Systems Neuroscience CISC 3250

Memory

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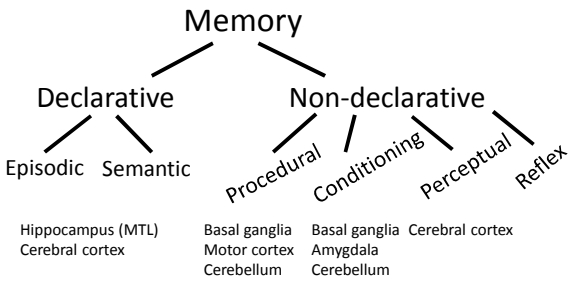
JMH 328A

Types of memory



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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)

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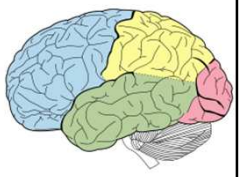
Short-term vs. long-term memory

- 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)



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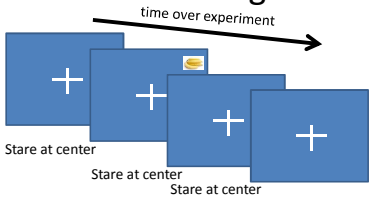
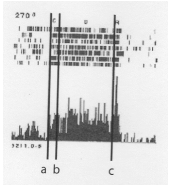
Working memory



Delayed "saccade" (move eyes) to target task



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

Funahashi et al. 1989

Banana picture from Fir0002/Flagstaffotos

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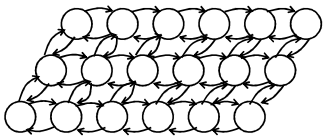
Neural dynamics in "cortical sheet"

- 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

$$h=\left(\sum_j w_j r_j^{feedfwd}\right)+\left(\sum_k w_k r_k^{lateral}\right)+\left(\sum_m w_m r_m^{feedback}\right)$$

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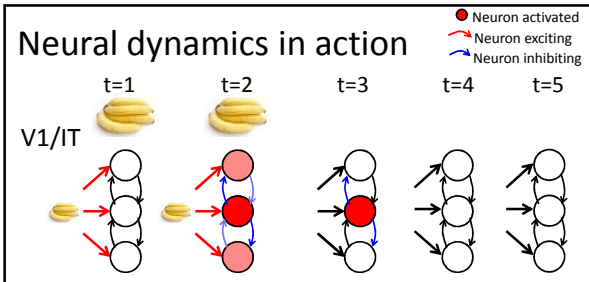
Neural dynamics in action



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

Neurons fire with h>0.7
- step response

Side neurons fire at r=0.5
Center neuron fires at r=1

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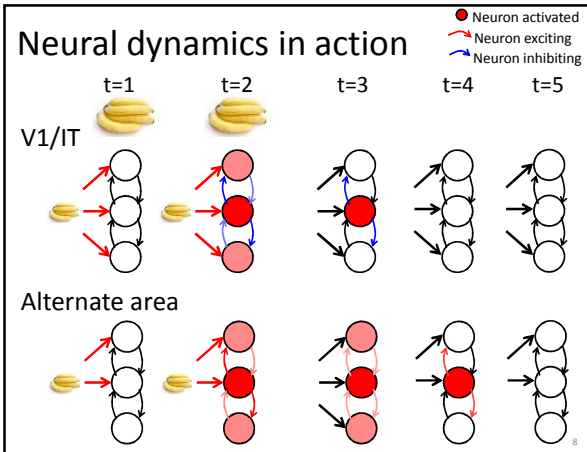
Neural dynamics in action



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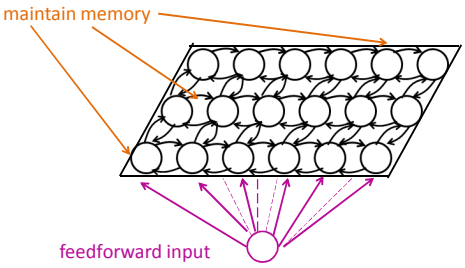
Neural system dynamics

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



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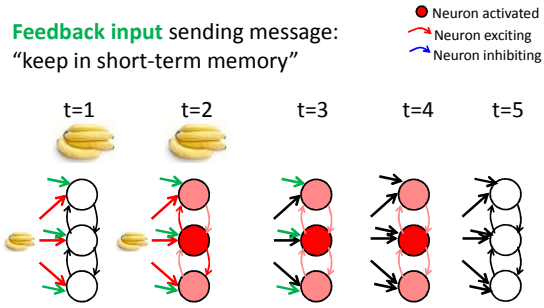
Neural dynamics in action

Feedback input sending message:
"keep in short-term memory"



Additional color code:
Dark green: .3

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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 – V1

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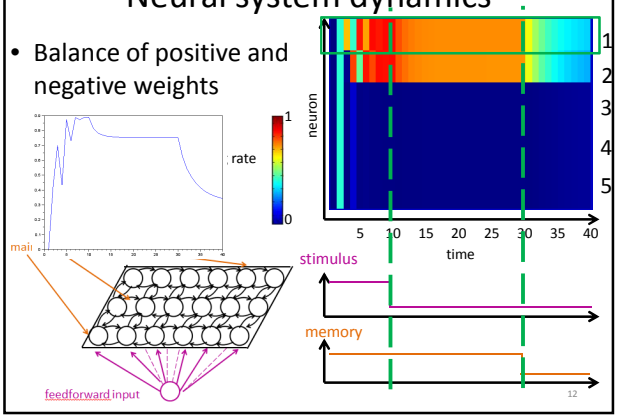
Neural system dynamics

- Balance of positive and negative weights



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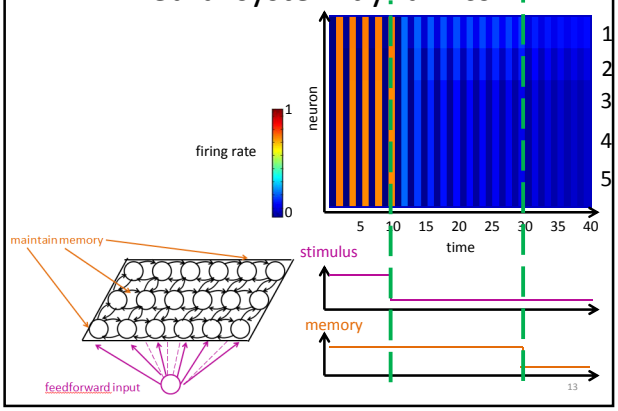
Neural system dynamics



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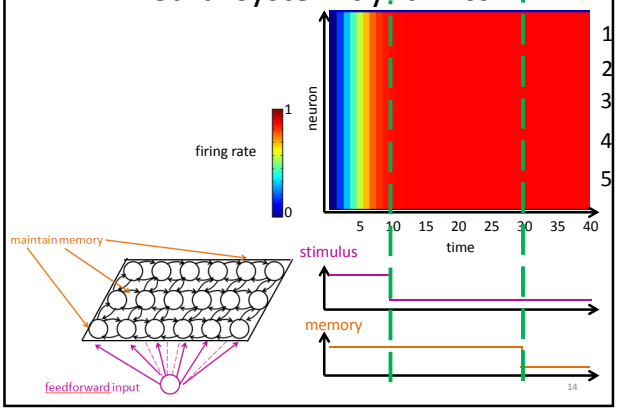
Neural system dynamics



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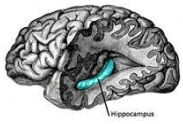
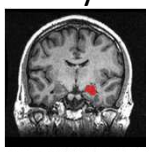
Anatomy of long term memory

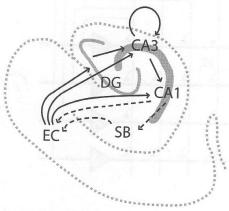




Hippocampus ("sea horse")

In medial temporal lobe (MTL)

- Input: Entorhinal cortex – EC
- Dentate gyrus – DG
- Cornus ammonis – CA1, CA3
- Perforant pathway: EC -> CA3



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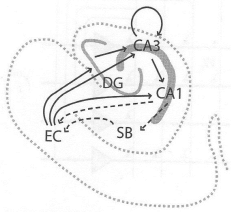
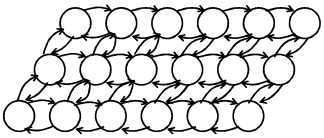
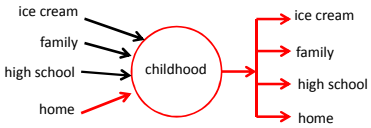
Recurrent networks

- Extensive collateral connections in CA3 enhance associative memory







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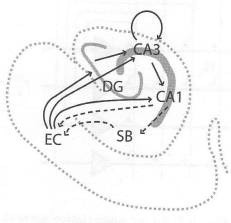
Recurrent networks

- 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

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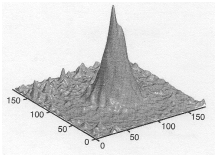
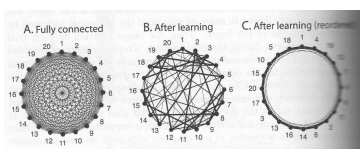
Learning locations

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



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



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

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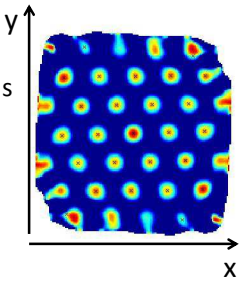
Further hippocampal representations

Grid cells
- In dorsocaudal medial EC
- Represent multiple locations



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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

Potential model

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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

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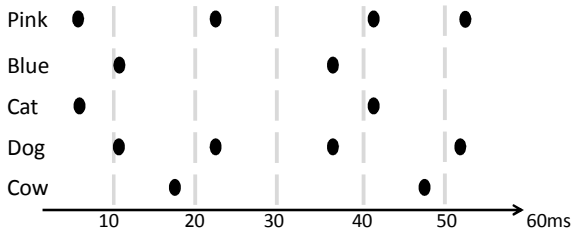
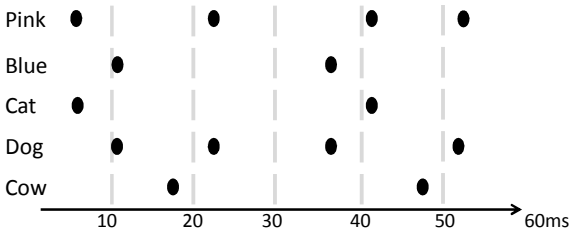
Binding problem

Neurons firing at "same time" represent same thing



Spurious synchronization



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

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