Modeling executive functions in the prefrontal cortex

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Prediction learning
Value of Stimuli (Primary/Learned goals and sub-goals)

Decision Making
Value of Actions (motor decision, options, planning)

- Interoception
- Motivational and emotional evaluation

- Exteroception
- Sensorimotor relations

Behavior and Cognition:
A matter of loops ...

DEFINING EXECUTIVE CONTROL FOR A COGNITIVE AGENT IN ECOLOGICAL CONDITIONS, BY AUTONOMOUS LEARNING
- ROLE OF THE LOOPS BETWEEN THE FRONTAL CORTEX AND THE BASAL GANGLIA FOR PREDICTING VALUES, DECISION MAKING AND PLANNING
- THE LIMBIC LOOPS DECIDE FOR THE GOAL AND THE ACTION
- THE ASSOCIATIVE LOOPS BIAS THE DEFAULT BEHAVIOR
- THE MOTOR LOOPS EXECUTE THE BEHAVIOR
- FORWARD MODELS ASSOCIATED WITH LIMBIC AND ASSOCIATIVE LOOPS
- THE TASK SET, POWERFUL CONCEPT TO DESCRIBE THIS PROCESS

AUTONOMOUS LEARNING

WE DEFINE OUR GOALS BY OURSELVES :
- DETECTION OF PRIMARY REINFORCERS
- LEARNING OF SECONDARY REINFORCERS
- ATTENTIONAL PROCESSES

WE HAVE A MOTIVATION TO ACT :
- FUNDAMENTAL NEEDS
- INTRINSIC MOTIVATION
- GOAL-DRIVEN BEHAVIOR

WE SELF-EVALUATE OUR PERFORMANCES :
- META-CONTROL

WE ASSOCIATE DIFFERENT KINDS OF LEARNING AND INFORMATION REPRESENTATION :
- CUES
- ABSTRACTIONS
- EPISODES
- WORKING MEMORY

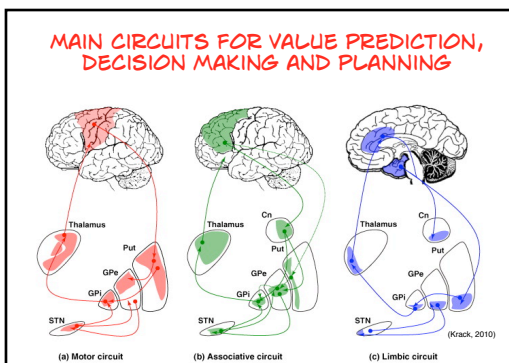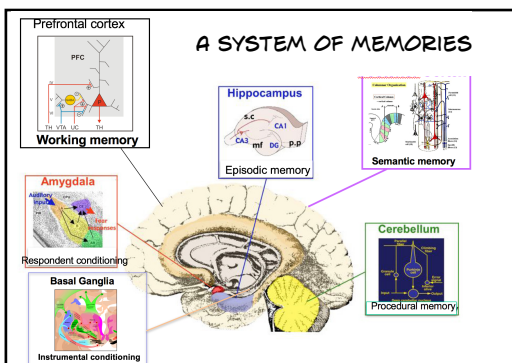**WE CUMULATE AND RE-EXPLOIT PREVIOUSLY LEARNT KNOWLEDGE AND STRATEGIES IN DIFFERENT CONTEXT :**
- LIFE-LONG LEARNING AND TRANSFER LEARNING

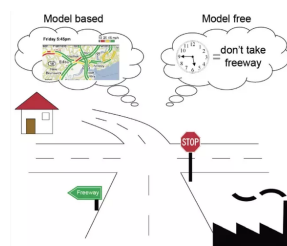**WE ADAPT EVEN IF THE WORLD IS CHANGING AND UNCERTAIN :**
- STOCHASTICITY AND VOLATILITY

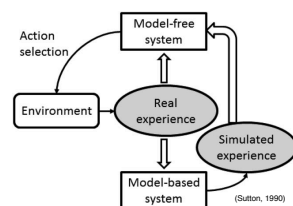# Modeling executive functions in the prefrontal cortex
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A SYSTEM OF MEMORIES

Prefrontal cortex
PFC
Working memory

Hippocampus
s.c
CA1
CA3 mf DG P-P
Episodic memory

Semantic memory

Amygdala
Respondent conditioning

Cerebellum
Procedural memory

Basal Ganglia
Instrumental conditioning

MAIN CIRCUITS FOR VALUE PREDICTION, DECISION MAKING AND PLANNING

Thalamus — Put — GPe — GPi — STN
(a) Motor circuit

Thalamus — Cn — Put — GPe — GPi — STN
(b) Associative circuit

Thalamus — Cn — Put — GPe — GPi — STN
(c) Limbic circuit

(Krack, 2010)

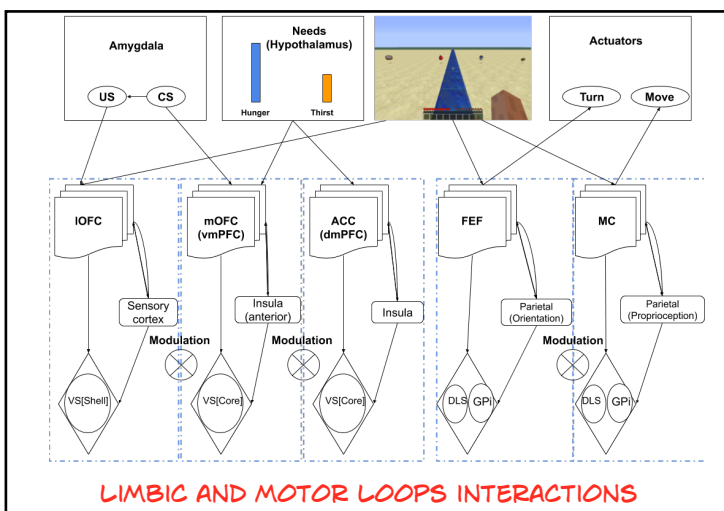## MODEL-BASED AND MODEL-FREE REINFORCEMENT LEARNING

Model based

Model free
don't take freeway

- MODEL-FREE (MF): LONG TO LEARN, COMPACT
- MODEL-BASED (MB): USE FORWARD MODELS, MORE FLEXIBLE BUT HEAVY TO COMPUTE
- WITH FORWARD MODELS, GOAL-DRIVEN STRATEGIES MORE TRACTABLE THAN STIMULI-DRIVEN STRATEGIES

Action selection

Model-free system

Environment — Real experience — Simulated experience

Model-based system
(Sutton, 1990)

- MF CONTROLS THE BEHAVIOR
- MB TRAINS MF BY REPLAYS (RETROSPECTIVE MEMORY) AND SIMULATIONS (PROSPECTIVE MEMORY)

ROLE OF THE LIMBIC LOOPS : FORAGING OR DECISION BETWEEN SEVERAL TARGETS ?

- **LOFC: LEARNS VALUES** OF STIMULI (PAVLOV); MENU DEPENDENT; SENSORY REPRESENTATION OF REWARDS, CONSUMMATORY BEHAVIOR, MODEL BASED; SELECT THE BEST TWO OPTIONS

- **MOFC:** REWARD REPRESENTATION FOR PREPARATORY BEHAVIOR (OPERANT, MODEL FREE), INTEGRATE LEVELS OF NEED; VALUE DIFFERENCE SIGNAL; **DECIDE FOR THE GOAL**

- **ACC:** INTEGRATE COST OF EFFORT TO **DECIDE FOR THE ACTION**; INVERSE VALUE DIFFERENCE SIGNAL; IF STRONG SIGNAL OF CONFLICT, ASK FOR A SWITCH

- **FEF: ORIENTATION** TOWARD THE GOAL
- **MC: MOVE FORWARD** FOR GOAL CONSUMPTION

LIMBIC AND MOTOR LOOPS INTERACTIONS

Amygdala
US — CS

Needs (Hypothalamus)
Hunger — Thirst

Actuators
Turn — Move

IOFC — mOFC (vmPFC) — ACC (dmPFC) — FEF — MC

Sensory cortex — Insula (anterior) — Insula — Parietal (Orientation) — Parietal (Proprioception)

Modulation

VS[Shell] — VS[Core] — VS[Core] — DLS GPi — DLS GPi

TASK SET
SET OF REWARDING S-R ASSOCIATIONS LEARNED IN THE SAME CONTEXT

- USE THE DEFAULT TASK SET, OR SWITCH OR CREATE A NEW ONE
- EXOGENOUS CONTROL (COMPETITION FROM STIMULI)
- ENDOGENOUS CONTROL (BIASING FROM GOALS)

Task-Set i
Task-Set 1
Action-Set 1
Action-Set n

(Domenech, 2015)
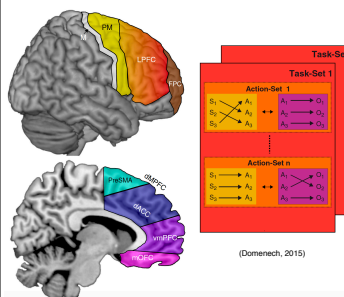
ASSOCIATIVE LOOPS : BIAS THE DEFAULT BEHAVIOR
TOP-DOWN CONTROL OF BEHAVIOR BY PFC AND HIPPOCAMPUS

- PFC CAN BIAS COMPETITION FOR NON-DOMINANT BEHAVIOR
- ROLE OF LPFC FOR WORKING MEMORY AND ATTENTIONAL PROCESSES

- THE HIPPOCAMPUS CAN RAPIDLY BIND ARBITRARY REPRESENTATIONS NOT YET FORMED IN THE CORTEX
- EXPLICIT REPRESENTATION OF EPISODES AND REPLAYS

- DEFINE SUBGOALS (INTENTIONS, MEANS) AND THOUGHTS (COVERT ACTIONS ENCODED BY THEIR PERCEPTUAL EFFECTS, FORWARD MODELS)