The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1860-1

Borsellino College 2007. Spike Trains to Actions: Brain Basis of Behavior

3 - 14 September 2007

Principles and theory in Pavlovian conditioning

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Principles and Theory in Pavlovian Conditioning

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Animals change their behaviour to a stimulus as a consequence of its *association* with another stimulus

("association" = there is a temporal correlation between occurrence of CS and US).

Terminology

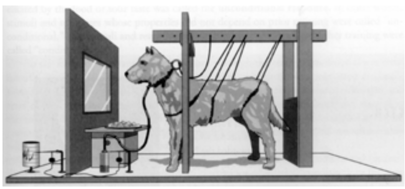
Instrumental (also "Operant") Conditioning
Animal learns to perform specified action to receive reward or avoid punishment
Vs
Pavlovian (also "Classical") Conditioning
Animal displays stereotyped response to a stimulus that signals reward or punishment

Terminology

Unconditioned Stimulus (US)	Stimulus with inherent biological important to animal (*eg, food or pain*)
Unconditioned Response (UR)	Response automatically elicited by US (*eg, consumption and salivation or withdrawal*)
Conditioned Stimulus (CS)	Initially neutral cue (*eg, noise*) that acquires significance through conditioning
Conditioned Response (CR)	Response elicited by CS following conditioning

Experimental Paradigms: Conditioned Salivation

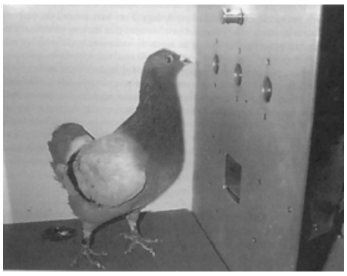
CS (metronome) presented for several seconds and followed by delivery of food into dog's mouth (US)



Result: after 20 or 30 CS-food presentations, dog begins to salivate when CS comes on (ie, before food delivered).

Experimental Paradigms: Sign Tracking

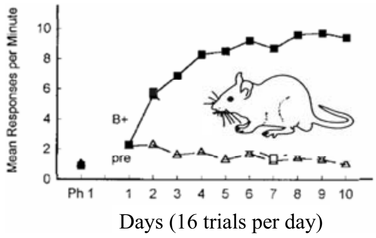
Also "autoshaping"
Small light ("response key") is illuminated for several seconds. Shortly after, food is delivered nearby.



Result: after about 30 or so pairings, pigeon begins to peck at response key.

Pavlovian or Instrumental?

Experimental Paradigms: Conditioned magazine approach



CS (noise or light) presented for 30 sec and followed by delivery of food (US)

Result: after 20 or 30 CS-food presentations, rat approaches food magazine when CS comes on (ie, before food delivered).

Theoretical issues in Pavlovian conditioning

- What is learned?
- What are the necessary and sufficient conditions for learning?
- What mechanisms underlie learning?

The content of conditioning

In many conditioning paradigms, the CR is the same as the UR

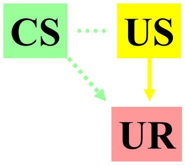
Eg:

- Pavlov's dogs salivate to food US and to CS;
- Disgust and nausea to toxic US and flavour CS;
- Rabbits blink to an airpuff US and to noise CS;
- pigeons peck at food grain and at light CS, and "drink" water and light CS.

The content of conditioning

Evidence that CR = UR led to **S-R** (stimulus-response) view of conditioning:

During conditioning, the CS is repeatedly followed by the UR (elicited by the US). Ultimately the CS comes to elicit the same response directly (CR).

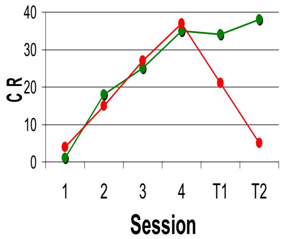


Nature of the conditioned response

- But other examples of conditioning in which CR ≠ UR:
  Eg: UR to shock is jumping and pain,
  whereas CR to CS is immobility and analgesia.
- Pigeons will condition to a diffuse noise as CS paired with food US, even though they cannot peck at it.
- Can prevent UR during conditioning without preventing acquisition of CR.
- CS must connect with memory of US (not just response evoked by US).
  Eg, effect of devaluing the US after conditioning…

The content of conditioning

Condition	Devalue	Test
CS1+ food1	–	**CS1?**
CS2+ food2	**food2+ illness**	**CS2?**



Holland (1990)

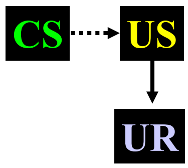
CR reflects value of US *at time of test* rather than at time of conditioning!

Holland (1990). Event representation in Pavlovian conditioning: Image and action. *Cognition, 37*, 105-131.

The content of conditioning

Devaluation results consistent with S-S (stimulus-stimulus) view of conditioning…

As a result of CS-US pairings, CS comes to activate a representation (or memory) of the US, and this evokes response



The conditions of conditioning

Temporal Contiguity:

Long known that temporal contiguity is important for conditioning

➔ that the CS and US occur close together in time.

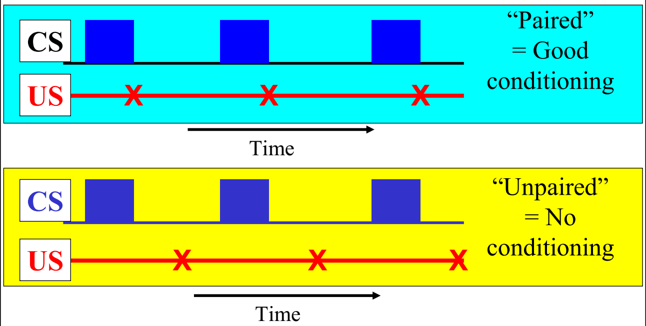
Rescorla (1988). Pavlovian conditioning: It's not what you think it is. *American Psychologist, 43*, 151-160.

But is contiguity enough?

- Once believed that temporal contiguity was necessary **and** sufficient for conditioning, now known that it is not sufficient.
- There are numerous instances under which animals fail to learn CS-US relation despite good temporal contiguity between the CS and US….

Is contiguity enough?

Early demonstrations that contiguity is sufficient….



Is contiguity enough?

Rescorla (1967) pointed out that these demonstrations confounded temporal contiguity with temporal correlation

– in Paired group, CS and US **always** occurred together (positive correlation);

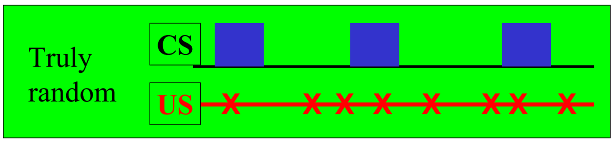
– in Unpaired group, CS and US **never** occurred together (negative correlation).

What happens of CS and US have zero correlation..?

Rescorla (1967). Pavlovian conditioning and its proper control procedures. *Psychological Review, 74*, 71-80

Is contiguity enough?

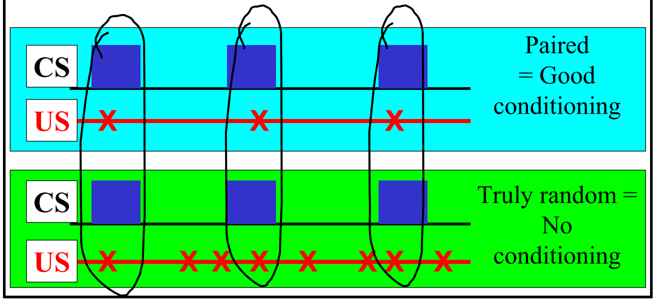
Rescorla investigated the outcome of a "*truly random*" schedule between CS and US.



…outcome was no conditioning

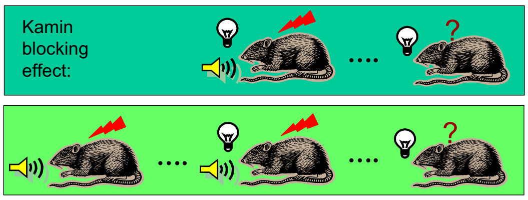
Contiguity is not enough

- The 2 regimes have identical contiguity between CS and US, but one produces conditioning and the other does not – CS and US must be correlated, not just co-occurring.



Blocking

- If 2 CSs conditioned in compound, competition between them is not only affected by relative salience.…
- Kamin (1968) showed that conditioning to one CS could be "blocked" by the presence of a second CS that *already served as a signal for the US*.



Kamin (1968). "Attention-like" processes in classical conditioning. In: M.R. Jones (Ed) *Miami symposium on the prediction of behavior: aversive stimulation*. Miami: Miami University Press. pp 9-31

What (if not contiguity)?

- Rescorla showed that temporal correlation (not just co-occurrence) is necessary for conditioning.
- He suggested that contingency is necessary for conditioning… Occurrence of US must be contingent on presence of CS

Positive contingency: $P(US|CS) > P(US|\overline{CS})$

Zero contingency: $P(US|CS) = P(US|\overline{CS})$

Contingency

Contingency implies causality:

- To extent that US only occurs when preceded by CS suggests that CS might cause the US
  (or that CS is reliably associated with cause of US)
- Thus conditioning is about understanding causal relationships among events in external world.
- *Eg, Clouds&rain; sex&pregnancy&birth.*

Contingency

Rescorla (1968) showed how contingency affects conditioning:

- Trained rats on partial reinforcement schedule: tone CS was followed by shock US on 40% of CS presentations

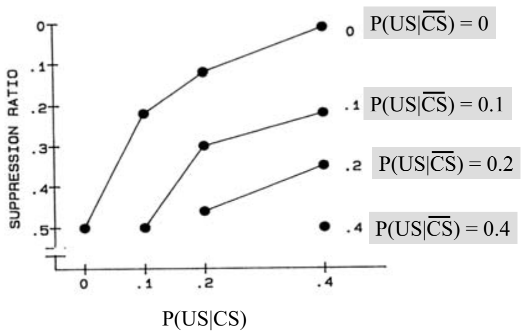
  ie: $P(US|CS) = 0.4$

- Then systematically varied rate of US occurrence in absence of CS

  ie: $P(US|\overline{CS}) = 0, 0.1, 0.2$, or 0.4.

Rescorla (1968). Probability of shock in the presence and absence of CS in fear conditioning. *Journal of Comparative & Physiological Psychology, 66*, 1-5.

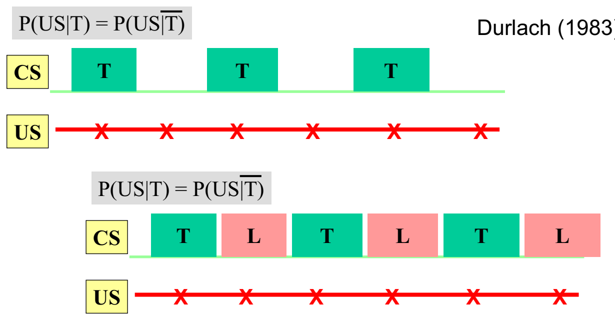
Contingency



Rescorla (1968)

But is contingency necessary?...

Durlach (1983)



Conditioning fails in the 1st schedule but is acquired reliably in 2nd

Durlach (1983). Effect of signaling intertrial unconditioned stimuli in autoshaping. *Journal of Experimental Psychology: Animal Behavior Processes, 9*, 374-389

Variations in processing the US

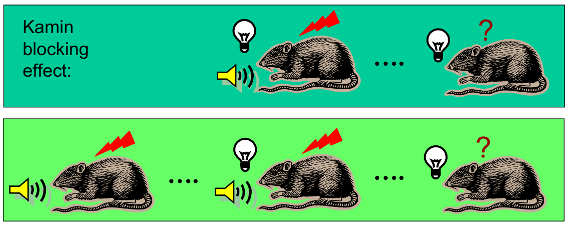
Kamin suggested that US must be *surprising* to stimulate new learning.

Animals won't learn anything on a trial in which all events are fully expected.

Learning is process by which we change our model of the external world whenever our expectations differ from what actually happens.

Variations in processing the US

Nothing is learned in blocking design because US is fully anticipated (as signalled by pre-trained CS)



RESCORLA & WAGNER (1972)

On any trial, the amount learned about the CS-US association is determined by the *discrepancy* between the experience of the US and how much it was expected.

"The less you know, the more you have to learn;
The more you already know, the less you learn."

Rescorla & Wagner (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In: Black & Prokasy (eds) *Classical conditioning II: Current research and theory*. NY: Appleton-Century-Crofts. pp 64-99.

Wagner & Rescorla (1972). Inhibition in Pavlovian conditioning: application of a theory. In: Halliday & Boakes (eds) *Inhibition and learning*. San Diego: Academic Press. pp 301-336

The Rescorla-Wagner model

The amount learned equals the extent that the strength (**V**) of the CS-US association is changed….

$$\Delta V \propto (\lambda - \Sigma V)$$

ΔV = change in CS-US association
λ = experience of US presentation
ΣV = expected experience of US, based on total associative strength of all CSs present

The Rescorla-Wagner model

$$\Delta V = k \times (\lambda - \Sigma V)$$

k = salience (intensity) of CS

parameters that regulate the rate of conditioning:

otherwise all conditioning would happen in one trial because ΔV would equal λ (because ΣV equals zero).

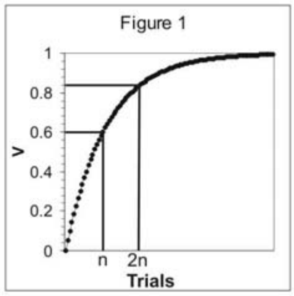
The Rescorla-Wagner model

$$\Delta V = k \times (\lambda - \Sigma V)$$

gets smaller

Associative strength (V) increases across trials, but increments in V get ever smaller

ie, learning is decelerated

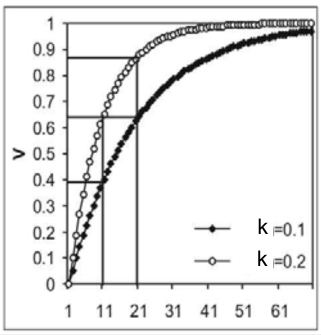


The Rescorla-Wagner model

$$\Delta V = k \times (\lambda - \Sigma V)$$

CSs with higher salience (*k*) condition faster.

But still ultimately reach λ.



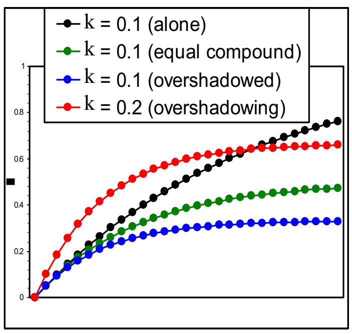
The Rescorla-Wagner model

$$\Delta V = k \times (\lambda - \Sigma V)$$

Overshadowing

Two CSs "share" V.

More salient CS "wins" lion's share and effectively blocks conditioning to weaker CS



The Rescorla-Wagner model

$$\Delta V = k \times (\lambda - \Sigma V)$$

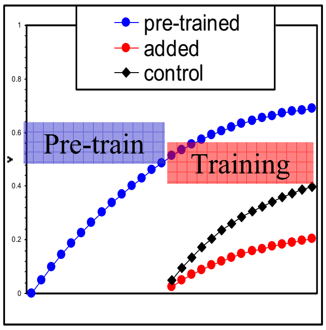
starts high

Blocking:

Pre-trained CS starts with high V.

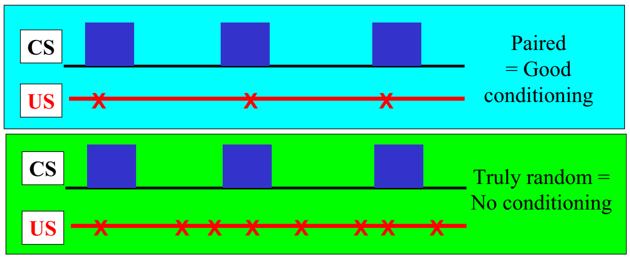
Therefore ΣV already large when new CS added

Therefore ΔV is small on each training trial with added CS.



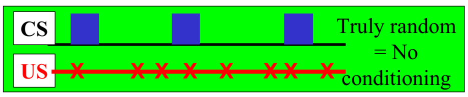
Rescorla-Wagner and Contingency

- Can the R-W model explain Rescorla's original demonstration of contingency?
- How can it account for effects of added US presentations?



The role of *the context* in the Rescorla-Wagner Model

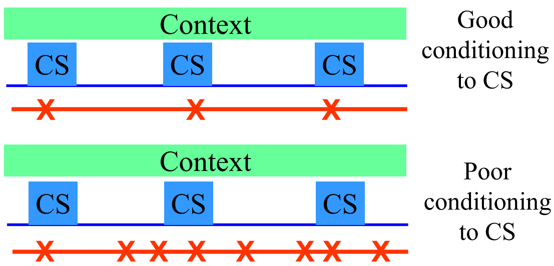
- Wagner pointed out that the physical chamber in which the rat is conditioned (ie, the context) can function as a CS in its own right
  - Rat doesn't *know* that lights and tones are CSs but context should be ignored.



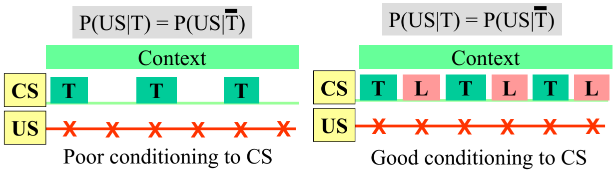
- If context is another (ever-present) CS, it can regulate (eg block or overshadow) conditioning to target CS…

The role of *the context* in the Rescorla-Wagner Model

- Added presentations of US (without CS) will condition the context, enabling it to effectively block the CS



Durlach's demonstration that signalling extra USs with another CS can rescue conditioning to target CS…



Light (L) overshadows conditioning to background context, thereby preventing context from blocking conditioning to tone (T)

Effects of non-reinforcement

- Animals also change their behaviour to a CS when it is **no longer** paired with the US.

  ie, when the temporal correlation between occurrence of CS and US is broken.
- The conditioned response (CR) stops: "extinction"

Extinction & the Rescorla-Wagner model

- By end of conditioning, the CS has acquired positive association with US. Ie. V is positive.
- If CS is then presented without US, generates negative discrepancy (US expected but absent).

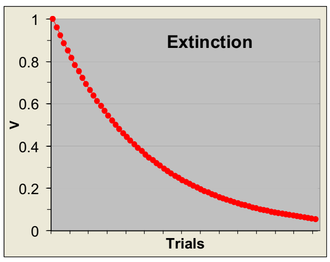
$$\Delta V = k \times (\lambda - \Sigma V)$$

As result, ΔV is negative (V begins to decrease).

= Extinction

Extinction & the Rescorla-Wagner model

According to R-W, V returns to zero, and thus extinction is essentially "unlearning"? (erasing previously learned association).



Extinction & the Rescorla-Wagner model

Extinction is NOT "unlearning":

- Prior learning survives extinction
  Responding can be restored….

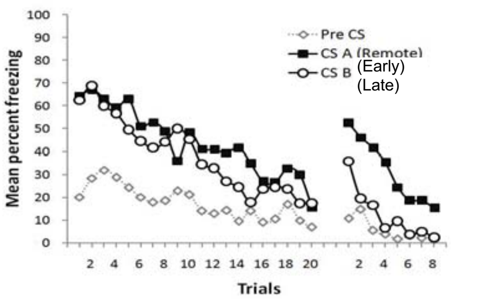
1. Spontaneous recovery of responding
2. Rapid reacquisition of responding
3. Renewal and reinstatement of responding

Spontaneous recovery

- Extinguished responding can spontaneously recover after a waiting period….

Conditioning	Early Extinction	Late Extinction	Test (next day)
CSA ➔ shock	CSA –		CSA?
CSB ➔ shock		CSB –	CSB?

Spontaneous recovery



Leung & Westbrook (unpublished)

What is Extinction?

…Extinction is new learning about the CS, learning that *masks* the original learning, but otherwise leaves it intact.

What is the "mask"?

Inhibition

Rescorla showed that animals can learn about a negative correlation between CS and US

Excitatory Learning	$P(US\|CS) > P(US\|\overline{CS})$
No Learning	$P(US\|CS) = P(US\|\overline{CS})$
Inhibitory Learning	$P(US\|CS) < P(US\|\overline{CS})$

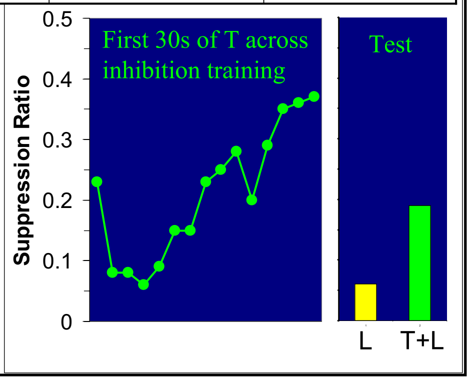
Rescorla (1969). Conditioned inhibition of fear resulting from negative CS-US contingencies. *Journal of Comparative & Physiological Psychology, 67*, 504-509.

Summation test for inhibition

L ➔ shock	T ➔ L ➔ $\overline{\text{shock}}$	L? vs T+L?

A CS with an inhibitory association with the US will reduce CRs to an excitatory CS.

=safety signal



Inhibition & the R-W model

- If preconditioned L is presented in compound with a new CS ("T") but no US is delivered, creates negative discrepancy (US expected but absent).

$$\Delta V = k \times (\lambda - \Sigma V)$$

What happens to V(T)?...

Because ΔV is negative, V(T) goes negative (having started at zero). = Inhibition

Inhibition & Extinction

- If omission of expected reinforcement is sufficient to condition inhibition to added CS…

L ➔ shock	T ➔ L ➔ $\overline{\text{shock}}$	T = CI

- could extinction also involve development of conditioned inhibition but to original CS?

Prediction….

According to R-W, what should happen when a novel CS (X) is combined with an inhibitory CS (Y) and reinforced?

$$\Delta V = k \times (\lambda - \Sigma V)$$

Group	Conditioning	Test
X	X ➔ US	X?
X+Y	X+Y ➔ US	X?

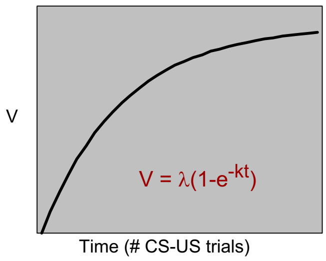
The Rescorla-Wagner (1972) model:

$$\Delta V_t = k \times (\lambda - \Sigma V_{t-1})$$

V_t = associative strength at time *t*

λ= limit of association

k = constant



Acquisition of a Pavlovian conditioned response

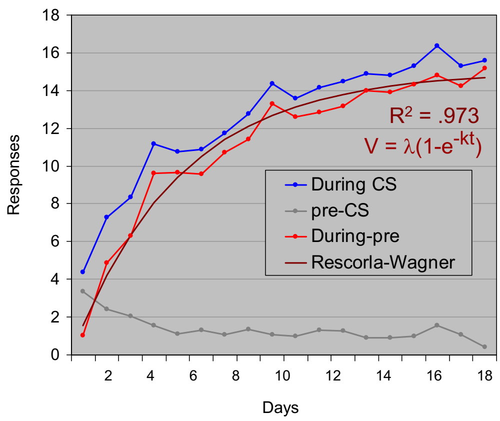
30s light (or 3kHz tone) ⇨ food

15 rats

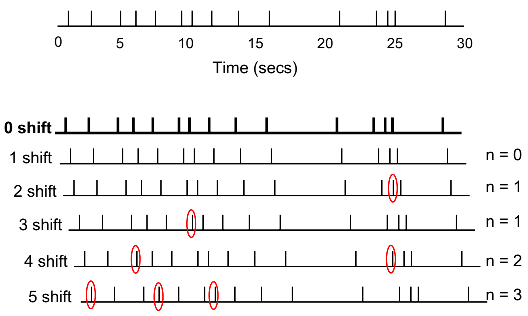
20 trials per day (iti = 5min, random) for 18 days

Record number of nose-pokes during each CS presentation & 30 sec before each CS.

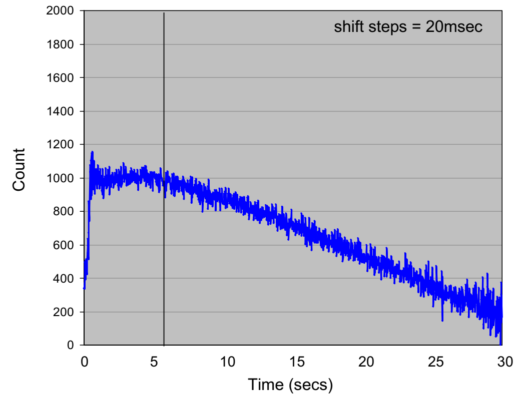
Acquisition of Pavlovian CR



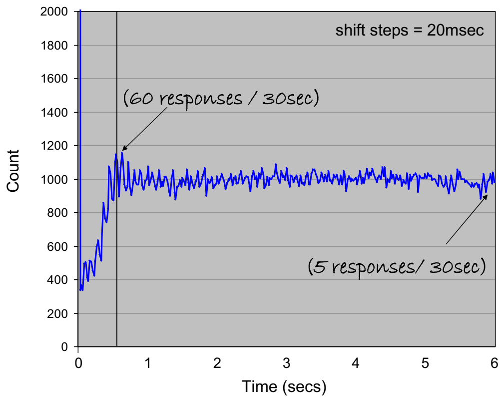
Autocorrelation of magazine approach



Autocorrelation of magazine approach



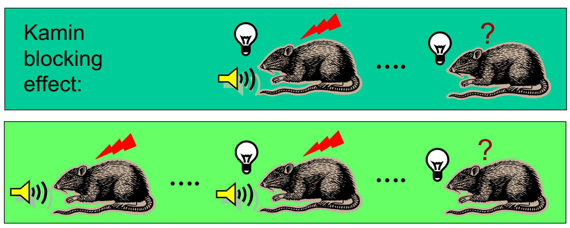
Autocorrelation of magazine approach



The Rescorla-Wagner (1972) model:

$$\Delta V_t = k \times (\lambda - \Sigma V_{t-1})$$

⇨ V is additive



Summation of Associative Strength

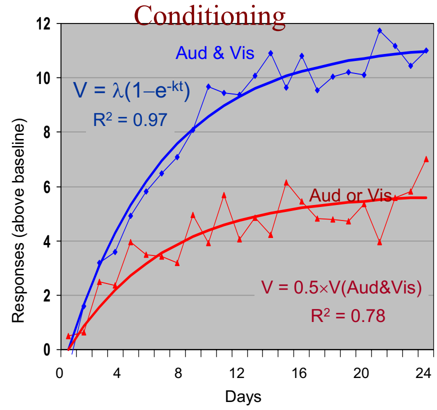
30s auditory + visual ⇨ food

20 trials per day for 24 days

30s auditory ?
30s visual ?
} 1 trial each per day

Record number of
nose-pokes during each CS

Summation of Associative Strength: Overshadowing in Compound Conditioning



Summation of Pavlovian conditioned responses

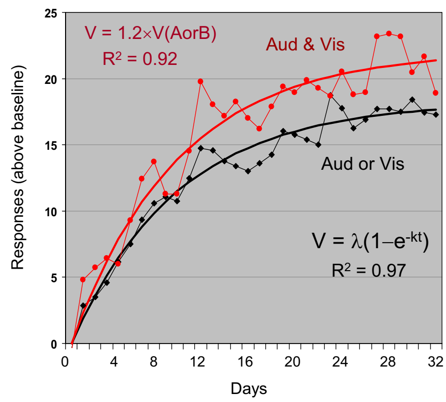
30s auditory ⇨ food
&
30s visual ⇨ food
} 12 trials each per day for 32 days

30s auditory + visual ?

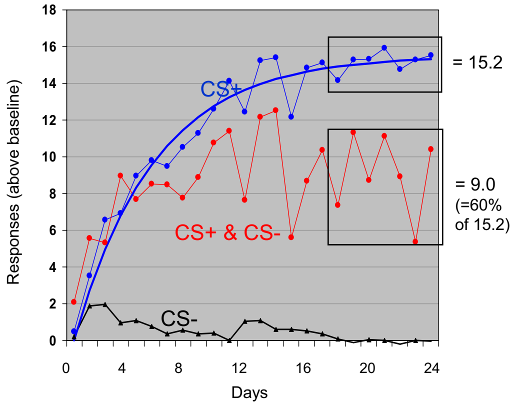
1 trial per day

Record number of
nose-pokes during each CS

Summation of Pavlovian conditioned responses



Summation of Pavlovian conditioned responses



Negative Patterning

A+ B+ AB-

strobe ⇨ food
white noise ⇨ food

strobe & noise ⇨ no food

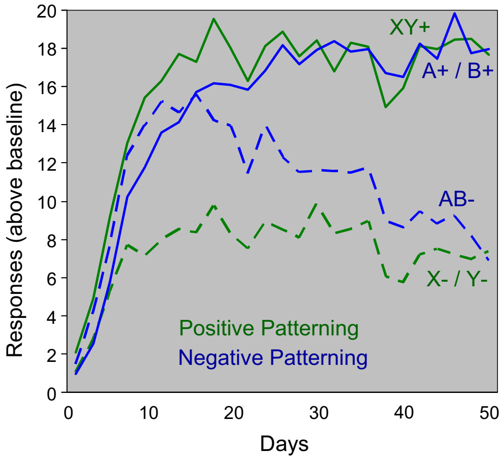
Positive Patterning

X- Y- XY+

light ⇨ no food
3kHz tone ⇨ no food

light & tone ⇨ food

n = 16

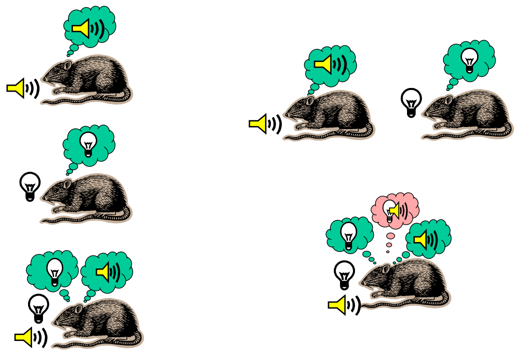


Elemental representations:

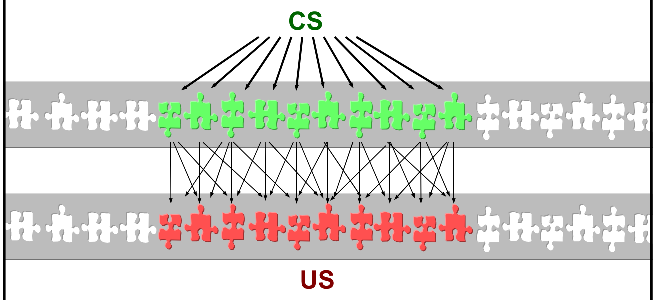
AB = A & B

Configural representations:

A = X; B = Y; AB = Z



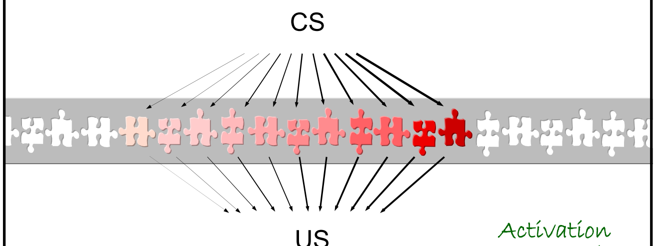
Stimuli comprised of many elemental features



individual elements become associated with outcome

Bush & Mosteller (1951b); Estes (1950)

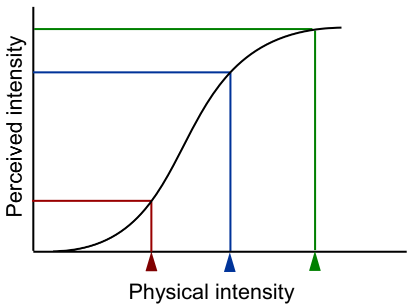
Stimuli comprised of many elemental features of varying activation strength



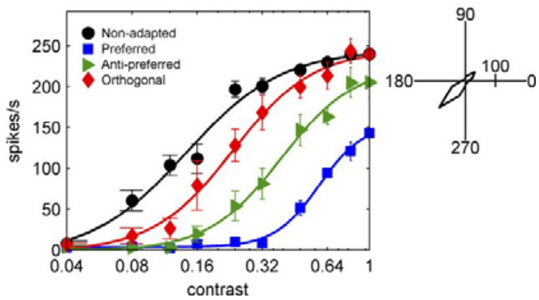
Activation strength

$$\Delta V_t = k \times (\lambda - \Sigma V_{t-1})$$

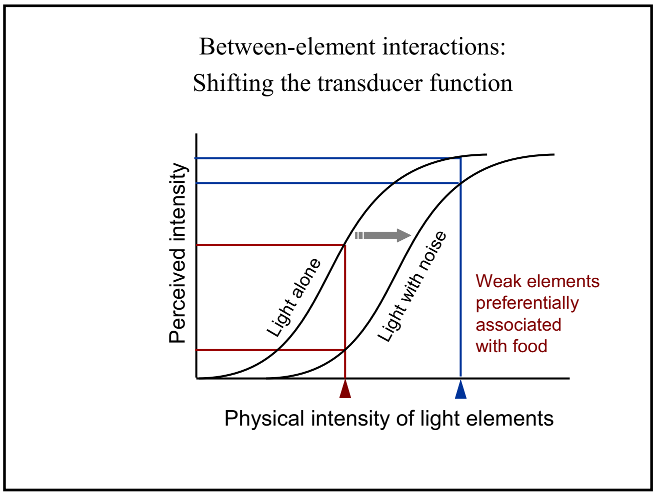
Non-linear transducer function

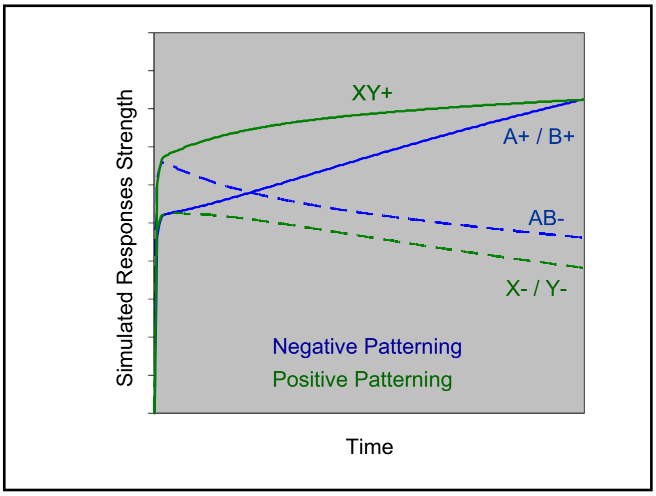


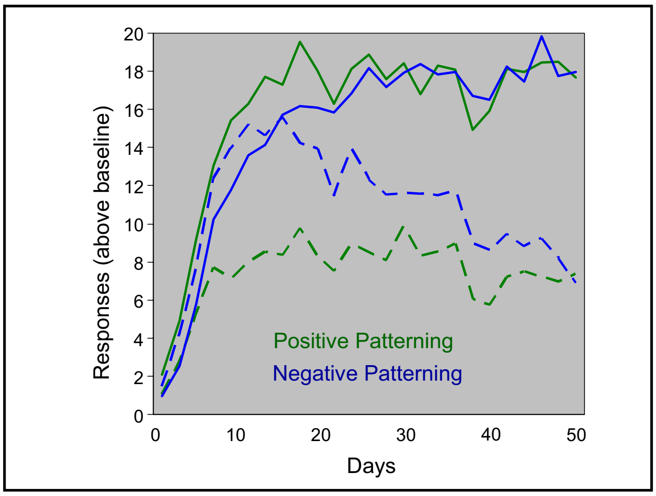
Adaptation-induced shift in tuning curve of a single neuron.

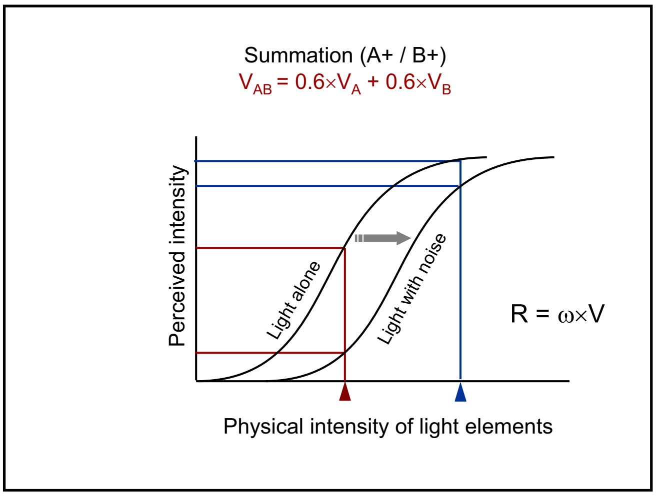


Crowder, Price, Hietanen, Dreher, Clifford & Ibbotson (2006). Relationship between contrast adaptation and orientation tuning in V1 and V2 of cat visual cortex. *J Neurophysiol 95*: 271-283


Between-element interactions:
Shifting the transducer function
Perceived intensity
Light alone
Light with noise
Weak elements
preferentially
associated
with food
Physical intensity of light elements


Simulated Responses Strength
XY+
A+ / B+
AB-
X- / Y-
Negative Patterning
Positive Patterning
Time


Responses (above baseline)
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
Days
Positive Patterning
Negative Patterning


Summation (A+ / B+)
V_AB = 0.6×V_A + 0.6×V_B
Perceived intensity
Light alone
Light with noise
R = ω×V
Physical intensity of light elements