PSYCH 260

Learning & Memory

Rick Gilmore

2021-11-30 07:48:48

Prelude

Today's topics

- Biological basis of learning & memory

Coming up…

- Quiz 4 next Tuesday (available after class)
- In-class lab next Tuesday

Memory capacity of the human brain?

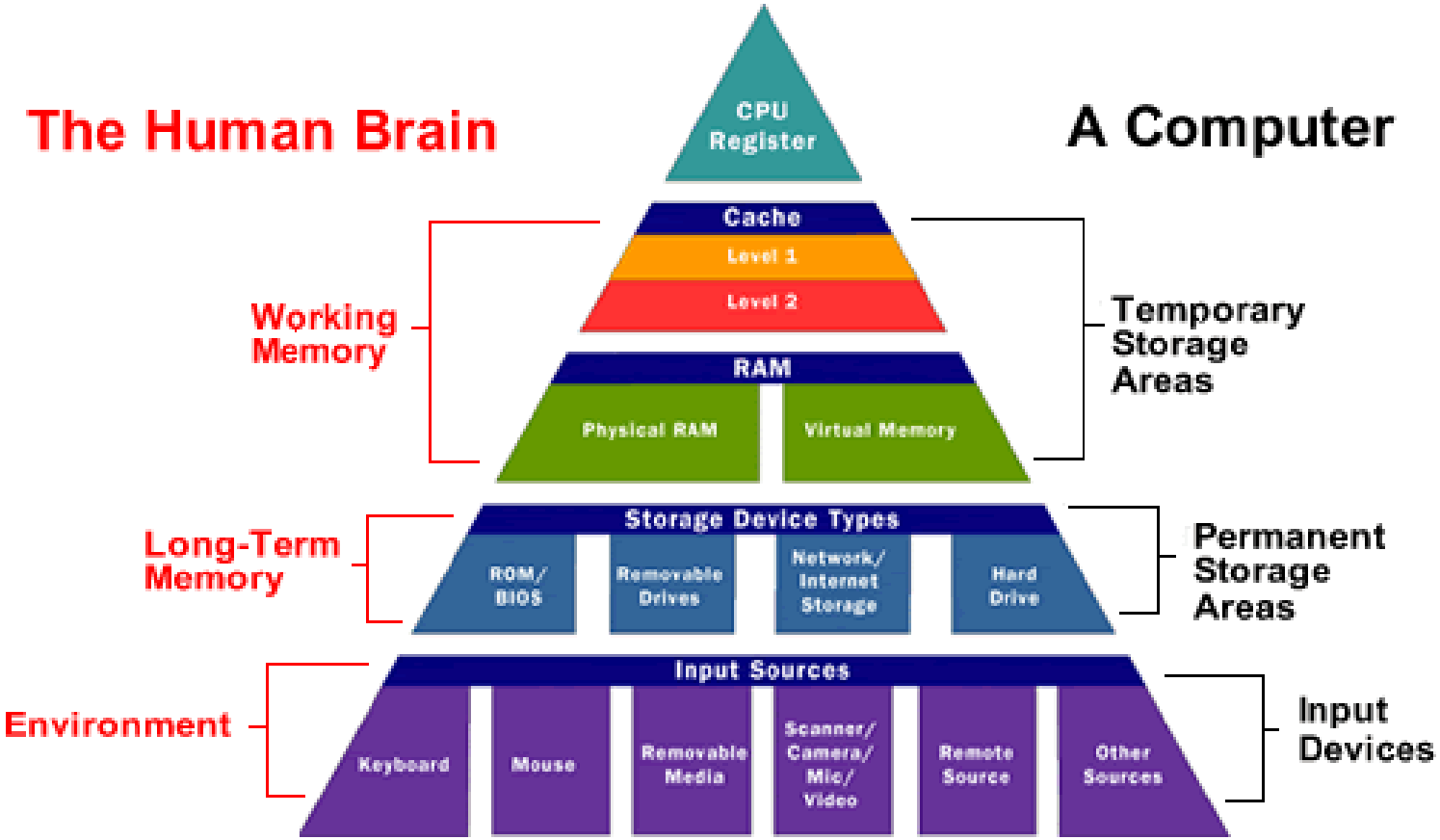
Memory capacity of the human brain?

- 1e12 neurons
- 1e3 synapses/neuron
- 1e15 synapses or 1.25e14 bytes
- 1e9 gigabyte, 1e12 terabyte, 1e15 petabyte

http://www.scientificamerican.com/article.cfm?id=what-is-the-memory-capacity

Meister (2019)

"Entirety of a human's lived experience could fit on a flash drive."


The Human Brain
A Computer
CPU Register
Cache
Level 1
Level 2
RAM
Physical RAM
Virtual Memory
Working Memory
Temporary Storage Areas
Storage Device Types
ROM/ BIOS
Removable Drives
Network/ Internet Storage
Hard Drive
Long-Term Memory
Permanent Storage Areas
Input Sources
Keyboard
Mouse
Removable Media
Scanner/ Camera/ Mic/ Video
Remote Source
Other Sources
Environment
Input Devices

Computer memory

- Random Access Memory (RAM), short-duration storage
- Hard-disk/flash drive storage, long-term duration
- Addressable (location ‘010101’)

Computer memory

- {text, sounds, images, video, data} all in binary [0,1] format
  - `00110000` == 48 (the number)
  - `00110000` == ‘0’ (the character zero)
- Write once, read many times

Computers vs. brains

- Computers have separate memory stores
  - brains store info everywhere
- Computers have addressable memory
  - brain memory??
- Computer memory can be non-volatile
  - brain memories fade
- Computer memory is veridical
  - brain memories are ‘reconstructions’

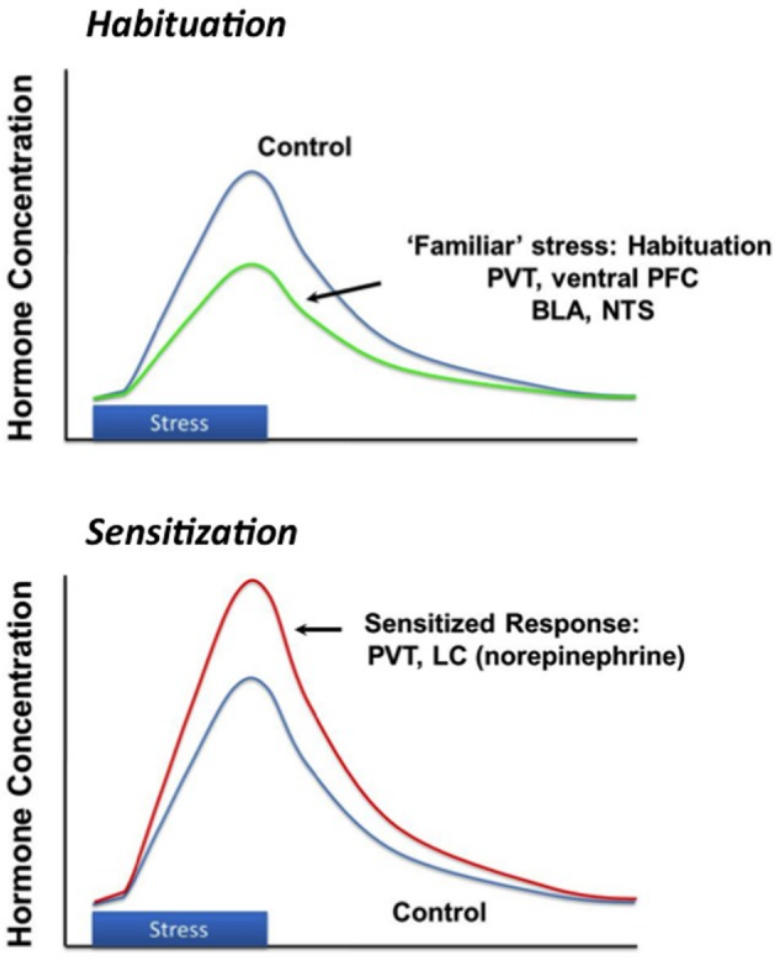
What is learning?

What is learning?

- A: Acquisition of new or change in existing knowledge, skills, …

Types of learning

- **Non-associative**
  - Change in response to repeated encounters with same stimulus/event
  - Habituation -> weaker response
  - Sensitization -> stronger response


Habituation
Hormone Concentration
Control
'Familiar' stress: Habituation
PVT, ventral PFC
BLA, NTS
Stress
Sensitization
Hormone Concentration
Sensitized Response:
PVT, LC (norepinephrine)
Control
Stress

- **Associative**
  - “Associates” two events/items with one another
  - Classical & operant/instrumental conditioning
  - Sequence, observational, episodic, semantic

What is memory?

What is memory?

- A: Information encoding, storage, retrieval

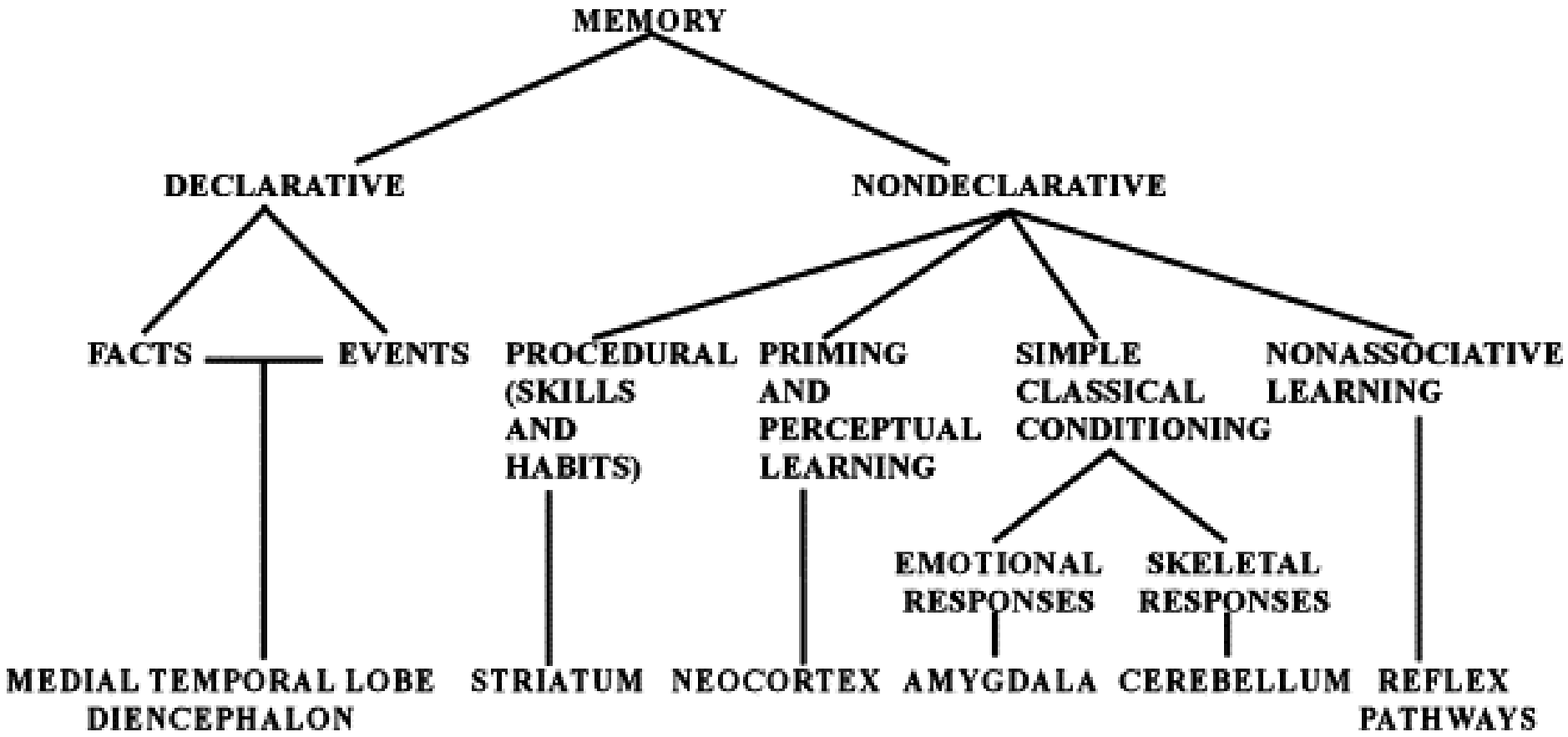
Dimensions of memory

- Short vs. long-term
    - Working memory ~ short-term maintenance for guiding action
- Explicit (declarative: semantic vs. episodic) vs. implicit (procedural)
- Retrospective (from the past) vs. prospective (to be remembered)
- Recognition (familiar or novel) vs. recall

Biological bases…

- Changes in patterns of neural activity
- Changes in connectivity
  - New synapses
  - Altered synapses (strengthened or weakened)

Memory systems in the brain



(Squire, 2004)

Donald Hebb's Insight

When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficacy, as on of the cells firing B, is increased. (Hebb, 1949, p. 62)

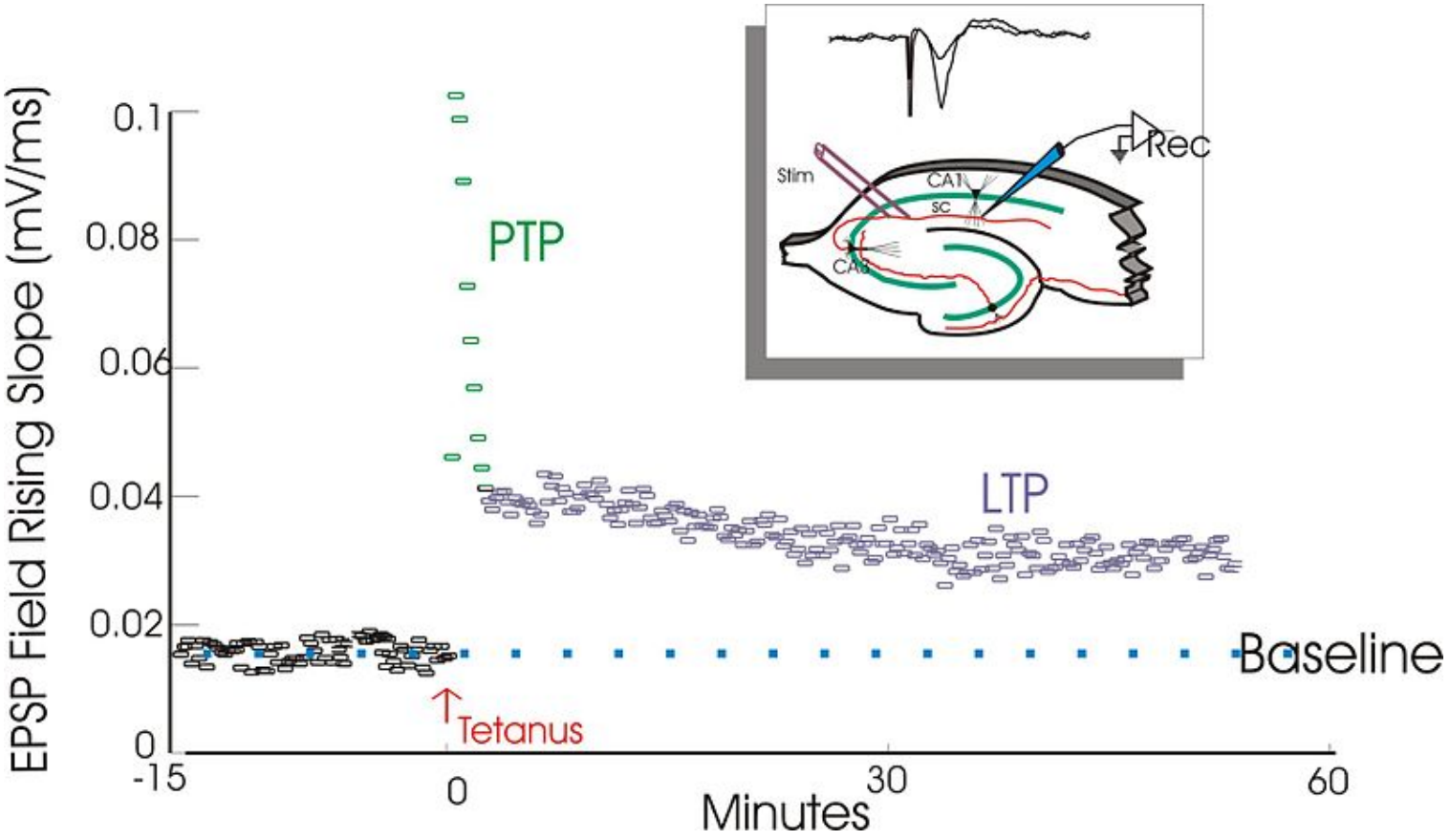
Neurons that fire together wire together. (Lowell & Singer, 1992, p. 211).

How to implement ‘Hebbian’ learning?

- Hebbian learning is associative
- Neuron A active + Neuron B active => associates/links co-activity

Long-term potentiation (LTP)

- Increase (potentiation) in synaptic strength based on recent co-activity
- Change at synapse == physical basis of Hebbian learning

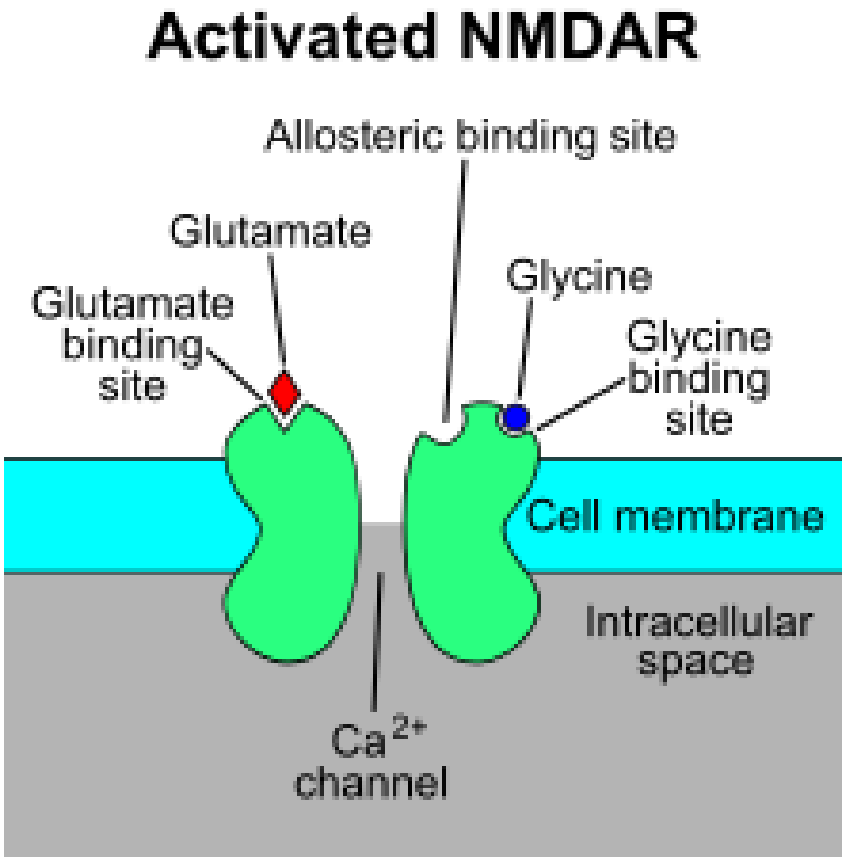


https://upload.wikimedia.org/wikipedia/commons/thumb/b
LTP_exemplar.jpg

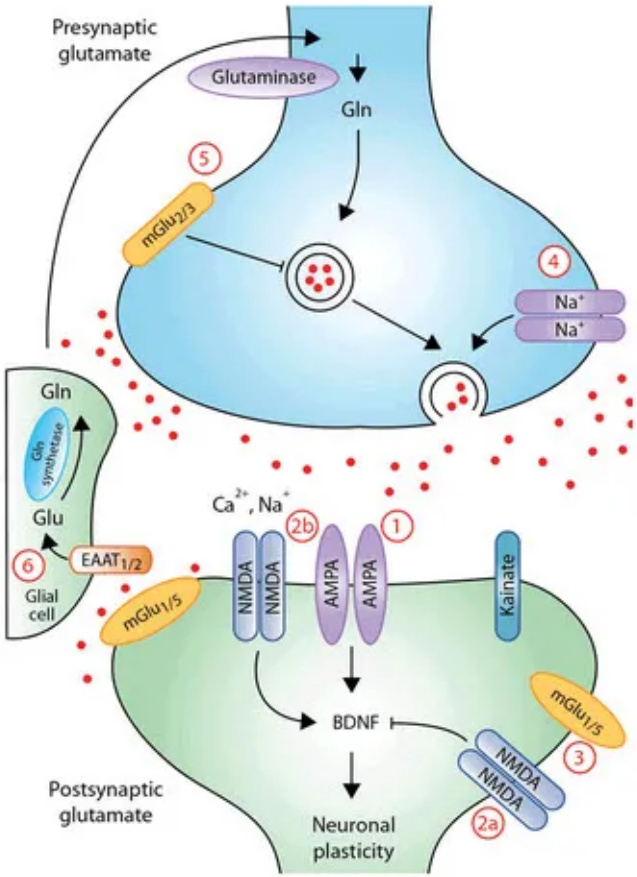
‘Hebbian’ learning via NMDA receptor

- *N-methyl-D-aspartate* receptor (NMDA-R)
- ‘Coincidence’ detector
    - Sending cell has released NT
    - Receiving cell is/has been recently active

NMDA receptor figure



https://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Activated_NMDAR.svg/220px-Activated_NMDAR.svg.png



https://i2.wp.com/www.gatewaypsychiatric.com/wp-content/uploads/2015/02/NMDA-Receptor-and-Depression.jpg?ssl=1

Example mechanism for 'Hebbian' learning

- Chemically-gated AND
  - Ligand- (glutamate/aspartate + glycine) gated
  - Sending cell active
- Voltage-gated
  - Zn^{++} or Mg^{++} ion 'plug' removed under depolarization
  - Na^{+} & Ca^{++} influx; K^{+} outflux
  - Receiving cell responds

NMDA receptors (NMDA-R) contribute to associative learning

- Associate (link)
  - Concept A -> Concept B
  - Neuron A -> Neuron B

I say Donald

You say…

Donald

- Trump
- Duck
- Draper

How does LTP (& LTD) work?

- Synapses can also be weakened via long-term depression (LTD)
- NMDA receptor one molecular mechanism for implementing LTP, LTD & spike-timing-dependent plasticity
- Ca++ entry triggers biochemical cascade

- Existing (AMPA) glutamate receptors made to stay open longer
- New AMPA glutamate receptors synthesized, inserted into postsynaptic membrane
- Change in quantity of glutamate released presynaptically

NMDA clinical significance

- *Memantine* (Alzheimer's Disease treatment) *blocks* NMDA-R
  - Controls over-activation and Ca^{++} excitotoxicity?
- Implicated in effects of *phencylidine* (PCP)
  - PCP can induce psychotic symptoms
  - Link to glutamate hypothesis of schizophrenia?

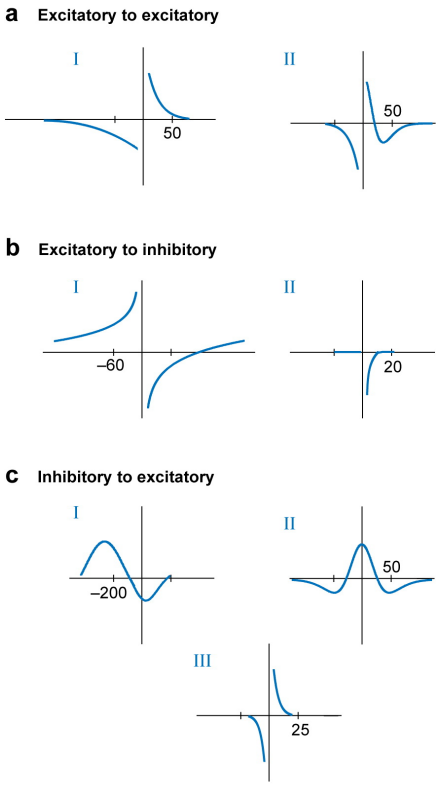
NMDA clinical significance

- *Ketamine* is an NMDA-R antagonist
  - anesthesia, sedation pain relief
  - short-term relief for depression
- Linked to analgesic (pain-relieving) effects of nitrous oxide (N_2O) or 'laughing' gas
- Ethanol inhibits (Ron et al., 2011)

Learning “causal chains”

- lightning THEN thunder
- unusual food THEN indigestion

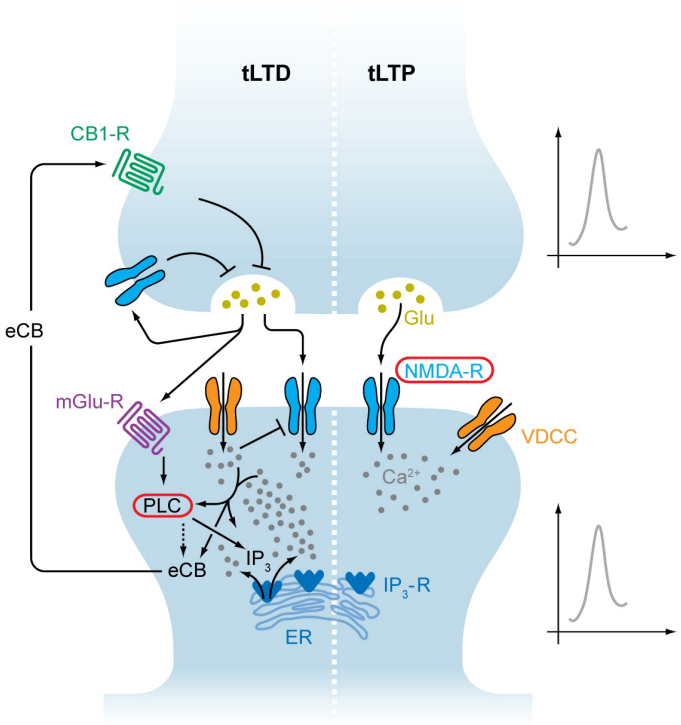
Spike-timing-dependent plasticity



Caporale N, Dan Y. 2008.
Annu. Rev. Neurosci. 31:25–46.

(Caporale & Dan, 2008)

Spike-timing-dependent plasticity



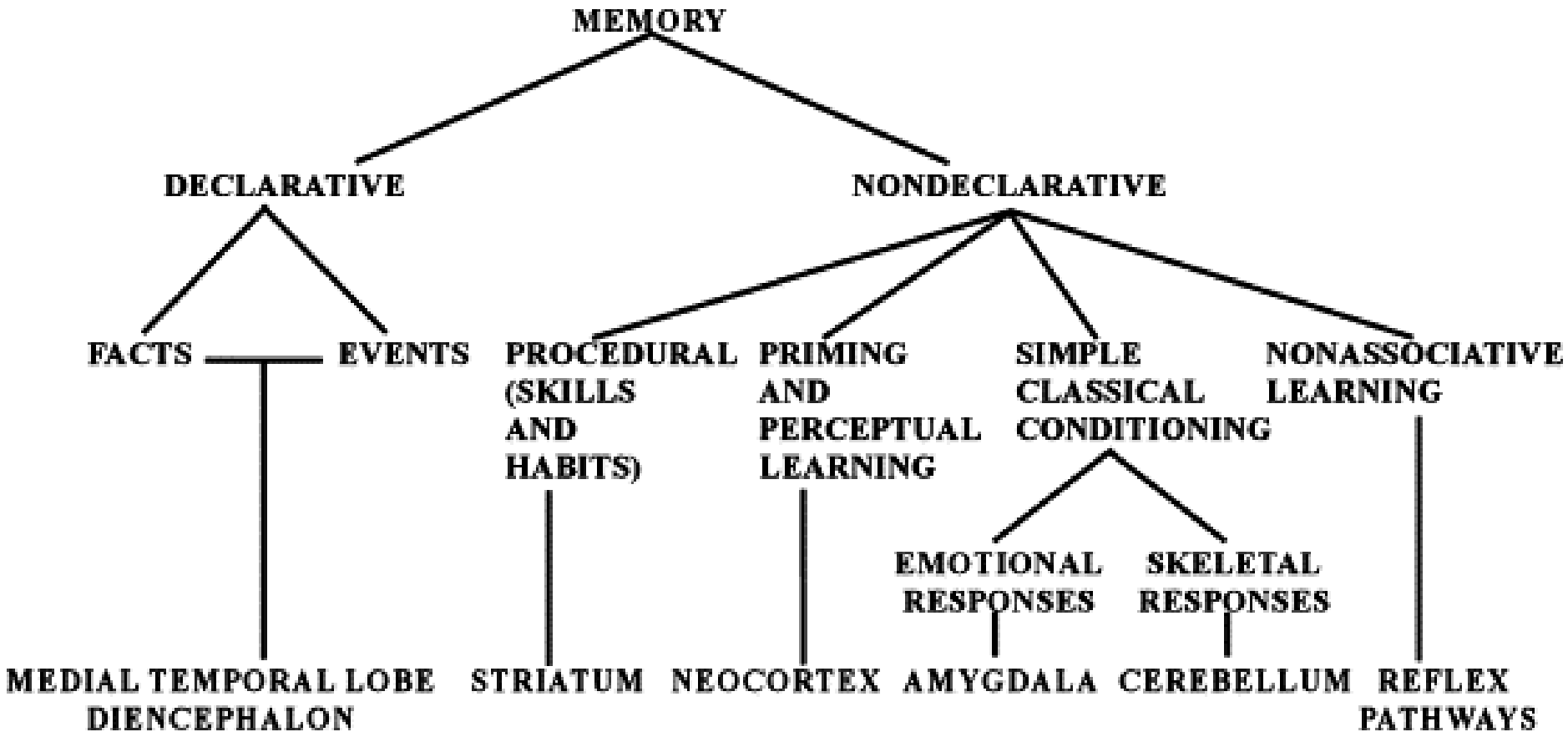
Caporale N, Dan Y. 2008.
Annu. Rev. Neurosci. 31:25–46.

(Caporale & Dan, 2008)

Spike-timing-dependent plasticity

- A before B: strengthen A->B
- A after B: weaken A->B
- *Neural Plasticity*
    - Lasting changes in neural firing, connectivity

Memory systems in the brain



(Squire, 2004)

Summary

- Learning and memory involve changes in neural firing, circuitry
- Hebbian learning a type of associative learning
- NMDA receptor as coincidence detector
    - Molecular basis of one form of long-term potentiation (LTP)
- Different types of information stored in different brain systems

Next time…

- More on learning and memory

References

Caporale, N., & Dan, Y. (2008). Spike timing-dependent plasticity: A hebbian learning rule. *Annu. Rev. Neurosci.*, *31*, 25–46. https://doi.org/10.1146/annurev.neuro.31.060407.125639

Squire, L. R. (2004). Memory systems of the brain: A brief history and current perspective. *Neurobiology of Learning and Memory*, *82*(3), 171–177. https://doi.org/10.1016/j.nlm.2004.06.005