Systems Neuroscience CISC 3250

Memory

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JMH 332

Types of memory

- Memory
  - Declarative
    - Episodic
    - Semantic
  - Non-declarative
    - Procedural
    - Conditioning
    - Perceptual
    - Reflex

Hippocampus (MTL)
Cerebral cortex

Basal ganglia
Motor cortex
Cerebellum

Basal ganglia
Amygdala
Cerebellum

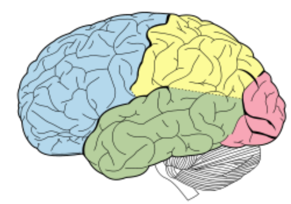
Cerebral cortex

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

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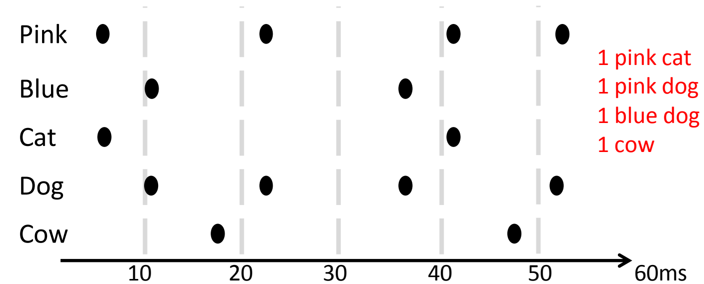
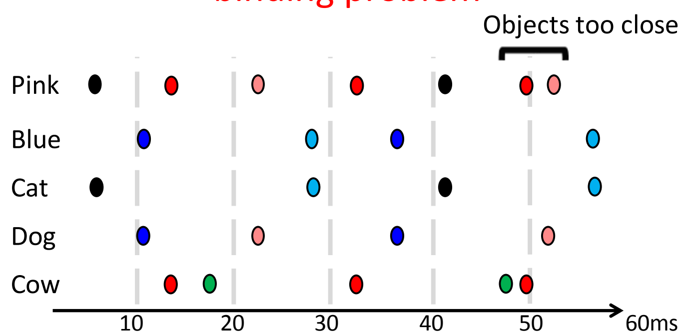
Binding hypothesis

Neurons firing at “same time” represent same thing



Spurious synchronization – binding problem



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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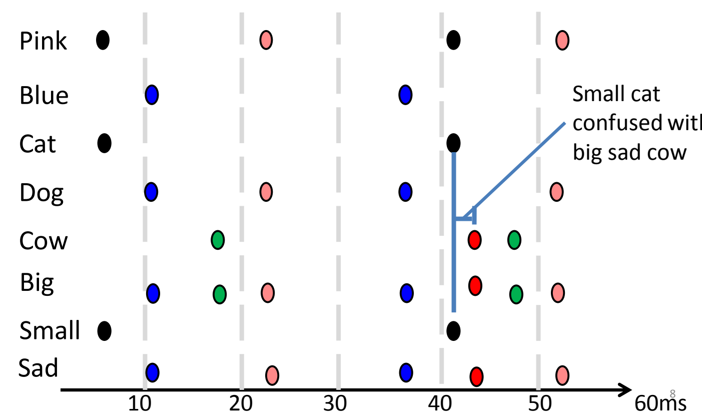
More features not increase risk of spurious synchronization



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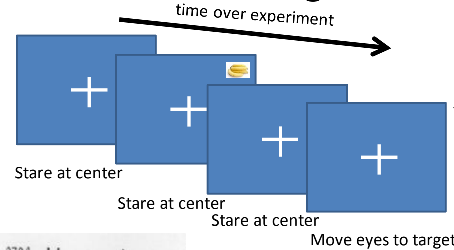
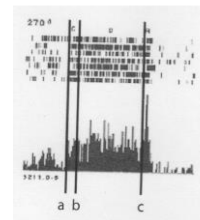
Note adding more features
(with more neurons!) to a concept/object
does **not** cause a problem – no risk of extra
overlap in time with more features

Working memory



Delayed "saccade" (move eyes) to target task

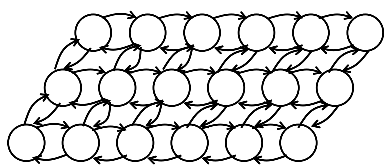


Neural memory in dlPFC for delayed-action task
a: stimulus display onset
b: stimulus display offset
c: performance of action

Funahashi et al. 1989

Neural dynamics in "cortical sheet"

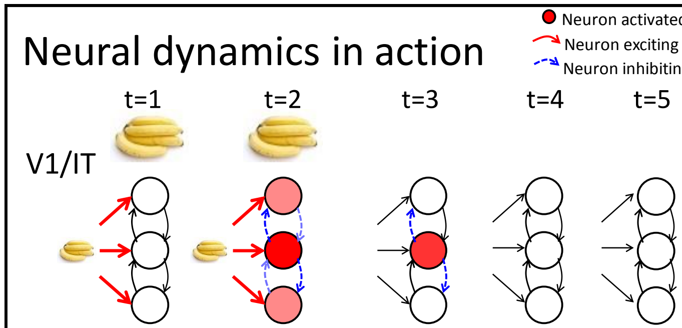
- Cortical sheet: group of neurons on same level of hierarchy interacting with lateral connections
- Balance between local cooperation and local inhibition



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

In V1, get feedfwd input from "eyes" (actually thalamus)
Get input from other V1 neurons (lat); get input from V2 (fdbk)

Neural dynamics in action



Neurons fire with r^{out}=h linear

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

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

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

Neural dynamics: equations and numbers

$w_{from,to}$

n1 n2 n3

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

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

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

	t=1	t=2	t=3	t=4
A	0	??	??	
B	0	??	??	
C	0	??	??	
(feedfwd)in	1	1	0	0

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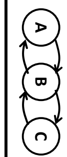
Neural dynamics: equations and numbers

$w_{x,y}$ is weight of neuron x onto neuron y



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

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

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

	t=1	t=2	t=3	t=4
A	0	0.5	0.1	-0.36
B	0	1	0.9	-0.02
C	0	0.5	0.1	-0.36
in	1	1	0	0

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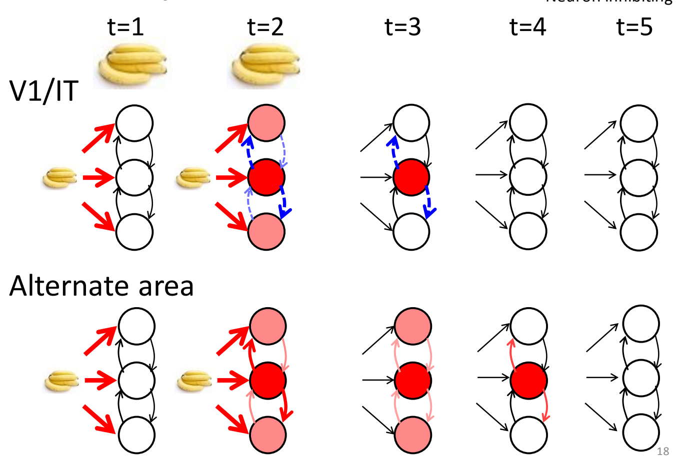
Neural dynamics in action

Neuron activated
Neuron exciting
Neuron inhibiting



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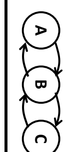
Neural dynamics, alternate area: equations and numbers

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



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

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

	t=1	t=2	t=3	t=4
A	0	1	1.5	
B	0	1	1.2=1+.2+.2	
C	0	1	1.5	
in	1	1	0	0

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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

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

By changing our weights, control speed of reset-to-zero (or prevent reset to zero)

	t=1	t=2	t=3	t=4	t=5
A	0	1	1.5	0.6	0.15
B	0	1	1.2	0.3	0.12
C	0	1	1.5	0.6	0.15
in	1	1	0	0	0

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

$w_{B,A}$=2 $w_{B,C}$=2 $w_{A,B}$=1 $w_{C,B}$=1

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

	t=1	t=2	t=3	t=4	t=5
A	0				
B	0				
C	0				
in	1	1	0	0	0

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

$w_{B,A}$=2 $w_{B,C}$=2 $w_{A,B}$=1 $w_{C,B}$=1

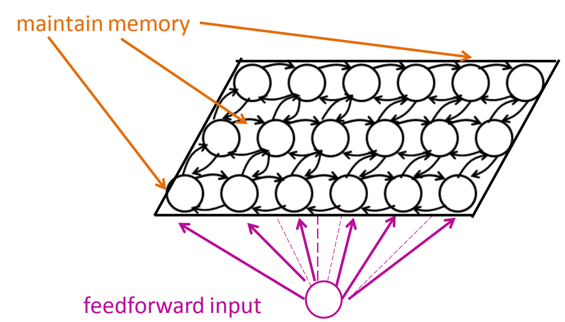
$w_{in,A} = 1$ $w_{in,B} = 1$ $w_{in,C} = 1$

Over-weighting -> epilepsy

	t=1	t=2	t=3	t=4	t=5
A	0	1	3	6	12
B	0	1	3	6	12
C	0	1	3	6	12
in	1	1	0	0	0

Neural system dynamics

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

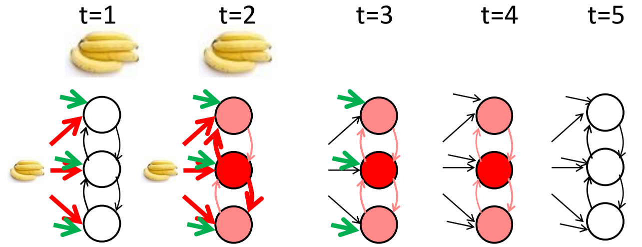


Neural dynamics in action

Frontal cortex – executive decision making – provides feedback input

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

Neuron activated
Neuron exciting
Neuron inhibiting



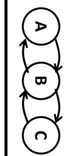
Additional color code:
Dark green: .3

Neural dynamics + memory

$w_{B,A}$=.5 $w_{B,C}$=.5 $w_{A,B}$=.5 $w_{C,B}$=.5

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

$w_{mem,A} = .3$, $w_{mem,B} = .3$, $w_{mem,C} = .3$



	t=1	t=2	t=3	t=4	t=5
A	0	1.3	1.3+.65=2		
B	0	1.3	1.3+.65+.65=2.6		
C	0	1+.3	2		
in	1	1	0	0	0
mem	1	1	1	1	0

Neural dynamics + memory

$w_{B,A}$=.5 $w_{B,C}$=.5 $w_{A,B}$=.5 $w_{C,B}$=.5
$w_{in,A} = 1$ $w_{in,B} = 1$ $w_{in,C} = 1$
$w_{mem,A} = .3$, $w_{mem,B} = .3$,
$w_{mem,C} = .3$

Remove feedforward: A, B, C rates decrease a bit

Remove top-down mem: A, B, C rates decrease faster

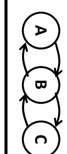
	t=1	t=2	t=3	t=4	t=5	t=6
A	0	1.3	1.95	1.6	1.43	.95
B	0	1.3	2.6	2.25	1.9	1.43
C	0	1.3	1.95	1.6	1.43	.95
in	1	1	0	0	0	0
mem	1	1	1	1	0	0

Neural dynamics + memory

$w_{B,A}$=.5 $w_{B,C}$=.5 $w_{A,B}$=.5 $w_{C,B}$=.5

$w_{in,A} = 0$ $w_{in,B} = 1$ $w_{in,C} = 0$

$w_{mem,A} = .5$, $w_{mem,B} = 0$, $w_{mem,C} = .5$



	t=1	t=2	t=3	t=4	t=5	t=6	t=7
A	0						
B	0						
C	0						
in	1	1	0	0	0	0	
mem	1	1	1	1	0	0	

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

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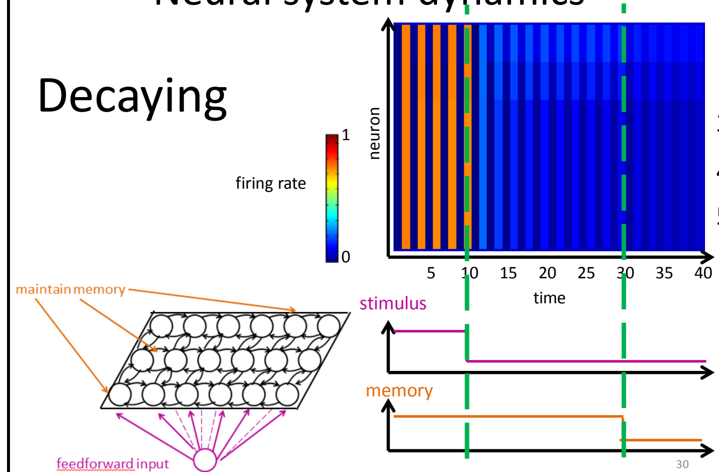
Neural system dynamics

Decaying



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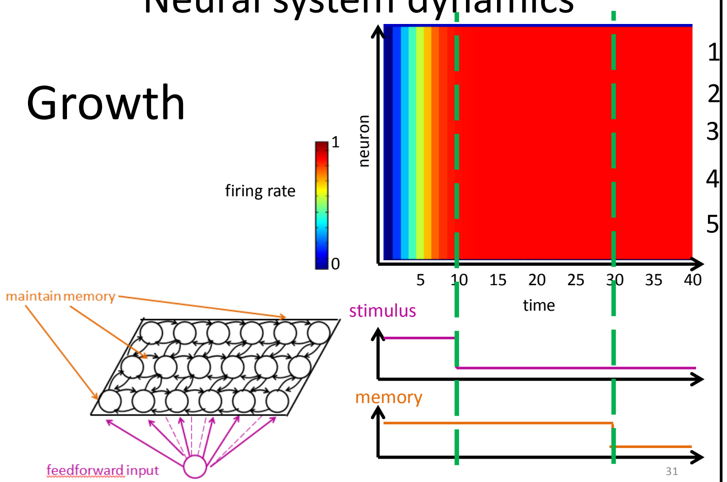
Neural system dynamics

Growth



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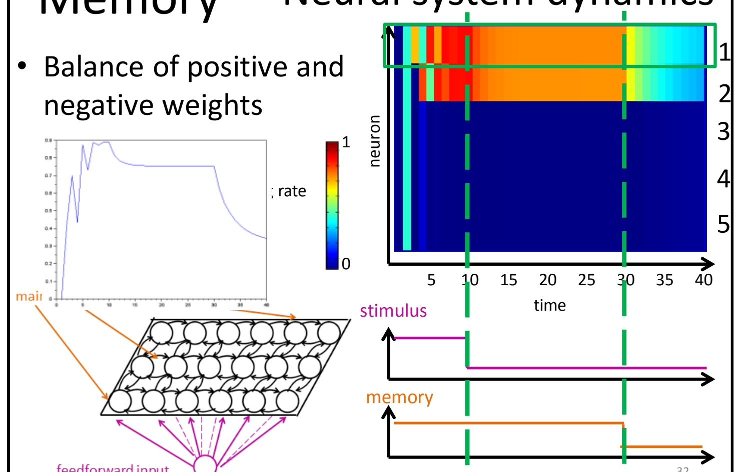
Memory

Neural system dynamics

- Balance of positive and negative weights



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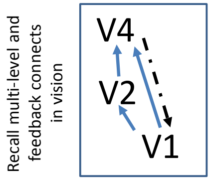
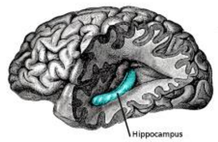
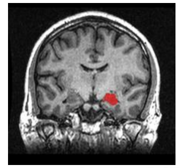
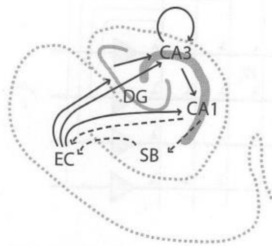
Anatomy of long term memory









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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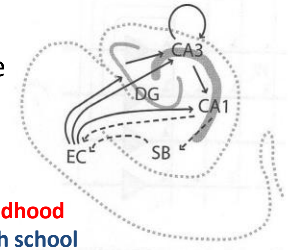
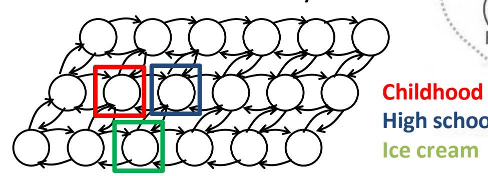
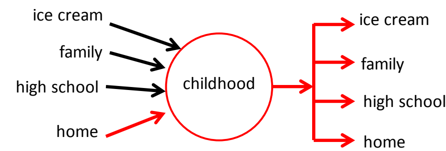
Recurrent networks

- Extensive col**lateral** connections in CA3 enhance associative memory







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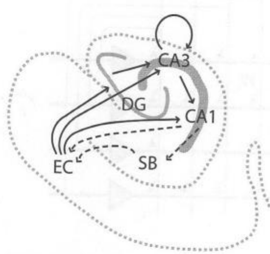
Recurrent networks

- Extensive col**lateral** 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/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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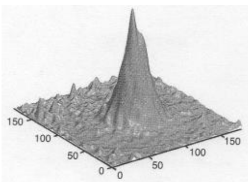
Learning locations

- 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

Proprioception – where I am in space
- From inner ears, muscles, etc
- From place cells

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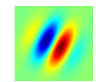
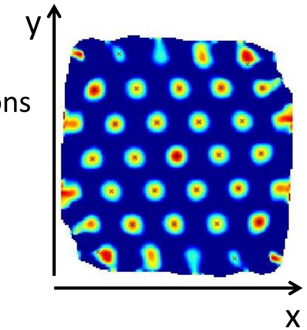
Further hippocampal representations

Grid cells
- In dorsocaudal medial EC
- Represent multiple locations

In other senses, often see Gabor wave:
Sine x Gauss



Here, just sine



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