Convolution-Based Model for Serial Order Memory

Presented By:
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Disclaimer

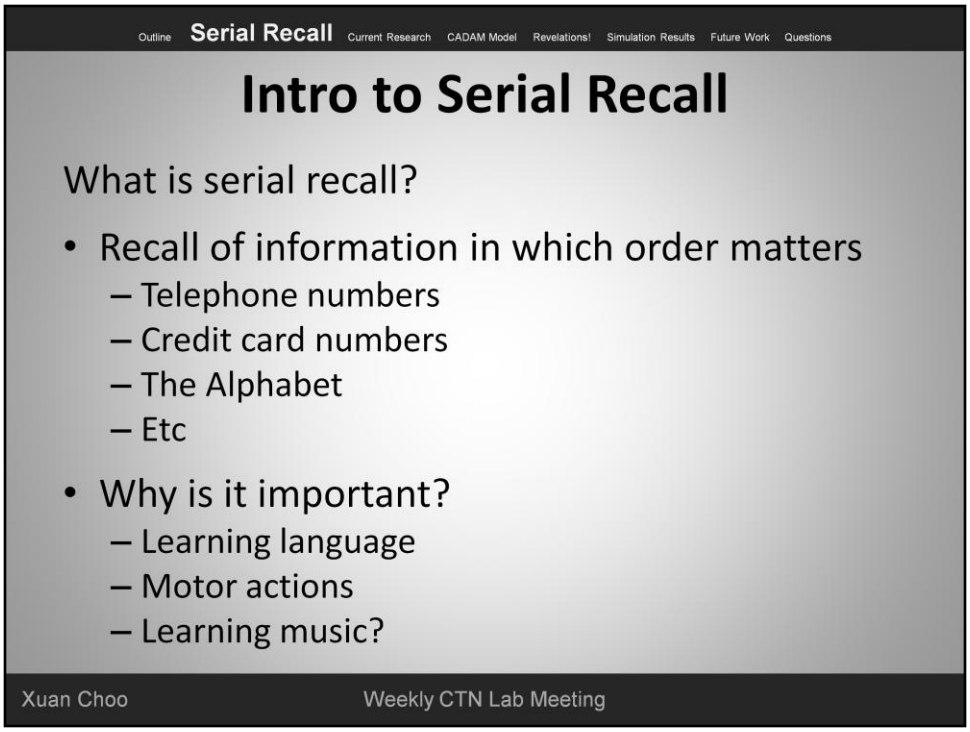
This presentation requires audience interaction.
Be prepared to participate!

Remember this!

7 6 8 8 1 3 6

Outline

- Introduction to Serial Recall
- Current State of Field
- The CADAM Model
- Struggles and Revelations!
- Simulation Results
- Future Work
- Questions

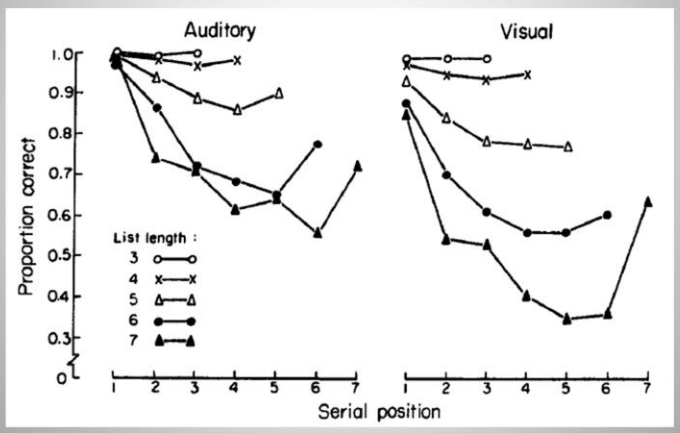


What is serial recall?
It is the recall of information where order matters.
For example, telephone numbers, credit cards, your student number, the alphabet, songs, your schedule …

Why is it so important?
Researchers think it is used in learning of languages
- Letter order in words, word order in sentences, etc
Motor actions
- Learning predefined motor actions (writing?)
Learning music?

Human Performance

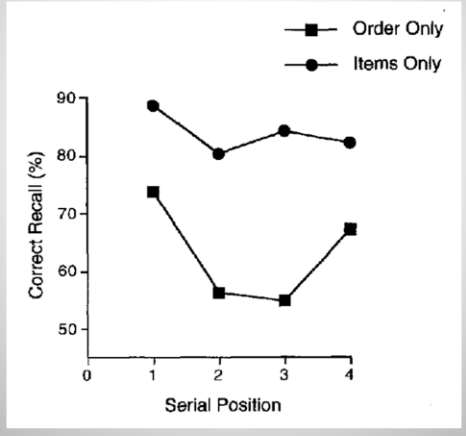
- Primacy and Recency effects



Primacy effect: Recall accuracy increases as items get closer to start of sequence
Recency effect: Recall accuracy also increase (but not as much) towards end of list

Human Performance

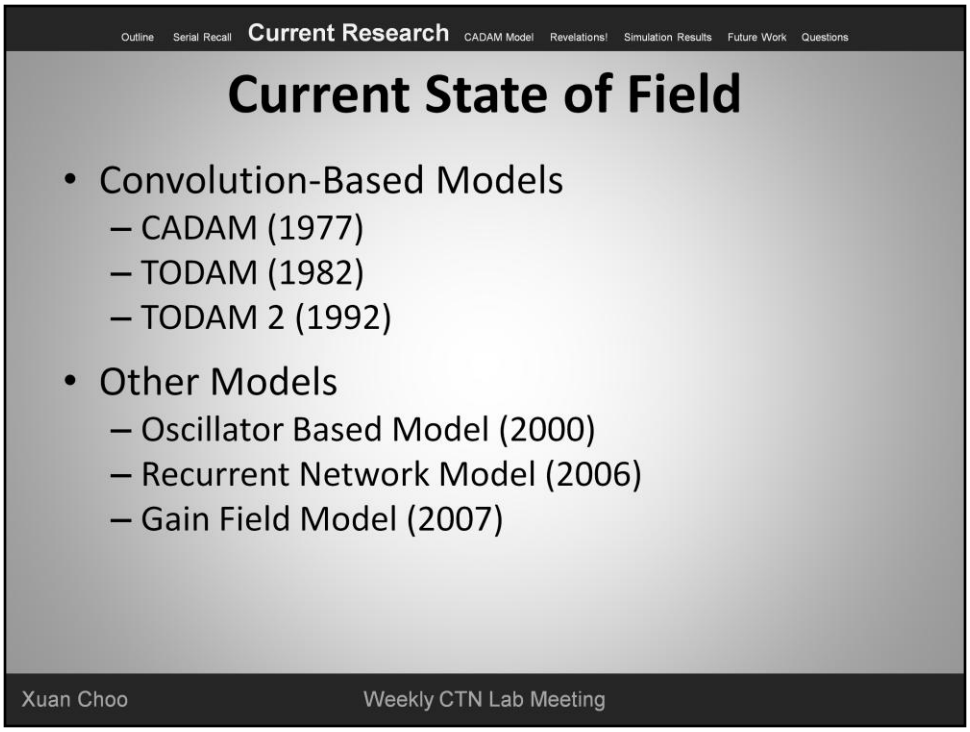
- Free recall



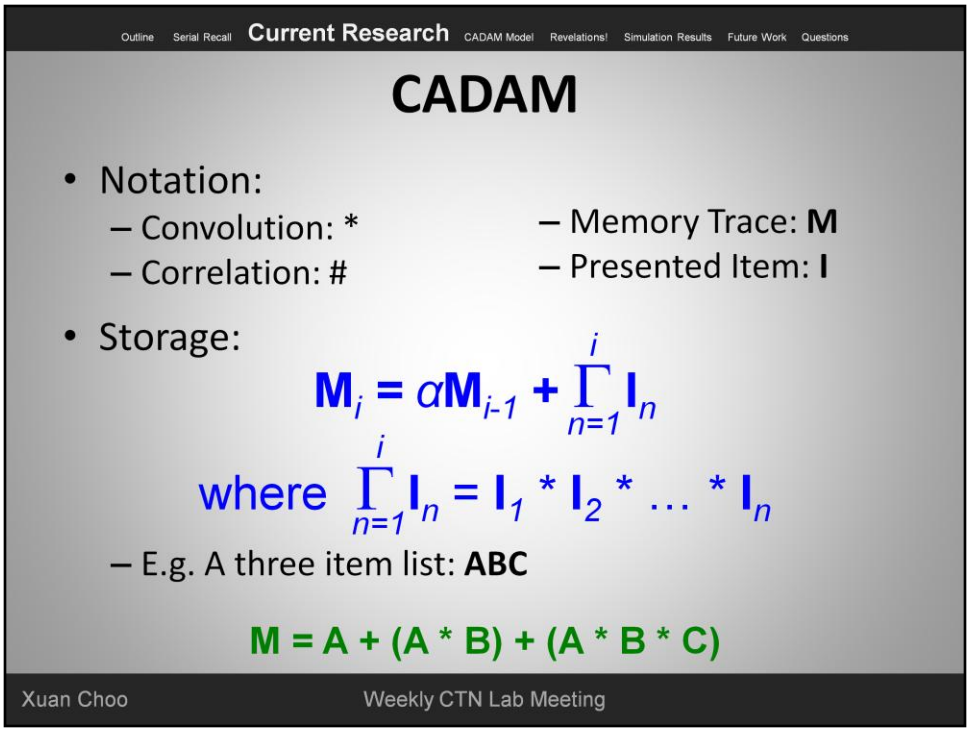
Free recall
- Recall without constraint to order
- No primacy or recency effects here!

Remember those numbers?

- Write them down on the piece of paper you have in front of you. (white squares)
- Then turn the paper over.



Here are some of the more well known models of serial recall
- Will elaborate on the convolution based models to give a general idea of how they work



Alpha is a forgetting parameter!
Note: This is in regular convolution, circular convolution operations are the same

CADAM – Cont.

- Retrieval: $\sum_{n=1}^{i-1} \mathbf{I}_n \# \mathbf{M} = \mathbf{I'}_j \rightarrow \mathbf{I}_j$
  - Example retrieval from sequence **ABC**:

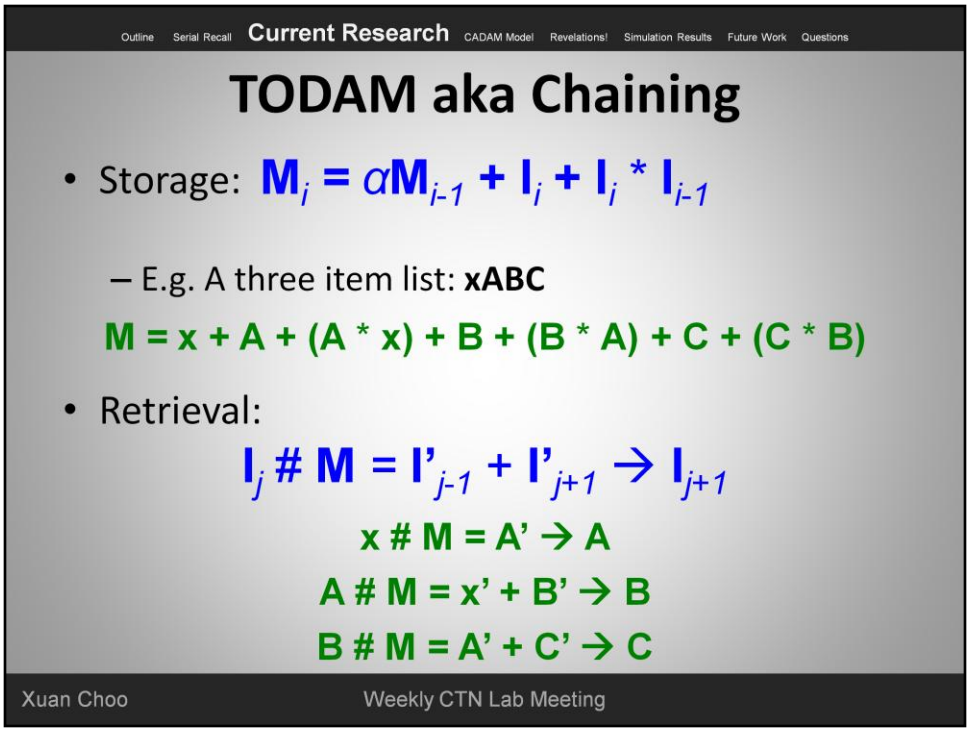
$$\mathbf{M = A + (A * B) + (A * B * C)}$$

$$\delta \# \mathbf{M = A' \rightarrow A}$$

$$(\delta * \mathbf{A}) \# \mathbf{M = B' \rightarrow B}$$

$$(\delta * \mathbf{A} * \mathbf{B}) \# \mathbf{M = C' \rightarrow C}$$

  - Note: δ = [0 … 0 1 0 … 0]

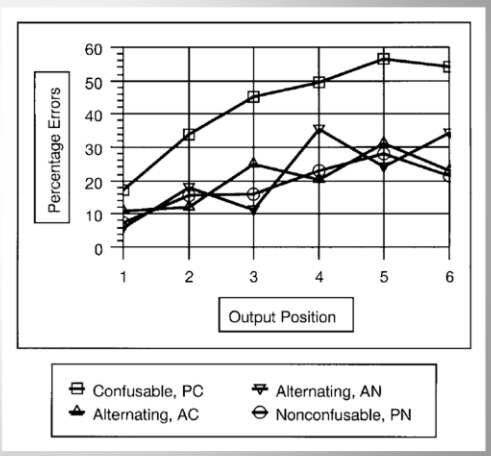


Because of chaining -> requires a “initiation” signal

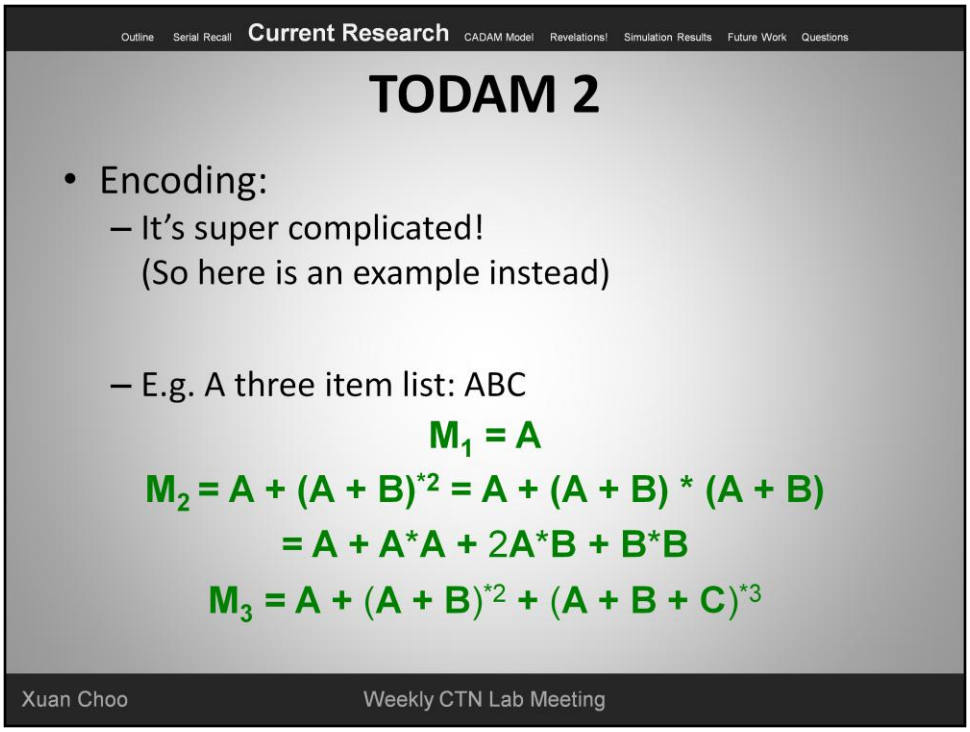
TODAM – Problems

Chaining has major problems

- Accuracy of items recall depends on recall accuracy of preceding items
- Possibility for loops



Chaining model problems
-The recall accuracy of items depends on the recall accuracy of preceding items. This contradicts human data where confusable items do not affect recall of subsequent items
-Also, possible for loops to occur within recall



Involved chunking and addition of chunks.
Each chunk is a the autocorrelation of the addition of all previous items

Chunking Model (Simplified)

- Information Retrieval:

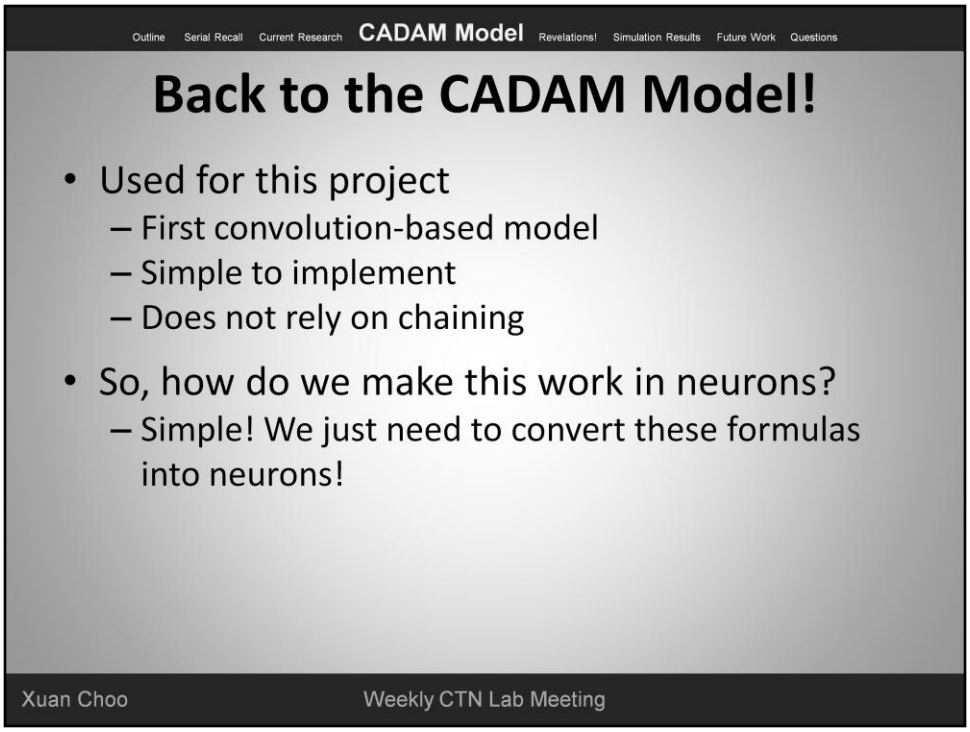
$$\delta \# M = A' \rightarrow A$$

$$A \# M = A' + 2B' \rightarrow B$$

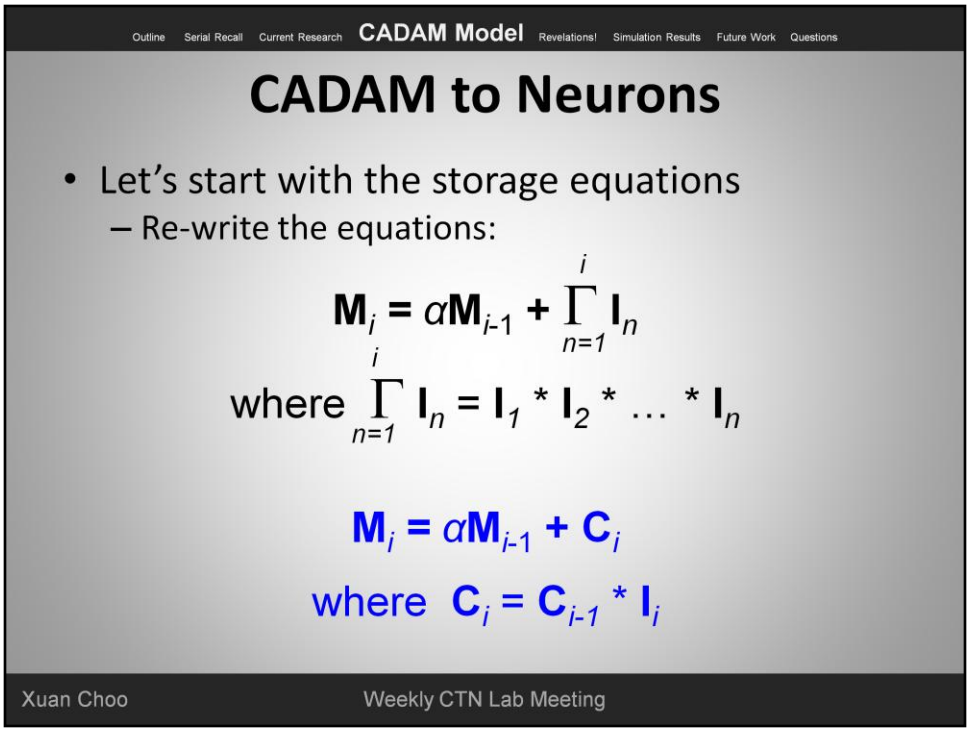
$$(A*B) \# M = 3A' + 3B' + 6C' \rightarrow C$$

More Numbers!

- First, on the paper with grey squares, write down the numbers from the previous set.
- Are you ready for the next set?
  (It won't matter if you are color blind)



-The CADAM model was the first convolution based model proposed.
It can also be used to form associative memory traces
It is very simple to implement, and does not rely on chaining.



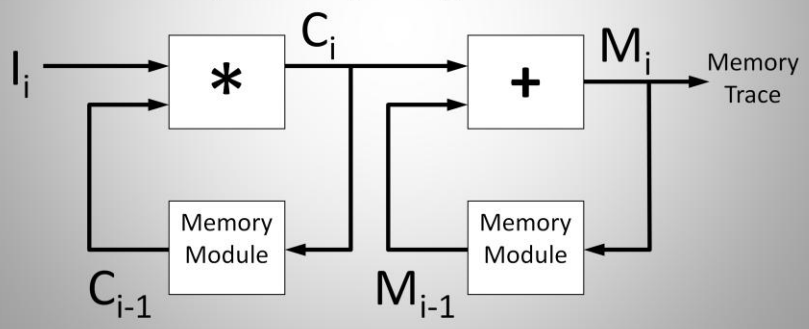
Equations are rewritten to exploit memory use in circuit

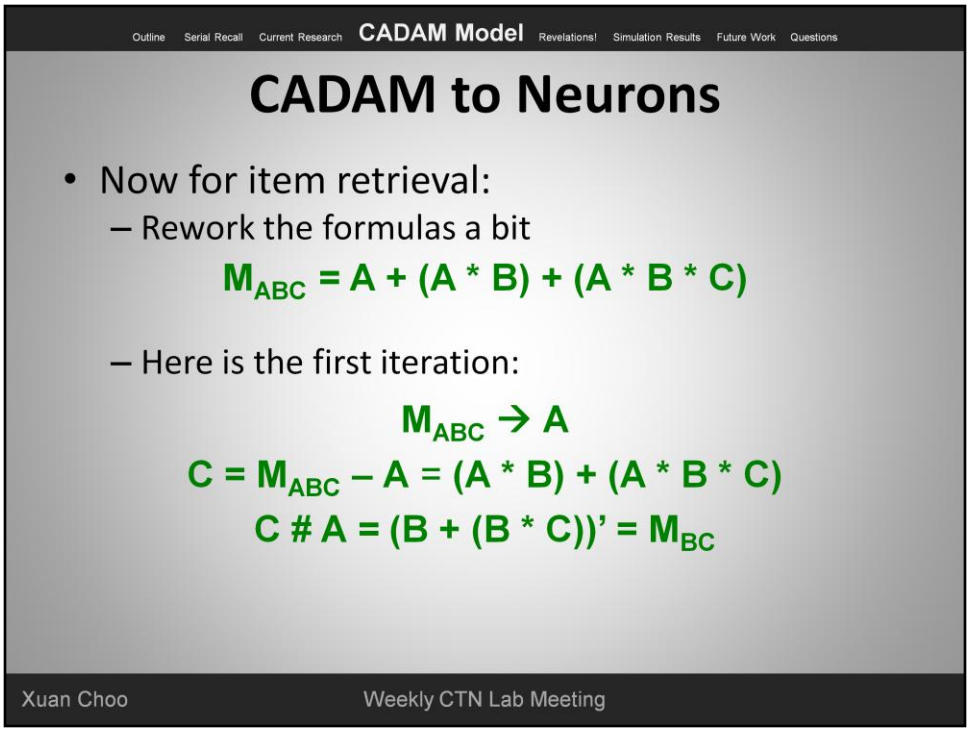
CADAM to Neurons Cont.

$$M_i = \alpha M_{i-1} + C_i$$

where $C_i = C_{i-1} * I_i$

- From the equations, design a network:





New method of decoding is derived.
Basically a loop, first iteration is show

CADAM to Neurons

- The example:

$$\mathbf{M_{ABC} \rightarrow A}$$

$$\mathbf{C = M_{ABC} - A = (A * B) + (A * B * C)}$$

$$\mathbf{C \# A = (B + (B * C))' = M_{BC}}$$

- The formulas:

$$\mathbf{M_{i-1} \rightarrow I_i}$$

$$\mathbf{C_i = M_{i-1} - I_i}$$

$$\mathbf{M_i = C_i \# I_i}$$

CADAM to Neurons

- Why not the original formulas?

$$\delta \# M = A' \rightarrow A$$

$$(\delta * A) \# M = B' \rightarrow B$$

$$(\delta * A * B) \# M = C' \rightarrow C$$

  - Easier to compute:
    - New method does not require convolution and correlation operation (just requires one correlation)
  - Results are the same

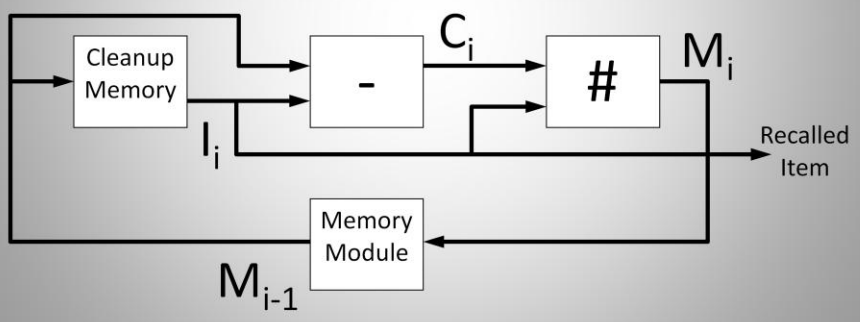
Remember the colored numbers?

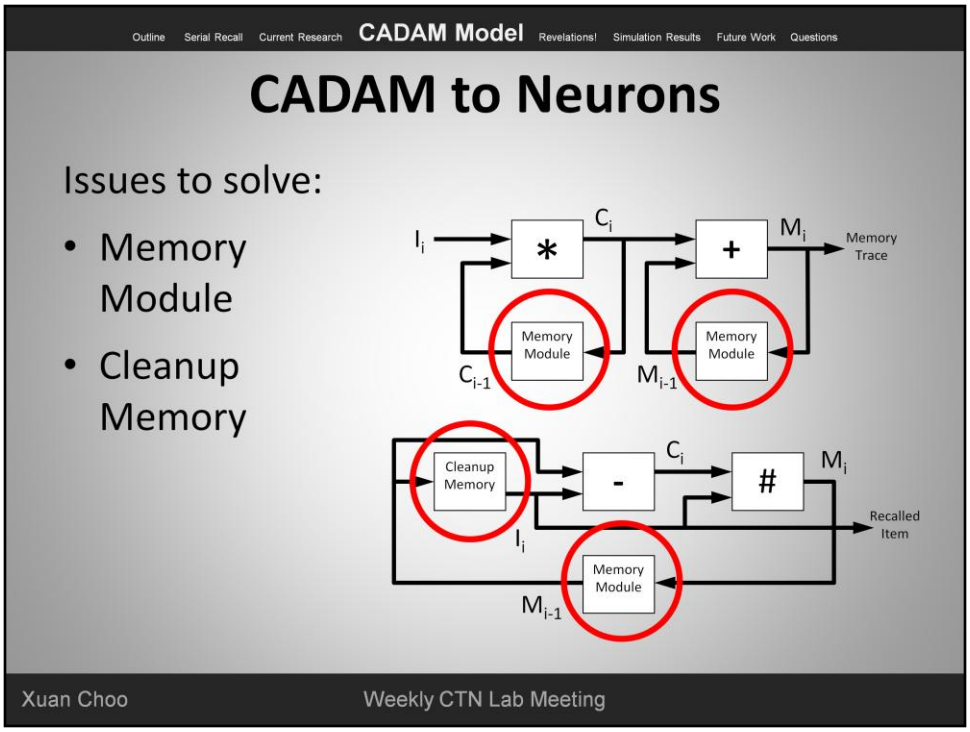
- Write them down on the piece of paper you have in front of you. (white squares)
- Then turn the paper over.

CADAM to Neurons

- Item retrieval network:

$M_{i-1} \rightarrow I_i$ $C_i = M_{i-1} - I_i$ $M_i = C_i \# I_i$

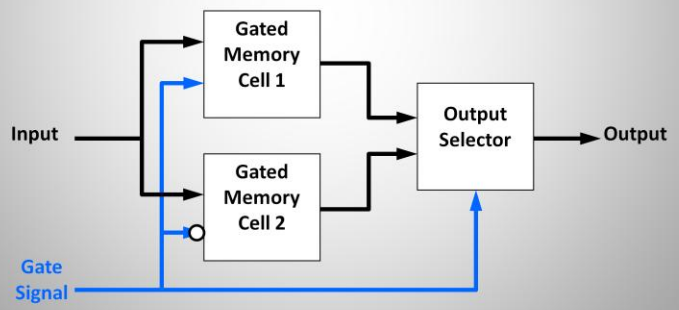




Note that the convolution and addition circuitry is feedforward, so the memory module needs to be able
to store values from the current cycle, while outputting the value from the previous cycle.

Struggles

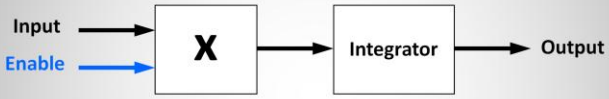
- Memory Module
  - How to store a value while outputting old value as well?
  - Put two memory cells in parallel, and gate them!

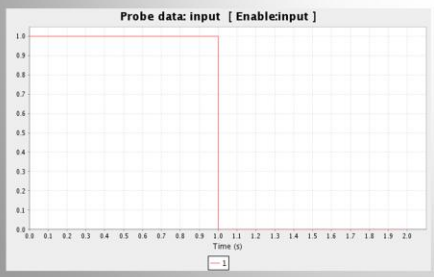


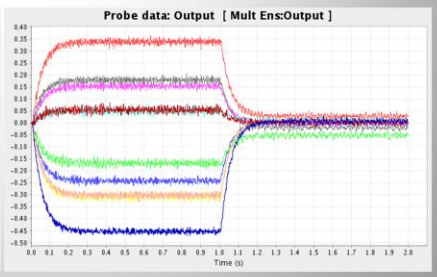
Other circuits were also tried:
- Playing around with time constants
- Chaining memory cells

More Struggles!

- How to create a gated memory cell?!
  - Try using a multiplier

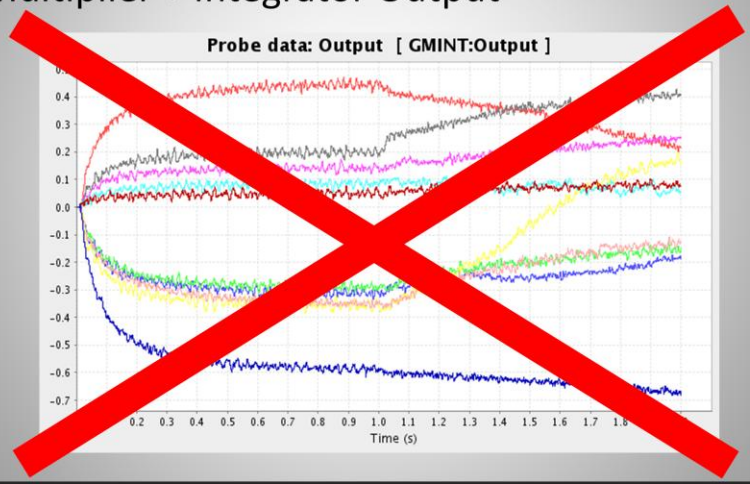


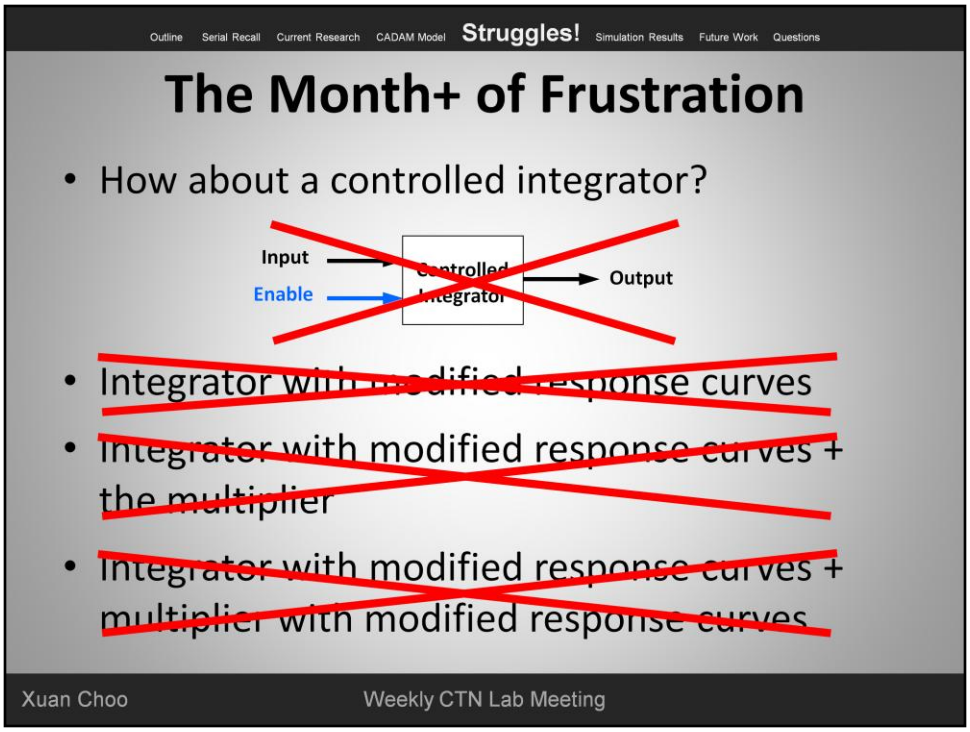




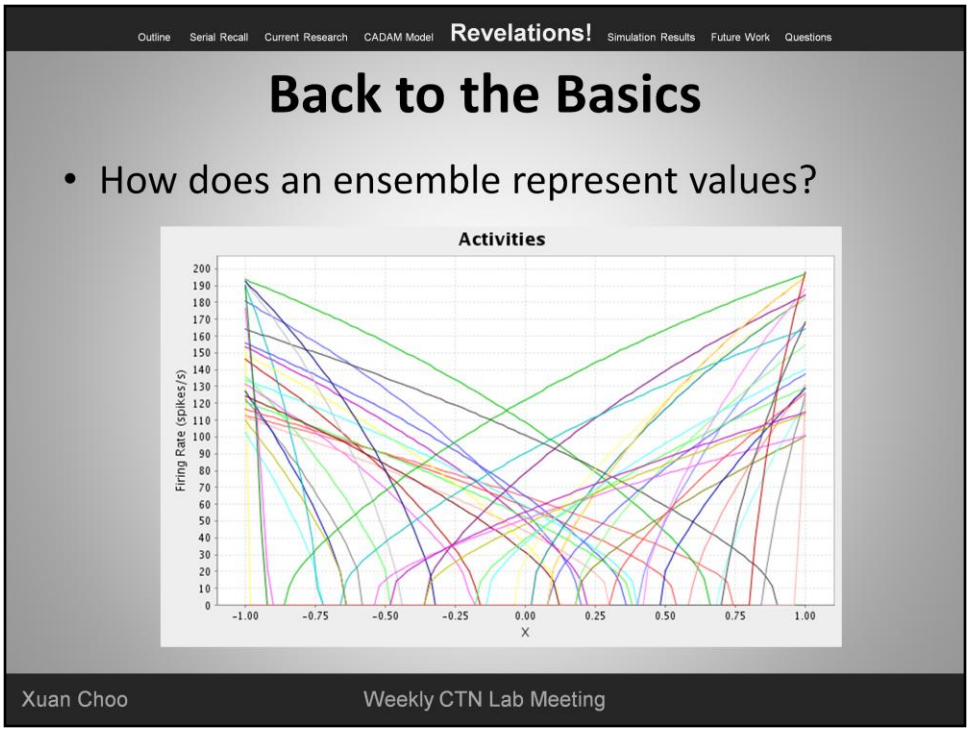
Struggles Cont.

- Multiplier + Integrator Output

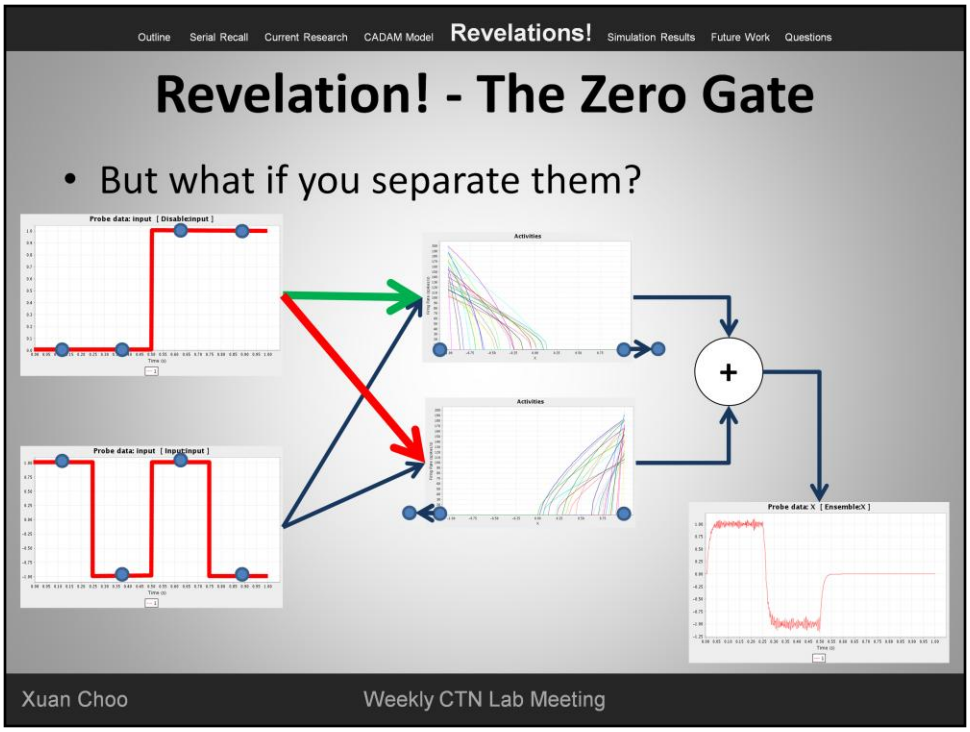




Controlled integrator, from NEF book
Modified response curves, with zero activity at x = 0 for both on and off neurons
Also tried cross-connecting two memory cells, like in a flip flop



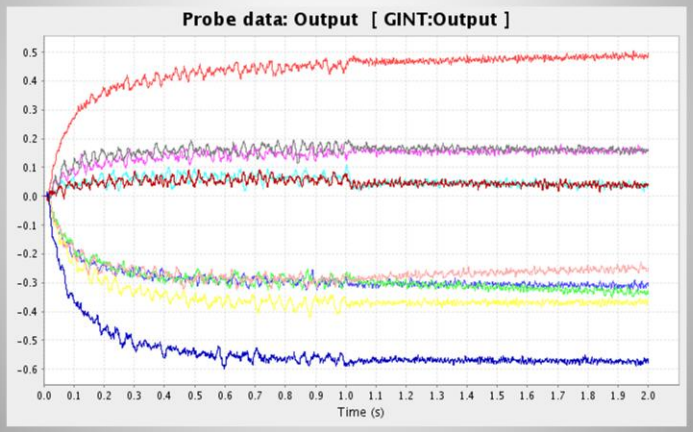
Ensembles have two sets of tuning curves, on & off.
- On neurons are good at representing positive values
- Off neurons are good at negative values
- But with their powers combined, they can represent anything! (The strength of the NEF, and the issue that is causing the problem here)



So we separate the on / off populations, and provide a gating signal to each.
** Point on slide how the input signal changes activity response
- When disable signal is high,

Gated Memory Cell

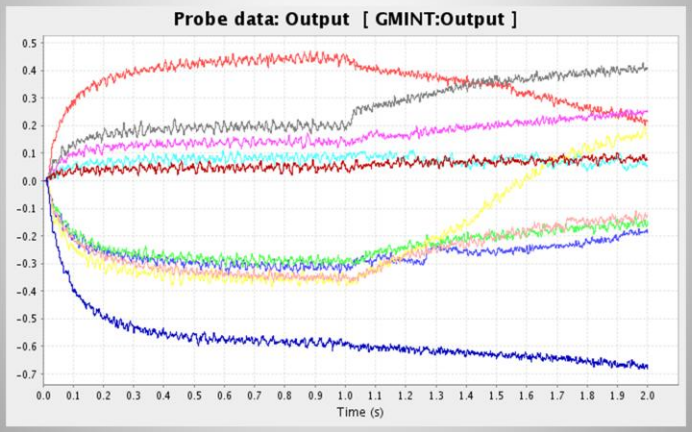
- Does it work?



Click black arrow to compare differences
And from C. Anderson's talk, seems like it is also found within the brain!

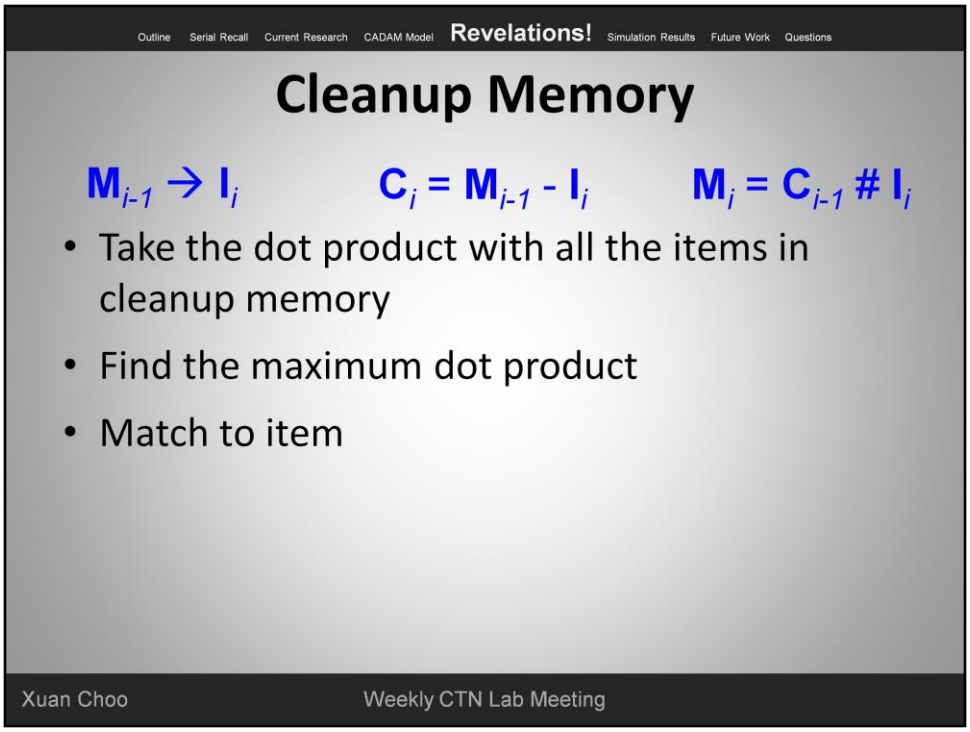
Lets Compare!

- Multiplier + Integrator Output

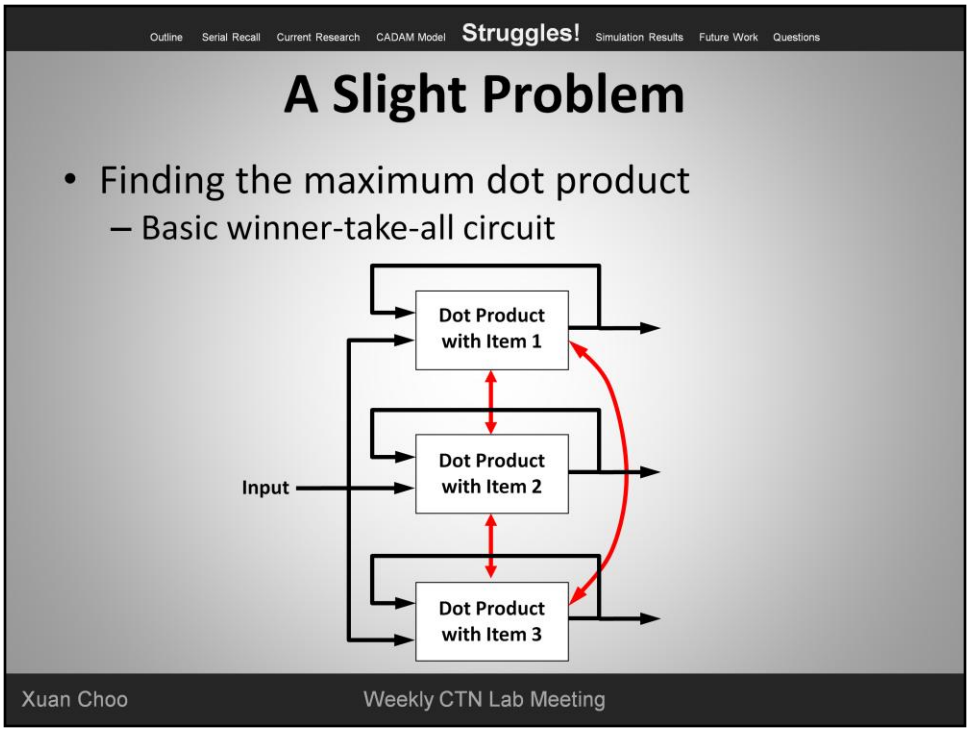


Last set, I promise!

- On the paper with grey squares, write down the numbers from the previous set (colored numbers).
- Are you ready for the next set?



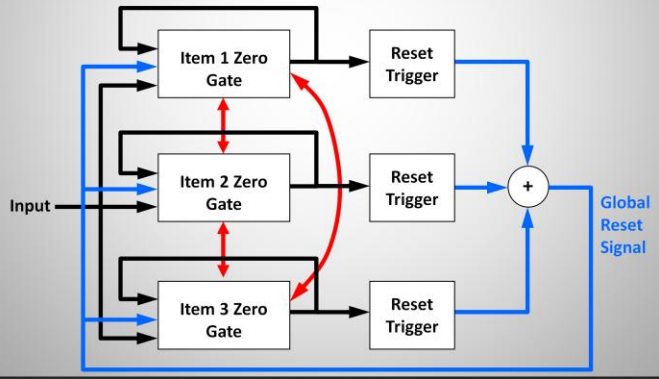
Needs to find the maximum dot product because need to always have result.
If no result (ie Ii = 0), formulas will crap itself in the next cycle



Red lines indicate lateral inhibition
Note the feedback
Problem: Once the maximum has been found, the recurrent connection will maintain it, even if input changes!

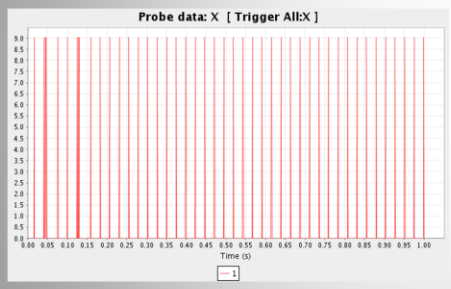
Cleanup Memory

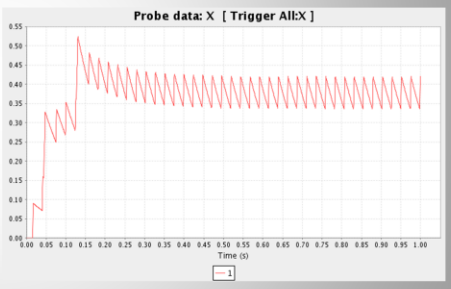
- How to fix?
  - Replace ensembles with zero gates
  - Add a reset circuit!



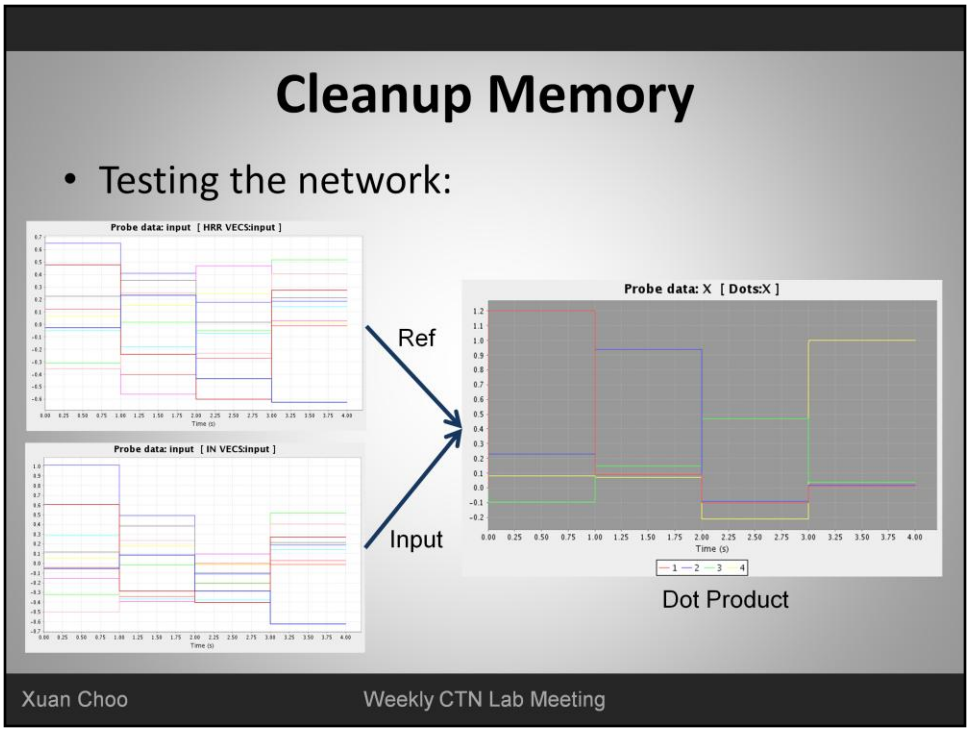
Cleanup Memory

- Re-use the reset signal to determine which item "won"!

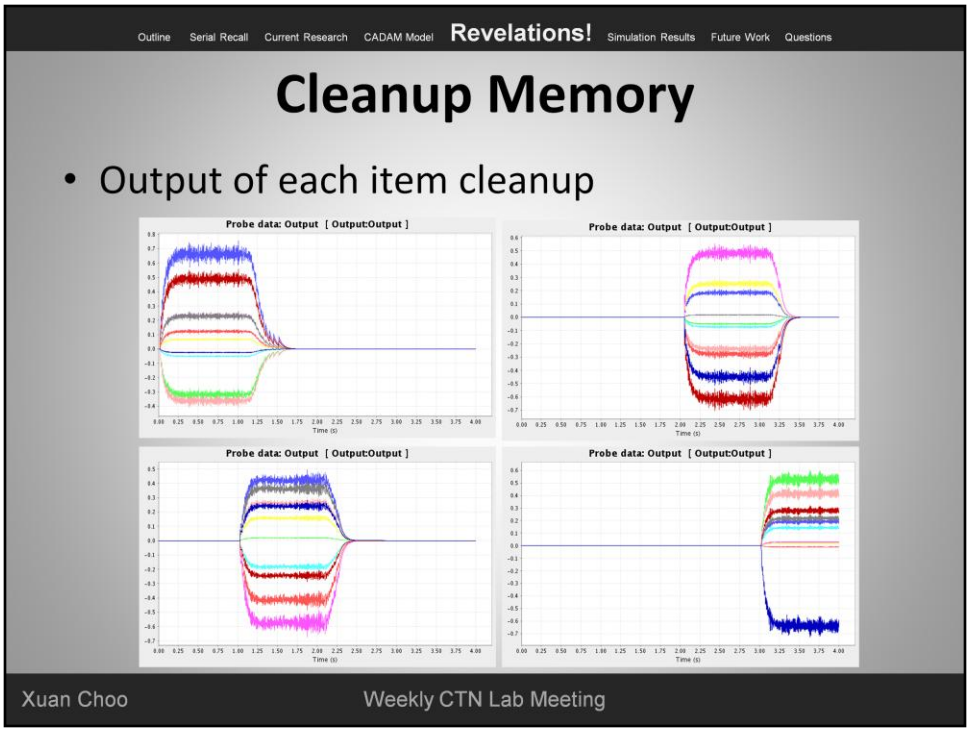




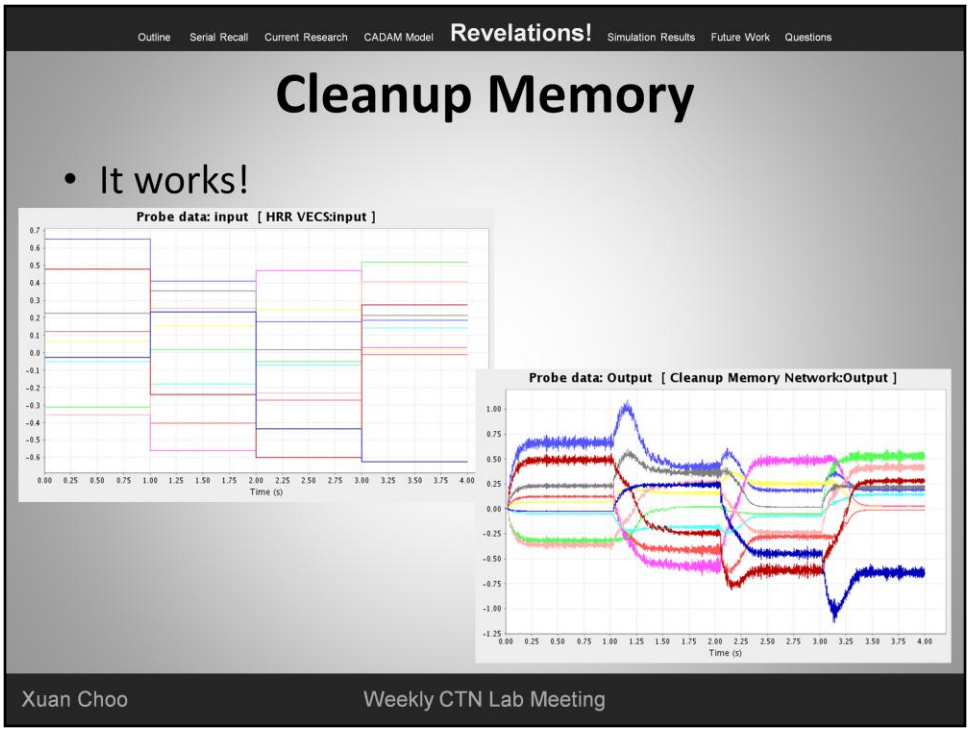
Filter and feed the reset signal to a circuit that will select the correct item…



The dot product indicates which item should be chosen.
- First 1 second, #1, after that, #2, etc, etc -> See diagram dot product.



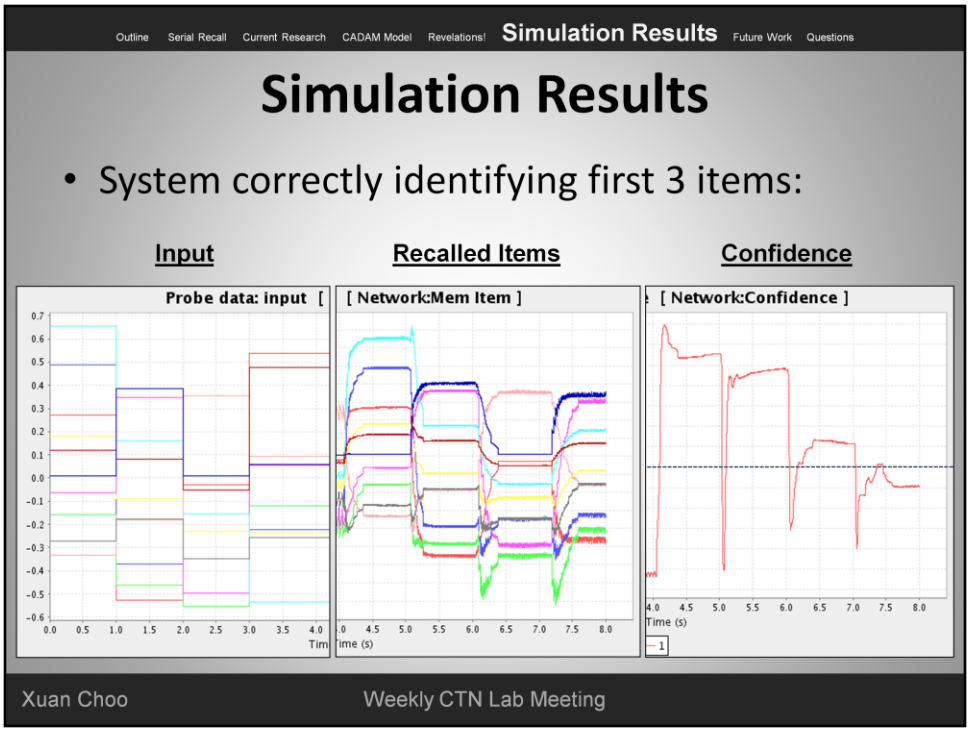
This is the output for each item ensemble in cleanup memory.
Top Left: Item 1, Top Right: Item 2
Bot Left: Item 3, Bot Right: Item 4
Note that all the item ensembles perform as expected.



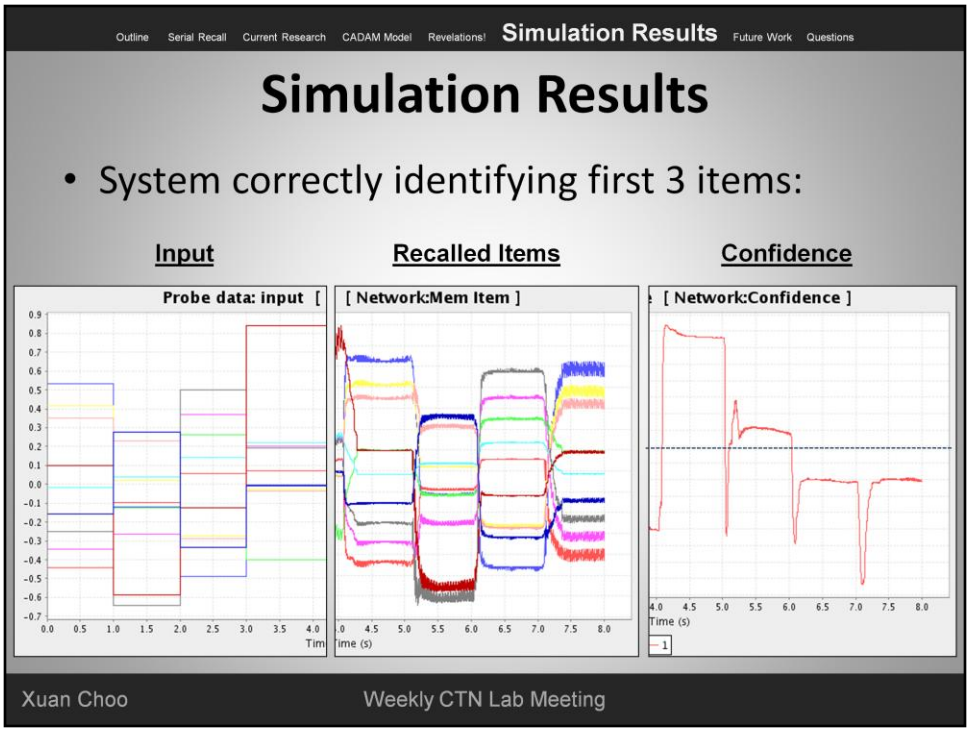
The is a comparison of the reference vectors (vectors placed in cleanup memory) With the output of the circuit selecting item 1, 2, 3 then 4 (from previous slide).

Almost there!

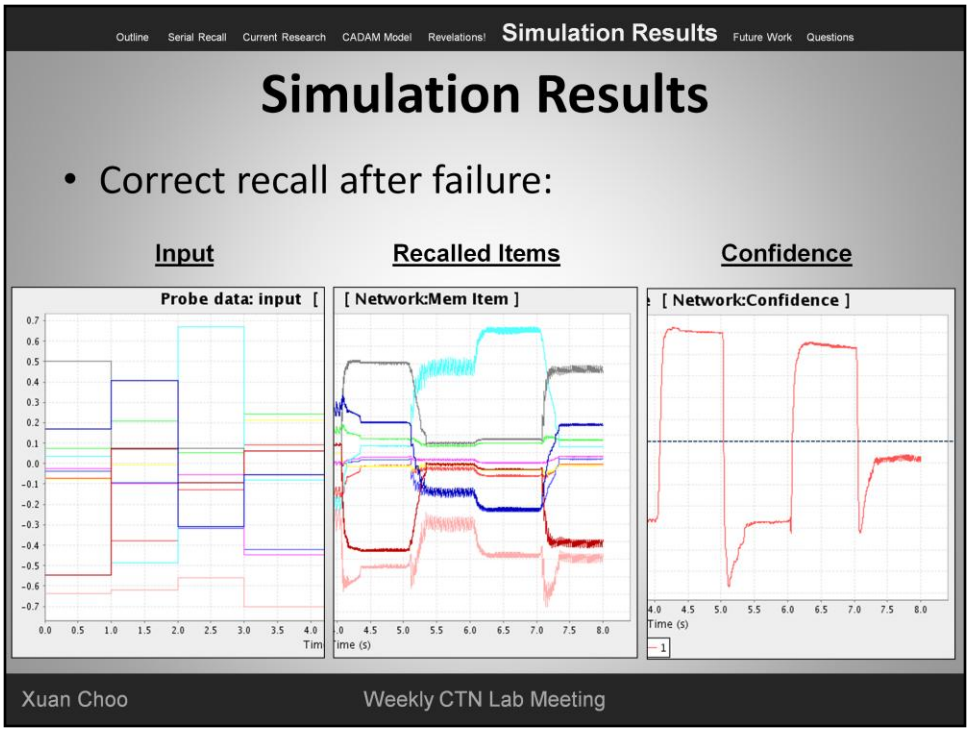
- Write down the numbers from the last set on the piece of paper you have in front of you. (white squares)
- Then turn the paper over.



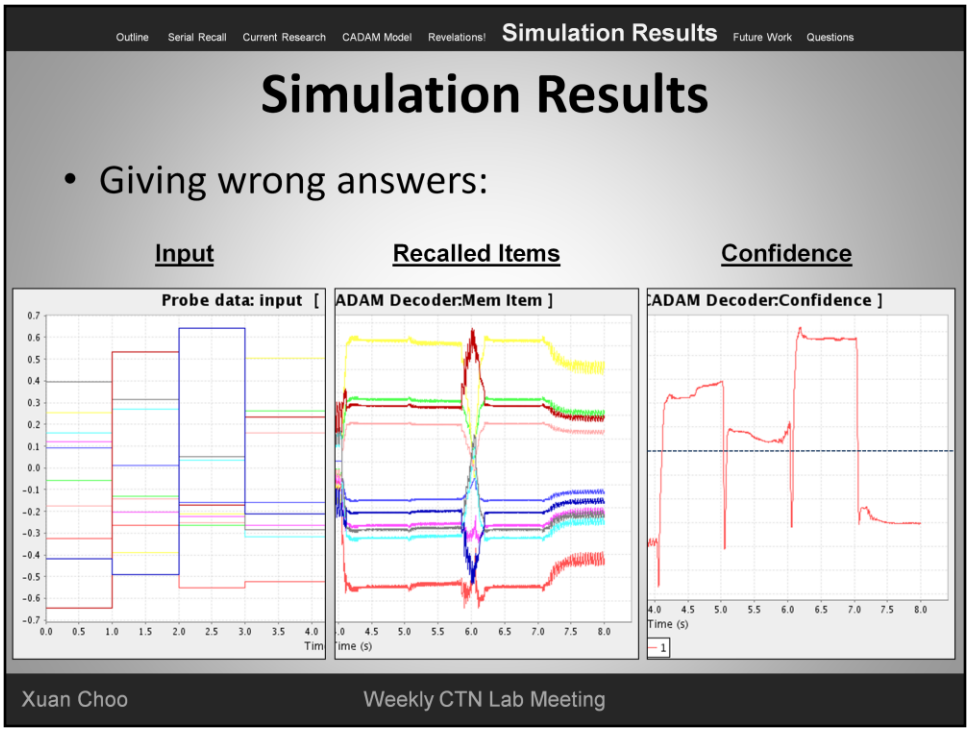
System correctly identifies items with above threshold confidence
Note the confidence threshold is arbitrary
Above confidence output can mean the subject indicated a response
Below threshold can mean the subject failed to recall, or skipped item



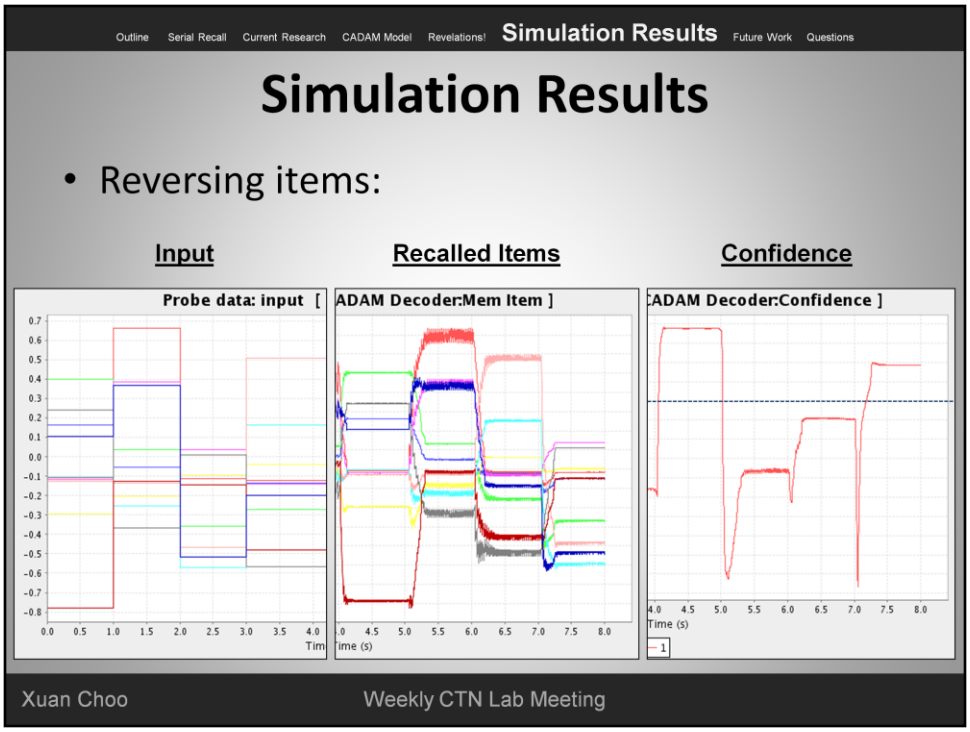
System correctly identifies items with 3rd item below confidence



System is able to recall 3rd item after failure to recall 2nd item. Can be thought of as skipping the 2nd item.



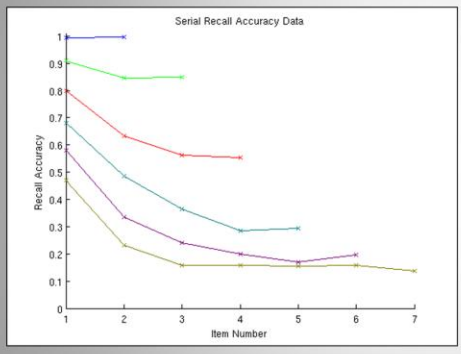
System gets everything wrong! (And is confident about it)



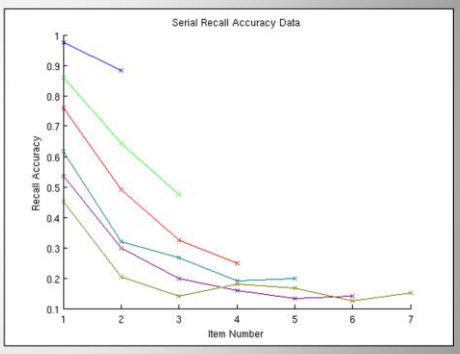
Last two items are reversed.

Simulation Results - Matlab

- Accuracy data for CADAM model



Matlab simulation using ideal formulas with forgetting rate of 0.8



Spiking neuron network

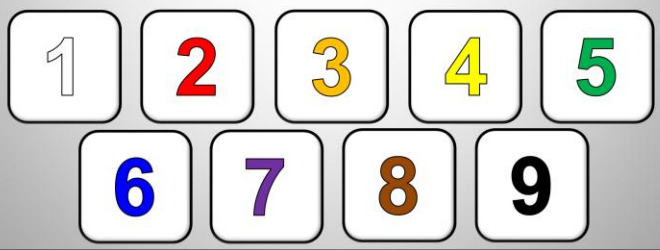
Lack of recency effects. =(

Future Work

- Need to improve / redesign cleanup memory
  - Cleanup memory items are hard-coded
  - Needs one set of ensembles per item
  - "Over engineered"
- Lack of recency effects
- Unable to perform:
  - Free recall
  - Backwards recall
  - Recall from arbitrary position in list

Phew!

- On the paper with grey squares, write down the numbers from the previous set (colored numbers).
- This time, I will provide the number – color association:



Tally your scores

- Answers:
  - Seq 1: 7 6 8 8 1 3 6
  - Seq 2: 3 8 5 5 1 9 4
  - Seq 3: 8 6 4 2 2 1 7
- For each sequence, count the number of items you got in the right spot.
- Which sequence did you get most correct?

Future Work

- Synesthesia and interaction of information from multi-modal sources
  - Visual
  - Auditory
  - Color
  - Smell
  - Touch
  - etc

Questions?

References

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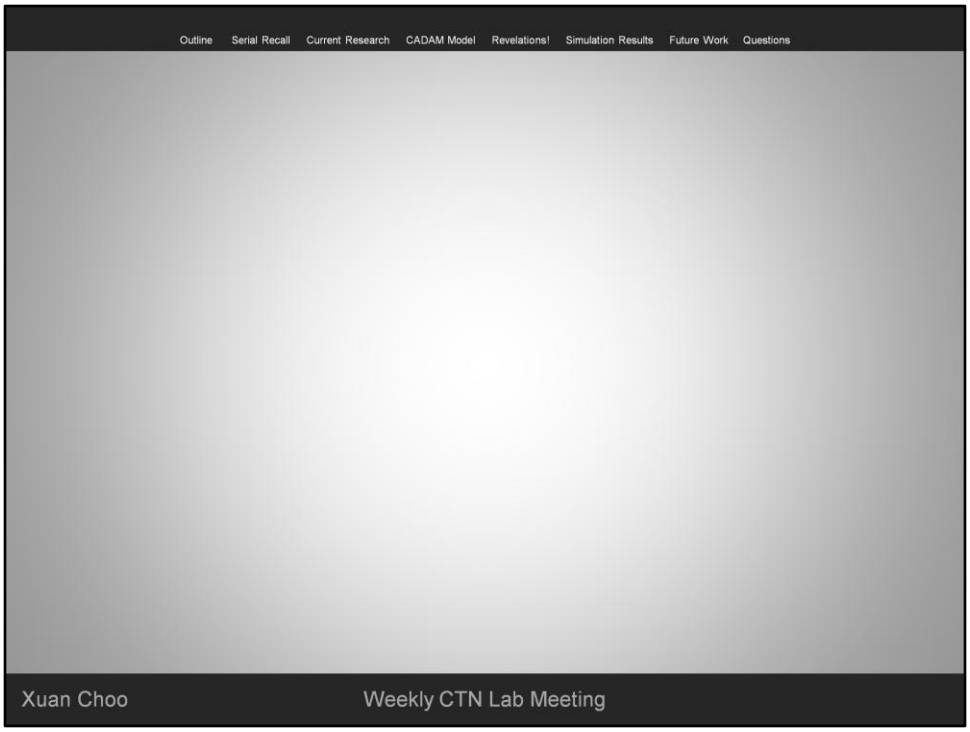
Outline
Serial Recall
Current Research
CADAM Model
Revelations!
Simulation Results
Future Work
Questions
Xuan Choo
Weekly CTN Lab Meeting