Advanced Research
Intelligent
Embedded
Systems

Emotional cognitive mechanisms for embedded systems

Intelligence for Embedded Systems

Ph. D. and Master Course

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Cognitive Embedded Systems

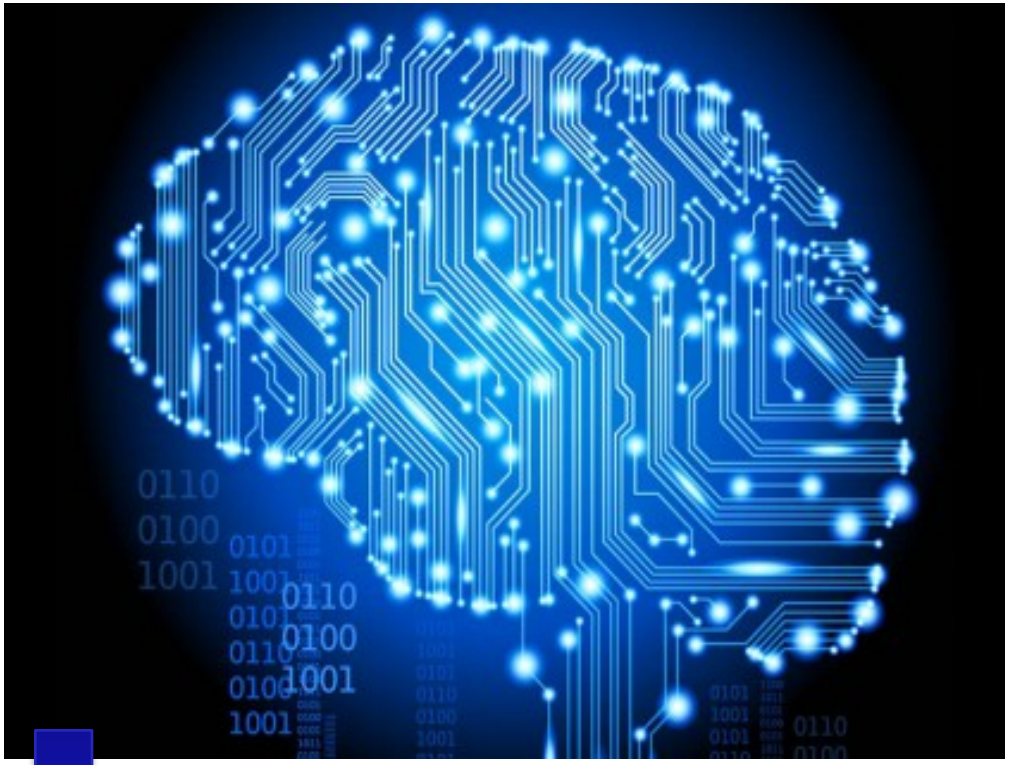
- The future of intelligent embedded systems is oriented towards the implementation, either in software or hardware, of cognitive mechanisms
- However, the predicted future is not something will happen decades from now
  - ✓ Adaptation is a basic form of cognition associated with elementary automatic reactions
  - ✓ Many embedded solutions present in the market introduce adaptation mechanisms at various levels
  - ✓ Technological advances in the hardware permit the execution of sophisticated embedded solutions

The future of embedded systems has started already…

What is a Cognitive Embedded System?

A cognitive embedded system is an embedded system that takes advantage of cognitive processes to propose intelligent solutions

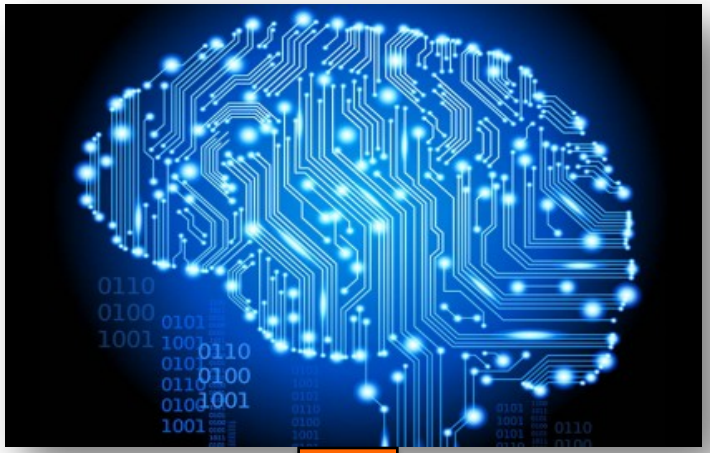
Cognitive processes in human brain



- Providing an engineering-oriented perspective of brain functions
- Functional description of some basic processes of the human brain, with a special focus on emotional and cognitive processing

Apply ”lessons” from the brain to embedded systems
(and not to duplicate the way the brain works)

Cognitive processes in human brain (2)



Intelligence for Embedded Systems

- Many **mechanisms** introduced in subsequent lectures,
  - adaptation mechanisms
  - energy efficiency
  - learning in non-stationary environments
  - cognitive fault diagnosis

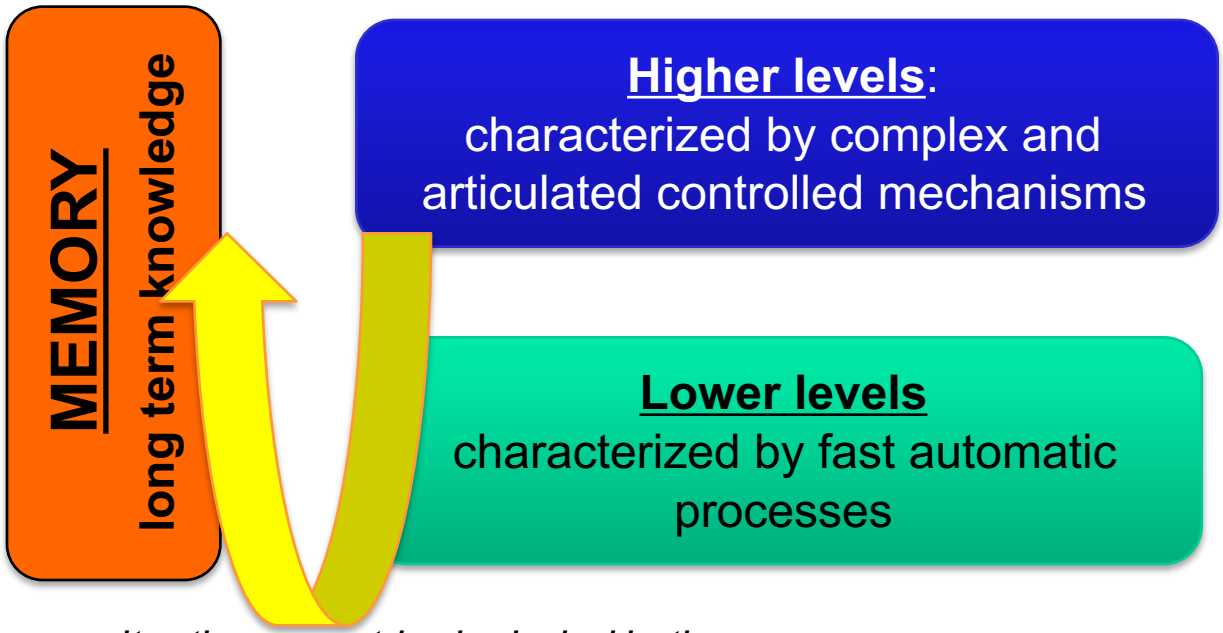
can be immediately **cast within a cognitive processing of human brain**

Emotional cognitive processing: an example

It’s just a picture!

Emotional cognitive structure

- Brain phenomena can be modeled as a **hierarchy of subsystems** differentiating in time activation and accuracy levels that, possibly, rely on a **memory** containing knowledge suitably stored for decision making



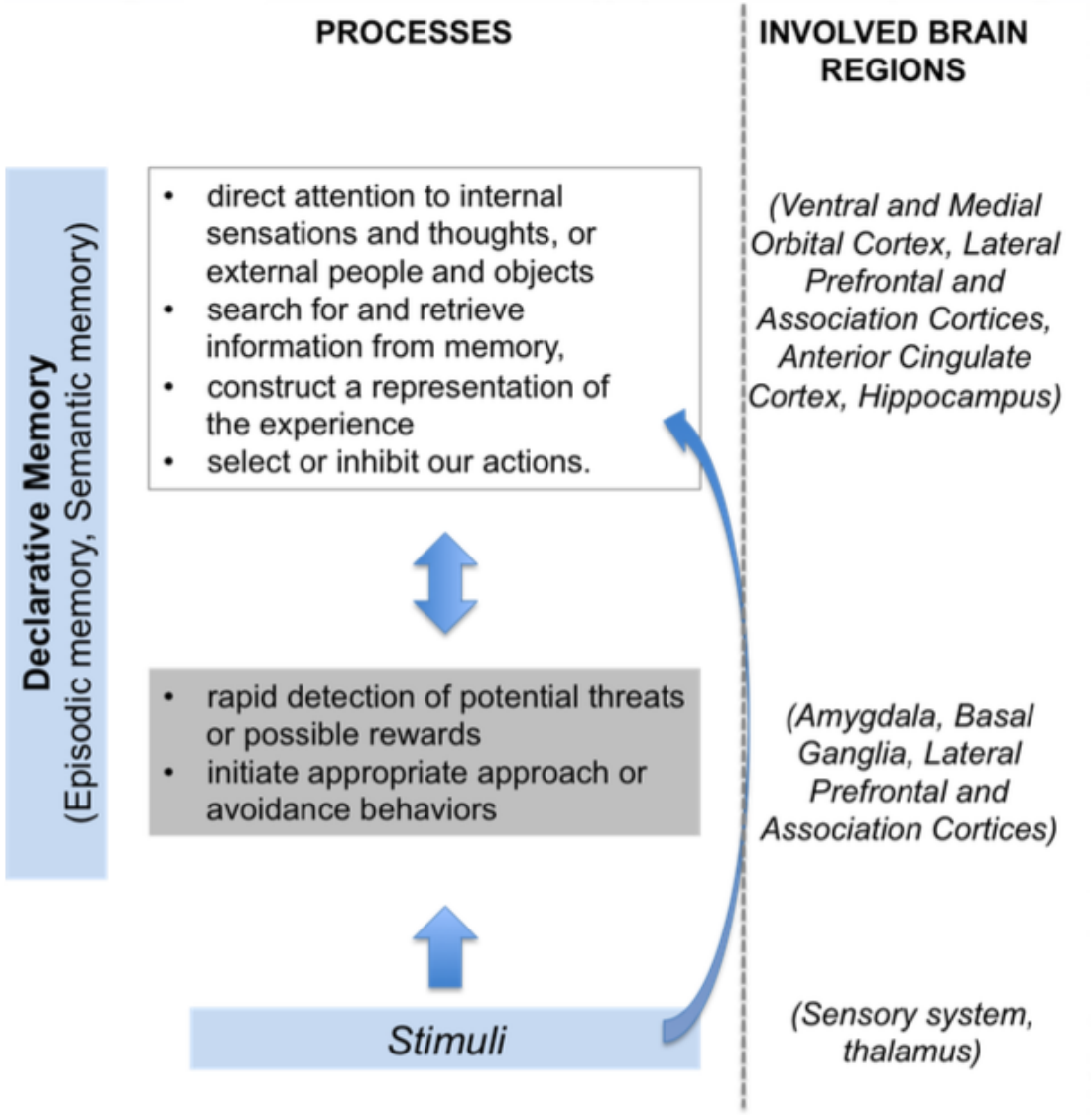
new situations must be included in the processing mechanism and stored in memory

Emotional cognitive structure: lower and upper levels

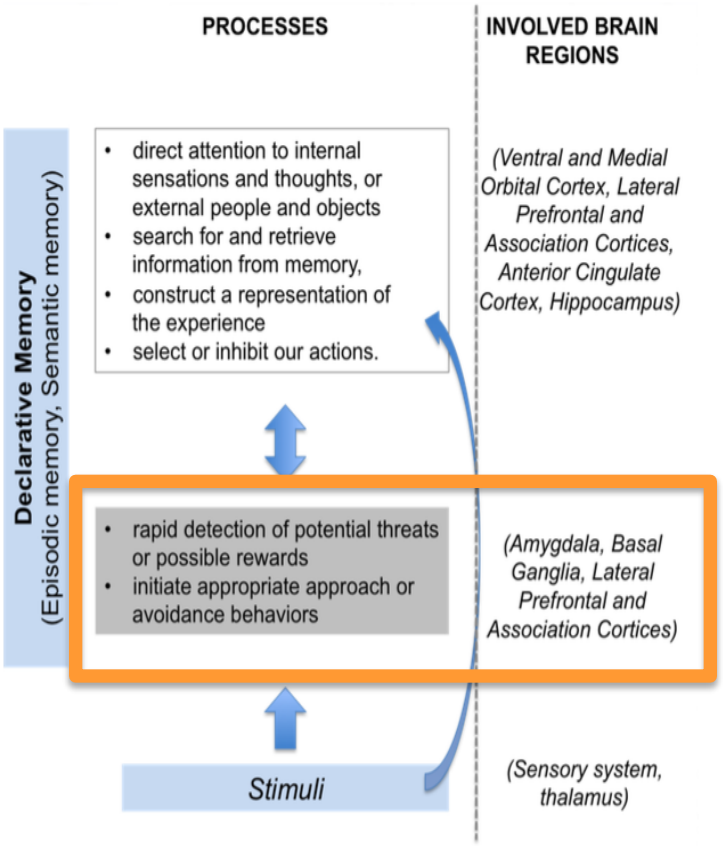
- **Lower levels (fast automatic processes)**
  - ✓ process stimuli to quickly take a decision and/or provide a prompt reaction
  - ✓ activate higher levels of knowledge processing
- **Higher level (complex controlled mechanisms)**
  - ✓ assess ongoing performance and abort/modify/complete actions and decisions made by lower levels
  - ✓ introduce feedback mechanisms by providing information to improve the learning

The joint activity of automatic and controlled processes allow us for modeling the emotional responses in humans

Automated and Controlled processes: the general overview



Automatic processes

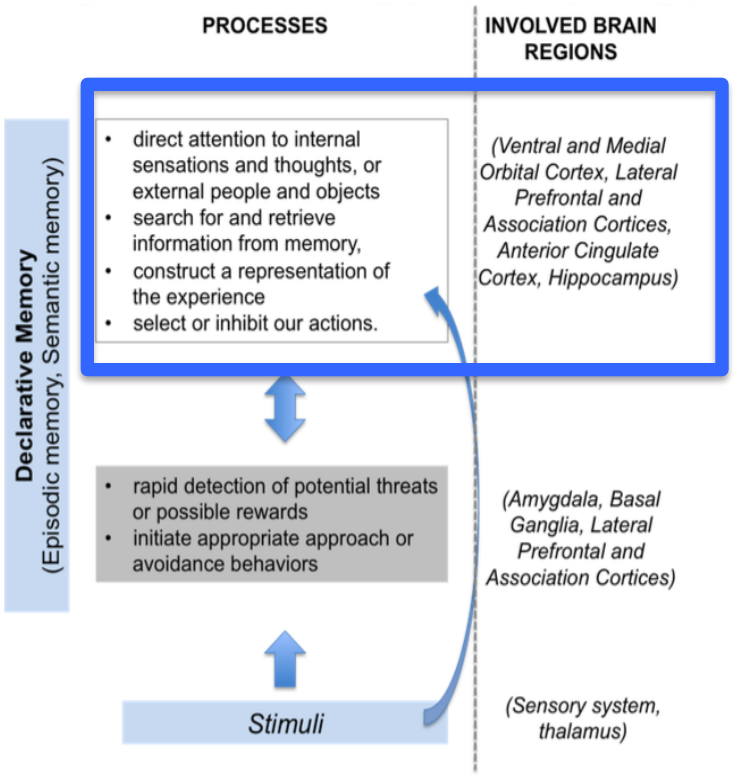


- **Lowest levels of the hierarchical cognitive system**
- Characterized by a **detection-reaction mechanism** designed to
  - ✓ quickly identify potential dangers
  - ✓ plan and schedule actions to get a reward
  - ✓ recall of previously acquired information related the situation/event/emotion
  - ✓ activation of a proper action/reaction, e.g., by increasing the heartbeat or the respiration rate and releasing stress-hormones following a perceived threat

Automatic processes (2)

- **Reduced latency** is more important than keeping under control the false positive rate following a **conservative primordial principle**:
  - *it is much better to react with an unnecessary action following a perceived -possibly new- threat than being insensitive to it*
- Meant to be **quick and effortless in generating an emotional response** to external stimuli such as presentation of faces, objects or events
- **Emotional response** (possibly together with additional environmental information) is then processed to **become part of the knowledge** (i.e., stored in the memory) to be recalled whenever necessary

Controlled processes



- **Consciously, we also direct attention to** our personal sensations, construct our emotional background, and select or inhibit actions depending on a lifetime experience
- After a preliminary automatic response, **cognitive processes are consciously activated** by higher levels of the cognitive hierarchical system

By deliberately monitoring, activating and processing emotions we can re-interpret and alter their meaning (learning mechanism), change the current personal experience and perception of the world as well as the way we interpret emotions and respond to stimuli

Controlled processes

- The use of computationally demanding processes in the generation and regulation of emotions is named *controlled emotion processing*
- The **main tasks carried out by controlled processes** can be summarized as
  - ✓ Select or inhibit the actions activated by automatic processes
  - ✓ Construct a representation of the emotional experience over time and perfect it according to the received external stimuli and the final situation outcome
  - ✓ Direct attention to internal sensations and thoughts
  - ✓ Search and retrieve information from the declarative memory

Processes and brain regions

Brain Regions	Function	Operations	Type of Process
Amygdala	Detecting, Learning about Stimuli	Detects potentially threatening stimuli and associates them with appropriate actions	Automatic
Basal Ganglia	Registering Rewards, Acquiring Habits, Selective gating of behavior	Mediates selection and initiation of actions, Automatizes sequences of behavior and reinforced thoughts	Automatic or controlled
Lateral prefrontal/ association cortices	Retrieving and Storing Semantic Emotion Knowledge	Identifies stimuli, differentiates feeling states; attributes emotional qualities to stimuli; repository of regulatory strategies, lay emotion knowledge	Retrieval can be automatic or controlled
Anterior Cingulate Cortex	Conflict Monitoring	Monitors on-going behavior and determines whether a change is necessary or not	Conflicts detected automatically, but making changes takes control
Ventral/ Medial Orbital Frontal Cortex	Context- dependent action selection	Inhibits on-going emotional responses based on analyses of context	Controlled
Hippocampus	Long-term strategies	Understanding spatial relations within the environment	Controlled

Amygdala

- **Complex and differentiated roles**
  - ✓ the detection of a threat by inspecting stimuli patterns
  - ✓ activating a reaction
  - ✓ modulating the long-term memory consolidation of stimuli-stimuli and stimuli-response association in the emotional declarative memory

How to cast it within the cognitive embedded systems framework?

The amygdala may be considered as a module processing stimuli patterns to detect threats. Similar to Change Detection Tests (CDTs)

Basal ganglia

- **Role**:
  - voluntary motor control (e.g., eyes control)
  - emotional processing leading to learn routine behaviors to attain rewards

Modeling time dependent events by means of dynamic systems or machine learning techniques (e.g., Markov processes) for forecasting purposes and define sequences of actions necessary to achieve a long-term goal by means of planning

Lateral prefrontal and association cortices (LPAC)

- Provides mechanisms enabling **the storage and retrieval of semantic emotion knowledge** as well as using the memory content to asses the relevance of stimuli and events
- **Access to this emotional database** is **automatic** during the generation of an emotional state, or when we **consciously** represent or label emotional states to draw inferences about those emotions we are experiencing

Knowledge management in recurrent adaptive classifiers. This knowledge is organized into concepts, each of which represents a memory of the state. Similar concepts can be fused together to improve/integrate the knowledge over time.

Anterior cingulate cortex (ACC)

- **Role**:
  - ✓ Assess the "congruence" of emotions and feelings that have been generated in response to external stimuli
  - ✓ Forecasting whether external stimuli would induce threats or pain in the future or not
- This capability, which is conscious, is **crucial in the activity planning** to achieve long-term goals.

The ACC activity is conceptually very close to the validation procedure of **hierarchical change detection tests**: in response to an event, signals are jointly evaluated to determine whether what perceived is a false alarm or represents a true change

Orbital and ventral-medial prefrontal cortices (OFC and VM-PFC)

- The role is closely related to the active approach modeling the human behavior:
  - **Emotions, stimuli and memory patterns** automatically generated by lower cognitive levels are **integrated and linked to the long-term memory** to define a "cognitive" high-level response
  - The **"cognitive" ability** resides in the capacity to **connect the memory systems with emotional systems** (amygdala) to evaluate the taken actions and recall associated somatic states

This approach is very close to cognitive analysis in distributed fault diagnosis systems where low level information is integrated and analysed by taking into account also the network topology (to distinguish among faults, change in the env. or model bias)

Hippocampus

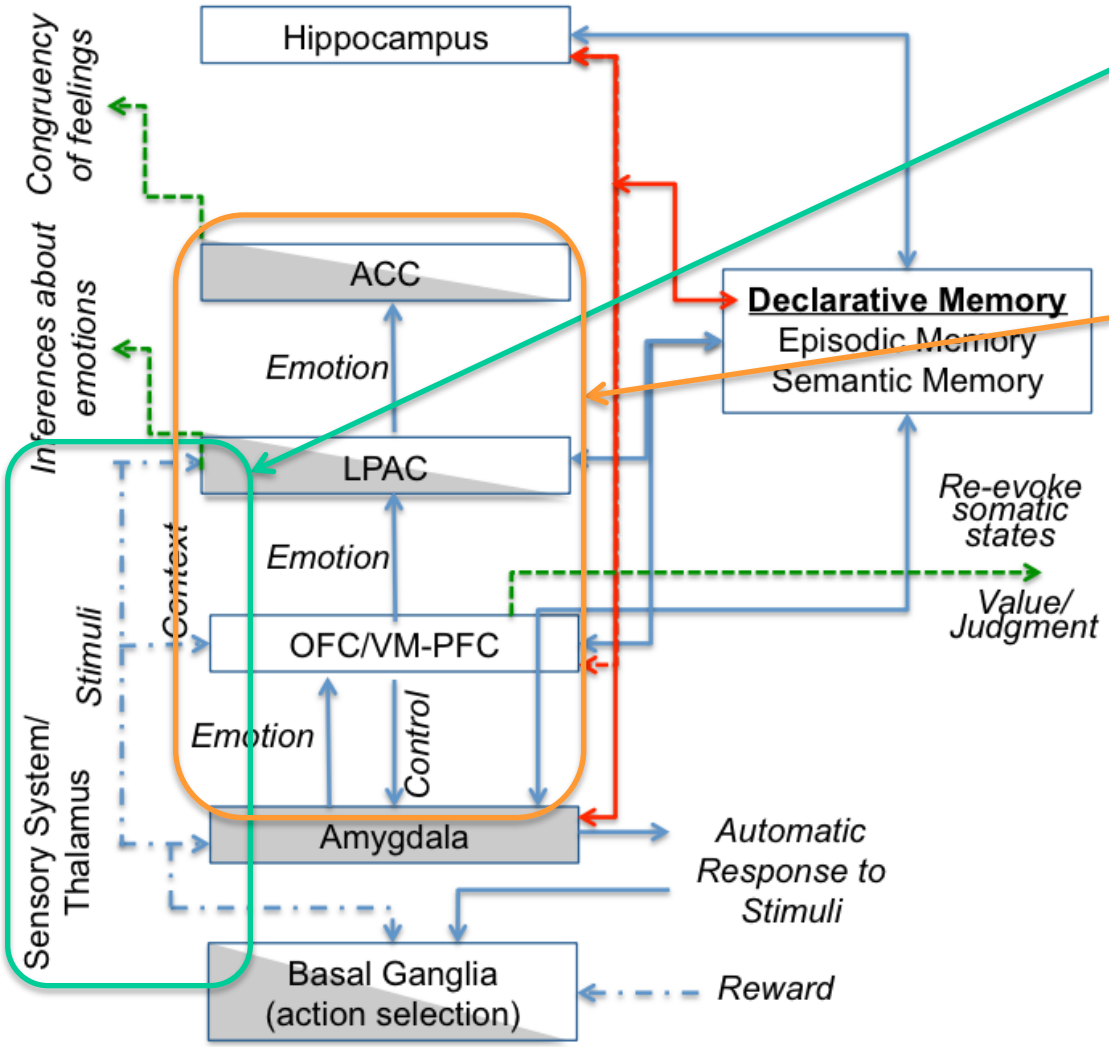
- An **old structure of cerebral cortex** that takes part in many declarative memory functions which refer to the memory of facts and events:
  - *Encoding and recalling information from the memory are the two main tasks of this fundamental subsystem.*
- **Interacts with the amygdala** in the formation of short-term memory, a preliminary step for the storage of long-term information

In intelligent embedded systems, the role of the hippocampus can be associated with the ability to recall previously acquired concepts whenever necessary (recurring concepts)

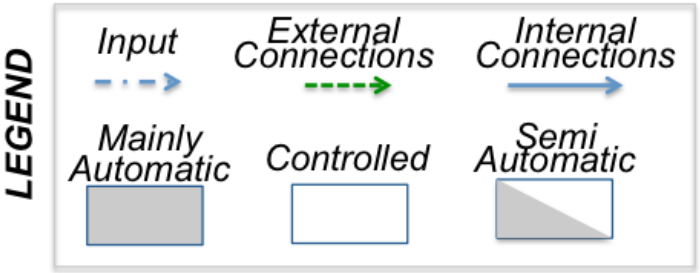
- **Emotions and decision making:**

Decision-making involves the orchestration of multiple neural structures and cognitive subsystems,
e.g., VM-PFC, amygdala, LPAC, and hippocampus

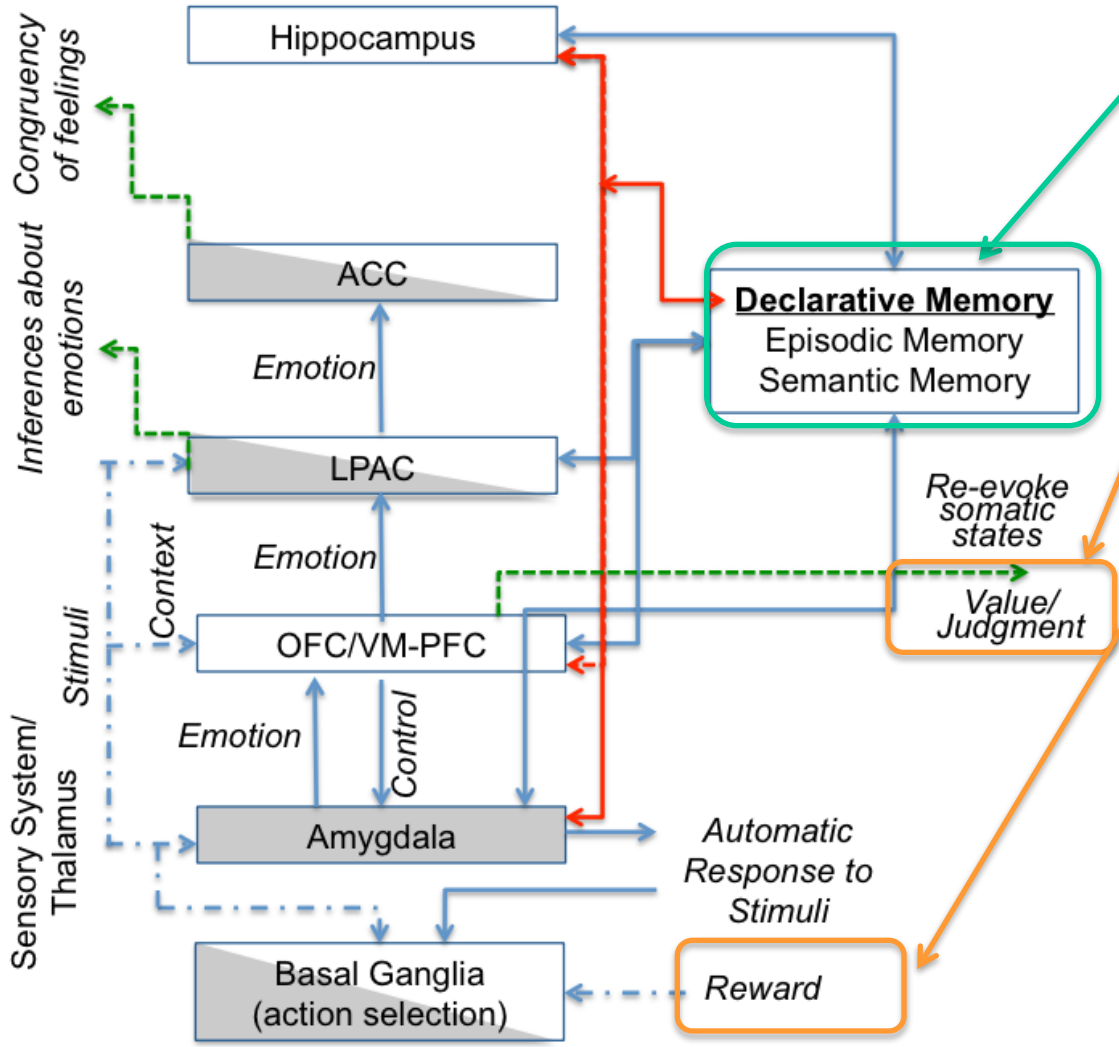
Emotion and decision-making



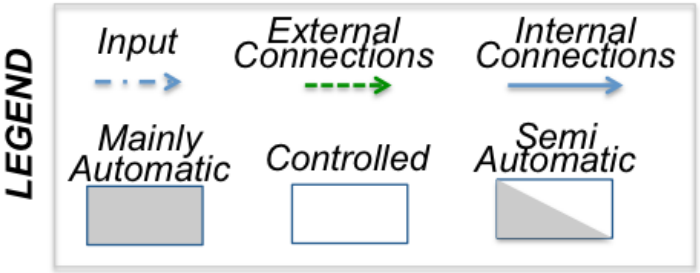
- **Sensory information** is acquired/processed by the sensory system/thalamus and forwarded to amygdala, OFC/VM-PFC and LPAC together with contextual information
- **Emotions are processed, integrated and abstracted** in the processing flow starting from the amygdala and ending with the LPAC, while the **congruency of these feelings/emotions is assessed in the ACC**



Emotion and decision-making (2)

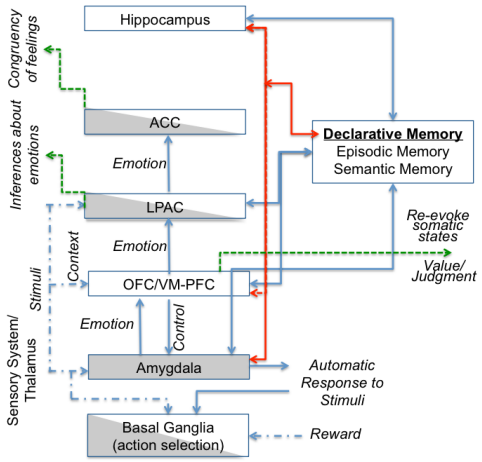


The **memory** of events/emotions/decisions then come into play through the hippocampus and the VM-PFC together with **information about the reward** (provided by the basal ganglia) and **the value/judgment** (provided by the VM-PFC)



- **All these mechanisms cooperate and constitute the basis of the decision-making process…**

Emotion and decision-making and adaptive classifiers



Interestingly, this complex process is very close to the processing in **adaptive classifiers** where an initial decision is initially taken by considering external stimuli and previously acquired information.