Declarative vs. non-declarative memory

- **Declarative**
  - “Spring break ended on March 22”
  - “Apples are edible, chairs are not edible”

- **Non-declarative**
  - Throwing a baseball
  - Pattern completion (seeing the dog behind the fence)

Short-term vs. long-term memory

- **Short-term memory** – aka “working” memory
  - Hold facts in memory for 1-200 seconds
  - Sometimes prolonged version of perception
  - Associated with prefrontal cortex (PFC)

- **Long-term memory**
  - Stores facts over years
  - Associated with hippocampus (also, amygdala)

For the final, ignore the next slides UNTIL “Limits of working memory”

I have updated the next few slides for your edification as future neuroscientists
Neural dynamics in “cortical sheet”

- Cortical sheet: group of neurons on same level of hierarchy interacting with lateral connections
- Balance between local cooperation and local inhibition
- \( r_{\text{out}} \) determined from
  \[
  h = \left( \sum_j w_j r_j^{\text{feedforward}} \right) + \left( \sum_k w_k r_k^{\text{ lateral}} \right) + \left( \sum_m w_m r_m^{\text{ feedback}} \right)
  \]

Neural dynamics in action

V1/IT

Neurons fire with \( r_{\text{out}} = h \) linear

Side neurons fire at \( r = 0.5 \)
Center neuron fires at \( r = 1 \)

Neural dynamics: equations and numbers

- \( r_{A,t}^{t+1} = w_{A,in} r_{in}^{t+1} + w_{AB} r_{B}^{t+1} \)
- \( r_{B,t}^{t+1} = w_{B,in} r_{in}^{t+1} + w_{BA} r_{A}^{t+1} + w_{BC} r_{C}^{t+1} \)
- \( r_{A,t}^{t+1} = w_{C,in} r_{in}^{t+1} + w_{CB} r_{B}^{t+1} + w_{CA} r_{A}^{t+1} \)

\( w_{B,A} = 0.4 \quad w_{B,C} = 0.4 \quad w_{A,B} = -0.1 \quad w_{C,B} = -0.1 \)
\( w_{in,A} = 0.5 \quad w_{in,B} = 1 \quad w_{in,C} = 0.5 \)

<table>
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<th>A</th>
<th>B</th>
<th>C</th>
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Neural system dynamics

- In an interconnected cortical sheet, neural activity can continue after feedforward input is gone
Neural system dynamics

Trappenberg 7.3.2

- **Memory activity**: balance of mutual excitation and mutual inhibition produces maintained (sparse) distributed coding during “working memory” time period
- **Growing activity**: mutual excitation produces global, non-stop activity over time – epilepsy
- **Decaying activity**: mutual inhibition suppresses continued neural activity after feedforward input is gone – V1

Anatomy of long term memory

Hippocampus (“sea horse”) 
In medial temporal lobe (MTL)
- Input: Entorhinal cortex – EC
- Dentate gyrus – DG
- Cornus ammonis – CA1, CA3
- Perforant pathway: EC -> CA3
Recurrent networks

- Extensive collateral connections in CA3 enhance associative memory

\[ \Delta w_{ij} = r_i r_j - r_i w_{ij} \]

Cells that fire together, wire together
Loop repeatedly increases weight ~ increasingly encourage simultaneous firing

Learning locations

- Rats learn neural representations of locations within a maze
- Hippocampal place cells in CA1, CA3

Connections between hippocampal neurons before (A) and after (B,C) learning

Further hippocampal representations

Grid cells
- In dorsocaudal medial EC
- Represent multiple locations

Connections between hippocampal neurons before (A) and after (B,C) learning

Learning/remembering

- Learning: neurogenesis in DG
- Retrieval: pattern completion in CA3
- Alternate between learning and retrieval phases
  - DG granule cells enable learning
  - Perforant pathway probes memory

Modeling limits of working memory

- How much can we hold in working memory?
  - 7±2 things
  - Things can be simple
  - Things can be complex

- Why is our working memory limited?
  - Binding hypothesis: distributed code with synchronous spiking ~ errors with spurious synchronization

Cells that fire together, wire together
Binding hypothesis

Neurons firing at “same time” represent same thing

Pink  ●  ●  ●  ●  ●
Blue  ●  ●  ●  ●  ●
Cat  ●  ●  ●  ●  ●
Dog  ●  ●  ●  ●  ●
Cow  ●  ●  ●  ●  ●

Spurious synchronization – binding problem

Pink  ●  ●  ●  ●  ●
Blue  ●  ●  ●  ●  ●
Cat  ●  ●  ●  ●  ●
Dog  ●  ●  ●  ●  ●
Cow  ●  ●  ●  ●  ●

If spikes occurring within 1 ms of each other are considered synchronous, hard to incorporate increasing number of spikes in fixed time

Note adding more features (with more neurons!) to a concept/object does not cause a problem – no risk of extra overlap in time with more features

Note: The diagrams show a time scale from 0 to 60 ms with spikes occurring at specific times for different categories (e.g., Pink, Blue, Cat, Dog, Cow).