Memory

Types of memory

Declarative
- Episodic
- Semantic

Non-declarative
- Procedural
- Conditioning
- Perceptual
- Reflex

Hippocampus (MTL)
Cerebral cortex
Basal ganglia
Cerebellum

Declarative vs. non-declarative memory

- **Declarative**
  - “Winter break ended on January 15”
  - “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)
Modeling limits of working memory

• How much can we hold in working memory?
  – 7±2 things
  – Things can be simple A Q R L G
  – Things can be complex

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

Spurious synchronization – binding problem

Objects too close!

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

Binding hypothesis

Neurons firing at “same time” represent same thing

<table>
<thead>
<tr>
<th>Pink</th>
<th>Blue</th>
<th>Cat</th>
<th>Dog</th>
<th>Cow</th>
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<tr>
<td>1 pink cat</td>
<td>1 pink dog</td>
<td>1 blue dog</td>
<td>1 cow</td>
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Spurious synchronization

More features not increase risk of spurious synchronization

Small cat confused with big sad cow
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

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

- $r^{out}$ determined from
  $h = \sum_j w_{j}^{feedfwd} r_j^{feedfwd} + \left( \sum_k w_k^{lateral} r_k^{lateral} \right) + \left( \sum_m w_m^{feedback} r_m^{feedback} \right)$

In V1, get feedfwd input from “eyes” (actually thalamus)
Get input from other V1 neurons (lat); get input from V2 (fbdk)

Working memory

- Time over experiment
- Delayed “saccade” (move eyes) to target task

Neural memory in dIPFC for delayed-action task
a: stimulus display onset
b: stimulus display offset
c: performance of action

Funahashi et al. 1989

Neural dynamics in action

V1/IT

Neurons fire with $r^{out}=h$ linear
Side neurons fire at $r=0.5$
Center neuron fires at $r=1$

At $t=1$: bananas start pushing n1,n2,n3 to fire
At $t=2$: banana push n1,n2,n3 up; n2 pull down n1,n3

Color code:
- Dark red: 1
- Light red: 0.5
- Dark blue: -0.4
- Light blue: -0.1

Neural dynamics size in “cortical sheet”

• Cortical sheet: group of neurons on same level of hierarchy interacting with lateral connections
• Balance between local cooperation and local inhibition

• $r^{out}$ determined from
  $h = \sum_j w_{j}^{feedfwd} r_j^{feedfwd} + \left( \sum_k w_k^{lateral} r_k^{lateral} \right) + \left( \sum_m w_m^{feedback} r_m^{feedback} \right)$
Neural dynamics: equations and numbers

\[ r_A^{t+1} = w_{A,in} r_{in}^t + w_{B,A} r_B^t \]
\[ r_B^{t+1} = w_{B,in} r_{in}^t + w_{B,A} r_A^t + w_{C,B} r_C^t \]
\[ r_C^{t+1} = w_{C,in} r_{in}^t + w_{B,C} r_B^t \]

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

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<td>??</td>
<td>??</td>
<td>??</td>
</tr>
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<tr>
<td>C</td>
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(feedwd)n

1 1 0 0 0

Neural dynamics: equations and numbers

V1/IT

Alternate area

Neural dynamics in action

Neuron activated
Neuron exciting
Neuron inhibiting

Neural dynamics, alternate area: equations and numbers

\[ w_{B,A} = 0.5 \quad w_{B,C} = 0.5 \quad w_{A,B} = 0.1 \quad w_{C,B} = 0.1 \]
\[ w_{in,A} = 1 \quad w_{in,B} = 1 \quad w_{in,C} = 1 \]

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\( w_{x,y} \) is weight of neuron x onto neuron y
Neural dynamics, alternate area: equations and numbers

\[ w_{B,A} = 2 \quad w_{B,C} = 2 \quad w_{A,B} = 1 \quad w_{C,B} = 1 \]
\[ w_{in,A} = 1 \quad w_{in,B} = 1 \quad w_{in,C} = 1 \]

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<tr>
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Neural system dynamics

• In an interconnected cortical sheet, neural activity can continue after feedforward input is gone

Feedback input sending message:
“keep in short-term memory”

Additional color code:
Dark green: .3

Neural dynamics + memory

\[ w_{B,A} = .5 \quad w_{B,C} = .5 \quad w_{A,B} = .5 \quad w_{C,B} = .5 \]
\[ w_{in,A} = 1 \quad w_{in,B} = 1 \quad w_{in,C} = 1 \]
\[ w_{mem,A} = .3 \quad w_{mem,B} = .3 \quad w_{mem,C} = .3 \]

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<td>1</td>
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Neural system dynamics

Trappenberg 7.3.2

• **Decaying activity**: mutual inhibition suppresses continued neural activity after feedforward input is gone – V1

• **Growing activity**: mutual excitation produces global, non-stop activity over time – epilepsy

• **Memory activity**: balance of mutual excitation and mutual inhibition produces maintained activity (sparse) distributed coding during “working memory” time period – PFC
Memory
- Balance of positive and negative weights

Neural system dynamics

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

Recurrence networks
- Extensive collateral connections in CA3
- Broader loop:
  EC -> CA3 -> CA1 -> EC

\[ \Delta w_{ij} = r_i r_j - r_i w_{ij} \]
Cells that fire together, wire together
Loop repeatedly increases weight – increasingly encourage simultaneous firing
Learning/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

Learning locations

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

Further hippocampal representations

Grid cells
- In dorsocaudal medial EC
- Represent multiple locations

Samsonowich, J Neurosci 1997
Neurons organized in 2D based on similarity of tuning curves

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