A Behavior-to-Brain Map
Version 1.0

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May, 2006

CS-TR-4803, UMIACS-TR-2006-24

Abstract:

Development and study of large-scale computational models of the human brain, and their use to simulate cognitive functions, is becoming increasingly feasible. However, construction of integrated models that span multiple cognitive systems (language, memory, reasoning, learning, sensorimotor control, executive functions, etc.) is currently inhibited by the absence of any systematic catalog of experimentally documented associations between specific behavioral functions and specific brain regions. In this report we provide a prototype for such a mapping in the form of a semantic network. While preliminary and not comprehensive, the results presented here support the idea that an online mapping between cognitive function and cortical/subcortical structures can be developed as a useful reference source.

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Overview

During the last several years there has been increasing interest in creating and studying large scale computational models of the brain. These models often span multiple brain regions and relate to human behavioral tasks or functional imaging results. Recent examples include system-level models of adaptive arm control (Grosse-Weintrup & Contreras-Vidal, 2006), functional imaging results (Winder et al, 2006), and language acquisition (Weems and Reggia, 2006) to name just a few. As the scope of these models expands, it will be increasingly important to have a catalog of experimental evidence of specific behavioral functions associated with the various cortical and subcortical brain regions, i.e., a mapping of individual brain structures to the cognitive functions with which they are evidently associated. Such a mapping is potentially useful in many ways: as an aid in developing brain-inspired models, as a coarse guide to the biological fidelity of a model once it is implemented, as an indicator of gaps in neuropsychological knowledge, as an educational tool, etc. This report documents some initial steps towards a behavior-to-brain map.

In this context we have recently compiled a partial online mapping of brain regions to behavioral functions in the form of a semantic network. We recognize that creating such a mapping is an ambitious goal and faces some major barriers. For example, there is a great deal of uncertainty and controversy in neuropsychology on how to relate specific brain regions to cognitive functions [Heilman & Valenstein, 2003]. In many cases, the mapping is not one-to-one, as some cognitive functions are distributed over multiple brain regions, and some regions contribute to multiple functions [Mesulam, 1990]. A complete mapping would need to address not only this issue of distributed versus local representation, but also coverage of functionality that can be represented at multiple levels of abstraction, issues of left-right hemispheric specialization of functions such as language and motor control, and the substantial individual variations that occur. What we describe here should be viewed as only one step towards a more thorough and documented mapping that might ultimately be constructed and made available as an online reference.

The current behavior-to-brain map is listed in the Appendices and is the main result of this report. This map is intended to be just a prototype; it is incomplete and no certification is made as to its correctness. It is intended primarily to establish that such a formal map between cognitive brain structures is feasible in spite of the barriers noted above. A more robust and complete map could be assembled over the next several years, but would require a substantial investment of time by domain specialists.

The scope of the current behavior-to-brain map is primarily directed towards neocortex and the associated subcortical structures (thalamus, basal ganglia, hippocampus, cerebellum, etc.) that are most closely associated with cognition. We only distinguish left and right regions when this is essential to capture qualitative hemispheric behavioral specializations. In such situations, we represent the functional specialization that usually occurs in right-handed individuals with left hemisphere dominance for language.

Relationships between neuroanatomic regions and behavioral functions in the mapping are represented as a hierarchical semantic network. Conceptually, the structure of the network consists of two hierarchies as pictured below

behavior   nervous system

"functions"
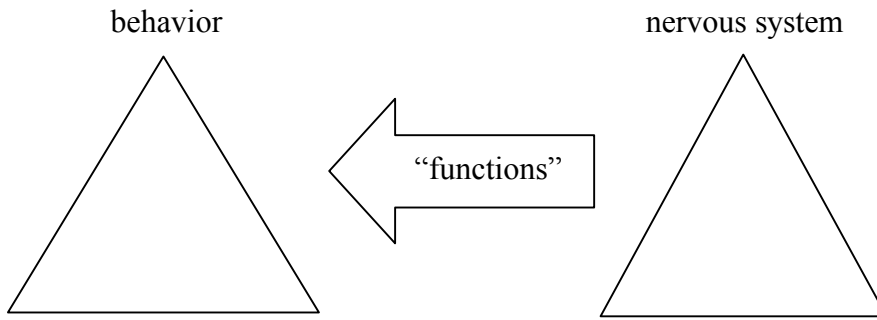
Each hierarchy has nodes that represent concepts. For example, in the behavior hierarchy on the left, 'memory' and 'learning' would be fairly high-level nodes. In the nervous system hierarchy, 'superior temporal gyrus' and 'nucleus accumbens' would be nodes representing anatomical structures. Links or connections in each hierarchy represent the relation 'is part of'. So, for example, in the nervous system hierarchy the node 'hippocampal formation' might have links with nodes 'hippocampus', 'dentate gyrus', and 'subiculum' immediately below indicating that these structures are part of the hippocampal formation. This can be visualized as

hippocampal formation
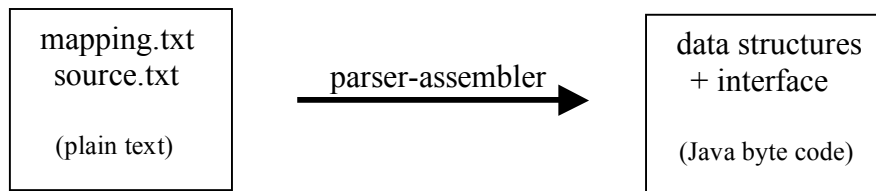
hippocampus   dentate gyrus   subiculum
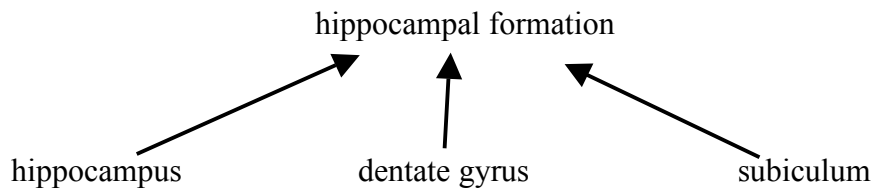
where arrows indicate the "is part of" relation. Nodes can have multiple parents, so the overall network can be viewed as composed of two tangled hierarchies. In other words, the data structure representing each hierarchy is not a tree; it is a single-rooted acyclic directed graph with a top-level node labeled either 'behavior' or 'nervous system', and links labeled 'part-of'.

Within each hierarchy, for the sake of simplicity, we currently do not distinguish between part-of and type-of relationships in the current version, representing all such relations by the part-of relationship. Individual nervous system structures within the anatomic hierarchy on the right are viewed as related to (associated with) individual behavioral and cognitive phenomena in the hierarchy on the left. Links between brain structures and cognitive functions are simply labeled 'function'. We do not use the term "causes" here because of the difficult conceptual issues this raises, leaving it implicit that in many cases a causal association is presumed to be involved. We use the term ``causes'' fairly loosely to mean "is currently believed to play a role in causing", in light of the uncertainties involved.

Online Implementation

We have implemented the function-to-brain mapping listed in the Appendices A and B online using a simple but formal knowledge representation language to allow this information to

be parsed for error detection, to facilitate its distribution to others, to support long-term maintenance, and to allow for the possibility of future extensions in capability should this prove desirable. Currently information is entered into two source files (plain ascii text) which are processed like this:

```
┌─────────────────┐                              ┌─────────────────┐
│   mapping.txt   │                              │ data structures │
│    source.txt   │   parser-assembler  ──────▶  │   + interface   │
│                 │                              │                 │
│   (plain text)  │                              │ (Java byte code)│
└─────────────────┘                              └─────────────────┘
```

The file *mapping.txt* contains the behavior-to-brain mapping specification. The file *source.txt* contains a list of labels for references. These labels are used in mapping.txt to indicate supporting experimental evidence for the function links in the mapping.

A parser checks the specified mapping information in the two input files for syntactic and some semantic errors. An assembler constructs the data structures implementing a semantic network representing the hierarchical and functional relationships, and their inverses (i.e., roughly 'has-parts' and 'is-function-of' relations). It also adds code that serves as a very simple interface to the data structures. The user interface currently allows one to see the contents of the semantic network built by the assembler, save information in files about inverse relations, and displays counts of nodes and links in the networks. For example, one can ask the current version of the system to display the information it knows about a specific neuroanatomical region, or about a specific behavioral function.

Details of the Formal Mapping Language

Anatomical structures, behavioral functions, and the relations between them, are all specified in the file *mapping.txt* using a simple knowledge representation language that is outlined below.

Atomic Elements

The most basic elements used in the file are symbols, strings and delimiters. A *symbol* is essentially a word or natural number. Specifically, a symbol is an uninterrupted sequence of upper/lower case letters and numerals, including the hyphen and apostrophe characters. Each of the following lines gives an example of a single symbol:

> language
> short-term
> 17
> Wernicke's
> afifi05

By *text*, we mean an arbitrary sequence of characters enclosed in square brackets:

[Text can include many characters, such as *#!$' (:.]

A *delimiter* is a single character that marks the start or end of something in the file. Delimiters include the blank space and end-of-line (newline, carraige return, etc.). In addition, each of the non-blank characters on the line below

( ) [ ] : , .

is a delimiter. However, except for the square brackets, when these same characters and the blank space are used between square brackets inside text, they are treated like any other alphanumeric characters in the text and have no special role as a delimiter.

All characters on a line following // in the files are treated as comments and ignored by the parser.

The source.txt File

The source.txt file defines single word labels for references or other sources of information that are used repeatedly in the mapping.txt file. The file source.txt begins with the single symbol SOURCES and consists of a sequence of *label-descriptors*, so is organized as

SOURCES
    label-descriptor
    label-descriptor
    ...
    label-descriptor

Each *label-descriptor* has the following syntax:

label text text ... text .

A *label* is a single symbol that will be used in the mapping.txt file to represent the text that is given following the label. One or more character strings designated as *text* must be present after the symbol (the ellipsis ... above indicates zero or more strings). For example,

afifi05
    [A. Afifi & R. Bergman, Functional Neuroanatomy]
    [McGraw-Hill, 2005] .

is a legal *label-descriptor*. It indicates that the label 'afifi05' represents the two lines of text that are given. Each list of text is viewed as information that, should it be displayed to the user, will be printed on its own line, spaced as given, but without the deliminating square brackets. Note that *label-descriptors* are always terminated by a period.

Top mapping.txt File

The file *mapping.txt* begins (following comments) with the statment

LOAD source.txt

which reads in and saves the labels for references that are used subsequently throughout the mapping.txt file. The remainder of file mapping.txt is divided into two sections, each of which begins with a single reserved symbol in all upper case. Thus, at the top level the file mapping.txt looks like this:

FUNCTIONS
  function-descriptor
  function-descriptor
    ...
  function-descriptor

STRUCTURES
  structure-descriptor
  structure-descriptor
    ...
  structure-descriptor

Each section is composed of one or more descriptors. All descriptors start with a function or structure name and end with a period.

The FUNCTIONS Section

The FUNCTIONS section defines the hierarchy of behavioral functions known to the system. Each function must have a single *function-descriptor* that provides information about that function. The syntax of a *function-descriptor* is

name
  synonyms-attribute
  source-attribute
  parts-attribute
   ...
  parts-attribute .

A *name*, both here and in the following, always represents a sequence of one or more symbols separated by a blank space and ended by a delimiter. The name of any behavioral function must be unique, although a function can have more than one name (synonyms; see below). The name of a function is followed by zero or more attributes that describe the function, and a period terminates the function description. For example,

unsupervised learning.

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is a perfectly legal and complete (if uninteresting) *function-descriptor* declaring that there is a function named 'unsupervised learning' but giving no further information about it. Of course, the parser may acquire information about this behavioral function from information at other locations in the source file, such as which brain regions are associated with this function. The attributes associated with a named behavioral function must be in the order listed above.

The *synonyms-attribute* gives any alternative names for a function, and each alternate must (like the primary *name*) uniquely identify the structure. The syntax of this synonym declaration is

[synonyms: *name*, *name*, ..., *name*]

where, as above, *name* is a sequence of symbols. For example,

episodic memory
    [synonyms: autobiographical memory].

indicates that there is a single behavioral function called both 'episodic memory' and 'autobiographical memory'.

The *source-attribute* has the syntax

[source: *line*, *line*, ... , *line*]

where *line* is either a *label* or a *string*. For example, assuming 'gazzaniga04' is defined as a *label* in the file source.txt, then the function declaration

recall
    [synonyms: retrieval]
    [source: "M. Rugg, Retrieval Processing in Human Memory, pp. 727-752 in"
        gazzaniga04].

indicates a reference for information about memory retrieval.

The *parts-attribute* specifies the different parts of the behavioral function currently being defined. In other words, it designates what the subfunctions are in the behavior hierarchy immediately below this function. More than one *parts-attribute* may be associated with a function, indicating that the function can be divided into sub-functions in multiple ways. A *parts-attribute* explicitly defines a "parts" relation between a function and its subfunctions, and implicitly defines a "part-of" relation between each sub-function and its parent function.

The syntax of a *parts-attribute* is

[parts (*type*): *name*, *name*, ... , *name*]

where the *type* specification is optional. The *type* is an arbitrary *symbol* that labels this set of parts. For example,

memory
    [parts (types): short-term memory, working memory, long-term memory]
    [parts (processes): storage, consolidation, recall].

declares a function named 'memory' that can be divided into parts in two different ways, as 'types' of memory and as memory 'processes'. If *(type)* is omitted, the default 'subfunctions' is used.

The STRUCTURES Section

The STRUCTURES section defines the hierarchy of neuroanatomic structures known to the system. Each neuroanatomic component must have a single *structure-descriptor* that provides information about that structure. The syntax of a *structure-descriptor* is

> *name*
>   *synonyms-attribute*
>   *source-attribute*
>   *function-attribute*
>   *parts-attribute*
>   *...*
>   *parts-attribute* .

Thus, the syntax of a *structure-descriptor* is essentially the same as that of a *function-descriptor*, including attribute order, except that a *function-attribute* may also be present. The *function-attribute*

[functions: *name, name, ..., name*]

designates which behavioral functions are associated with this part of the nervous system. For example,

> abducens nerve
>   [synonyms: sixth cranial nerve]
>   [source: manter03   "   pp. 104-105"]
>   [functions: lateral eye movement].

indicates that a function associated with the abducens nerve is 'lateral eye movement'. The names of any function listed in the *function-attribute* must have been declared previously as a *function-descriptor* in the FUNCTIONS section of the file.

The *parts-attribute*'s have the same syntax and semantics as those associated with behaviroal functions, and multiple *parts-attribute*'s may be present for any structure. For example,

central nervous system
    [synonyms: cns]
    [parts (regions): brain, spinal cord]
    [parts (pathways): sensory pathways, motor pathways, ...]
    [parts (systems): cognitive system, motor system, ...].

indicates that the 'central nervous system' is composed of three parallel and inter-related hierarchies, 'regions', 'pathways' and 'systems'. In the current mapping.txt file, the 'systems' entitites may have often have parts that are in the 'regions' and/or 'pathways' hierarchies. For example, the *structure-descriptor*

language system
    [functions: language]
    [parts: Broca's area, left arcuate fasciculus, ...].

indicates that the language system is composed of both regions such as Broca's area and pathways such as the arcuate fasciculus.

The parser checks the information specified in mapping.txt for syntactic and some semantic errors. Examples of semantic errors would be a referenced but undeclared function in a *function-attribute*, or declared entities that are not part of a hierarchy. The assembler constructs a semantic network representing hierarchical and other relationships, adding implicit relations (e.g., 'part-of' relations from a structure to a larger structure that includes it, 'structures' relations from a behavior function to neuroanatomic structures that are associated it). The parser and assembler also compute and can display various numerical measures and flags apparently missing information. The assembler also adds code that serves as a simple interface to the data structures. All software is implemented in Java, using a natural set of classes (Functions, Structures, etc.).

User Interface

Only a very simple user interface is currently implemented. After the parser/assembler finishes network construction, a main menu allows the user to save the constructed semantic network in a human-readable file that includes not only the relations explicitly encoded in the file mapping.txt, but also the reverse relations ('has parts', 'is-function-of'). Other choices include viewing the errors detected by the parser and viewing the information encoded about specific selected structures or functions. A network profile can also be generated, and this lists the number of structures and functions, the number of sources (references), the number of structure-to-function links, etc. Sub-menus allow refinements of these choices.

Conclusion

We have presented a partial mapping of brain regions to behavioral functions, formulated as a semantic map, that focuses on cerebral cortex and subcortical structures. While there are many difficulties involved in creating such a mapping, our conclusion from this exercise is that none of these would prevent extending this work to a full and complete behavior-to-brain

mapping. Doing so would require substantial work, both in expanding the knowledge in the mapping and in extending the software. There is an enormous multi-disciplinary literature available today related to such an effort, and this literature continues to grow fairly rapidly, in substantial part due to the number of ongoing functional imaging studies. We have examined only a fraction of this literature so far. Needed software extentions include a graphical user interface and substantial quality control methods.

References Cited

Grosse-Ventrup M & Contreras-Vidal J. The Role of the Striatum in Adaptation Learning: A Computational Model, 2006, under review.

Heilman K & Valenstein E. *Clinical Neuropsychology*, Oxford University Press, 2003.

Mesulam M. Large-Scale Neurocognitive Networks, *Annals of Neurology*, 28, 1990, 597-613.

Weems S & Reggia J. Simulating Single-Word Processing, 2006, under review.

Winder R, Cortes C, Reggia J & Tagamets M. A Learning Method for Matching Experimental fMRI to a Model of Visual Working Memory, 2006, under review.

Appendix A: Behavior-to-Brain Map (file mapping.txt)

// Cognition-to-Brain Map, Version 1.0, 2006 University of Maryland
//
// Contributors:
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//
// Information in this file is preliminary and intended only for internal
// use at this time. No warranty is given for either the correctness or
// completeness of the mapping information. See the file source.txt for
// published information supporting the indicated associations.

LOAD source.txt

FUNCTIONS   // ---

behavior
 [synonyms: functionality]
 [source: heilman03 kandel91]
 [parts: perception, movement, cognition, consciousness, emotion,
      motivational drives].

perception   // -------- perception ----------------------------
 [parts: vision, audition, object perception, somatosensation, olfaction, gustation,
  proprioception, pain, vestibular function, polysensory integration, novelty detection].

vision
 [parts: visual input transmission, visual object perception, visuospatial processing,
    visual motion perception, face perception, visual attention, subconscious vision,
    visual word perception].

visual input transmission.
visual object perception
 [parts: color vision, visual feature extraction, figure-ground separation,
      visual object components, shape recognition].
color vision [parts: hue discrimination, color constancy].

visual feature extraction
 [parts: visual edge detection, visual edge orientation, visual intensity, visual contrast].
visual edge detection.
visual edge orientation.
visual intensity [synonyms: brightness, luminance].

visual contrast.
visual word perception.

figure-ground separation.
visual object components
  [parts: basic shapes, processing of gratings, processing of lines].
basic shapes.
processing of gratings
 [parts: processing of cartesian gratings, processing of non-cartesian gratings].
processing of cartesian gratings.
processing of non-cartesian gratings.
processing of lines [synonyms: processing of bars].
shape recognition.

visuospatial processing [parts: visuospatial perception].

visuospatial perception
 [parts: visual position, visual distance estimation, depth perception, place recognition].
visual position.
visual distance estimation.
depth perception [synonyms: stereo vision, stereopsis].
place recognition.

visual motion perception
 [parts: visual motion direction, visual motion speed, visual motion acceleration,
  optical flow, subconscious motion detection, inertial motion detection,
  biological motion perception].
visual motion direction.
visual motion speed.
visual motion acceleration.
optical flow.
subconscious motion detection.
inertial motion detection.

// 'reading' is with language

face perception [parts: visual feature extraction].
visual attention.

audition
 [parts: auditory input transmission, sound detection, sound perception,
      sound recognition, sound intensity, sound frequency, sound localization].
auditory input transmission.
sound detection.
sound perception.
sound recognition.
sound intensity.

sound frequency.
sound localization.

somatosensation
 [parts: sensorimotor integration, somatosensory input transmission, tactile perception, pain perception, thermosensation, vibration perception].

sensorimotor integration
 [synonyms: somatosensory integration].
somatosensory input transmission.
tactile perception
 [parts: touch detection, two-point discrimination, tactile object recognition,
     tactile object perception].
touch detection.
two-point discrimination.
tactile object perception.
tactile object recognition
 [synonyms: stereognosis].

object perception
 [parts: visual object perception, tactile object recognition]. // declared above

pain perception.
thermosensation.
vibration perception.

olfaction
 [parts: odor perception, odor recognition].
odor perception.
odor recognition.

gustation
 [parts: taste perception, taste recognition].
taste perception.
taste recognition.

proprioception
 [parts: static limb position, dynamic limb position, joint angles, movement awareness,
   posture maintenance].
static limb position.
dynamic limb position.
joint angles.
movement awareness [synonyms: kinesthesia].
posture maintenance.

vestibular function.
polysensory integration
 [synonyms: multi-modal sensory integration, multisensory integration].

movement   // ----------- movement --------------------
 [parts: voluntary movements, reflex movements, motor control].

voluntary movements
 [synonyms: internally-guided movements, self-initiated movements]
 [parts: eye movements, face movements, tongue movements, neck movements,
       respiration, limb movements, trunk movements, posture maintenance, gait,
         hand movements].
eye movements
 [synonyms: EOM's, extraocular eye movements]
 [parts: lateral eye movement, medial eye movement, eye depression, eye elevation,
                 saccades, reward-oriented saccadic eye movement].
lateral eye movement.
medial eye movement.
eye depression.
eye elevation.

face movements.
tongue movements.
neck movements.
respiration.
limb movements
 [parts: hand transport, aiming, reaching, throwing, catching, prehension]
 [parts: bimanual movements, sequence production].
hand transport.
aiming.
reaching.
throwing.
catching.
prehension.
bimanual movements.
sequence production.

trunk movements.
posture maintenance.
gait.

reflex movements
 [synonyms: involuntary movements]
 [parts: pupil reflex, corneal reflex, eye blink reflex, jaw jerk, swallowing reflex, respiration,
     limb deep tendon reflexes,plantar responses].
pupil reflex.
corneal reflex.
eye blink reflex.
jaw jerk.
swallowing reflex.
respiration.

limb deep tendon reflexes.
plantar responses.

motor control
 [source: shadmehr05]
 [parts: movement planning, feedback control, movement direction, action selection, amplitude
    control, movement scaling, speed control, adaptive gating, visuomotor control, self-initiated
    movements, object avoidance, timing, visceromotor control]
 [parts: forward models, inverse models, coordination, motor programming, motor estimation,
motor execution].
movement planning
 [synonyms: motor planning, premotor planning]
 [parts: limb planning, direction planning, distance planning].
action selection
 [synonyms: response selection].
movement scaling
 [synonyms: movement parameters]
 [parts: movement amplitude, movement speed].
adaptive gating.
visuomotor control
  [parts: targeted movements, object-oriented movements, tracking movements].
visceromotor control.
self-initiated movements.
object avoidance.
timing.
forward models
 [parts: forward kinematic models, forward dynamic models].
forward kinematic models.
forward dynamic models.

inverse models
 [parts: inverse kinematic models, inverse dynamic models].
inverse kinematic models.
inverse dynamic models.

coordination
 [parts: finger coordination, limb coordination, body coordination, eye-hand coordination].
finger coordination.
limb coordination.
body coordination.
eye-hand coordination.

motor programming.
motor execution.
motor estimation.

cognition   // --------- cognition--------------------
 [parts: memory, object recognition, pattern recognition, pattern completion,

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reasoning, judgment, language, motor control, learning, executive processes].

memory   // --------- memory--------------------
 [source: squire87]
 [parts(types): short-term memory, working memory, long-term memory,
            intermediate-term memory]
 [parts(processes): encoding, storage, consolidation, recall].

short-term memory
 [parts: visual short-term memory, auditory short-term memory].
working memory
 [parts: spatial working memory, object working memory, visual working memory,
      auditory working memory, working memory manipulation].
intermediate-term memory.

long-term memory
 [parts: perceptual memory, declarative memory, procedural memory].

perceptual memory
 [parts: visual memory, auditory memory, tactile memory,
   olfactory memory, gustatory memory].
visual memory.
auditory memory.
tactile memory.
olfactory memory.
gustatory memory.

declarative memory
 [synonyms: explicit memory]
 [parts: semantic memory, episodic memory, relational memory].
semantic memory
 [synonyms: associative memory, reference memory]
 [parts: semantic encoding, semantic retrieval].
associative memory.
reference memory.
episodic memory
 [parts: autobiographical memory, non-autobiographical episodic memory].
autobiographical memory.
non-autobiographical episodic memory.

relational memory.

procedural memory
 [synonyms: implicit memory]
 [parts: skills, adaptation, priming, classical conditioning].
skills.
adaptation.
priming.

classical conditioning.
encoding
 [parts: semantic encoding, episodic encoding].
storage.
consolidation.
recall [synonyms: retrieval, memory access]
 [source: rugg04]
 [parts: emotional recall, episodic retrieval, semantic retrieval, autobiographical recall].
emotional recall.
episodic retrieval.
semantic retrieval.
autobiographical recall.

 // --------------------- pattern recognition ------------------------

pattern recognition
 [parts: spatial pattern recognition, temporal pattern recognition,
 categorization, novelty detection].
spatial pattern recognition.
temporal pattern recognition.
categorization.
novelty detection.

pattern completion
 [parts: spatial pattern completion, temporal pattern completion].
spatial pattern completion.
temporal pattern completion.

object recognition
 [parts: visual object recognition, tactile object recognition, face recognition].
visual object recognition.
tactile object recognition.
face recognition.

 // --------------------- judgment --------------------------------

judgment.

 // ----------------------- reasoning ---------------------------

reasoning
 [parts: association, spatial reasoning, cause-effect reasoning,
   deduction, analogical reasoning, case-based reasoning,
   mathematical reasoning].

association
 [parts: binding, use of context, pattern association, semantic association].
binding

[parts: unimodal sensory binding, polysensory integration].
unimodal sensory binding.
polysensory integration.

use of context
 [parts: context switching, selective attention].
context switching.
selective attention.

pattern association
 [parts: temporal pattern association, spatial pattern association].
temporal pattern association.
spatial pattern association.

spatial reasoning [parts: visuospatial reasoning, sound localization].

visuospatial reasoning
 [parts: object recognition, figure-ground separation, spatial relationships,
     visual distance estimation, spatial orientation, spatial map formation, mental rotation,
     coordinate transformations].
spatial relationships.
spatial map formation.
mental rotation.
coordinate transformations.
spatial orientation.
sound localization.

cause-effect reasoning [parts: abduction, mechanism understanding].
abduction [synonyms: explanatory reasoning].
mechanism understanding.

deduction [parts: rule-based deduction, mathematical reasoning].
analogical reasoning.
case-based reasoning.
mathematical reasoning [parts: arithmetic, symbolic mathematics].
arithmetic.
symbolic mathematics.

 // ------------------------ language ----------------------------

language [parts: spoken language, written language].

spoken language
 [parts(behavioral): comprehension, language production, repetition, naming]
 [parts(linguistic): phonology, morphology, syntax, semantics, pragmatics].
comprehension.
language production.
repetition.

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naming [parts: object naming, face naming, word naming, categorization].
object naming.
face naming.
word naming.
phonology [parts: phonological mapping, articulation].
articulation.
morphology.
syntax.
semantics.
pragmatics.

written language [parts: reading, writing].
reading
 [parts: visual letter recognition, visual word recognition, visual sentence recognition,
     reading comprehension, reading aloud].
visual letter recognition [synonyms: letter visual feature extraction].
visual word recognition.
visual sentence recognition.
reading comprehension.
reading aloud.

writing.

  // ------------------------ learning -----------------------------

learning
 [parts: supervised learning, reinforcement learning, unsupervised learning]
 [parts: stimulus-response learning, perceptual learning,
   declarative learning, procedural learning].

supervised learning.
reinforcement learning
 [parts: reward expectation, reward detection, reward processing,
     reward prediction, stimulus-action-reward association].
reward expectation.
reward detection.
reward processing.
reward prediction.
stimulus-action-reward association.

unsupervised learning.

stimulus-response learning [synonyms: associative learning]
  [parts: classical conditioning, operant conditioning].
classical conditioning.
operant conditioning.

perceptual learning

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[parts: visuospatial learning, auditory learning, somatosensory learning, olfactory learning,
  gustatory learning].
visuospatial learning.
auditory learning.
somatosensory learning.
olfactory learning.
gustatory learning.

declarative learning [parts: semantic learning, relational learning, episodic learning].
semantic learning.
relational learning.
episodic learning.

procedural learning [parts: motor plan learning, sequence learning].
motor plan learning [synonyms: skill learning].
sequence learning [synonyms: motor learning]
 [parts: temporal sequence learning, spatial sequence learning].

 // ----------------------- control, drives --------------------------

executive processes
 [parts: attention control, meta-cognition, creativity,
   planning, performance monitoring, goal formation, navigation,
   action initiation, decision making, deception, theory of mind].

attention control
 [parts: voluntary attention, involuntary attention, stimulus selection,
   stimulus tracking, suppression of irrelevant stimuli, attention shift].
voluntary attention [synonyms: active attention].
involuntary attention [synonyms: passive attention].
stimulus selection [parts: visual attention, auditory attention, spatial attention].
auditory attention.
spatial attention.

stimulus tracking.
suppression of irrelevant stimuli.
attention shift.

meta-cognition.
creativity.
planning.
performance monitoring
 [parts: error detection, inhibition, reorienting, competition monitoring, conflict detection].
error detection.
inhibition.
reorienting.
goal formation.
competition monitoring.

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navigation [parts: destination identification, course planning, object avoidance].
destination identification.
course planning.
object avoidance.

action initiation.
decision making [parts: decision uncertainty, decision certainty].
deception.
theory of mind [parts: action observation, action simulation, mental simulation].
action observation.
action simulation.
mental simulation.

consciousness [parts: arousal, wakefulness, sleep, self-awareness].
arousal.
wakefulness.
sleep.
self-awareness.

emotion
 [synonyms: affect, emotions]
 [parts: fear, anger, depression, surprise, happiness, pleasure, excitation,
   frustration, anticipation, embarrassment, affection, anxiety, agitation, humor, emotion control].
fear.
affection [synonyms: love].
anger.
depression [synonyms: sadness, grief].
surprise.
happiness.
pleasure.
excitation.
frustration.
anticipation.
embarrassment.
anxiety.
agitation.
humor.
emotion control.

motivational drives [synonyms: motivation]
 [parts: hunger, thirst, reproductive motivation, altruism,
   avoidance of adversive stimuli, reward optimization].
hunger.
thirst.
reproductive motivation.
altruism.
avoidance of adversive stimuli.

reward optimization.

STRUCTURES // --

nervous system
 [source: norback81]
 [functions: behavior]
 [parts(regions): central nervous system, peripheral nervous system].

central nervous system [synonyms: cns]
 [parts (regions): brain, spinal cord]
 [parts (pathways): sensory pathways, motor pathways, inter-regional pathways]
 [parts (systems): cognitive system, motor system, striatothalamocortical loops,
    sensory system, limbic system, language system, coordination system, autonomic system].

brain
 [functions: cognition]
 [parts: telencephalon, diencephalon, brainstem, cerebellum].
telencephalon [parts: cerebral hemisphere, corpus callosum].

cerebral hemisphere   // --------- cerebral hemispheres --------------------
 [parts: frontal lobe, parietal lobe, occipital lobe, temporal lobe, cingulate gyrus, insula,
   subcortical structures].

frontal lobe
 [source: fletcher01]
 [functions: working memory, episodic memory, short-term memory]
 [parts(Brodmann): area 4, area 6, area 8, area 9, area 10, area 11, area 12,
   area 44, area 45, area 46, area 47]
 [parts(gyri): precentral gyrus, supplementary motor cortex, frontal eye field,
   superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, medial frontal cortex,
   cingulate gyrus, orbital gyri, pars orbitalis, gyrus rectus, pars triangularis,
   pars opercularis].
area 4 [synonyms: BA 4]
 [source: middleton00]
 [functions: voluntary movements, movement parameters].
area 6 [synonyms: BA 6]
 [source: middleton00]
 [functions: voluntary movements].
area 8 [synonyms: BA 8]
 [functions: eye movements].
area 9 [synonyms: BA 9]
 [source: wheeler97 miller01 braver97 smith99 middleton00]
 [functions: episodic memory, working memory, short-term memory, planning].
area 10 [synonyms: BA 10]
 [source: wheeler97 miller01 braver97 smith99 ramnani04]
 [functions: episodic memory, working memory, short-term memory, planning,

attention control, meta-cognition].
area 11 [synonyms: BA 11]
 [source: wheeler97 miller01 braver97 smith99]
 [functions: episodic memory, working memory, short-term memory].
area 44 [synonyms: BA 44]
 [parts: left area 44, right area 44].
left area 44
 [source: newman03]
 [functions: spoken language]
 [source: fiez97]
 [functions: phonological mapping].
right area 44.
area 45 [synonyms: BA 45, area triangularis]
 [source: freedman03]
 [functions: categorization]
 [parts: left area 45, right area 45].
left area 45
 [source: newman03]
 [functions: spoken language].
right area 45.
area 46 [synonyms: BA 46]
 [source: wheeler97 miller99 miller01 braver97 freedman03 smith99 middleton00]
 [functions: episodic memory, working memory, short-term memory,
         visual working memory, spatial working memory, categorization].
area 47 [synonyms: BA 47]
 [parts: left area 47, right area 47].
left area 47
  [source: fiez97, ricci99]
  [functions: semantic retrieval, associative memory, context switching].
right area 47.

precentral gyrus
 [synonyms: primary motor cortex, MI]
 [parts: area 4].
supplementary motor cortex
 [synonyms: SMA, MII, premotor area, supplementary motor area]
 [source: middleton00 grezes2001]
 [functions: internally-guided movements, sequence production, sequence learning,
     action observation]
 [parts: area 6].
frontal eye field [synonyms: FEF]
 [functions: saccades, eye movements]
 [parts: area 8].
superior frontal gyrus
 [source: rypma99]
 [functions: working memory].
middle frontal gyrus
 [source: rypma99]

[functions: working memory].
inferior frontal gyrus
 [source: rypma99 buckner99]
 [functions: working memory, encoding]
 [parts(side): left inferior frontal gyrus, right inferior frontal gyrus].
left inferior frontal gyrus
 [source: burton05]
 [functions: auditory memory, spoken language, semantics].
right inferior frontal gyrus
 [source: burton05]
 [functions: visual memory].

medial frontal cortex
 [source: phan2002 ridderinkhof2004]
 [functions: emotion, performance monitoring, decision uncertainty, reorienting].
orbital gyri.
pars orbitalis.
gyrus rectus.
pars triangularis
 [source: newman03]
 [functions: spoken language, semantics].
pars opercularis
 [source: newman03]
 [functions: spoken language, syntax].

parietal lobe
 [source: afifi05 " Chaps. 17, 18"]
 [parts(Brodmann): area 1, area 2, area 3, area 5, area 7,
     area 23, area 31, area 39, area 40, area 43]
 [parts(gyri): postcentral gyrus, superior parietal lobule,
    inferior parietal lobule, supramarginal gyrus, angular gyrus, precuneus].
postcentral gyrus [synonyms: primary somatosensory cortex, SI]
 [functions: somatosensation]
 [parts: area 1, area 2, area 3].
primary somatosensory cortex [parts: area 1 area 2 area 3].
area 1 [synonyms: BA 1]
 [functions: somatosensation].
area 2 [synonyms: BA 2]
 [functions: somatosensation].
area 3 [synonyms: BA 3]
 [functions: somatosensation].
area 5 [synonyms: BA 5, somatosensory association cortex]
 [source: afifi05 " p. 242"]
 [functions: somatosensation, tactile object perception, stereognosis,
         two-point discrimination, pain perception].
area 7 [synonyms: BA 7, somatosensory association cortex]
 [source: afifi05 " p. 242", ehrsson2000]
 [functions: somatosensation, tactile object perception, stereognosis,

two-point discrimination, pain perception, hand movements]
[parts: area 7a, area 7b].
area 7a [synonyms: BA 7a]
 [source: anderson88]
 [functions: coordinate transformations].
area 7b [synonyms: BA 7b]
 [source: rizzolatti98]
 [functions: action observation, biological motion perception].
area 39 [synonyms: BA 39, angular gyrus]
 [source: dehaene03 afifi05 "   p. 242 kjaer2002]
 [functions: adaptation, coordinate transformations, multisensory integration, self-awareness]
 [parts: left area 39, right area 39].
left area 39
 [functions: comprehension, naming, written language, arithmetic].
right area 39.
area 40 [synonyms: BA 40]
 [source: dehaene03 afifi05 "   p. 242"]
 [functions: adaptation, coordinate transformations, multisensory integration]
 [parts: left area 40, right area 40].
left area 40
 [functions: comprehension, naming, arithmetic, spatial attention].
right area 40.
area 43 [synonyms: BA 43, subcentral cortex].
superior parietal lobule.
inferior parietal lobule.
supramarginal gyrus
 [source: grezes2001]
 [functions: action observation, action simulation]
 [parts: left supramarginal gyrus, right supramarginal gyrus].
left supramarginal gyrus
 [source: price00]
 [functions: language production].
right supramarginal gyrus.
angular gyrus [parts: left angular gyrus, right angular gyrus].
left angular gyrus
 [source: binder97 caplan03 booth02 dronkers04]
 [functions: naming, language production, semantics, written language].
right angular gyrus.
precuneus
 [source: kjaer2002]
 [functions: self-awareness].

// -------------- Occipital cortex
occipital lobe
 [parts(Brodmann): area 17, area 18, area 19]
 [parts(gyri): inferior occipital gyrus, middle occipital gyrus,
    superior occipital gyrus, lingual gyrus, cuneus]
 [parts: lateral occipital cortex, extrastriate cortex].

area 17
 [synonyms: BA 17, V1, primary visual cortex, striate cortex]
 [functions: visual edge detection, visual edge orientation,
  visual intensity, color vision, visual motion perception].
area 18
  [synonyms: BA 18, secondary visual cortex, parastriate]
  [parts: V2, V3]
  [functions: depth perception, visual object perception, visual feature extraction,
   visuospatial perception].
area 19 [synonyms: BA 19, V4, peristriate]
 [source: desimone93 walsh93 gallant93]
 [functions: figure-ground separation, color constancy, hue discrimination,
        color constancy, processing of cartesian gratings,
        processing of non-cartesian gratings].
V2 [source: vonderHeydt00]
 [functions: visual feature extraction].
V3
 [functions: visual object perception]
 [parts: V3a, VP].
V3a [source: tootell97]
 [functions: visual motion perception, visuospatial perception, depth perception].
VP
 [functions: visual object perception]
 [parts: V4v, V4d].
V4v
 [source: schein90 desimone87 gallant00]
 [functions: hue discrimination, visual object components, visual edge orientation,
        visual attention].
V4d [synonyms: V4d-topo, V4d-topologue]
 [source: tootell01]
 [functions: depth perception].
inferior occipital gyrus.
middle occipital gyrus [synonyms: lateral occipital gyrus]
 [parts: area 18, area 19].
superior occipital gyrus [parts: area 19].
lingual gyrus [parts: area 18, area 19].   // areas 18 and 19 are also defined above
cuneus [parts: area 18, area 19].   // areas 18 and 19 are also defined above
extrastriate cortex [parts: area 18, area 19, MT].
lateral occipital cortex [synonyms: LO].

temporal lobe
 [parts(Brodmann): area 20, area 21, area 22, area 26, area 27,
   area 28, area 29, area 30, area 34, area 35, area 36, area 37, area 38,
   area 41, area 42]
 [parts(gyri): superior temporal gyrus, middle temporal gyrus,
   inferior temporal gyrus, lateral occipitotemporal gyrus,
   medial occipitotemporal gyrus, lingual gyrus,
   parahippocampal gyrus, entorhinal cortex]

[parts(subcortical): hippocampal formation, amygdala].
area 20 [synonyms: BA 20]
 [source: sprague77 henson01]
 [functions: visual memory, visual object perception, visual word perception,
        visuospatial learning].
area 21 [synonyms: BA 21]
 [source: huang2004]
 [functions: visual object perception, visual attention]
 [parts: left area 21, right area 21].
left area 21 [source: tagamets00 gornotempini98]
 [functions: visual word perception, face naming].
right area 21
 [functions: face recognition].
area 22 [synonyms: BA 22]
 [source: binder97]
 [functions: phonology]
 [parts: anterior area 22, posterior area 22].
anterior area 22.
posterior area 22.
area 26 [synonyms: BA 26, ectosplenial area].
area 27 [synonyms: BA 27].
area 28 [synonyms: BA 28]
 [functions: novelty detection, long-term memory].
area 29 [synonyms: BA 29, granular retrolimbic area].
area 30 [synonyms: BA 30, agranular retrolimbic area].
area 34 [synonyms: BA 34, dorsal entorhinal cortex].
area 35 [synonyms: BA 35, perirhinal cortex].
area 36 [synonyms: BA 36, ectorhinal cortex].
area 37 [synonyms: BA 37]
 [functions: visual object perception, object recognition].
area 38 [synonyms: anterior temporal cortex, temporal pole, temporopolar cortex, BA 38]
 [functions: semantic memory]
 [parts: left area 38, right area 38].
left area 38
 [source: mummery00]
 [functions: semantic memory, semantics].
right area 38.
area 41 [synonyms: BA 41]
 [functions: audition].
area 42 [synonyms: BA 42].
superior temporal gyrus [source: maunsell83]
 [parts: left superior temporal gyrus, right superior temporal gyrus,
        medial superior temporal gyrus].
left superior temporal gyrus.
right superior temporal gyrus.
medial superior temporal gyrus [synonyms: MST, V5a]
 [functions: visual motion perception, eye movements].
middle temporal gyrus [parts: area 21].

inferior temporal gyrus [synonyms: IT]
 [source: dumoulin00]
 [parts: fusiform gyrus, area 20, area 37, perirhinal cortex, area TE, area TEO, V5].
fusiform gyrus
 [functions: visual object perception, object recognition]
 [parts: area 37, fusiform face area, fusiform word area].
fusiform face area
 [source: kanwisher97]
 [functions: face recognition].
fusiform word area
 [functions: visual word recognition].
perirhinal cortex [source: murray01]
 [functions: object recognition, long-term memory, binding, association].
entorhinal cortex [parts: area 28, area 34].
area TE [source: li93 miller93 freedman03]
 [functions: visual short-term memory, object recognition, categorization].
area TEO [source: schwartz83]
 [functions: shape recognition].
V5 [synonyms: MT, MT+]
 [functions: visual motion perception, optical flow].

lateral occipitotemporal gyrus.
medial occipitotemporal gyrus.

parahippocampal gyrus [parts: parahippocampal place area].
parahippocampal place area [synonyms: PPA]
  [functions: place recognition].

 // ------------------------ cingulate gyrus ---------------------------

cingulate gyrus
 [parts: anterior cingulate cortex, midcingulate cortex, posterior cingulate cortex,
    retrosplenial cortex].

anterior cingulate cortex [synonyms: pACC, perigenual-ACC, ACC]
 [parts: area 24, area 25, area 32, area 33, subgenual subregion].
area 24 [synonyms: BA 24]
 [source: macdonald00 cohen00 davidson02]
 [functions: performance monitoring, emotions, affect, fear, pleasure, agitation]
 [parts: area 24', area 24d].
area 25 [synonyms: BA 25, subgenual cingulate]
 [source: davidson02 bush00 phan2002]
 [functions: motivational drives, visceromotor control, sadness].
area 32 [synonyms: BA 32]
 [source: macdonald00 cohen00 davidson02 mayberg03]
 [functions: response selection, performance monitoring, emotion control, depression]
 [parts: area 32'].
area 33 [synonyms: BA 33, pregenual cingulate]

[source: macdonald00 cohen00 davidson02]
[functions: performance monitoring]
[parts: area 33'].
subgenual subregion [synonyms: SGSR]
[functions: visceromotor control].

midcingulate cortex [synonyms: MCC, dACC]
[functions: premotor planning, response selection, performance monitoring, error detection,
anticipation, working memory]
[parts: area 33', area 24', area 24d, area 32'].
area 33'.
area 24'.
area 24d.
area 32'
[functions: response selection].

posterior cingulate cortex [synonyms: PCC]
[source: kjaer2002]
[functions: visuospatial processing, self-awareness]
[parts: caudomedial subregion, area 23, area 31].
area 23 [synonyms: BA 23].
area 31.
caudomedial subregion.

cingulate gyrus [source: lenartowicz05]
[functions: working memory]
[parts: area 23, area 33].
retrosplenial cortex [synonyms: RSC]
[functions: memory access]
[parts: area 29, area 30].
area 29.
area 30.

hippocampal formation   // --------- hippocampal formation -----------------
[parts: hippocampus, parahippocampal gyrus].
amygdala [source: manter03 "   pp. 195-7" ledoux92 phan2002 paton06]
[parts: basolateral amygdala, central nucleus of amygdala, corticomedial amygdala]
[functions: fear, emotion, classical conditioning, reward processing].

hippocampus   [source: eichenbaum99 fortin02 tulving98 henke97 henke99]
[functions: long-term memory, short-term memory, working memory,
    relational memory, episodic memory, associative memory, semantic memory]
[parts: dentate gyrus, CA1, CA3, subiculum].
dentate gyrus [source: eldridge05]
[functions: episodic memory, storage].
CA1 [source: kesner04]
[functions: temporal pattern association, intermediate-term memory].
CA3 [source: kesner04]

[functions: spatial pattern association, spatial pattern completion, novelty detection,
        short-term memory].
subiculum [source: eldridge05]
 [functions: episodic memory, recall].

Insula [source: charan05 phan2002]
 [functions: encoding, emotional recall].

subcortical structures [parts: internal capsule, basal ganglia].
internal capsule.

basal ganglia   // --------- basal ganglia --------------------
 [source: cote91 afifi05 " Chs. 13 & 14"]
 [functions: motor control, reinforcement learning, procedural learning,
        sequence learning, decision making, movement planning]
 [parts: globus pallidus, striatum, ventral tegmental area, nucleus accumbens,
      subthalamic nucleus, substantia nigra].

striatum [synonyms: neostriatum]
 [source: samejima05]
 [functions: action selection]
 [parts: caudate nucleus, putamen].
caudate nucleus
 [source: delgado04 kawagoe04 gerardin04]
 [functions: action selection, reward prediction, motivational drives, affection].
putamen
 [source: gerardin04]
 [functions: movement scaling, stimulus-action-reward association]
 [parts: anterior putamen, posterior putamen].
anterior putamen
 [source: hikosaka99 gerardin04]
 [functions: motor programming, sequence learning, visuomotor control].
posterior putamen
[source: gerardin04 hikosaka99]
 [functions: motor execution, sequence production].
globus pallidus
 [synonyms: paleostriatum, pallidum]
 [functions: action selection]
 [parts: internal pallidal segment, external pallidal segment].
internal pallidal segment
 [source: turner97 middleton94]
 [synonyms: GPi, medial pallidal segment]
 [functions: amplitude control, action selection, sensorimotor integration, adaptive gating,
        spatial working memory].
external pallidal segment
 [source: arkadir04, turner97]
 [synonyms: GPe, lateral pallidal segment]
 [functions: movement direction, adaptive gating].

ventral tegmental area
 [synonyms: VTA]
 [source: mirenowicz96]
 [functions: reward processing, reward prediction].
nucleus accumbens
 [source: kelley04, haber99]
 [functions: motivation].
subthalamic nucleus
[synonyms: STN]
 [source: darbaky05]
 [functions: reward detection, reward expectation, motor execution].

substantia nigra
 [source: magarinos94, parent94]
 [functions: sensorimotor integration]
 [parts: substantia nigra pars reticulata, substantia nigra pars compacta].
substantia nigra pars reticulata
 [synonyms: SNr]
 [source: sato02]
 [functions: reward-oriented saccadic eye movement].

substantia nigra pars compacta [synonyms: SNc]
 [source: mirenowicz96]
 [functions: reward prediction].

 // --------------------- diencephalon ---------------------

diencephalon   [parts: thalamus, hypothalamus, epithalamus, subthalamus].
thalamus [source: norback81 " Ch. 13" afifi05   " Chs. 11 & 12"]
 [parts:
    anterior nuclear group, medial nuclear group, lateral nuclear group,
    intralaminar nuclei, midline nuclei, reticular nucleus, metathalamus].

anterior nuclear group
 [functions: emotions, episodic memory]
 [parts: principal anterior nucleus, anterodorsal nucleus].
principal anterior nucleus.
anterodorsal nucleus.

medial nuclear group [synonyms: dorsomedial nucleus]
 [functions: emotions, motivation, judgment]
 [parts: magnocellular dorsomedial nucleus, parvicellular dorsomedial nucleus,
    paralaminar dorsomedial nucleus].
magnocellular dorsomedial nucleus.
parvicellular dorsomedial nucleus.
paralaminar dorsomedial nucleus.

lateral nuclear group
 [parts: lateral dorsal nucleus, lateral posterior nucleus, pulvinar,
    ventral anterior nucleus, ventral lateral nucleus,
    ventral posterior nucleus].
lateral dorsal nucleus
 [functions: emotion].
lateral posterior nucleus
 [functions: visual input transmission, visual attention, pain].
pulvinar
 [functions: visual input transmission, visual attention, pain].
ventral anterior nucleus
 [functions: motor execution].
ventral lateral nucleus
 [functions: motor execution].
ventral posterior nucleus
 [functions: somatosensory input transmission].

intralaminar nuclei
 [functions: arousal, pain, motor control]
 [parts: centromedian nucleus, parafascicular nucleus].
centromedian nucleus.
parafascicular nucleus.

midline nuclei
 [functions: emotion].
reticular nucleus
 [functions: arousal].
metathalamus
 [synonyms: metathalamic group]
 [parts: medial geniculate bodies, lateral geniculate bodies].
medial geniculate bodies
 [functions: auditory input transmission].
lateral geniculate bodies
 [functions: visual input transmission].

hypothalamus.
epithalamus.
subthalamus.

brainstem   // --------- brainstem --------------------
 [parts: midbrain, pons, medulla].
midbrain [synonyms: mesencephalon]
 [parts: midbrain tegmentum, central gray matter, crus cerebri,
        substantia nigra, tectum].   // SN defined with basal ganglia

midbrain tegmentum
 [parts: mesencephalic nucleus of trigeminal nerve, nucleus of trochlear nerve,
        interpeduncular nucleus, nucleus parabrachialis pigmentosa,

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dorsal tegmental nucleus, ventral tegmental nucleus,
        pedunculopontine nucleus, lateral dorsal tegmental nuclei,
        dorsal raphe nucleus, parabigeminal area, locus ceruleus,
        red nucleus, oculomotor nucleus, interstitial nucleus of Cajal,
        rostral interstitial nucleus of the medial longitudinal fasciculus].
mesencephalic nucleus of trigeminal nerve.
nucleus of trochlear nerve.
interpeduncular nucleus.
nucleus parabrachialis pigmentosa.
dorsal tegmental nucleus.
ventral tegmental nucleus.
pedunculopontine nucleus
 [synonyms: nucleus tegmenti pedunculoponis].
lateral dorsal tegmental nuclei.
dorsal raphe nucleus
 [synonyms: nucleus supratrochlearis].
parabigeminal area.
locus ceruleus
 [synonyms: nucleus pigmentosus].
red nucleus.
oculomotor nucleus.
interstitial nucleus of Cajal.
rostral interstitial nucleus of the medial longitudinal fasciculus
 [synonyms: RiMLF].

central gray matter
 [synonyms: periaqueductal gray matter].
crus cerebri
 [synonyms: cerebral peduncle].
tectum
 [parts: superior colliculus, inferior colliculus].
superior colliculus
 [functions: subconscious motion detection, subconscious vision, visual input transmission].
inferior colliculus
 [functions: sound detection, auditory input transmission].

pons [synonyms: metencephalon].
medulla [synonyms: myelencephalon, bulb

cerebellum   // --------- cerebellum--------------------
 [source: miall01]
 [functions: timing, forward models, inverse models, coordination]
 [parts: cerebellar hemisphere, vermis, flocculus, nodulus, nuclei].
cerebellar hemisphere
 [parts: anterior lobe, posterior lobe, flocculonodular lobe].
anterior lobe.
posterior lobe.
flocculonodular lobe.

vermis
 [parts: superior vermis, inferior vermis].
superior vermis.
inferior vermis.
nuclei
 [parts: dentate nucleus, interpositus nucleus, fastigial nucleus].
dentate nucleus
 [source: dum02, middleton94]
 [parts: dorsal dentate loop, ventral dentate loop]
 [functions: adaptation, associative learning, sequence learning,
          spatial working memory].
dorsal dentate loop
 [parts: primary motor cortex, premotor cortex, cerebellar hemisphere,
    dentate nucleus, anterior interpositus, ventralposteriorlateral nucleus].
ventral dentate loop
 [parts: prefrontal cortex, posterior parietal cortex, lateral hemisphere,
        ventral lateral nucleus, dorsomedial nucleus].
interpositus nucleus
 [source: burton78]
 [functions: feedback control, speed control].
fastigial nucleus
 [source: shaikh05]
 [functions: inertial motion detection, spatial orientation].

spinal cord.   // --------- spinal cord ---------------------

peripheral nervous system   // ----- peripheral nervous system -----------
 [parts: cranial nerves, peripheral nerves].

cranial nerves   // --------- cranial nerves ------------------
 [parts: olfactory nerve, optic nerve, oculomotor nerve, trochlear nerve,
     trigeminal nerve, abducens nerve, facial nerve, acoustic nerve,
     glossopharyngeal nerve, vagus nerve, accessory nerve, hypoglossal nerve].
olfactory nerve [synonyms: first cranial nerve]
 [functions: olfaction].
optic nerve [synonyms: second cranial nerve]
 [functions: vision].
oculomotor nerve [synonyms: third cranial nerve]
 [functions: eye movements].
trochlear nerve [synonyms: fourth cranial nerve].
trigeminal nerve [synonyms: fifth cranial nerve].
abducens nerve [synonyms: sixth cranial nerve]
 [source: manter03   " pp. 104-105"]
 [functions: lateral eye movement].
facial nerve [synonyms: seventh cranial nerve].
acoustic nerve [synonyms: eighth cranial nerve].
glossopharyngeal nerve [synonyms: ninth cranial nerve].
vagus nerve [synonyms: tenth cranial nerve].

accessory nerve [synonyms: eleventh cranial nerve].
hypoglossal nerve [synonyms: twelfth cranial nerve].

peripheral nerves.

        // -------------- pathways -------------------- sensory pathways.

motor pathways.

inter-regional pathways [parts: corpus callosum, fornix, arcuate fasciculus].
corpus callosum [parts: anterior corpus callosum, posterior corpus callosum].
anterior corpus callosum.
posterior corpus callosum.

arcuate fasciculus
 [parts: left arcuate fasciculus, right arcuate fasciculus].
left arcuate fasciculus
 [functions: repetition].
right arcuate fasciculus.

fornix.

        // -------------- systems --------------------- cognitive system.
motor system
 [functions: motor planning, motor programming, motor control, motor learning,
      adaptation, motor estimation]   // CRC motor estimation????????
 [parts: motor loop, oculomotor loop, cerebellum].   // REVISE
sensory system
 [parts: visual system, auditory system, olfactory system, somatosensory system, gustatory
system].

visual system [source: ungerleider82]
 [parts: ventral visual pathway, dorsal visual pathway].
ventral visual pathway
 [functions: visual object perception]
 [parts: V2v, VP, V4v, inferior temporal cortex, area TE, area TEO].
dorsal visual pathway
 [functions: visuospatial perception]
 [parts: V2d, V3a, V4d, area 40].

auditory system.
olfactory system.
somatosensory system.
gustatory system.

language system   // Separate spoken/written?
 [functions: language]
 [parts: Broca's area, left arcuate fasciculus, Wernicke's area,

left angular gyrus, left supramarginal gyrus].
Broca's area
 [functions: language production, repetition]
 [parts: left area 44, left area 45].
Wernicke's area
 [functions: comprehension, repetition]
 [parts: left posterior area 22].

striatothalamocortical loops
 [source: afifi05 "   pp. 189-192"]
 [parts: motor loop, oculomotor loop, dorsolateral prefrontal loop,
        lateral orbitofrontal prefrontal loop, limbic loop].
motor loop
 [functions: limb movements]
 [parts: MI, SI, somatosensory association cortex, premotor cortex, SMA,
        putamen, GPi, GPe, SNr, STN, ventral lateral nucleus,
        ventral anterior nucleus, centromedian nucleus].
oculomotor loop
 [functions: eye movements]
 [parts: FEF, area 9, area 10, area 7b, area 39, caudate nucleus,
        GPi, GPe, SNr, STN, superior colliculus,
        ventral anterior nucleus, dorsomedial nucleus].
dorsolateral prefrontal loop
 [functions: visuomotor control,decision making]
 [parts: area 9, area 10, area 7b, area 39, caudate nucleus, GPi, GPe,
        SNr, STN, ventral anterior nucleus, dorsomedial nucleus].
lateral orbitofrontal prefrontal loop
 [functions: reinforcement learning]
 [parts: lateral orbitofrontal cortex, anterior cingulate, temporal gyrus,
   caudate nucleus, GPi, ventral anterior nucleus, dorsomedial nucleus].
limbic loop
 [functions: reward processing, motivational drives]
 [parts: anterior cingulate, temporal gyrus, ventral striatum, ventral pallidum,
        entorhinal cortex, hippocampus, dorsomedial nucleus].

coordination system.
autonomic system.

Appendix B: Reference Labels (file source.txt)

// Cognition-to-Brain Map, Version 1.0, 2006 University of Maryland
//   Jose Contreras-Vidal   Kinesiology, NACS; UMCP
//   Carlos R. Cortes   MPRC; UMB
//   James Reggia   Comp. Sci,. UMIACS; UMCP
//   Malle Tagamets   MPRC; UMB
//   Matt Tinnirella   MPRC; UMB
//   Scott Weems   CASL; UMCP

SOURCES   // --

afifi05
  [A. Afifi & R. Bergman. Functional Neuroanatomy, McGraw-Hill, 2005].
anderson88
  [Andersen R and Zipser D. 1988, The role of posterior parietal cortex in]
  [coordinate transformations. Can. J. Physiol. Pharmacol., 66, 488-501.].
arkadir04
  [D. Arkadir, G. Morris, E. Vaadia, H. Bergman. 2004. Independent coding of movement]
  [direction and reward prediction by single pallidal neurons. Neuroscience, 24, 10047-56].
binder97
  [J. Binder, J. Frost, T. Hammeke, R. Cox, S. Rao & T. Prieto. 1997. Human brain]
  [language areas identified by magnetic resonance imaging. Journal of]
  [Neuroscience, 17(1), 353-362].
booth02
  [J. Booth, D. Burman, D. Gitelman, T. Parrish & M. Mesulam. 2002. Functional]
  [anatomy of intra- and cross-modal lexical tasks. Neuroimage, 16(1). 7-22].
braver97
  [T. Braver, J. Cohen, L. Nystrom, J. Jonides, E. Smith, & D. Noll. 1997. A]
  [parametric study of prefrontal cortex involvement in human working memory.]
  [Neuroimage, 5, 49-62].
buckner99
  [R. Buckner, W. Kelley, S. Petersen. (1999). Frontal cortex ontributes to human]
  [memory formation. Nature Neuroscience, 2, 311-314].
burton78
  [J Burton, N Onoda. 1978. Dependence of the activity of interpositus and red nucleus]
  [neurons on sensory input data generated by movement. Brain Res.152(1):41-63].
burton05
  [M. Burton, P. Locasto, D. Krebs-Noble & R. Gullapalli. 2005. A systematic]
  [investigation of the neuroanatomy of auditory and visual processing. Neuroimage,]
  [26(3), 647.661].
bush00
  [G.Bush, P.Luu, and M.Posner. 2000. Cognitive and emotional influences in anterior cingulate]
  [cortex, Trends in Cogn Sciences 4:215].
caplan03
  [D. Caplan. 2003. Aphasic syndromes, In K. Heilman & E. Valenstein (Eds.),]
  [Clinical Neurophysiology (pp14-34). New York: Oxford University Press].

charan05
  [R. Charan, M. Cohen &C. Brozinsky. 2005. Working memory maintenance]
  [contributes to long-term memory formation: neural and behavioral evidence.]
  [Journal of Cognitive Neuroscience, 17(7), 994-1010].
cipolotti05
  [L. Cippolotti & M. Moscovitch. 2005. The hippocampus and remote autobiographical]
  [memory, Hippocampus, 4(12), 792-793].
cohen00
  [J. Cohen, M. Botvinick, & C. Carter. 2000. Anterior cingulate and prefrontal]
  [cortex: who's in control? Nature Neuroscience, 3(5), 421-423].
cote91
  [L. Cote & M. Crutcher, The Basal Ganglia, Ch. 42, in]
  [E. Kandel, J. Schwartz, & T. Jessell. Principles of Neural Science,]
  [Elsevier, 1991].
darbaky05
  [Y. Darbaky, C. Baunez, P. Arecchi, E. Legallet,P. Apicella P. 2005. Reward-related]
  [neuronal activity in the subthalamic nucleus of the monkey. Neuroreport. 16, 1241-44].
davidson02
  [R. Davidson, D. Pizzagalli, J. Nitschke & K. Putnam. 2002. Depression:]
  [perspectives from affective neuroscience. Annual Review of Psychology, 53,]
  [545-574].
dehaene03
  [Dehaene S. Acalculia and number processing disorders, in Behavioral Neurology]
  [and Neuropsychology, T. Feinberg & M. Farah (eds.), McGraw-Hill, 2003, 207-224.].
deleonibus05
  [E. DeLeonibus, A. Oliverio & A. Mele. 2005. A study of the dorsal striatum]
  [and nucleus accumbens in allocentric and egocentric memory consolidation.]
  [Learning and Memory, 12(5), 491-503].
delgado04
   [M.R. Delgado, V.A. Stenger, J.A. Fiez. 2004. Motivation-dependent]
   [responses in the human caudate nucleus. Cerebral Cortex. 14(9):1022-1030].
desimone93
  [Desimone, R.; Moran, J.; Schein, S. J.; Mishkin, M. (1993) A role for the corpus]
  [callosum in visual area V4 of the macaque. Vis. Neurosci. 10, 159-171].
desimone87
  [Desimone, R.; Schein, S. J. (1987) Visual properties of neurons in area V4 of the]
  [macaque: Sensitivity to stimulus form. J. Neurophysiol. 57, 835-868].
dronkers04
  [N. Dronkers, D. Wilkins, R. Van Vilin, B. Redfern & J. Jaeger. 2004. Lesion]
  [analysis of the brain areas involved in language comprehension. Cognition,]
  [92, 145-177].
dum02
  [R.P. Dum, C. Li, PL Strick PL. 2002. Motor and nonmotor domains in the monkey dentate.]
  [Ann N Y Acad Sciences. 978, 289-301].
dumoulin00
  [Dumoulin S.; Bittar, R.; Kabani, N.; Baker, C., Jr.; Le Goualher, G.; Bruce, P.;]
  [Evans, A. (2000) A new anatomical landmark for reliable identification of human]
  [area V5/MT: A quantitative analysis of sulcal patterning. Cereb. Cortex 10, 454-463].

ehrsson2000
  [H.H.Ehrsson, A.Fagergren, T.Jonsson, G.Westling, R.S.Johansson, and H.Forssberg,]
  [Cortical activity in precision- versus power-grip tasks: an fMRI study,]
  [Journal of Neurophysiology 83, 2000, 528].
eichenbaum99
  [H. Eichenbaum, P. Dudchenko, E. Wood, M. Shapiro, & H. Tanila. 1999. The]
  [hippocampus, memory, and place cells: Is it spatial memory or memory space?]
  [Neuron, 23, 209-226].
eldridge05
  [L. Eldridge, S. Engel, M. Zeineh, S. Bookheimer & B. Knowlton. 2005. A]
  [dissociation of encoding and retreival processes in the human hippocampus.]
  [Journal of Neuroscience, 25(13), 3280-3286].
fiez97
  [J Fiez. Phonology, semantics, and the role of the left inferior prefrontal cortex]
  [Human Brain Mapping 5, 1987, 79-83].
fletcher01
  [P. Fletcher & R. Henson. 2001. Frontal lobes and human memory. Brain,]
  [124(5), 849-881].
fortin02
  [N. Fortin, K. Angster, H. Eichenbaum. 2002. Critical role of the hippocampus]
  [in memory for sequences of events. Nature Neuroscience, 5, 458-452].
freedman03
  [Freedman, D. J.; Riesenhuber, M.; Poggio, T.; Miller, E. K. (2003) A comparison]
  [of primate prefrontal and inferior temporal cortices during visual categorization.]
  [J. Neurosci. 23, 5235-5246].
gallant93
  [Gallant, J. L.; Braun, J.; Van Essen, D. C. (1993) Selectivity for polar, hyperbolic]
  [and cartesian gratings in macaque visual cortex. Science 259, 100-103].
gallant00
  [Gallant, J. L.; Shoup, R. E.; Mazer, J. A. (2000) A human extrastriate area]
  [functionally homologous to macaque V4. Neuron 27, 227-235].
gazzaniga04
  [M. Gazzaniga (ed.), The Cognitive Neurosciences III, MIT Press, 2004].
gerardin04
  [E. Gerardin, JB Pochon, JB Poline, L. Tremblay, PF Van de Moortele, R Levy, B Dubois B,]
  [D Le Bihan, S. Lehericy S. 2004. Distinct striatal regions support movement selection,]
  [preparation and execution. Neuroreport. 15(15), 2327-2331].
gornotempini98
  [Gorno-Tempini, M. L.; Price, C. J.; Josephs, O.; Vandenberghe, R.; Cappa,]
  [S. F.; Kapur, N.; Frackowiak, R. S. (1998) The Neural Systems Sustaining Face]
  [and Proper-Name Processing. Brain 121 (Pt 11), 2103-2118].
grezes2001
  [J.Grezes and J.Decety. (2001). Functional anatomy of execution, mental simulation,]
  [observation, and verb generation of actions: A meta-analysis, Human Brain Mapping 12:1].
haber99
  [S. Haber, N. McFarland. 1999. The concept of the ventral striatum in nonhuman primates.]
  [Ann N Y Acad Sci. 877:33-48].
hazy05

[T. Hazy, M. Frank, & R. O'Reilly. 2005. Banishing the homunculus: Making]
[working memory work. Neuroscience, 9, in press].
heilman03
[K. Heilman & E. Valenstein. Clinical Neuropsychology,]
[Oxford Universtiy Press, 2003] .
henke97
[K. Henke, A. Buck, B. Weber & H. Wieser. 1997. Human hippocampus establishes]
[associations in memory. Hippocampus, 7(3), 249-256].
henke99
[K. Henke, B. Weber, S. Kneifel, H. Wieser & A. Buck. 1999. Human hippocampus]
[associates information in memory. Proceedings of the National Academy of]
[Sciences of the United States, 96(10), 5884-5889].
henson01
[Henson, R. N. (2001) Repetition effects for words and nonwords as indexed by]
[event-related fMRI: A preliminary study. Scand. J Psychol 42, 179-186].
hickock00
[G. Hickock & D. Poeppel. 2004. Dorsal and ventral streams: A framework for]
[understanding aspects of the functional neuroanatomy of language. Cognition,]
[92, 67-99].
hikosaka99
[O. Hikosaka,H. Nakahara,M.K. Rand,K. Sakai,X. Lu, K. Nakamura, S. Miyachi,K. Doya K.]
[1999. Parallel neural networks for learning sequential procedures. Trends Neurosciences]
[22(10), 464-471].
huang2004
[Huang, L.; Chen, X.; Shou, T. (2004) Spatial Frequency-Dependent Feedback of]
[Visual Cortical Area 21a Modulating Functional Orientation Column Maps in Areas 17]
[and 18 of the Cat. Brain Res. 998, 194-201].
kandel91
[E. Kandel, J. Schwartz, & T. Jessell. Principles of Neural Science,]
[Elsevier, 1991].
kanwisher97
[Kanwisher N, McDermott J, Chun M. (1997) The fusiform face area: a module in human]
[extrastriate cortex specialized for face perception. J Neuroscience, 17:4302-4311].
kawagoe04
[R. Kawagoe, Y. Takikawa, O. Hikosaka O.2004. Reward-predicting activity]
[of dopamine and caudate neurons--a possible mechanism of motivational]
[control of saccadic eye movement. J Neurophysiology 91(2):1013-1024].
kelley04
[A.E. Kelley AE. Ventral striatal control of appetitive motivation: role in]
[ingestive behavior and reward-related learning. Neurosci Biobehav Rev. 2004. 27, 765-76].
kesner04
[Kesner, R. P.; Lee, I.; Gilbert, P. (2004) A behavioral assessment of hippocampal]
[function based on a subregional analysis. Rev. Neurosci. 15, 333-351].
kjaer2002
[T.W.Kjaer, M.Nowak, and H.C.Lou, Reflective self-awareness and conscious states:]
[PET evidence for a common midline parietofrontal core, Neuroimage 17:1080 (2002)].
krakauer05
[J. Krakauer & R. Shadmehr. 2005. Consolidation of motor memory. Trends in]

[Neuroscience, 10, 1-6].
ledoux92
  [LeDoux, J. E. (1992) Brain Mechanisms of Emotion and Emotional Learning]
  [Curr. Opin. Neurobiol. 2, 191-197].
 ledoux93
  [J. Ledoux. 1993. Emotional memory systems in the brain. Behavioral Brain]
  [Research, 58(1-2), 69-79].
lenartowicz05
  [A. Lenartowicz & A. McIntosh. 2005. The role of anterior cingulate in working]
  [memory is shaped by functional connectivity. Journal of Cognitive Neuroscience,]
  [17(7), 1026-1042].
li93
  [Li, L.; Miller, E. K.; Desimone, R. (1993) The representation of stimulus familiarity in anterior
inferior temporal cortex. J. Neurophysiol. 69, 1918-1929].
macdonald00
  [A. MacDonald, J. Cohen, V. Stenger, & C. Carter. 2000. Dissociating the]
  [role of the dorsolateral prefrontal cortex in cognitive control. Science,]
  [288, 1835-1837].
magarinos94
  [C Magarinos-Ascone, E. Garcia-Austt, W. Buno. 1994. Polymodal sensory and]
  [motor convergence in substantia nigra neurons of the awake monkey.]
  [Brain Res. 646(2):299-302].
manter03
  [S. Gilman & S. Newman, Manter and Gatz's Essentials of Clinical]
  [Neuroanatomy and Neurophysiology, F. A. Davis, 2003].
maunsell83
  [Maunsell, J. H.; Van Essen, D. C. (1983) The connections of the middle temporal]
  [visual area (MT) and their relationship to a cortical hierarchy in the macaque]
  [monkey. J. Neurosci. 3, 2563-2586].
mayberg03
  [H. Mayberg. Modulating dysfunctional limbic-cortical circuits in depression: towards]
  [development of brain-based algorithms for diagnosis and optimised treatment,]
  [British Medical Bulletin. 65, 2003, 193].
miall01
  [RC Miall, GZ Reckess, H Imamizu. 2001. The cerebellum coordinates eye and hand]
  [tracking movements. Nat Neurosci. 4(6):638-644].
middleton94
  [F.A. Middleton, P.L. Strick. 1994. Anatomical evidence for cerebellar and basal]
  [ganglia involvement in higher cognitive function. Science. 266(5184):458-461].
middleton00
  [FA Middleton, PL Strick. 2000. Basal ganglia and cerebellar loops: motor and]
  [cognitive circuits. Brain Res Brain Res Rev. 31(2-3):236-50].
miller93
  [Miller, E. K.; Li, L.; Desimone, R. (1993) Activity of neurons in anterior inferior]
  [temporal cortex during a short-term memory task. J. Neurosci. 13, 1460-1478].
miller99
  [Miller, E. K. (1999) The Prefrontal Cortex: Complex Neural Properties for]
  [Complex Behavior. Neuron 22, 15-17].

miller01
  [E. Miller & J. Cohen. 2001. An integrative theory of prefrontal cortex function.]
  [Annual Review of Neuroscience, 24, 167-202].
mirenowicz96
  [J. Mirenowicz, W. Schultz W. 1996. Preferential activation of midbrain dopamine]
  [neurons by appetitive rather than aversive stimuli. Nature. 379(6564), 449-451].
mummery00
  [Mummery, C. J.; Patterson, K.; Price, C. J.; Ashburner, J.; Frackowiak, R. S.;]
  [Hodges, J. R. (2000) A voxel-based morphometry study of semantic dementia:]
  [Relationship between temporal lobe atrophy and semantic memory. Ann. Neurol.]
  [47, 36-45].
murray01
  [Murray, E. A.; Richmond, B. J. (2001) Role of perirhinal cortex in object]
  [perception, memory, and associations. Curr. Opin. Neurobiol. 11, 188-193].
newman03
  [S. Newman, M. Just, T. Keller, J. Roth & P. Carpenter. 2003. Differential]
  [effects of syntactic and semantic processing on the subregions of Broca's area.]
  [Cognitive Brain Research, 16(2), 297-307].
norback81
  [C. Norback & R. Demarest, The Human Nervous System, McGraw-Hill, 1981].
owen97
  [A. Owen. 1997. The functional organization of working memory processes within]
  [human lateral frontal cortex: the contribution of functional neuroimaging.]
  [European Journal of Neuroscience, 9(7), 1329-1339].
parent94
  [A. Parent, LN. Hazrati. 1994. Multiple striatal representation in primate]
  [substantia nigra. J Comp Neurol. 344(2):305-320].
paton06
  [J Paton, M Belova, S Morrison & C. Salzman. The primate amygdala represents]
  [the positive and negative value of visual stimuli during learning,]
  [Nature, 439, 2006, 865-870].
phan2002
  [K.L.Phan, T.Wager, S.F.Taylor, and I.Liberzon, Functional Neuroanatomy of]
  [Emotion: A Meta-Analysis of Emotion Activation Studies in PET and fMRI,]
  [NeuroImage 16:331 (2002)].
phelps06
  [E. Phelps. 2005. Emotion and cognition: Insights from studies of the human]
  [amygdala. Cognition, 57, 27-53].
price00
  [C. Price. 2000. The anatomy of language: contributions from functional]
  [neuroimaging. Journal of Anatomy, 197, 225-259].
ramnani04
  [Ramnani, N., Owen, A. M. (2004) Anterior Prefrontal Cortex: Insights into Function]
  [From Anatomy and Neuroimaging. Nat. Rev. Neurosci. 5, 184-194].
ricci99
  [P. T. Ricci, B. J. Zelkowicz, R. D. Nebes, C. C. Meltzer, M. A. Mintun, J. T. Becker.]
  [1999. Functional neuroanatomy of semantic memory: Recognition of semantic]
  [associations. NeuroImage 9, 88-96].

ridderinkhof2004
  [K.R.Ridderinkhof, M.Ullsperger, E.A.Crone, and S.Nieuwenhuis. (2004). The role of the]
  [medial frontal cortex in cognitive control, Science 306:443].
rizzolatti98
  [G.Rizzolatti and M.A.Arbib, (1998). Language within our grasp,]
  [Trends Neurosci. 21:188].
rugg04
  [Rugg M. Retrieval Processing in Human Memory, pp. 727-752 in]
  [M. Gazzaniga (ed.), The Cognitive Neurosciences III, MIT Press, 2004].
rypma99
  [B. Rypma, V. Prabhakaran, J. Desmond, G. Glover & J. Gabrielli. (1999). Load-]
  [dependent roles of frontal brain regions in the maintenance of working]
  [memory. NeuroImage, 9(2), 216-226].
samejima05
  [K. Samejima, Y. Ueda, K. Doya, M. Kimura. 2005. Representation of]
  [action-specific reward values in the striatum. Science. 310(5752), 1337-1340].
sato02
  [M. Sato, O. Hikosaka O. 2002. Role of primate substantia nigra pars reticulata in]
  [reward-oriented saccadic eye movement. J Neurosci. 22(6), 2363-2373].
schein90
  [Schein, S. J.; Desimone, R. (1990) Spectral properties of V4 neurons in the]
  [macaque. J. Neurosci. 10, 3369-3389].
schwartz83
  [Schwartz, E. L.; Desimone, R.; Albright, T. D.; Gross, C. G. (1983) Shape]
  [recognition and inferior temporal neurons. Proc. Natl. Acad. Sci. U. S. A 80, 5776-5778].
shadmehr05
  [R. Shadmehr, SP Wise. 2005. Computational Neurobiology of Reaching and Pointing:]
  [A Foundation for Motor Learning, MIT Press, Cambridge MA].
shaikh05
  [A.G. Shaikh, F.F. Ghasia, J.D. Dickman, D.E. Angelaki. 2005. Properties of cerebellar]
  [fastigial neurons during translation, rotation, and eye movements.]
  [J Neurophysiol. 93(2):853-863].
smith99
  [E. Smith & J. Jonides. 1999. Storage and executive processes in the frontal]
  [lobes. Neuroimage, 283(12), 1657-1661].
smith05
  [C. Smith & L. Squire. 2005. Declarative memory, awareness, and transitive]
  [interference. Journal of Neuroscience, 25(44), 10138-10146].
sprague77
  [Sprague, J. M.; Levy, J.; DiBerardino, A.; Berlucchi, G. (1977) Visual cortical]
  [areas mediating form discrimination in the cat. J. Comp Neurol. 172, 441-488].
squire87
  [L. Squire, Memory and Brain, Oxford Univ. Press, 1987].
tagamets00
  [Tagamets, M. A.; Novick, J. M.; Chalmers, M. L.; Friedman, R. B. (2000)]
  [A parametric approach to orthographic processing in the brain: an fMRI study.]
  [J. Cogn Neurosci. 12, 281-297].
tootell97

[Tootell, R. B.; Mendola, J. D.; Hadjikhani, N. K.; Ledden, P. J.; Liu, A. K.; Reppas,]
[J. B.; Sereno, M. I.; Dale, A. M. (1997) Functional analysis of V3A and related]
[areas in human visual cortex. J. Neurosci. 17, 7060-7078].
tootell01
[Tootell, R. B.; Hadjikhani, N. (2001) Where is "dorsal V4" in human visual cortex?]
[Retinotopic, topographic and functional evidence. Cereb Cortex 11: 298-311].
tulving98
[E. Tulving & H. Markowitsch. 1998. Episodic and declarative memory: role of]
[the hippocampus. Hippocampus, 8(3), 198-204].
turner97
[R.S. Turner, M.E. Anderson. 1997. Pallidal discharge related to the]
[kinematics of reaching movements in two dimensions. J Neurophysiology]
[77(3), 1051-1074].
ungerleider82
[Ungerleider L.G., Mishkin M. (1982) Two cortical visual systems. In: Ingle D.J.,]
[Goodale M.A., and Mansfield R.J.W., eds. Analysis of visual behavior]
[Cambridge, MA: MIT Press, 549-586].
vonderHeydt00
 [von der, H. R.; Zhou, H.; Friedman, H. S. (2000) Representation of Stereoscopic]
 [edges in monkey visual cortex. Vision Res. 40, 1955-1967].
walsh93
[Walsh V, Carden D, Butler SR, Kulikowski JJ (1993) The effects of V4 lesions on]
[the visual abilities of macaques: hue discrimination and colour constancy. Behav.]
[Brain Res., 53: 51-62].
wheeler97
[M. Wheeler, D. Stuss & E. Tulving. 1997. Toward a theory of episodic memory:]
[the frontal lobes and autonoetic consciousness. Psychological Bulletin, 121]
[(3), 331-354].