers for authors are partially implemented in the Brede Database (Nielsen, 2003). This has also been suggested by (Falagas, 2006) for more broader application.

7.3 Computational neuroscience

The Blue Brain Project aims at modeling the neocortical column of the somatosensory cortex of young rats based on the NEURON program and using supercomputers, and is introduced in (Markram, 2006).

7.4 Unclassified

OSIRIS (Ligier et al., 1994): This seems to be an image analysis/processing program rather than a database. http://www.expasy.ch/www/UIN/html1/projects/osiris/osiris.html

M. Bota and M. A. Arbib. The NeuroHomology Database. Neurocomputing, 38-40, pp. 1627-1631, 2001.

(Hirsch and Koslow, 1999)

(Miller et al., 2001; Gardner et al., 2001b).

(Guimond et al., 1997): retrieval of corresponding brain structures from a database of medical images.

Database Challenges and Solutions in Neuroscientific Applications (1997). Ali E. Dashti, Shahram Ghandeharizadeh, James Stone, Larry W. Swanson, Richard H. Thompson

8 Meta-analyses

8.1 Function/location meta-analysis

Data source	Purpose	Method	Reference
BrainMap™	Assessment of variation in activation focus	'Functional volumes modeling': Probability density modeling incorporating sample size	(Fox et al., 1997b; Fox et al., 1999; Fox et al., 2001; Fox et al., 1997a)
Lesion database (BRAID)	Determine association between 14 functional variables and 90 brain structural variables in elderly people	Manual delineation of infarct-like lesions. Chi-square contingency table test between pairs of functional and structural variables.	(Letovsky et al., 1998; Herskovits, 2000a)
Lesion database (BRAID)	Determine association between lesion sites and development of secondary attention-deficit hyperactivity disorder (S-ADHD) in children	Manual delineation of lesion from MRI, Mann-Whitney and Fisher exact test statistics in a brain image database (BRAID)	(Herskovits et al., 1999; Herskovits, 2000a)
Lesion database (BRAID)			(Herskovits, 2000b)
Literature	Determination of areas involved in language production		(Indefrey and Levelt, 2000; Indefrey and Levelt, 1999)
Literature (25 studies)	Distinction between dorsolateral and frontopolar cortex	Hotelling's T^2 statistics used to compare two groups of activations in Talairach space. χ^2 used for region test.	(Christoff and Grabrieli, 2000, page 176)
Literature	Determining of different activation between 5 sets of activation foci each set involving different cognitive demand	Multidimensional Kolmogorov-Smirnov applied multiple times.	(Duncan and Owen, 2000)
Literature (28 studies)	Determination of areas involved in syntactic parsing	Region-based analysis (102 areas) with P-value threshold determined from a binomial distribution.	(Indefrey, 2001)
BrainMap™	Novelty detection in nomenclature	Probability density modeling through adaptive kernel density modeling conditioned on anatomical labels.	(Nielsen and Hansen, 2002c; Nielsen et al., 2001)
Literature (9 studies)	Prediction of areas involved in single word reading	Probability density modeling through kernel density modeling of 154 Talairach coordinates	(Turkeltaub et al., 2002; Turkeltaub et al., 2001)

Table 18: Mathematical meta-analyses in functional neuroimaging.

Table 18 displays some of the meta-analyses that use mathematics/statistics. For an early review see (Fox et al., 1998). For a more recent overview see (Wager et al., 2007).

Meta-analysis of Talairach coordinates was pioneered by Peter T. Fox et al. under the name "functional volumes modeling" (FVM) (Fox et al., 1997b; Fox et al., 1999; Fox et al., 1997a). These original studies used parametric Gaussian models. Non-parametric modeling of the distribution of brain foci was first described in two unpublished studies with Gaussian mixture modeling (Nielsen and Hansen, 1999) and adaptive Gaussian kernel density modeling (Nielsen and Hansen, 2000). Later studies include adaptive Gaussian kernel density modeling for database outlier detection (Nielsen and Hansen, 2002c; Nielsen et al., 2001; Nielsen et al., 2000), Gaussian kernel density modeling in connection with single word processing (Turkeltaub et al., 2002; Turkeltaub et al., 2001), kernel density estimation in connection with Broca's area and verbal working memory (Chein et al., 2002; Chein et al., 2001), kernel density modeling with a spheric uniform kernel in emotion (Wager et al., 2003), and a model combining kerndel density modeling with a Gaussian mixture model (Neumann et al., 2008). Another study is (Wager et al., 2004). A large number of similar studies appears in a special issue of the *Human Brain Mapping*, volume

25, issue 1 (Fox et al., 2005b). Functional volumes modeling is sometimes referred to as "voxelization" or "activation likelihood estimation" (ALE). Some form of meta-analysis with the use the BrainMap™ database has been briefly described (Mahurin et al., 1995).

Determining statistical thresholds in one set of voxelized Talairach coordinates is described in (Turkeltaub et al., 2002; Turkeltaub et al., 2001) and (Nielsen, 2005). Statistical methods for determining whether two sets are different are described in (Christoff and Grabrieli, 2000; Duncan and Owen, 2000) and (Nielsen and Hansen, 2004a; Nielsen et al., 2004b; Nielsen et al., 2005; Nielsen et al., 2004a) and (Laird et al., 2005a). The multidimensional Kolmogorov-Smirnov used in (Duncan and Owen, 2000) is originally from (Peacock, 1983) and is also described and implemented in (Press et al., 1992, section 14.7). Hotelling's T^2 test was also used in (Berman et al., 1999, page 212) but not in connection with a meta-analysis. Statistical tests on warped coordinates are described in (Steel and Lawrie, 2004).

The Brede Toolbox automatically performs multivariate analyses such as singular value decomposition (principal component analyses), independent component analyses, non-negative matrix factorization and K-means on voxelized Talairach coordinates on the entire Brede Database (Nielsen, 2003; Nielsen et al., 2004c). Another multivariate analysis method, "replicator dynamics", is suggested in (Neumann et al., 2005).

A number of meta-analytic studies have grown out of the BRAID database: (Herskovits et al., 1999; Megalooikonomou et al., 1999; Megalooikonomou et al., 2000; Megalooikonomou and Herskovits, 2001; Lazarevic et al., 2001; Herskovits et al., 2002).

Descriptive statistics of activation foci appears in (Markowitsch and Tulving, 1994), where the fraction of fundus activations over 30 PET studies is found.

Function/location meta-analysis without spatial information other than the text can also extract relevation associations. Name entities has been extracted from well over 100,000 PubMed abstracts with the use of Unified Medical Language System (UMLS) and manually developed rules for rule-based name entity extraction (Hsiao et al., 2007). This system extracted phrases/terms for brain function and neuroanatomy and built an interactive visualization system to display the function-anatomy graph.

Table 19: Meta-analysis in Talairach space of brain function. KDE is kernel density estimation (in Talairach space). .

Area	Function	Method	Description	Reference
Left inferior frontal cortex	Semantic and phonological processing	Tables, plots	Phonological processing dorsally while semantic ventrally	(Poldrack et al., 1999)
Anterior cingulate	Cognition, emotion			(Bush et al., 2000)
Many	Cognition	Tables, plots		(Cabeza and Nyberg, 2000)
Inferior frontal	Phonological processing	Plots		(Burton, 2001)
Prefrontal	Cognition, emotion	Plots, warp transformation, MANOVA, KDE	Resampling was used for significance test	(Steel and Lawrie, 2004)
Orbitofrontal		Plots		(Kringelbach and Rolls, 2004)
Medial frontal	Self/Other	Clustering(?)		(Seitz et al., 2005)

Area	Function	Method	Description	Reference
Posterior cingulate	As many as possible	Text clustering, Hotelling's test	Text mining on PubMed abstract for clustering articles. Thereafter determination of segregation between coordinates in clustered articles	(Nielsen et al., 2005)

8.2 Connectivity analyses

Species	System	Reports	Areas	Conn.	Levels	Method	References
Rat	Hippocampus	$>$ 900 (14000)	23		0–3, c, x	2D and 5D MDS (from SAS MDS), Cluster analysis (SAS 6.09 MODECLUS), Venn diagram	(Burns and Young, 2000)
Macaque	Cortical sensory	(Felleman and Van Essen, 1991)	30/14		$<, \leq, \emptyset, \geq, >$	Hierarchical analysis	(Hilgetag et al., 2000b)
Cat	Cortical sensory	(Scannell et al., 1995)	22		$<, \leq, \emptyset, \geq, >$	Hierarchical analysis	*as above*
Cat	Cortical	Part of (Scannell et al., 1999)	55	892	0–3	Optimal set analysis, MDS (SAS MDS), Cluster analysis (SAS MODECLUS), small-world coefficient	(Hilgetag et al., 2000a)
Macaque	Visual	(Felleman and Van Essen, 1991)	32	319		*as above*	*as above*
'Primate'		(Young, 1993)	73	834		*as above*	*as above*
Macaque	Somatosensory motor	(Felleman and Van Essen, 1991)	15	66		*as above*	*as above*
Primate	Cortical	19 (CoCoMac-Stry)	39	"3897 tests"	0–3	Optimal set analysis, MDS (SAS MDS), small-world coefficient	(Stephan et al., 2000a)

Table 20: Connectivity analyses

An early program for connectivity analysis is "Connection" (Nicolelis et al., 1990).

(Kaiser and Hilgetag, 2004) used data from CoCoMac together with spatial positions from Caret to get an approximation for the wiring length in cortex.

(Toro and Paus, 2006) described a co-activation analysis of functional activation recorded in the BrainMap™ database and constructed a program for interactive visualization of the 6-D probabilistic map. A smaller co-activation study analysing data from 126 papers focused on connections from the basal ganglia (Postuma and Dagher, 2006).

A database with volumes for anatomo-functional connectivity might become available (Poupon et al., 2006).

There is a number of studies using the connectivity of the small worm *Caenorhabditis elegans* (WormAtlas), e.g., for examining the small-world phenomenon (Watts and Strogatz, 1998), or explaining the neuronal placement (Chen et al., 2006; Ahn et al., 2006) and (Kaiser and Hilgetag, 2005, Society for Neuroscience).

8.3 Unclassified

Meta-analysis of ERP in schizophrenia (Bramon et al., 2001).

(Young and Scannell, 2000)

9 Neuroscience terminology

Nomenclature for receptors and ion channels is found in (Alexander et al., 1999). The Mai atlas (Mai et al., 1997) has a hierarchy for selected brain structures. A text mining system for neuroanatomical terms has been applied for thalamic nuclei (Srinivas et al., 2005).

Table 21 lists some fo the frameworks for description of neuroscience terms, particularly neuroanatomy. Other frameworks: GRAFIP (Hudelot et al., 2006) and the system of (Dameron et al., 2004; Golbreich et al., 2005) where they are able to link the terms to 3D data.

Jörg Niggemann: Representation of Neuroanatomical Knowledge: The Description Language ADL. Terminology and Knowledge Engineering (Vol. 1) 1990: 200-209

Table 22: Functional and cytoarchitectonic areas. See also http://defiant.ssc.uwo.ca/Jody_web/fMRI4Dummies-/functional_brain_areas.htm and (Heimer, 1994, pages 285–286).

Name	Description	Reference
cmc	Caudal cingulate motor area. Posterior cingulate motor areas. Human area corresponding to macaque 24d	(Zilles et al., 1995)
cmr	Rostral cingulate motor area. Human area corresponding to macaque 24c. Anterior cingulate motor areas	(Zilles et al., 1995)
DP	Dorsal prelunate area. An area in the macaque bordering V3A, V4, 7a, LIP, VIP according to Felleman and Van Essen. Seems to be mostly used by Van Essen.	(Andersen, 1985; Van Essen, 2003; Felleman and Van Essen, 1991)
F1	Designation used by Matelli for macaque primary motor cortex.	(Matelli et al., 1985; Matelli et al., 1991)
F2	Macaque area in Brodmann area 6	(Matelli et al., 1985; Matelli et al., 1991)
F3	Macaque area in Brodmann area 6	(Matelli et al., 1985; Matelli et al., 1991)
F4	Macaque area in Brodmann area 6	(Matelli et al., 1985; Matelli et al., 1991)
F5	Macaque area in Brodmann area 6. Reported to contain “canonical” and “mirror” neurons	(Matelli et al., 1985; Matelli et al., 1991; Picard and Strick, 2001)
F6	Macaque area in Brodmann area 6.	(Matelli et al., 1985; Matelli et al., 1991)
F7	Macaque area in Brodmann area 6	(Matelli et al., 1985; Matelli et al., 1991)
FA	Precentral area	(von Economo and Koskinas, 1925, pp. 218, 260+)
FB	Agranular frontal area	(von Economo and Koskinas, 1925, pp. 260+)
FBA		
FC	Intermediate frontal area	(von Economo and Koskinas, 1925, pp. 260+, 315+)
FCBm		
PCop		

Name	Description	Reference
FD	Granular frontal area	(von Economo and Koskinas, 1925, pp. 260+, 336–364)
FDΔ		
FDΓ		
FDC		
FDE		
FDL		
FE	Frontopolar area	(von Economo and Koskinas, 1925, pp. 260+, 364–373)
FEF	Frontal eye field. Precentral cortex	
FEL	Limbic frontopolar area	(von Economo and Koskinas, 1925, p. 371)
FF	Orbital area	(von Economo and Koskinas, 1925, pp. 260+, 373+)
FG	Rectus gyrus area	(von Economo and Koskinas, 1925, pp. 260+, 384+)
FH	Prefrontal area	(von Economo and Koskinas, 1925, pp. 391+)
FI	Area frontoinsularis	(von Economo and Koskinas, 1925, p. 219)
FK	Area piriformis frontalis	(von Economo and Koskinas, 1925, p. 219)
FL	Area parolfactoria	(von Economo and Koskinas, 1925, p. 219)
FM	Area geniculata	(von Economo and Koskinas, 1925, p. 219)
FN	Area praecommissuralis	(von Economo and Koskinas, 1925, p. 219)
FST	Fundus superior temporal. Floor of superior temporal area	
hMT	Human correspondent to MT	
IA	Insula	(Bonin and Bailey, 1947, p. 78)
IB	Insula	(Bonin and Bailey, 1947, p. 78)
KO	Kinetic occipital. A shape/contour (from motion?) selective area	
LA	Anterior limbic area in macaque corresponding to Brodmann area 24. Heterotypic and agranular cortex	(Bonin and Bailey, 1947, pp. 26 and 78)
LC	"Posterior part of the cingulate gyrus and extends into the cingulate sulcus". Corresponding to Brodmann area 23.	(Bonin and Bailey, 1947, p. 78)
LIP	Lateral intraparietal area	
LO	"Lateral occipital".	
M1	Primary motor cortex.	
MDP	Medial dorsal parietal area	
MST	Medial superior temporal area	

Name	Description	Reference
MST1	Lateral-anterior area of MST on the floor and the posterior bank of the STS	(Komatsu and Wurtz, 1988)
MSTd	Dorsal division of MST on the anterior bank of STS	
MT	Middle temporal area. Visual motion area. Particular in monkey. Almost the same as V5.	
MT+	Middle temporal area plus. Used for humans. Sometimes viewed as a complex comprising "MT" and MST. Visual motion.	(Huk et al., 2002)
MTf	Fovial region of MT	(Komatsu and Wurtz, 1988)
OA		
OB		
OC	Striate area in macaque	(Bonin and Bailey, 1947, p. 27)
PA		
PB	"Posterior wall of the central sulcus" in macaque. Part of koniocortex and heterotypical cortex. Corresponding to Brodmann area 3.	(Bonin and Bailey, 1947, pp. 28–29)
PC		
PCop		
PD		
PE		
PEm		
PF		
PFC		
PG		
PO	Parieto-occipital area. The same as V6	
pre-SMA	rostral SMA.	
SEF	Supplementary eye field.	
SMA	Supplementary motor area. Probably consists of SMA-proper and pre-SMA	(Zilles et al., 1995)
SMA-proper	Caudal part of SMA	(Zilles et al., 1995)
SSA	Supplementary sensory area	
TA	"Area temporalis superior" according to Economo. An area in the temporal lobe. A subarea of BA22	(Bonin and Bailey, 1947, pp. 76–77)
TAa	Temporal area TAa. A subdivision of TA	(Seltzer and Pandya, 1978)
TB		
TC	The temporal pole of the macaque	(Bonin and Bailey, 1947, p. 77)
TCB		
TE	Inferotemporal area. "Lateral surface of the temporal lobe below the superior temporal sulcus (except at the pole)" in the macaque	(Bonin and Bailey, 1947, pp. 42 and 76)
TE1	Subdivision 1 of TE. Inferotemporal area in macaque.	(Seltzer and Pandya, 1978)

Name	Description	Reference
TE2	Subdivision 2 of TE. Inferotemporal area in macaque.	(Seltzer and Pandya, 1978)
TE3	Subdivision 3 of TE. Inferotemporal area in macaque.	(Seltzer and Pandya, 1978)
TEa	Subdivision a of TE. Inferotemporal area in macaque.	(Seltzer and Pandya, 1978)
TEc		
TEm	Subdivision m of TE. Inferotemporal area in macaque.	(Seltzer and Pandya, 1978)
TEO		
TEr		
TF		(Bonin and Bailey, 1947, pp. 42–43)
TG		(Bonin and Bailey, 1947, pp. 38–39)
TH		(Bonin and Bailey, 1947, p. 78)
TS1	Area in the supratemporal plane (in macaque)	
TS2	Area in the supratemporal plane (in macaque)	
TS3	Area in the supratemporal plane (in macaque)	
TSA	Transitional sensory area. Upper bank of cingulate sulcus (Macaca)	(Morecraft et al., 2004)
V1	Visual area one. Primary visual cortex. Striate cortex. Brodmann area 17.	
V2	Visual area two. Extrastriate. Approximately(?) Brodmann area 18 (with V3).	(Roland and Zilles, 1998)
V2d	Visual area two, dorsal. Cuneus.	
V2v	Visual area two, ventral. Lingual gyrus	
V3 complex	Group of areas consisting of V3 and V3A (and V3B? ...). Orientation and form sensitive. Color insensitive.	
V3	A visual area between V2 and V4. Sometimes V3 is used to designate only the dorsal part of V3, aka V3d. V3 is not a superarea of V3A	(Zeki, 1969; Van Essen, 2003)
V3A	A dorsal area next to V3	
V3B	Visual area three, B. Possible the same area as KO. V3A are possibly two area: V3A and V3B according to human studies by Smith and Press, see Van Essen 2003	(Smith et al., 1998; Press et al., 2001a; Van Essen, 2003; Zeki et al., 2003)
V3d	Visual area three, dorsal. Lower visual field	(Van Essen, 2003)
V3v	Visual area three, ventral. Upper visual field. Situated between V2 (V2v) and V4 (V4v)	(Van Essen, 2003)
V4	Visual area four. Brodmann area 19. Color sensitive. The prelunate gyrus in macaque	(Zeki, 1973), (Zeki, 1977, figure 16)
V4d	Visual area four, dorsal.	

Name	Description	Reference
V4t	Visual area four transitional. An area between V4 and MT.	
V4v	Visual area four, ventral. Also VA	
V5	Visual area five. Motion sensitive. Brodman area 19(?).	(Zeki et al., 1991)
V5+	Visual area. Used by some to denote human V5 in constrast to monkey V5	
V5A		
V6	Visual area six. Also PO. Eye position-related activity	(Galletti et al., 1995)
V6A	Corresponds to MDP (Van Essen, 2003)	(Van Essen, 2003)
V7	Visual area seven. Dorsal human visual area lying anterior to V3A	(Press et al., 2001a; Tootell and Hadjikhani, 2001; Van Essen, 2003)
V7A	Posterior parietal area.	
V8	Visual area eight. Color vision. Disputed to be the same area as V4. It is defined in human, not (yet?) in macaque	(Hadjikhani et al., 1998; Zeki et al., 1998; Tootell and Hadjikhani, 1998; Tootell and Hadjikhani, 2001)
VA	Ventroanterior area.	
VIP		
vMST	The floor of superior temporal sulcus (in macaque)	(Vanduffel et al., 2001)
VP	Another name for V3v. Van Essen seems to use VP rather than V3v	(Van Essen, 2003)

Table 22 shows some of the functional areas, cytoarchitectonic area (excluding Brodmann areas) as well as some anatomical area with abbreviations. For visual areas see also http://cogsci.ucsd.edu/˜sereno/brain.html. (Van Essen, 2003) describes the differences and similarities between human and macaque cortical areas. Human and macaque areas for speech perception are displayed in (Scott and Johnsrude, 2003, Figure 1), and (Petrides and Pandya, 1994) is a comparative study of human and macaque for the frontal cortex.

Common modifiers are: anterior/posterior, dorsal/ventral, superior/inferior, caudal/rostral, ipsilateral/contralateral, lateral/medial, and floor/fundus, bank and lip.

Cytoarchitectonic areas with respect to Brodmann's scheme are displayed in table 23. Classic cytology references are (Brodmann, 1909; Brodmann, 1994; von Economo and Koskinas, 1925; von Economo, 1929; Bonin and Bailey, 1947) and Braak. The nomenclature used for macaque by (Bonin and Bailey, 1947) is based on that from Economo-Koskinas for humans (von Economo and Koskinas, 1925). A structured overview of Brodmann areas (and other areas) is also available from the CoCoMac database (http://cocomac.org). Furthermore, this database provides data on the relationship between brain areas (called "mapping" in the database), e.g., whether an area is a subarea of another, see also http://www.cocomac.org/regionalmap.pdf. Illustrations of the spatial organization and characteristics of Brodmann areas appear at http://spot.colorado.edu/˜dubin/talks/brodmann/brodmann.html.

Name	Description	Reference
BAMS	"The Brain Architecture Management System". Brain structure hierarchy, connections and chemicals	(Bota et al., 2003; Bota and Arbib, 2004; Bota and Swanson, 2006; Bota and Swanson, 2007), http://brancusi.usc.edu/bkms/
BIRNLex	Ontology for, e.g., neuroanatomy, behavioral processes, diseases.	http://fireball.drexelmed.edu/birnlex-/OWLdocs/
BrainInfo	Merging of *NeuroNames* and *Template Atlas*	(Bowden and Dubach, 2003), http://braininfo.rprc.washington.edu/
BrainMap™	The BrainMap™ database includes, e.g., a taxonomy for "behavioral domains"	http://brainmap.org
Brede Database	Small taxonomy for neuroanatomy (WOROI) and, e.g., brain functions, neuroreceptors, brain diseases (WOEXT). Used for classifying experiments and locations in the Brede Database.	(Nielsen, 2003; Nielsen, 2005), http://hendrix.imm.dtu.dk-/services/jerne/brede-/index_roi_alphabetic.html, http://hendrix.imm.dtu.dk-/services/jerne/brede-/index_ext_alphabetic.html
CoCoMac	Brain areas such as Brodmann areas. Mapping between them called "objective relational transformation" (ORT).	(Stephan et al., 2001; Stephan et al., 2000b; Stephan and Kötter, 1999), http://cocomac.org/
FMA	Foundational Model of Anatomy. A Web-based ontology for anatomy, including the brain. An item such as "straight gyrus" is defined with synonyms, latin name, part-of information, arterial supply and whether it has dimension, mass and boundary.	(Rosse and Mejino Jr., 2003), http://sig.biostr.washington.edu-/projects/fm/.
(Jerne, "Volumes of Interest")	List of words and phrases used in the "lobar anatomy" field of BrainMap™. Generation of volumes and determination of related volumes.	(Nielsen and Hansen, 2002a), http://hendrix.imm.dtu.dk/services-/jerne/ninf/voi.html
MeSH	A hierarchy of medical terms used in conjunction with the PubMed webservice	http://www.nlm.nih.gov/mesh/
NeuroNames	A hierarchy and thesaurus of neuroanatomical names with an Internet service. See also *BrainInfo*	(Bowden and Martin, 1995; Bowden and Martin, 1997; Bowden and Dubach, 2003; Martin et al., 1990) http://rprcsgi.rprc.washington.edu-/neuronames/
OpenGALEN	Ontology for clinical data which include, e.g., neuroanatomy	http://www.opengalen.org/, (Rector et al., 1998)
Petilla 2005	GABAergic interneurons	(Alonso-Nanclares et al., 2005) http://www.columbia.edu/cu/-biology/faculty/yuste/petilla/, Background: (Yuste, 2005)
SBML	Systems Biology Markup Language	(Hucka et al., 2003), http://sbml.org/

Table 21: Neuroscience terminology, taxonomies and ontologies.

Table 23: Brodmann areas. BA and the Brodmann area numbers. EK refers to Economo-Koskinas identifiers (von Economo and Koskinas, 1925; Zilles and Palomero-Gallagher, 2001) and (Roland, 1992, figure 5.20).

BA	EK	Area	Description	Reference
1	PC	Intermediate postcentral area	Postcentral region	(Brodmann, 1994, p. 112), (Zilles and Palomero-Gallagher, 2001, table 1)
2	PD, PDE	(Caudal) postcentral gyrus		(Brodmann, 1994, p. 112), (Zilles and Palomero-Gallagher, 2001, table 1)
3		(Rostral) postcentral gyrus		(Brodmann, 1994, p. 112)
3a	PA1			(Zilles and Palomero-Gallagher, 2001)
3b	PB1, PB2		Primary somatosensory area	(Zilles and Palomero-Gallagher, 2001)
4		Giant pyramidal area	Precentral region, primary motor cortex	(Brodmann, 1994, p. 113)
4a		4 anterior	"slightly larger, more densely packed pyramidal cells in layer III than [. . .] 4p"	(Geyer et al., 1996), Jülich atlas
4p		4 posterior	Between 3a and 4a towards the bottom of the precentral gyrus.	(Geyer et al., 1996)
5		Preparietal area	Parietal region	
6		Agranular frontal area		(Brodmann, 1994, p. 115)
7		Superior parietal area		
8		Intermediate frontal area		(Brodmann, 1994, p. 116)
9		Granular frontal area		
10		Frontopolar area		
11				
12				
13			Does not appear in humans	
14			Does not appear in humans	
15			Does not appear in humans	
16			Does not appear in humans	
17		Striate area		(Brodmann, 1994, p. 119)
18		Occipital area		(Brodmann, 1994, p. 120)
19		Preoccipital area		(Brodmann, 1994, p. 120)
20		Inferior temporal area		(Brodmann, 1994, p. 124)
21		Middle temporal area		(Brodmann, 1994, p. 121)

BA	EK	Area	Description	Reference
22		Superior temporal area		(Brodmann, 1994, p. 121)
23	LC2	Ventral posterior cingulate	Isocortex	(Brodmann, 1994, p. 126–127)
23a			Isocortex, (Proisocortex?). Could be classified as 30 (Kobayashi)	(Vogt et al., 2001; Kobayashi and Amaral, 2000)
23b			Isocortex	(Vogt et al., 2001; Vogt et al., 1987; Vogt and Pandya, 1987)
pv23b		Posteroventral	Thalamic projections mainly from anterior nuclei	(Shibata and Yukie, 2003)
d23b		Dorsal		(Shibata and Yukie, 2003)
23c			Isocortex. Lower bank of the cingulate sulcus. Part of caudal cingulate motor area (M4)	(Morecraft et al., 2004)
23d			Curvature of the depth of the cingulate sulcus. Part of caudal cingulate motor area (M4)	(Morecraft et al., 2004)
23e		External	Dorsal 23. (Macaca fascicularis). Related to 23c	(Kobayashi and Amaral, 2000)
23i		Internal	Rostral and ventral compared to 23e. (Macaca fascicularis). Related to 23b.	(Kobayashi and Amaral, 2000)
23v		Ventral	The most inferior part of 23. (Macaca fascicularis)	(Kobayashi and Amaral, 2000)
24		Ventral anterior cingulate		(Brodmann, 1994, p. 127)
24a			Proisocortex	
24b			Proisocortex	
24c			Part of rostral cingulate motor area (M3)	(Morecraft et al., 2004)
24d			Part of rostral cingulate motor area (M3)	(Morecraft et al., 2004)
25		Subgenual		(Brodmann, 1994, p. 127)
26	LF	Ectosplenial	In the retrosplenial region. “es” of Braak	(Brodmann, 1994, p. 128), (Vogt et al., 2001, p. 358) (Braak, 1979)
27		Presubicular area, Parahippocampal		(Brodmann, 1994, p. 128)
28		Ectorhinal area		(Brodmann, 1994, p. 129)
29		Granular retrolimbic	Granular. In the retrosplenial region in the depth of the callosal sulcus	(Brodmann, 1994, p. 128), (Vogt et al., 2001)
29a			Periallocortex (Macaca mulatta)	(Morris et al., 1999)
29b			Periallocortex (Macaca mulatta)	(Morris et al., 1999)
29c			Transitional periallocortex/proisocortex (Macaca mulatta)	(Morris et al., 1999)

BA	EK	Area	Description	Reference
29d			Proisocortex. Most medial part of 29. (Macaca mulatta)	(Morris et al., 1999)
29l		Lateral 29		(Kobayashi and Amaral, 2000; Vogt et al., 2001)
29m		Medial 29		(Kobayashi and Amaral, 2000; Vogt et al., 2001)
30	LD	Agranular retrolimbic	Dysgranular. Proisocortex. In the retrosplenial region in the lib of the callosul sulcus. "Variable thickness layer IV that is interrupted by large NFP-ir neurons in layers IIIc and Va"	(Brodmann, 1994, p. 128), (Vogt et al., 2001; Morris et al., 1999; Morecraft et al., 2004)
30v			Transition between 29 and visual association cortex	(Kobayashi and Amaral, 2000)
31	LC1	Dorsal posterior cingulate		
32		Dorsal anterior cingulate		(Brodmann, 1994, p. 127)
33		Pregenual		
34				
35				
36		Ectorhinal area, (Parahippocampal?)		(Brodmann, 1994, p. 122)
36'd				(Vogt et al., 2001)
36'v				(Vogt et al., 2001)
37				
38		Temporopolar		(Brodmann, 1994, p. 124)
39	PG	Angular	"Corresponds broadly to the angular gyrus". Myeloarchitectonic PG and PEG (Eidelberg-Galaburda)	(Brodmann, 1994, p. 119), (Eidelberg and Galaburda, 1984), (Zilles and Palomero-Gallagher, 2001, table 1)
40		Supramarginal		
41		Medial (anterior transverse temporal area		(Brodmann, 1994, p. 125), Jülich atlas
42		Lateral (posterior) transverse temporal area		(Brodmann, 1994, p. 125)
43	PDF			(Zilles and Palomero-Gallagher, 2001, table 1)
44		Opercular area	Subfrontal region	
45		Triangular area	Subfrontal region	
46		Middle frontal area		
46d		Dorsal area 46		
46v		Ventral area 46 (also v46)		

BA	EK	Area	Description	Reference
47		Orbital area	Subfrontal region	
48				
49				
50				
51				
52		Parainsular		(Brodmann, 1994, p. 125)

10 PET and SPECT

10.1 Molecular imaging

Table 24: Tracers. Partially based on (Gjedde, 2001; Smith et al., 2003; Knudsen and Svarer, 2002) and list from Turku PET Centre http://www.turkupetcentre.fi/pet_tracers.html. Compound initial keys: SB (SmithKline Beecham), GR (Amersham Phamarcia Biotech?).

Transmitter	Enzyme, receptor or metabolism	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
Several	D2+5HT2 +α_1	[C-11]NMSP (*N*-methyl-spiperone)	(Wong et al., 1984; Morris et al., 1993), Nysberg S 1993.
Dopamine	DOPA-decarboxylase	[F-18]FDOPA	
	D1	[C-11]NNC 112	(Halldin et al., 1998; Abi-Dargham et al., 2000), Slifstein and Laruelle 2000(?)
	D1	[C-11]NNC 756	(Laihinen et al., 1994)
	D1	[H-3]SCH 23390	(De Keyser et al., 1988; Hall et al., 1988)
	D1	[C-11]SCH 23390	(Farde et al., 1987; Wang et al., 1998; Chan et al., 1998; Karlsson et al., 2002)
	D1	[C-11]SCH 39166	(Laihinen et al., 1994)
	D2/D3	[C-11]-epidepride	(Langer et al., 1999), Almeida P 1999, Hall H 1997
	D2/D3	[I-123]-epidepride	(Leslie et al., 1996; Kuikka et al., 1997; Varrone et al., 2000; Fujita et al., 2004), Kornhuber J 1995, Kessler RM 1991(?), Almeida P 1999, Goldsmith and Joyce 1996.
	D2/D3	[I-125]-epidepride	(Hall et al., 1996; Hall et al., 1997)
	D2/D3	[F-18]-fallypride	(Mukherjee et al., 2002)
	D2/D3	[C-11]FLB 457	(Farde et al., 1997b; Olsson et al., 1999; Okubo et al., 1999; Vilkman et al., 2000; Kaasinen et al., 2001; Suhara et al., 2001; Cselényi et al., 2002), Sudo Y, 2001, Talvik 2003.
	D2/D3	[I-125]NCQ 298	(Hall et al., 1997)
	D2	[H-3]-raclopride	(Hall et al., 1988)
	D2/D3	[C-11]-raclopride	(Breier et al., 1998; Kestler et al., 2000), Farde 1987, Volkov N 1993
	D2	[H-3]-spiroperidol	(De Keyser et al., 1988)
	D2	[I-123]IBZM (iodobenzamide)	(Leslie et al., 1996), Kung HF 1990, Laulumaa V 1993, Seibyl 1996
	D2/5HT-2A	[F-18]FESP	See under 5HT-2A
		[I-123]IBZP	
	D2	[I-123]IDF	
	D2	*R*-[C-11]SKF 82957	
	D4	[C-11]SCH 66712	

Transmitter	Enzyme or Receptor	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
	DAT	[C-11]CFT, [C-11]WIN 35,428	Wong 1993, Rinne 2004
	DAT	[F-18]CFT, [F-18]WIN 35,428	Laakso 1998, Nurmi 2000a, 2000b, Laakso 2000
	DAT	[C-11]beta-CFT	Rinne 1998
	DAT	[C-11]-cocaine	(Telang et al., 1999)
	DAT	[N-C-11-methyl](-)-cocaine	Logan J 1990
	DAT	[F-18]-cocaine	
	DAT	[C-11]FPCIT	
	DAT	[C-11]PE2I	(Halldin et al., 2003)
	DAT	[C-11]RTI 32	
Norepinephrine (noradrenaline)	NET	[C-11]MeNER	(Wilson et al., 2003), Schou M 2003 (post mortem)
Histamine	H1	[C-11]-doxepin	(Yanai et al., 1992; Tagawa et al., 2001)
	H1	[C-11]-pyrilamine	(Yanie et al., 1992)
Serotonin (5-HT)	(Metabolism)	α-[C-11]MTrp ([C-11]AMT or α-[C-11]methyl-L-tryptophan)	(Okazawa et al., 2000).
		[C-11]-HTP, [C-11]-5-hydroxy-L-tryptophan	Hagberg 2002
		Tryptophan hydroxylase	
		5-hydroxy-tryptophan-decarboxylase	
	5HT-1(?)	[H-3]serotonin	(Pazos et al., 1987a)
	5HT-1A	[H-3]8-hydroxy-2-[N,N-di-N-propyl-amino]tetralin	(Pazos et al., 1987a)
	5HT-1A	[H-3]8-OHDPAT	
	5HT-1A	[C-11] CPC-222	Houle 1997
	5HT-1A	[O-methyl-C-11]WAY-100635	Pike 1995
	5HT-1A	[Carbonyl-C-11]WAY-100635	(Farde et al., 1998; Ito et al., 1999; Tauscher et al., 2001; Andrée et al., 2002; Rabiner et al., 2002; Parsey et al., 2002; Borg et al., 2003), Parsey 2000 Pike 1996, Gunn 1998, Slifstein and Laruelle 2000(?)
	5HT-1A	[Carbonyl-C-11]Desmethyl-WAY-100635	(Andrée et al., 2002)

Transmitter	Enzyme or Receptor	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
	5HT-1A	[F-18]MPPF	Passchier 2000, 2001
	5HT-1B	[H-3]GR 125743	(Varnäs et al., 2001)
	5HT-1C	[H-3]mesulergine	(Pazos et al., 1987a)
	5HT-1D	[H-3]GR 125743	(Varnäs et al., 2001)
	5HT-2	N1-[C-11]-methyl-2-bromo-LSD	(Wong et al., 1987)
	5HT-2	[C-11]ketanserin, [C-11]R 41,468	Baron JC 1985
	5HT-2	[H-3]ketanserin, [H-3]R 41,468	(Pazos et al., 1987b; Eastwood et al., 2001), (Geyer et al., 1998; Kötter et al., 2001, Monkey), Laruelle 1993
	5HT-2	[C-11]NMKET (*N*-Methylketanserin)	Frost JJ 1990 (abstract)
	5HT-2	[F-18]-setoperone	(Blin et al., 1990; Meyer et al., 1999; Yatham et al., 2000), Cho 1999.
	5HT-2A	[H-3]-spiperone + Ketamine	(Marcusson et al., 1984)
	5HT-2A	[H-3]MDL-100907	(Hall et al., 2000)
	5HT-2A	[C-11]MDL-100907	(Gründer et al., 1997; Ito et al., 1998; Watabe et al., 2000), (Lundkvist et al., 1996, monkey), (Offord et al., 1999, review)
	5HT2A	[C-11]NMSP + MDL 100,907	(Andree et al., 1998)
	5HT-2A	[F-18]-altanserin	(Biver et al., 1994; Sadzot et al., 1995; Rosier et al., 1996; Meltzer et al., 1998; Meltzer et al., 1999; van Dyck et al., 2000b; Price et al., 2001; Kaye et al., 2001; Sheline et al., 2002; Forutan et al., 2002; Adams et al., 2004; Bailer et al., 2004; Liptrot et al., 2004; Mintun et al., 2004; Sheline et al., 2004; Adams et al., 2005)
	5HT-2A	[F-18]-deutero-altanserin	(van Dyck et al., 2000a)
	5HT-2A/D2	[F-18]FESP, 3-(2'-[F-18]fluoroethyl)-spiperone	(Moresco et al., 2002; Messa et al., 2003; Moresco et al., 2004)
	5HT-2A	[I-123]-5-I-R91150	(Baeken et al., 1998; Audenaert et al., 2003; Goethals et al., 2004)
	5HT-3	[C-11]MDL 72222	
	5HT-4	[C-11]SB207145	

Transmitter	Enzyme or Receptor	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
	SERT	[C-11]ADAM	Shiue GG 2003 (in vitro, rat and baboon)
	SERT	[C-11]AFA	
	SERT	[C-11]AFM	
	SERT	[C-11]-cyano-imipramine	(Takano et al., 2002)
	SERT	[C-11]DAPA	
	SERT	[C-11]DAPP	(Houle et al., 2000)
	SERT	[C-11]DASB	(Houle et al., 2000; Ichise et al., 2003; Frankle et al., 2004; Kim et al., 2006; Praschak-Rieder et al., 2007)
	SERT	[C-11]MADAM	Chalon 2003
	SERT	[C-11](+)McN-5652	(Szabo et al., 1995; Szabo et al., 1996; Buck et al., 2000; Takano et al., 2002; Frankle et al., 2004), McCann 1998, Parsey 2000, Szabo 1999, Simpson 2003, Szabo 2004, Ikoma 2002
	SERT	[C-11]-NS 4194	
	SERT	[I-123]ADAM	
	SERT	[I-123]β-CIT	Brücke 1993, Semple 1999, (Neumeister et al., 2000)
	SERT	[C-11]β-CIT	Farde 1994
	SERT	[I-123]ZIENT	Chen 2000
	5HT-1A mRNA		(Burnet et al., 1995)
	5HT-2A mRNA		(Burnet et al., 1995)
GABA	GABA-A (BZ)	[C-11]-flumazenil, [C-11]FMZ	(Holthoff et al., 1991; Gründer et al., 2001), Koeppe 1991
	Microglia GABA-A (BZ)	[C-11](R)-PK11195	Banati
	GABA-A (BZ)	[F-18]-fluoroethyl-flumazenil (FEF)	(Gründer et al., 2001)
	GABA-A (BZ)	[I-123]Iomazenil	Laruelle 1993, Onishi Y 1996
	GABA-A (BZ)	NNC 13-8241	(Kuikka et al., 1996)
	GABA-A (BZ)	Ro 15-4513	
	GABA-A (BZ)	[C-11] Ro 15-1788	(Persson et al., 1985)
	GABA-A (BZ)	Diazepam	
	GABA-A	[H-3]Muscimol	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
Glutamate	AMPA	[H-3]AMPA	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
	Kainate	[H-3]kainate	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
	NMDA	[H-3]MK-801	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
Opioid	μ, κ	[F-18]-cyclofoxy	Carson RE 1993

Transmitter	Enzyme or Receptor	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
	nonselective	[C-11]-diprenorphine	Jones 1988, Jones 1994, Frost 1990, Sadzot 1991, Prevett 1994
	μ	[C-11]-carfentanil	(Frost et al., 1989; Zubieta et al., 1999), Frost 1985, Frost 1990
	δ	[C-11]MeNTI	(Smith et al., 1999)
Sigma	σ_1	[C-11]SA4503	Kawamura
Acetylcholine	Nicotine	[C-11]-nicotine	
	nAChR $\alpha4\beta2$	[F-18] A85380	
	$\alpha1$	[H-3]Prazosin	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
	$\alpha2$	[H-3]Idazoxan (RX781094)	
	$\alpha2$	[H-3]UK-14304	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
	α 2A/2B		H. De Vos 1992.
	M1	[H-3]pirenzepine	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
	M2	[C-11]-tropanyl-benzilat (TRB)	Koeppe 1994, Lee 1996
	M2	[F-18] FP-TZTP	(Podruchny et al., 2003)
	Muscarinic	[C-11]NMPB (N-[C-11]methyl-4-piperidyl benzilate)	(Zubieta et al., 1998; Yoshida et al., 2000), Zubieta 2001, Sudo 1998, Kakiuchi 2001 (monkey)
	M2/M4	[H-3]oxotremorine-M	(Geyer et al., 1998; Kötter et al., 2001, Monkey)
		[C-11]scopolamine	Frey 1992
		[I-123]QNB (quinuclidinyl-iodo-benzilate)	
	Acetylcholinesterase activity	N-[C-11]methyl-piperidin-4-yl propionate, [C-11]PMP	(Koeppe et al., 1999)
	Acetylcholinesteras activity	N -[C-11]methylpiperidin-4-yl acetate, [C-11]MP4A	(Nagatsuka Si et al., 2001)
—	Monoamine oxidase A	[C-11]Deprenyl	
—	Monoamine oxidase B	[C-11]Clorgyline	
—	Vesicular monoamine transporter 2	[C-11]DTBZ	

Transmitter	Enzyme or Receptor	Radiosubstrate or ligand	Reference for PET, SPECT or autoradiography
—	—	[C-11]-methyl-tetrahydroamino-acridine	(Traykov et al., 1999)
—	—	[C-11]-vinpocetine	(Gulyás et al., 2002)

Table 24 lists a number of the radiotracers for PET and SPECT human brain imaging. Another list is the North American PET directory of radiotracers available from http://www.snidd.org/petsearch.cfm.

Binding characterstics are available from http://www.gpcr.org/7tm/ligand/Seeman/S1A.html

10.2 Molecular neuroimaging and personality

(Farde et al., 1997a; Breier et al., 1998; Kestler et al., 2000; Suhara et al., 2001; Moresco et al., 2002). With CBF: (Johnson et al., 1999; Youn et al., 2002)

11 Magnetic resonance imaging (MRI)

Table 25: MRI sequences and techniques. See also General MRI Acronym Directory .

Name	Type	Description	Reference
ASL	Perfusion	Arterial spin labeling	(Detre et al., 1994)
DW		Diffusion weighted	
EPI		Echo planar imaging	
EPISTAR	Perfusion	Echo planar imaging and signal targeting with alternating radiofrequency	(Edelman et al., 1994)
FAIR	Perfusion	Flow-sensitive alterating inversion recovery	(Kim, 1995; Kwong et al., 1995)
FISP	GRE	Fast Imaging with Steady-State Precession	
FLAIR	IR	Fluid Attenuation Inversion Recovery	
FLASH	GRE	Fast Low Angle Shot	
GE-MBEST		Gradient Echo Modulus Blipped Echo planar Shot Technique	
GEMS		Gradient Echo Multi Slice	
GRASS	GRE	Gradient Recalled Acquisition in the Steady State	
GRE		Gradient echo	
HASTE		Half-Fourier single shot turbo spin-echo	
IR	T1	Inversion recovery. Initial 180-pulse (inversion) followed by a 90-pulse	
MPRAGE		Magnetization Prepared RApid Gradient Echo	
PICORE	ASL, tagging		Wong et al 1997
PRESTO			
QUIPPS	ASL	Quantitative imaging of perfusion using a single subtraction	(Wong et al., 1998)
RR-EPI		Robarts Research Echo Planar Imaging	
SE	T1, T1, PD, diffusion	Spin echo. Slice selective 90 pulse and one or more 180-pulse	
SE-MBEST		Spin Echo Modulus Blipped Echo planar Single pulse Technique	
SEMS		Spin Echo Multi Slice	
SENSE		Sensitivity Encoding	(Puessmann et al., 1999), http://www.mr.ethz.ch-/sense/
SPGR	GRE	Spoiled Grass	
Spiral	Readout	Readout in a spiral pattern in the k-space	
SR	T1	Saturation recovery	
SS-FSE		Single shot fast spin echo	
STAR		Signal Targeting with Alternating Radiofrequency	
STIR			

Name	Type	Description	Reference
Turbo FLASH	FLASH		
Turbo-PICORE	ASL, tagging		Wong et al 2000
UNFAIR	ASL	Uninverted FAIR	

Object Oriented Development Interface for NMR (ODIN, http://od1n.sourceforge.net/) including Pulsar is a collection of for generation and simulation of MR sequences.

11.1 Contrast agents

- Gadolinium diethylenetriaminepenta-acetic acid (Gd-DTPA) in fMRI: (Belliveau et al., 1991).
- Iron: Superparamagnetic iron oxide (SPIO), ultra small paramagnetic iron oxide particles (USPIO). CASRN: 1317-61-9 (ferrosoferric oxide) (?).
  - Monocryalline iron oxide MION: fMRI In rat (Palmer et al., 1999), fMRI in monkey (Vanduffel et al., 2001), Leite NeuroImage 16, 2002.
  - Combidex™ (Advanced Magnetics) in fMRI in rat: (van Bruggen et al., 1998), Combidex®
  - SPBPA (?)
  - AMI-227 (?) (Sinerem or Combidex)
  - NC 100150. (Clariscan, PEG-Ferron) (?)
- Mn^{2+}. Pautler 2002

12 Anatomical tracing

A list of tracer substances is available in table 26. A much more extensive list is available from http://cocomac.org in the "tracer substance" field: http://cocomac.org/Help/Tracer.asp

"Afferent" ("sensory") means a pathway from the peripheral system towards the central system, while "efferent" ("Motor") is from the central to the peripheral system.

Table 26: Tracing techniques (Far from complete).

Name	Transport	Description	Reference
Calbindin-D28K	A		
FB	R	Fast blue. Fluorescent neuronal tracer.	
HRP	HR	Horseradish peroxide.	
TAA		Tritiated amino acid	
WGA-HRP		Wheat germ agglutinin-conjugated horseradish peroxidase	
MRI DWI			
MRI resting state			
Strycnine			

13 File formats

Alois Schlögl maintains a list of signal data formats mostly for EEG and other biomedical signals: http://www-dpmi.tu-graz.ac.at/~schloegl/matlab/eeg/.

13.1 Neuroimaging volume data file formats

Table 27: Neuroimaging volume file formats. ECAT and Interfile information kindly provided by Frédéric Schoenahl. Not all information might be accurate.

Name	Ext.	Description	Conversion software	Reference
AFNI	BRIK, HEAD	Format with two files: binary BRIK data file and ACII HEAD header file. (Presumably) only used in AFNI.	AFNI	http://afni.nimh.nih.gov-/afni/afni_faq.shtml-#BRIKformat http://afni.nimh.nih.gov-/afni/docREADME-/README.attributes
ANALYZE	img, hdr	Format with two files: Binary img data file and binary hdr header file. There are different versions of ANALYZE files, see Mayo Clinic's information.	Mayo Clinic's ANALYZE, NIH's ImageJ, Andrew Jankes' software,	
ANALYZE (SPM)	img, hdr, (mat)	Variation of an ANALYZE file format (version 7) with offset and scale fields added. Widespread file format and used in SPM. SPM also uses an extra Matlab file to describe a 3D transformation.	Andrew Jankes' software, Matthew Brett's ana4dto3d http://www.mrc-cbu.cam.ac.uk/Imaging-/ana4dto3d.html	http://www.fil.ion.ucl.ac.uk-/spm/distrib.html#AzeFmt
Bruker	.5X1 (?)		pvconv http://pvconv.sourceforge.net/	http://www.mrc-cbu.cam.ac.uk-/Imaging/Common-/brukerformat.shtml
COR	(none and ".info")	MGH-NMR COR format used in FreeSurfer. One file for each coronal slice. Prefix as converted by FreeSurfer is "COR".	`mri_convert` program in FreeSurfer.	?
Curry (CDR)	iso(???)	Current density result from the Curry Program	CdrSPM 1.0 from Seoul National University converts to SPM ANALYZE.	
Descriptor	des, dat	File format used by RIC, San Antonio	HIPG's Alice™	http://ric.uthscsa.edu-/projects/chsn/des.html
DICOM		Extensive image data format. Different variants: DICOM3, DICOM2 (ACR-NEMA)	NIH's ImageJ, The commercial dicomread.m and dicominfo.m from Matlab Image Processing toolbox (works both on Siemens and GE DICOM), MedX. SPM2, IDICON, DicomWorks. See also next row.	http://medical.nema.org-/dicom.html, Newsgroup: comp.protocols.dicom, David Clunie's Medical Image Format Site

Name	Ext.	Description	Conversion software	Reference
DICOM Super-Mosaic (?)	IMA (?)	Format used in Siemens Syngo (It is not clear — for the author — which subset of DICOM is used by Siemens and GE and is supported, more information is needed)	volumestack from xmedcon (see, e.g., http://xmedcon.sourceforge.net-/faq/stack.html, kulCONV, MRIcro, Pieter Vandemaele's dcmsmosaic.c, MySplitMosaic.m	Newsgroup: comp.protocols.dicom.
ECAT	.s .S .v .V .a .A .N	Format by CTI/Siemens primarily for PET and SPECT able to store 2D/3D sinograms and volumes as well as bull-eyes. Filename extensions are lowercase for data, uppercase for database entry containing sinogram, volume, attenuation data, normalization data, respectively. 'One file (datablock) per dataset, which contains a binary header with common fields in nuclear medicine (dose.. patient name..) + an image-type specific subheader, and the image data coded in function of the image-type'.	cti2analyze (ftp://dormeur.topo.ucl.ac.be-/pub/ecat/); (x)medcon (http://xmedcon.sourceforge.-net/, version 6.4 of ECAT);	
GE		General Electric scanner format	Souheil Inati's GE2SPM (http://dbic.dartmouth.edu-/~inati/tools/ge2spm.php). Krish Singh's ge2spm (http://www.aston.ac.uk-/lhs/staff/singhkd/mri3dX-/mri3dX_download.html) in BrainTools	
Interfile	HDR, IMG (CRV, ROI, H01, I01, C01, R01)	Format for nuclear medicine (SPECT) with a binary image file and an ASCII header (not the same header as ANALYZE though they have the same file extension)	(x)medcon (http://xmedcon.-sourceforge.net/); IDICON Interfile/DICOM Conversion Program http://www.inf.u-szeged.hu-/~idicon/shortdoc.html	http://www.keston.com-/Interfile/, (Todd-Pokropek et al., 1992), Extension for PET http://www.irsl.org-/~kris/petinterfile.html
MINC	mnc	File format from MNI in Montreal. Related to NetCDF. Used in MNI's and Keith Worsley's software. 3D and 4D versions.	EMMA, Andrew Jankes' ana2mnc—mnc2ana http://www.cmr.uq.edu.au-/ rotor/software/, Satrajit Ghosh's 'MINC to Analyze' http://www.cns.bu.edu-/~satra/software.php	http://www.bic.mni.mcgill.ca-/software/minc/minc.html, http://poldracklab.psych.-ucla.edu/spm/minc_spm.html
NetCDF		General array data format		http://www.unidata.ucar.edu-/packages/netcdf/index.html

Name	Ext.	Description	Conversion software	Reference
NIfTI-1	nii, hdr, img	A standard by "Neuroimaging Informatics Technology Initiative". Extension of ANALYZE. Planned support in AFNI, FSL and SPM.	http://nifti.nimh.nih.gov-/dfwg/src/	(Cox et al., 2004), http://nifti.nimh.nih.gov/dfwg/
PFF		"The Pittsburgh File Format". A file format used in Pittsburgh fMRI community		http://lib.stat.cmu.edu-/~fiasco/overview/pff_intro.html
SDT	sdt, spr	Format used in Stimulate		http://www.cmrr.umn.edu-/stimulate/stimUsersGuide-/node57.html
Siemens	IMA	Internal format used by Siemens. Not DICOM format although it has the same file extension, see (SPM mailing 2002-04-18) (???)	(x)medcon, visionToSPM	
Simple File Format	sfd, sfh	Used at Hvidovre Hospital, Denmark	sf_utils.tar.gz from Hvidovre Hospital.	http://www.drcmr.dk-/software/index.html
VAPET	(none)	File format used in VA Medical center, PET imaging service, Minneapolis. Exists in a 3D and 4D version. Header information is in the beginning of the file in ASCII representation	MRIWarp from the Technical University of Denmark	
UNC	s???	Multi-dimensional data format from University Of North Carolina. Used by BAMM		http://www-bmu.psychiatry.cam.ac.uk-/BAMM/FBAMM-/FILEFORMAT-/unc.html, unc2mnc, http://www.cmr.uq.edu.au-/~rotor/software/
VISTA	.v	?	?	? http://www.cs.ubc.ca/nest-/lci/vista/vista.html
XPrime		? (File format known from Hvidovre Hospital)	MRIWarp from the Technical University of Denmark	

Table 13.1 displays some of the file formats for functional neuroimaging (volumes). See also Andrew Janke's list at http://www.cmr.uq.edu.au/~rotor/minc/ as well as the list in connection with (x)medcon (http://xmedcon.sourceforge.net/docs/content.html). Chris Rorden has also a list of conversion software: http://www.psychology.nottingham.ac.uk/staff/cr1/mricro.html#otherconv.

The "Medical Image Format FAQ" is available, e.g., at http://www.cs.uu.nl/wais/html/nadir/medical-image-faq/.html.

SPM uses a specific prefixing scheme for processed files: A character is added in front of the filename: masked files (m), realign/reslice (r), spatial smoothing (s), spatial normalization (n), slice timing (a) and warped (w). MRIcro uses (l) for exported region of interests volume files.

NIfTI-1 is a new standard that is planned to be supported by Brain Voyager, AFNI, FSL and SPM (Cox et al., 2004). It is based on ANALYZE.

13.2 Other file formats

The Protein Data Bank format is for atomic coordinate files with the extension `.mod`, see http://www.umass.edu/microbio/rasmol/pdb.htm. These can be read by molecular visualization programs, such as RasMol

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Index