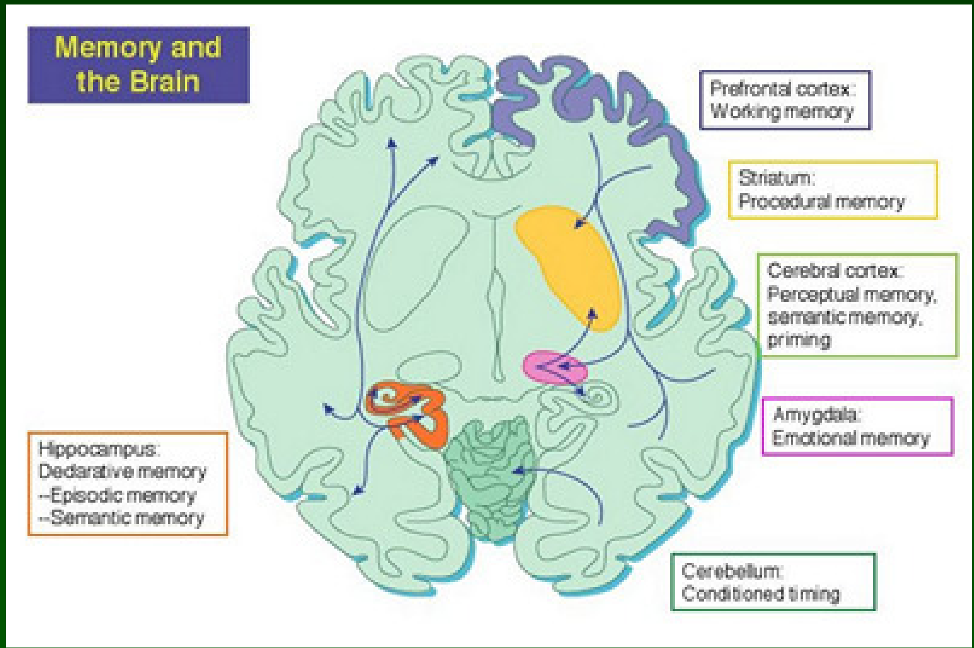
Selected topics in cognitive neuroscience and biomodeling

L10: Memory



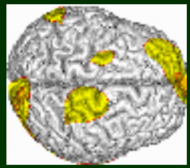
Włodzisław Duch

Neurocognitive Laboratory & Dept. of Informatics

Nicolaus Copernicus University, Poland

Google: Wlodek Duch

What it will be about

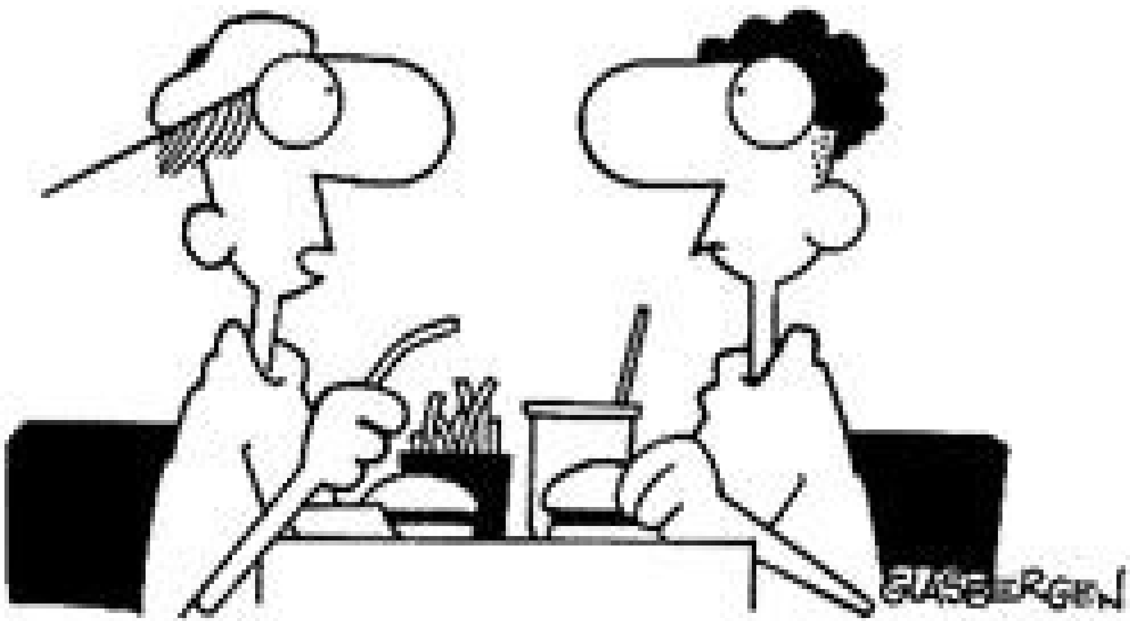


1. Memory types
2. Episodic memory and hippocampus.
3. Three memory subsystems
4. Working memory and dopamine.
5. Basal ganglia.
6. 7 sins of memory.

What is memory?

- Any external or internal activity may leave a trace changing the brain and influence behavior; such traces are memories, impressions of brain activations formed through neuroplasticity in the substrate of the brain.
- There is no separate memory subsystem, it is rather the ability to change brain activity, memory cannot be separated from other functions.
- Division by senses: visual, auditory, tactile, olfactory, taste, motor.
- By functions: spatial, object, recognition, episodic, semantic, procedural vs. declarative, or implicit vs. explicit, associative, working memory.
- By time: buffer memory (very short), short, middle, long term.
- By mechanisms: passive memory based on synaptic plasticity (long term), active dynamic memory based on priming on short or longer time scales.
- Semantic and procedural memory result from slow "digesting" of many processes, internal and external.
- Memory activation requires specific apparatus to decode it, like DVD player.

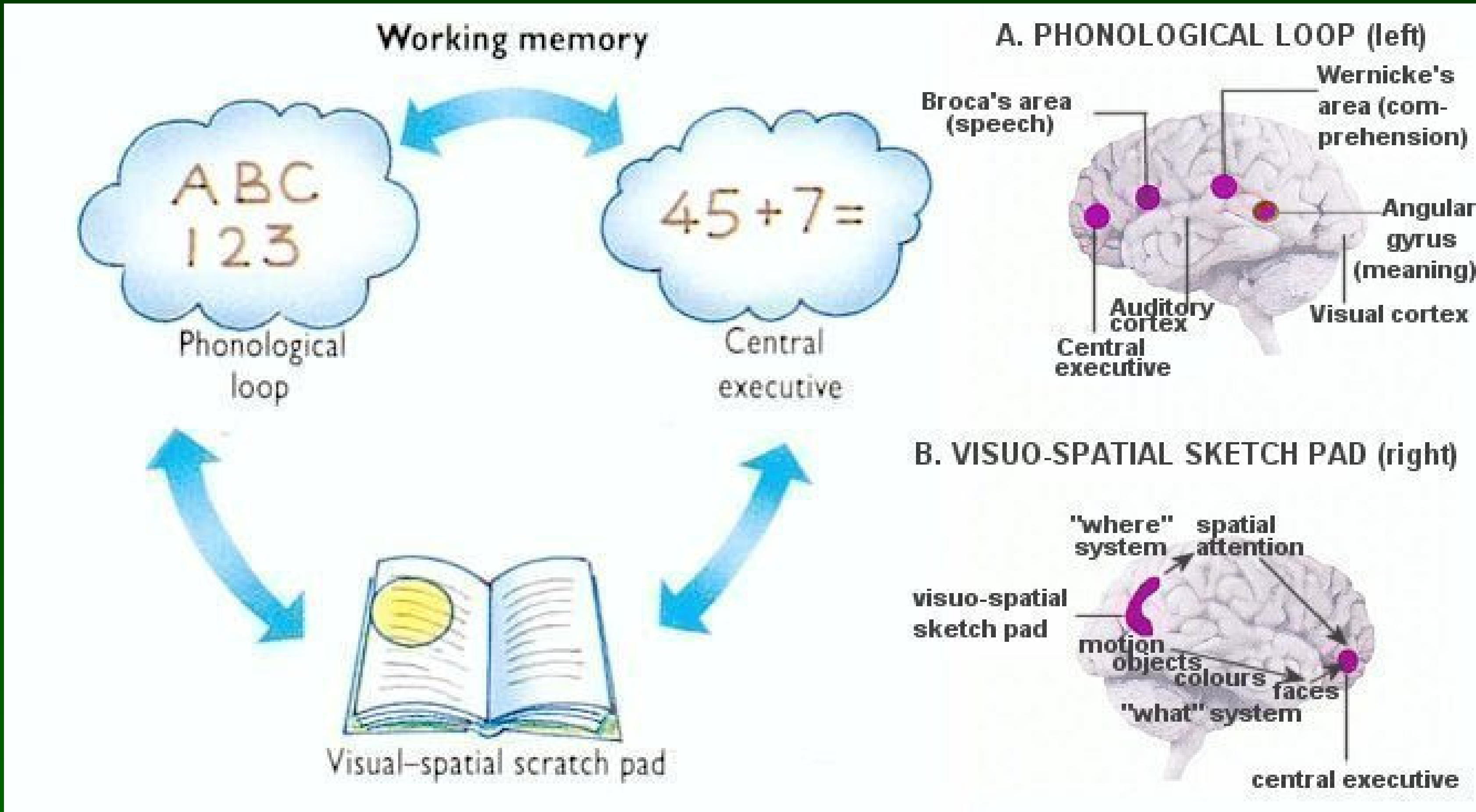
Back-up your memory!



"I forgot to make a back-up copy of my brain, so everything I learned last semester was lost."

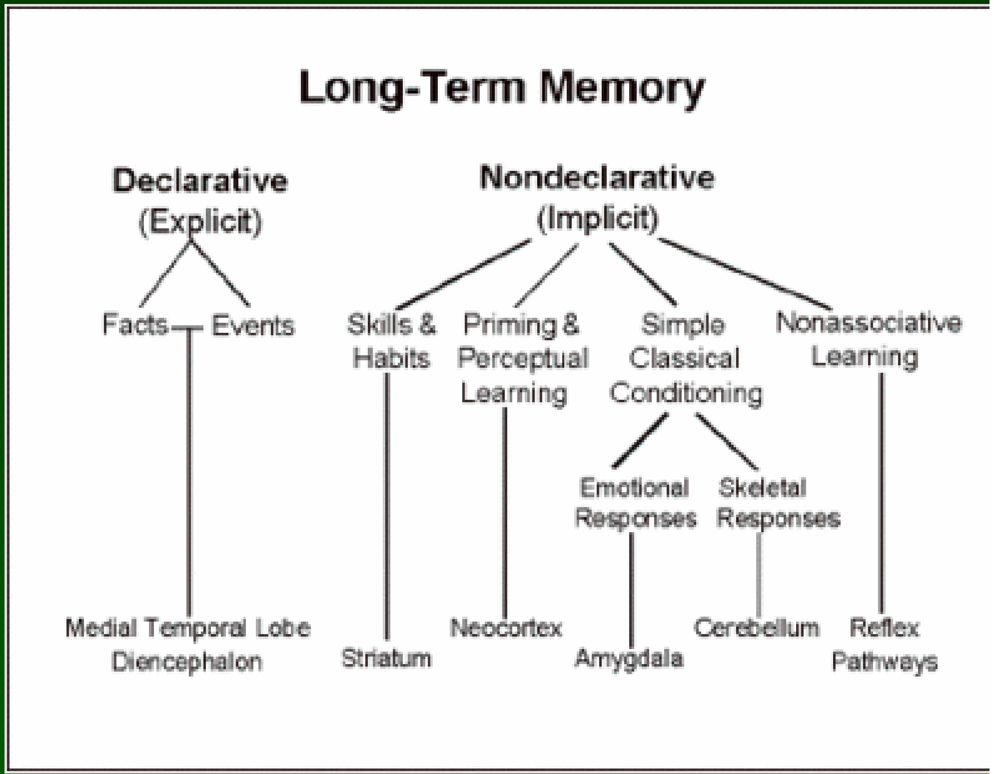
Working and Short-term Memory

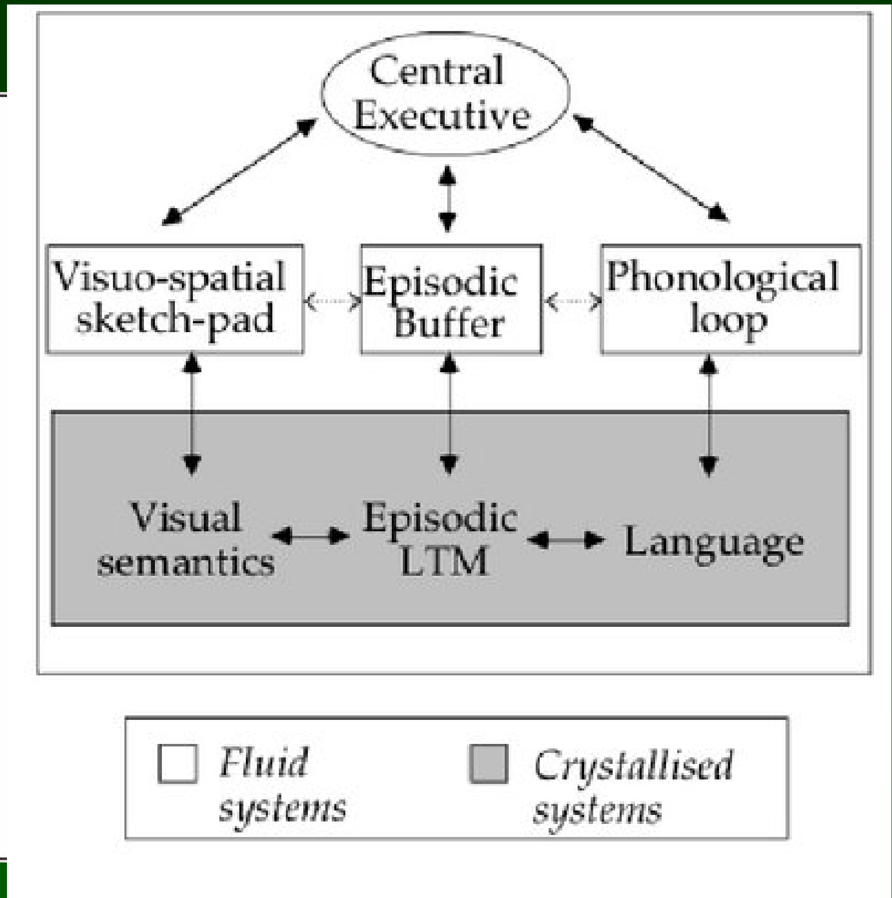
- Basic subdivisions.



Long-Term and Working Memory

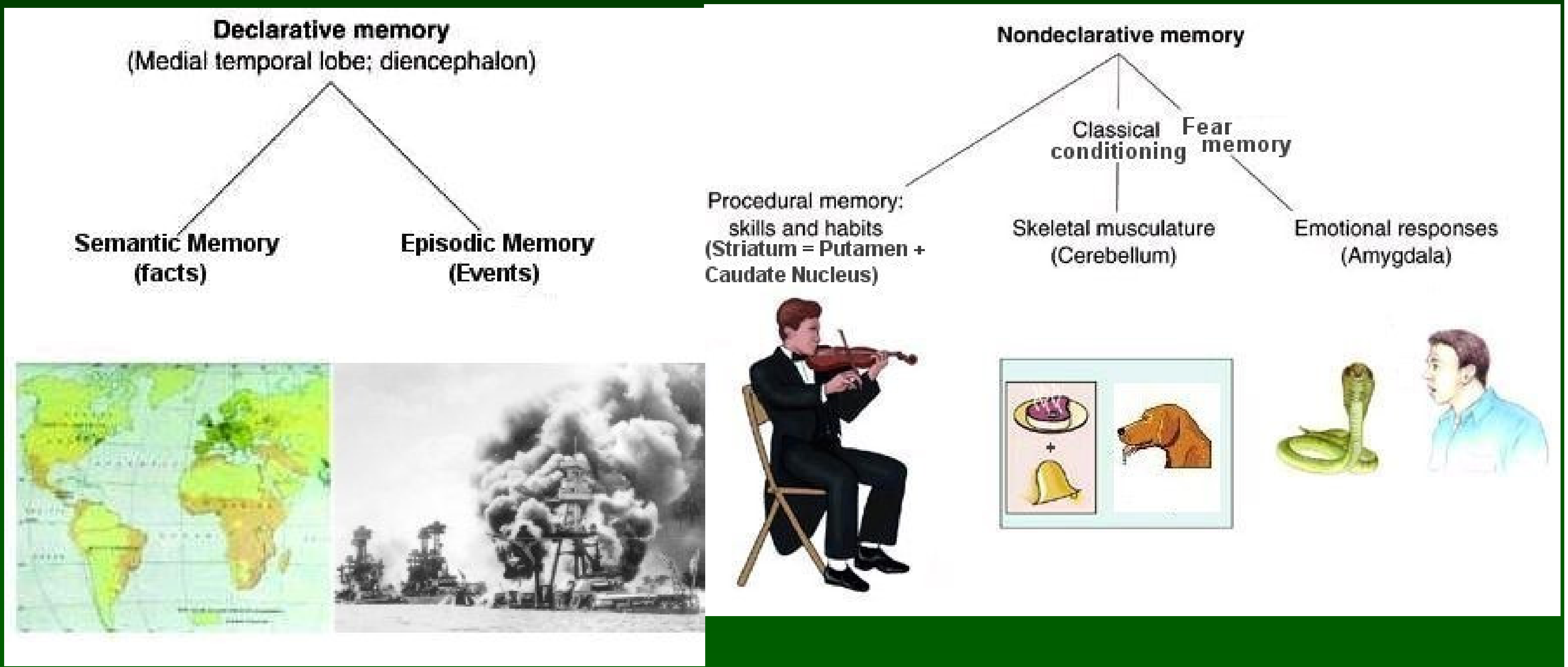
- Basic subdivisions.





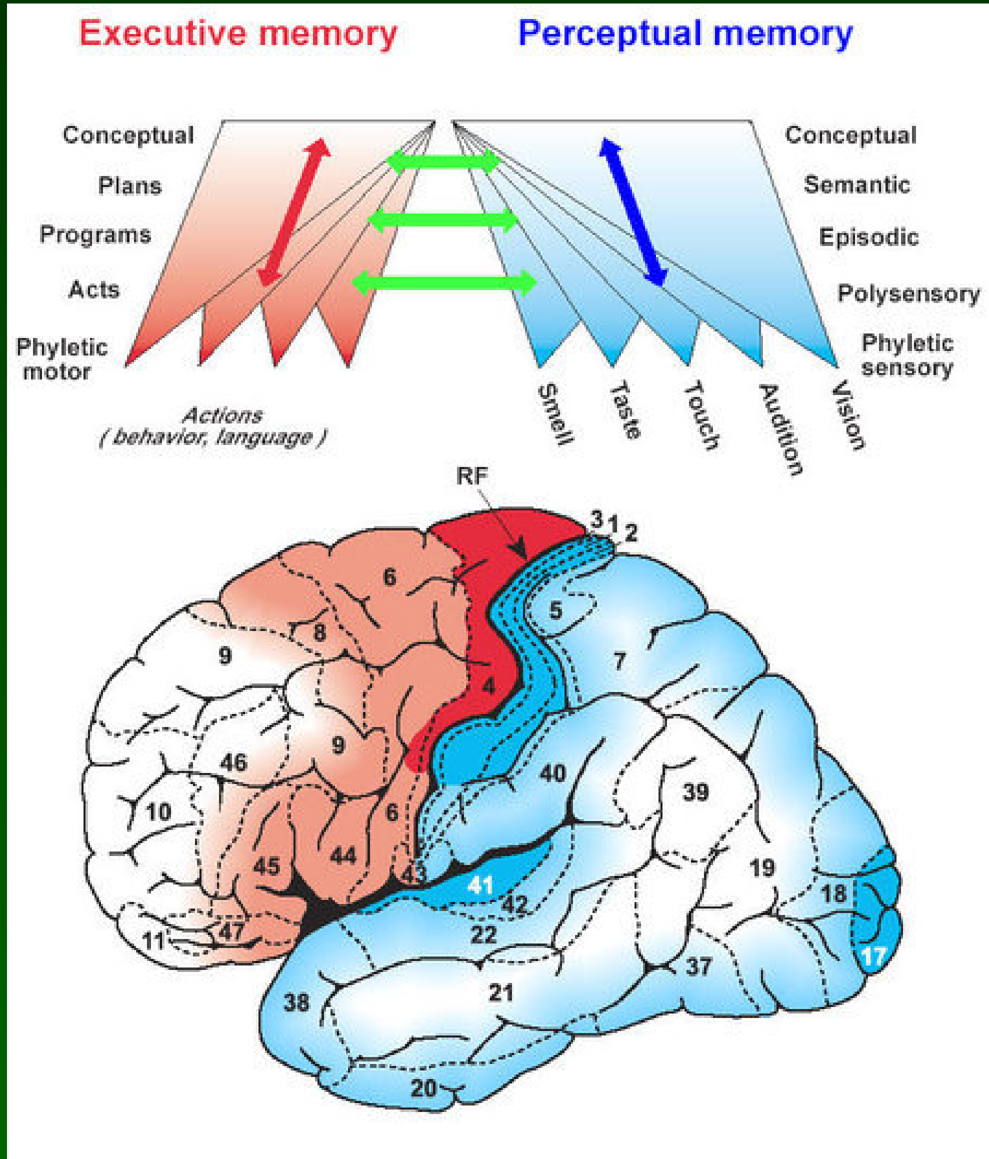
Non-declarative and declarative

- Semantic & episodic vs. procedural and conditioning memory.



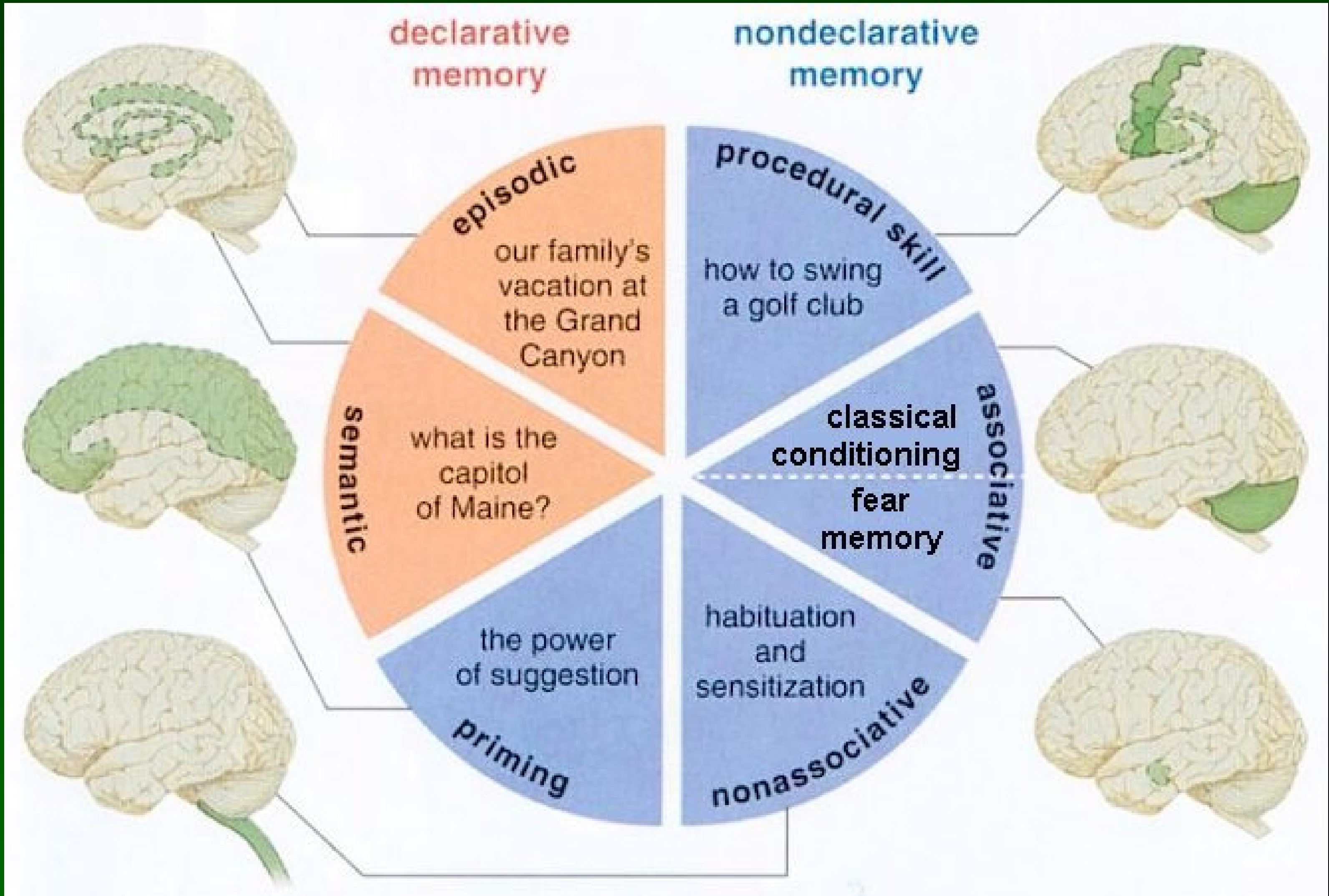
Executive/perceptual memory

Another functional division: action and perception or executive/perceptual memory, roughly frontal/posterior brain areas.

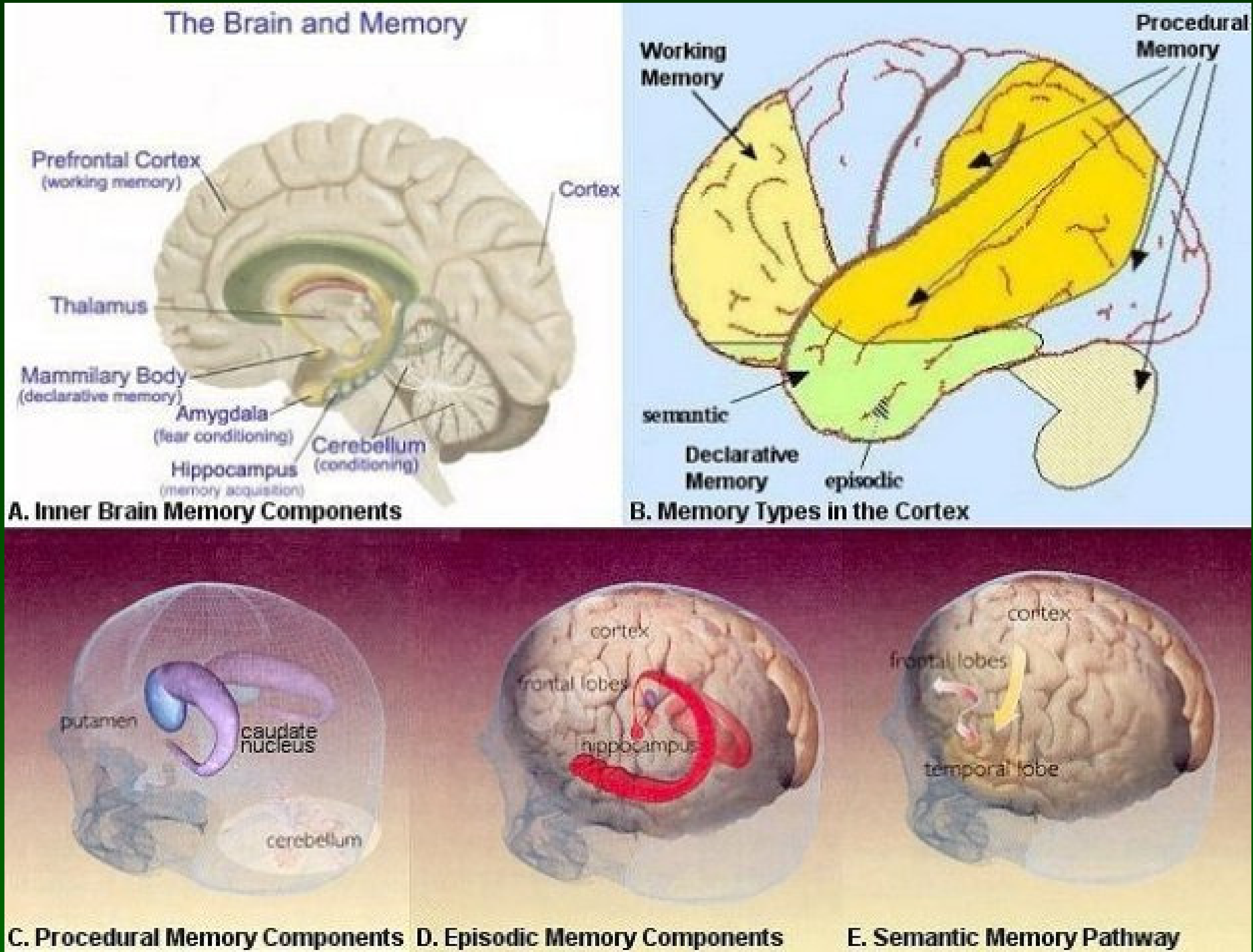


Memory types

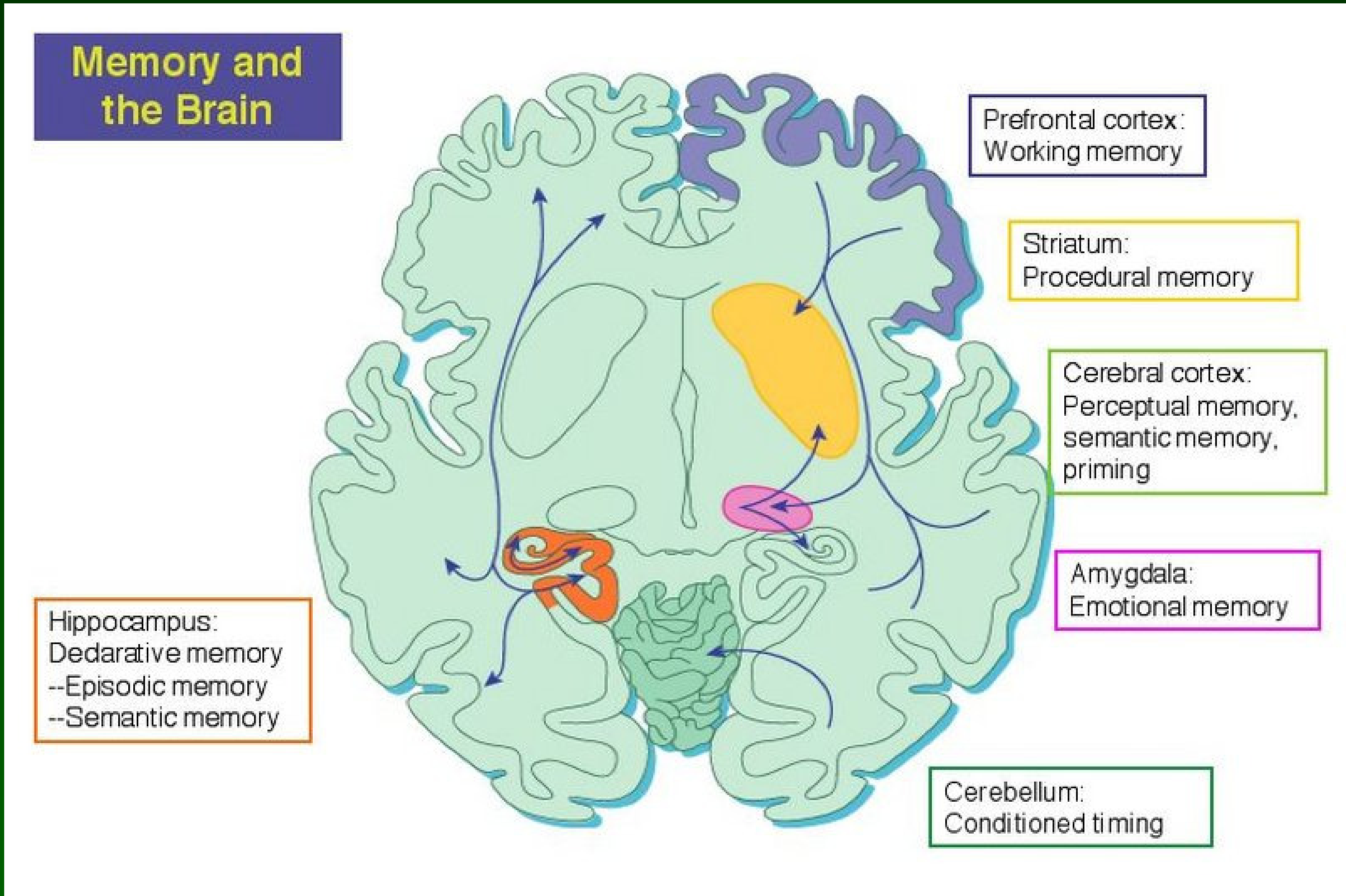
- Declarative - nondeclarative subdivision of memory types.



Memory in the brain



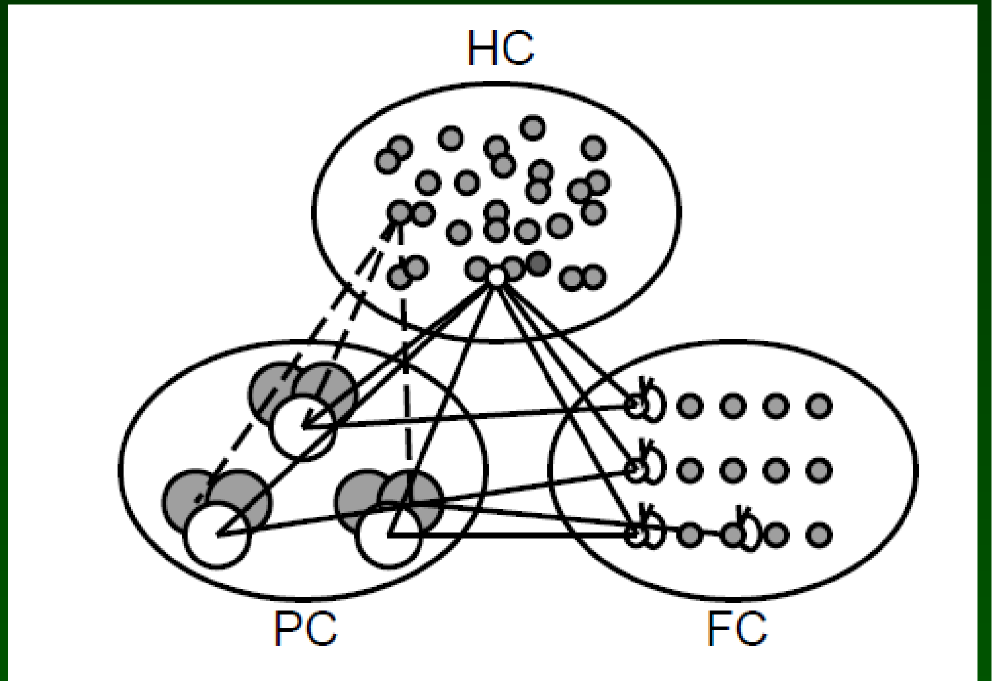
Memory in the brain



Emotional memory: see Joseph LeDoux lab and books.

3 main memory subsystems

- Posterior cortex (PC): includes rear parietal cortex and motor cortex; sensorymotor actions, specialization, distributed representations.

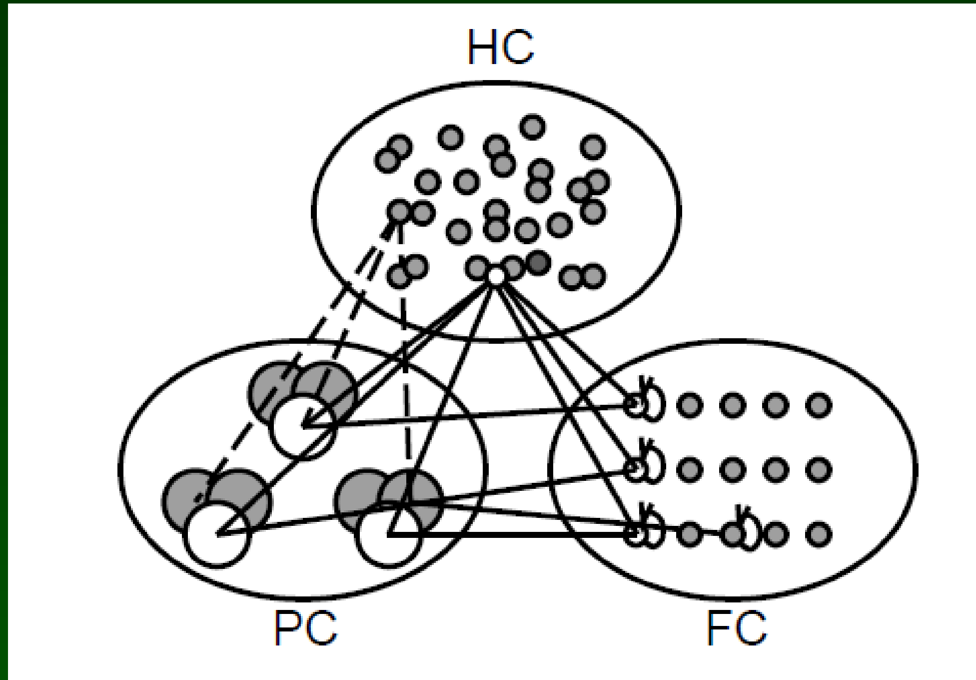


- Frontal cortex FC – prefrontal cortex, higher cognitive behaviors, isolated representations.
- Hippocampus HC – hippocampus and related structures, memory, rapid learning, sparse representations.
- There are 3 main regions, but more are needed to implement other types of memory: recognition, procedural, semantic.

Why 3 subsystems?

Stability-plasticity dilemma!

- Learning must be slow in order to grasp statistically important relationships, and to precisely analyze sensory data and control motions, but we also need a mechanism for rapid learning.



- Compromise: slow learning in the cortex – stable world view - and rapid learning in the hippocampus – new important facts quickly memorized.
- Retaining active information and simultaneously accepting new information in a distributed system, avoiding interference.

Ex. Penguins are birds, but cannot fly! Do not change the typical bird category.

Hippocampus

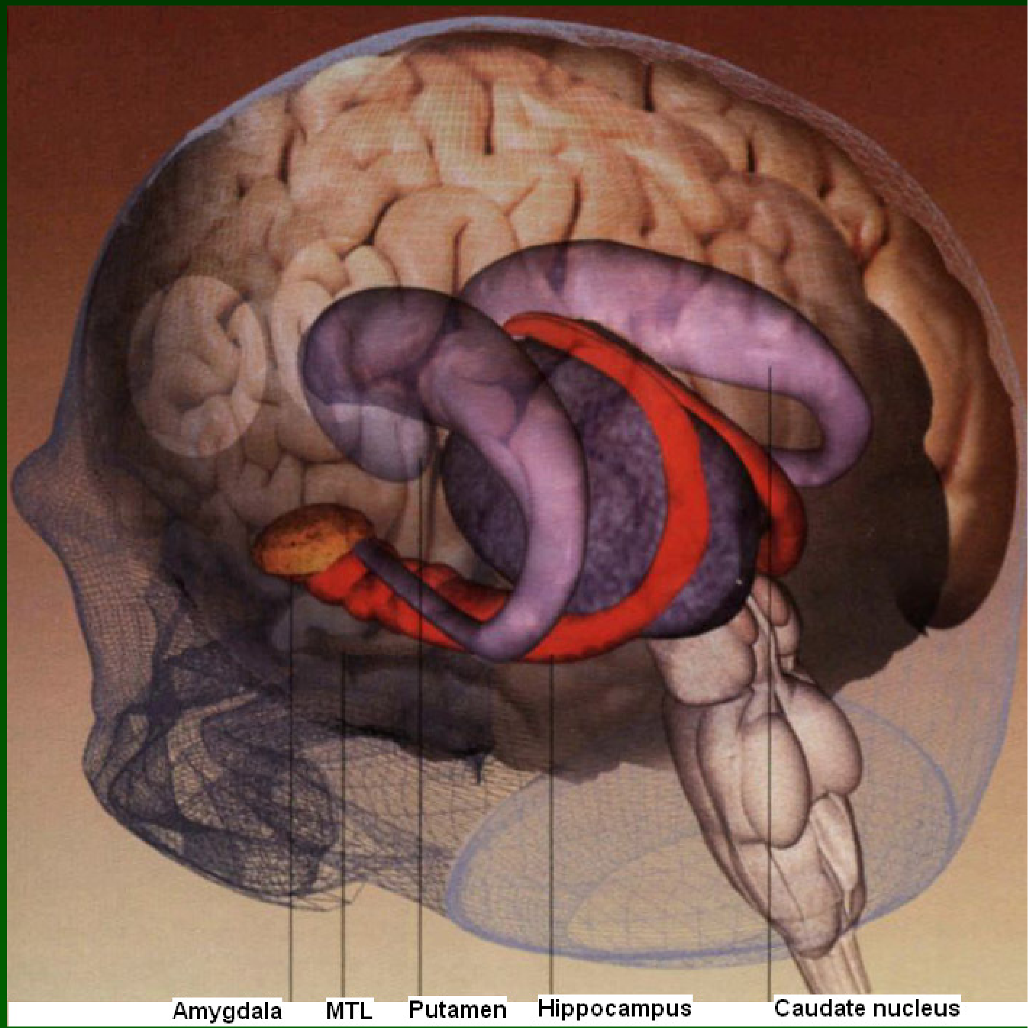
Hippocampal formation (red color), anatomy and connectivity:

signals reach many uni-modal and multi-modal association areas through the surrounding cortex: entorhinal, perirhinal and parahippocampal cortex.

Many functions:

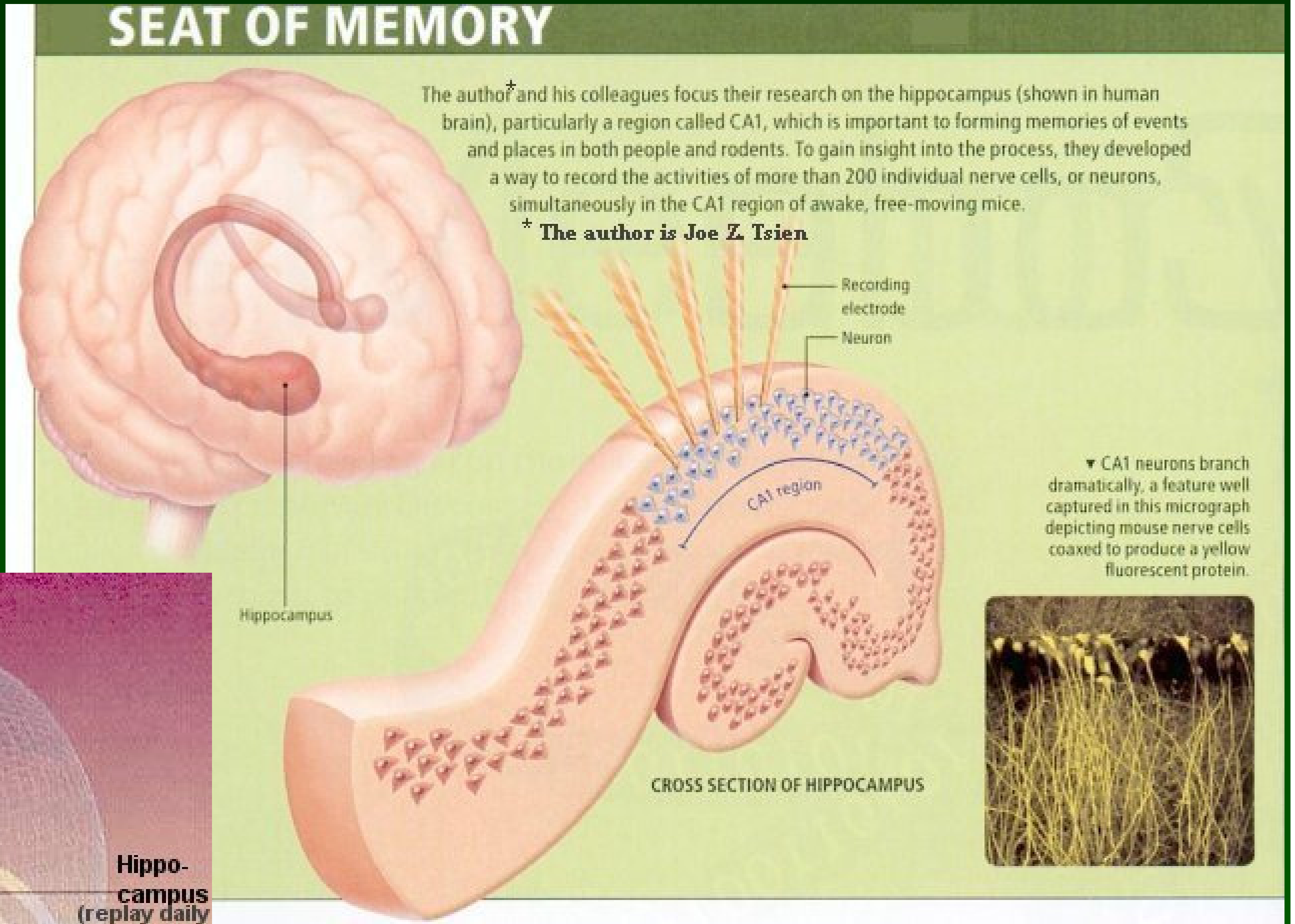
- Spatial memory – grid and place cells
- Consolidation of long-term memory
- Learning

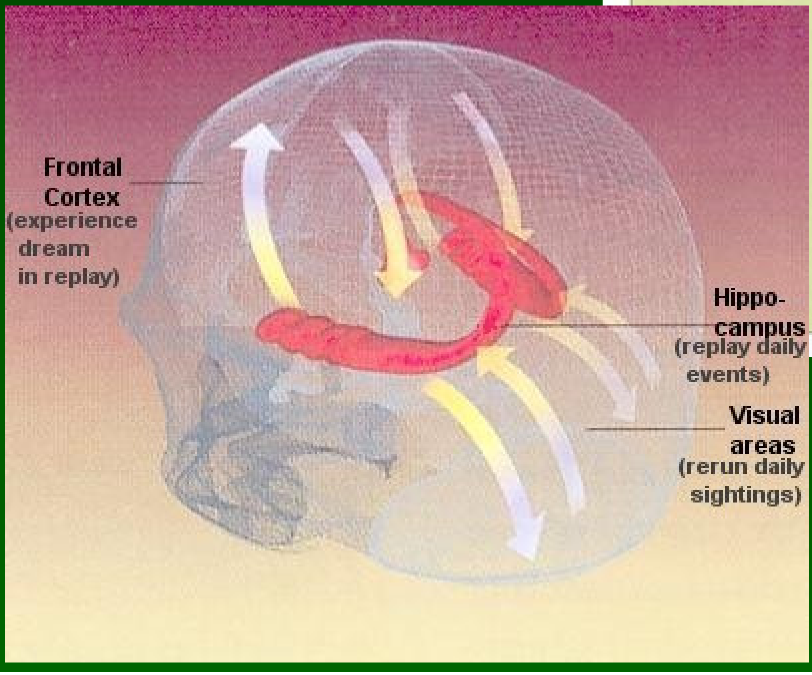
  Mnemotechnics: memory palace, or method of loci.



Spatial memory

Hippocampus is well connected to sensory cortices and to the frontal parts of the brain.



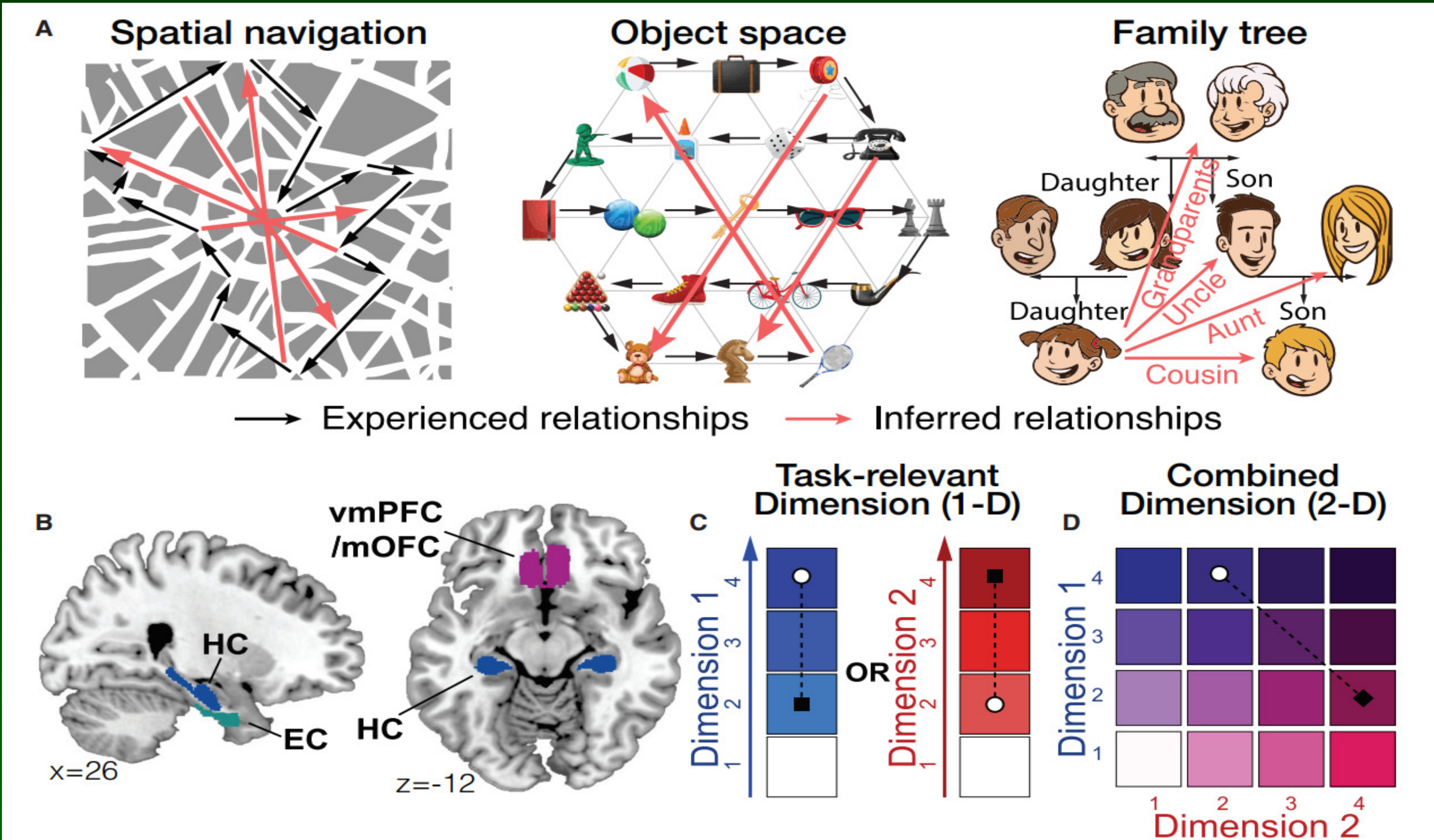


Hippocampus plays a major role in memory consolidation and in spatial memory required for orientation and navigation.

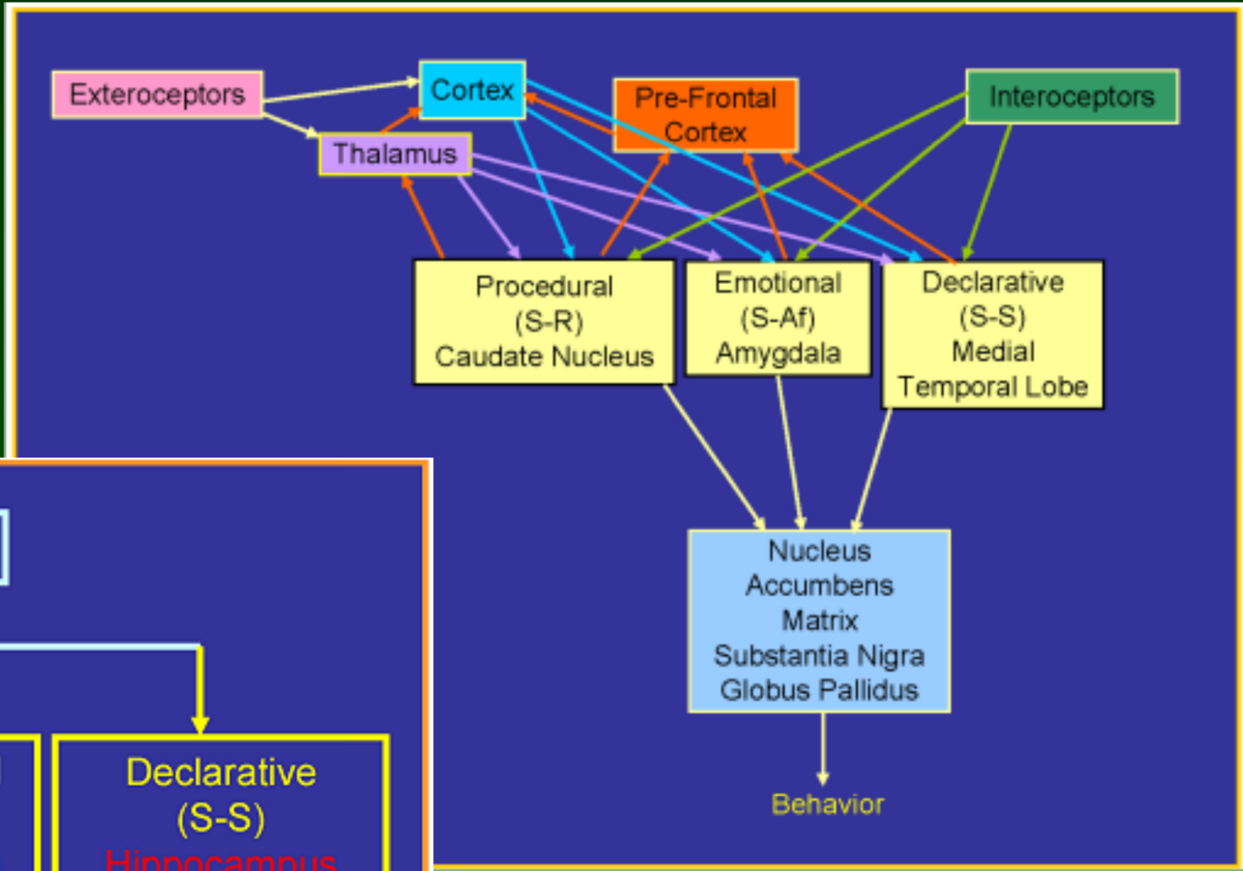
Abstract Cognitive Maps

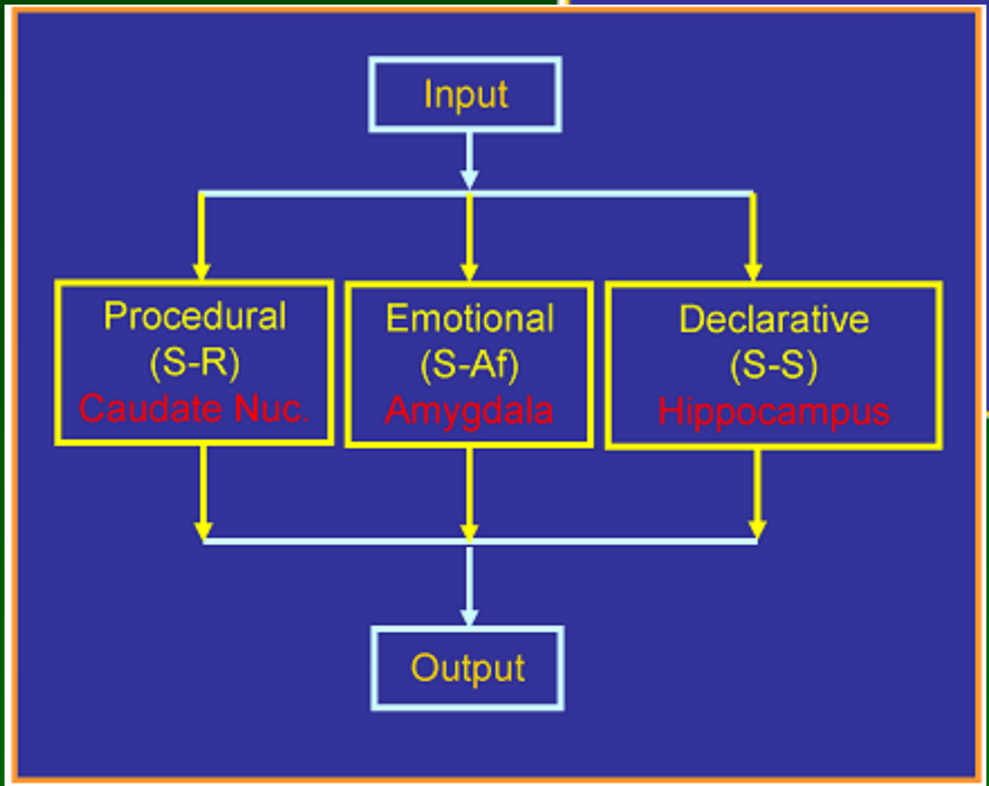
Nobel Prize for grid/place cells to Edvard & May-Britt Moser and J. O'Keefe.

S.A. Park et al, Map Making: Constructing, Combining, and Inferring on Abstract Cognitive Maps. Neuron 07, 1226-1238.E8, 2020.



Memory interactions

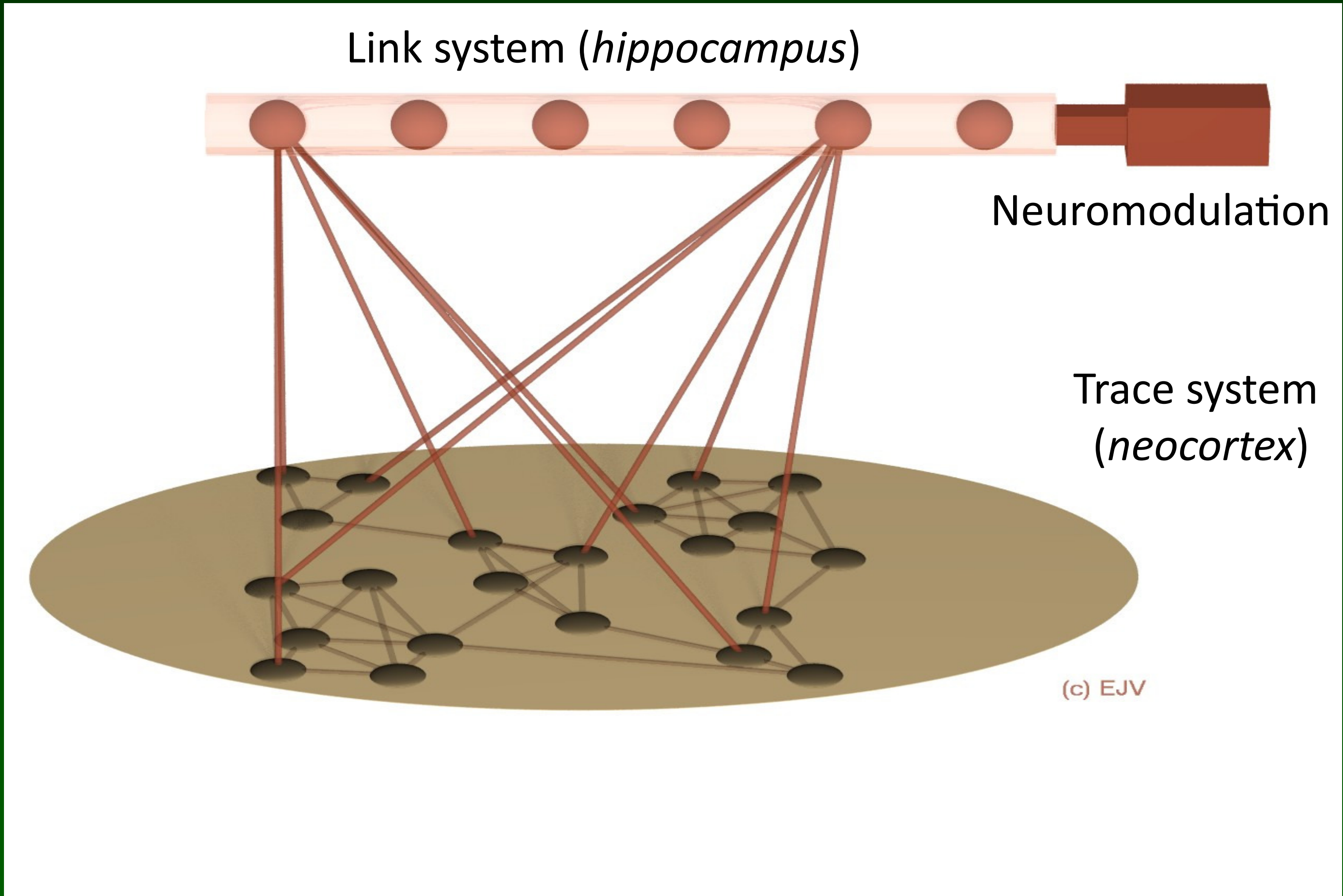




Controlled/automatic action

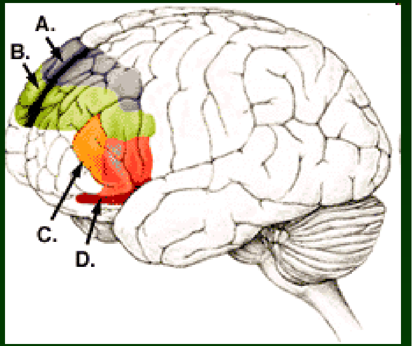
- Automatic: routine, simple, low level, sensory-motor, conditional reflexes, associations – easy to model with a network (but emotional memory and phobias have not been modeled).
- Controlled: conscious, elastic, requiring sequences of actions, selection of elements from a large set of possibilities – usually realized in a descriptive way with the help of systems of rules and symbols.
- Models postulating central processes: like in a computer, working memory with a central monitor, having influence over many areas.
- Here: emergent processes, the result of global constraint fulfillment, lack of a central mechanism.
- The prefrontal cortex can exert control over the activity of other areas, so it's involved in controlled actions, including the representation of "me" vs. "others", social relationships etc.

Trace-link model (J. Murre)



Hippocampus may recreate activation of the cortex => episodic memory. Brain stem and emotion-related areas (nucleus accumbens, amygdala) provide increase plasticity. This model explains many features of amnesia.

Working memory



Prefrontal cortex plays central role in maintaining active working memory and has the required properties: isolated self-activating attractor networks with broad attraction basins.

Neuroanatomy, connectivity and minicolumns in PFC predispose it to be a specialized area for active memory.

Human PFC has a number of areas that specialize in different types of WM"

- A. PR – spatial relations.
- B. PR – spatial for volitional, self-ordered tasks.
- C. PR – spatial, objects, verbal, volitional actions and analytical thinking.
- D. PR – objects, analytical thinking.

Typical experiments are done on macaques (multi-electrode direct recordings) and humans (fMRI), involve delayed choice requiring WM maintenance.

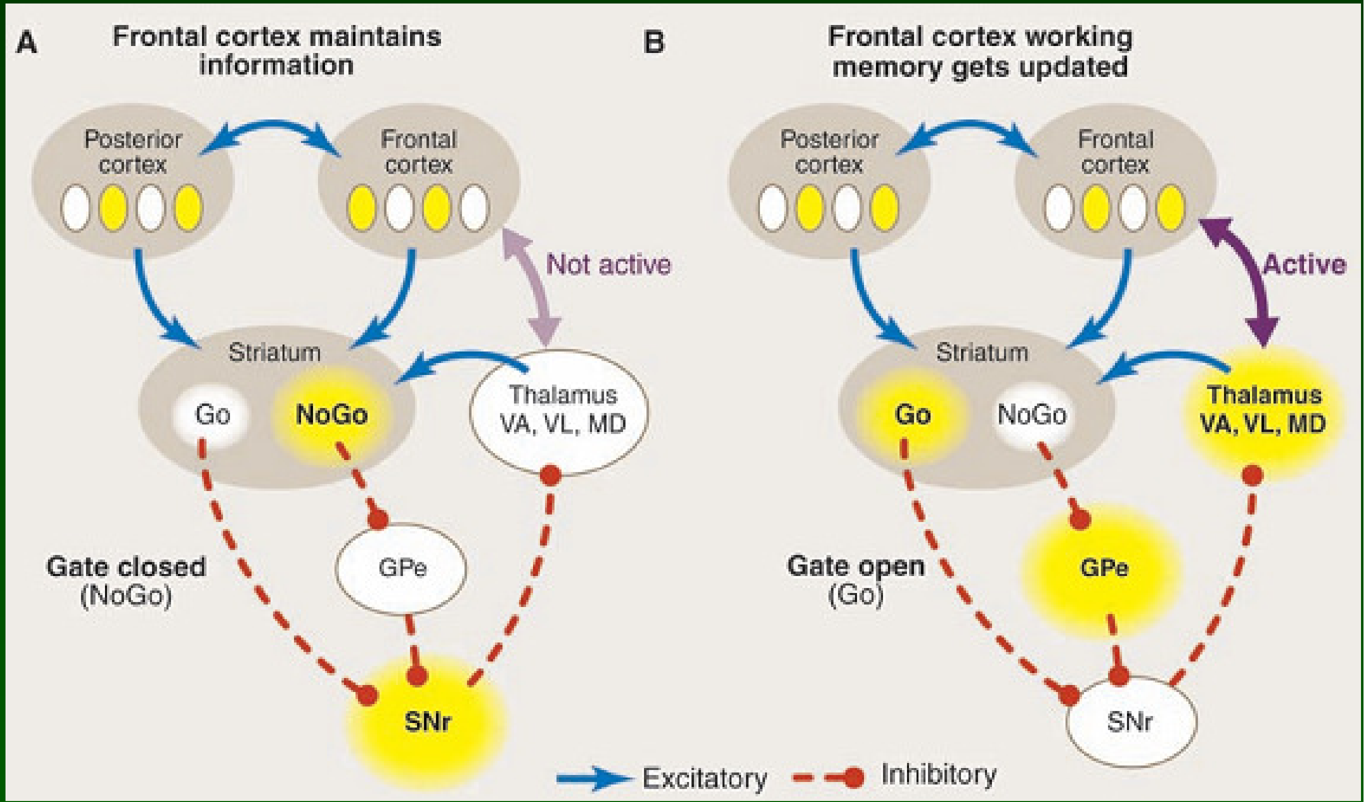
They show differences between PFC maintaining representations for a long time, and PC and IT, able to sustain activity only for a short time.

Dynamic gating of WM

Dynamic gating idea (OReilly, R.C, Biologically Based Computational Models of High-Level Cognition. Science, 314, 91, 2006).

Dopamine in PFC comes mostly from VTA and SNr areas in the in the midbrain.

Dopamine amplifies the influence of external inputs, regulating access to the working memory, providing dynamic gating.



Striatum: large subcortical structures – caudate nucleus, putamen nucleus, part of larger basal ganglia system, all are important for procedural memory and learning behaviors. Cerebellum is also strongly involved in procedural memory.

Role of consciousness

Declarative vs. procedural knowledge

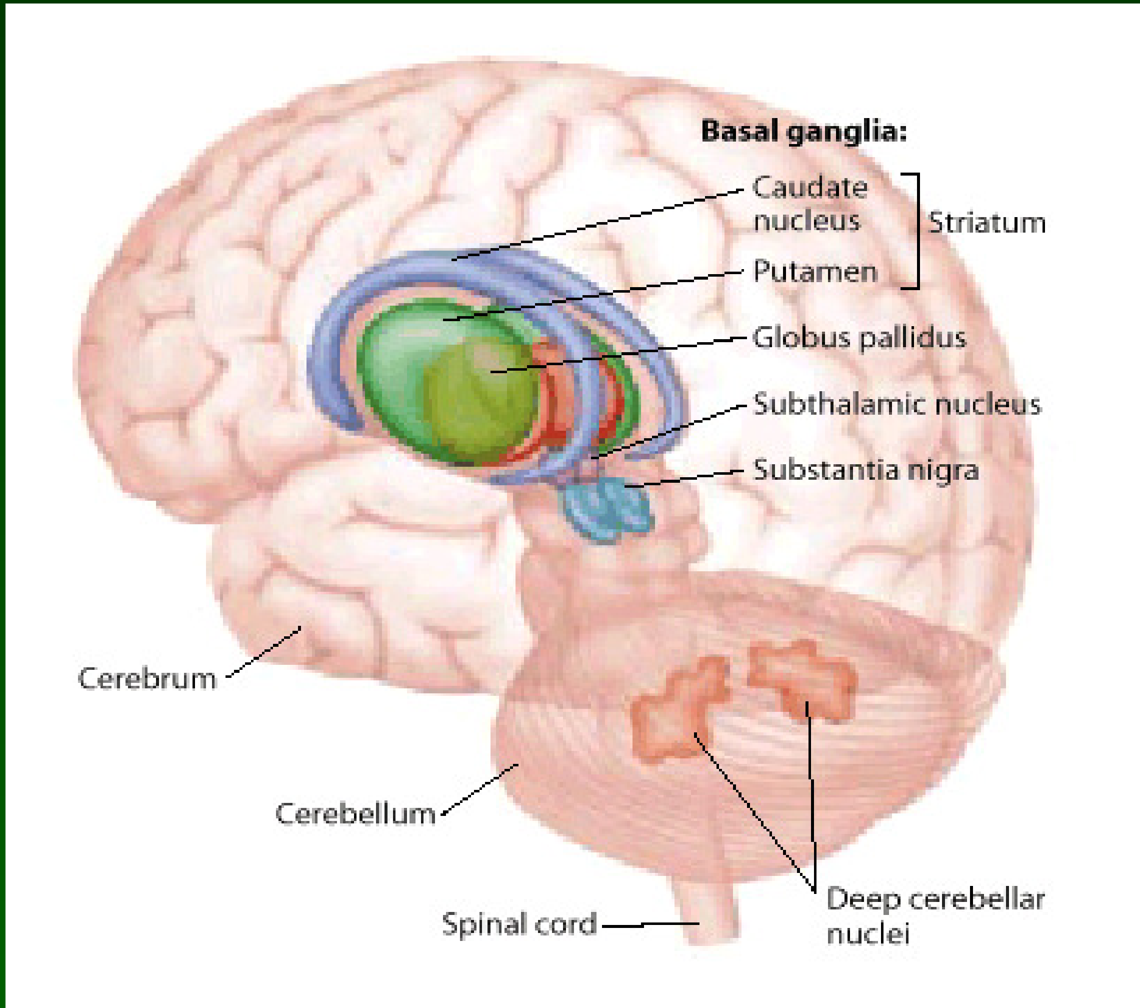
- Declarative: often expressed symbolically (words, gestures). Procedural: more oriented towards sequences of actions.

Explicit vs. implicit knowledge

- Controlled action relies on explicit and declarative knowledge.
- Automatic actions rely on implicit and procedural knowledge.
- Consciousness => states existing for a noticeable period of time, integrating reportable sensory information about different modalities, with an influence on other processes in the brain.
- Each system, which has internal states and is complex enough to comment on them, will claim that it's conscious.
- Processes in the prefrontal cortex and the hippocampus can be recalled as a brain state or an episode, can be interpreted (associated with concept representation).

Basal ganglia

Thalamo-striato-cortical activity loops involve basal ganglia.

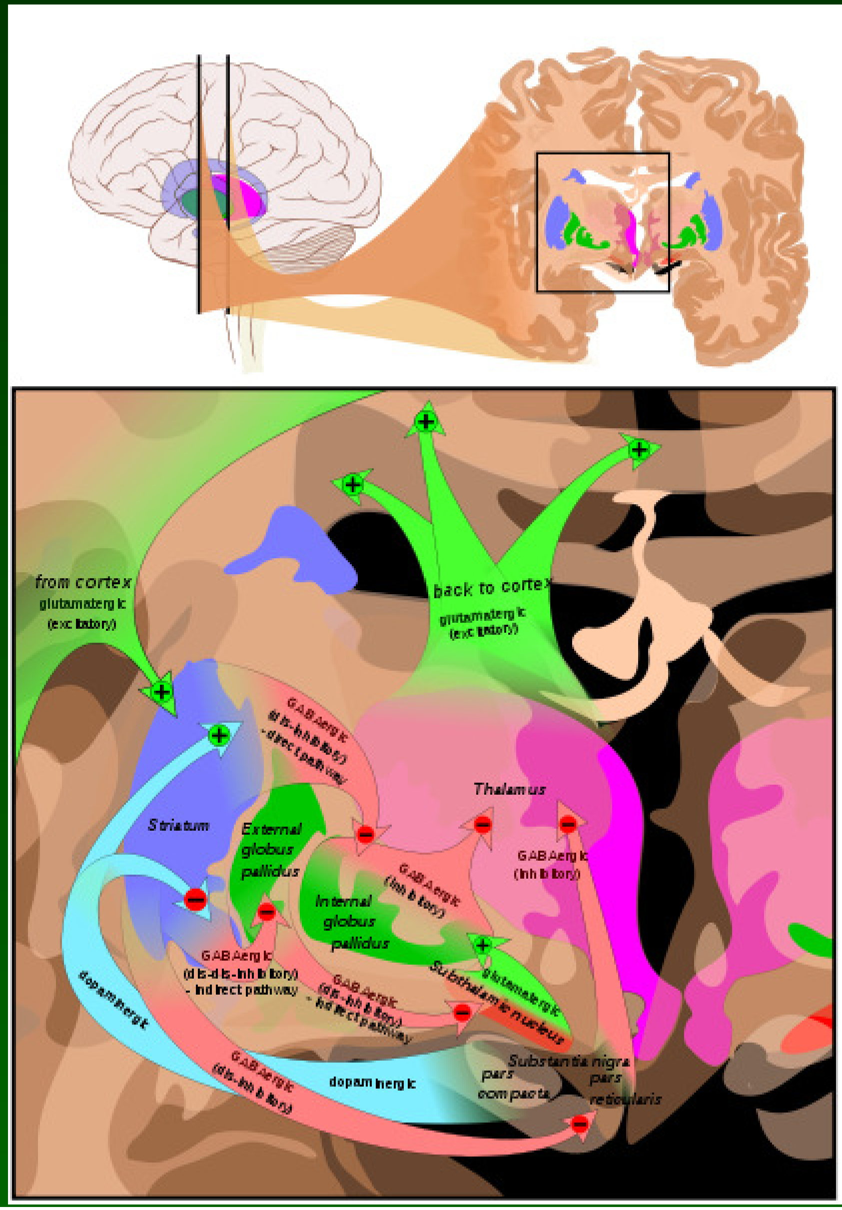


Basic BG structures: GP – Globus Pallidus, Putamen and Substantia Nigra.

Basal ganglia circuits

Wikipedia on basal ganglia.
Striatum is shown in blue.
Upper part shows coronal slices superimposed to include the basal ganglia structures.
+ and - signs in arrows indicate the excitatory or inhibitory pathways.

Green arrows refer to excitatory glutamatergic pathways,
red arrows refer to inhibitory GABAergic pathways and turquoise arrows refer to dopaminergic pathways that are excitatory on the direct pathway and inhibitory on the indirect pathway.



Addiction

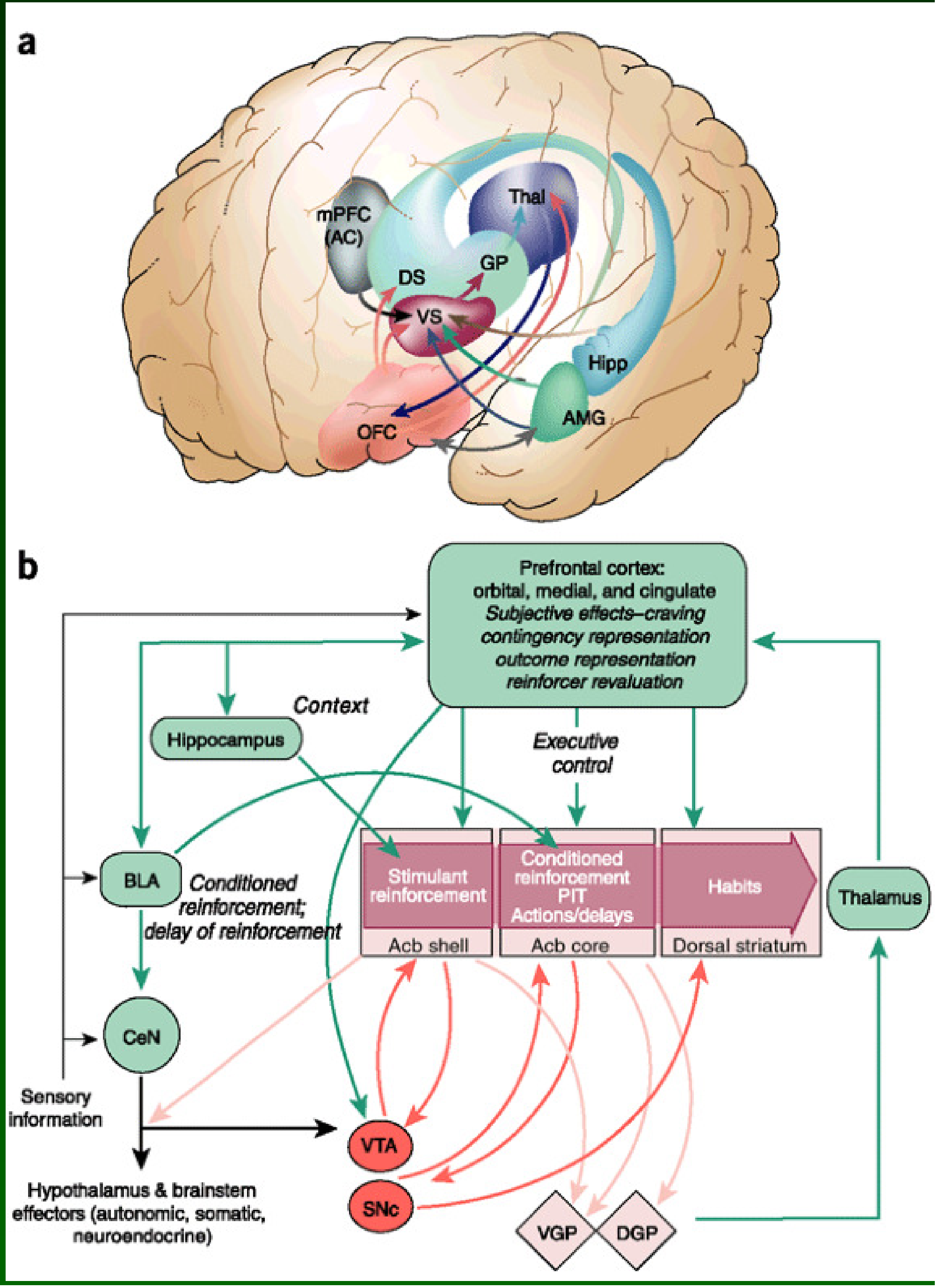
Limbic circuits involved in learning drug addictions, from hedonic use to habitual and to compulsive use.

PFC => striatal control, ventral to dorsal striatum dopaminergic innervation.

Green/blue=glutamate, orange= dopamine; pink=GABA projections.

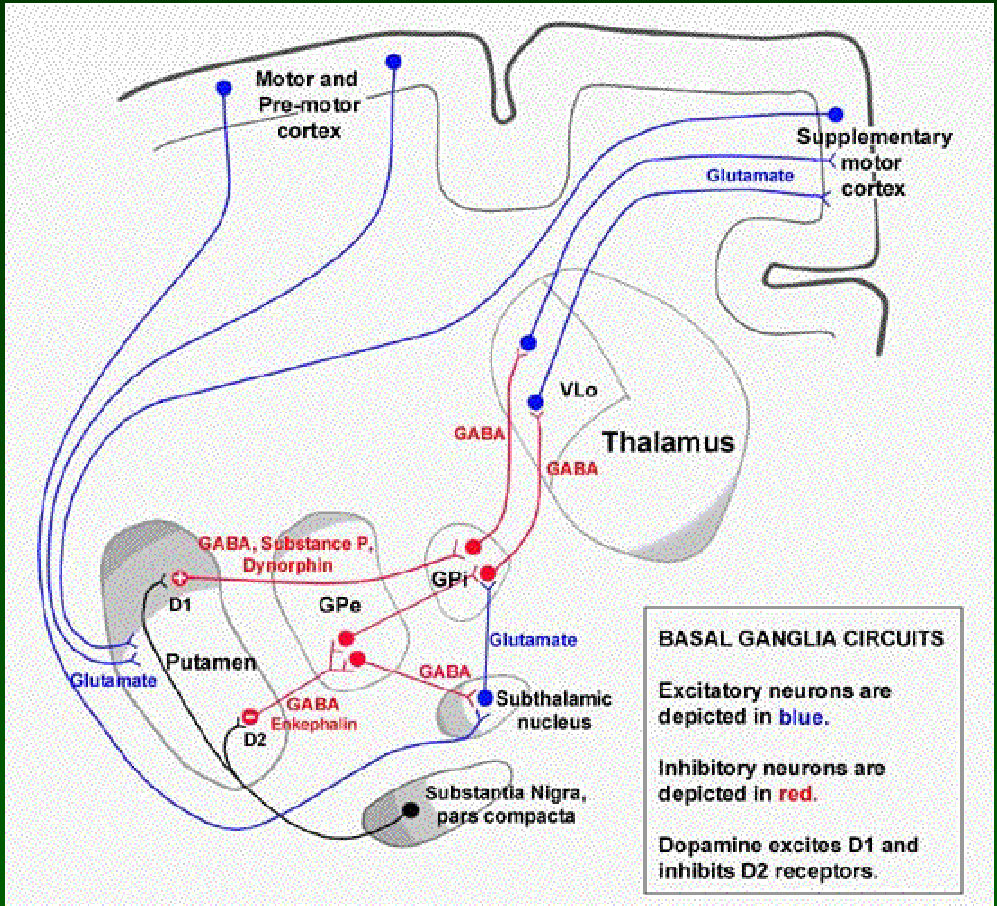
Acb=n. accumbens; AMG= amygdala; BLA basolateral; CeN, central nucleus; VTA=ventral tegmental area; SNc, substantia nigra; GP=globus pallidus (D, dorsal; V, ventral); Hipp = hippocampus; mPFC= medial prefrontal cortex; AC = anterior cingulate; OFC= orbitofrontal cortex; VS, ventral striatum; DS, dorsal striatum; Thal, thalamus.

BJ Everitt, TW Robbins, Nature Neuroscience 8, 1481 (2005). Neural systems of reinforcement for drug addiction: from actions to habits to compulsion.



Basal ganglia loops

More detailed view of the thalamo-striato-cortical loops.



Red lines = inhibitory connections, using mostly GABA neurotransmitters.

Blue lines = excitatory connections, mostly glutaminian transmitter.

Black lines = dopamine, mostly inhibition, some excitation.

Dysfunctions of these loops lead to Parkinson, Huntington and many other diseases.

Major large structures: GP – Globus Pallidus and Putamen; deeper structure releasing dopamine: Substantia Nigra.

Other types of memory

Traditional approach to memory assumes functional, cognitive, monolithic canonical representations of memory states.

Modeling approach shows many brain subsystems that participate in some form of memory, with various characteristics, handling different type of representations and information.

Recognition memory: have you seen it before?
Experiments are done usually with lists of items.

Internal signal, feeling „I recognize it", is sufficient, recall is not needed.

Model of hippocampus is useful also here, it also allows for memory recall. For recognition memory this is too much, the main role belongs here to the old perirhinal cortex, close to the olfactory bulb.

Cued recall requires recognition of memory states with sufficient cues.

Free recall shows various effects of where items are played on the list. Those memorized best are at the beginning and the end of the list, chunking of information on the list also has a role.

7 sins of memory

Daniel L. Schacter, The Seven Sins of Memory: How the Mind Forgets and Remembers. Houghton Mifflin Co, 2001

1) The Sin of Transience: decreasing accessibility is normal with aging, but damage to the hippocampus and temporal lobe can cause extreme forms.

2) The Sin of Absent-mindedness: lapses of attention and forgetting to do things, both at the the encoding stage and the retrieval stage.

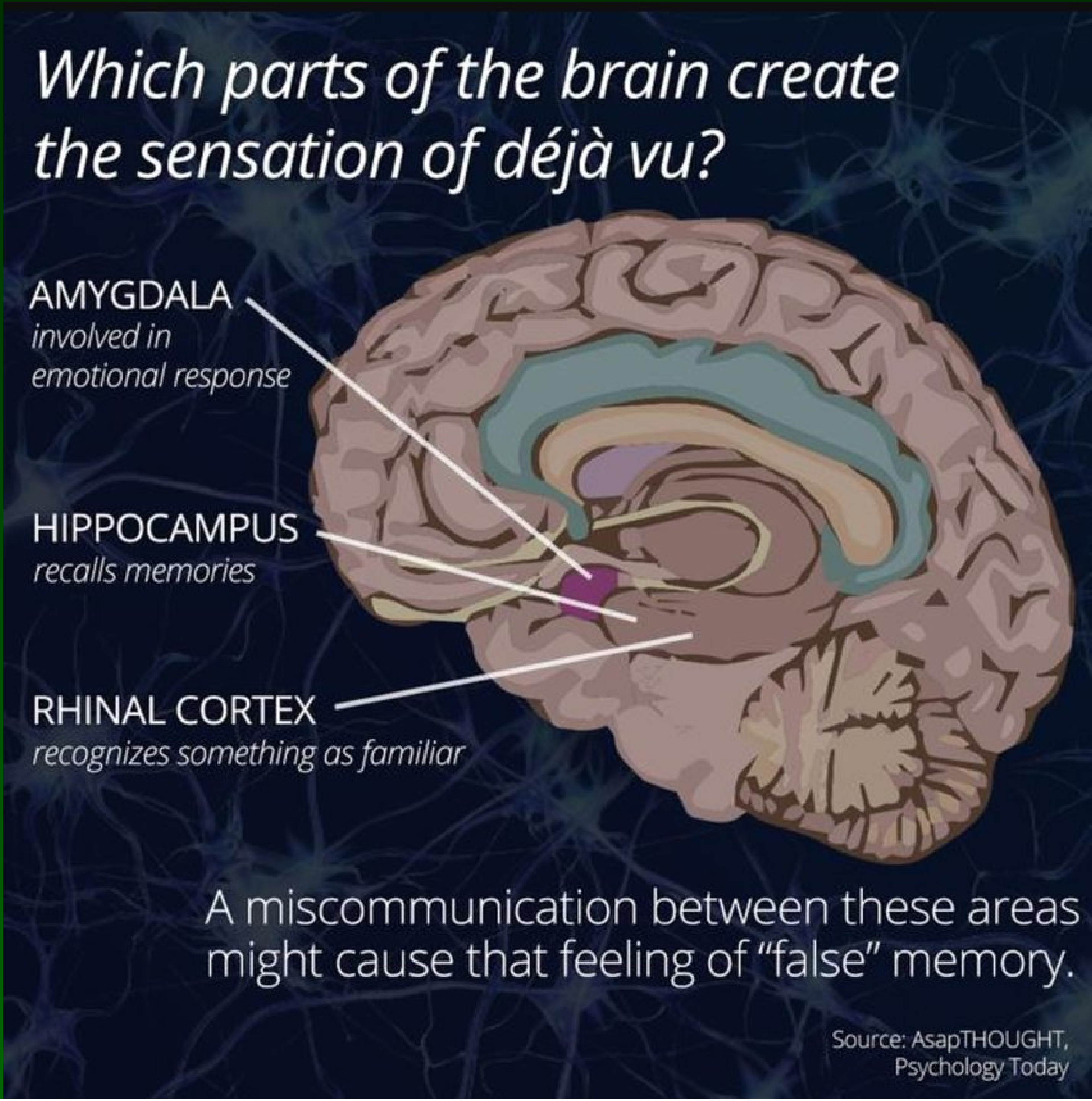
3) The Sin of Blocking: temporary inaccessibility of stored information, such as tip-of-the-tongue syndrome.

4) The Sin of Suggestibility: slipping suggestions into memory, priming.

5) The Sin of Bias: distortions produced by current knowledge and beliefs.

6) The Sin of Persistence: intrusive memories that wont go away, PTSD.

7) The Sin of Misattribution: attribution of memories to incorrect sources or believing that you have seen or heard something you haven't. Déjà Vu.


Which parts of the brain create the sensation of déjà vu?
AMYGDALA
involved in emotional response
HIPPOCAMPUS
recalls memories
RHINAL CORTEX
recognizes something as familiar
A miscommunication between these areas might cause that feeling of "false" memory.
Source: AsapTHOUGHT, Psychology Today