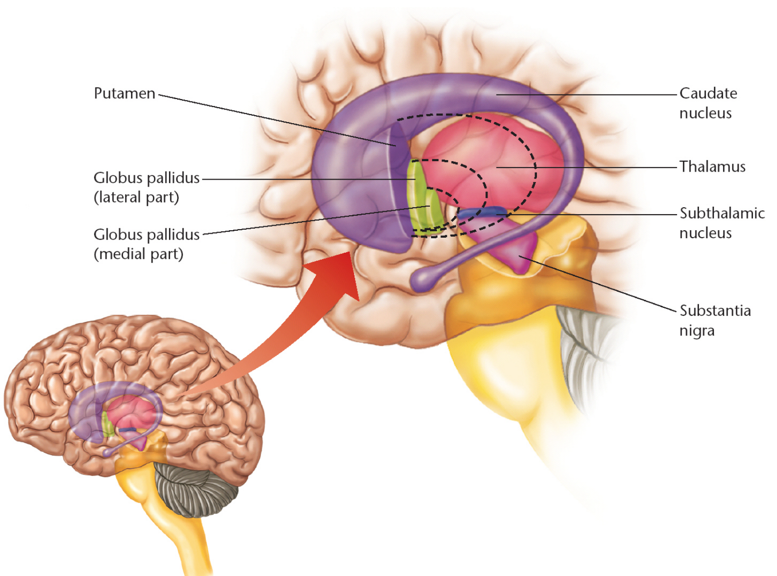
Basal Ganglia

- Shepherd (2004) Chapter 9
- Charles J. Wilson
- Instructor: Yoonsuck Choe; CPSC 644 Cortical Networks

Introduction

- A set of nuclei in the forebrain and midbrain area in mammals, birds, and reptiles.
- Most prominent forebrain subcortical telencephalic structure in many species.
- No direct connection to sensory/motor organs, and has been difficult to assign a specific functional role.
- Damage leads to severe deficits of movement. Parkinson's disease (hard to make movement). Huntington's disease (erratic interfering movements). Affects voluntary/purposive motion, and spares reflexive movements.

Basal Ganglia at a Glance

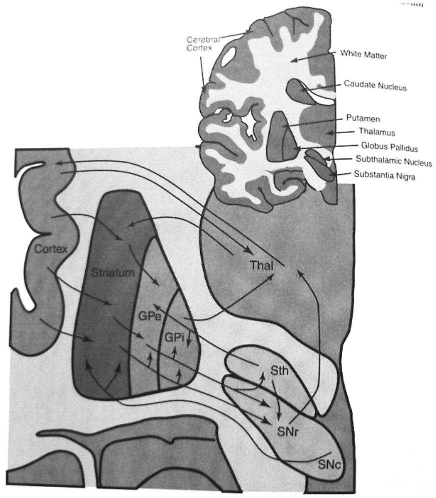


http://cti.itc.virginia.edu/~psyc220/kalat/JK246.fig8.15.basal_ganglia.jpg

Role of the BG

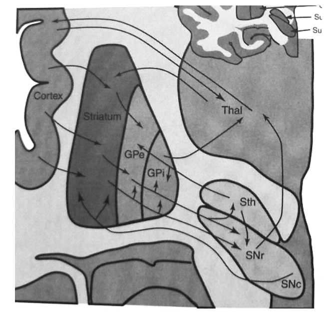
- Involvement in the generation of goal-directed voluntary movement.
- Current views suggest a more general role in selection of movement, goals, strategies, and interpretation of sensory information.
- Selection made based on the past history of success in similar circumstances.

Connections to and from BG



- Linked to sensory, motor, cognitive, and motivational areas.
- Caudate nucleus, putamen, globus pallidus, substantia nigra, and subthalamic nucleus.

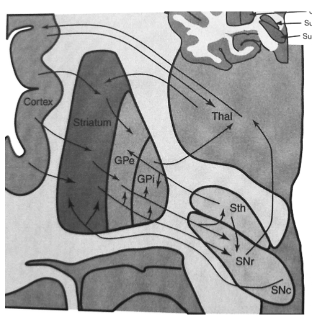
Input Connections to BG



Received in neostriatum (caudate, putamen, nucleus acumbens)

- Cortex: sensory, motor, and association areas.
- Thalamus: intralaminar nuclei
- BG: domapinergic inputs from substantia nigra, serotonergic from dorsal raphé nucleus, and from the basolateral nucleus of the amygdala

Output Connections from BG

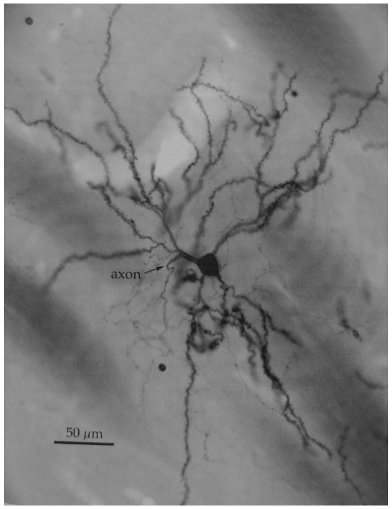


- Neostriatum to other BG structures: GPe, GPi, pars reticulata of SN, etc.
- GPi and SNr project outside of BG (all are inhibitory):
  - $\longrightarrow$ ventral tier thalamic nuclei $\longrightarrow$ frontal cortex
  - lateral habenular nucleus and deep layers of superior colliculus
- GPe projects to subthalamic nucleus (input from cortex, sends to GPe/i).

Major Pathways in BG

- Input: to mostly neostriatum.
- Projections from neostriatum:
  - Direct pathway: direct projection to GPi and SN, modulating BG output directly.
  - Indirect pathway: projection to GPe only.
  - Reciprocal connections between BG components.

Neuronal Elements of BG (I)



- Principal neurons: spiny dendrites (trunk diameter 2–3 μm), 12–20 μm soma, 300–500 μm arbor. Form the direct pathway.

Neuronal Elements of BG (II)

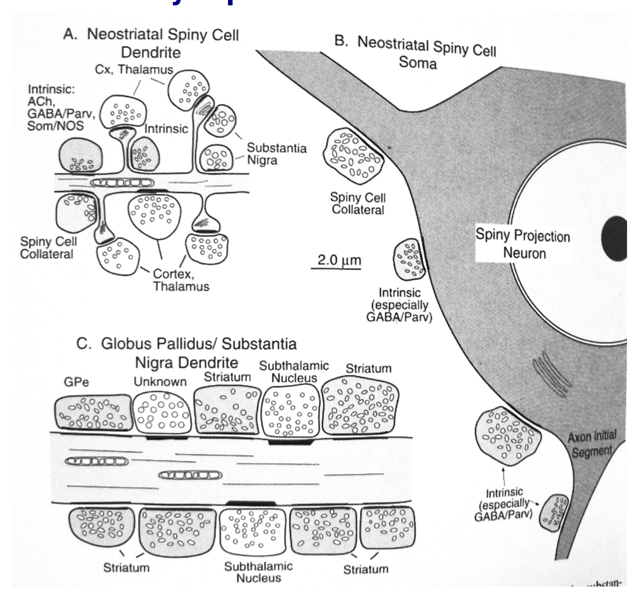
Interneurons: many different kinds, but overall very scarce in NS.

- Cholinergic interneurons
- GABA/Parvalbumin-containing interneurons
- SOM/NOS-containing interneurons

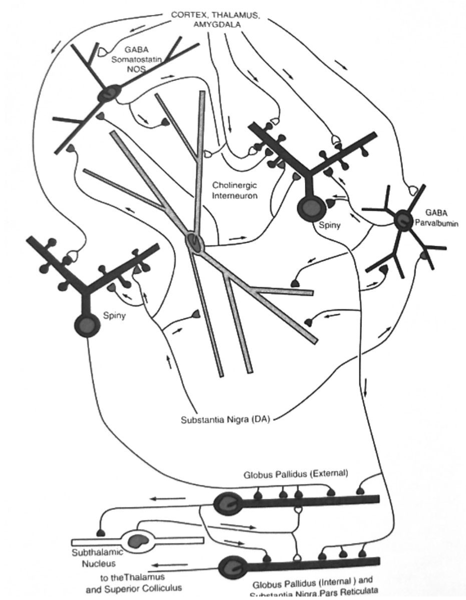
Cell Populations

- 100 million neurons in human NS.
- 2.8 million neurons in rat NS.
- 11,000 afferent synapses (originating from cortex and thalamus) on NS cells in rats.
- Single cortical axon can innervate 1% to 15% of the volume in NS. This results in very sparse connections: near-by neurons in NS do not receive input from the same cortical axon.
- Most spiny neurons are electrophysiologically silent most of the time.

Synaptic Connections

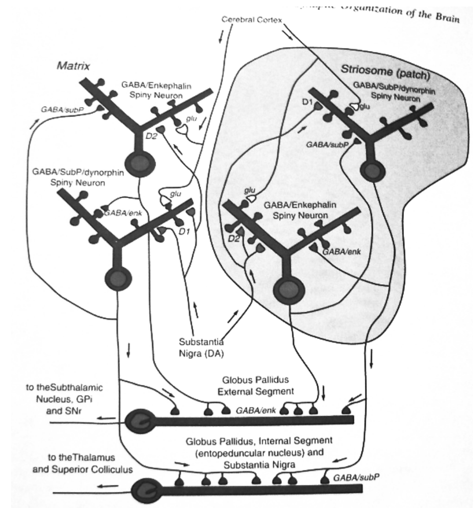


Basic Circuit (I)



- GABA/SOM/NOS interneurons: inhibitory
- Cholinergic interneurons: modulatory
- GP: tonic firing at high rates, exerting constant inhibition on the targets (thal, SC, etc.)
- Spiny cells: inhibitory (disinhibits GP targets!)

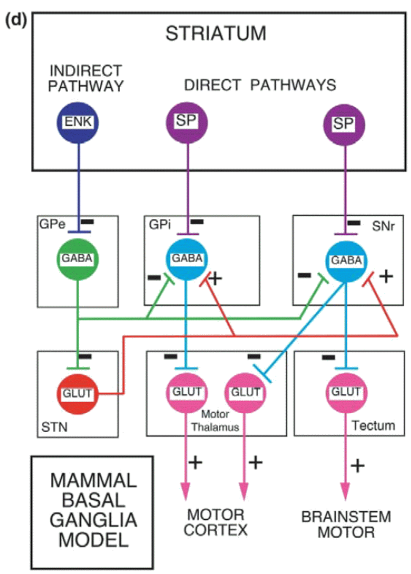
Basic Circuit (II)



Striosomes (patches) vs. matrix

- Cortical projections preferentially project to one or the other.
- They project to different targets: stirosomes $\longrightarrow$ SNc (dopaminergic neurons), matrix $\longrightarrow$ SNr (nondopaminergic proj. to thal and SC).

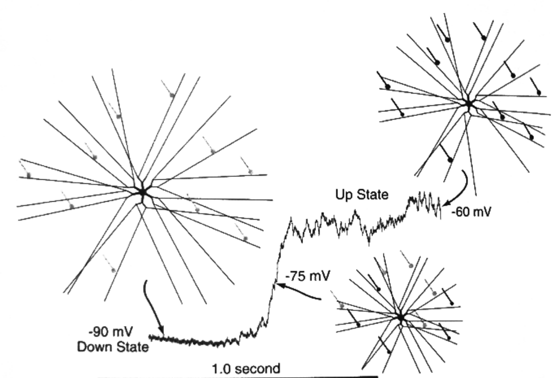
Direct vs. Indirect Pathway



- Direct: projects to GPi and SN
- Indirect: projects to GPi

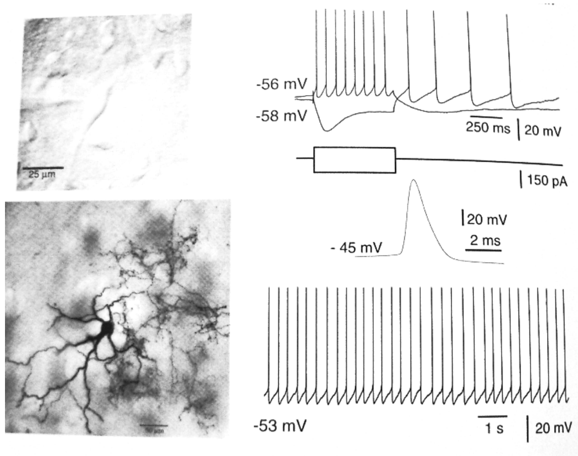
Doupe et al. (2005) *Trends in Neurosci.* 28:353–363.

Change in Electrotonic Length



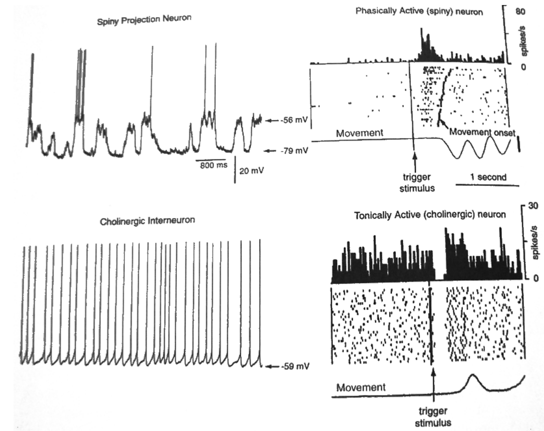
- Up state and down state, depending on membrane voltage.
- Membrane voltage determines effective electrotonic length of dendrites.

Cholinergic Neurons



- Different firing mode for depolarizing or hyperpolarizing input.
- Slow action potential.
- Spontaneous firing in the absence of input.

Functional Operations

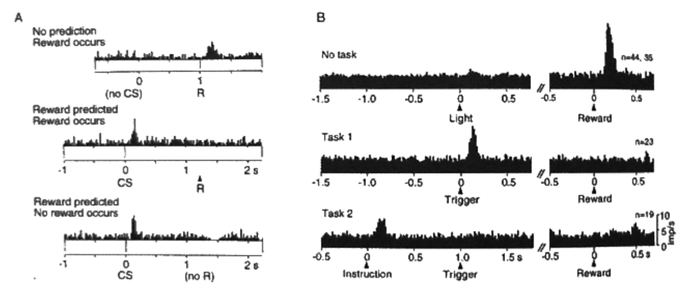


- Neostriatal spiny neurons: mostly silent. Short bursts, locked to the onset of movements. Firing happens in prolonged up-state.
- Cholinergic neurons are like pacemakers.

Complex Integrative Tasks

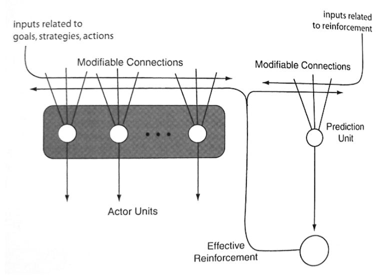
- NS as “detectors of specific cortical activity pattern that represent candidate movements, goals, strategies, or interpretations of sensory patterns.”
- Convergence of cortical and thalamic inputs based upon functionally similar rather than spatially proximal.
- Learning of statistical patterns in cortical activity, and re-coding them.
- Some breakthrough discoveries: LTP and LTD in striatum depend on dopamine. Dopaminergic neurons fire in distinct pattern during learning.

Reinforcement Learning in BG



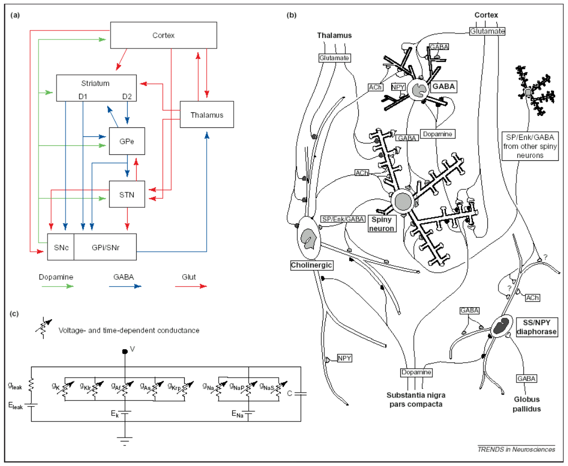
- “Dopaminergic neurons fire in response to the resolution of uncertainty about the prospects for reward.”
- The neurons fire when the animal recognizes an opportunity of reward following a behavioral sequence.
- Dopaminergic neurons respond to “earlier and earlier good predictors” of reward.

Actor-Critic Model



- Striatum may be learning to predict the “value” of various cortical/thalamic input patterns.
- Amygdala or frontal cortex input may signal reward.
- Actor-Critic
  - Neurons in matrix learn strategies associated with rewarded behavioral sequences (Actor).
  - Inputs to striosomes may signal reward: neurons in striosomes learn more accurate prediction of reward (Critic).

Some Other Models of BG



- “ ... conduct a reinforcement-driven dimensionality reduction that takes input from multiple sensory, motor, affective and cognitive sources, and relay compressed encoding of this information to areas of the brain involved in executive planning and selection of action.” [Bar Gad et al.]

Gurney et al. (2004) *Trends in Neurosci.* 27:453–459.