A Behavioral Interpretation of Memory

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Thanks to:
Daniele Ortu
Laurel Ciavarri

Former students whose work I have raided.

2

A bit of history

- Ebbinghaus, 1885, initiated130 years of memory research
  - Assumed memory was a unitary process
  - Created ~2000 CVC “nonsense” syllables (German)
  - Read random samples in a monotone to the beat of a metronome. Used only himself as subject.
  - Gathered an immense amount of data

3

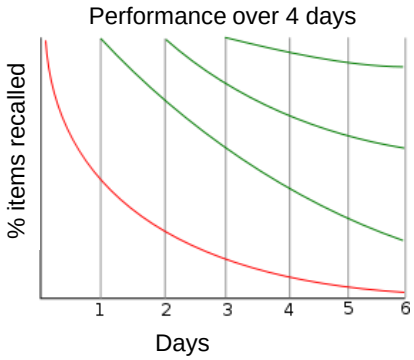
Some findings

- Modeled “forgetting curves”:
  - Descending curves, rapid forgetting over 20 min, less over 1st hour, leveling off after a day.
- And “learning curves” (savings)
- Found serial-position effect

4

Forgetting curves

Percent of items recalled after original learning (red) and relearning on three successive days (green). Note savings over three relearnings.



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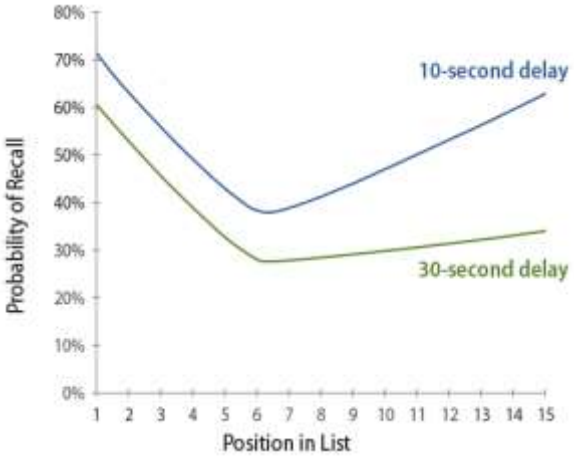
After: https://en.wikipedia.org/wiki/Forgetting_curve#/media/File:ForgettingCurve.svg

Serial position effect



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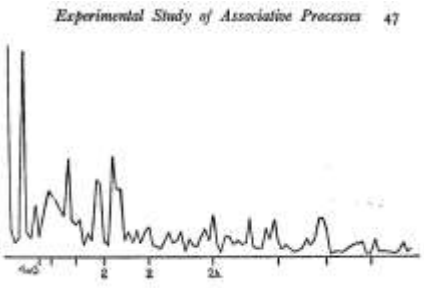
Credit: https://baymard.com/blog/serial-position-effect

Idealized learning curve

7

Thorndike: Time to escape from puzzle box:

Note high variability in data



Skinner: Lever-presses per minute: Note instantaneous change in rate

8

- But Ebbinghaus's work, like many of those who followed in his footsteps, misconceived the nature of the task.
- Memory is not a uniform, orderly process, with some given percent of loss every so many hours.
- Some things are never forgotten, while many things are forgotten instantly.
- Nonsense syllables are in an intermediate limbo, with no special status, and little generality.

9

Memory research post Ebbinghaus

- Incalculable profusion of studies.
- Most work in the past 60 years has been guided by the computer metaphor and appeals to hypothetical internal processes:
  - Encoding
  - Processing
  - Storage
  - Retrieval

10

Forgetting as the failure at one of those stages

- Encoding error
- Trace decay
- Ineffective storage (consolidation error)
- Retrieval error

"Interference" can occur at any stage

11

Classical storage model

- Sensory memory (a few seconds)
- Short-term memory (~30 seconds)
- Long-term memory (indefinite)

12

Sperling's Sensory memory expt.

50 msec exposure to a 3 X 3 grid of letters

y	f	n
p	j	b
r	t	k

Immediate recall: 4-5 letters recalled

13

Sensory memory expt. cont'd.

- Condition 2
  - As soon as the display disappeared, a tone was sounded
  - High, medium, or low
  - Subjects were to report top, middle, or bottom row respectively
- Result: Letters in corresponding row were reported correctly, no matter which tone.
- If tone was delayed, performance deteriorated
- Conclusion: Sensory memory lasts only a second or two

14

Auditory sensory memory

- One of two tones (770Hz or 870Hz) presented for 1/50th second (20msec).
- Subjects had to report which tone.
- A masking stimulus (820 Hz) was presented for ½ second. Onset of masking stimulus varied
- Masking stimulus destroyed discrimination when presented immediately.
- Deleterious effect of masking stimulus declined up to about ¼ second.

15

Short-term memory expt.

- Present a series of random consonants, e.g., F R J
- Immediately followed by a number, e.g., 572
- Subjects count backwards by 3 from that number.
- At various delays, asked to report the letters.

- Results: Performance declined steadily to about chance levels after 20 seconds.
- Conclusion: in the absence of rehearsal, short-term memory lasts only about half a minute.

16

Little cumulative progress

- Profusion of competing memory models.
- Hypothetical nature of the models makes them hard to evaluate and easy to generate.
- Data inconsistent

- E.G. “the magic number 7 plus or minus 2”

17

- Anders Ericsson’s work at FSU
- One subject, who began with a normal digit-span memory, was able to increase his recall of random digits to over 100.
- Showed the relevance of strategic behavior in recall.

18

The Problem of Memory

- Memory as behavior:
  - What is the behavior to be explained?
- Memory as current behavior, not past behavior
  - If we are 'reliving' an experience, we are behaving in the present, not in the past.
- What needs to be explained is one's behavior at the moment of recall. What are the variables that evoke it?

19

Unsatisfactory answers

- Storage
- Action-at-a-temporal distance
- Simply the endurance of stimulus control

20

Unsatisfactory answer #1: The storage metaphor

- Memories are ‘inside us’ in memory storehouses. When we are asked a question, we search around until we come to the right memory. That induces a verbal report of the memory.

21

3 problems with the storage metaphor

1) A look into the nervous system finds no boxes of memories, so we need to flesh out the metaphor in terms of neurons, synapses, glial cells, capillaries, ventricles, and any other actual structures.

Unfortunately, nobody knows how to do that in a way that preserves the metaphor of the storage of “memories”

22

2) We often make mistakes. If memories are stored, why don't we get them right?

For example:

A) Roediger & McDermott: Present a list of words all related to, but not including, (for example) "sleep." Many subjects will subsequently recall seeing the word sleep, often with high confidence.

B) Elizabeth Loftus: Recall is malleable

Recall can be affected by leading questions, by subsequent information, by suggestions: "How fast was the car going when it smashed into the blue van?"

Recall is suggestible: Hearing stories vs. living the stories; confusing movies with life (Ronald Reagan); systematic questioning "planting" memories. Well-known problem in eye-witness testimony, cases of childhood abuse, racial profiling.

23

3) The Indexing Problem

– The storage metaphor has an indexing problem. If memories are stored, how are they indexed? How do we look up the entry for yesterday's breakfast? It can't be stored under "Yesterday's breakfast," because the index would have to be updated every day at midnight.

24

Unsatisfactory answer #2: Memory as action at a distance

- "What color was the house you lived in as a kid?" "Grey."
- According to this scheme, your behavior is presumed to be evoked by the actual color of the house, "reaching forward in time." [Metaphor of action-at-a-distance in physics]
- Faces same problem as storage metaphor, only worse:
  - We would never be wrong.
  - We would never forget.
  - No physical or physiological mechanism—mere magic. The house might have been torn down, or repainted, or imaginary.

25

Unsatisfactory answer #3: Memory as nothing more than the endurance of stimulus control

- Monday:
  - "What did you have for breakfast yesterday?"
  - "A bagel and cream cheese."
  - "Excellent! That's what the videotape shows. You win a new toaster!"
- Tuesday:
  - "What did you have for breakfast yesterday?"
  - "Scrambled eggs and toast."

26

- The problem is that “bagel” was reinforced in the presence of the question. But when the question was asked again, and everything else was held constant, we got a different answer the next day.
- The constellation of environmental events was constant, but the behavior varied.
- What’s different?

- Answer: the mnemonic behavior of the individual.

27

Was hast du vor zwei Wochen von morgen gefrühstückt?

1) Go to Google Translate
2) Enter the text
3) Read the translation
4) Start “figuring it out:”
    1) What day is tomorrow?
    2) Where was I two weeks ago?
    3) What was my schedule?
    4) Who was I with? Etc.
5) So in some cases, memory is an interactive process. It’s problem solving.

28

Two types of memory Phenomena

1) Memory as the retention of stimulus control
   - A stimulus was present at the time of learning and is presented again at a later time. Its presentation evokes the behavior of interest.

2) Memory as a problem-solving phenomenon
   - The stimulus present at the time of learning is NOT present at the time of recall. Present conditions do not evoke the behavior of interest directly. The "answer" is partly under control of mediating behavior

29

Part II: Memory as endurance of stimulus control

- The principle of reinforcement:
  - Reinforcement increases the probability of a response *in the same context* in the future.
  - In this sense, memory is implicit in all learning.

30

Stimulus control

- Review of stimulus discrimination:

  Red light – Peck key – Reinforcement

  Blue light – Peck key – Extinction

  - The red light is like a switch: it can turn key pecking on and off.
  - When the red light is presented at a later time, we expect the pigeon to peck the key. We do not need to appeal to a concept of memory.
  - In this sense, all discriminated behavior is memory. But the term "memory" adds nothing to the account.

31

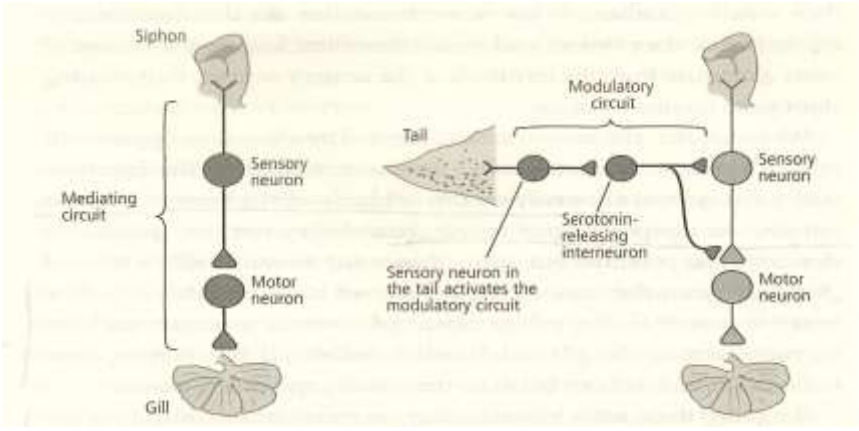
Physiological foundations of stimulus control: What is stored?

32

Stimulus control can be potentiated by several known processes (at least)

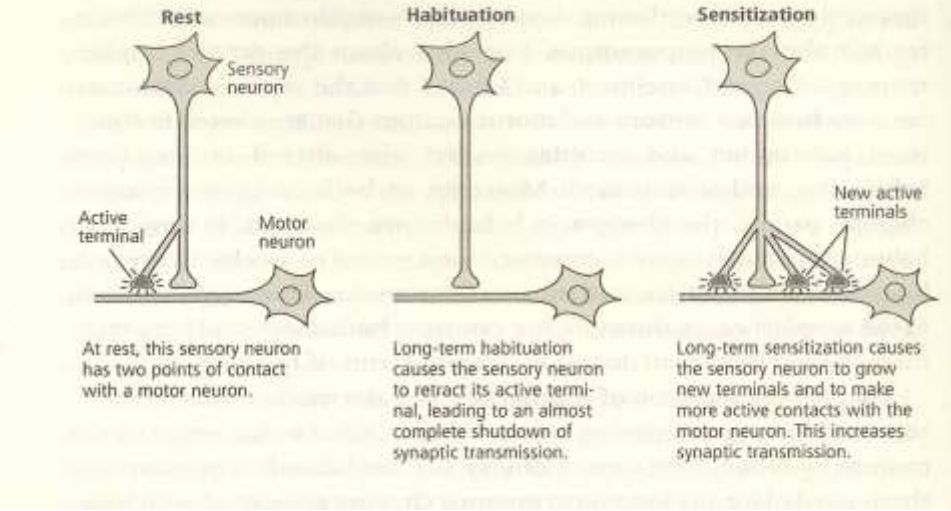
1) By increasing the production and emission of neurotransmitters in the upstream neuron
2) By increasing the number of synapses
3) By increasing the density of receptors in the downstream neuron

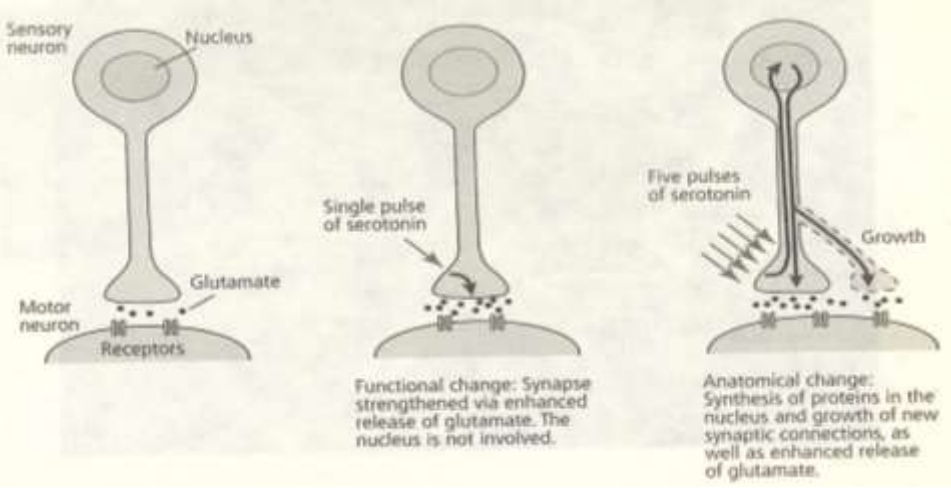
33



Schematic diagram of neural network in Aplysia (Kandel, 2006)

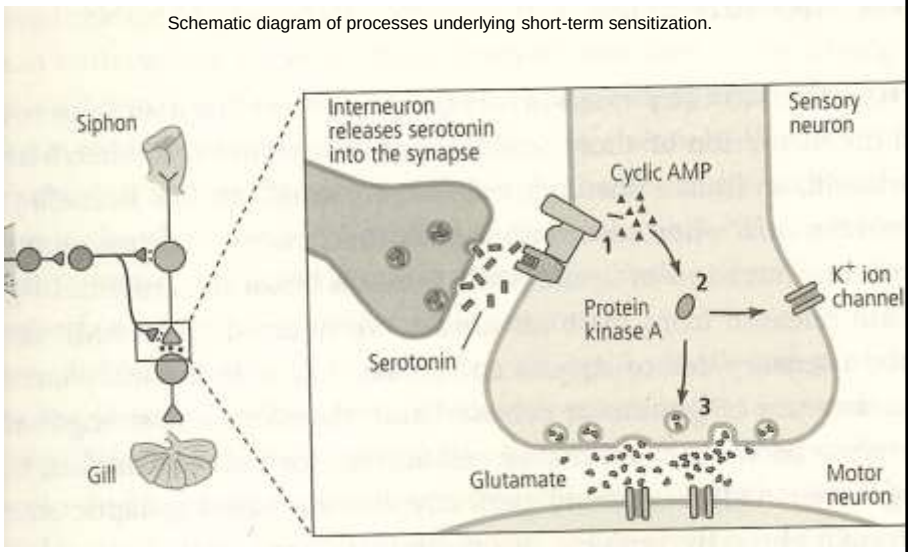
The circuit on the left mediates a (weak) reflex. The modulatory circuit on the right regulates the strength of the synaptic connections in the reflex.

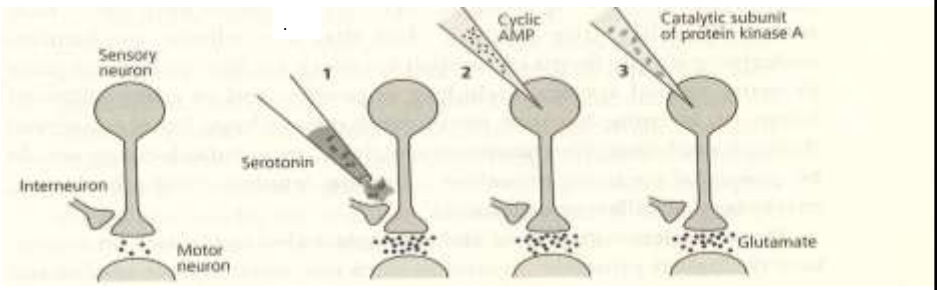




Effect of repeated or strong stimulation by neuromodulators (arising from threatening stimulus)

Schematic diagram of processes underlying short-term sensitization.



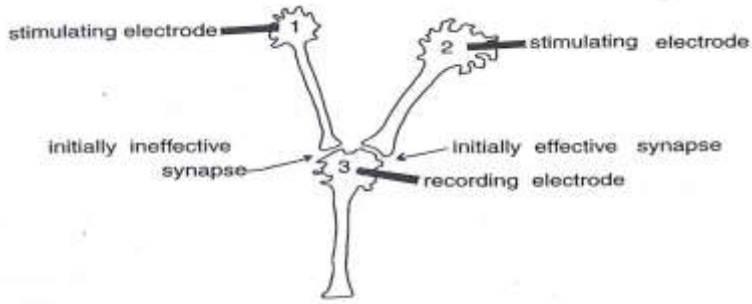


Three ways of artificially inducing sensitization at a synapse:

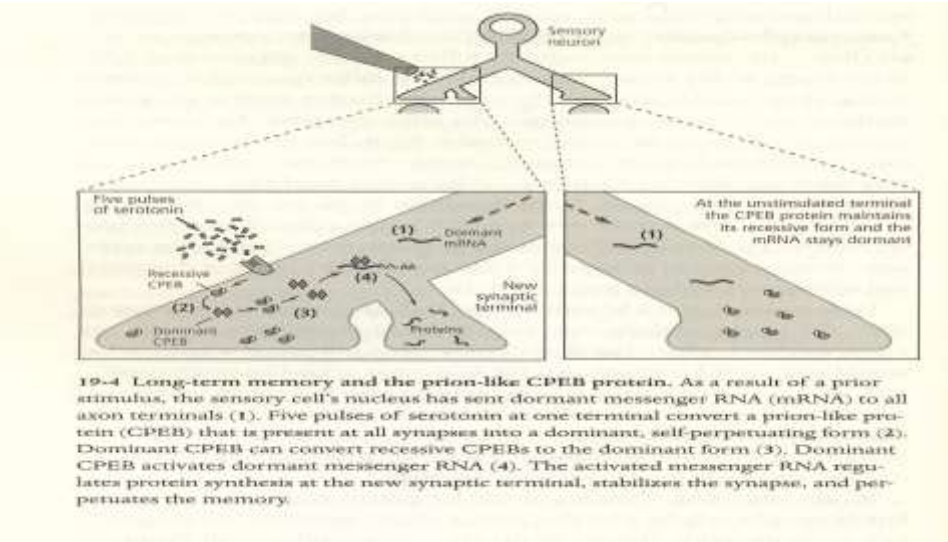
1) Injecting serotonin into extracellular fluid at synapse 2) Injecting cyclic AMP into cell body 3) Injecting component of protein kinase A into cell body

These represent three stages of the natural process shown on the left.

From Kandel (2006)

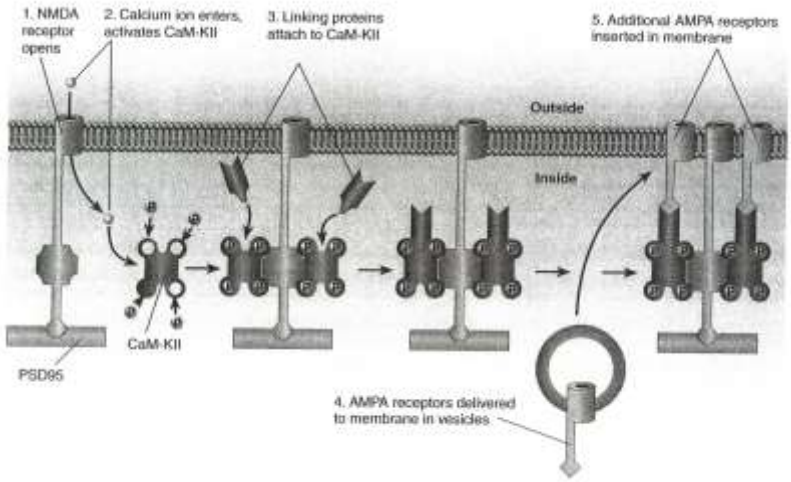


Schematic diagram of Kandel's experiments showing classical conditioning in the sea snail (Aplysia).



19-4 Long-term memory and the prion-like CPEB protein. As a result of a prior stimulus, the sensory cell's nucleus has sent dormant messenger RNA (mRNA) to all axon terminals (1). Five pulses of serotonin at one terminal convert a prion-like protein (CPEB) that is present at all synapses into a dominant, self-perpetuating form (2). Dominant CPEB can convert recessive CPEBs to the dominant form (3). Dominant CPEB activates dormant messenger RNA (4). The activated messenger RNA regulates protein synthesis at the new synaptic terminal, stabilizes the synapse, and perpetuates the memory.

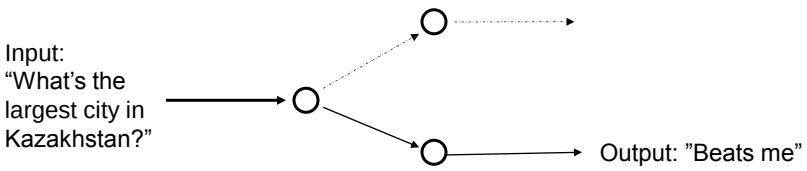
Increasing the density of receptors in downstream neuron



41

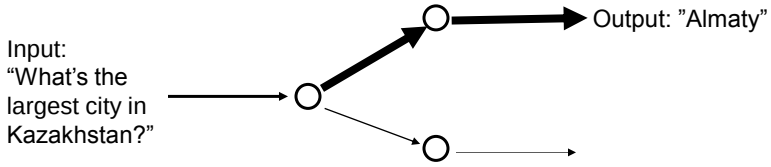
Neural network simulations of learning

Simulations use processes analogous to reinforcement.



42

Following training



Where is the "memory" of Almaty? The memory is in the connections, but there is no "essence of Almaty" there.

43

- What is stored? Changes in circuitry (the neurotransmitters, the density of receptors, the density of new synapses, transformation of prion-like proteins).
- That is, <u>changes in efficiency of passing signals</u> (the machinery of pathways).
- Such changes can accommodate the relationship between SD and behavior, but not a static concept like stored memories.
- That is, you find the increased efficacy of an SD, but not a "representation of yesterday's breakfast."

44

Factors that affect the endurance of stimulus control

- Reinforcement parameters
  - Relevance to "flashbulb memories"
- Discrimination training
- Frequency and fluency
- Stimulus salience
- Blocking
- Response competition (Retroactive and proactive interference
- "Decay"

45

- Memory in this sense is just learning. All variables relevant to the acquisition of stimulus control will be important:
  - Reinforcement
  - Discrimination training,
  - Frequency
  - Fluency
  - Competing behavior
  -

46

How long does stimulus control endure?

- In the absence of “decay,” stimulus control can apparently endure indefinitely. Skinner’s rats
- Henry the pigeon
- Abundant anecdotal evidence from humans.

47

- However, Kandel’s work suggests:
  - Habituation entails the degrading of synaptic efficacy when a defensive reflex is elicited in absence of threat.
  - Synaptic efficacy seems to decline in the absence of use.
  - But “decay” is not a systematic or orderly process.

48

Extinction vs. forgetting

- Extinction is a kind of discrimination training, not the erasing of prior learning.
- E.g., repeated acquisition and extinction.

49

Ortu's work on recognition

- Priming
- Familiarity
- Recognition

50

- Priming: Multiple effects of stimulus presentation

51

- Familiarity: Discrimination of response strength
  - Conference blues: You know the face but can't say why, where, or when.
  - "When responding to a stimulus for the second time, one may discriminate that the responses to the stimulus the second time differ from the responses to the first presentation of the stimulus."

52

Relevant phenomena

- Habituation
- At the neural level—response suppression: "The magnitude of neural responses decreases with repeated stimulus presentation." (Mediated by neurons in the perirhinal cortex, which are sensitive to repeated presentations of stimuli. Damage to these cells destroys discrimination of old/new stimuli in infrahumans.)
- Discrimination of strength of collateral behavior

53

Recognition

- Apparently mediated by discrimination of collateral behavior:
- Skinner on "multiple control": a stimulus commonly potentiates a variety of responses concurrently:
  - "Waterloo"
    - Napoleon
    - War
    - Wellington
    - 1815
    - Etc.

54

Skinner (1974) on “reminding”

- An incidental stimulus may "remind" us of a person, place, or event if it has some resem-blance to that person, place, or event. Being reminded means being made likely to respond, possibly perceptually. A name may remind us of a person in the sense that we now see him. This does not mean conjuring up a copy of the person which we then look at; it simply means behaving as we behaved in his presence upon some earlier occasion.

55

At the neural level, the hippocampus appears to mediate the integration of patterns of correlated events. This explains, in part, why damage to the hippocampus is so devastating to memory in humans.

56

Aphasias

- "Mystery" of inconsistent aphasias goes away when we understand the specificity of stimulus control.
- E.g., subject can't name "spoon" but can ask for a spoon to eat soup.
- Damage is specific to the particular connections lost, not necessarily to the "concept."
- Hence people with, e.g., early Alzheimer's can appear to lose and regain memories from day to day, although it is likely a stimulus control effect.

57

Memory Phenomena: A Fundamental Dichotomy Part III

- Memory as a problem-solving phenomenon
  - The stimulus present at the time of learning is NOT present at the time of recall. Present conditions do not evoke the behavior of interest directly.

58

Memory as Problem Solving

- Memory and problem solving are not merely two similar phenomena, with some common features.
- They are a single phenomenon. Memory is just an example of problem solving, nothing more.

59

Problem Defined

- A target response is in the repertoire
- It is scheduled for reinforcement
- The target response is not prepotent under current conditions

60

Multiple causation in problem solving:

- Problem solving is the behavior of marshalling supplementary stimuli, i.e., stimuli that combine with the nominal SDs of the "problem" to make a target response more likely.
  - Look at a map
  - Look in a dictionary
  - Look on the internet
  - Ask a friend
  - Make a diagram
  - Reduce fractions
- Example of the square root problem

61

Multiple causation in problem solving: Marshalling supplementary stimuli

- My pet example: The square root of 841 is an integer. What is it?
- "Well, it's less than 100.
- 50 times 50 is . . . 2500, so it must be smaller than 50.
- 10 times 10 is 100, so it's bigger than 10.
- 20 times 20 … 400. Too small.
- 30 times 30 is 900. Oh!
- It's between 20 and 30.
- 20-something, but twenty-what?
- 21? It might be 21.
- 22. . . 23 . . . 24 . . . 25 . . .
- It's close to 900, so it must be in the high 20s.
- 28 or 29?
- 28 times 28 would end in 4.
- 29 times 29 would end in 1.
- It must be 29."

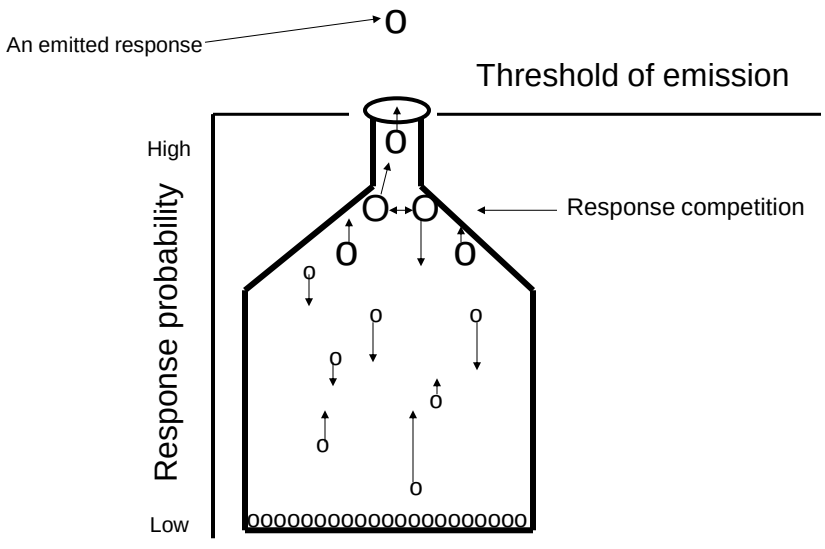
62

Recall

Where were you on Sept. 21, 2011? (Three years later)

Well, let's see, according to my calendar, that was a Wednesday. I was teaching behavior analysis and statistics that day. Let me consult my syllabus . . . we did a pigeon lab. Ok, that was the semester I ran one lab in the morning, one in the evening. I must have been running a lab that night. Who was in that class? According to my class list, Sonia and Helen were in that class. I remember Sonia working alone with her bird on a chaining task one night. Could that have been the 21st? No, the 21st would have been too close to the beginning of the semester; she wouldn't have got to chaining yet. She had excellent luck with that bird. What would she have done before the chaining experiment? Wait, that would only have been the second session of the semester. They were still working on shaping. Yes, I remember the night they worked on shaping. One group shaped their birds up in one session, but most of them didn't.

63



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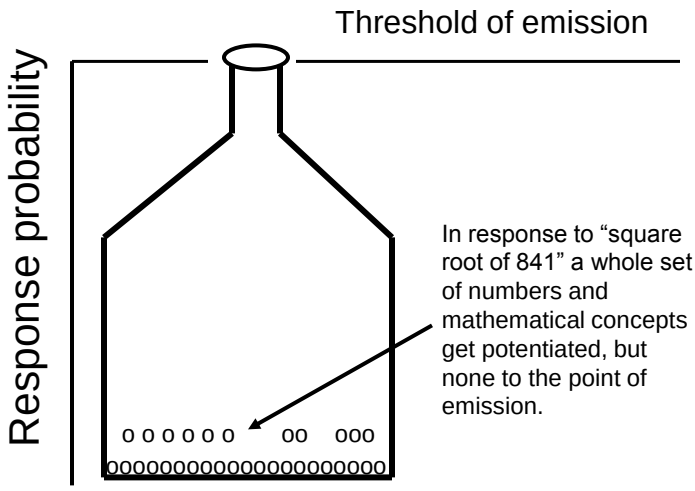
Threshold of emission
Response probability
In response to “square root of 841” a whole set of numbers and mathematical concepts get potentiated, but none to the point of emission.

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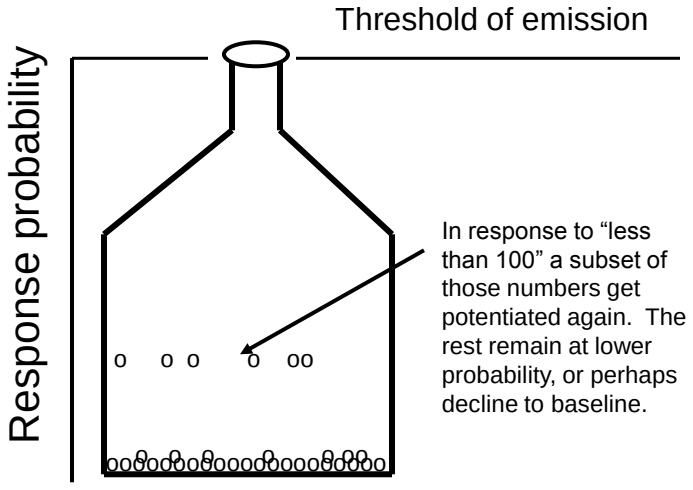
Threshold of emission
Response probability
In response to “less than 100” a subset of those numbers get potentiated again. The rest remain at lower probability, or perhaps decline to baseline.

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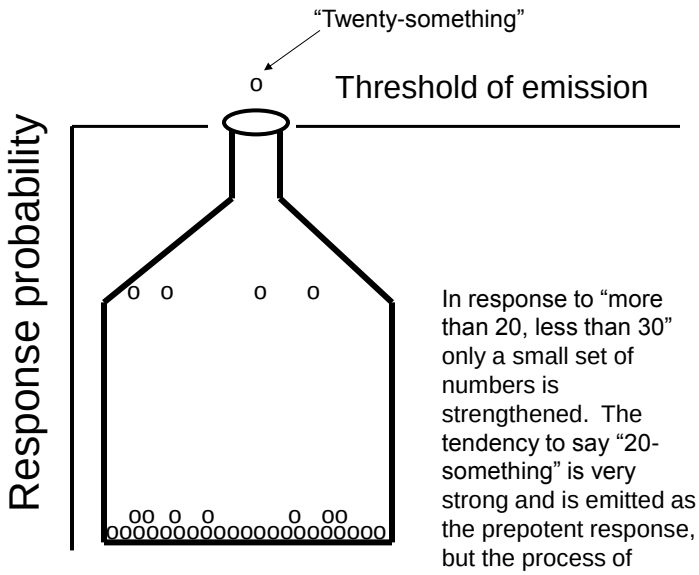

In response to "more than 20, less than 30" only a small set of numbers is strengthened. The tendency to say "20-something" is very strong and is emitted as the prepotent response, but the process of winnowing continues.

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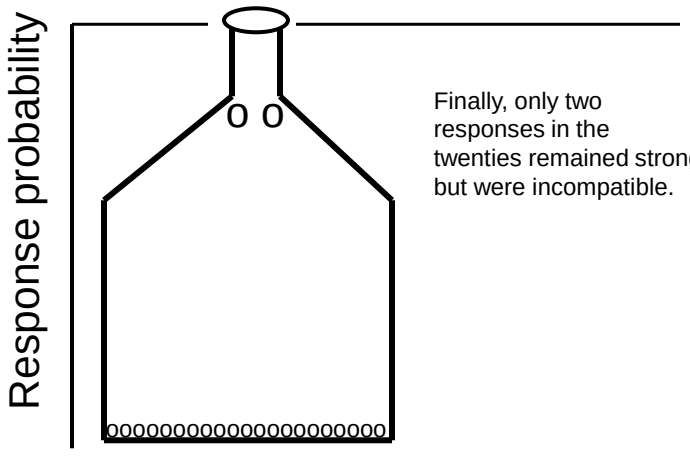
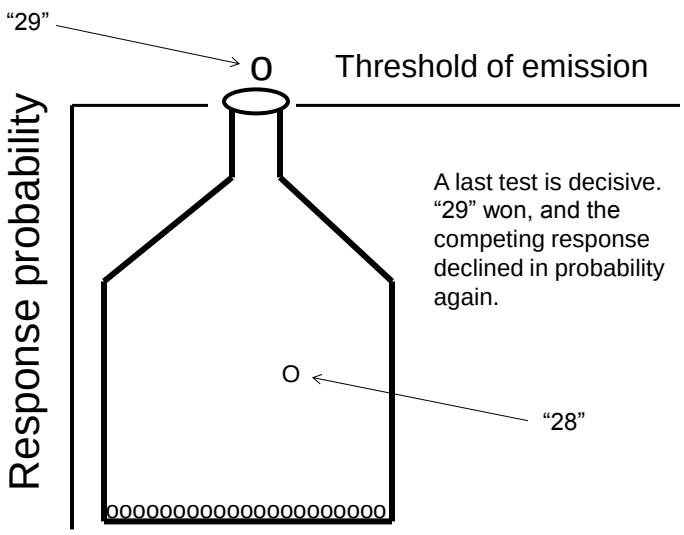
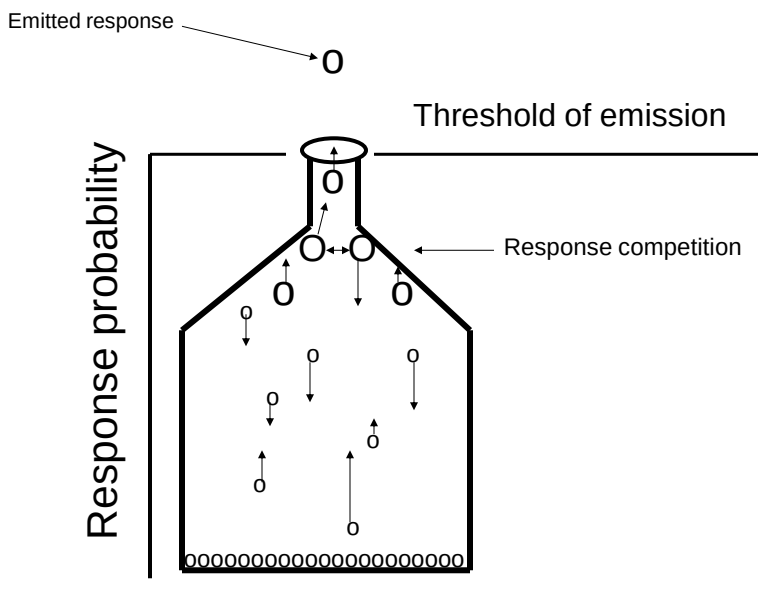


Finally, only two responses in the twenties remained strong but were incompatible.

68


"29"
Threshold of emission
Response probability
A last test is decisive. "29" won, and the competing response declined in probability again.
"28"

69


Emitted response
Threshold of emission
Response probability
Response competition

70

Metaphor of the Flask

- The task of the learner:
  - To make a target response “easier to hit”
  - To work on the repertoire to increase the probability of the target response, i.e., by introducing supplementary SDs.
  - We learn that certain kinds of things must later be recalled, and we engage in various acquisition strategies (mnemonics) to make them easier.
  - At the time of recall, we engage in various problem solving strategies to make the target response more probable (“float up the flask”).

71

Conditioned Perception

- Perceptions are behaviors:
  - Proust and the madeleine
  - They can be evoked by discriminative stimuli
  - One can lead to another, like a waterfall, giving us a rush of related conditioned perceptions: a reminiscence
  - The conditioning of perceptions depends on experience:

72

- Bruner & Postman expt: What we “see” is conditional upon our experience.
- McGurk experiment: What we “hear” is conditional upon our experience
- Conclusion: Perception is behavior
  - Presumably unconditioned (strong), and
  - Conditioned (weak)

73

The Problem of Conditioned Perceptions

- Experimentally difficult, if not impossible
- Even interpretation is difficult:
  - What are the three terms of the three-term contingency? Suppose I see a frog on the breakfast table in the morning. Later in the day I remember the frog; I can “see” the frog sitting on the table.
    - Stimulus: the frog
    - Behavior: Perception of the frog; that is, seeing it as a frog and not as a patch of green on the tablecloth.
    - Reinforcer: Effective action. I can try to touch the frog, or shoo it away, or sit at another table, etc. The visual interpretation of our world must be a powerful conditioned reinforcer.

    What makes a memory vivid? If powerful reinforcers or punishers are associated with it. Some days blend together with other days in a boring stream. But let us do something new and exciting, and we will remember it clearly.

74

Example: Those “impressionist” pictures that you must look at with eyes unfocused.

Eventually a scene emerges.

You can recall the scene, but you cannot recall the picture before it “popped into focus.”

That is, once you perceived it, once you interpreted it, it became “meaningful.”

“Meaningful” interpretation must be a conditioned reinforcer, because we can recall conditioned perceptions of meaningful stimuli but not meaningless ones.

75

- At time of recall, we can “see” the frog, but we cannot “see” the tablecloth on which the frog sat.
- That is, we form conditioned perceptions when we engage in discriminative behavior with respect to our world, but not when we simply experience stimuli. That is, we “didn’t notice” the tablecloth.
- Conditioned perception seems to depend in part on expertise (the blindfold chess player, the mathematician).
- Possibly there are some innate differences between people

- But it **must** be the case that perceptual behavior is being conditioned all the time. Why? Because we can so easily imagine scenes from our past.

76

Two types of memory strategies

1) Acquisition strategies

   Strategies deployed at the time of original learning to make correct recall more likely.

   They make a web of interlinked associations that make a large target for recall to hit.

2) Recall strategies

   Strategies deployed at the time of recall to "hit" one or more interlinked responses that will in turn evoke the target response

77

Recall as a Learned Phenomenon: Acquisition strategies

- Acquisition strategies: At the time of original learning. We have learned that some things are worth remembering, so we make it more likely that we will.
- Imagine that you are going to have a quiz on my next slide, and that you'll be graded on your performance.
- What would you do?

78

Types of acquisition strategies

- Rehearsal
- Orientation
- Attending
- Classify
- Describe
- Organize
- Elaboration
- Mnemonics
- Telling a story
- Fading prompts
- Test and retest
- The tricks of the skilled mnemonist

79

- Acquisition strategies do not provide supplementary stimuli. Rather, they strengthen behavior with respect to stimuli that are likely to be provided by properties of a later recall task or by recall strategies

80

Example of acquisition strategies, e.g., for remembering pi.

- Learn a set of associations between numbers and letters: 0=CH, 1= T, 2=N, 3=D, 4=R, 5=P, 6=S, 7=L, 8=G, 9=B, for example.
- Break the number into trigrams:; 314, 159, 265, 358, etc.
- Convert to letters and think of words: DTR = DocToR, TPB = TyPeBblood, NSP= iNSPector, and so on.
- Make up a story using e.g., the method of loci

81

Anders Erikson's research

- Undergraduates tested on random digit recall.
- Baseline = ~7 digits
- Repeated practice led to improvement, sometimes dramatic improvement
- One subject acquired strategies for recalling over 100 random digits.
- How? ……

82

Recall as a Learned Phenomenon: Recall strategies

- Strategies we deploy at the time of the test
  - Go through the alphabet (e.g., for a name)
  - Recite one's schedule
  - Fix a day, or date, or time.
  - Think of related topics.
  - Find a salient anchor.

83

Recall strategies and acquisition strategies work together to make the target response more likely.

- Acquisition strategies create a web of mutually evocative responding, giving us more and bigger "targets" to hit.
- Recall strategies probe for one of those targets.

84

- Memory as a stimulus control phenomenon (stimulus present at the time of learning and at the time of recall) does not need special treatment. It's just an example of learning.
- Memory when the stimulus is not presented again is a kind of problem solving.

85

Implications of the Behavioral View of Memory

- Once a strategy has been employed and a response emitted, it may be directly evoked by the question: e.g. you now know that 42 is the square root of 1764, and you no longer need to employ problem solving or recall strategies.
- Strategies are special to the individual: what works for me may not work for you.
- Strategies are acquired. We must learn to provide ourselves with supplementary stimuli to solve problems, and we must learn to remember. It isn't a basic process.
- There is no qualitative difference between a "correct" memory and an error. They are both behavior controlled by their antecedents.

86

Conclusion

- A behavioral interpretation of memory identifies two qualitatively different circumstances in which we invoke memory:
- 1) The endurance of stimulus control
- 2) Memory as problem solving
- The two types call for very different explanations and to ignore the difference leads to confusion. To acknowledge the difference fosters understanding and perhaps to effective application—e. g. Vince Carbone's workshop.

87

Some additional topics if time permits

- Abnormal memory
  - 1) "photographic memory"
    - Luria's S
  - 2) Impaired memory
    - Alzheimers & Down Syndrom
- The mystery of acquisition in children
- Blocking

88