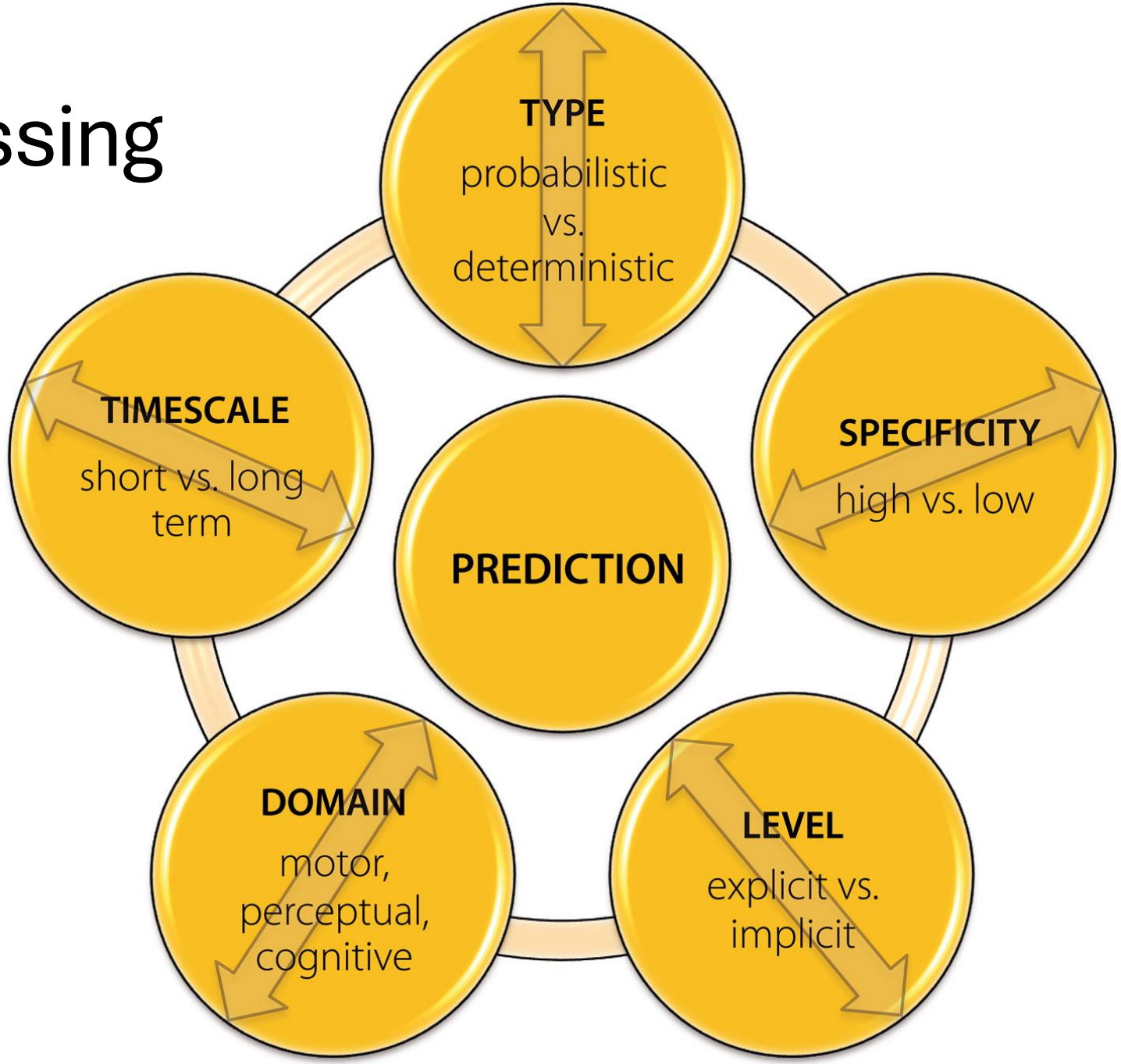
Action – High-Level Cognition

10/7/24

Predictive Processing

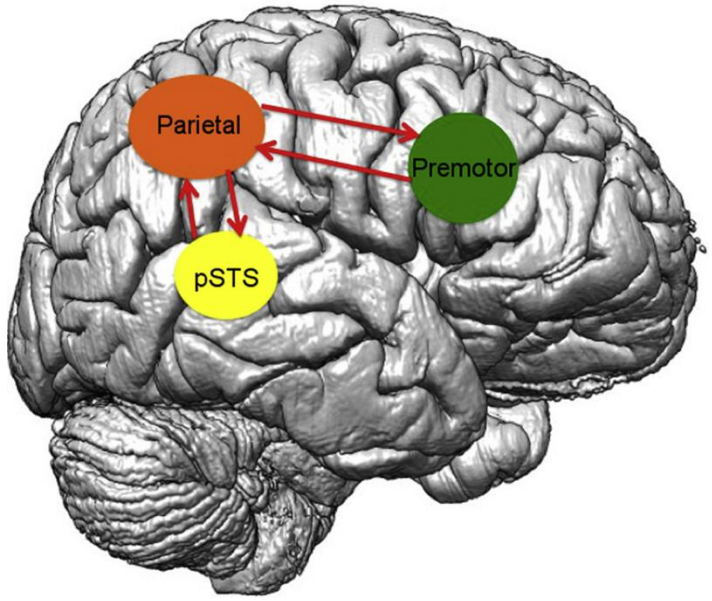
- Remember- the brain is a “prediction machine”
- It is not like there is one master prediction. There are predictions at every layer, in every domain. It is predictions all the way down
- Predictions underly **action**

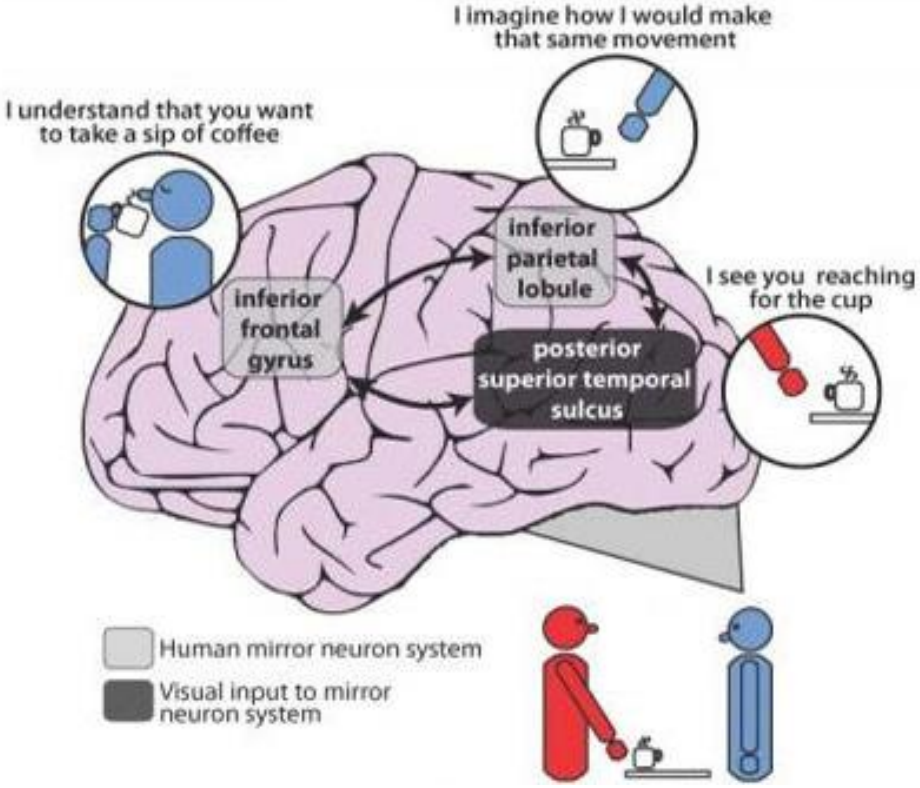


Never Let Them Know Your Next Move

Action Observation Network

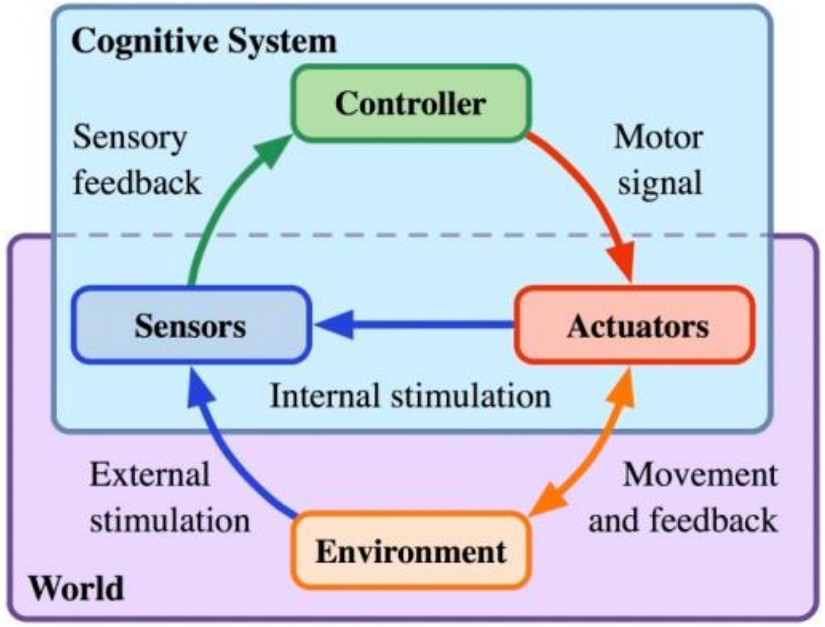
- Network activated both when performing an action and when observing others performing an action
- Helps generate mental models of how an action should unfold, helping the brain continuously compare the intended action with the sensory feedback, updating the model as you go
- This is where mirror neurons are!
- Mismatch between the model and the sensory input causes an **error signal** that informs the brain it needs to either modify motor commands or update its model of what is happening

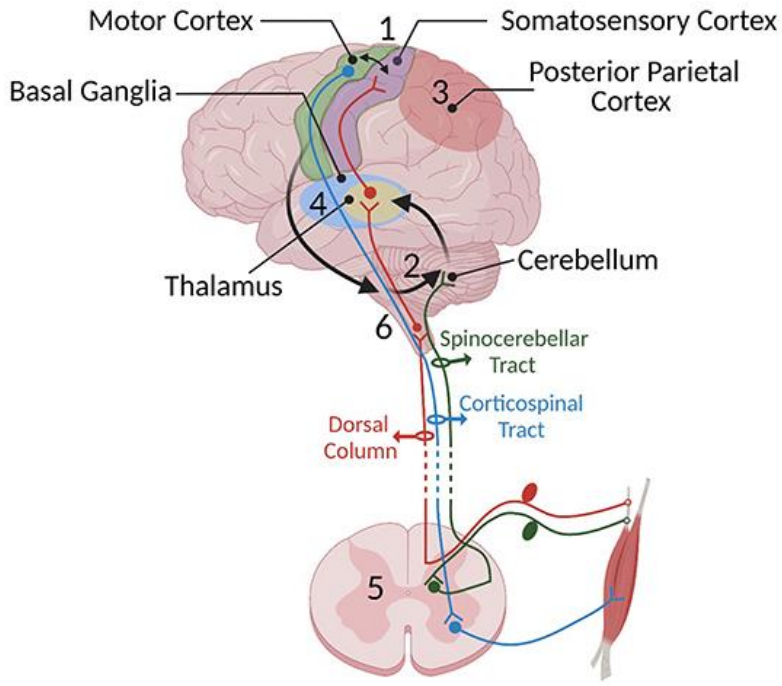




Principles of Action

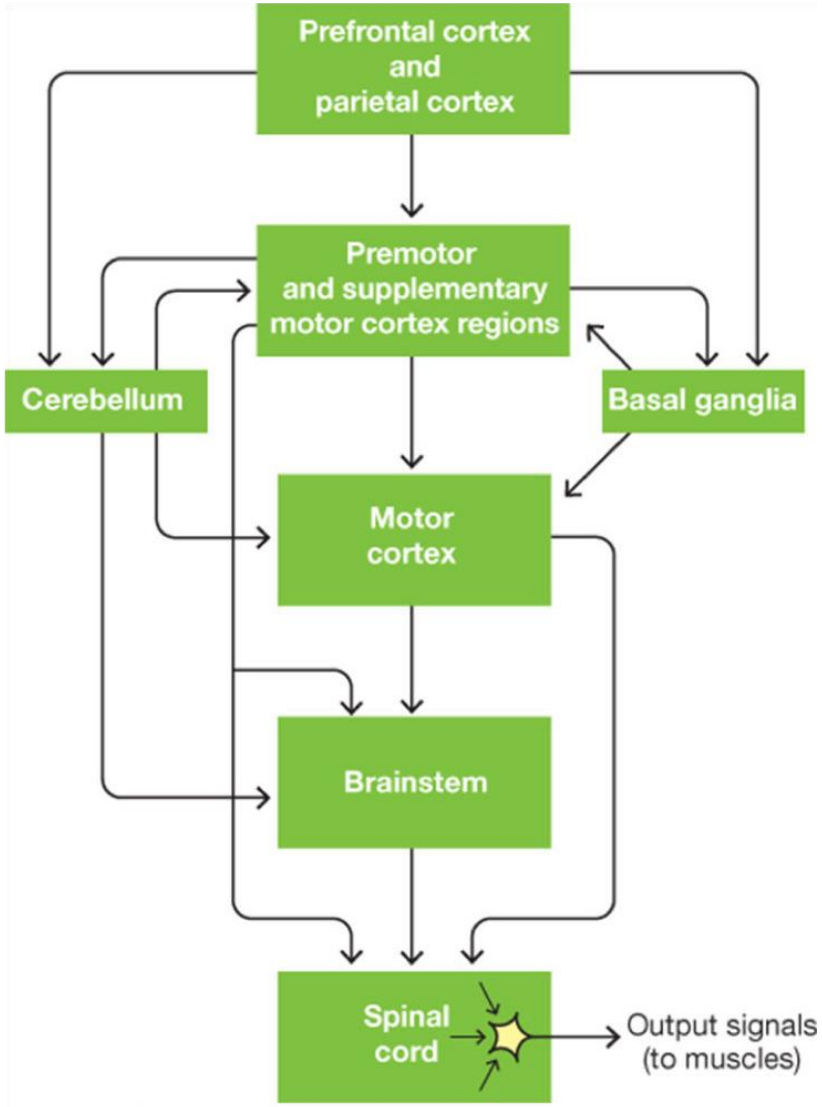
- **Action**: the outcome of conscious and subconscious cognitive processes that translate the goals, intentions, and mental models of a person to behavior and motor output
- **Motor output**: the physical act of moving muscles
  - Does not necessarily involve the CNS (e.g., reflexes)
- A convenient analogy: Action is to Perception as Sensation is to Motor Output
  - We can talk about the base layer of physically moving muscles (Motor output; akin to talking about the base layer of biological sensors), and we can talk about the neurocognitive structure that controls and regulates that activity (Action; akin to talking about perception making sense of sensory input)
- **Sensorimotor loop**: Action + Perception is the complete circuit of neurocognitive behavior
  - While we make distinctions for the purpose of studying and understanding, the reality is that these two processes are deeply interwoven with each other
- **Predictive processing**: mental models/internal representations guide both perception and action





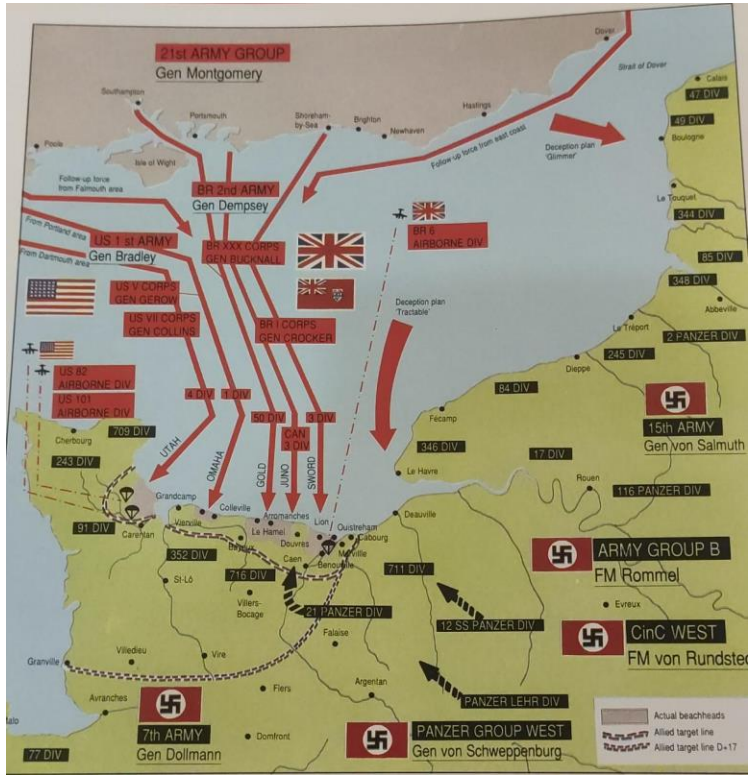
Motor System Hierarchy

- **Prefrontal cortex** and **parietal cortex**: higher-level planning and intention
  - Integrate sensory information ("how" pathway) and contextual factors to form goals and create plans
  - "I'm going to pick up a cup to drink"
- **Premotor** and **supplementary motor cortex**: movement planning
  - Translate high-level goals into specific sequences of movements and prepare for execution
  - Preparing hand shape and coordinate reach-to-grasp sequence
- **Motor cortex**: direct command of voluntary movements
  - Send motor signals to specific muscles for execution of movement
  - Precise motor signals to arm and hand muscles
- **Brainstem**: movement control and posture
  - Integrate regulatory signals to send coordinated action signal
  - Adjusting posture and other positions to maintain balance and coordination
- **Spinal cord**: transmission and execution of commands
  - Deliver motor signals to the muscles and mediate reflex arcs for rapid responses
  - Actual motor signals that engage the muscles to move to pick up the cup



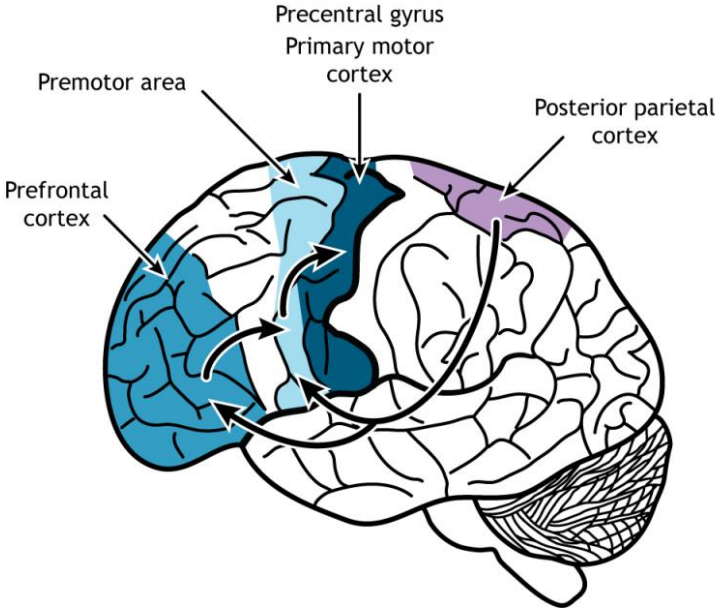
Prediction vs Monitoring

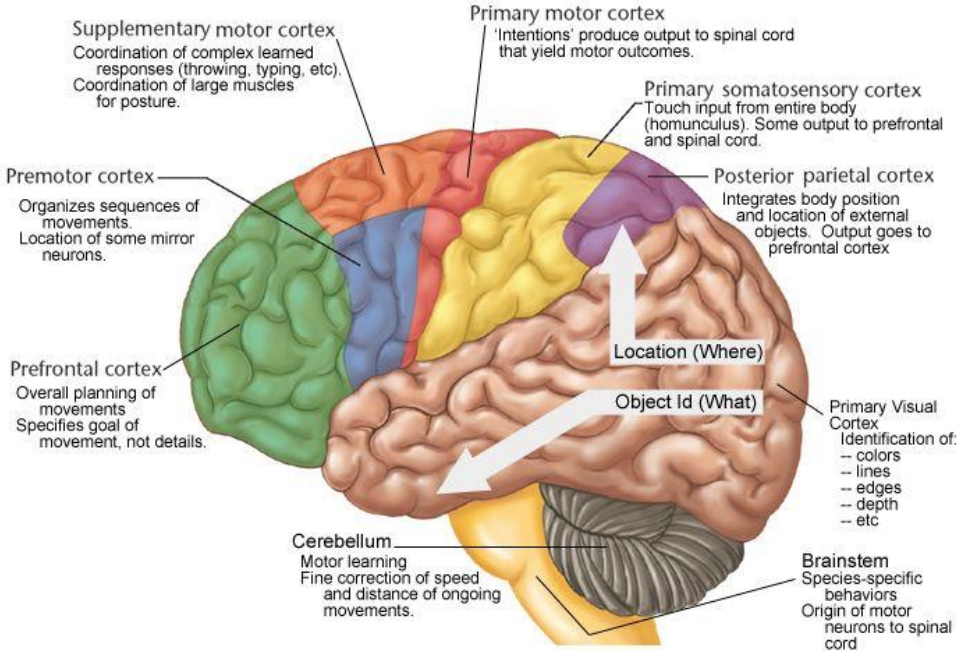
- **Prediction**: process by which the brain produces an expected outcome of a planned movement before it occurs
  - Anticipating sensory feedback based on an internal model
  - **Premotor cortex** (motor plans) and **cerebellum** (forward model that simulates sensory consequences of motor plans)
- **Monitoring**: process of comparing actual sensory feedback with predicted feedback during and after an action
  - Detecting discrepancies between predicted and actual outcomes to correct ongoing movements and update internal models
  - **Parietal cortex** (integrates sensory input and body model) and **cerebellum** (detects prediction errors and refines movement)
- Prediction comes first – forward model to anticipate sensory consequences
- Monitoring provides **active feedback**, ensuring accuracy, critical for error correction and learning



Motor Planning

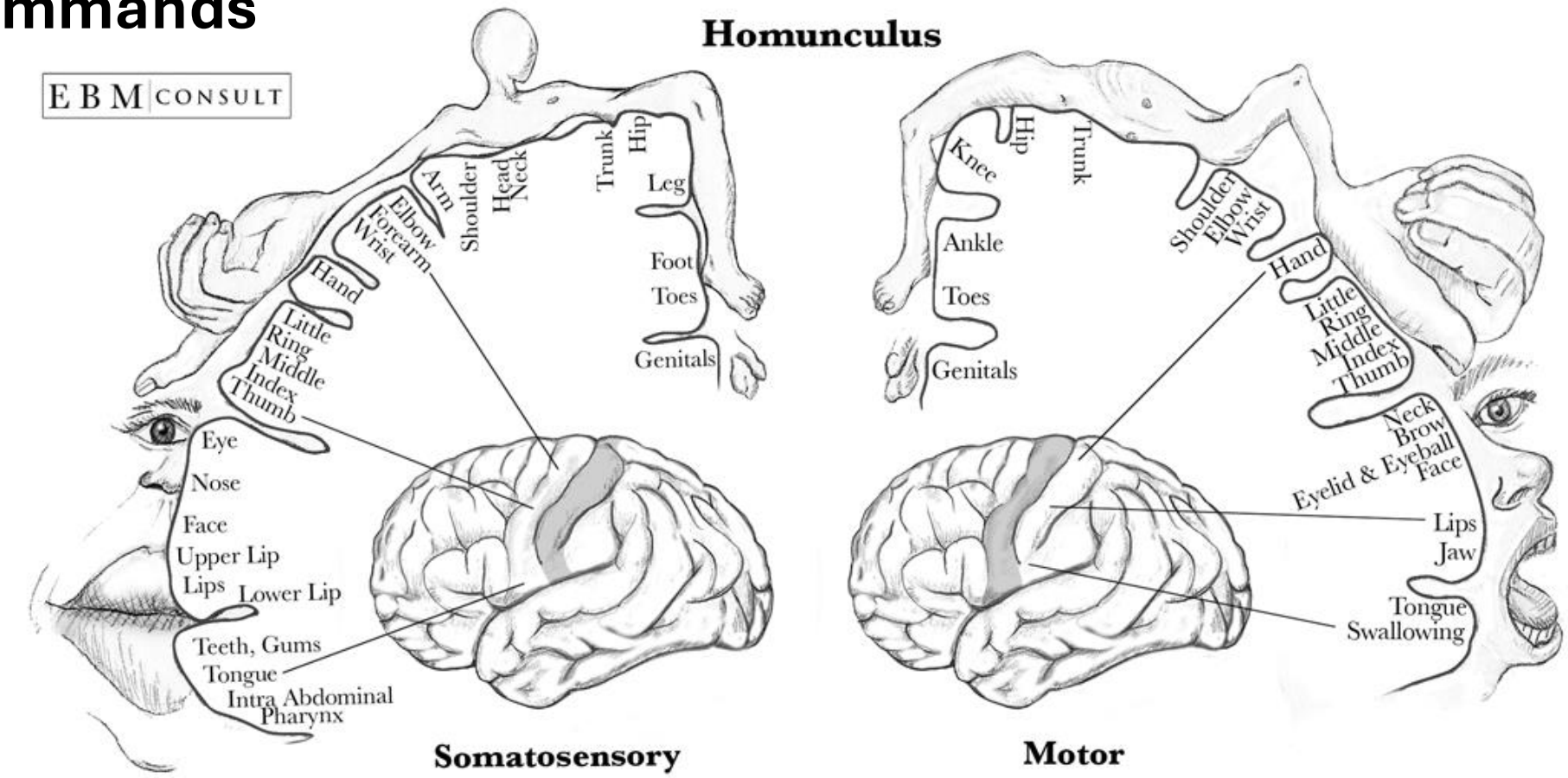
- **Prefrontal cortex (PFC)**: determine what action to perform and why
  - Evaluate goals, weigh options, and select the most appropriate option
  - Predict the consequences of a behavior
- **Dorsolateral prefrontal cortex (dlPFC):** breaking down actions into an action sequence
  - Develop an abstract model of how the sequence will unfold, hold it in working memory
- **Premotor cortex (PMC):** translate goal into a motor plan
  - Create concrete motor commands
- **Supplementary motor area (SMA):** internal coordination
  - Create motor imagery and rehearsal, internal simulation





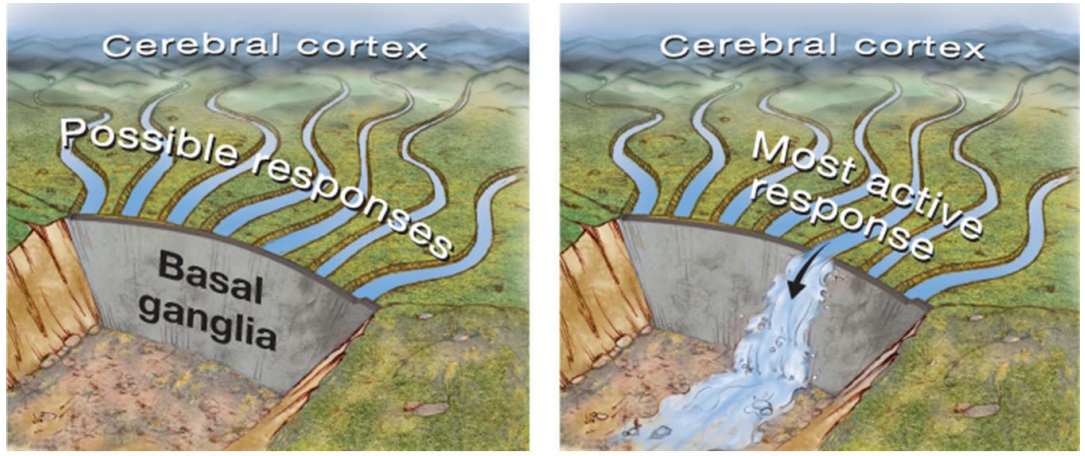
Motor Homunculus

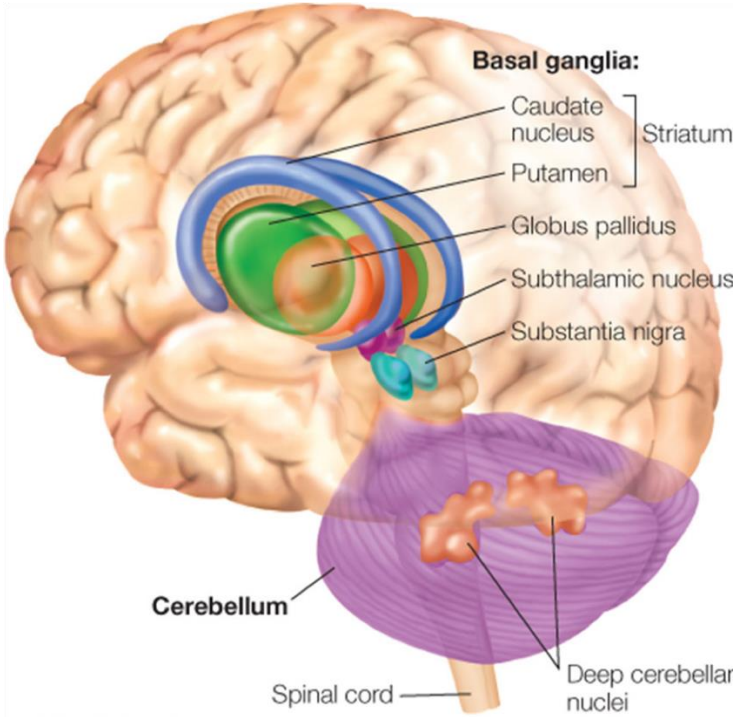
- Motor cortex has homunculus, just like somatosensory, but for **commands**



Basal Ganglia

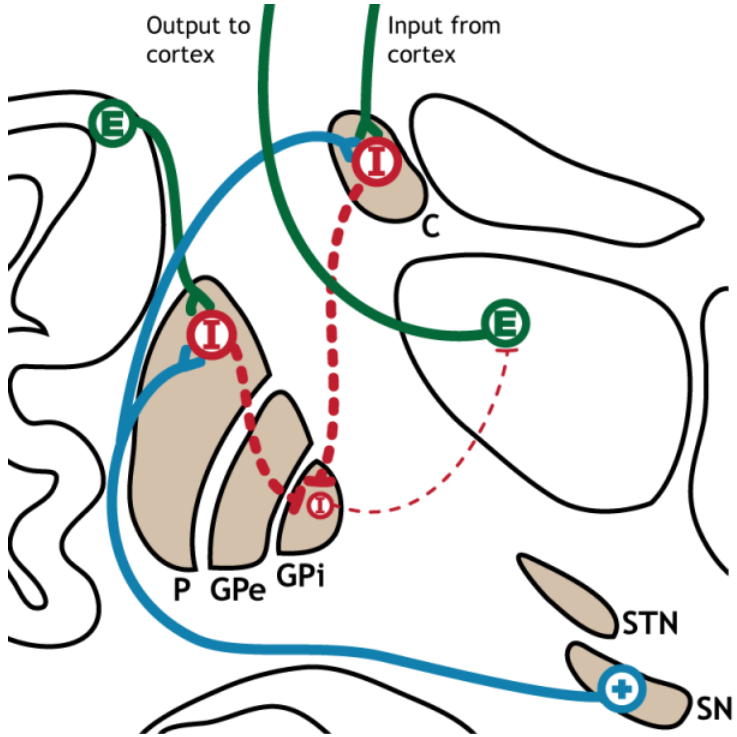
- Specialized for **reinforcement learning**
  - More integrated with “what” pathway
- **Action selection**: filter and select the most appropriate action from competing motor plans
  - Facilitate intended action and inhibit all the others
- **Motor control**: Regulates signals sent to motor cortex to modulate motor initiation to control the speed, force, amplitude of movements
- **Habit formation**: Encodes motor habits and automatic behaviors through dopaminergic reinforcement learning mechanisms





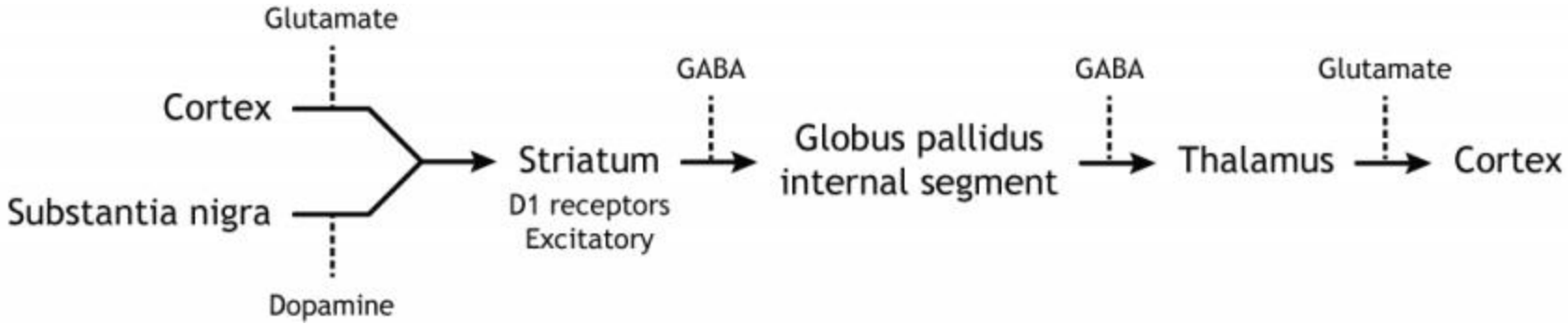
Direct Pathway in Basal Ganglia

- Reinforcing and selecting goal-directed actions
- Facilitates actions that are considered desirable, rewarding, or appropriate
- “Go” signal
- Works best with **high certainty** or **reward**
- Can reinforce frequently-selected actions to slowly become **habitual**



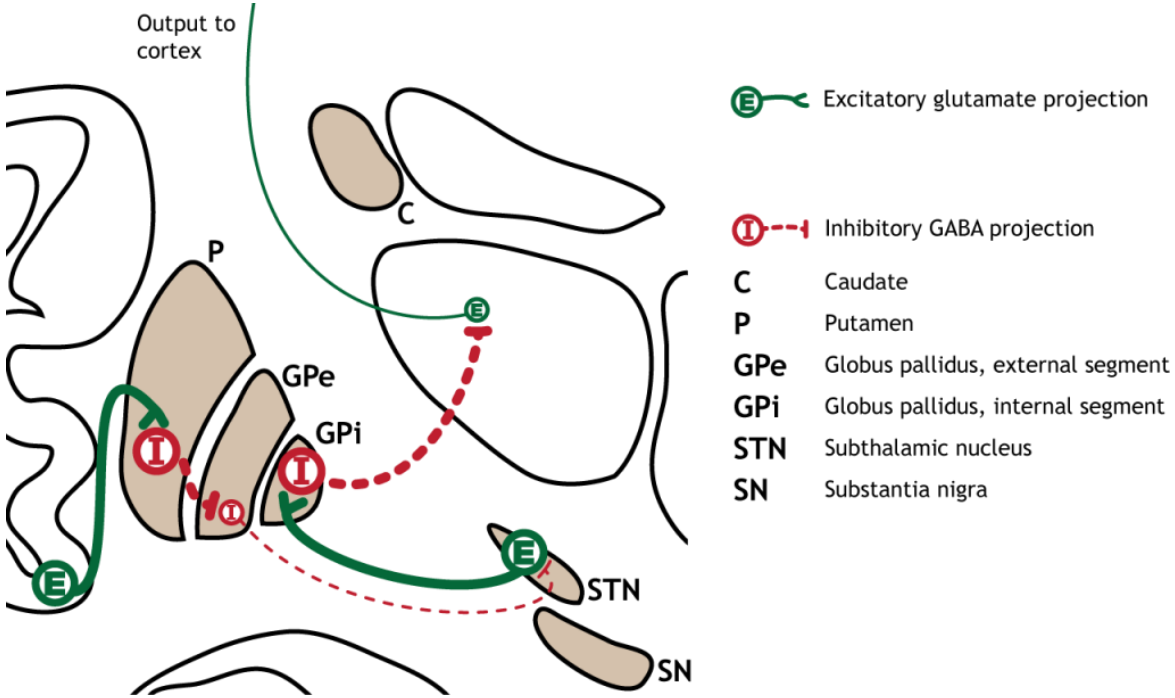
Excitatory glutamate projection
Excitatory dopamine projection
Inhibitory GABA projection

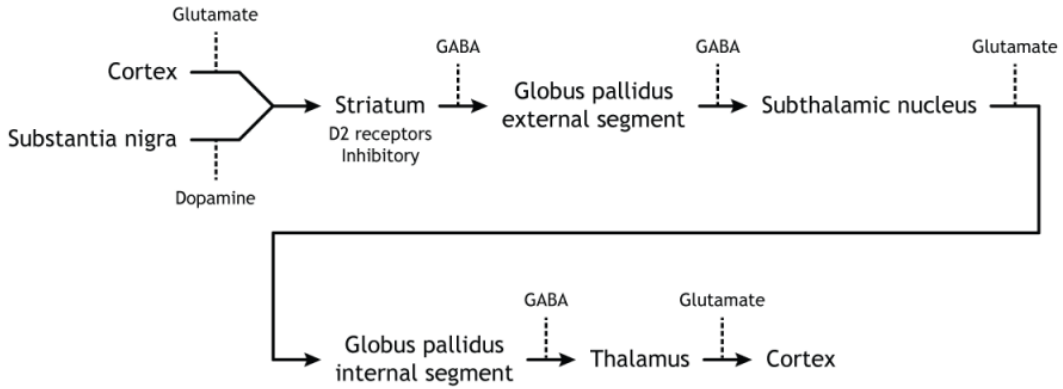
C	Caudate
P	Putamen
GPe	Globus pallidus, external segment
GPi	Globus pallidus, internal segment
STN	Subthalamic nucleus
SN	Substantia nigra



Indirect Pathway in Basal Ganglia

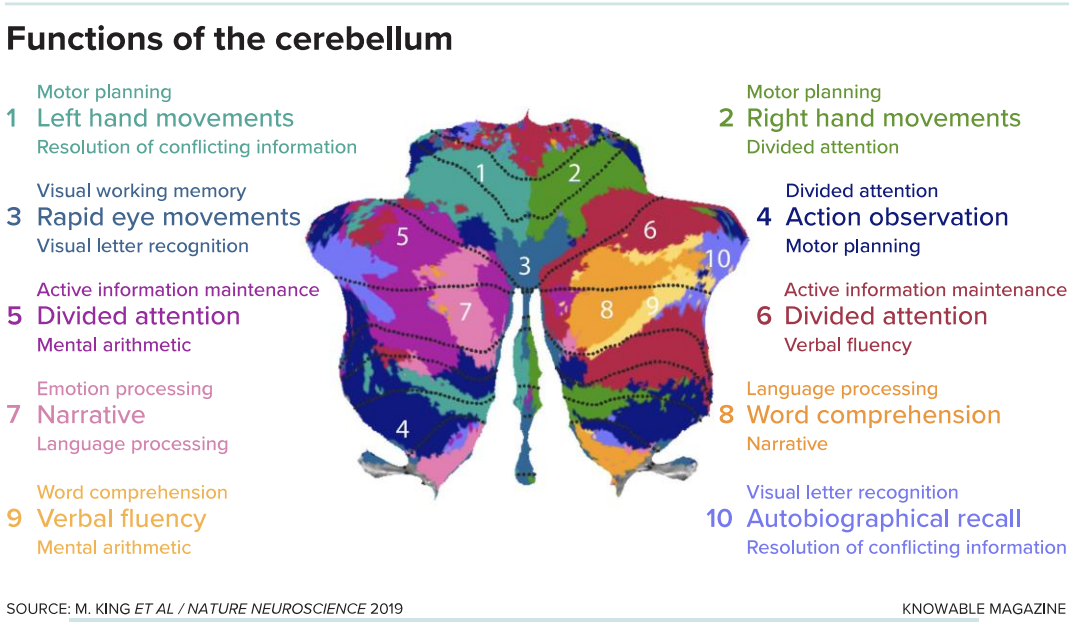
- Regulating and inhibiting actions
- Suppresses actions that are undesirable, competing, or inappropriate
- “No-go” signal
- Critical for **impulse control**, **self-regulation**
- Works with **high ambiguity** or **low reward certainty**, to delay action until additional information is processed
- Can help override automatic or habitual behaviors

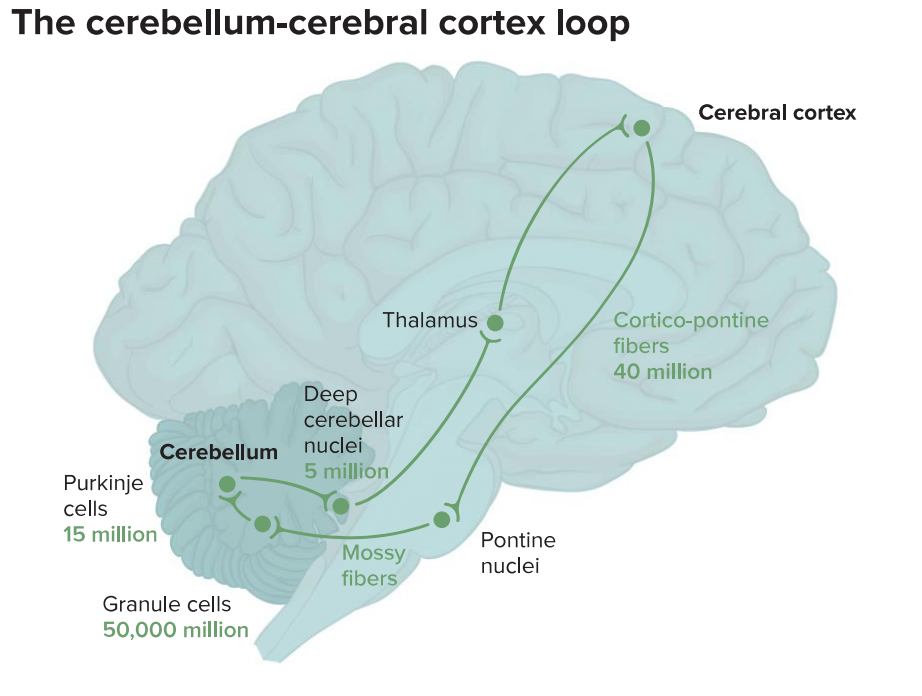


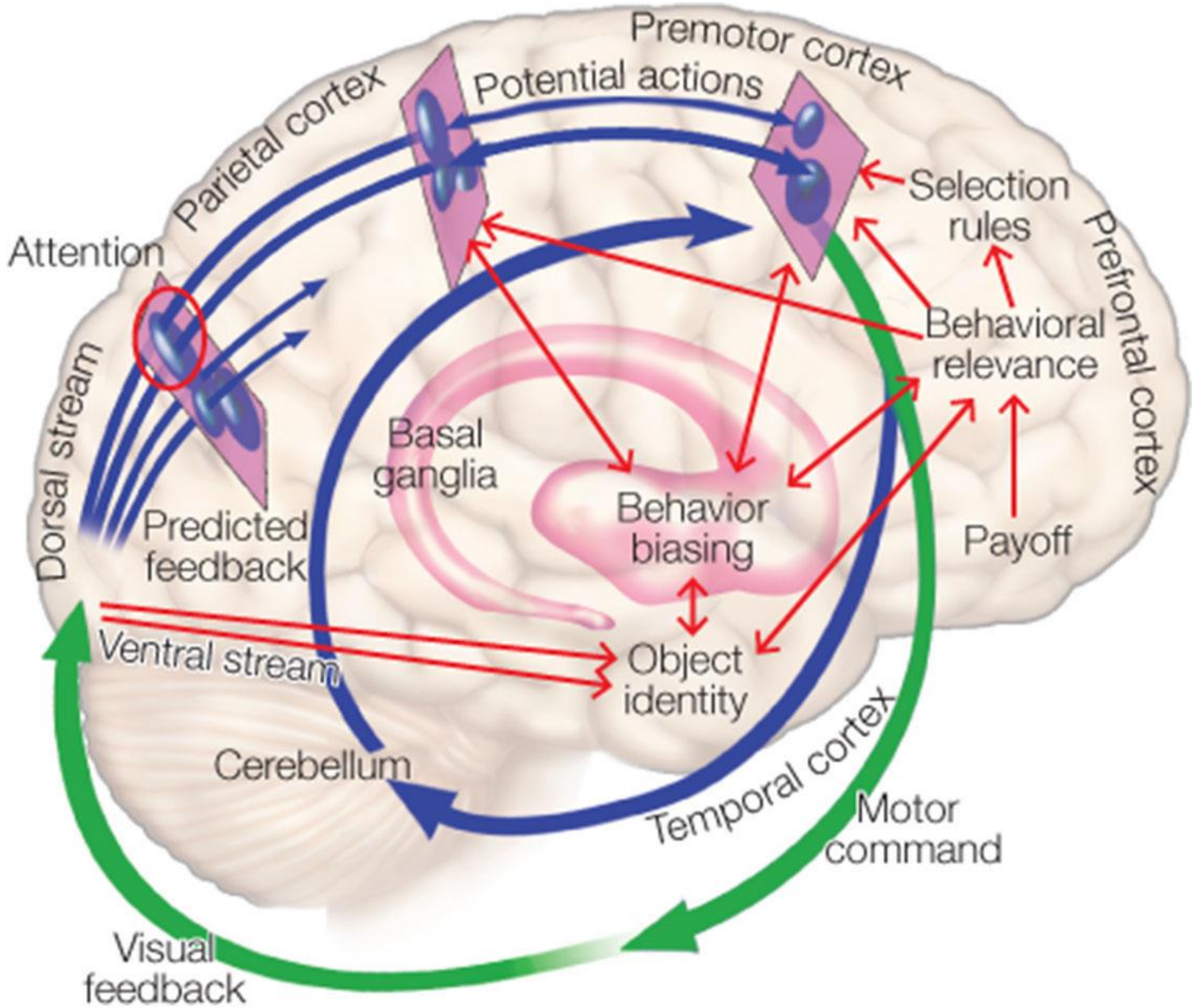


Cerebellum

- Specialized for **error detection/correction**
  - More integrated with “how” pathway
- Receives input:
  - **Somatosensory and proprioceptive** (spinocerebellar pathways) – raw
  - **Vestibular** (vestibular nuclei in brainstem) – partially processed
  - **Visual and auditory** (from primary sensory cortices) – heavily processed and abstracted (“what”, “where”, “how”)
  - **Efference copies** (motor cortex)
    - Internal model of the motor plans
- Integrates all these signals to create **error signals** (deviations from expected inputs) that can be fine-tuned and corrected
- Cerebellum appears to be much more integrated with emotion and higher cognition that previously thought
- **Universal cerebellar transform (UCT)** – idea that the cerebellum performs the exact same prediction/error-correction computation on all input signals (motor, sensory, cognitive)
  - like training an AI with supervised learning – refinement of models







Affordance Competition Hypothesis

- The brain continuously generates, evaluates, and competes between multiple possible actions (**affordances**) simultaneously
- Integration of perception, action, and decision-making into a single unified framework
- The brain is constantly proposing possible plans of action, and setting them in dynamic competition with each other
- There are always alternative plans lying in wait, anticipating possible new scenarios
- Metaphor: your cognitive system has an internal marketplace that is always responding to new information and balancing what it values