Systems Neuroscience  
CISC 3250

Memory

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JMH 332

Types of memory

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)
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

Binding hypothesis

Neurons firing at “same time” represent same thing

Spurious synchronization – binding problem

Objects too close!

More features not increase risk of spurious synchronization

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.

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
  \[ h = (\sum_j w_{ij}^{feedfwd}) + (\sum_k w_{kr}^{lateral}) + (\sum_m w_{mr}^{feedback}) \]

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 in V1/IT

- t=1: Neuron activated
- t=2: Neuron exciting
- t=3: Neuron inhibiting
- t=4: Neuron activated
- t=5: Neuron excited

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

Neurons fire with $r^{out}=h$ linear
- Side neurons fire at $r=0.5$
- Center neuron fires at $r=1$
Neural dynamics:
equations and numbers

- $r_A^{t=2} = w_{A,in}r_{in}^{t=1} + w_{B,A}r_B^{t=1}$
- $r_B^{t=2} = w_{B,in}r_{in}^{t=1} + w_{A,B}r_A^{t=1} + w_{C,B}r_C^{t=1}$
- $r_C^{t=2} = w_{C,in}r_{in}^{t=1} + w_{B,C}r_B^{t=1}$

$w_{B,A} = -0.4$  $w_{B,C} = -0.4$  $w_{A,B} = -0.1$  $w_{C,B} = -0.1$

$w_{in,A} = 0.5$  $w_{in,B} = 1$  $w_{in,C} = 0.5$

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<tr>
<td>B</td>
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Neural dynamics in action

V1/IT

Alternate area

Neural dynamics, alternate area:
equations and numbers

$w_{B,A} = 0.5$  $w_{B,C} = 0.5$  $w_{A,B} = 0.1$  $w_{C,B} = 0.1$

$w_{in,A} = 1$  $w_{in,B} = 1$  $w_{in,C} = 1$

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Neural dynamics, alternate area: equations and numbers

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

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Neural dynamics, alternate area: equations and numbers

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

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<td>1</td>
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Neural system dynamics

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

![feedforward input](image)
Neural dynamics in action

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

Additional color code:
Dark green: .3

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 (sparse) distributed coding during “working memory” time period – PFC

Neural system dynamics
Decaying

Growth
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

Recurrent 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

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