Brain mechanisms for interleaving routine and creative action

Alan H. Bond, Ph.D.

http://www.exso.com/alan_us.html
ABond@mednet.ucla.edu
CENTER FOR COGNITIVE PHENOMICS
NEUROPSYCHIATRIC INSTITUTE
UNIVERSITY OF CALIFORNIA AT LOS ANGELES
760 Westwood Plaza, C8−746, Los Angeles, California 90095

Abstract

1. We argue that cortical areas, particularly frontal areas, are involved in the selection and control of routine action which originates in the basal ganglia.

2. Cortical areas initiate routine action, and monitor and terminate it.

3. Normally, there will be an interleaving of creative cortical action and routine action.

4. We model routine action via the basal ganglia, which learn association connections among source areas and target areas.

5. We outline examples of routinization and interleaving for the Tower of Hanoi problem, for routinization of motor control, of problem solving action, and of eye movement.

6. We argue that the connections among the basal ganglia, thalamus and cortex provide a basis for real time control and monitoring of a stream of routine actions generated by the basal ganglia.

For basic papers on our approach, see
Alan H. Bond. An Information-processing Analysis of the Functional Architecture of the Primate Neocortex, Journal of Theoretical Biology, vol 227, pp. 51-79, 2004.
Alan H. Bond. A Computational Model for the Primate Brain based on its Functional Architecture, Journal of Theoretical Biology, vol 227, pp. 81-102, 2004.

Basal ganglia loops

Basal ganglia loops

Research by Alexander et al: G. Alexander, M. DeLong, and P. L. Strick. *Parallel organization of segregated circuits linking basal ganglia and cortex*. Annual Review of Neuroscience, 9:357--381, 1986, has shown that the basal ganglia are not an intermediate level of motor control between cerebrum and thalamus, but instead participate in four loops starting in the cortex and ending in the cortex.

These comprise:

(i) the sensory-motor loop, corresponding to routine motor action

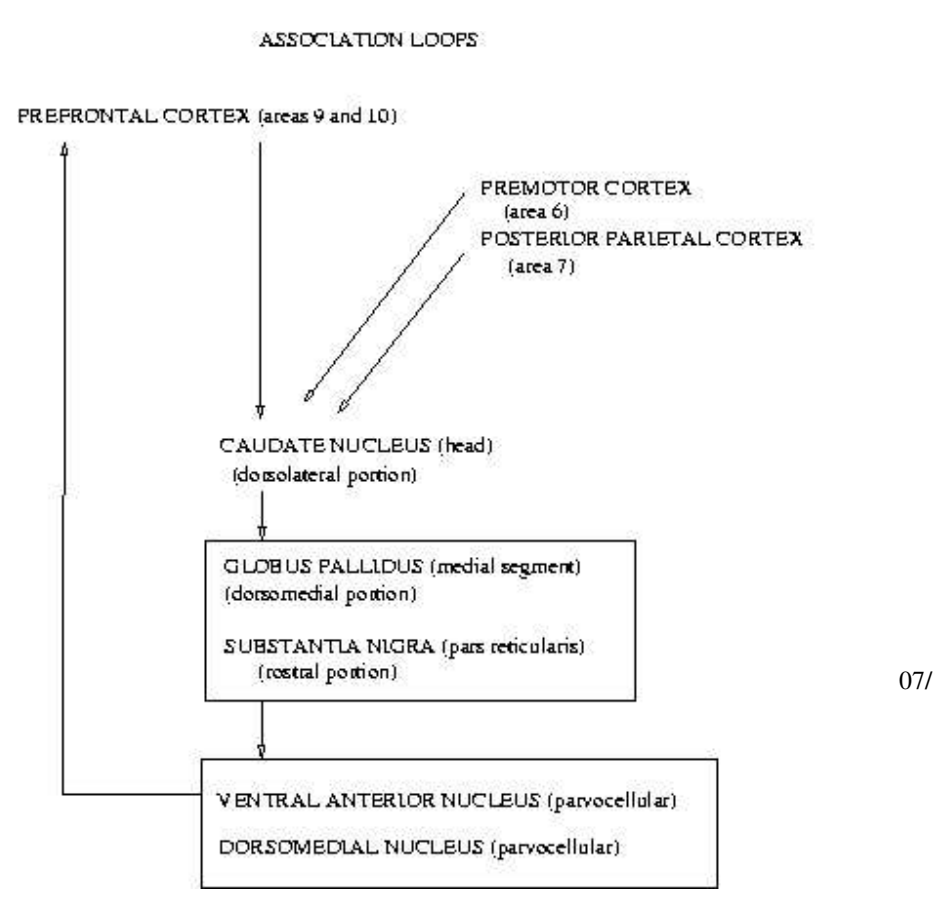
(ii) the oculomotor loop, corresponding to routine eye movement

(iii) the association loop, corresponding to routine planning, and

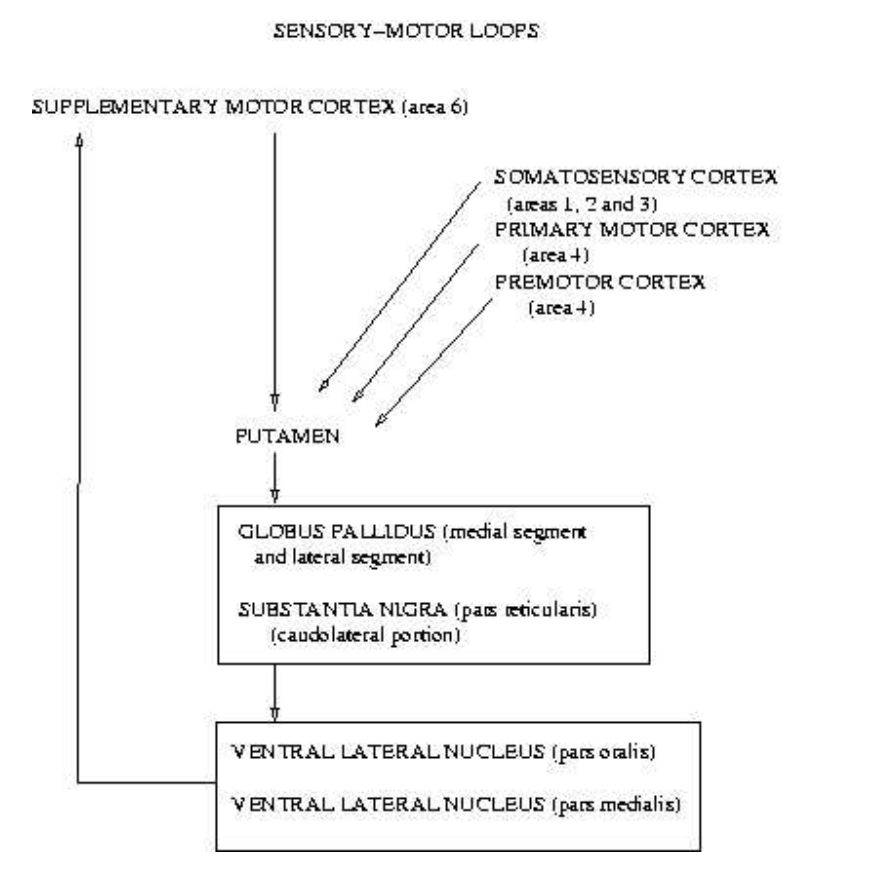
(iv) the limbic loop, corresponding to routine goal setting.

The figures are from Charles R. Noback, Normal L. Strominger, and Robert J. Demarest. *The human nervous system: introduction and review* Lea and Febinger, Philadelphia, 1991, pp. 385-388.

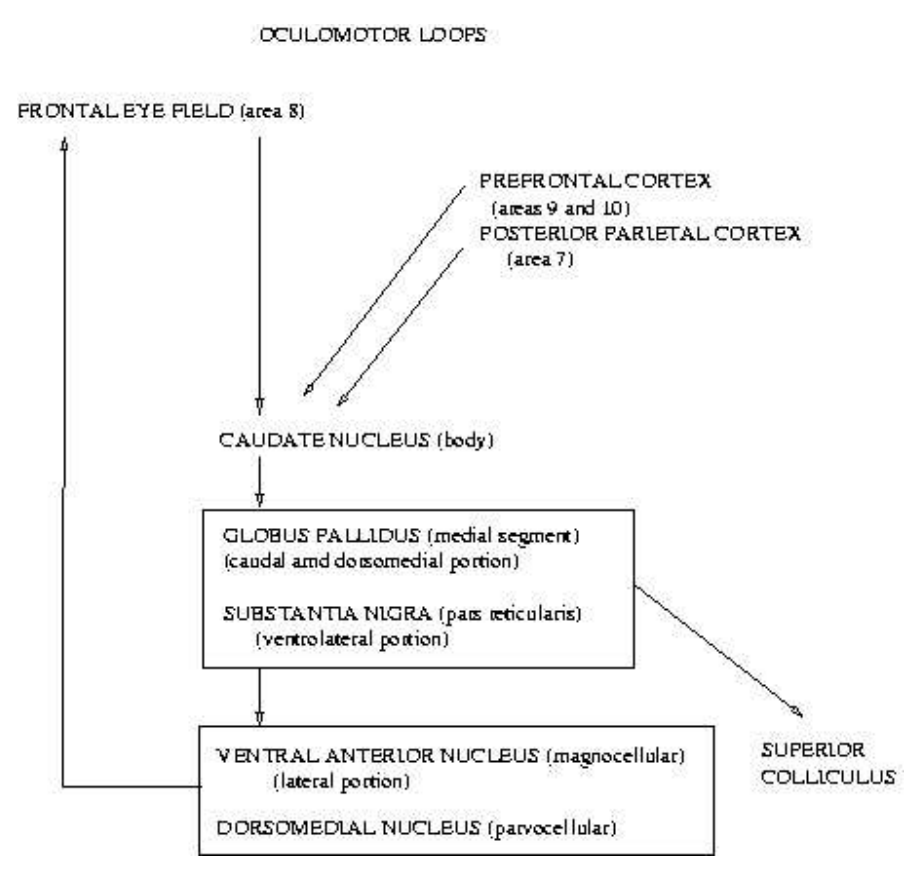
Basal ganglia - association loop



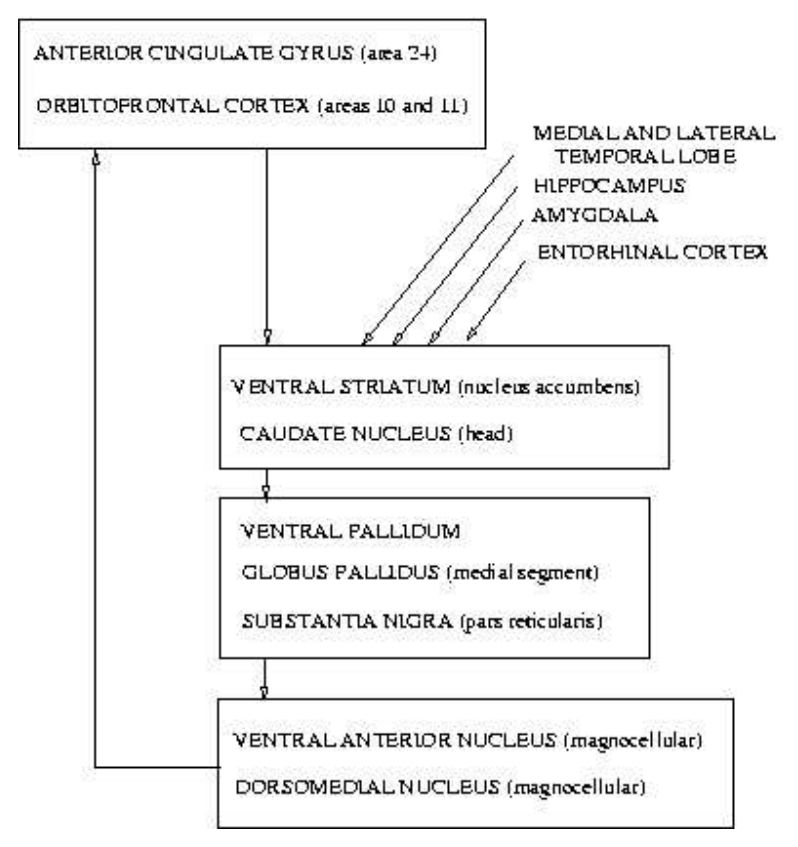
Basal ganglia - sensorimotor loop



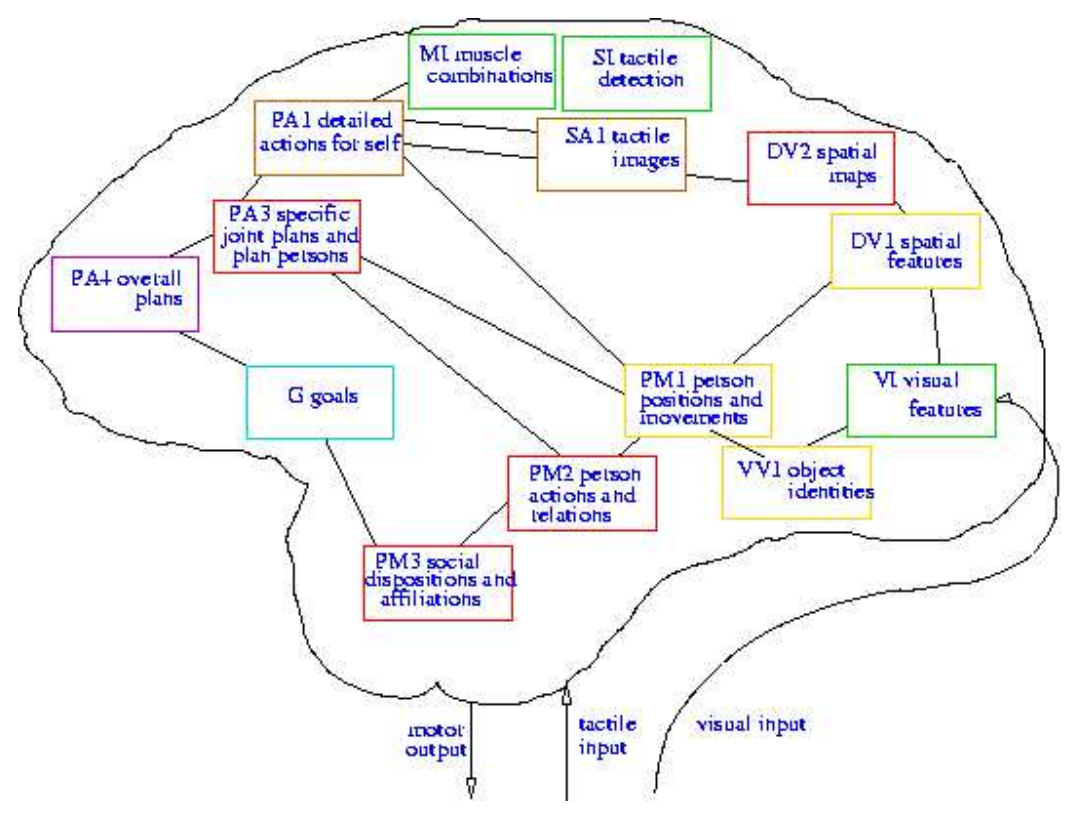
Basal ganglia - oculomotor loop



Basal ganglia - limbic loop

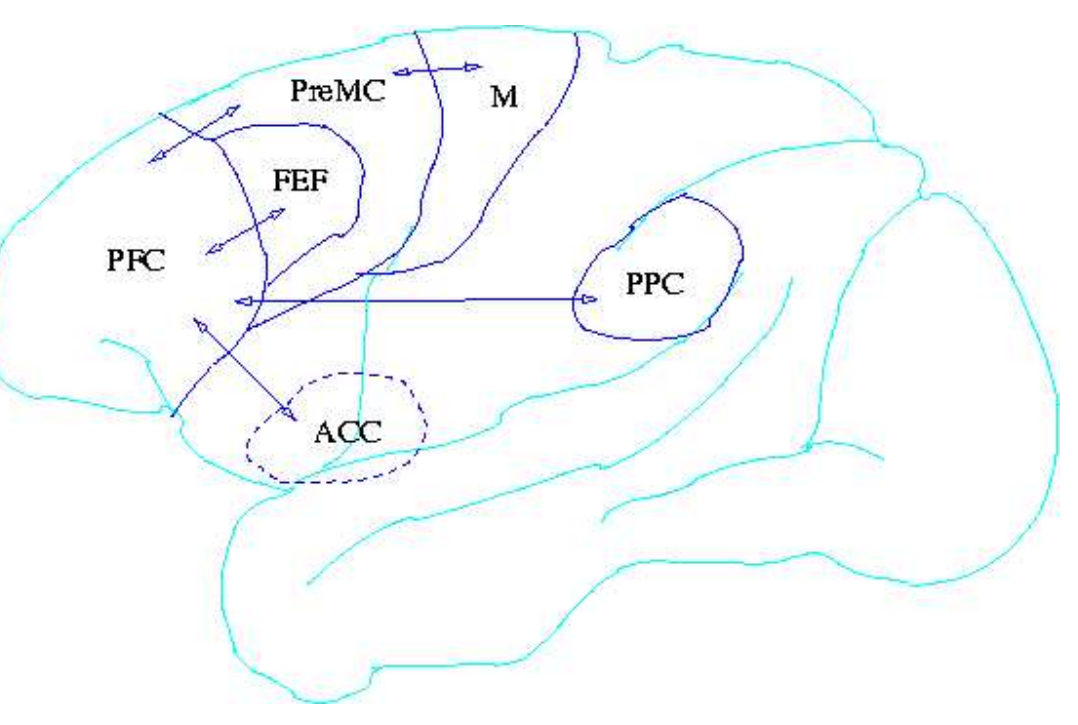


Our system model of the neocortex

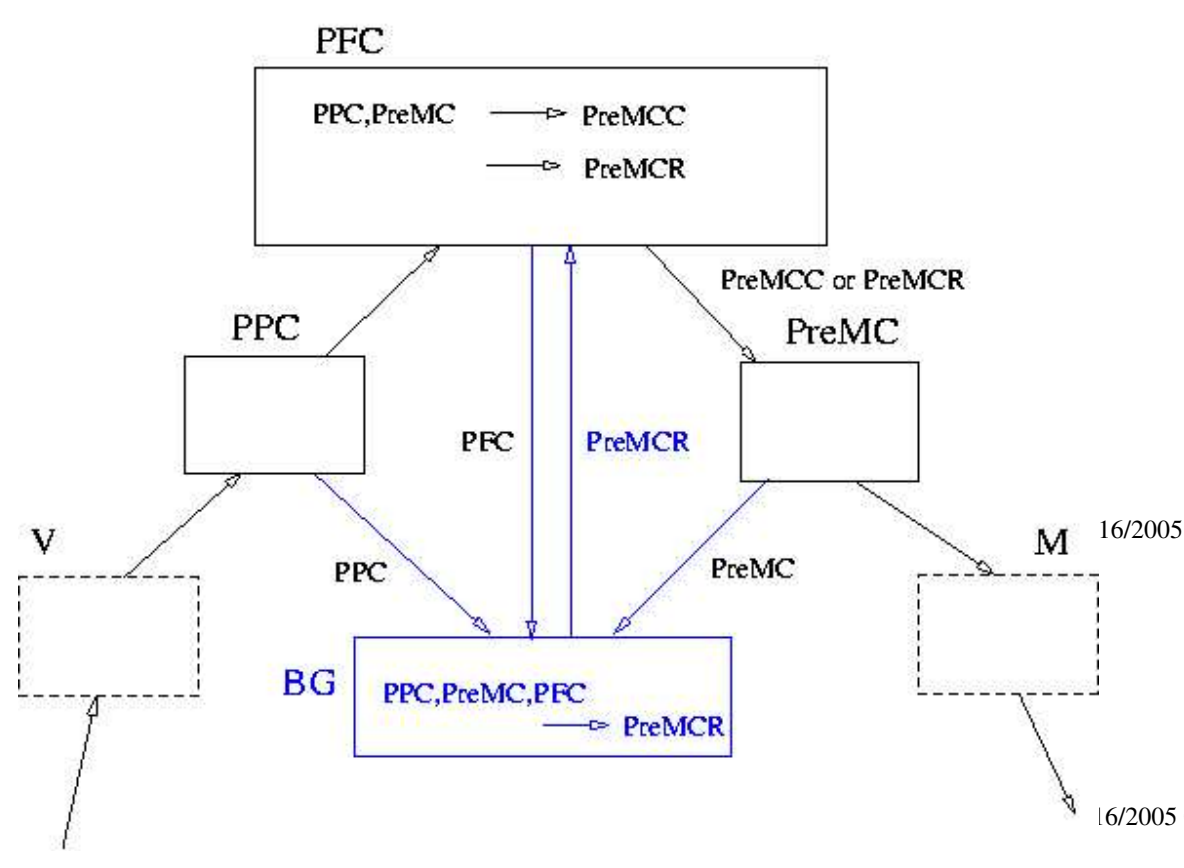


Loops and the neocortex

Cortical areas involved in association loop



Association loop mechanism in relation to cortical perception-action hierarchy



Our proposed mechanism

We can define the *source areas* for the association loop to be premotor cortex, posterior parietal cortex and prefrontal cortex, and the *target area* to be the prefrontal cortex. These areas can arguably be seen as being involved in preparation of higher-level information to be sent to the main output area of the loop, i.e. the prefrontal cortex.

Using our prior analysis of cortical neuroanatomy, we see that, in general, for all four loops, for each connection from the cortex or other area to the basal ganglia there is a direct cortical connection to the target area. Thus each basal ganglia loop forms a connection system which runs parallel to part of the cortical connection system.

So what are the members of the association loop typically doing?
(i) PPC, the posterior parietal cortex is concerned with visual perception to create nonegocentric maps.
(ii) PreMC, the premotor cortex generates descriptions of motor actions at the intention and coordinate level.
(iii) PFC, the prefrontal cortex, generates plans and actions at the relation level. One could write the association as:
if PPC and PreMC and PFC then PFC
so this assertion is upwards, from more concrete towards more abstract information.

Thus we conclude that the basal ganglia build a plan based on lower level inputs and outputs. The end result is rules in the basal ganglia and also for example PFC, of the general form:
(a) in the basal ganglia:
if PPC and PreMC and PFC then PreMCR
and (b) in PFC
PreMCR is a possible action.

Interleaving

What we intend by this notation is that the basal nuclei generate the suggested routine action PreMCR for PreMC, but they do not send it to PreMC, but instead to PFC for permission.

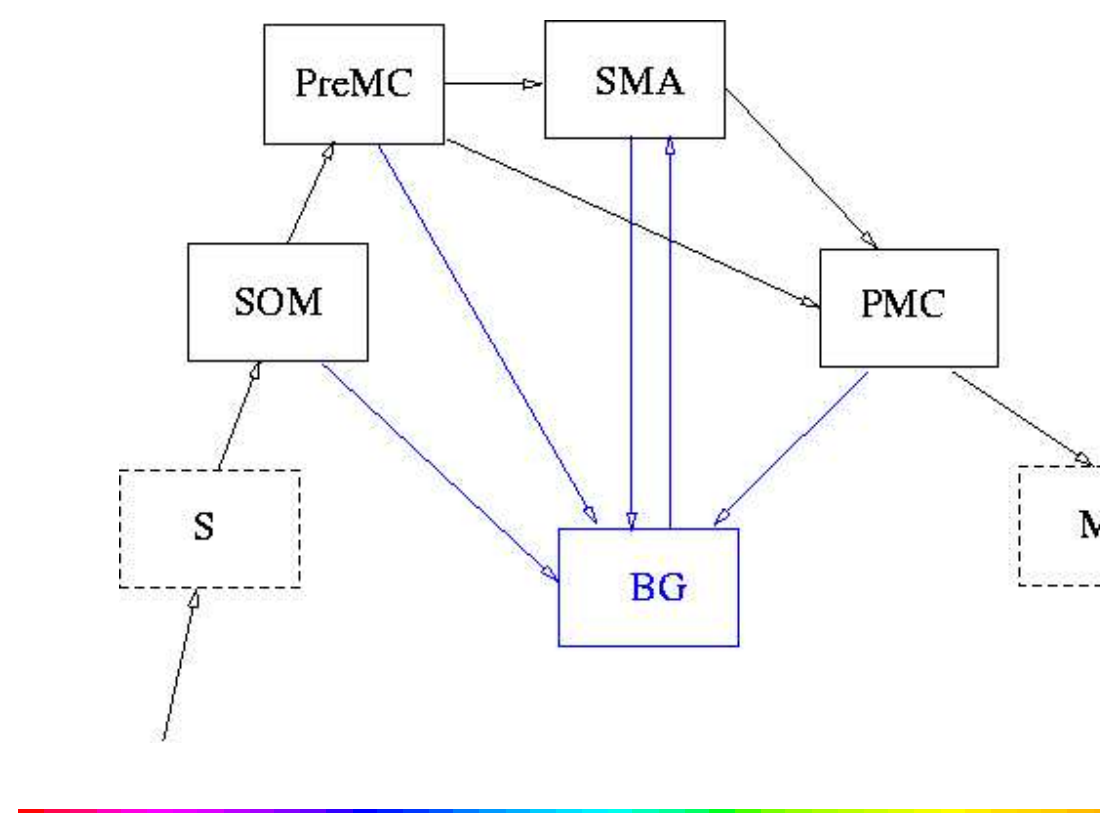
PFC may have an alternative creative action PreMCC to send to PreMC, however it can perform logic to make a decision between sending PreMCC or PreMCR to module PreMC.

Thus according to this theory the upper module is the regulator or controller of the routine action.

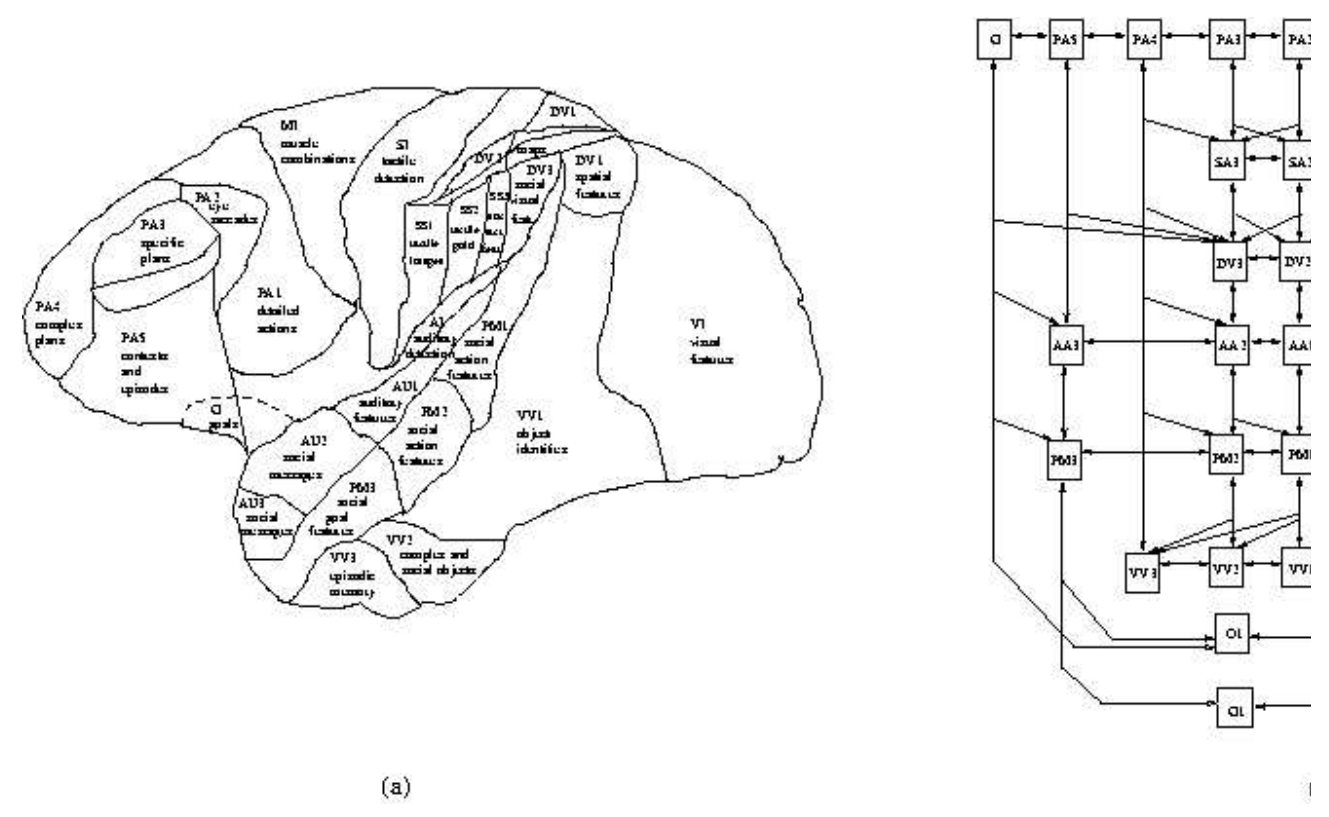
One main consideration is that in situations warranting routine action, this can proceed quickly. Thus PFC would simply select PreMCR without doing any or much computation.

This is to allow a rapid stream of actions to be generated by the basal ganglia and sent to module PreMC.

Sensorimotor loop mechanism in relation to cortical perception-action hierarchy

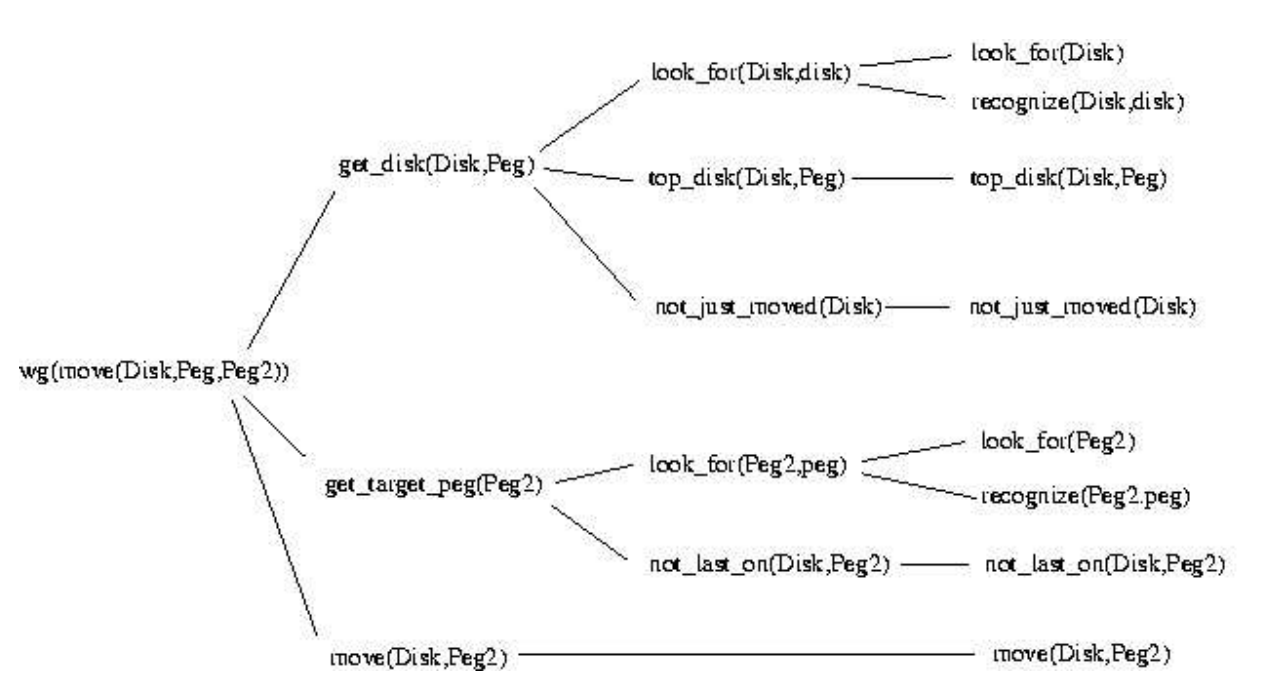


The perception-action hierarchy of the neocortex



Example - the Tower of Hanoi

Tower of Hanoi selection strategy as a cortical plan



The Tower of Hanoi creative action

We show in the figure the plan for the selective search strategy for solving the Tower of Hanoi problem, which tends to be used initially by naive subjects.

This is actually represented in the associative memory of the planning module as a set of descriptions (or codes):
(wg(move(Disk,Peg,Peg2)),[get_disk(Disk,Peg),get_target_peg(Peg2),move(Disk,Peg2)])
(get_disk(Disk,Peg),[look_for(Disk,disk),top_disk(Disk,Peg),not_just_moved(Disk)])
(get_target_peg(Peg2),[look_for(Peg2,peg),not_last_on(Disk,Peg2)])
(move(Disk,Peg2),[move(Disk,Peg2])
and so on.

We are thus assuming that the planning module has
(i) descriptions (or codes) representing the information in each plan component,
(ii) a neural circuit mechanism for association, given a key, to activate the corresponding plan description, and
(iii) a neural circuit mechanism sequencing through a list of descriptions, activating one, waiting for completion, then activating the next.
When a description is generated, it may be sent to another module, such as premotor cortex, frontal eye fields, or the hippocampus.

The Tower of Hanoi routinization

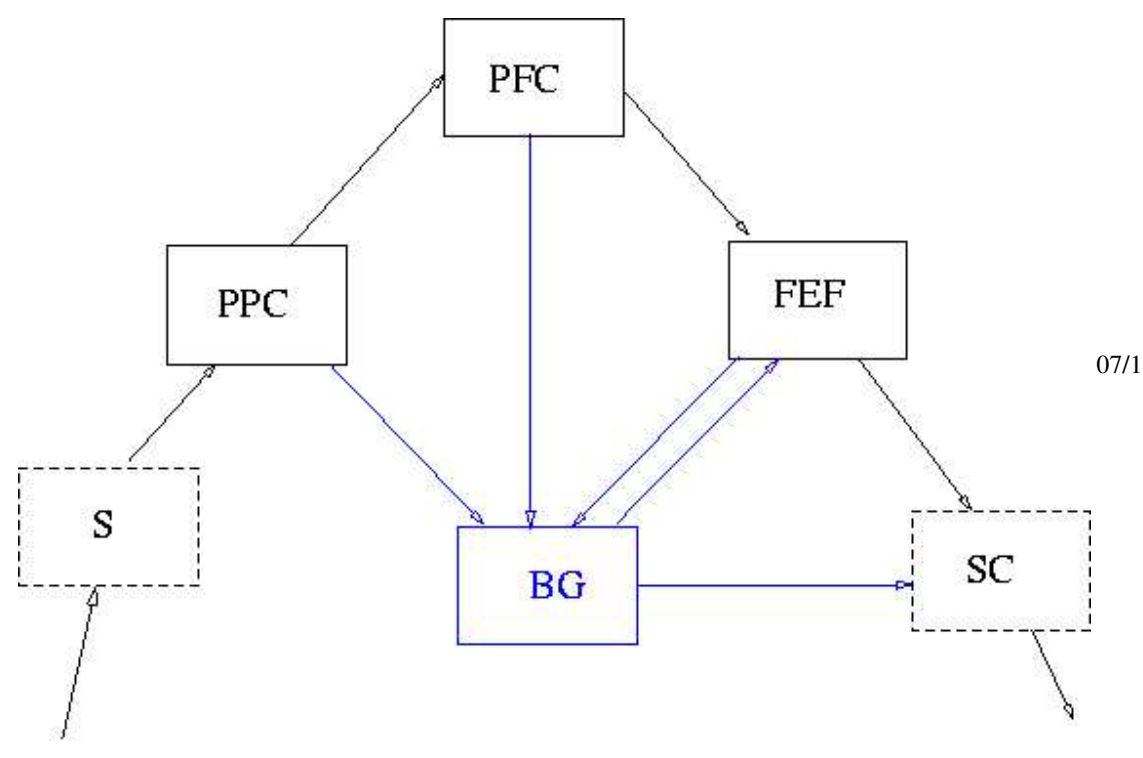
Initially, a search would take place, resulting in moving disk 1 from peg 1 to peg 2. If this is repeated and reinforced, then a routine form could be developed by the basal ganglia:
move(Disk,Peg,Peg2) -> [get_disk(1,1),get_target(2), move_disk(1,2)]
i.e. the basal ganglia would generate these codes in turn and send them to the planning module.

There could also be an oculomotor routines; by look_for(Disk,disk) we mean a description which is sent to parietal and FEF areas to generate a saccade to a given object and to recognize if it is a disk or not:
look_for(Disk) -> [lookfor(1),recognize(1,disk)]
top_disk(Disk,Peg) -> [top_disk(1,1)]
look_for(Peg2,peg) -> [lookfor(2),recognize(2,peg)]
There could also be a sensorimotor routine; by move(Disk,Peg2) we mean a description sent to premotor cortex to generate a physical movement:
move(Disk,Peg2) -> [move(1,2)]

Then when the working goal wg(move(Disk,Peg,Peg2)) is activated in the initial context, the basal ganglia would generate the sequence.
The cortical mechanism would compare the two possible choices (creative) get_disk(Disk,Peg) (routine) get_disk(1,1) and would choose the latter.
When the latter is complete, the cortical mechanism would sequence to the next action, i.e., get_target_peg(Peg2) or get_target_peg(2), and so on.

There will be different levels of routinization. The one illustrated here is the choice of a subset or a single individual from alternatives. A further level is to eliminate checks, so get_disk(1,1) would not be visually checked, or checked in episodic memory as not just moved.
Eventually, one could reach a fully routinized form move(Disk,Peg,Peg2) -> move(1,2) without any checks.

Oculomotor loop mechanism in relation to cortical perception-action hierarchy



Center for Cognitive Phenomics at UCLA Neuropsychiatric Institute

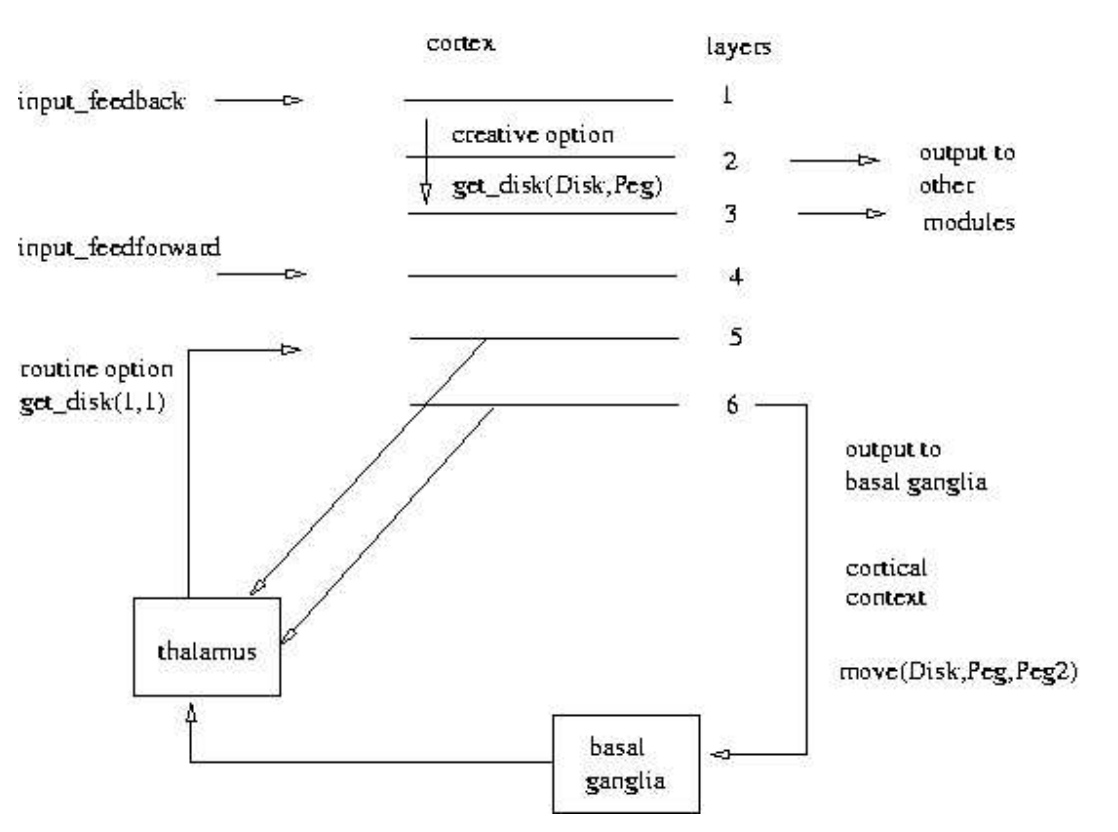
Cognitive Phenotyping for Neuropsychiatric Therapeutics

Principal Investigator: Robert M. Bilder, Ph.D. E-mail: rbilder@mednet.ucla.edu

The exploratory Center for Cognitive Phenomics (CCP) aims to accelerate identification and efficient measurement of cognitive phenotypes across syndromes and across species to advance interdisciplinary research on neuropsychiatric therapeutics. Cognitive abnormalities have been identified in all major neuropsychiatric disorders, offer quantitative phenotypes for genomic studies and clinical trials, and provide strong bridging relations to neural systems models. The CCP will iteratively refine cognitive phenotypes in interdisciplinary research using neurobehavioral, neuroimaging, and neuropsychopharmacological approaches to provide translational validation of physiological endophenotypes. The CCP will coordinate activities of a large group of experts at UCLA and elsewhere to: 1.) Generate cross-disorder and cross-species catalogs of phenotypes; 2.) Develop a phenotype selection algorithm to identify the most promising candidates for research; 3.) Design a phenomics database for empirical data representation, data mining, and hypothesis testing; and 4.) Support proof-of-concept pilot projects. To advance these aims, the CCP will initiate core services for: High-Throughput Cognitive Phenotyping; Neuroimaging; and Translational Neuropsychopharmacology. The CCP will initially leverage UCLA campus-wide resources to provide bridging infrastructure and expertise in: Genomics, Pharmacogenomics, and Statistical Genetics; Biostatistics and Psychometrics; Bioinformatics; Clinical Trial Design and Regulatory Affairs; and Bioethics. The CCP aims to overcome bottlenecks in the discovery of treatments for neuropsychiatric syndromes that are caused by the use of traditional behavioral "symptom" phenotypes, which are heterogeneous, overlapping, and difficult to translate to basic research. The long-term goal is establishment of a mature CCP that will provide the international research community with efficient, well-validated phenotype assays; a cognitive phenomics data repository linked to genomics, proteomics, and other biological knowledge-bases; and novel strategies for interdisciplinary research on neuropsychiatric therapeutics.

A possible role for the thalamus

A possible role for the thalamus



A possible role for the thalamus

Interleaving.
The planning module has to retain *supervisory control* (Sheridan 1992) over routinized action. In situations requiring full evaluation of the proposed course of action, the system might have to reach a viable state, which could take 300 milliseconds. Routine action, on the other hand, can be used for faster actions such as steering a bike. The phenomena of action slips show how action breaks at the boundaries between these two modes of action.

Neural circuitry and the thalamus
We show in the diagram the cortical layers and the connections involved in our scheme.
Most of the thalamus is concerned with receiving a wide range of sensory, subcortical and cortical inputs and sending outputs to the cortex.
It is only the limited parts, mainly the ventral group of thalamic nuclei that are involved in the basal ganglia loops and receive inputs from the globus pallidus and substantia nigra.

A possible role for the thalamus
This suggests a possible role for the thalamus, namely that it could help regulate the rapid flow of routine action, so that once a routine course of action is selected by the neocortex, the stream of routine actions can flow faster than cortical decision speeds. The cortex would send a message to the thalamus allowing it to let this stream through.
Before this, while the cortex is monitoring and deciding on selecting a routine action, the thalamus would prevent this rapid flow.

Conclusions

Summary and conclusions

In this paper, we first discussed the nature of routine and creative action, and that control decisions should be made in cortical planning modules.

We then discussed the basal ganglia loops and mapped these onto our system-level brain model.

We then discussed how initiation, monitoring and control of routine action could be achieved by providing the planning module with the ability to monitor a stream of routine action descriptions, and to allow this to flow or else to instead make creative actions.

We finally outlined in a neural level of description how different cortical layers and the thalamus might be involved in routinized mental action.

Limbic loop mechanism in relation to cortical perception-action hierarchy