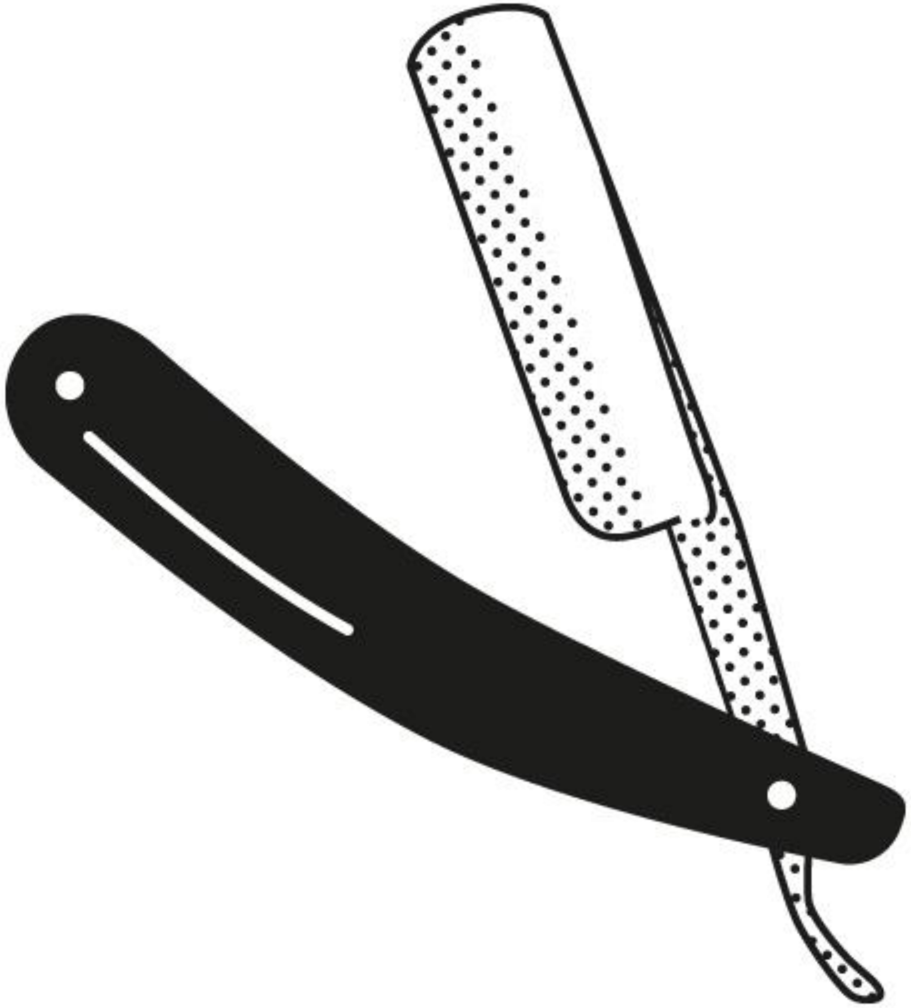
The Minimal Brain



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Objectives

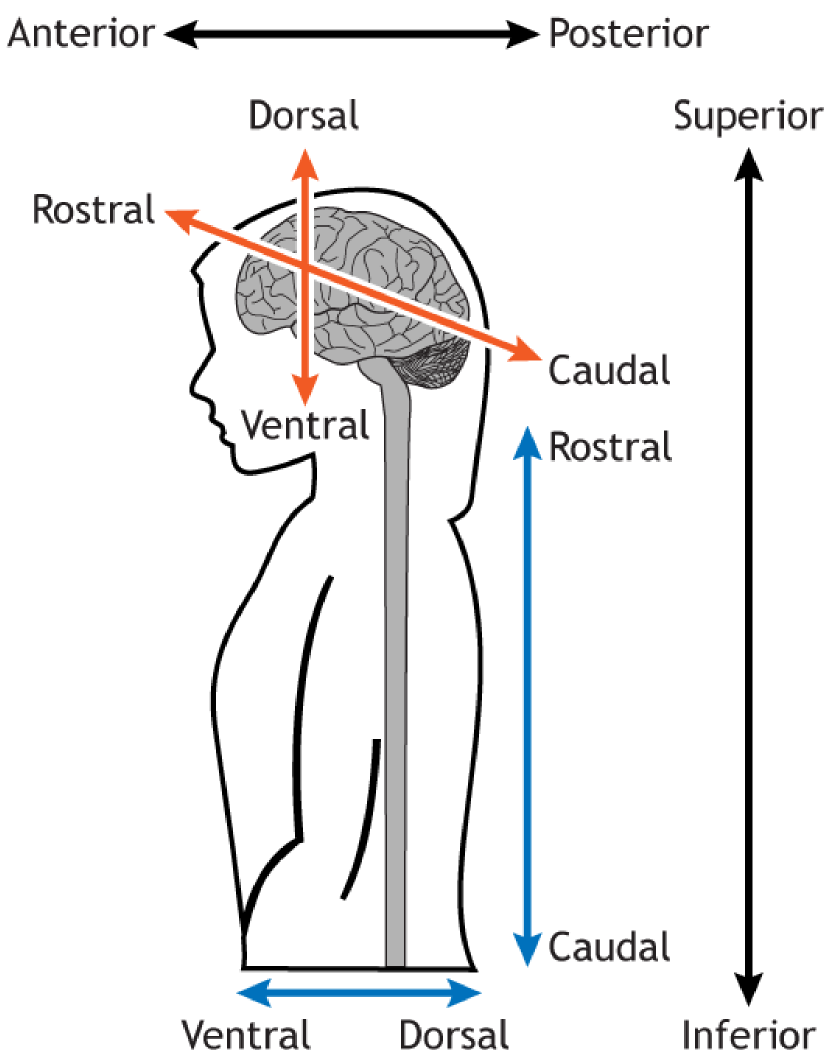
a) Understand the idea of a hypothetical “minimal brain”

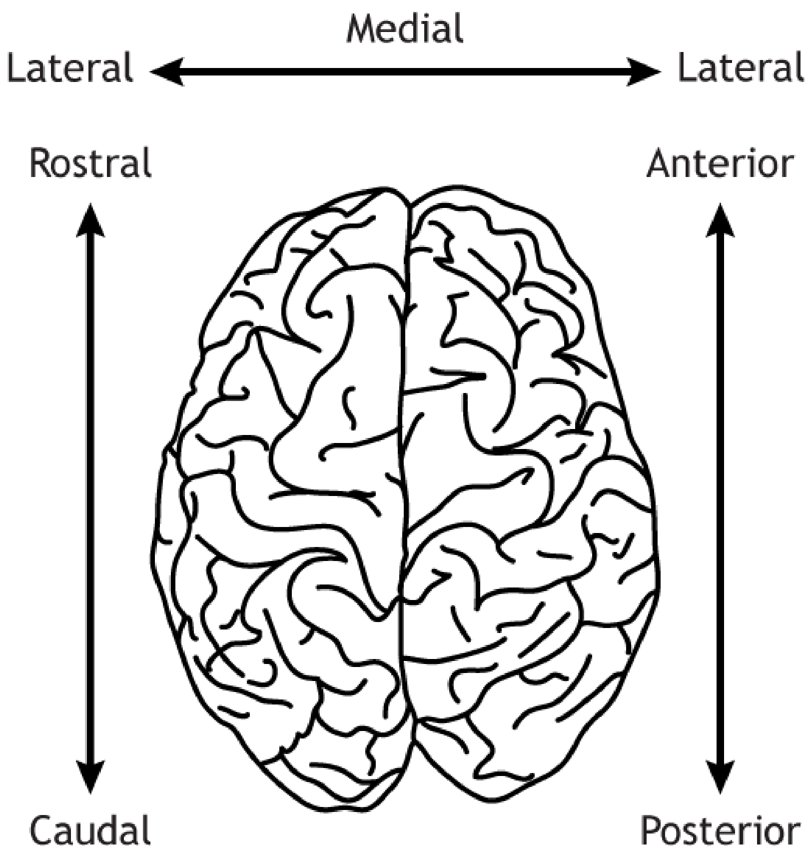
b) Understand that action flexibility necessitates uncoupling sensory and motor components

c) Review some brain regions/sectors and some functions to which they contribute

d) Demonstrate that a brain region needs to be situated in the context of multi-region circuits (i.e., *in combination* with other areas)

Anatomical Terminology





Contents

The Second Visual System

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The primary visual cortex (V1): the **occipital cortex**

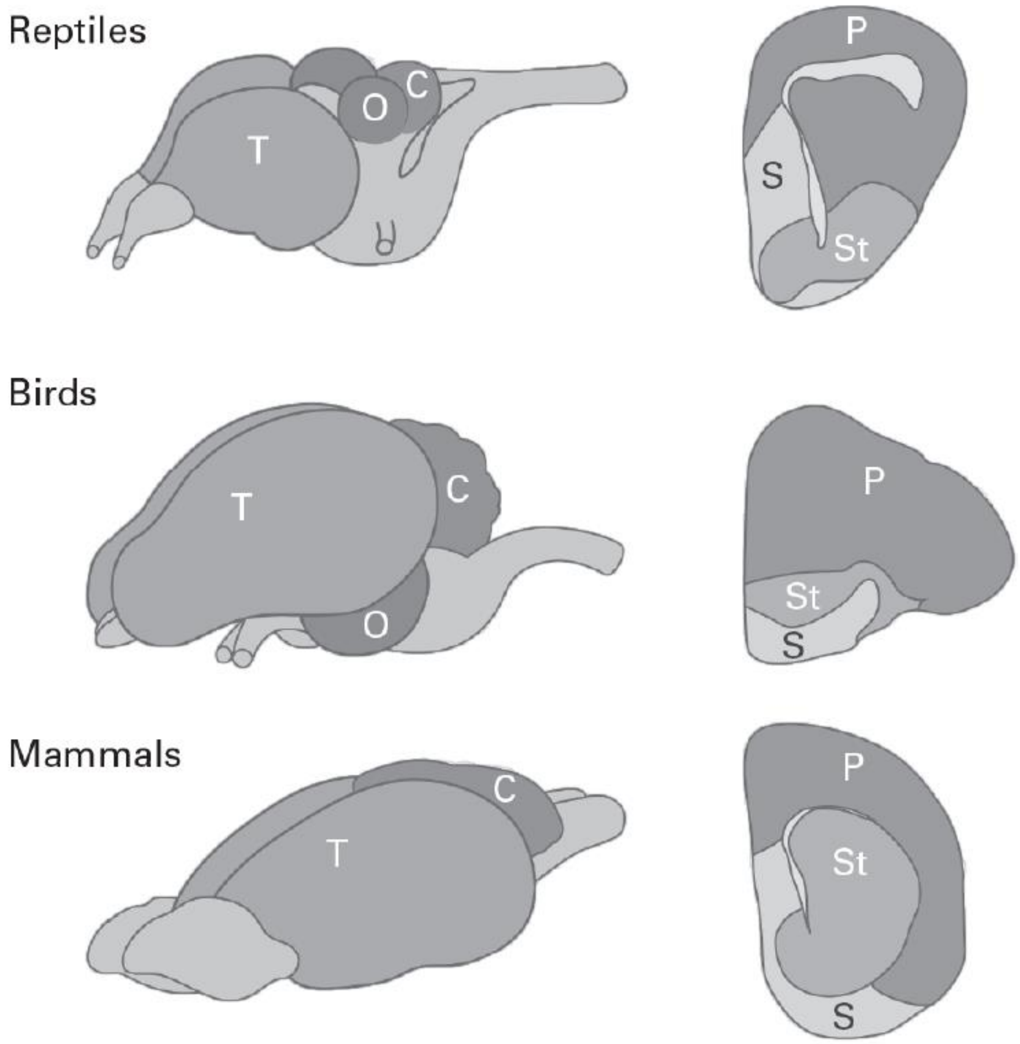
- 1880s: Experiments with dogs and monkeys
- Systematic study of clinical cases
- 1981, Hubel : how cells in V1 generate responses to respond to contours

The secondary visual system: the **superior colliculus**

- 1917, Riddoch: WWI combatants, visual cortex destroyed, could still see motion
- 1973: blind patients could see better than random guessing

The Superior Colliculus (SC) ⊂ Dorsal Midbrain

- Beautifully layered
  - o humans ~7 layers, lizards ~14 layers
- ***Optic tectum***: another word for superior colliculus in vertebrates (‘O’ in the figure)
- Retinal projections to the superior colliculus are ***topographic***
  - o i.e., preserves the spatial layout
  - o Cells in the colliculus form a map of the external visual space



The Superior Colliculus (SC) ⊂ Dorsal Midbrain

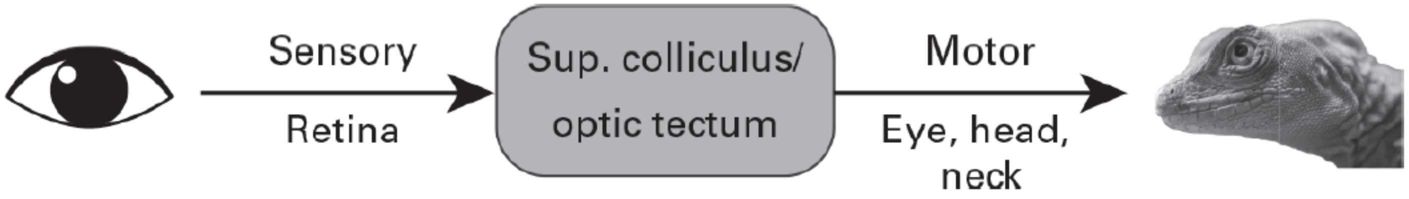
- Layers:
  - There is always a clear distinction between ***superficial layers*** (receive input from the visual system) and ***deeper layers*** (receives and projects to various motor-related areas)
  - The mammalian superior colliculus

Lamina I		Superficial Layers
Lamina II		
Lamina III	Consists of axons coming from the optic tract	
Lamina IV	Thickest layer (as thick as all the other layers together)	Intermediate Layers
Lamina V		
Lamina VI		Deep Layers
Lamina VII	Lies directly above the periaqueductal gray	

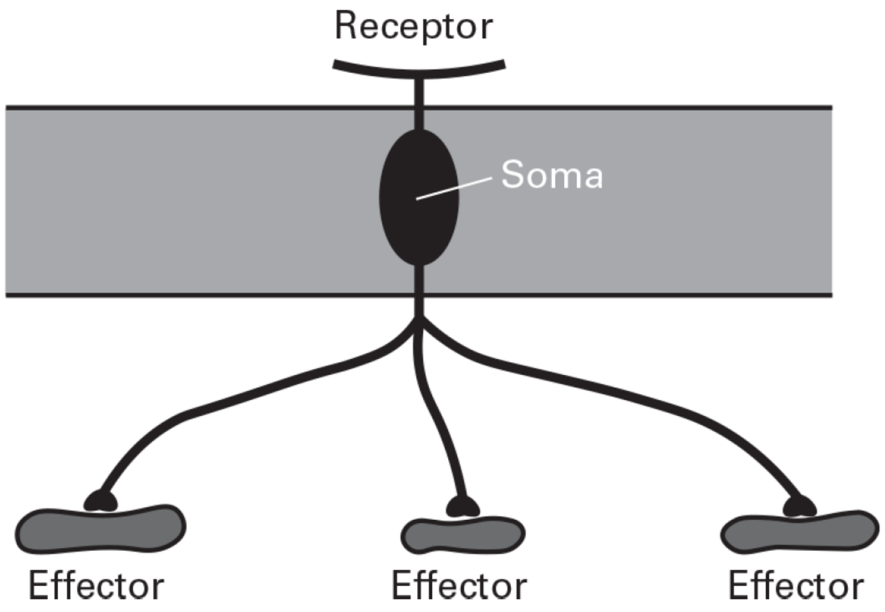
Sensorimotor Transformation

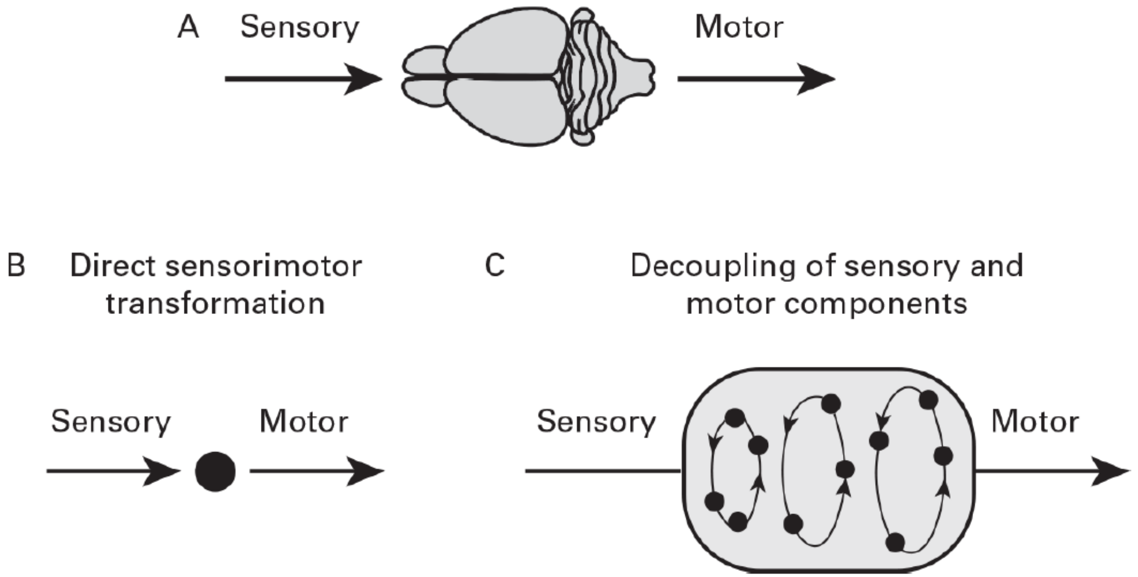
“Phrased differently, we can think of the brain, with all its different parts, as evolution’s solution to the ***problem of uncoupling inputs from outputs***. Without this flexibility, animals are bound to perish.”

Sensorimotor Transformation



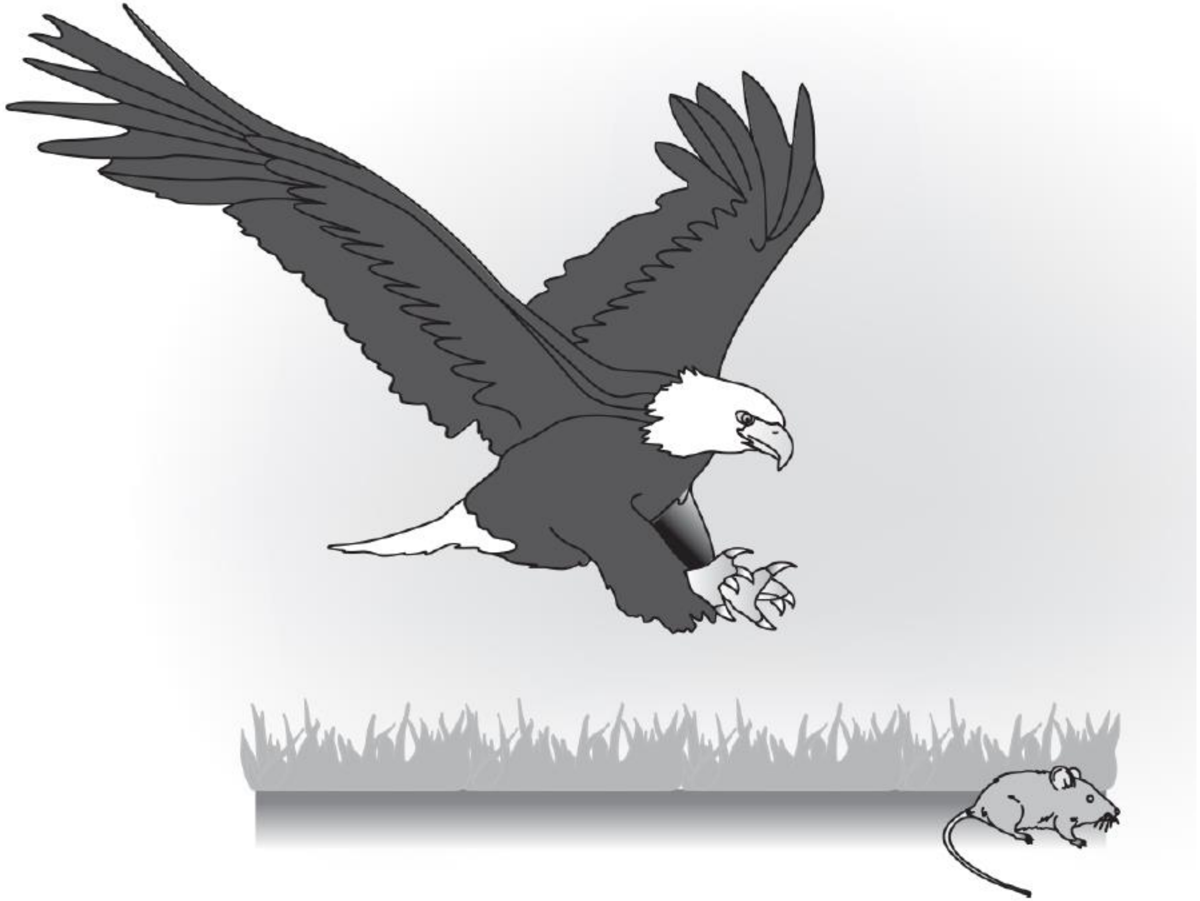
- Sensory stimuli (***receptor*** end) trigger motor responses (***effector*** end)
- Uncoupling input from output provides ***increased flexibility***.





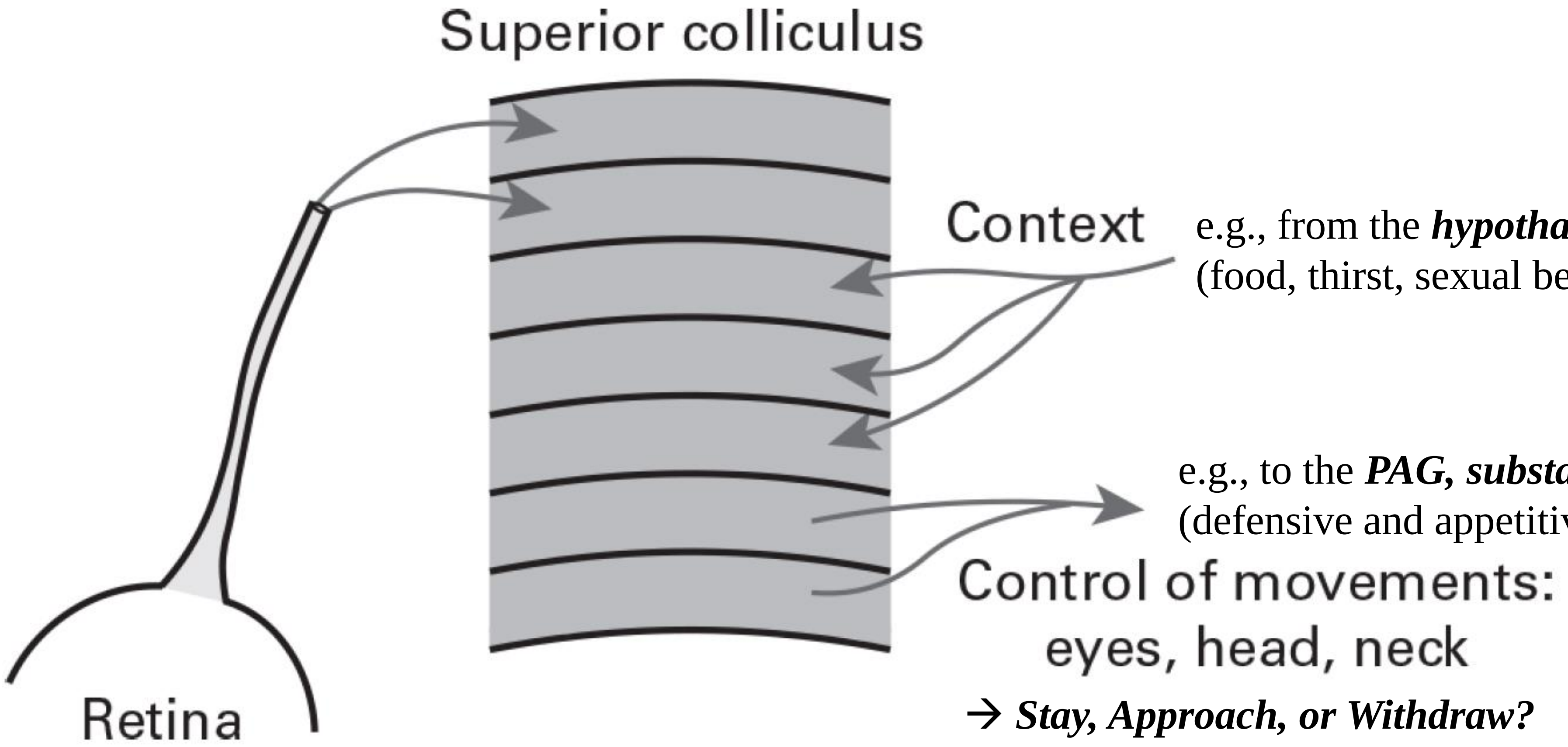
Keep course, Move away, or Move toward

- Small rodents: if unexpected movement is **overhead**, flee; otherwise, if movement is in the **lower field**, consider further exploration
- The **position** of the stimulus in the visual field plays an important role in its classification (as harmless, interesting, or emergency)



Context Sensitivity

Context Sensitivity (external and internal)



e.g., from the ***hypothalamus***
(food, thirst, sexual behavior,)

e.g., to the ***PAG, substantia nigra***
(defensive and appetitive behavior)

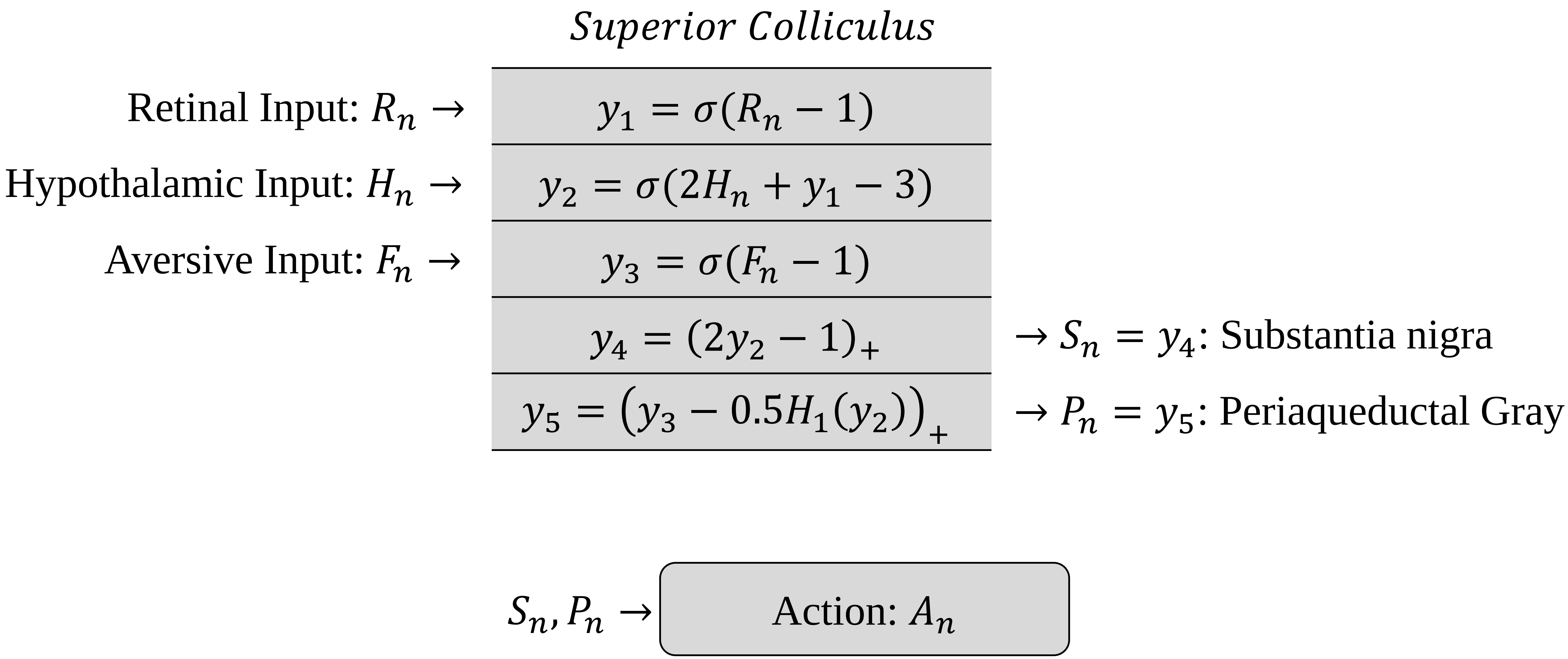
→ ***Stay, Approach, or Withdraw?***

Deep Neural Networks

- Use multiple linear layers with ***nonlinear activation function σ*** in between.
  - $\sigma \in \{\text{ReLU, Sigmoid, tanh, } \dots\}$
- The Multilayer Perceptron Model with L layers is a ***nonlinear mapping***: $x \mapsto y_L$

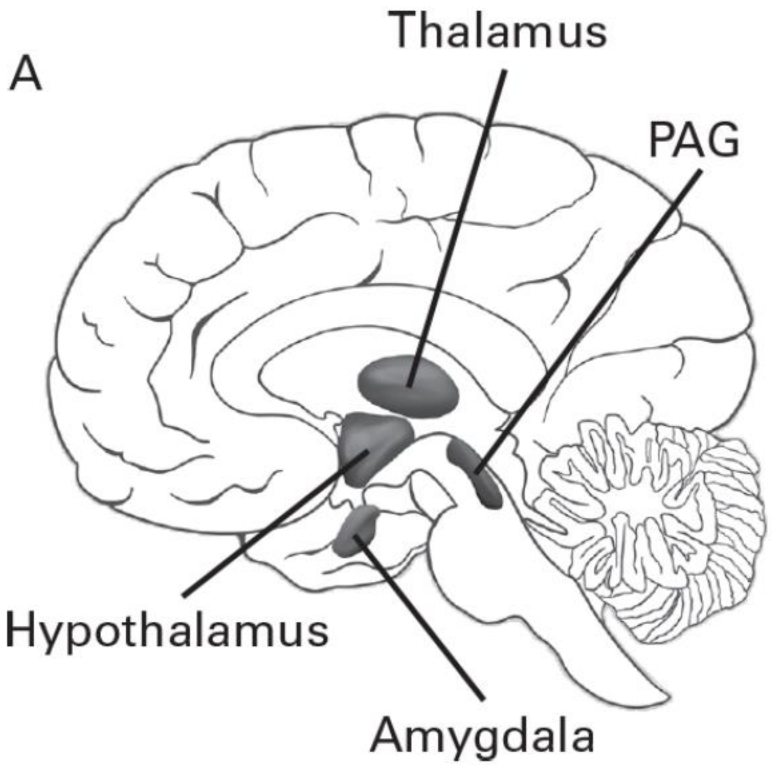
$$
\begin{aligned}
y_L &= W_L y_{L-1} + b_L && \in \mathbb{R} \\
y_{L-1} &= \sigma(W_{L-1} y_{L-2} + b_{L-1}) && \in \mathbb{R}^{n_{L-1}} \\
&\vdots \\
y_2 &= \sigma(W_2 y_1 + b_2) && \in \mathbb{R}^{n_2} \\
y_1 &= \sigma(W_1 x + b_1) && \in \mathbb{R}^{n_1}
\end{aligned}
$$

where $x \in \mathbb{R}^n, W_l \in \mathbb{R}^{n_l \times n_{l-1}}, b_l \in \mathbb{R}^{n_l}$. σ is applied element-wise.



Superior Colliculus
Retinal Input: $R_n \rightarrow$
Hypothalamic Input: $H_n \rightarrow$
Aversive Input: $F_n \rightarrow$
$y_1 = \sigma(R_n - 1)$
$y_2 = \sigma(2H_n + y_1 - 3)$
$y_3 = \sigma(F_n - 1)$
$y_4 = (2y_2 - 1)_+$
$y_5 = \left(y_3 - 0.5H_1(y_2)\right)_+$
$\rightarrow S_n = y_4$: Substantia nigra
$\rightarrow P_n = y_5$: Periaqueductal Gray
$S_n, P_n \rightarrow$
Action: A_n

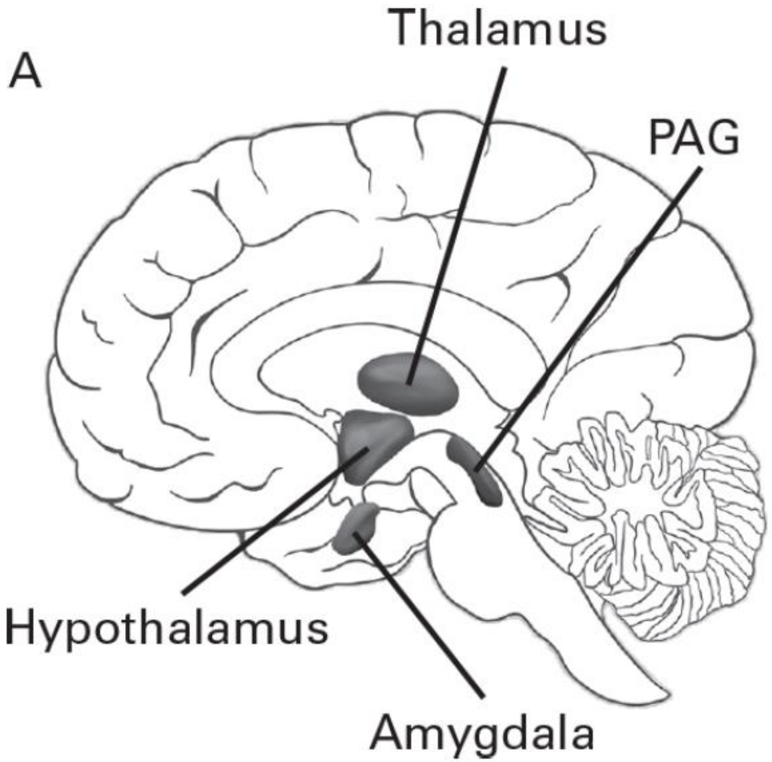
Hypothalamus: Internal Context Signals



- The hypothalamus is involved in multiple ***basic*** life-preserving operations
  - Homeostatic mechanisms
  - Neuroendocrine outputs
  - Wakefulness/sleep
  - Hunger, thirst
  - Sex
  - Defensive behavior
  - …

Generating Behavior

Coordinating Defensive Actions



- PAG: Periaqueductal Gray
  - Adjacent to the superior colliculus
  - Surrounds a channel containing cerebrospinal fluid
- PAG processes <u>outputs from the SC</u> into <u>defensive behaviors</u>
- In a rat or a cat,
  - Excitation of “active” column → facing, backing off, full-blown flight reaction
  - Excitation of “passive” column → freezing behavior

Appetitive Behaviors: Food and Sex

- ***Lordosis behavior*** (=presenting) is a body posture indicates female receptivity to copulation (facilitates penetration by the penis)
  - Lordosis behavior is impaired when PAG is lesioned → ***PAG*** contributes to this behavior

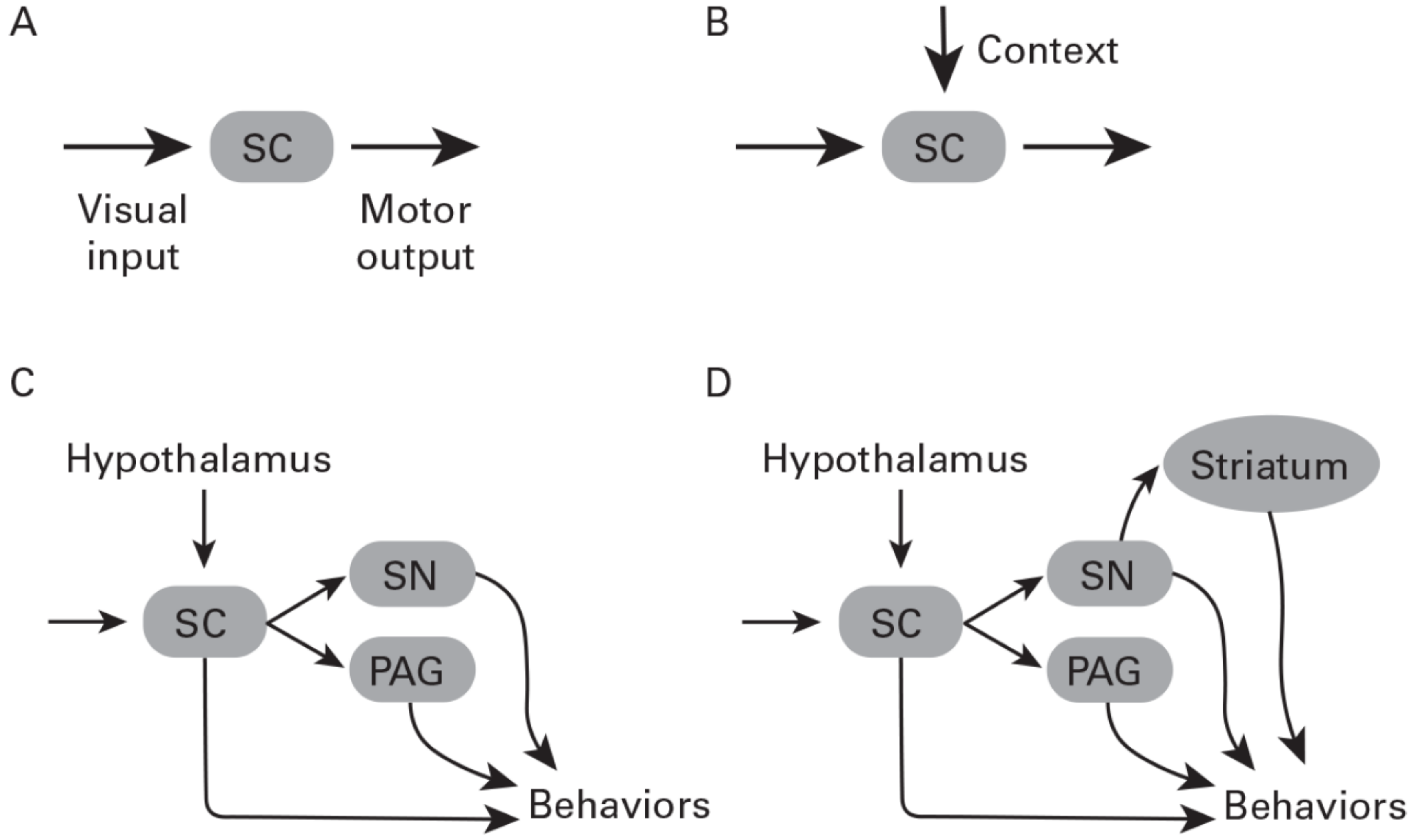
- ***Substantia nigra*** ($\subset$ midbrain) is directly connected to the SC and striatum
  - The substantia nigra synthesizes and uses ***dopamine***
  - ***Dopamine*** is important during the processing of novel or salient stimuli in the striatum
  - The ***striatum*** participates in *motivated behaviors* (e.g., liked foods)
  - The SC can directly participate in appetitive behaviors due to its connection to the substantia nigra

(Sidenote) Neurotransmitters

- Norepinephrine: projection systems go almost ***everywhere*** throughout the brain
- Dopamine-containing cells project to the ***basal ganglia***. The [substantia nigra + basal ganglia] system is the root of Parkinson's disease.
- Drugs that lead to ***addiction*** increase levels of dopamine in the striatum (PET)
- But! Dopamine is ***not*** a "reward molecule" – its effect varies based on where it operates – the brain region, circuit, and behavioral context
- Schizophrenia is understood to be caused by overactive dopaminergic projections from the midbrain to the cortex

The minimal brain

The "minimal brain"



The "minimal brain"

- The pieces constitute a *minimal brain* with sensory inputs, motor outputs, and in-between parts. The circuit helps answer the question, "stay, approach, or withdraw?"
- But can we separate this minimal brain from the rest?
- We cannot simply point to a brain structure and say that a ***behavior resides there***.
- Anatomically ***distributed*** circuits bring about the behaviors in question
- So, we start from a location of interest and gradually expand it to areas to which it is connected. But first, we must familiarize ourselves with areas implicated in ***cognition, perception, and emotion.***