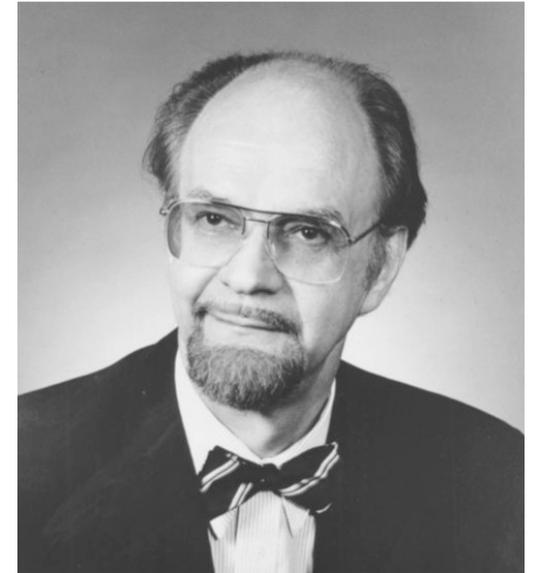


# The Memory System

"For Nature, the famous tinkerer, to have produced neurocognitive machinery that brings the past in to the present is clearly a much greater achievement than evolving eyes or the (marvelous) visual system.

Many animals have eyes and visual systems... A system that turns time's arrow into a loop has evolved only once, in only one species, although other species would presumably benefit from it as much as do humans. The singular existence of episodic memory in nature presumably reflects the complexity and biological cost of such a system, in terms of both the structural components and their operations"



(Tulving, 2002)



What would life be like without memory?

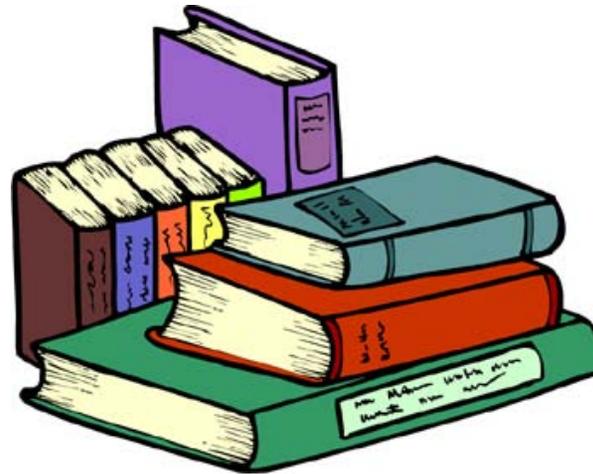


# Why does a cognitive system need memory?

- Learning
- Inference
- Integration across space and time
  - Eg. Scene perception and speech processing
- Recognition
- Reasoning and Problem Solving

# Three central capabilities

- Acquisition
- Storage
- Retrieval

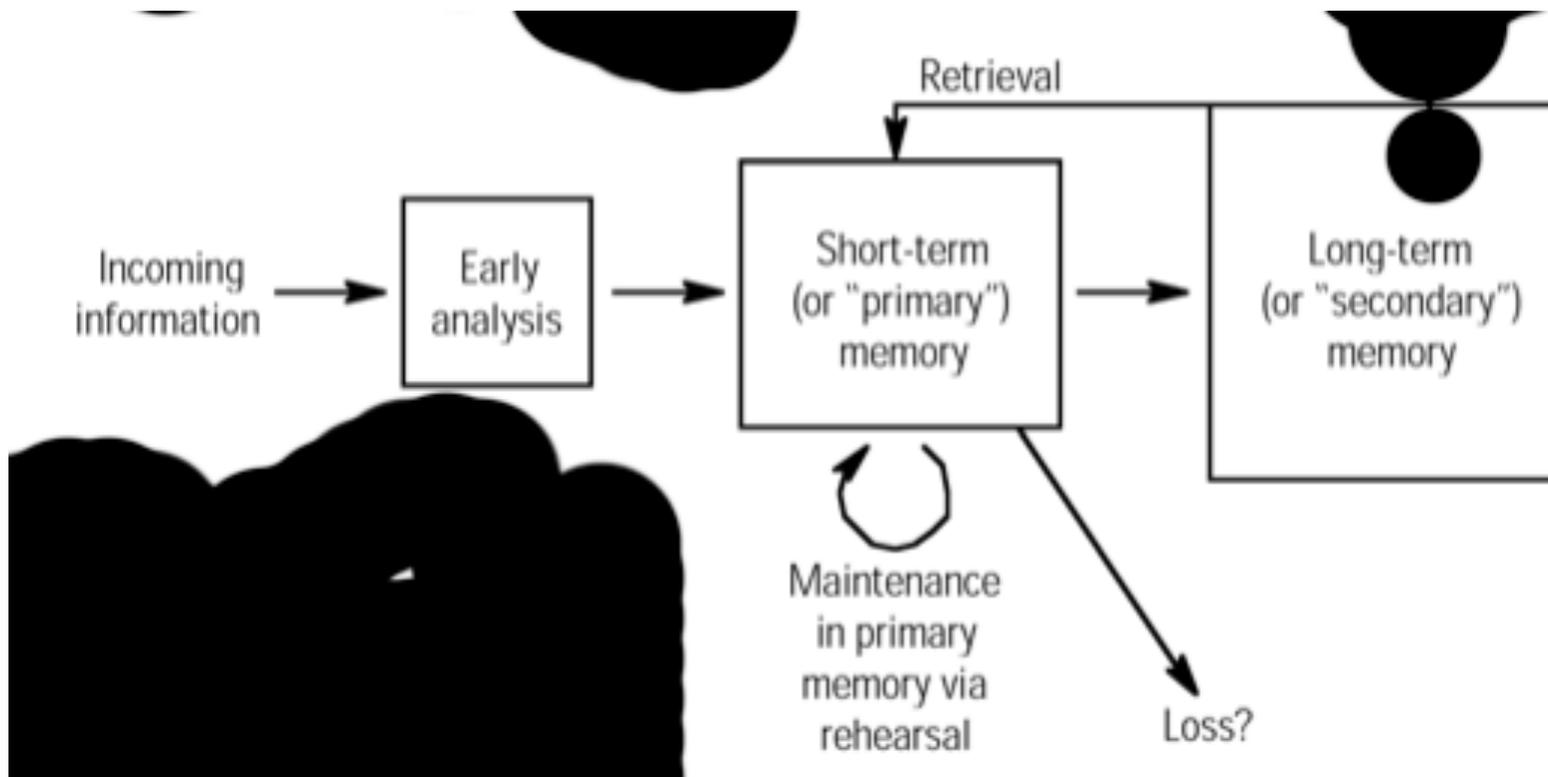


# How are these capabilities organized?

- Atkinson & Shiffrin (1965)
- Basic model has three stages:

**3-store model a.k.a. Modal Model**

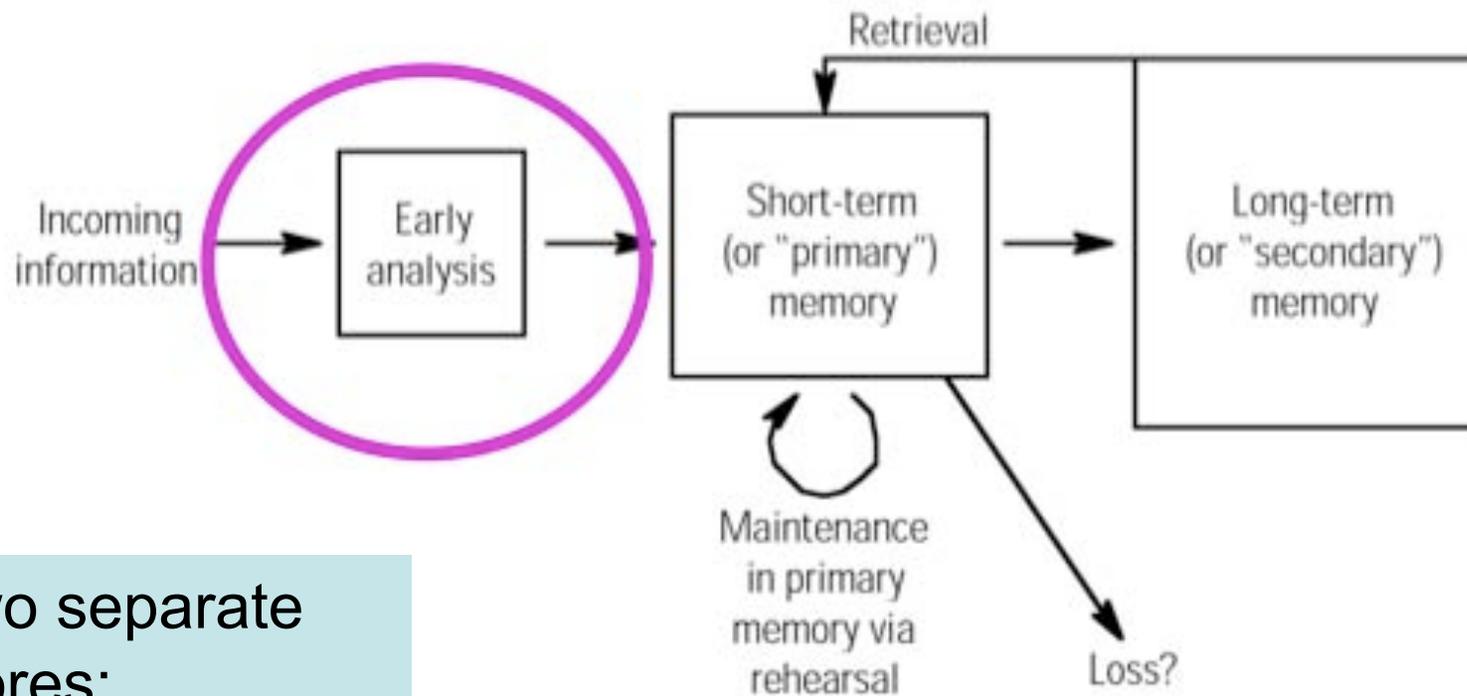
# The Modal (3-store) Model



# Three-store model: overview

- Sensory store: (rapid decay, unlimited capacity, pre-categorical)
  - Sperling: Visual iconic memory
  - Echoic memory
- Short-term store: (limited capacity, maintenance through rehearsal)
  - Often described as “working memory”
  - Recency effect in serial position curve
- Long-term store (unlimited capacity)
  - permanent storage of information
  - primacy in serial position curve

# Modal (3-store) model



Two separate stores:  
Iconic & echoic memory

# Demonstration of Iconic Memory

- Sperling Experiment
- Participants saw displays of letters and were asked to recall as many as possible...

X A P M

L R Q Z

J I C N



# Sperling Tone Conditions

- Participants see the same kind of array
- They are asked to recall one row, which has 4 characters... a number they should be able to remember
- But! Which row they have to recall depends on the type of tone they hear after they see the letters.

X A P M ←

High pitch tone means:  
recall top row

L R Q Z ←

Medium pitch tone means:  
recall middle row

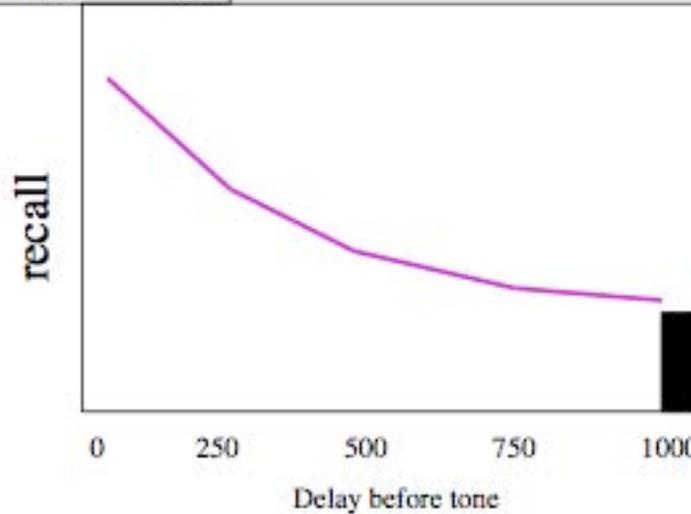
J I C N ←

Low pitch tone means:  
recall middle row

Participants must wait for the tone, before they can start reporting the letters they saw... otherwise they will get not know which row to report

### Sensory Memory: Sperling

X	A	P	M	High
L	R	Q	Z	Med
J	I	C	N	Low



Longer time (ms) before recall

--> worse memory for items

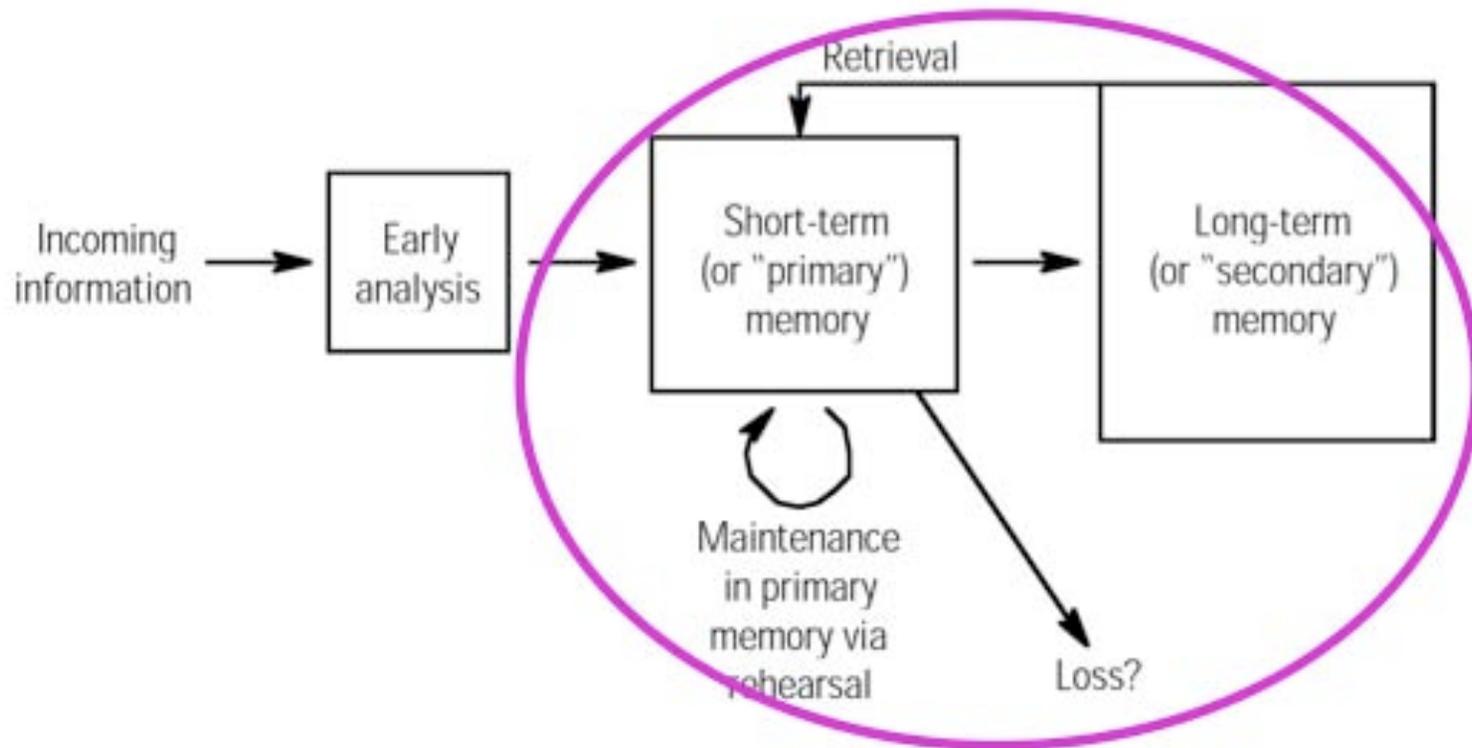
# What does this show about Iconic Memory?

- Only keeps track of a few items (4-5)
- Seems to be **very** short
  - Decays within one second
  - Starts to decay immediately

# Echoic Memory

- Analogous to Iconic memory, but for auditory domain
- Seems to last longer than Iconic memory... up to a few seconds!
- Why?
  - Used in language
  - Sounds may be more time-dependent than images, since sound unfolds over time

# The Rest of the Modal Model



# Short Term Memory

- Sometimes called just “working memory”
- Temporary storage of information that is being used/processed
- Information decays (if not rehearsed)

# Experiment: Memory test

- The task:

remember as many words as you can

bottle

# Now... recall

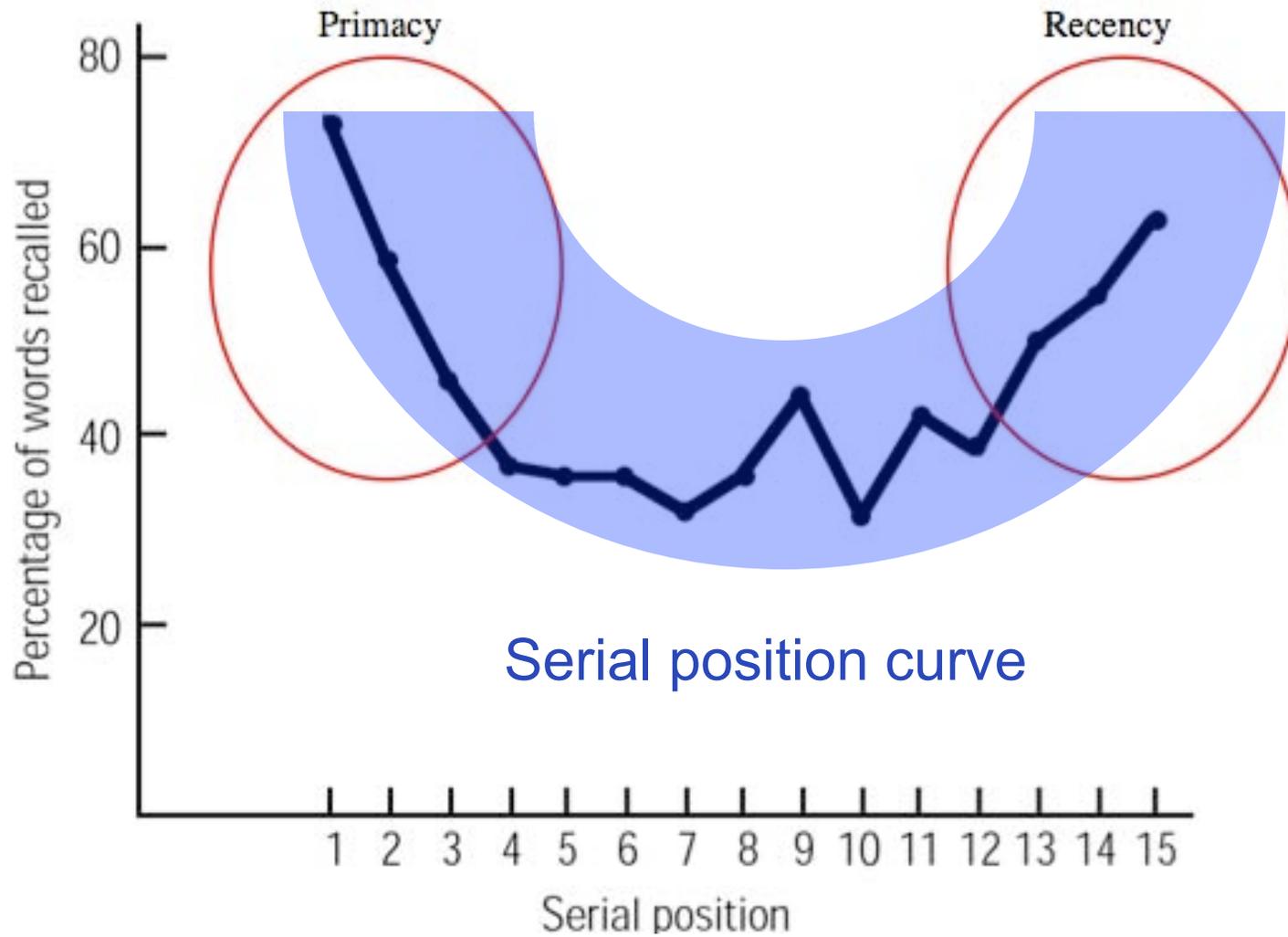
- Write down as many of the words as you can
- What strategies do you use to remember the words?

house  
corn  
yellow  
fish  
potato  
mud  
book  
shoe  
cake  
foot  
egg  
bottle

**Serial position** (order in the list you saw) affects how likely the word is to be recalled.

**Primacy effect** -- first few words are more likely to be remembered

**Recency effect** -- the last few (most recent) words are more likely to be remembered



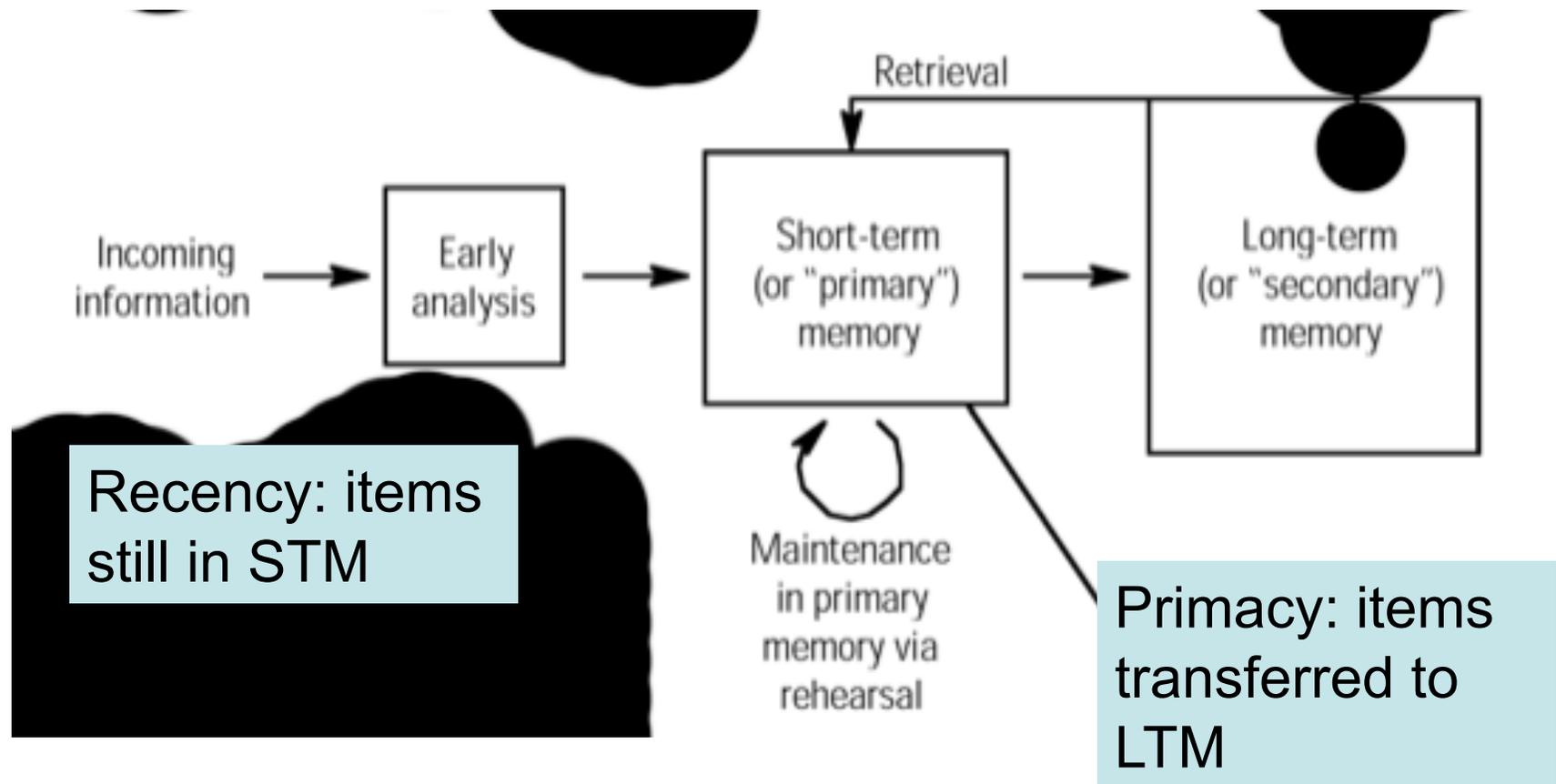
# Explaining the Recency Effect

- Words are rehearsed to keep in working memory
- Memory resources are limited -- so only recent items are still in working memory
- During recall, the contents of working memory are retrieved first

# Explaining the Primacy Effect

- First words get more attention (Rundus, 1971)
- First words have a higher chance of being transferred to LTM
- This leads an advantage for recalling the first few items

# Primacy and Recency



# What about the middle?

- Items in the middle don't get put into LTM as easily
  - Working memory is getting full, so few resources are left
  - Resources are needed to transfer to LTM
- By the end of the list, they have decayed from working memory

# How are items kept in working memory?

- Memory Rehearsal Model
- First proposed as a mathematical model by Atkinson and Shiffrin (1965)
- Maintenance loop was added to the 3-stage model to explain how items are retained in working memory -- what keeps memories from decaying?

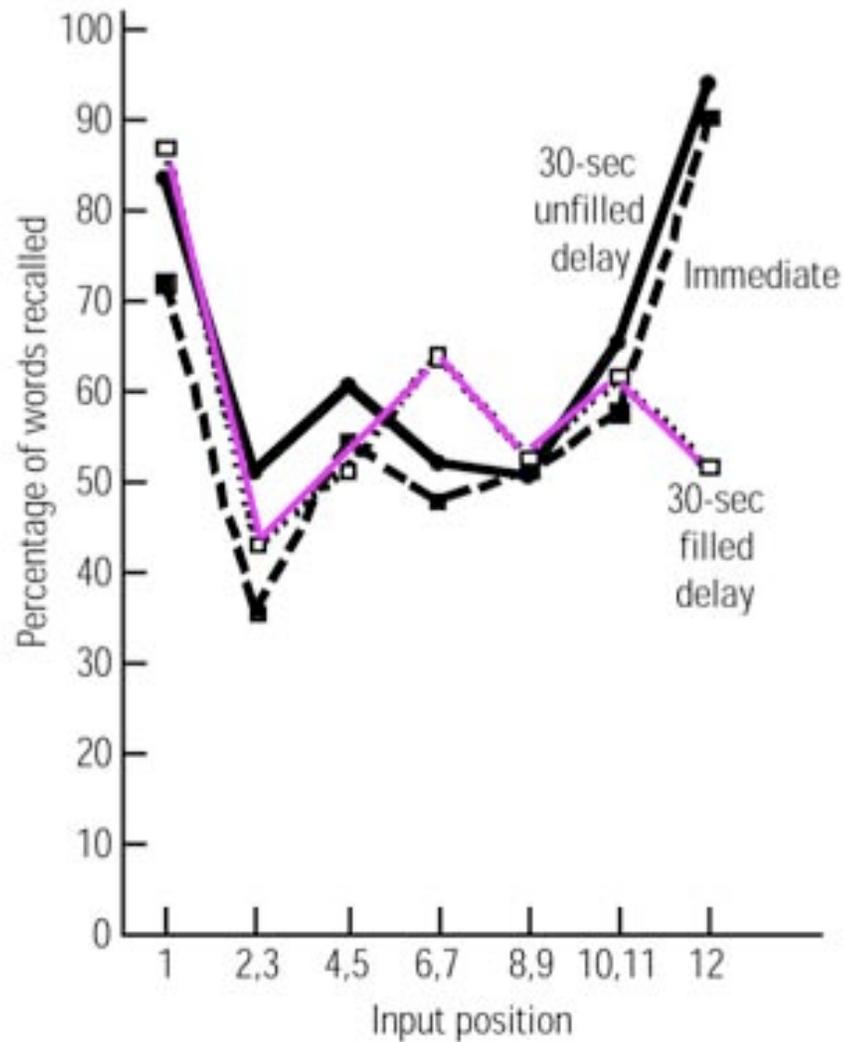
# Experimental Evidence for Rehearsal

- Rundus (1971)
- Probability of recall is related to the total # of times something is rehearsed, not just the length of time that goes by.
- With forced rehearsal strategies:
  - Three-item rehearsal

# Evidence for 3-stage Model

- Interpolated activity eliminates recency
  - “Interpolated activity”: doing another task between learning and recall
- Why?
  - Prevents rehearsal (during interpolated activity)
  - Affects working memory (STM) only

# Interpolated Activity Eliminates Recency



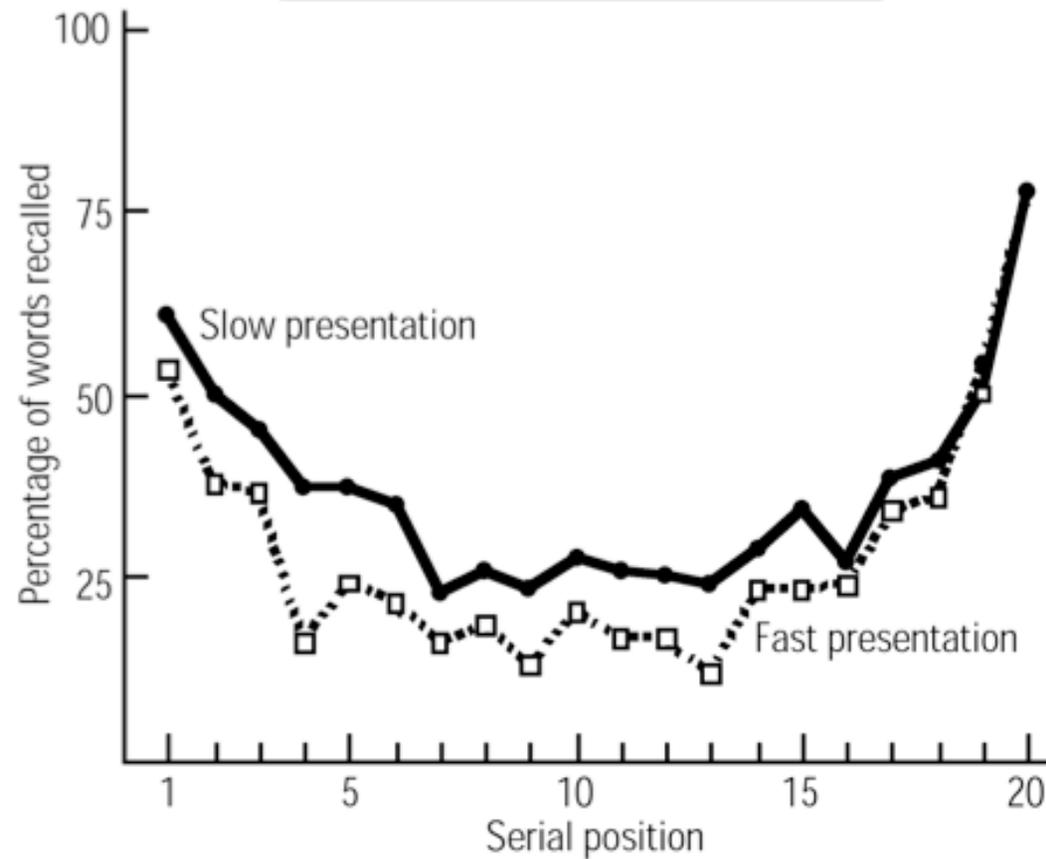
# Evidence for 3-stage Model

- interpolated activity only impairs working memory
- this is evidence that working memory and LTM are two separate things -- it shows a **dissociation** between working memory and long term memory

# Presentation rate & memory

- Slower rate of presentation affects primacy, but doesn't affect recency
- Allows more rehearsal of each item
- More items make it to LTM
- Doesn't affect STM at all

# Slow Rate Improves Primacy



# The Modal Memory Model: three-store model

- **Sensory store:** rapid decay, unlimited capacity, pre-categorical
  - Sperling: Visual iconic memory
- **Short-term store:** limited capacity, maintenance through rehearsal
  - Recency in serial position
- **Long-term store:** unlimited capacity, little or no decay
  - primacy in serial position

# The Modal Model: Changes

Why add to the model?

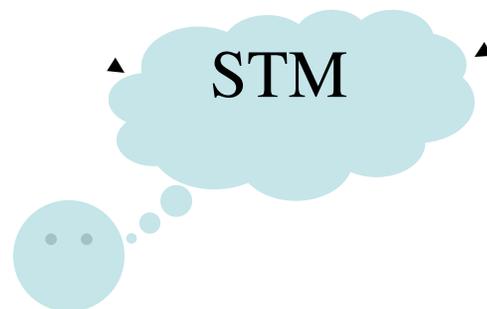
- STM seems to be more than a passive store
  - E.g. rehearsal is an active process
- Time in STM is not the main factor that determines whether info is stored in LTM
- There are multiple forms of STM, which don't interfere with each other (use different resources)
  - E.g. Verbal and Spatial working memory

# Change 1: Working Memory is an active workspace

- Not just a simple kind of short term storage...
- Stores information *while it's being processed*
- Information is transferred to STM from sensory memory, or is retrieved from long term memory

Info. from  
the world

Info.  
from LTM



# Working Memory: limited capacity

- George Miller's "magic number" of items:  $7 \pm 2$



My problem is that I have been persecuted by an integer. For seven years this number has followed me around, has intruded in my most private data, and has assaulted me from the pages of our most public journals. This number assumes a variety of disguises, being sometimes a little larger and sometimes a little smaller than usual, but never changing so much as to be unrecognizable. The persistence with which this number plagues me is far more than a random accident.

# Working Memory: limited capacity

- What counts as an item?
  - Seems to depend on the way information is treated by the cognitive system
- Items can be “chunked” -- multiple items grouped together come to be treated as one.

□

# STM holds $7 \pm 2$ “chunks” of information



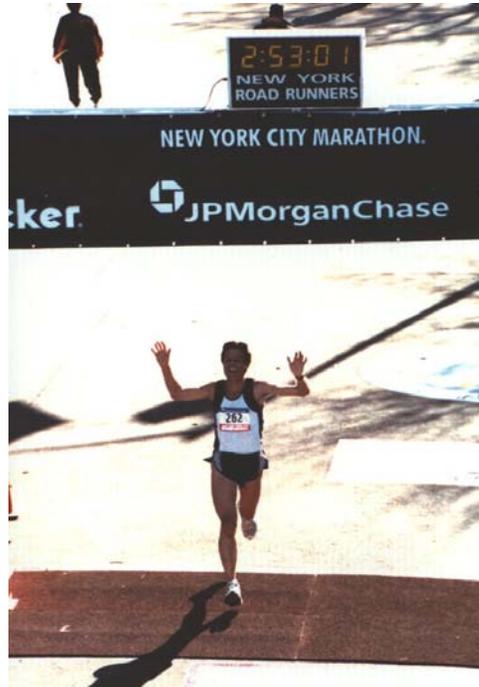
We must recognize the importance of grouping or organizing the input sequence into units or *chunks*. Since the *memory span is a fixed number of chunks*, we can increase the number of bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before.

Commonly cited chunking example: area codes

585 - 275 - 4 81 2 = 6 items

# What counts as a chunk?

- Chase and Ericsson: what information counts as an chunk depends on how you organize information



# Secrets of a Mind-Gamer: How I trained my brain and became a world-class memory athlete

Joshua Foer

Dom DeLuise, the comedian ( and five of clubs ), was implicated in the following unseemly acts in my mind's eye: He hocked a fat globule of spittle ( nine of clubs ) on Albert Einstein's thick white mane ( three of diamonds ) and delivered a devastating karate kick ( five of spades ) to the groin of Pope Benedict XVI ( six of diamonds ). Michael Jackson ( king of hearts ) engaged in behavior bizarre even for him. He defecated ( two of clubs ) on a salmon burger ( king of clubs ) and captured his flatulence ( queen of clubs ) in a balloon ( six of spades ).

0	2	2	1	2	1	0	9	4	Row 4
2	1	3	6	7	0	1	1	5	Row 5
4	8	1	7	6	4	6	0	7	Row 6
3	7	9	5	8	3	4	4	8	Row 7
8	6	8	5	9	8	2	5	2	Row 8
9	9	7	6	1	6	7	8	6	Row 9
6	4	0	8	2	4	5	6	1	Row 10
3	3	6	9	2	7	6	3	0	Row 11
5	0	1	4	3	6	8	7	7	Row 12
4	1	3	7	4	9	9	8	0	Row 13
2	4	2	2	5	9	1	1	9	Row 14
1	2	3	1	0	8	3	3	1	Row 15
7	8	5	6	1	0	7	6	8	Row 16
0	7	6	4	6	3	8	6	9	Row 17
7	6	4	8	1	1	2	8	1	Row 18
5	9	8	5	9	2	4	2	0	Row 19
2	8	1	0	7	4	6	7	0	Row 20
4	1	9	0	3	6	7	8	3	Row 21
3	1	7	7	2	5	2	9	4	Row 22
7	3	6	1	4	8	6	9	6	Row 23
8	6	8	6	8	7	1	3	7	Row 24

## Numbers

Mental athletes use a variety of elaborate mnemonic systems to remember numbers. One of the most basic techniques, known as the Major System, was invented in the 17th century. It is nothing more than a simple code to convert digits into sounds. Those sounds can then be turned into words, which in turn become images for a memory palace. The code works something like this:

0	1	2
S	T or D	N
3	4	5
M	R	L
6	7	8
Sh or Ch	K or G	F or V
9		
P or B		

The number 32, for example, would translate into MN; 33 would be MM; and 34 would be MR. To make those consonants meaningful, you're allowed to freely intersperse vowels. So the number 32 might turn into an image of a man; 33 could be your mom; and 34 might be the Russian space station Mir. Similarly, the number 86 might be a fish; 40 a rose; and 92 a pen. You might visualize 3,219 as a man (32) playing a tuba (19) or maybe a person from Manitoba (3,219).





1



2



3

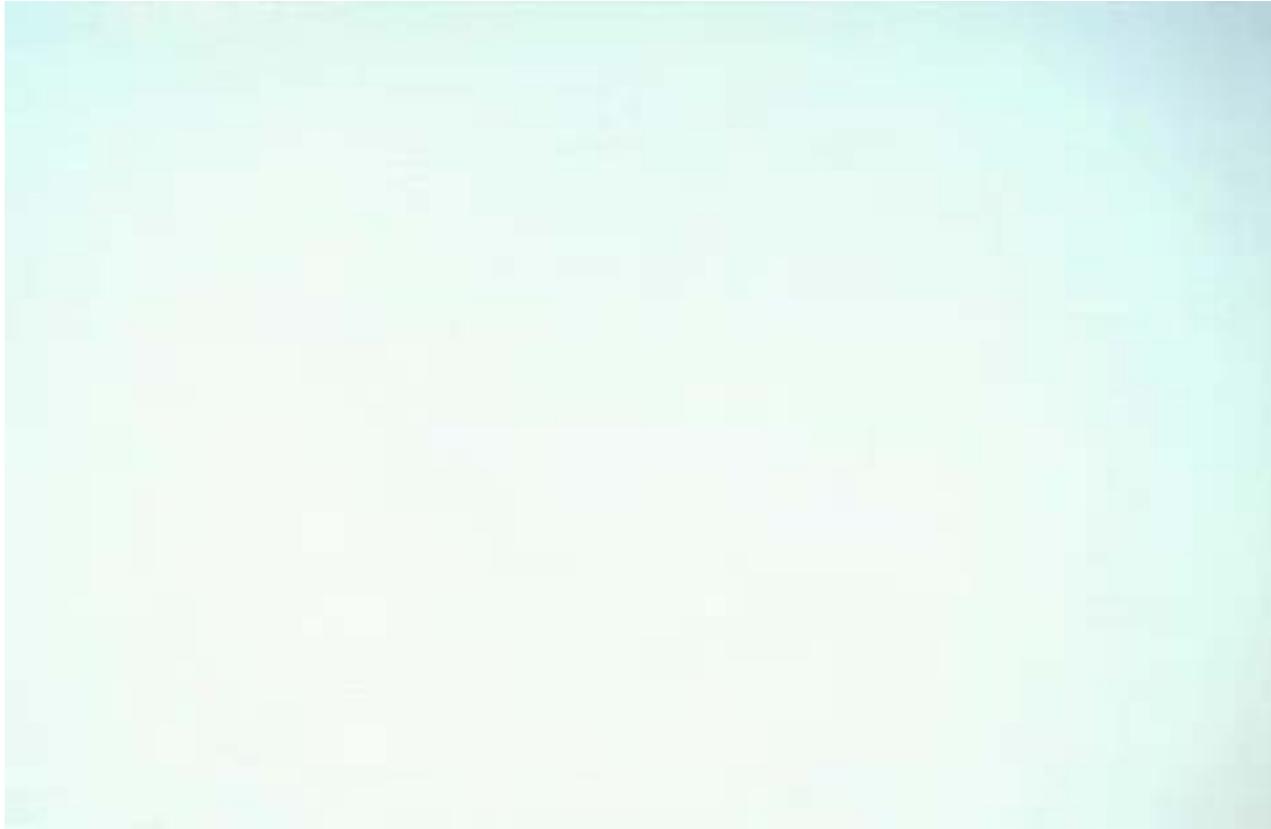


4

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## Names

To memorize names, mnemonists take advantage of a phenomenon called the Baker/baker paradox: it's easier to remember that someone is a baker than that his name is Baker. The trick is to figure out ways to visualize Bakers as bakers. To remember the name Edward Bedford, **1** for example, a mnemonist might visualize Edward Bedford lying on the bed of a Ford truck **2**, then deciding that wasn't distinctive enough, see him fording a river on a floating bed **3**. To remember his first name was Edward, he might put Edward Scissorhands next to him, shredding the mattress as he pads across the river **4**. That unforgettable image becomes indelibly associated with the man's name.



# How is Working Memory Capacity Measured?

- **Digit span task** -- how many sequential numbers can you remember?
- Average is  $7 \pm 2$  (5-9 numbers)
- The number of digits you can maintain in working memory is your **digit span**

# Another Way of Measuring Working Memory Capacity

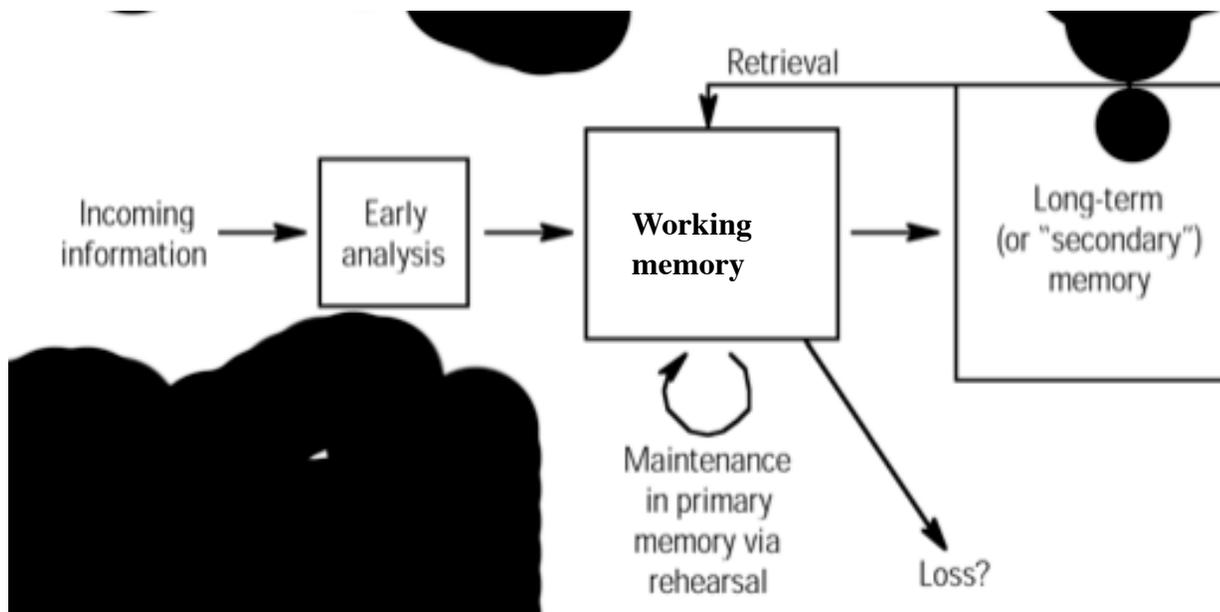
- Sentence span task
  - “The cow jumped over the moon.”
  - “The ringing telephone on is the table.”
  - “Elephants have two tusks.”
- Recall last words: moon, table, tusks

# What these tasks show

- The number of items recalled is always 5-9, regardless of item type:
  - Words
  - Numbers
  - Letters
  - ...
  - Chunks of information

# Working memory is active

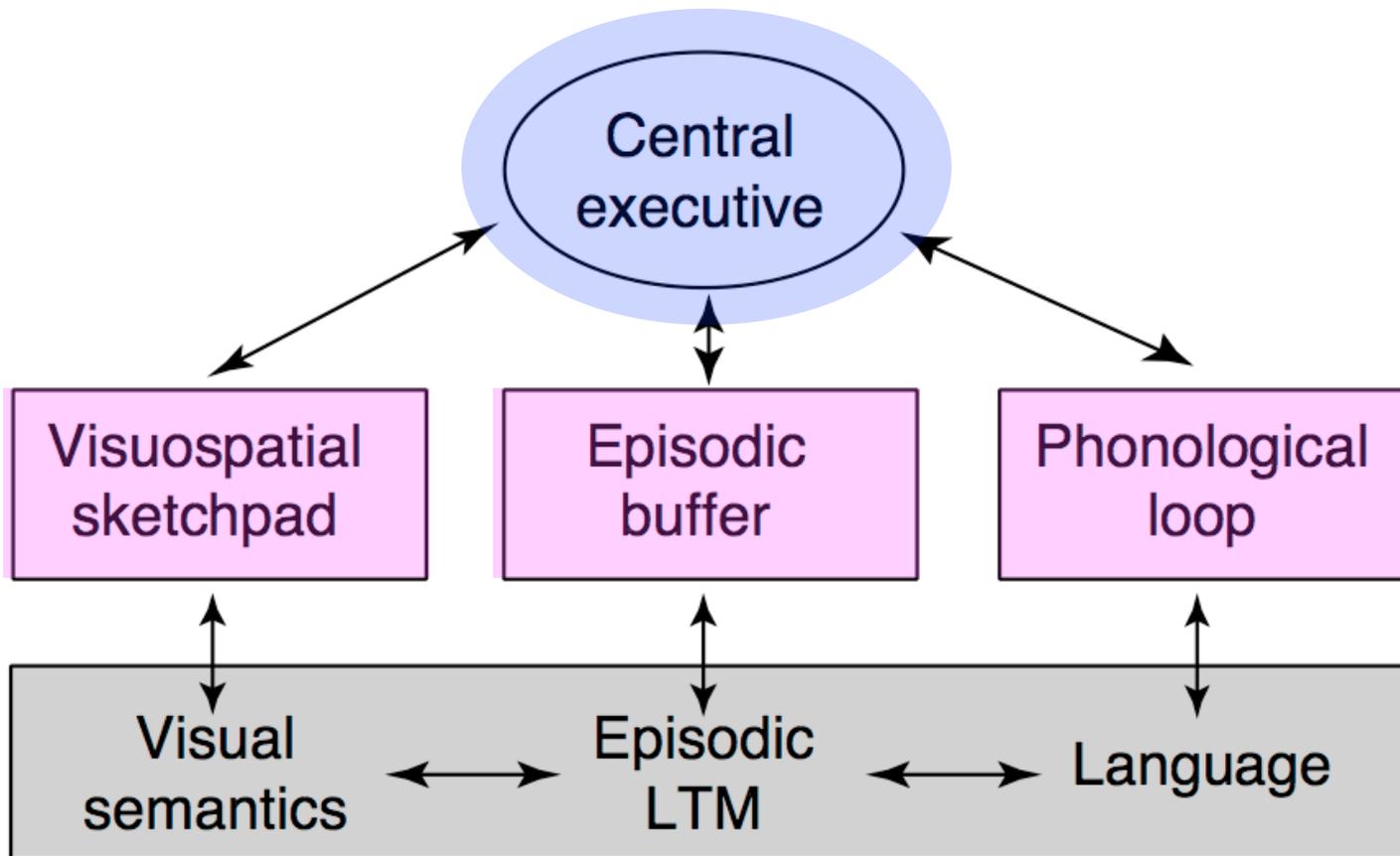
- Not mere storage
- Also involves processing (“working on” the information)



# Change 2: working memory has multiple components

- Baddeley and Hitch (1974):
  - Central Executive system
  - Sub-systems:
    - Visuospatial scratch pad
    - Phonological rehearsal loop
    - Episodic buffer

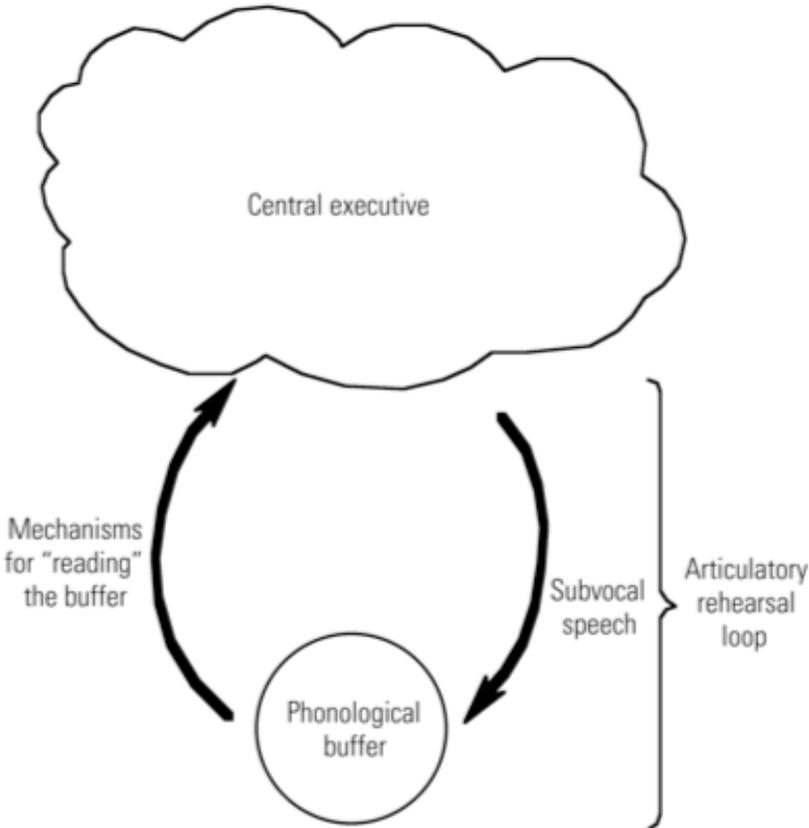
# What is the central executive?



# Evidence for Central Executive

- The central executive
  - Task-general resources: used by the central executive to select responses
  - Evidence from neuropsychology
  - Frontal cortex involved in tasks that use the central executive

# Recall... the phonological loop



# Evidence for Speech-Based Code

- Phonological Similarity Effect
  - Similar sounding words result in impaired recall of those words
- For example- try to remember these words:

- Can-man-mat-cat-cap-pin
- People will report words like “pan” and “map”, which were not there

▫

# Evidence for Speech-Based Code

- Phonological Similarity effect is powerful: even applies to picture names
- Similarly named pictures impair recall
- For example, try to remember these pictures:

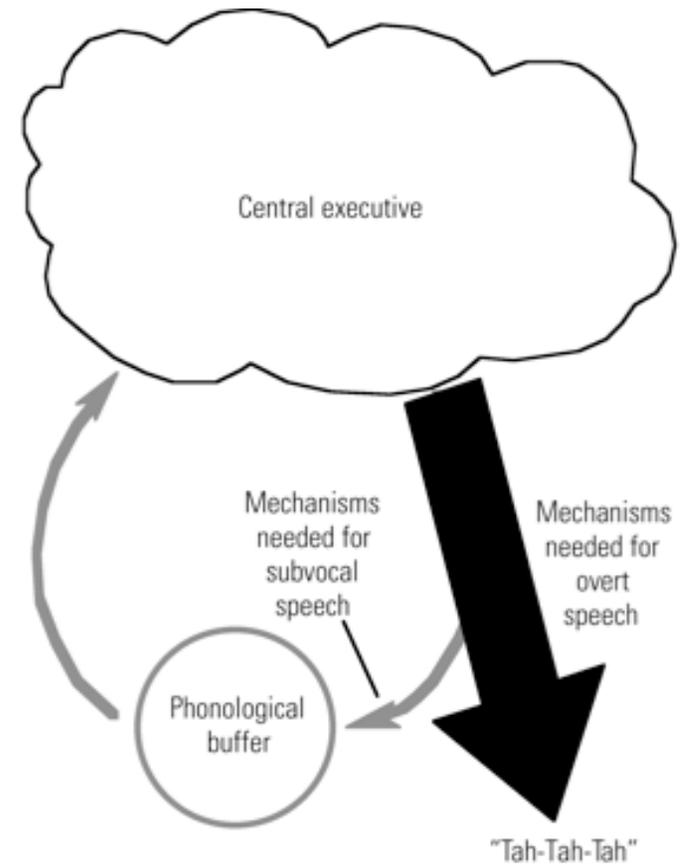
- Goat-boat-brush-blush-bush
- People exhibit a higher rate of memory error when pictures are named similarly, just like with words
- Conclusion: the pictures must be encoded verbally, rehearsed in working memory through the phonological loop

# More Evidence for Speech-Based Code

- Irrelevant speech effect
  - Hearing speech unrelated to the task impairs recall
  - Irrelevant speech automatically enters the phonological loop, and interferes with task-related information
  - Similar representations are more easily confused

# Evidence for Phonological Loop

- Overt vocalization (“tah tah tah”) interferes with rehearsal
- This results in decay of sounds from the phonological loop
  - Decreases performance
  - Eliminates sound-alike errors
  - Doesn’t affect other central executive functions, like problem solving



# Evidence for Limited Capacity of the Phonological Loop

## Word Length Effect :

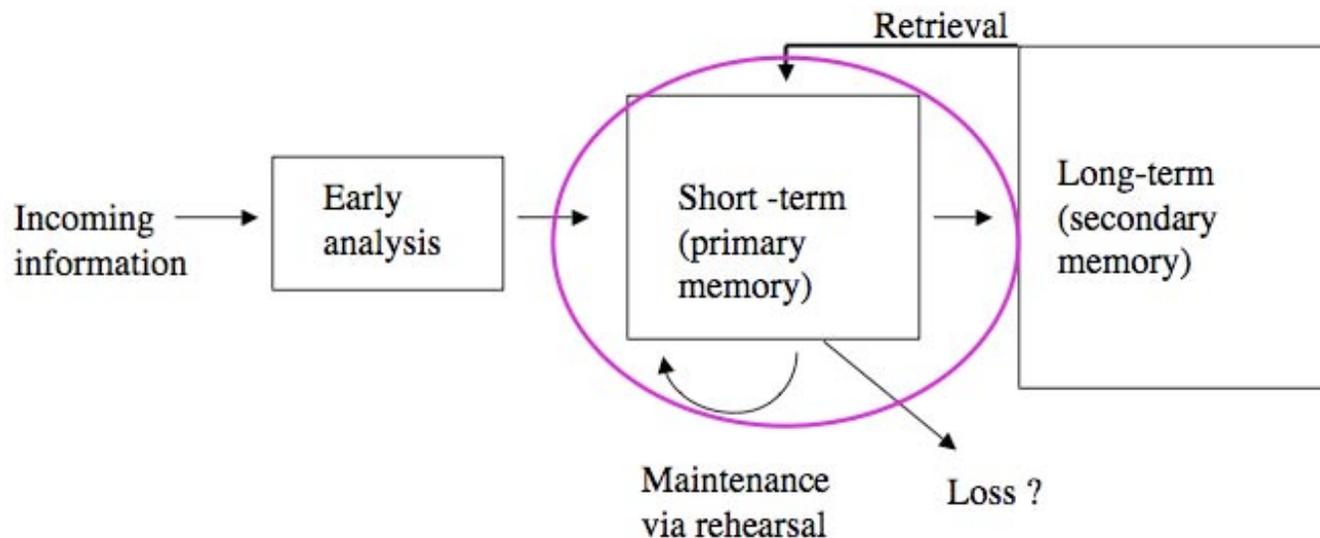
- Longer words mean that fewer items are recalled
  - AIRPLANE - CATERPILLAR - MOSQUITO
  - CAT - MAN - FOG - STAR - BAT - RUG
- More syllables take more time to say
- Longer syllables take more time: (e.g. “spools” > “in”)

# Summary: Working Memory is a system

- Central Executive
- Assistant systems
  - Phonological Rehearsal Loop
  - Visuospatial Buffer
  - Episodic buffer

# Change 3: long term storage

- How does information enter LTM?
- OLD View: time in STM increases probability of transfer to LTM



# How does information enter LTM?

- More time in STM doesn't necessarily improve transfer to LTM
- Why?
  - *Maintenance* rehearsal -- keeping something in working memory -- doesn't increase the likelihood of transfer to LTM

# How does information enter LTM?

## Elaborative Rehearsal

- Elaborative rehearsal:
  - involves **more complex, deeper processing** of information
  - increases the likelihood of transfer to LTM

# Rehearsal Can Involve Different Levels of Processing

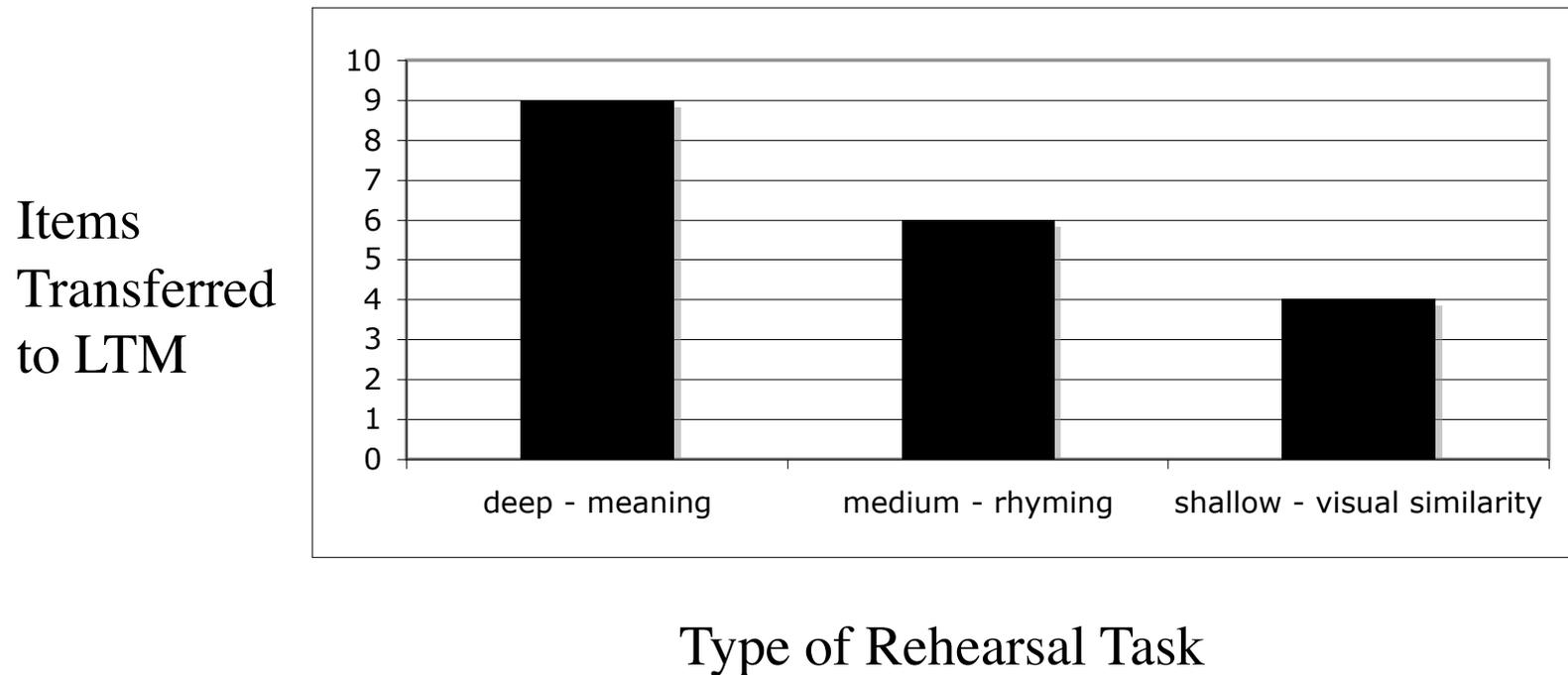
Sample levels of processing experiment:

<u>Type of processing</u>	<u>Task</u>
“Shallow”	Are these words in same typeface HOUSE-trick
“Medium”	Do these words rhyme? BALL-TALL
“Deep”	Are words synonyms? CAR-AUTOMOBILE

Elaborative rehearsal involves deep processing

# Levels of Processing Results

- Deeper processing --> better recall



# Effects of Intention to Learn

- There is no additional effect of trying to learn the information.
  - E.g. If two people are both processing word meanings, someone trying to learn the words doesn't do better than someone who isn't trying.
- Conclusion: deeply processing information is more important to learning than effort.