BEHAVIORAL ECONOMICS AND NEUROECONOMICS:
Cooperation, Competition, Preference, and Decision Making

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GENERAL THEMES OF THIS TALK

How understanding human cognition, emotion, and decision making can impact economic theory

- **How emotions impact decisions**
- **Decision making under risk**

e.g., Prospect Theory Kahneman & Tversky

How a mathematical understanding of cooperative-competitive dynamics can impact economic theory

- **voting paradox Condorcet, Arrow**
- **market equilibria Nash**
- **preferences: do we know what we like?**
- **totalitarian, socialist, democratic trends**
- **the rich get richer**

NOBEL MEMORIAL PRIZES IN ECONOMICS

1972 Kenneth Arrow
1978 Herb Simon
1992 Gary Baker
1994 John Nash
2001 George Akerlof
2002 Daniel Kahneman

Kahneman: **"for having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty"**

BEHAVIORAL ECONOMICS

This is a major issue in behavioral economics:

"Behavioral economics explores why people sometimes make irrational decisions, and why and how their behavior does not follow the predictions of economic models. Notable individuals in the study of behavioral economics are Nobel laureates Gary Becker (motives, consumer mistakes; 1992), Herbert Simon (bounded rationality; 1978), Daniel Kahneman (illusion of validity, anchoring bias; 2002) and George Akerlof (procrastination; 2001)."

Investopedia

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How do irrational decision-making properties arise in the brain?

Given Darwinian selection, how do irrational properties of decision-making survive at all?

Why are not only adaptive properties selected by evolution?

A MAJOR INSIGHT FROM BRAIN MODELING

Adaptive processes selected by evolution may lead to irrational behaviors when activated in certain environments

Occasional irrational behavior is the price we pay for adaptive processes: part of the "human condition"

Folk Wisdom: Parents know that their children should avoid certain "bad influences"

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WHAT design principles and mechanisms have been selected by evolution?

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WHAT design principles and mechanisms have been selected by evolution?

HOW do certain environments contextually trigger irrational decisions?

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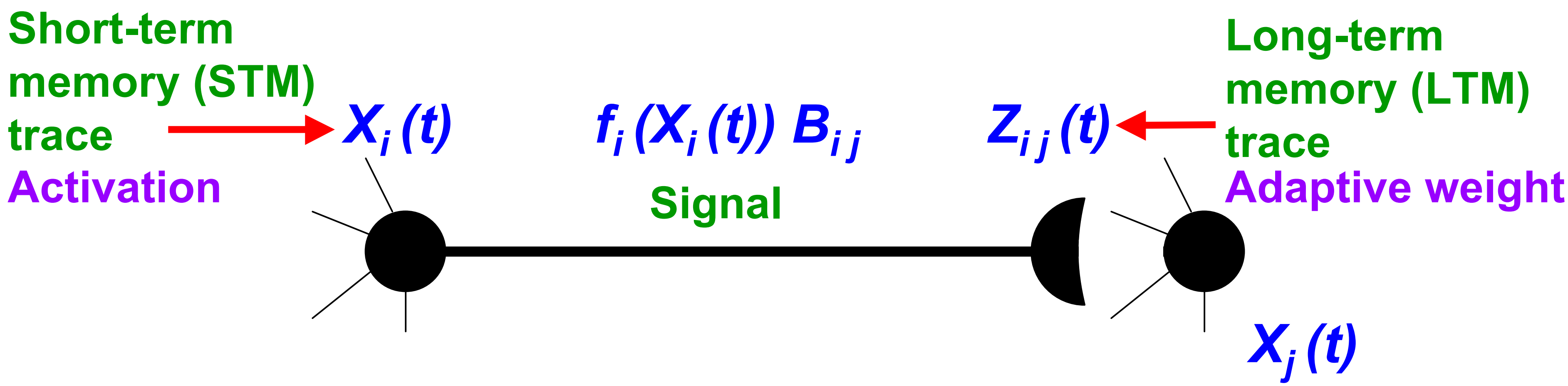
CONTINUOUS AND NONLINEAR

Grossberg, PNAS, 1967, 1968



STM EQUATION

ADDITIVE MODEL

$$\frac{d}{dt}X_i = -A_iX_i + \sum_{j=1}^{n} f_j(X_j)B_{ji}Z_{ji}^{(+)} - \sum_{j=1}^{n} g_j(X_j)C_{ji}Z_{ji}^{(-)} + I_i$$

PASSIVE DECAY — POSITIVE FEEDBACK — NEGATIVE FEEDBACK — INPUT

Special case:

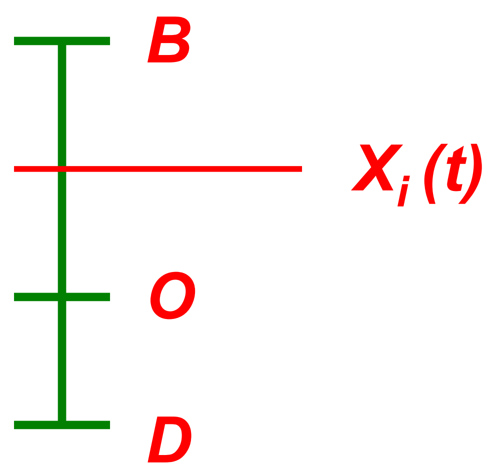
$$\frac{d}{dt}X_i = -A_iX_i + \sum_j f_j(X_j)Z_{ji} + I_i$$

SHUNTING MODEL

MASS ACTION, MEMBRANE EQUATIONS

Bounded activations

Automatic gain control



$$\frac{d}{dt}X_i = -A_i X_i + (B - X_i)[\sum_{j=1}^{n} f_j(X_j)C_{ji}Z_{ji}^{(+)} + I_i]$$

$$-(X_i + D)[\sum_{j=1}^{n} g_j(X_j)E_{ji}Z_{ji}^{(-)} + J_i]$$

INCLUDES THE ADDITIVE MODEL

LEARNING AND LTM EQUATION

Hebbian and Anti-Hebbian Properties

Passive Memory Decay

$$\frac{d}{dt} Z_{ij} = -F_{ij} Z_{ij} + G_{ij} f_i(X_i) h_j(X_j)$$

Gated Memory Decay

$$\frac{d}{dt} Z_{ij} = h_j(X_j)[-F_{ij} Z_{ij} + G_{ij} f_i(X_i)]$$

Early experimental support:
Levy, 1985; Levy, Brassel, and Moore, 1983; Levy and Desmond, 1985; Rauchecker and Singer, 1979; Singer, 1983

A SMALL NUMBER OF DYNAMICAL EQUATIONS

Activation, or short-term memory, equations

Learning, or long-term memory, equations

Habituation, or medium-term memory, equations

…

SHUNTING COOPERATIVE-COMPETITIVE NETWORKS

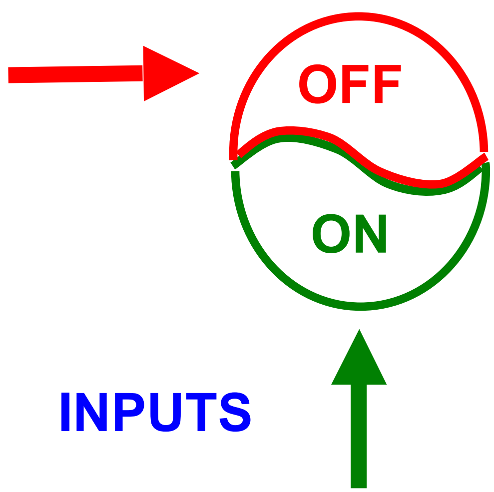
COMPETITION IS UNIVERSAL IN THE BIOLOGICAL WORLD

DARWIN

Survival of the fittest

Species level

WHY ON THE CELLULAR LEVEL?!



WHAT IS A CELL?

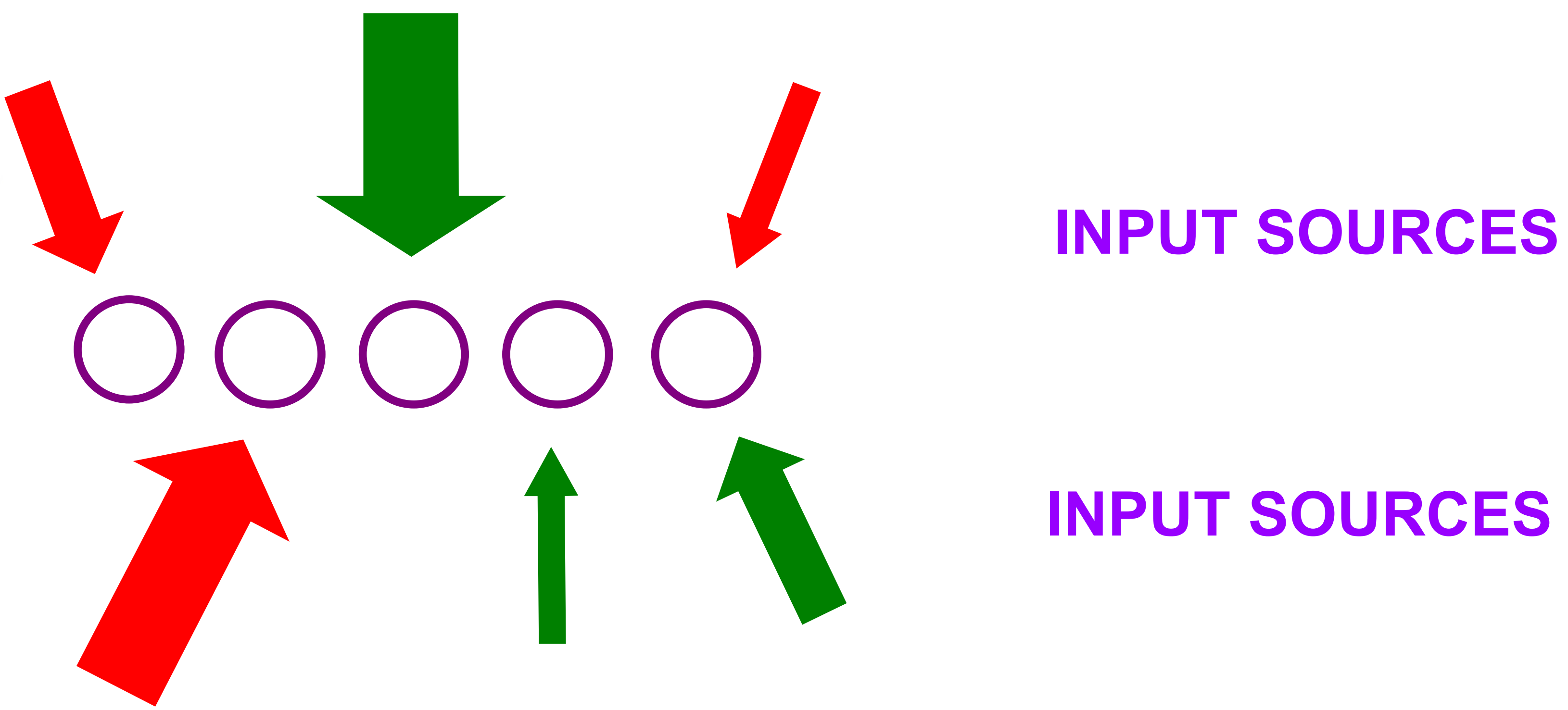
WHAT IS A CELL?

It contains a finite number of active and inactive sites
Infinity does not exist in biology!

NOISE-SATURATION DILEMMA (1968-1973)

How are feature patterns processed
in noisy cells with finitely many sites
without being contaminated by either noise or saturation?

PATTERN PROCESSING BY CELL NETWORKS

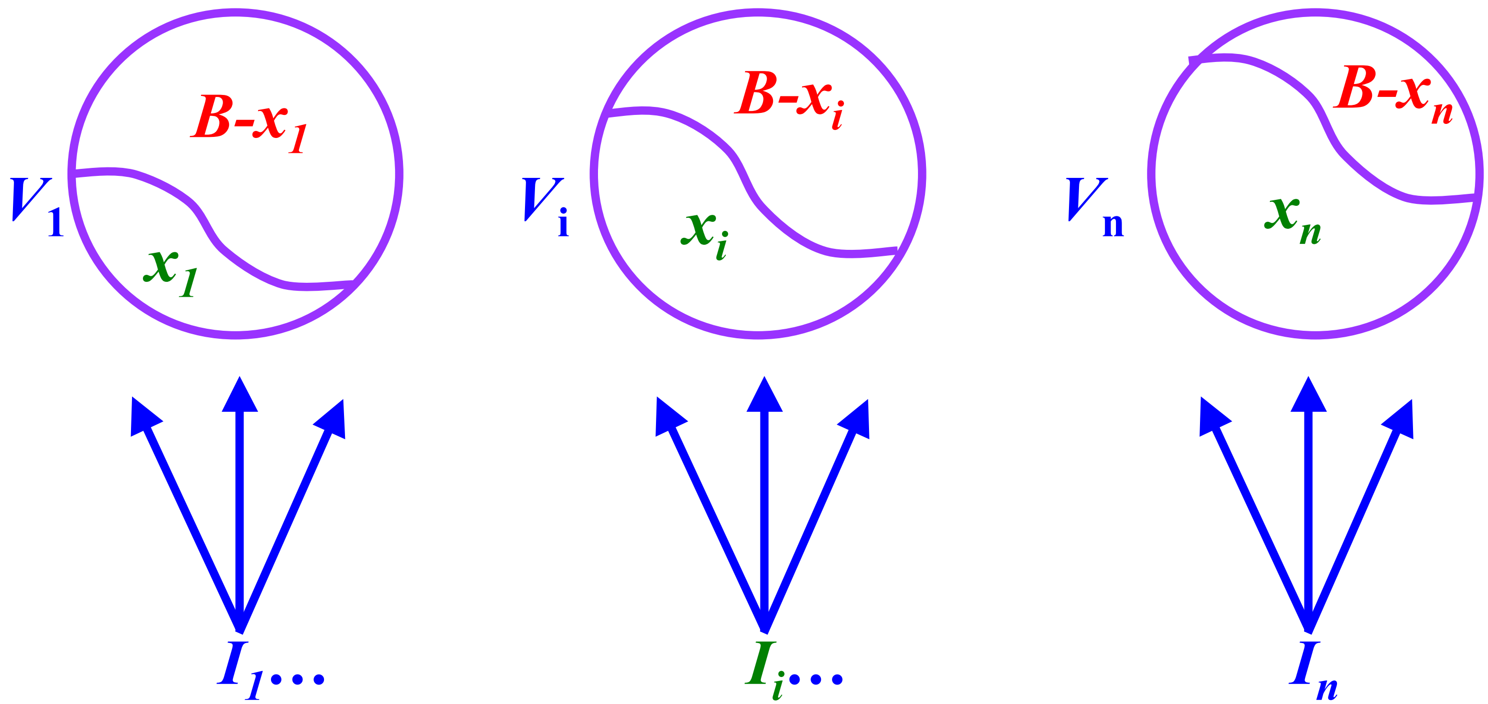


Total NUMBER and SIZE of inputs to each cell can vary wildly through time.

How do cells maintain their SENSITIVITY to input PATTERNS whose overall SIZE changes wildly through time?

COMPUTING IN A BOUNDED ACTIVITY DOMAIN

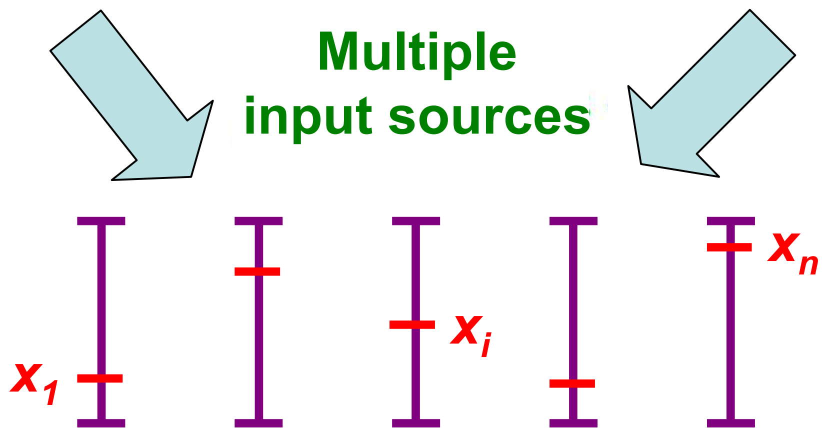
Thought experiment



B	excitable sites
$x_i(t)$	excited sites
$B\text{-}x_i(t)$	unexcited sites

NOISE-SATURATION DILEMMA

Grossberg, 1968-1973

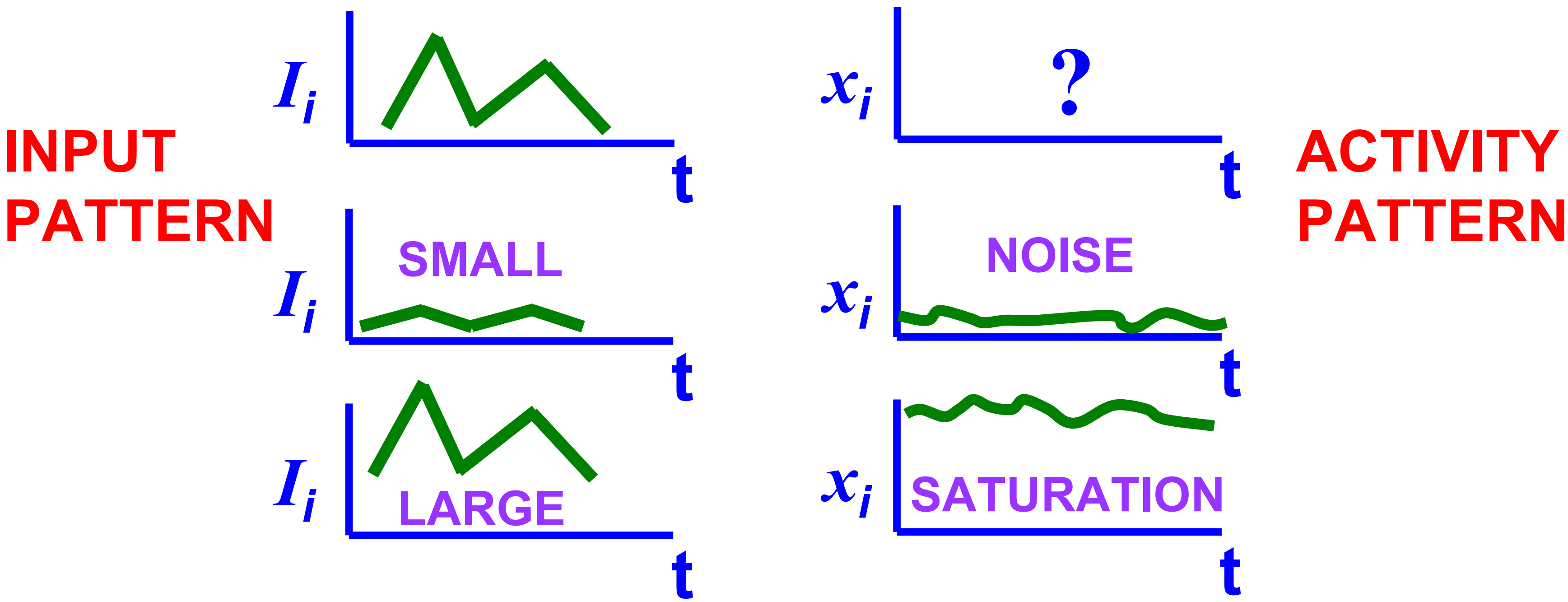


BOUNDED ACTIVITIES

If activities x_i are sensitive to SMALL inputs, then why don't they SATURATE to large inputs?

If x_i are sensitive to LARGE inputs, then why don't small inputs get lost in system NOISE?

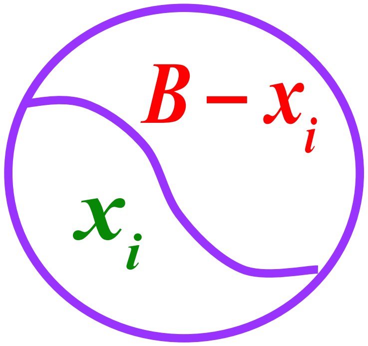
NOISE-SATURATION DILEMMA

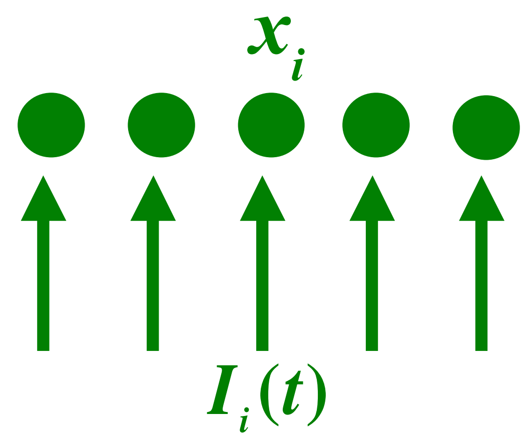


PROBLEM: remain sensitive to input **RATIOS** $\theta_i = \frac{I_i}{\sum_j I_j}$

as total input $I = \sum_j I_j \to \infty$

SHUNTING SATURATION





NO INTERACTIONS

(a) (b)

$$\frac{d}{dt}x_i = -Ax_i + (B - x_i)I_i$$

(a) Spontanous decay of activity x_i to equilibrium

(b) Turn on unexcited sites B - x_i by inputs I_i (mass action)

Inadequate response to a SPATIAL PATTERN of inputs:

$$I_i(t) = \theta_i I(t)$$

θ_i relative intensity (cf., reflectance)

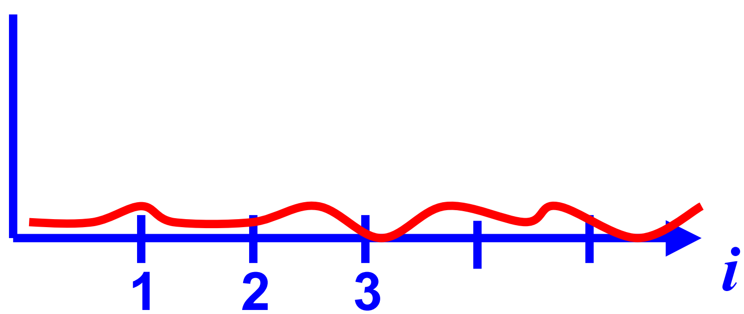
$I(t)$ total intensity (cf., luminance)

SHUNTING SATURATION

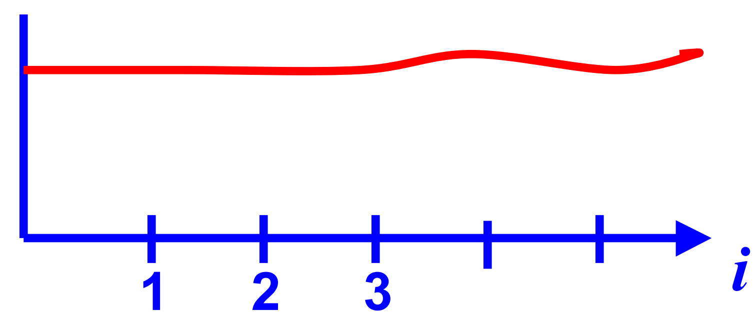
At equilibrium: $$0 = \frac{d}{dt}x_i = -Ax_i + (B - x_i)I_i$$

$$x_i = \frac{BI_i}{A + I_i} = \frac{B\theta_i I}{A + \theta_i I} \rightarrow B \quad as \quad I \rightarrow \infty$$

$$I_i = \theta_i I,\; I = \sum_j I_j$$



I **small: lost in noise**



I **large: saturates**

Sensitivity loss to relative intensity as total intensity increases

COMPUTING WITH PATTERNS

How to compute the pattern-sensitive variable:

$$\theta_i = \frac{I_i}{\sum_{k=1}^{n} I_k} \quad ?$$

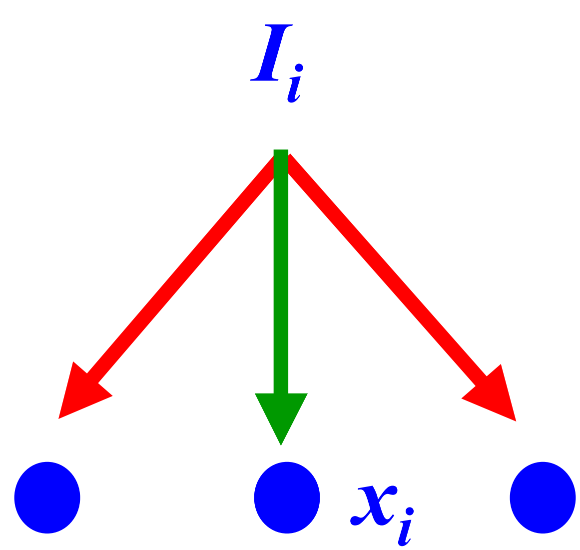
Need interactions! What type?

$$\theta_i = \frac{I_i}{I_i + \sum_{k \neq i} I_k}$$

$$I_i \uparrow \Rightarrow \theta_i \uparrow$$ excitation

$$I_k \uparrow \Rightarrow \theta_i \downarrow$$ inhibition

On-center off-surround network:



SHUNTING ON-CENTER OFF-SURROUND NETWORK

Mass action:

$$\frac{d}{dt}x_i = -Ax_i + (B - x_i)I_i - x_i \sum_{k \neq i} I_k$$

Turn on unexcited sites **Turn off excited sites**

At equilibrium:

$$0 = \frac{d}{dt}x_i = -(A + I_i + \sum_{k \neq i} I_k)x_i + BI_i = -(A + I)x_i + BI_i$$

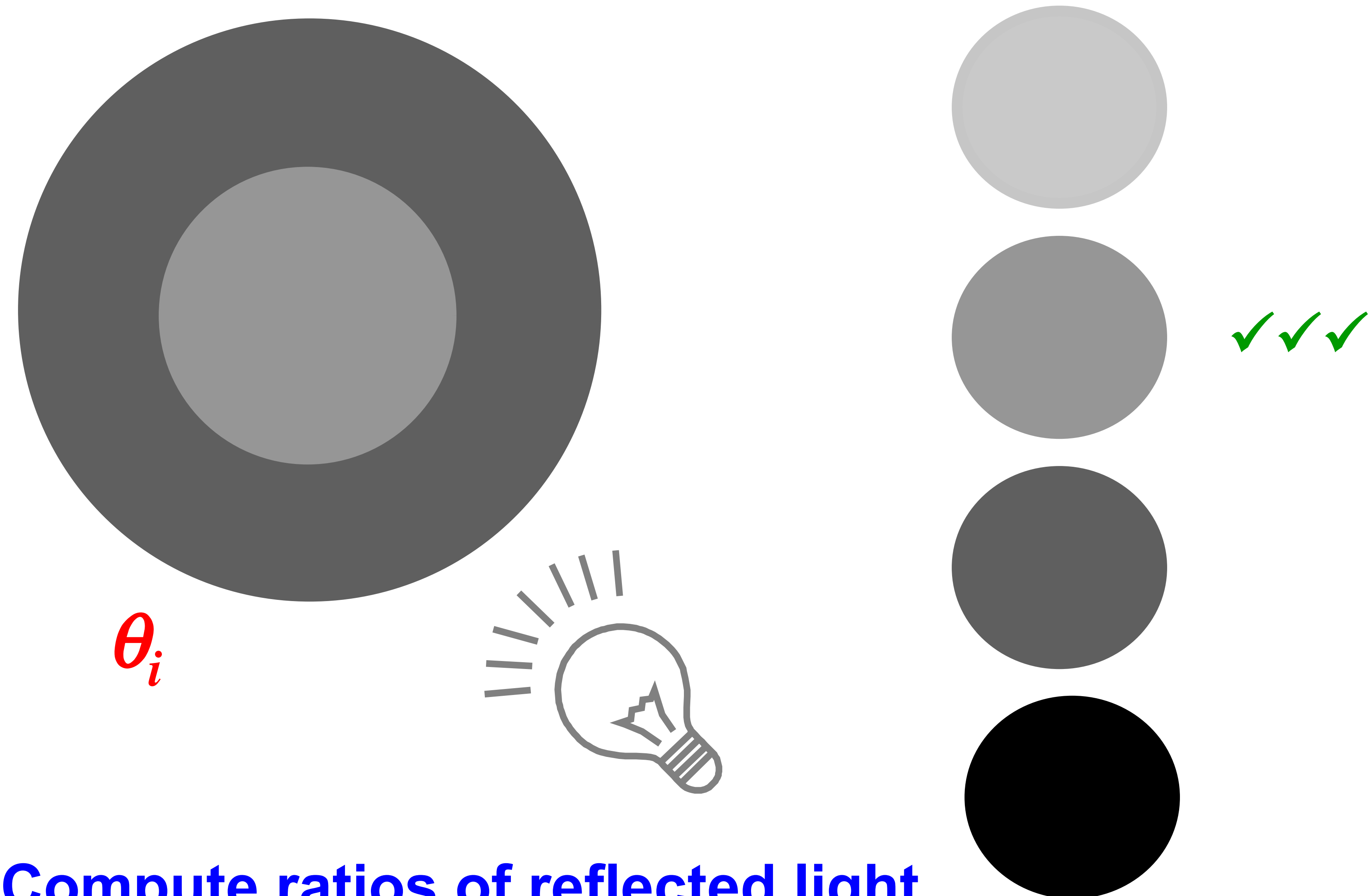
$$x_i = \frac{BI_i}{A+I} = \frac{B\theta_i I}{A+I} = \theta_i \frac{BI}{A+I}$$

No saturation!
Infinite dynamical range
Automatic gain control
Compute ratio scale
Weber law

$$x = \sum_{k=1}^{n} x_k = \frac{BI}{A+I} \leq B$$

Conserve total activity
NORMALIZATION
Real-time probability

VISION: BRIGHTNESS CONSTANCY



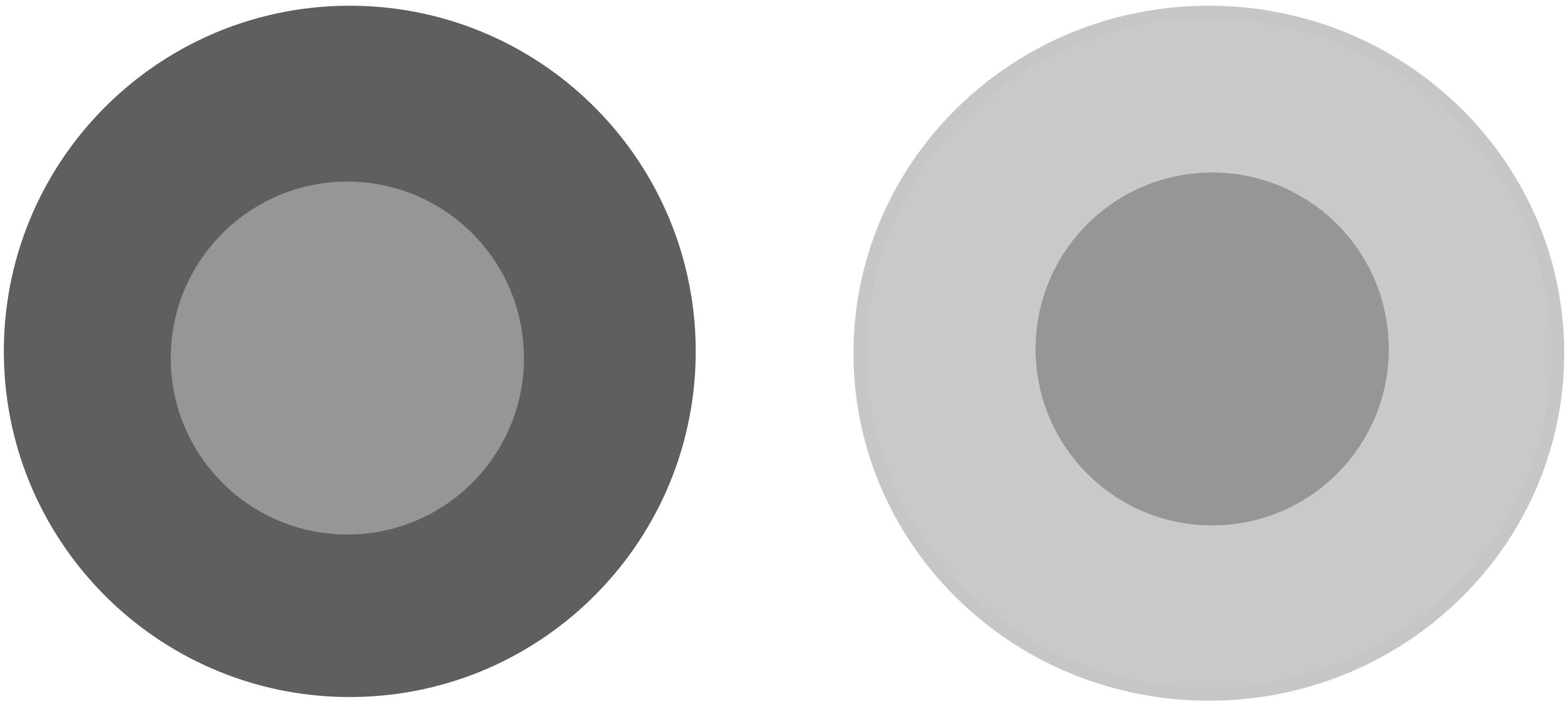
Compute ratios of reflected light

Reflectance processing

VISION: BRIGHTNESS CONTRAST

CONSERVE A TOTAL QUANTITY

Total Activity Normalization



LUCE Ratio scales in choice behavior

ZEILER Adaptation level theory

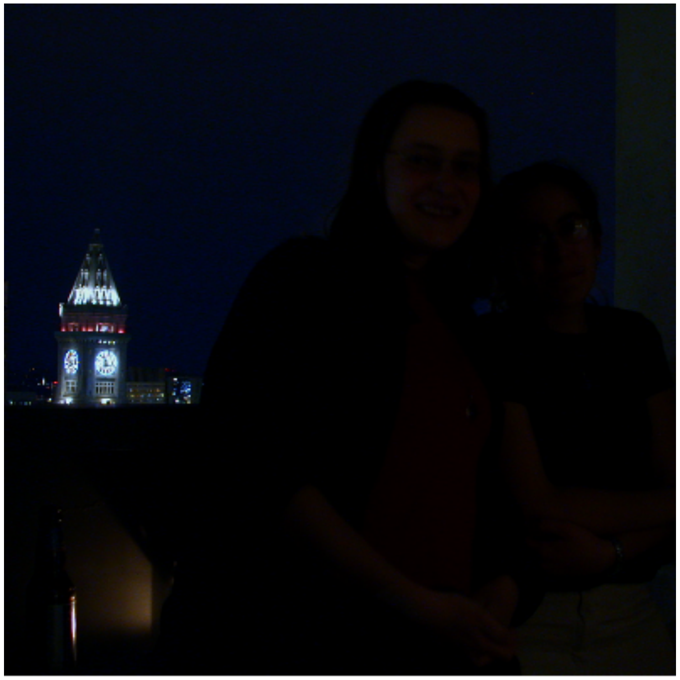
LIGHT ADAPTATION

Ten orders of magnitude of daily variations of ambient illumination

Martin (1983)

Grossberg and Hong (2006)

INPUT



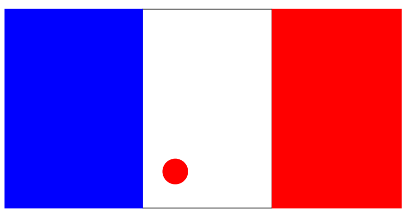
MODEL SIMULATION

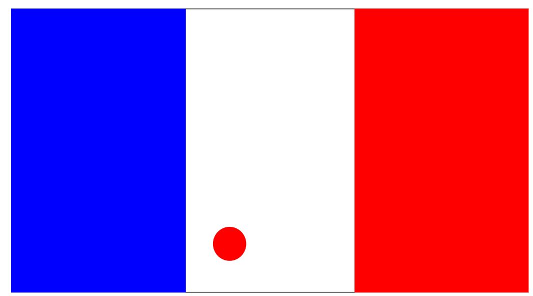
APPLICATIONS IN MORPHOGENESIS

e.g., self-regulation during development

Shape preserved as size increases

French flag problem (Wolpert)





Cellular models! vs. chemical or fluid models

Turing; Gierer and Meinhardt

WHY IS THIS RELEVANT TO ECONOMICS?

TWO LANGUAGES FOR THE SAME MATH

SHUNT: mass action interactions

ON-CENTER OFF-SURROUND:

cooperation within groups
competition between groups

NOISE-SATURATION DILEMMA:

maintain group rankings
despite wild input perturbations

CLASSIFY properties of

FEEDFORWARD COMPETITIVE NETWORKS

BEHAVIORAL CONTRAST IN SPACE:

Do we know what we like?

A source of irrational decision making

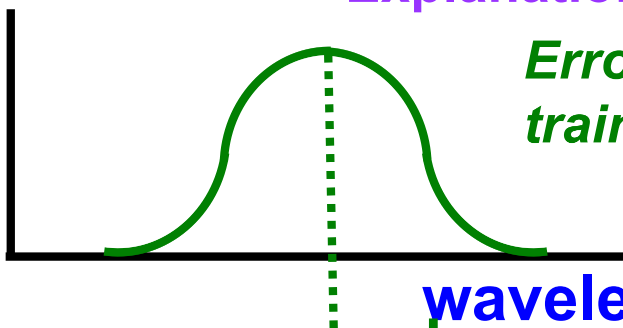
Operant conditioning: Key pecking in pigeons

Grusec, 1968; Honig, 1962; Terrace, 1966

An example of total activity normalization

Explanation: Grossberg, 1975

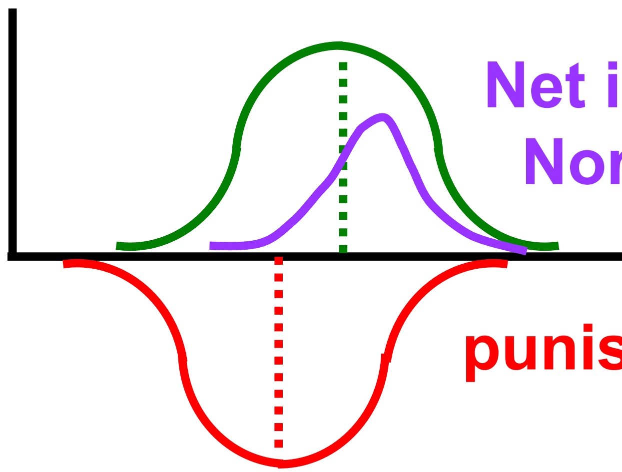
# of pecks



Errorless training

wavelength

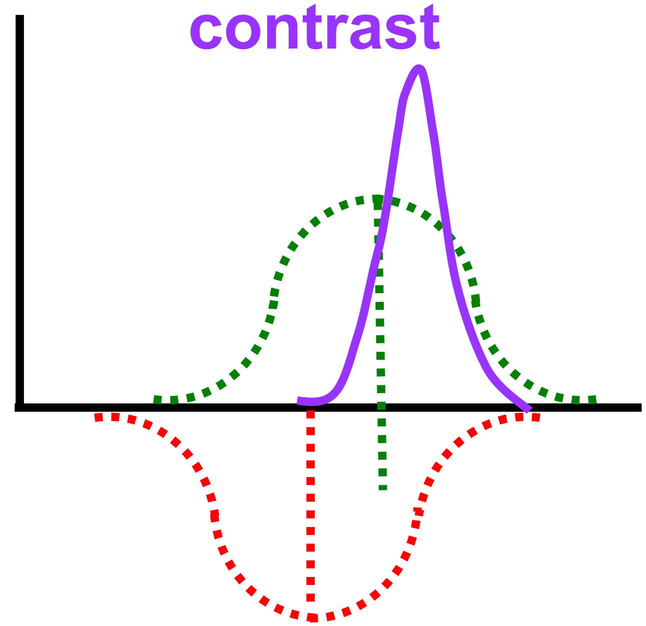
reward



Net is smaller: Normalize!

punishment

Peak shift and contrast



Can prefer an option that was not previously rewarded

That was Behavioral Contrast in SPACE

What about Behavioral Contrast in TIME?

What kind of data can be explained by that?

That was Behavioral Contrast in SPACE

What about Behavioral Contrast in TIME?

What kind of data can be explained by that?

WORKING MEMORY!

WORKING MEMORY

STM storage of event *sequences*

Short-term memory (STM) storage of a sequence of items;
e.g., a new telephone number
Have trouble repeating it if you are distracted first

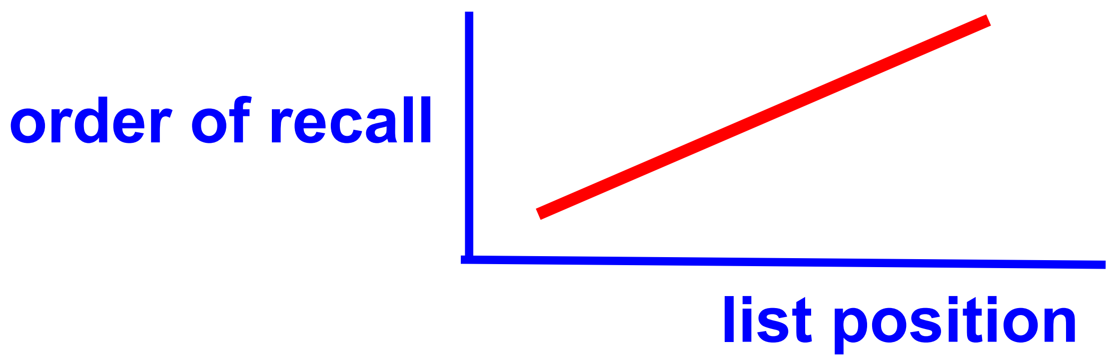
NOT just persistence of a single item

vs. LTM: you can repeat your name even after you are distracted
Events stored in LTM have been *learned*

WORKING MEMORY

STM storage of event *sequences*

Correct order of recall: Past before future



This sounds simple enough, however…

BEHAVIORAL CONTRAST IN TIME:

Bounded Rationality Simon, 1957

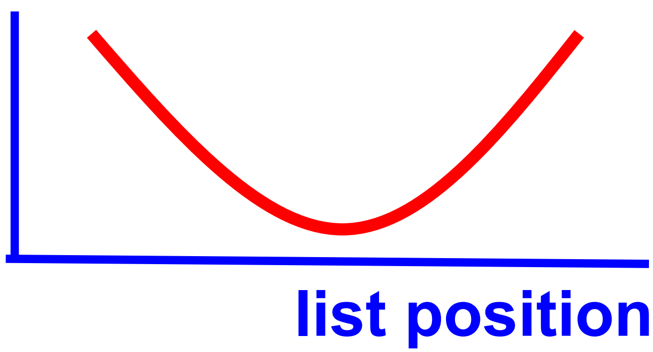
How to design a WORKING MEMORY to code TEMPORAL ORDER INFORMATION in STM before it is stored in LTM?

Speech, language, sensory-motor control, cognitive planning

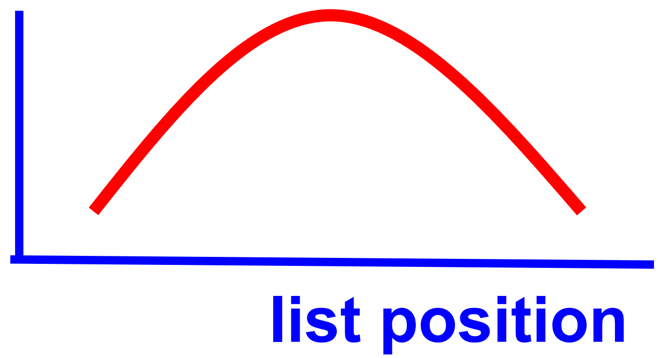
e.g., repeat a telephone number unless you are distracted first

Temporal order STM is often imperfect, e.g.: FREE RECALL

Probability of recall



Order of recall



Why?

A SMALL NUMBER OF DYNAMICAL EQUATIONS

Activation, or short-term memory, equations

Learning, or long-term memory, equations

Habituation, or medium-term memory, equations

…

LTM INVARIANCE PRINCIPLE

Grossberg et al, 1978+

CLAIM: These errors are consequences of an adaptive design!

Heuristics:

It does not pay to store anything in working memory if you cannot learn about it

Otherwise, a list would seem novel no matter how many times it was experienced

LTM Invariance principle:

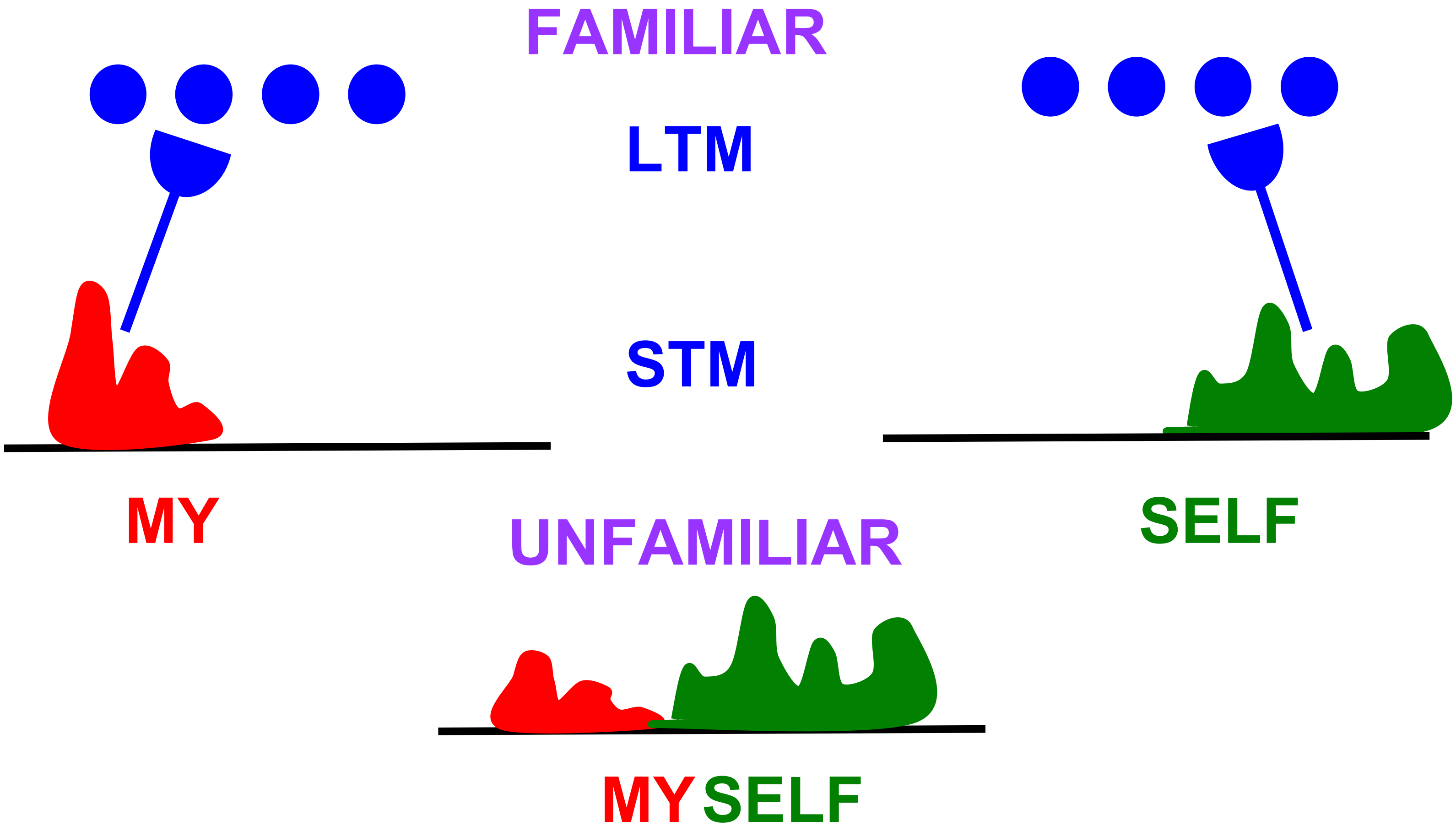
Working memories are *designed* so that storage of new items in STM does not disrupt LTM of previously stored item groupings

LTM INVARIANCE PRINCIPLE

Working memories are *designed* so that storage of new items in STM does not disrupt LTM of previously stored item groupings

e.g., suppose you have already learned the words
MY, ELF, and SELF
How do you store the new word MYSELF without forcing unselective forgetting of its familiar subwords?

LTM INVARIANCE PRINCIPLE



How does STM storage of SELF influence STM storage of MY?

It should not recode LTM of either MY or SELF!

LTM INVARIANCE PRINCIPLE

The brain can only store the correct temporal order of relatively short lists in WM in order to correctly and stably remember any lists at all

STABILITY of learned temporal order in LTM implies non-veridical storage of temporal order in STM

WORKING MEMORY MODELS:
ITEM AND ORDER, OR COMPETITIVE QUEUING

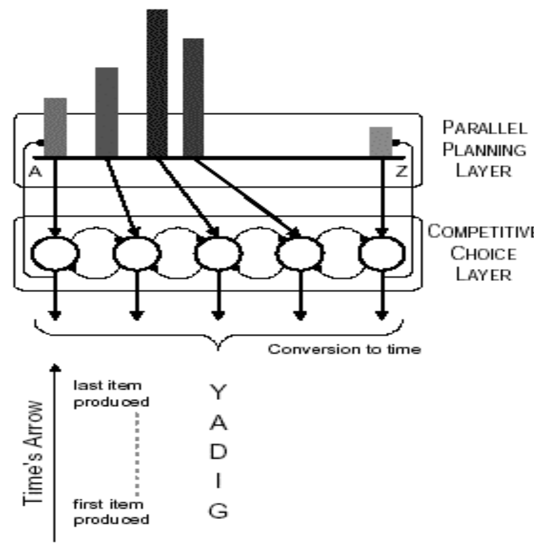
Primacy gradient of working memory activation stores correct temporal order at content-addressable cells

Maximally activated cell population is performed first

Suppress activity of chosen cell population
Inhibition of return

Iterate until entire sequence is performed

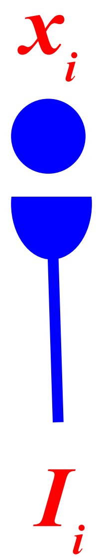
Grossberg (1978)
Houghton (1990)
Page & Norris (1998)



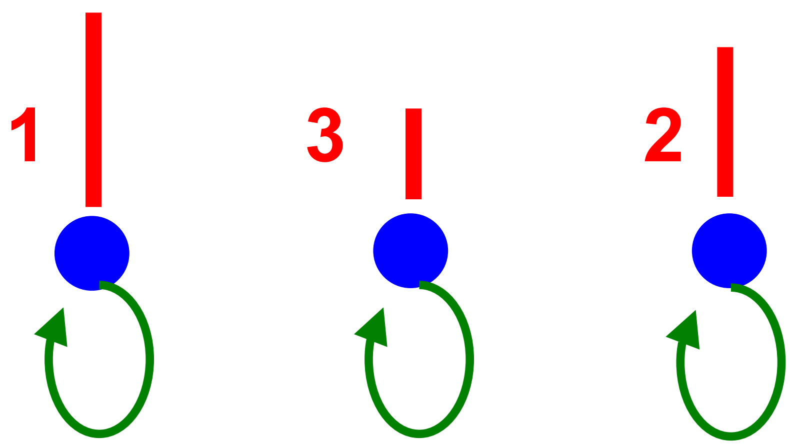
Event sequence in time stored as an evolving spatial pattern of activity

ITEM AND ORDER WORKING MEMORIES

1. Content-addressable item codes:

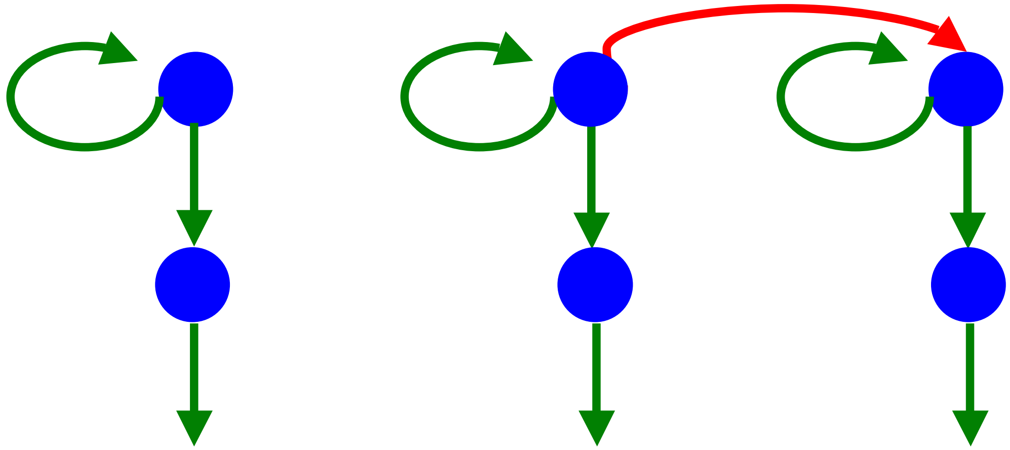


2. Temporal order stored as relative sizes of item activities:



ITEM AND ORDER WORKING MEMORIES

3. Competition between working memory cells

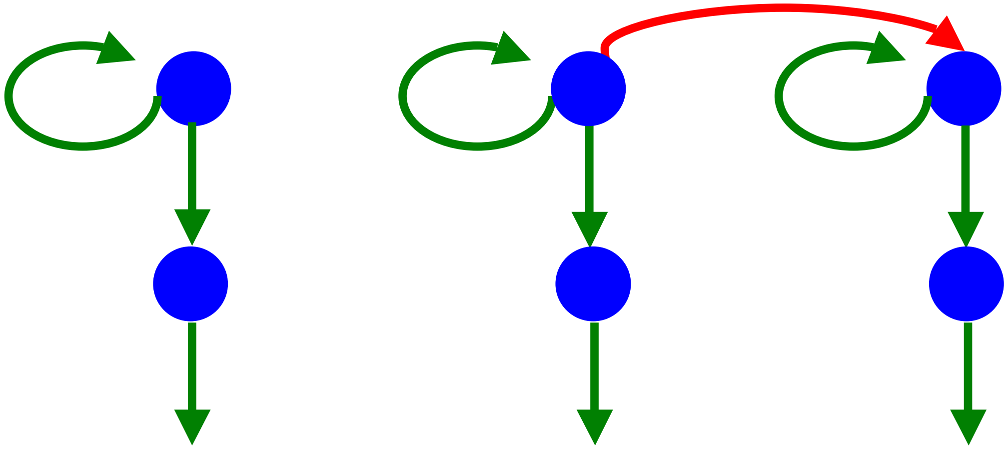


Competition balances the positive feedback
that enables the cells to remain active

Without it, cell activities may all saturate at their maximal values
NOISE-SATURATION DILEMMA again!

ITEM AND ORDER WORKING MEMORIES

3. Competition between working memory cells



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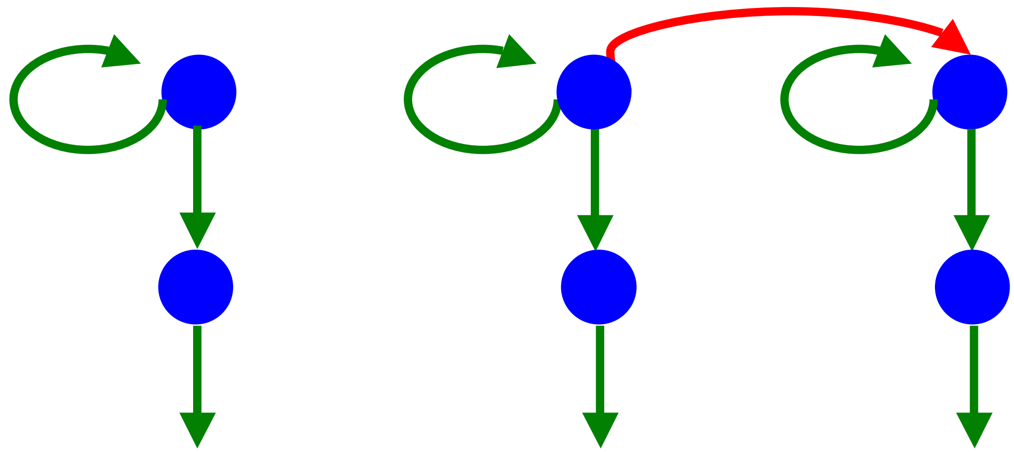
NOISE-SATURATION DILEMMA again!

TOTAL ACTIVITY tends to NORMALIZE!

ITEM AND ORDER WORKING MEMORIES

3. Competition between working memory cells



Competition balances the positive feedback
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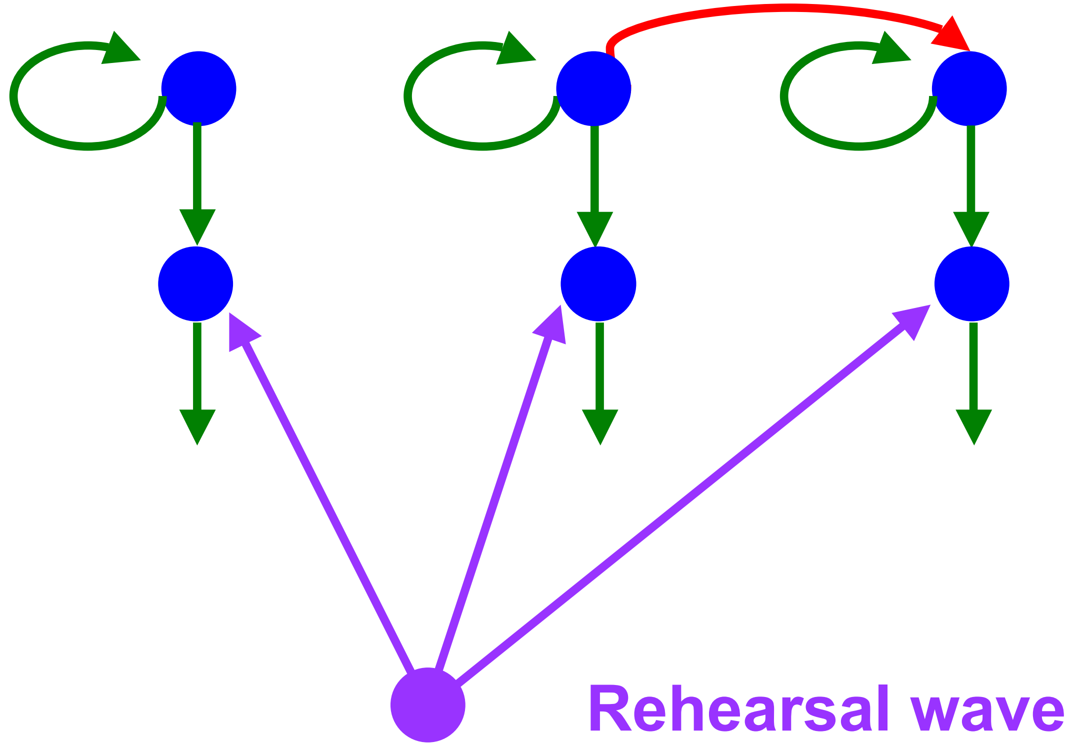
Without it, cell activities may all saturate at their maximal values
NOISE-SATURATION DILEMMA again!

A recurrent shunting on-center off-surround network
satisfies the LTM Invariance Rule!
Clarifies how working memories may arise during evolution

ITEM AND ORDER WORKING MEMORIES

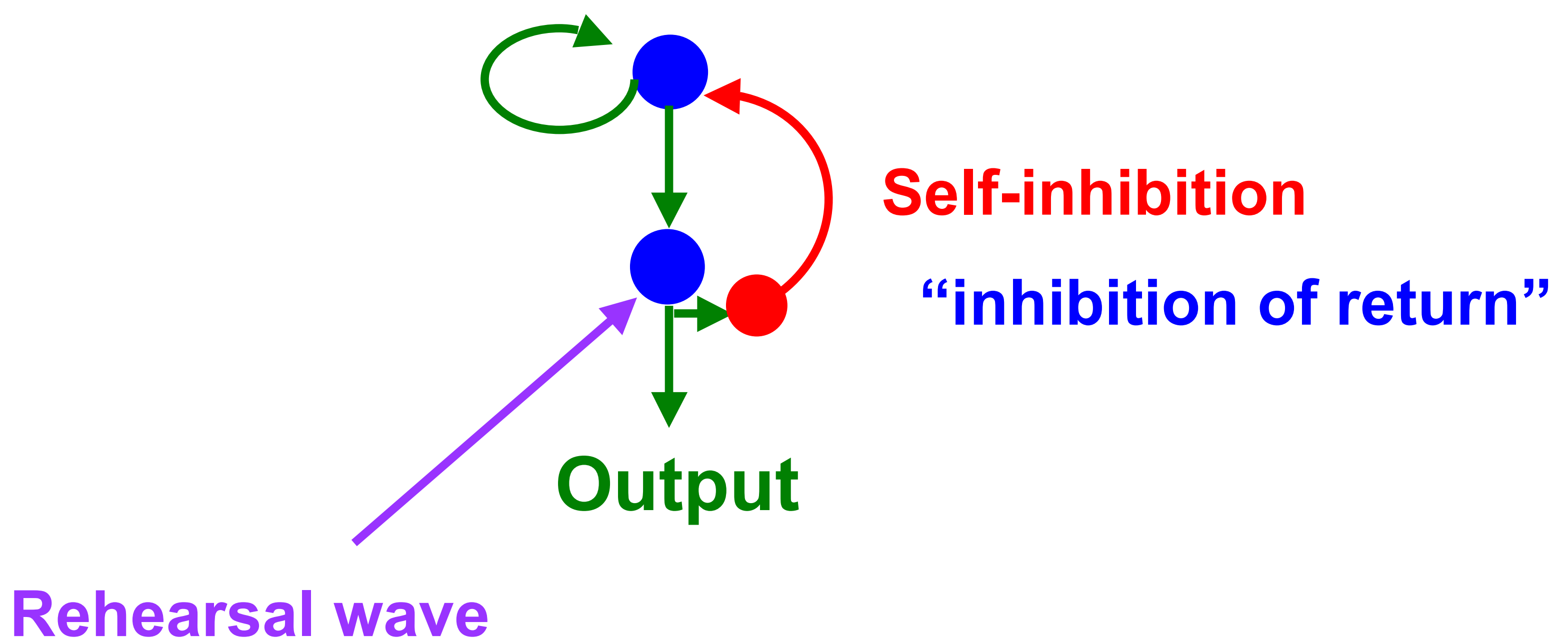
4. Read-out by nonspecific rehearsal wave



Largest activity is the first out

ITEM AND ORDER WORKING MEMORIES

5. STM reset: Self-inhibition prevents perseveration



ITEM AND ORDER WM EXPLAINS ERROR LATENCY DATA

Abstract: "Several competing theories of short-term memory can explain serial recall performance at a quantitative level. However, most theories to date have not been applied to the accompanying pattern of response latencies, thus ignoring a rich and highly diagnostic aspect of performance. This article explores and tests the *error latency* predictions of four alternative mechanisms for the representation of serial order. Data from three experiments show that latency is a negative function of transposition displacement, such that list items that are reported too soon (ahead of their correct serial position) are recalled more slowly than items that are reported too late. We show by simulation that these data rule out three of the four representational mechanisms. The data support the notion that serial order is represented by a *primacy gradient* that is accompanied by *suppression of recalled items*."

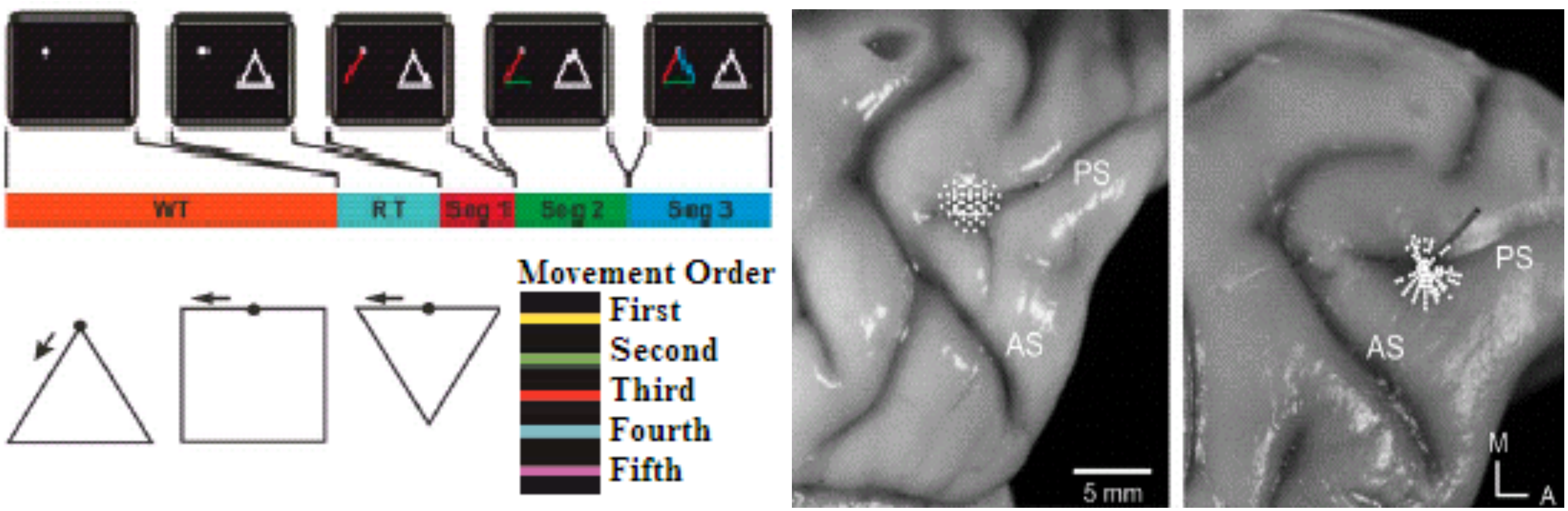
Farrell, S. and Lewandowsky, S. (2004). Modelling transposition latencies: Constraints for theories of serial order memory. *Journal of Memory and Language*, 51: 115-135.

NEUROPHYSIOLOGY OF SEQUENTIAL COPYING

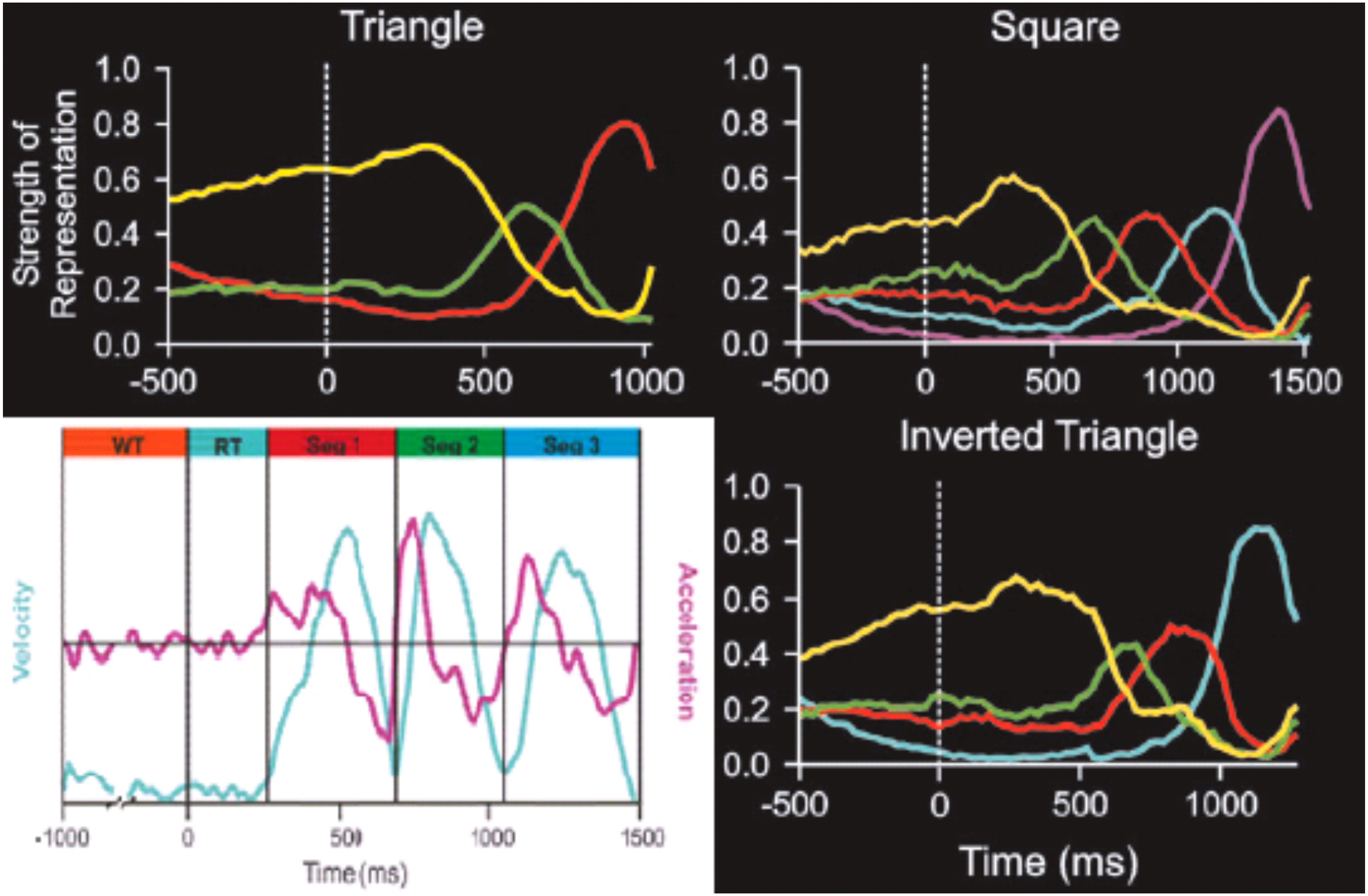
First neurophysiological support for the working memory prediction in Grossberg (1978):

Extra-cellular recording in macaque peri-principalis region during joystick controlled copying

Averbeck, Chafee, Crowe & Georgopoulos (2002, 2003a, 2003b)

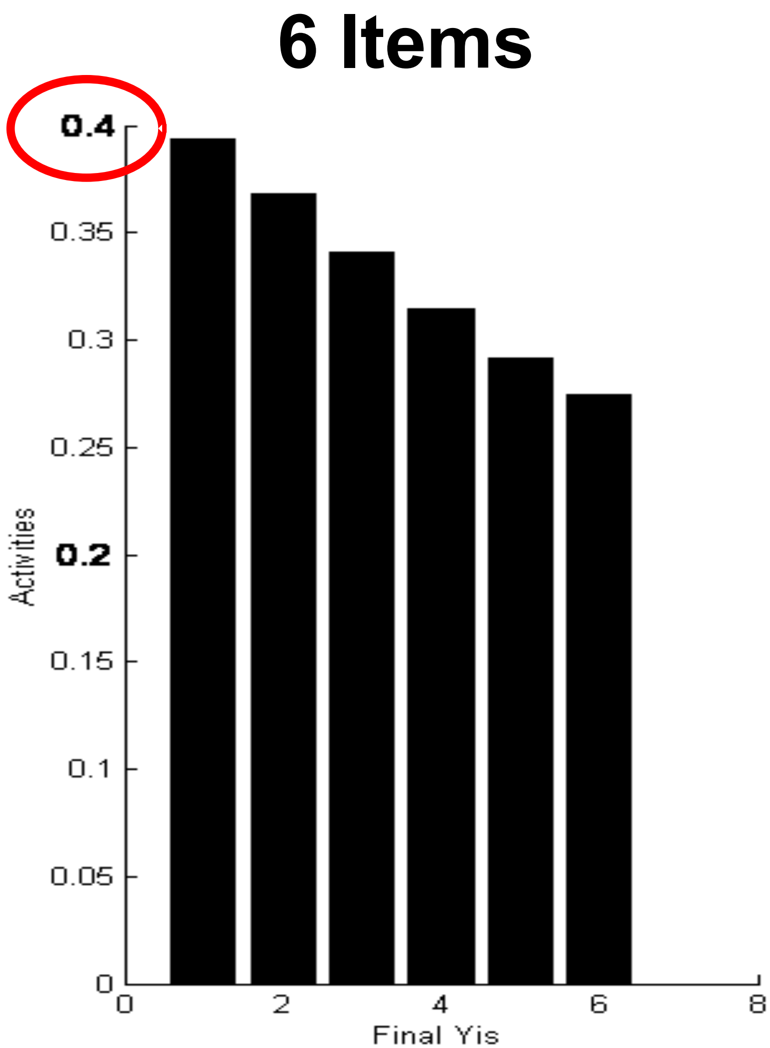


NEUROPHYSIOLOGY OF SEQUENTIAL COPYING

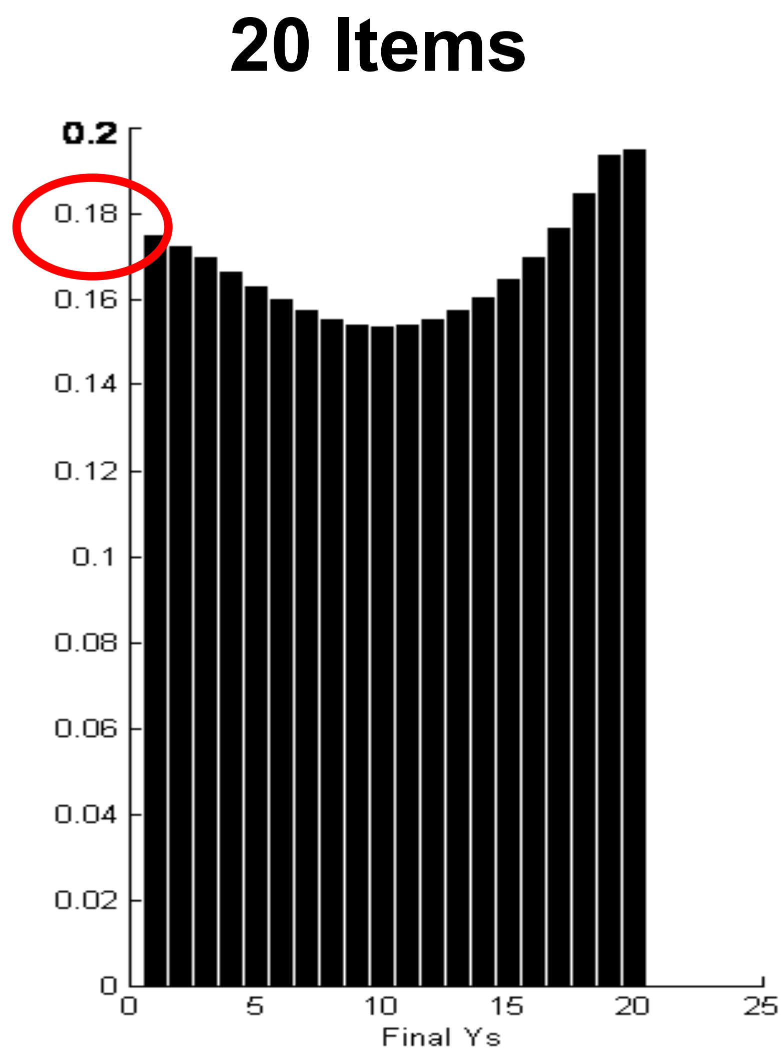


PRIMACY BECOMES BOW AS MORE ITEMS STORED

PRIMACY GRADIENT



BOWED GRADIENT

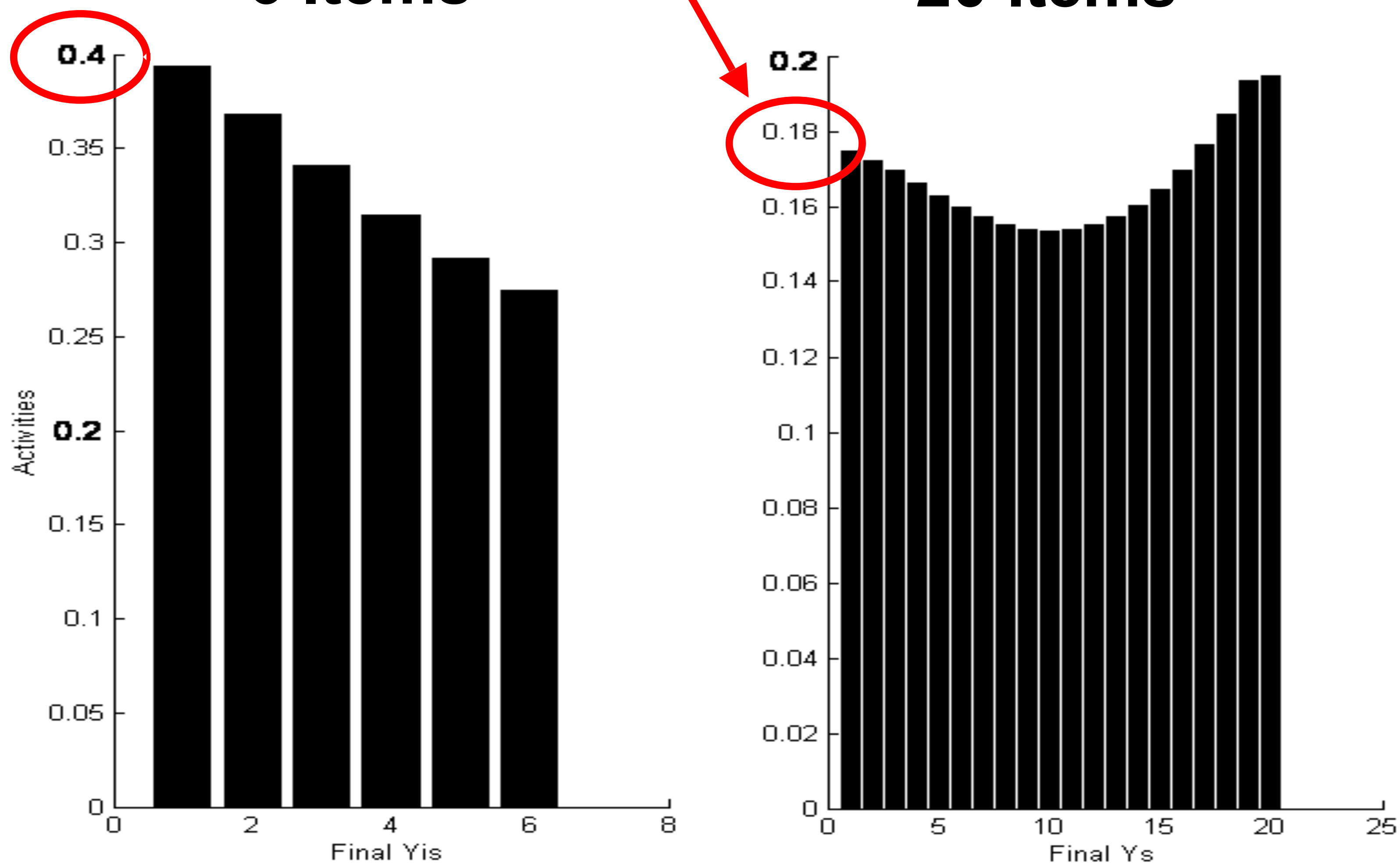


PRIMACY BECOMES BOW AS MORE ITEMS STORED

PRIMACY GRADIENT **BOWED GRADIENT**

Total activity tends to NORMALIZE: upper bound on active cells

6 Items **20 Items**



BOUNDED RATIONALITY

STABILITY of temporal order in LTM
implies non-veridical storage
of temporal order of long lists in STM

Limits the CAPACITY of working memory
and causes BOUNDED RATIONALITY (Simon, 1957)

Adaptive function of this limitation:
ability to learn and stably remember event sequences!

Classify distributed information processing and working memory storage by FEEDBACK networks

Grossberg, 1973+

COMPETITIVE FEEDBACK NETS

Is this a rich enough framework?

It's TOO BIG! Smale, 1976

An arbitrary n-dimensional autonomous system of ODEs

can be embedded in an

(n+1)-dimensional competitive system of ODEs

COMPETITIVE AND COOPERATIVE SYSTEMS

$$\frac{dx_i}{dt} = f_i(x_1. x_2,\ldots,x_n)\ ,\ i = 1,2,\ldots,n$$

Competitive System: $$\frac{\partial f_i}{\partial x_j} \leq 0,\ i \neq j$$

Cooperative System: $$\frac{\partial f_i}{\partial x_j} \geq 0,\ i \neq j$$

Cooperative effects can occur WITHIN a population in a competitive system; e.g., the on-center

COMPETITIVE FEEDBACK NETS

Competitive systems can do EVERYTHING!

IDENTIFY and CLASSIFY the the much smaller class of competitive systems that were selected by evolution!

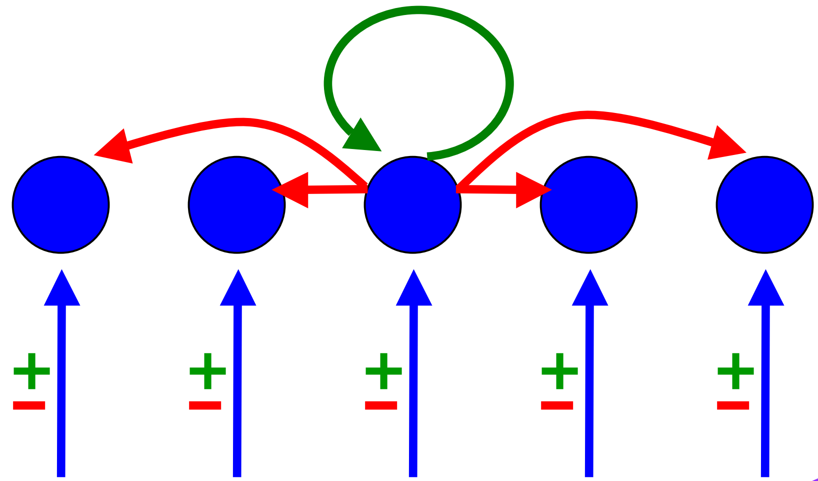
My mathematical articles in the 1970's and 1980's began this task

Introduced new mathematical methods

Discovered and classified many interesting properties

….lots more needs to be done!

SHORT TERM MEMORY



Solve
Noise-Saturation
Dilemma

$$\frac{d}{dt}x_i = -Ax_i + (B - x_i)[I_i + f(x_i)] - X_i\left[J_i + \sum_{j \neq i} f(x_j)\right]$$

How does the choice of feedback signal function?

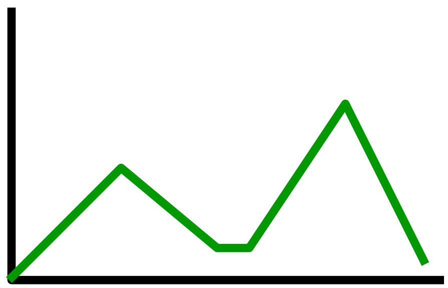
$$x_i \longrightarrow f(x_i)$$

influence pattern transformation and memory storage?

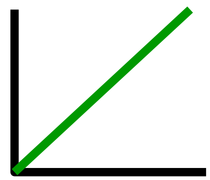
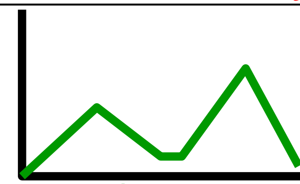
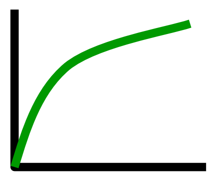
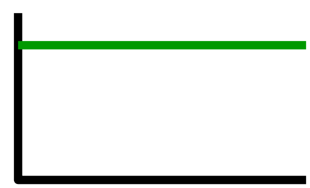
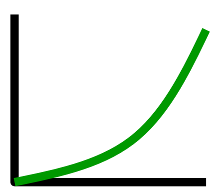
NONLINEAR SIGNALING AND CHOICE IN COOPERATIVE-COMPETITIVE NETS

Grossberg, 1973, Studies in Applied Math

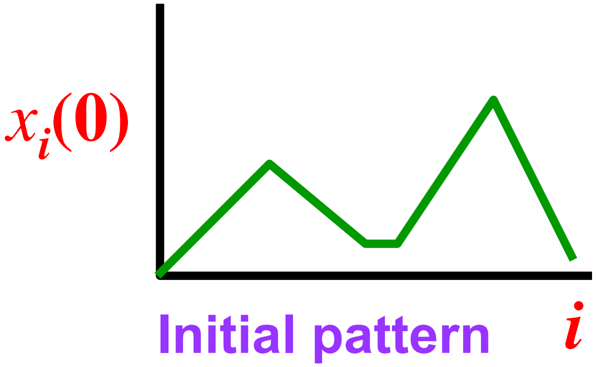
$x_i(0)$

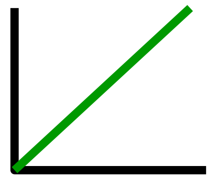
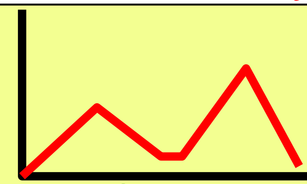
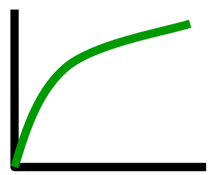
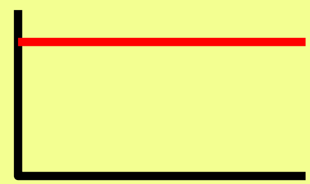
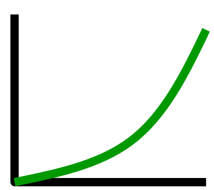


Initial pattern i

	f	$X_i(\infty) = \dfrac{x_i(\infty)}{\sum_j x_j(\infty)}$	$x(\infty) = \sum_j x_j(\infty)$
	 Linear	 ✓ Perfect storage of any pattern (∞)	Amplifies noise (or no storage) ✗
Nonlinear	 Slower-than-linear	 ✗ Saturates	Amplifies noise ✗
Nonlinear	 Faster-than-linear	 ? Chooses max Winner-take-all Bayesian Categorical perception	Suppresses noise ✓ Normalizes total activity Quantizes total activity Finite state machine

"POLITICAL" INTERPRETATION



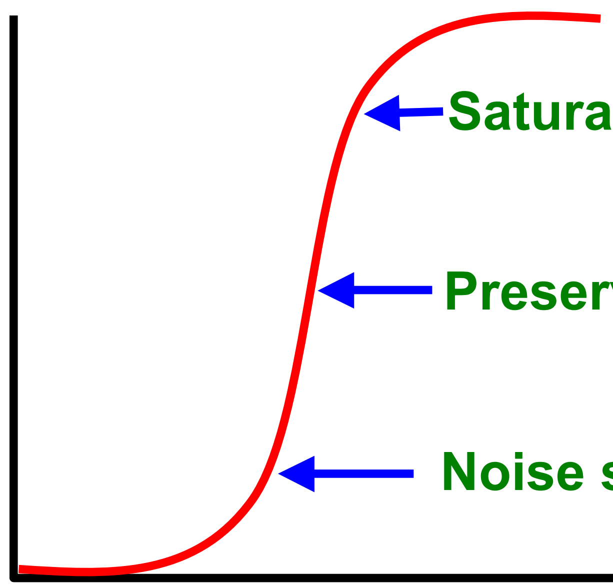
	f	$X_i(\infty) = \dfrac{x_i(\infty)}{\Sigma_j x_j(\infty)}$	$x(\infty) = \Sigma_j x_j(\infty)$
DEMOCRACY	 Linear	 Perfect storage of any pattern (∞)	Amplifies noise (or no storage)
SOCIALISM	 Slower-than-linear	 Saturates	Amplifies noise
TOTALITARIANISM	 Faster-than-linear	 Chooses max Winner-take-all Bayesian Categorical perception	Suppresses noise Normalizes total activity Quantizes total activity Finite state machine

NOISE SUPPRESSION WITHOUT WTA CHOICE?

Is winner-take-all the only way to suppress noise?

e.g., suppress all but the
most salient feature of an object

SIGMOID SIGNAL FUNCTION
Distributed Processing and Noise Suppression



HYBRID SIGNAL:

Saturates pattern: every signal is bounded
Slower-than-linear

Preserves pattern and normalizes
Approximately linear

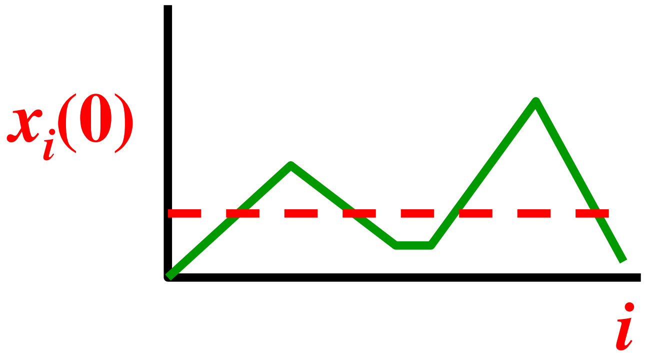
Noise suppression and contrast-enhancement
Faster-than-linear

The faster-than-linear part suppresses noise and starts to contrast-enhance the pattern

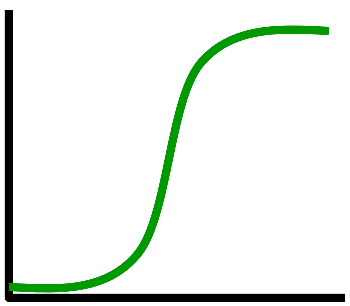
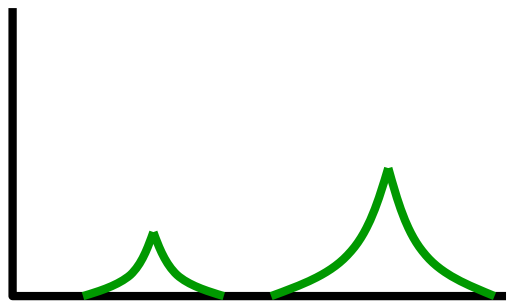
As total activity normalizes, the approximately linear range is reached and tends to store the partially contrast-enhanced pattern

SIGMOID SIGNAL FUNCTION

Distributed processing and noise suppression



Quenching Threshold

f	$X_i(\infty)$	$x(\infty)$
 Sigmoid	 √ Tunable filter Stores infinitely many contrast-enhanced patterns	Suppresses noise √

The QT can be dynamically tuned; e.g., pay attention better after unexpected event; choose max…

COMPETITION AND DECISION

Grossberg, 1977+

$$\frac{dx_i}{dt} = f_i(x), \quad \frac{\partial f_i}{\partial x_j}(x) \le 0, \quad i \ne j, \quad x = (x_1, x_2, ..., x_n) \in R^n$$

How to classify biologically useful competitive systems?

Keep track of who is winning!

Every competitive system induces a decision scheme

Embed series of discrete decisions into continuous system

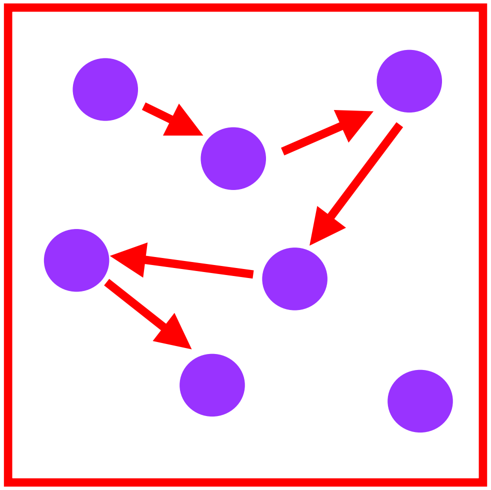
Defines "decision hypersurfaces" far from equilibrium

EVERY COMPETITIVE SYSTEM INDUCES A DECISION SCHEME

Gedanken Petri Dish

Track where are the most noticeable changes?

The system JUMPS when a new winner emerges



JUMPS = local decisions

Every competitive system has a Liapunov Functional!

$$L(x_t) = \int_0^t \max_i f_i(x(v))dv$$

This functional measures the energy that keeps the states moving through their decisions

EVERY COMPETITIVE SYSTEM INDUCES A DECISION SCHEME

$$\frac{dx_i}{dt} = f_i(x), \quad \frac{\partial f_i}{\partial x_j}(x) \le 0, \quad i \ne j, \quad x = (x_1, x_2, \ldots, x_n) \in R^n$$

Write:

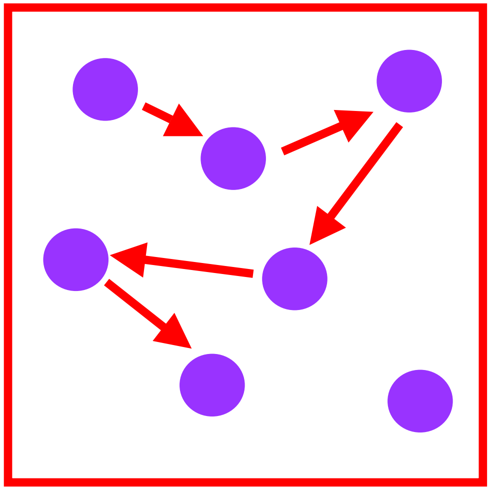
$$\frac{dx_i}{dt} = a_i(x_i) M_i(x)$$

$a_i(x_i) \ge 0$ **Amplification function**

$\frac{\partial M_i(x)}{\partial x_j} \le 0$ **Competitive balance**

e.g., Volterra Lotka equations:

$$\frac{dx_i}{dt} = x_i \left(A_i - \sum_{k=1}^{n} B_{ik} x_k \right)$$



Gedanken Petri Dish

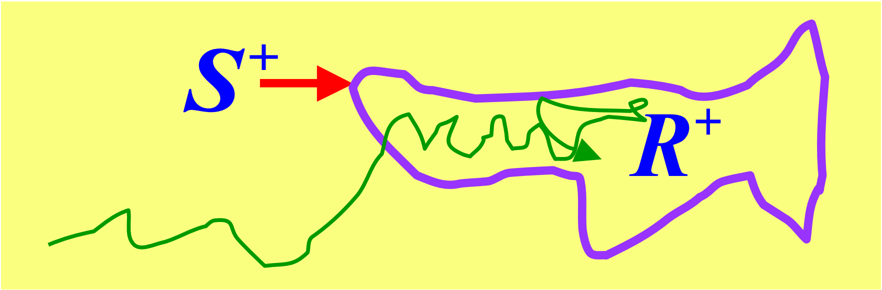
TRACK THE WINNER: POSITIVE IGNITION

$$\frac{dx_i}{dt} = a_i M_i, \quad a_i \geq 0, \quad M^+(x) = \max_k M_k(x)$$

POSITIVE IGNITION: If $M^+(x(T)) \geq 0$ then $M^+(x(t)) \geq 0, \; t \geq T$

If competition ignites, then some activity always increases

POSITIVELY INVARIANT REGION: $R^+ = \{x \in R : M^+(x) \geq 0\}$



COMPETITION THRESHOLD: $S^+ = \{x \in R : M^+(x) = 0\}$

$$x \notin R^+ \quad \Rightarrow \quad M^+(x) < 0 \quad \Rightarrow \quad \forall \frac{dx_i}{dt} \leq 0 \quad \Rightarrow \quad x(t) \to x(\infty)$$

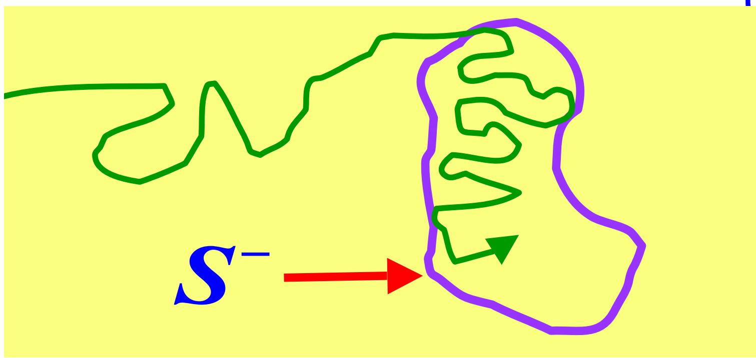
TRACK THE WINNER: NEGATIVE IGNITION

$$\frac{dx_i}{dt} = a_i M_i, \quad a_i \geq 0, \quad M^-(x) = \min_k M_k(x)$$

NEGATIVE IGNITION: If $M^-(x(T)) \leq 0$ then $M^-(x(t)) \leq 0, \ t \geq T$

If competition ignites, then some activity always decreases

POSITIVELY INVARIANT REGION: $R^- = \{x \in R : M^-(x) \leq 0\}$



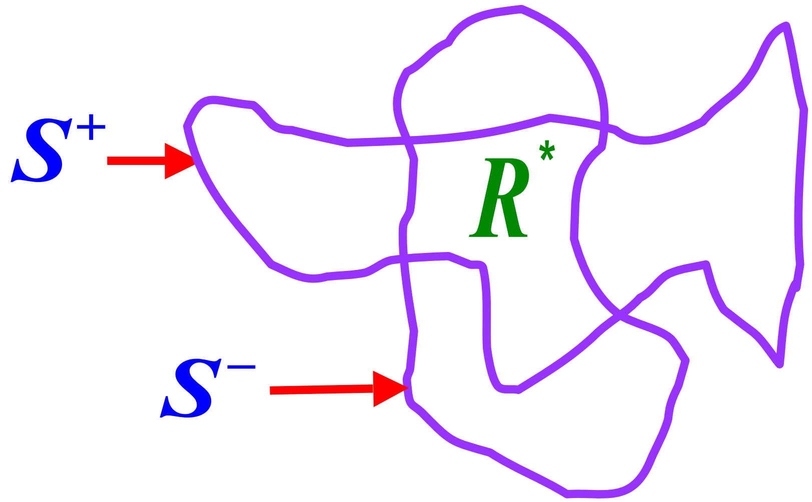
COMPETITION THRESHOLD: $S^- = \{x \in R : M^-(x) = 0\}$

$$x \notin R^- \quad \Rightarrow \quad M^-(x) > 0 \quad \Rightarrow \quad \forall \frac{dx_i}{dt} \geq 0 \quad \Rightarrow \quad x(t) \to x(\infty)$$

TRACK THE WINNER

All variables converge outside the invariant region

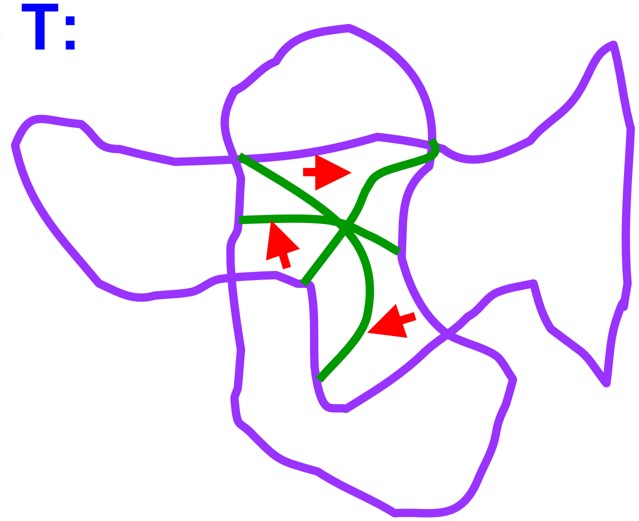
$$R^* = R^+ \cap R^-$$



Inside R^* keep track of the maximal variable

Who is winning!

JUMP ( ) from i to j at time T:



Classify all possible jumps to prove sustained oscillations (jump cycles) or convergence (no cycles)

VOTING PARADOX

Condorcet, Arrow

In pairwise elections: **V_1 beats V_2**

V_2 beats V_3

V_3 beats V_1

What happens when they all compete?

***Intransitive* global contradiction: sustained oscillations**

May and Leonard (1975)

$$\dot{x}_1 = x_1(1 - x_1 - \alpha x_2 - \beta x_3)$$

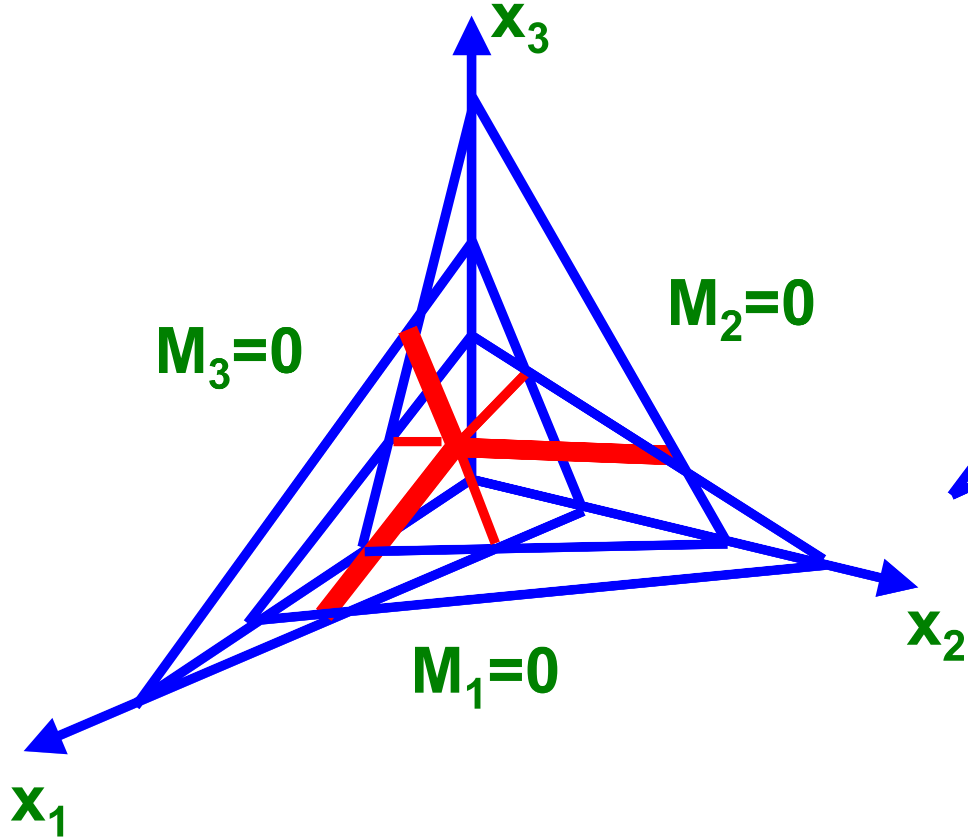
$$\dot{x}_2 = x_2(1 - \beta x_1 - x_2 - \alpha x_3)$$

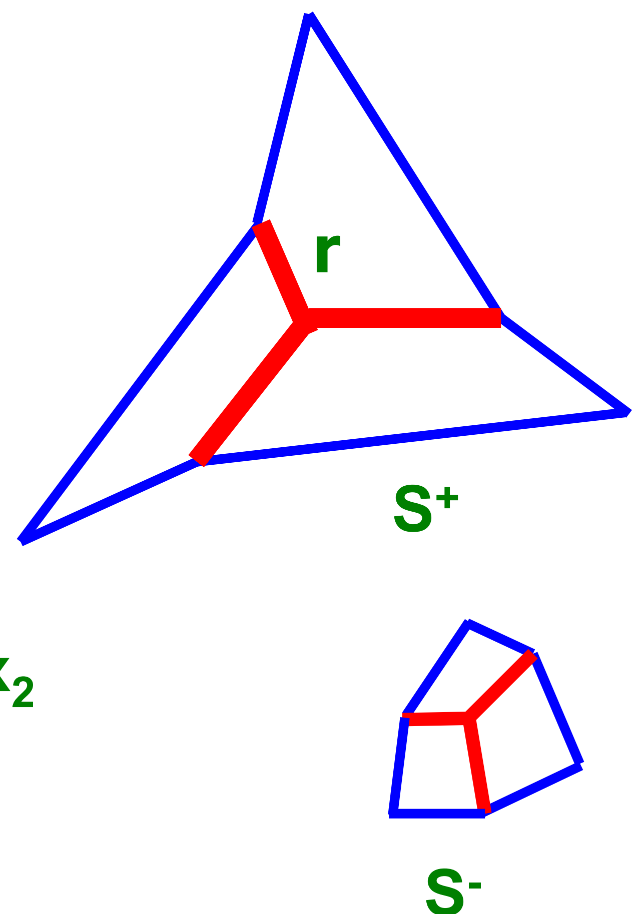
$$\dot{x}_3 = x_3(1 - \alpha x_1 - \beta x_2 - x_3)$$

$$\beta > 1 > \alpha, \alpha + \beta \geq 2$$

IGNITION SURFACES IN VOTING PARADOX

Grossberg, 1978

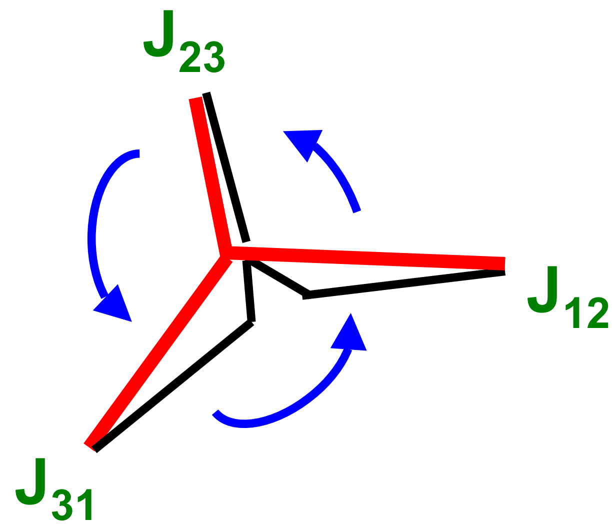




$$\rho = \frac{1}{1+2+\beta}(1,1,1)$$

JUMP SETS IN VOTING PARADOX

Jump sets: $v_1 \rightarrow v_2 \rightarrow v_3 \rightarrow v_1$.



Generate infinitely many jumps:

Given any $x(0) \in R_+^3$,

if $\int_0^\infty M^+\left(x(t)\right)dt = \infty$,

then there exist infinitely many jumps

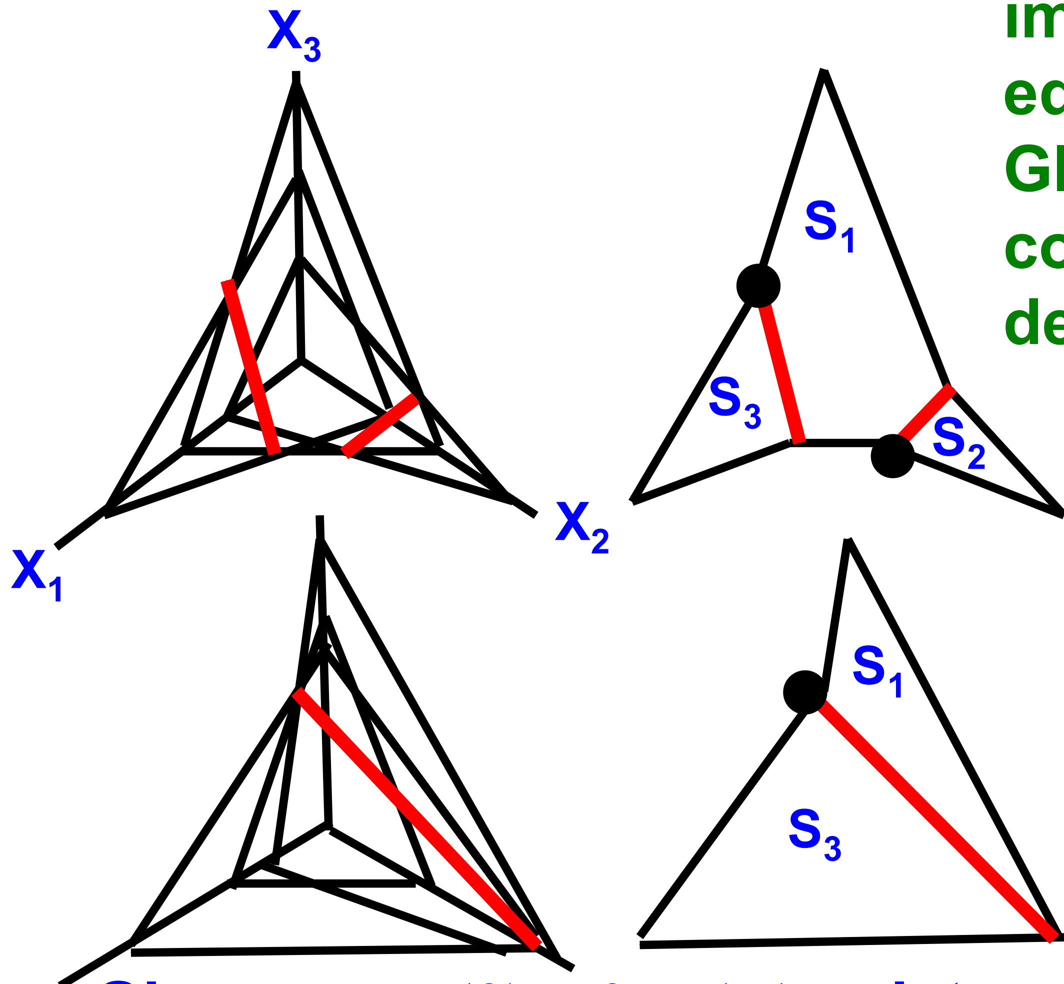
i.e., let $L^+(x_t) = \int_0^t M^+(x(v))dv$

$L^+(x_\infty) = \infty$ imply ∞ jumps

GLOBAL PATTERN FORMATION

e.g., 3-dimensional Volterra-Lotka:

No cycle on S+ implies global equilibrium: Globally consistent decision scheme



Given any $x(0) \geq 0$, $x(\infty)$ exists.

Since $\int_0^\infty M^+(x(t))dt < \infty$ and $M^+ \geq 0$,

$$M^+(x(\infty)) = 0.$$

INVISIBLE HAND:

Price stability and balanced books despite firm self-interest

An economic example as a special case of a general principle of competitive dynamics

**"By preferring the support of domestic to that of foreign industry,
he intends only his own security; and by directing that industry
in such a manner as its produce may be of the greatest value,
he intends only his own gain, and he is in this, as in many other cases,
led by an invisible hand to promote an end
which was no part of his intention.
Nor is it always the worse for the society that it was not part of it.
By pursuing his own interest he frequently promotes that of the society
more effectually than when he really intends to promote it."**

Smith, The Wealth of Nations, 1776

An emergent property of a PROPERLY DESIGNED competitive market

**Not true in general: ANYTHING is possible in a competitive system!
"free market"?!**

PROBLEM OF COMMUNICATION (LEIBNIZ)

How to get global consensus when all individuals speak in different languages, or are limited by local ignorance?

Complexity without chaos

Arbitrary individual differences in arbitrarily many individuals can be reconciled to yield global consensus if there exist proper communal understandings

A sufficient condition:
Competitive feedback is absolutely stable if an adaptation level exists

GLOBAL PATTERN FORMATION: ABC THEOREM

Grossberg, J. Math. Analy. & Applics., 1978, 66, 470.

$$\dot{x}_i = a_i(x)\left[b_i(x_i) - c(x)\right],$$

$$i = 1,2,\ldots,n.$$

n can be any number of units: cells, firms

Individual differences (essentially arbitrary):

$a_i(x)$ amplification $a_i \geq 0$

$b_i(x_i)$ signal

Competitive adaptation level $c(x) : \dfrac{\partial c}{\partial x_k} \geq 0.$

Then given any $x(0) \geq 0$,

$x(\infty) = \lim_{t \to \infty} x(t)$ exists.

VOLTERRA-LOTKA
WITH STATISTICALLY INDEPENDENT INTERACTIONS

$$\dot{x}_i = A_i(x)\left[1 - \sum_{k=1}^{n} B_{ik}(x) f_k(x_k)\right]$$

$$B_{ik}(x) = g_i(x_i) h_k(x_k)$$

$$\dot{x}_i = a_i(x)\left[b_i(x_i) - c(x)\right]$$

$$a_i(x) = A_i(x) g_i(x_i)$$

$$b_i(x_i) = g_i^{-1}(x_i)$$

$$c(x) = \sum_{k=1}^{n} f_k(x_k) h_k(x_k).$$

contrast the voting paradox

complementarity principle for competitive systems

WORKING MEMORY STORAGE

Recurrent narrow on-center, broad off-surround net

$$\frac{dx_i}{dx} = -A_i x_i + \left(B_i - C_i x_i\right)\left[I_i + f_i\left(x_i\right)\right] - \left(C_i x_i + D_i\right)\left[J_i + \sum_{k \neq i} f_k\left(x_k\right)\right]$$

This can be written as:

$$\frac{dx_i}{dt} = a_i\left(x\right)\left[b_i\left(x_i\right) - c\left(x\right)\right]$$

where

$$a_i\left(x\right) = C_i x_i$$

$$b_i\left(x_i\right) = -A_i C_i^{-1} - I_i J_i - x_i^{-1}\left[A_i D_i C_i^{-1} + \left(B_i + D_i\right)\left(I_i + f_i\left(\frac{x_i - D_i}{C_i}\right)\right)\right]$$

$$c\left(x\right) = \sum_{k=1}^{n} f_k\left(\frac{x_k - D_k}{C_k}\right)$$

ADAPTATION LEVEL

Macromolecular evolution

Quasi-species; Eigen, Naturwissenschaften, 1978, 65, 7-41

$$\dot{x}_i = x_i\left[k_i x_i^{P-1} - C_0^{-1}\sum_{j=1}^{n} k_j x_j^{P}\right]$$

$$i = 1,2,\ldots,n;\ p = 0,1,2.$$

Who Wins?

Macromolecular selection

e.g. Lacker's equations for selection during ovulation

THE INVISIBLE HAND

Price stability and balanced books despite firm self-interest

x_i = production rate of i^{th} firm, $i = 1,2,\ldots,n$; n arbitrary

$P(x)$ = publicly known market price of the item

Competition: $$\frac{\partial P}{\partial x_i} \leq 0,\ i = 1,2,\ldots,n.$$

$c_i(x_i)$ = costs + investments + savings per item in i^{th} firm

$$\dot{x}_i = a_i(x_i)\underbrace{\left[P(x) - c_i(x_i)\right]}_{\text{profit per item}}$$

Only the market price P(x) is known by all firms

IF each firm's production rate is sensitive to its expected net profit using its unique and private internal strategy

THEN price stabilizes and each firm balances its books

THE INVISIBLE HAND

Price stability and balanced books despite firm self-interest

x_i = production rate of i^{th} firm, $i = 1,2,\ldots,n$; n arbitrary

$P(x)$ = publicly known market price of the item

Competition: $$\frac{\partial P}{\partial x_i} \leq 0,\ i = 1,2,...,n.$$

$c_i(x_i)$ = costs + investments + savings per item to i^{th} firm

$$\dot{x}_i = a_i(x_i)\underbrace{\left[P(x) - c_i(x_i)\right]}_{\text{profit per item}}$$

Only the market price P(x) is known by all firms

IF each firm's production rate is sensitive to its expected net profit using its unique and private internal strategy

THEN price stabilizes and each firm balances its books

Does not say who gets rich and who goes out of business

DECISION-MAKING UNDER RISK

PROSPECT THEORY

AFFECTIVE BALANCE

A SMALL NUMBER OF DYNAMICAL EQUATIONS

Activation, or short-term memory, equations

Learning, or long-term memory, equations

Habituation, or medium-term memory, equations

PROSPECT THEORY
decision making under risk

Kahneman & Tversky, Econometrika, 1979

Nobel Prize, 2002

A reaction to utility theory (Bernoulli, 1738) and axiomatic utility theory (von Neumann and Morgenstern, 1944) and the idea that humans always make rational choices

e.g., explains REFLECTION EFFECT

Choices involving gains tend to be risk averse

Choices involving losses tend to be risk taking

GAMBLER'S FALLACY

Shift in the amount of risk a decision maker will accept after a homogeneous sequence of losses (or gains) relative to the risk accepted after a mixed sequence with both losses and gains

FRAMING EFFECT

Preferences depend on whether outcomes of choices are stated positively or negatively

LIMITATIONS OF PROSPECT THEORY
decision making under risk

Kahneman & Tversky, Econometrika, 1979

Nobel Prize, 2002

1. Cannot explain all important decision making data

e.g., PREFERENCE REVERSALS

In binary choice situations, an individual may prefer an alternative that was judged to be worth less than the non-preferred alternative

e.g., when presented alone, choice A is worth $10 and
B is worth $8,
but during binary choice, B is preferred to A

2. Stated in FORMAL AXIOMS that are derived from data

MISSING LINK

How do irrational decisions arise from adaptive mechanisms that are selected by evolution?

What is their neural basis?

AFFECTIVE BALANCE THEORY

Grossberg & Gutowski, 1987, Psychological Review

Explains key data that Prospect Theory explains

Explains PREFERENCE REVERSALS also

Provides neural explanation of decision-making data:

Shows how adaptive cognitive-emotional mechanisms can generate irrational decisions when they are activated in certain environments

AFFECTIVE BALANCE THEORY

Grossberg & Gutowski, 1987, Psychological Review

Explains key data that Prospect Theory explains

Explains PREFERENCE REVERSALS also

Provides neural explanation of decision-making data

Shows how adaptive cognitive-emotional mechanisms can generate irrational decisions when they are activated in certain environments

Raises issues about VALUE

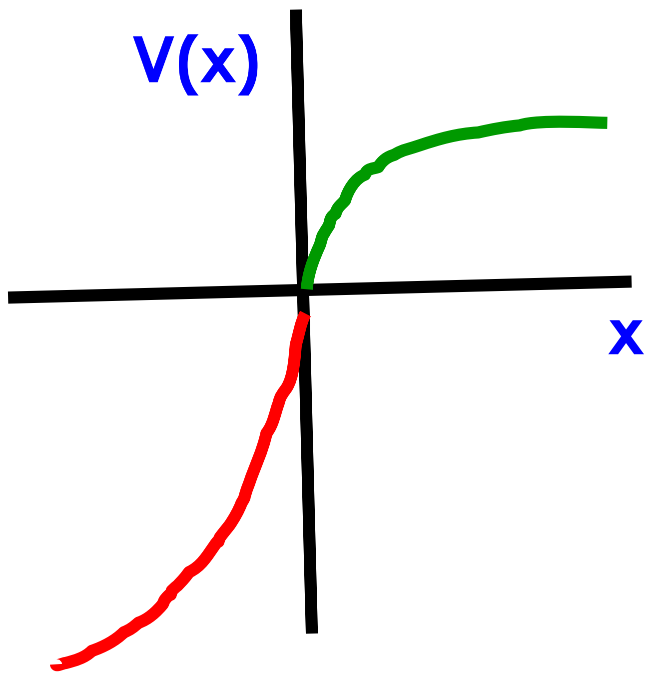
REWARD and PUNISHMENT

REINFORCEMENT LEARNING

PROSPECT THEORY

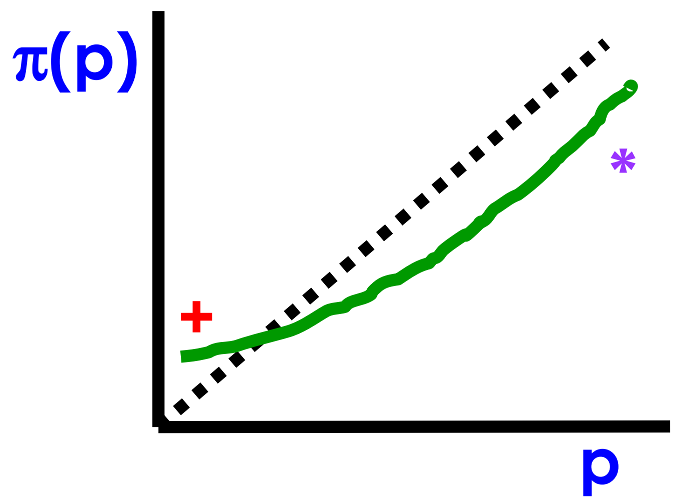
Value function V(x) converts event x into subjective value

- concave for positive changes or gains
- convex for negative changes or losses
- marginal value decreases with larger magnitudes
- steeper for losses than for gains



PROSPECT THEORY

Decision weight function π(p) converts event with probability p into a decision weight that multiplies value of a risky alternative



Subcertainty and subproportionality
e.g., small probabilities (+) are overweighted
large probabilities (*) are underweighted

PROSPECT THEORY

Integration rule $\pi(p)V(x)$ defines net contribution of event with probability p to overall value of the alternative

Choices are determined by which event has the biggest weighted sum

$$\pi(p_1)V(x_1) - \pi(p_2)V(x_2) > 0$$

AFFECTIVE BALANCE THEORY

Need to briefly review several topics

AFFECTIVE BALANCE THEORY

Need to briefly review several topics

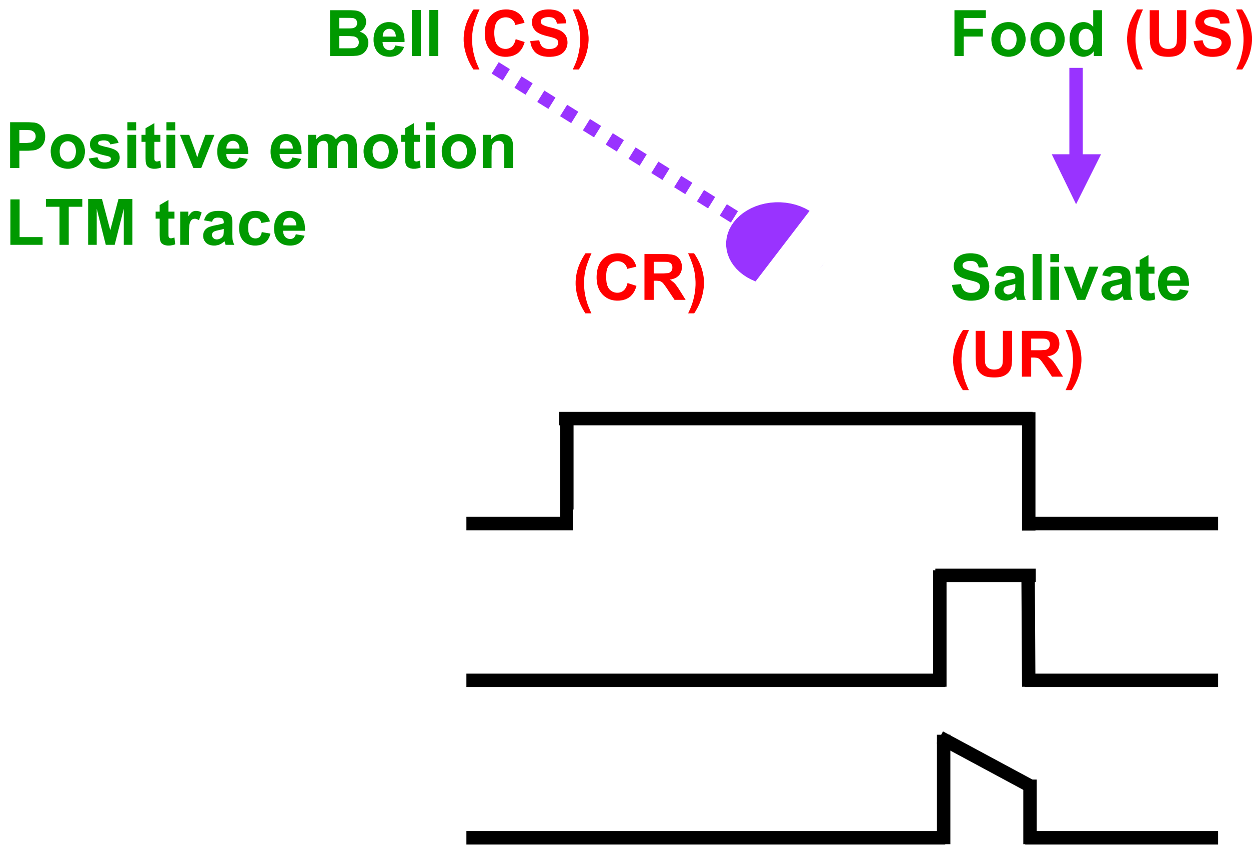
…with a very light touch!

Consider the simplest type of

COGNITIVE-EMOTIONAL LEARNING

CLASSICAL CONDITIONING

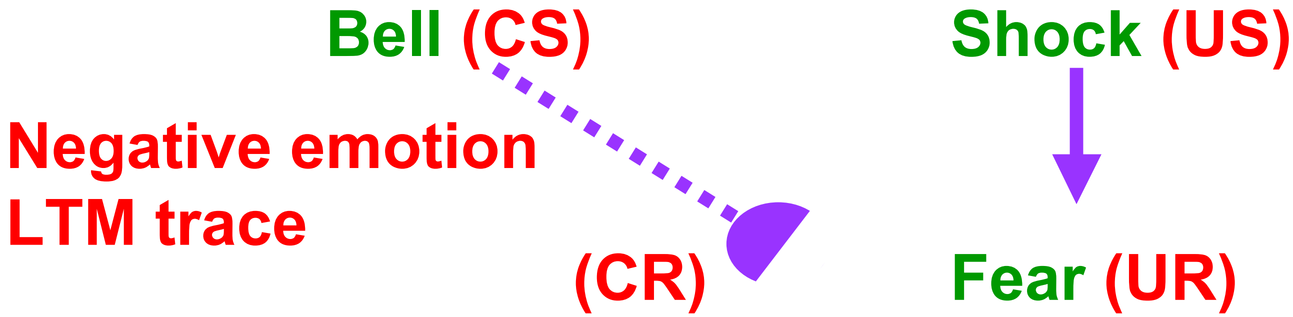
Nonstationary prediction

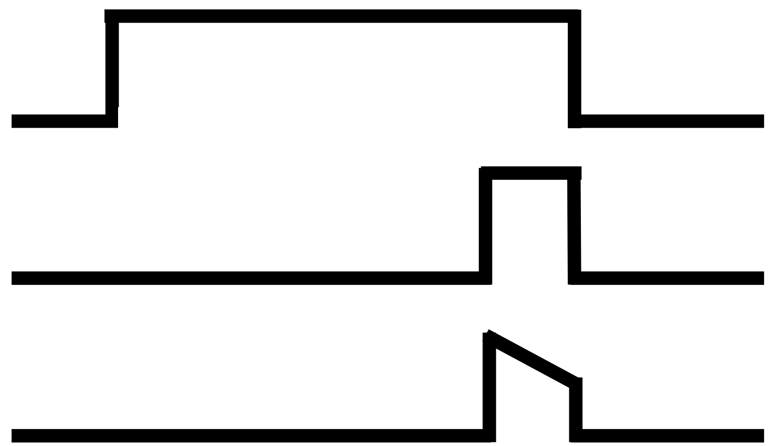


ASSOCIATIVE LEARNING

CLASSICAL CONDITIONING

Nonstationary prediction



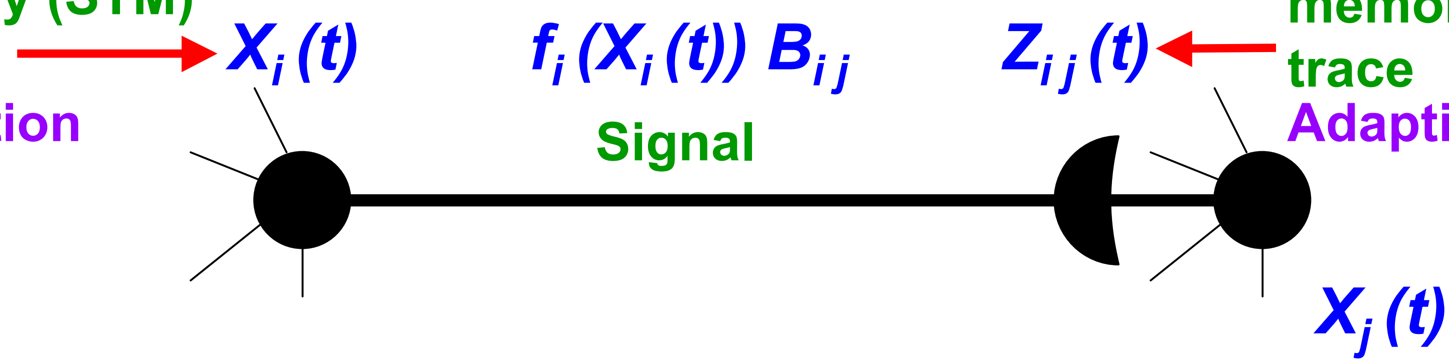


ASSOCIATIVE LEARNING

CONTINUOUS AND NONLINEAR

Grossberg, PNAS, 1967, 1968

Short-term memory (STM) trace
Activation



Long-term memory (LTM) trace
Adaptive weight

STM EQUATION

ADDITIVE MODEL

$$\frac{d}{dt}X_i = -A_iX_i + \sum_{j=1}^{n} f_j(X_j)B_{ji}Z_{ji}^{(+)} - \sum_{j=1}^{n} g_j(X_j)C_{ji}Z_{ji}^{(-)} + I_i$$

PASSIVE DECAY | POSITIVE FEEDBACK | NEGATIVE FEEDBACK | INPUT

Special case:

$$\frac{d}{dt}X_i = -A_iX_i + \sum_j f_j(X_j)Z_{ji} + I_i$$

LINKING PROSPECT THEORY TO AFFECTIVE BALANCE THEORY

$$\pi(p_1)V(x_1) \quad \text{vs.} \quad f(x_1)Z_1$$

Decision weight

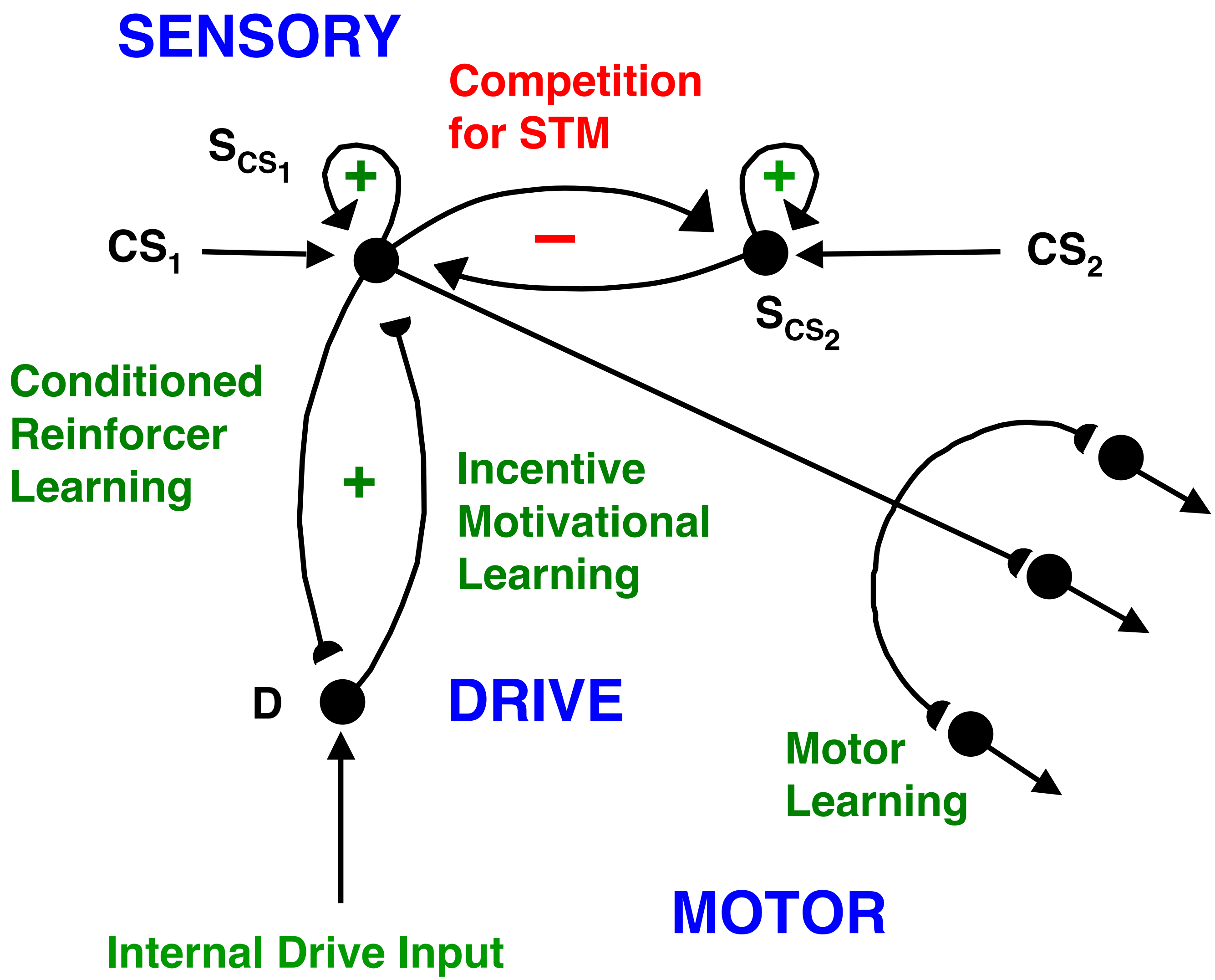
Value function

STM

LTM

3 TYPES OF REPRESENTATIONS AND LEARNING

Grossberg, 1971



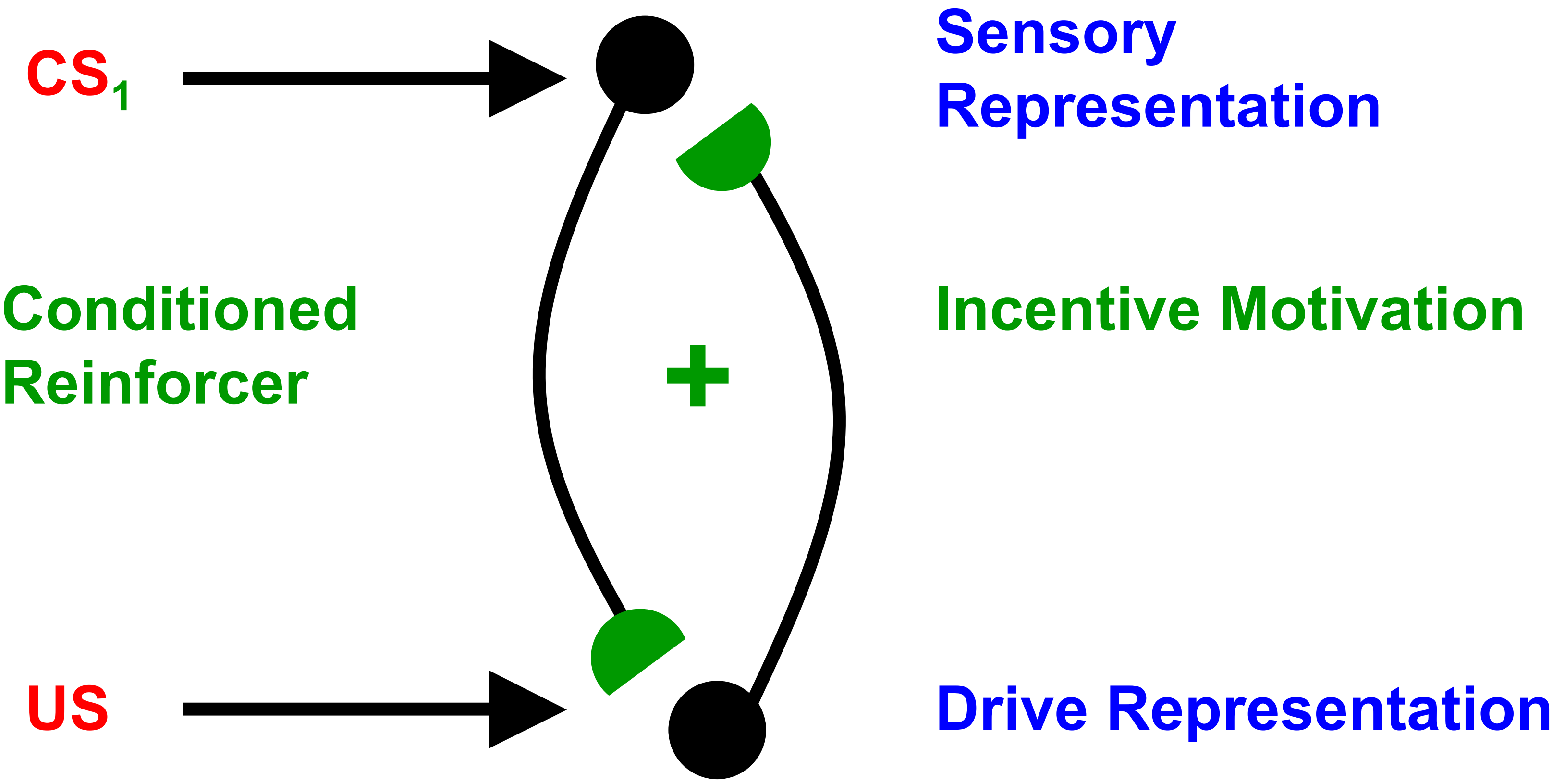
DRIVE REPRESENTATIONS

Sites where reinforcement and homeostatic inputs interact to generate emotional and motivational output signals

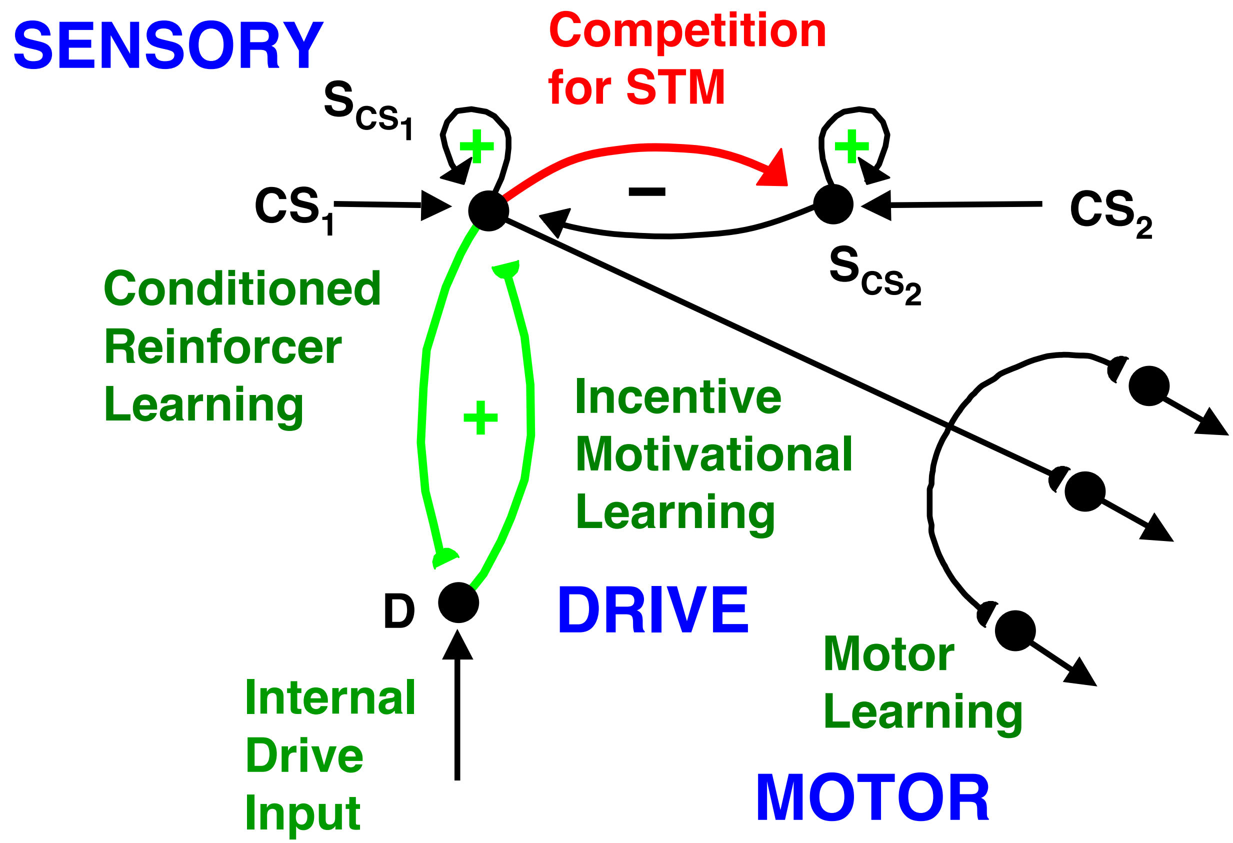
CONDITIONED REINFORCER and INCENTIVE MOTIVATIONAL LEARNING:

How Neutral Events Learn Value

CS_1 becomes a conditioned reinforcer by learning to activate a strong reinforcer-motivational (emotional) feedback pathway



LIMITED CAPACITY STM AND AFFECTIVE LTM

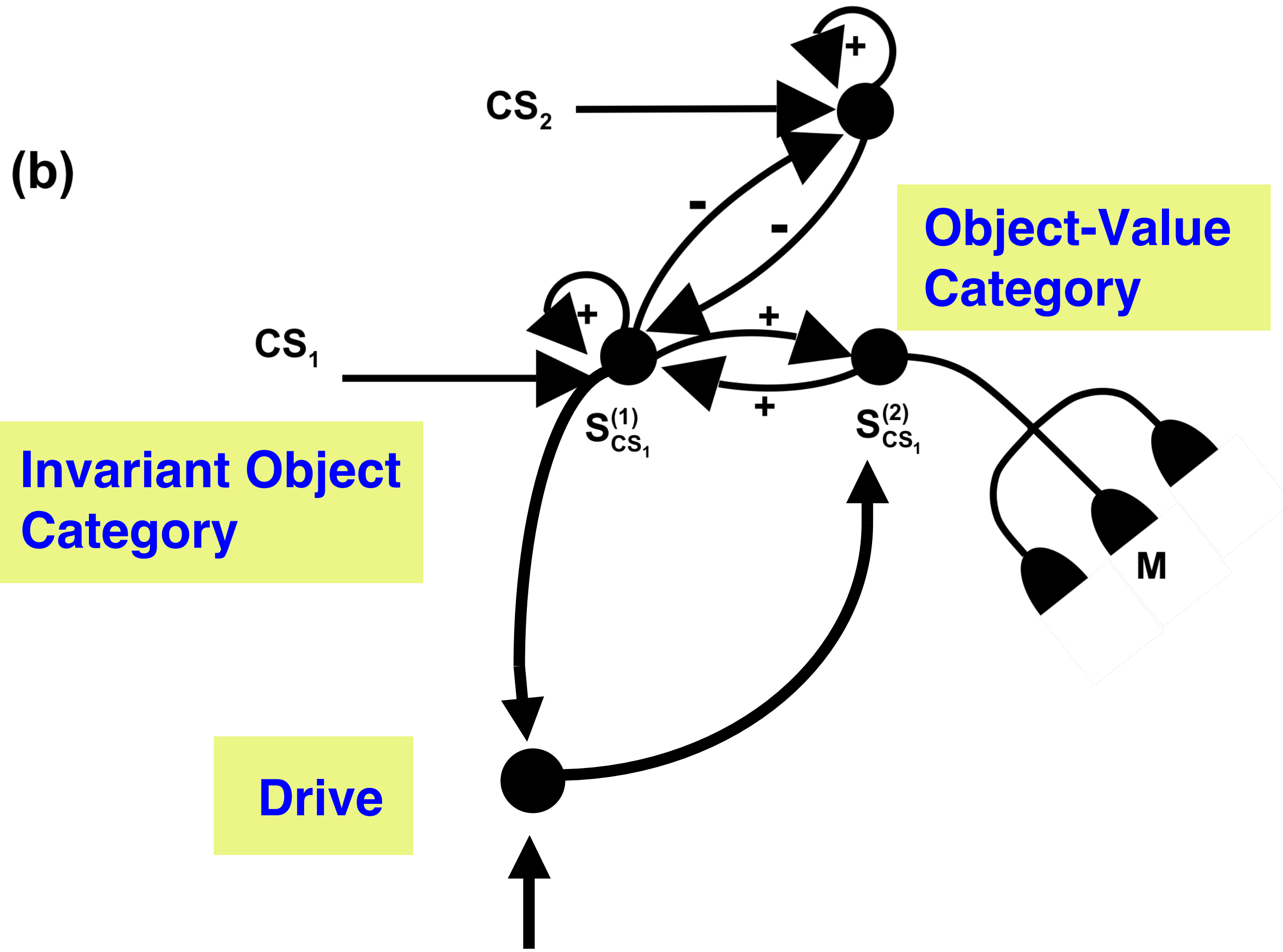


1. Sensory representations compete for LIMITED CAPACITY STM
2. Previously reinforced cues amplify their STM via POSITIVE FEEDBACK
3. Other cues lose STM via self-normalizing COMPETITION:

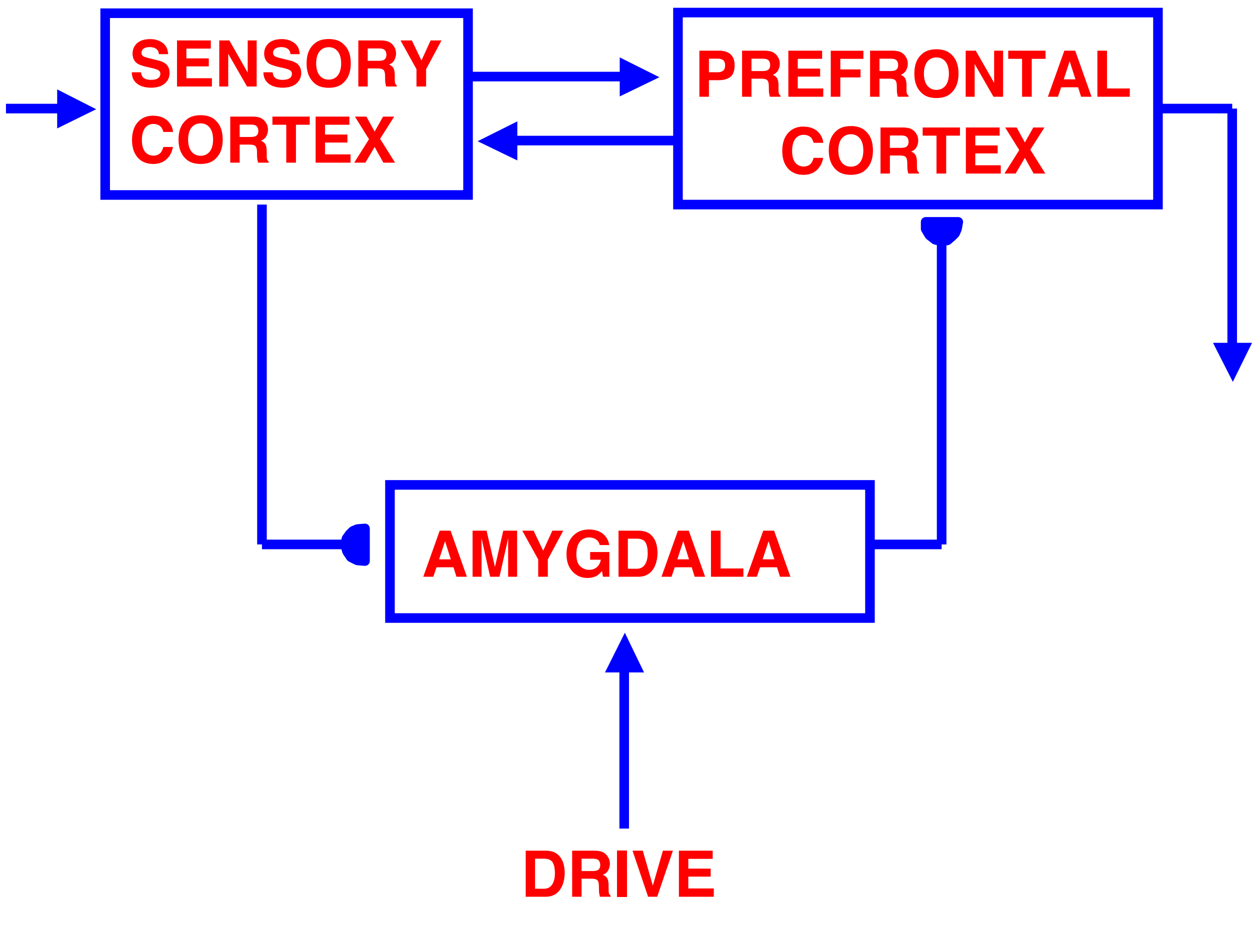
Pay attention to winners!

TWO SENSORY STAGES:
OBJECT-VALUE CATEGORIES

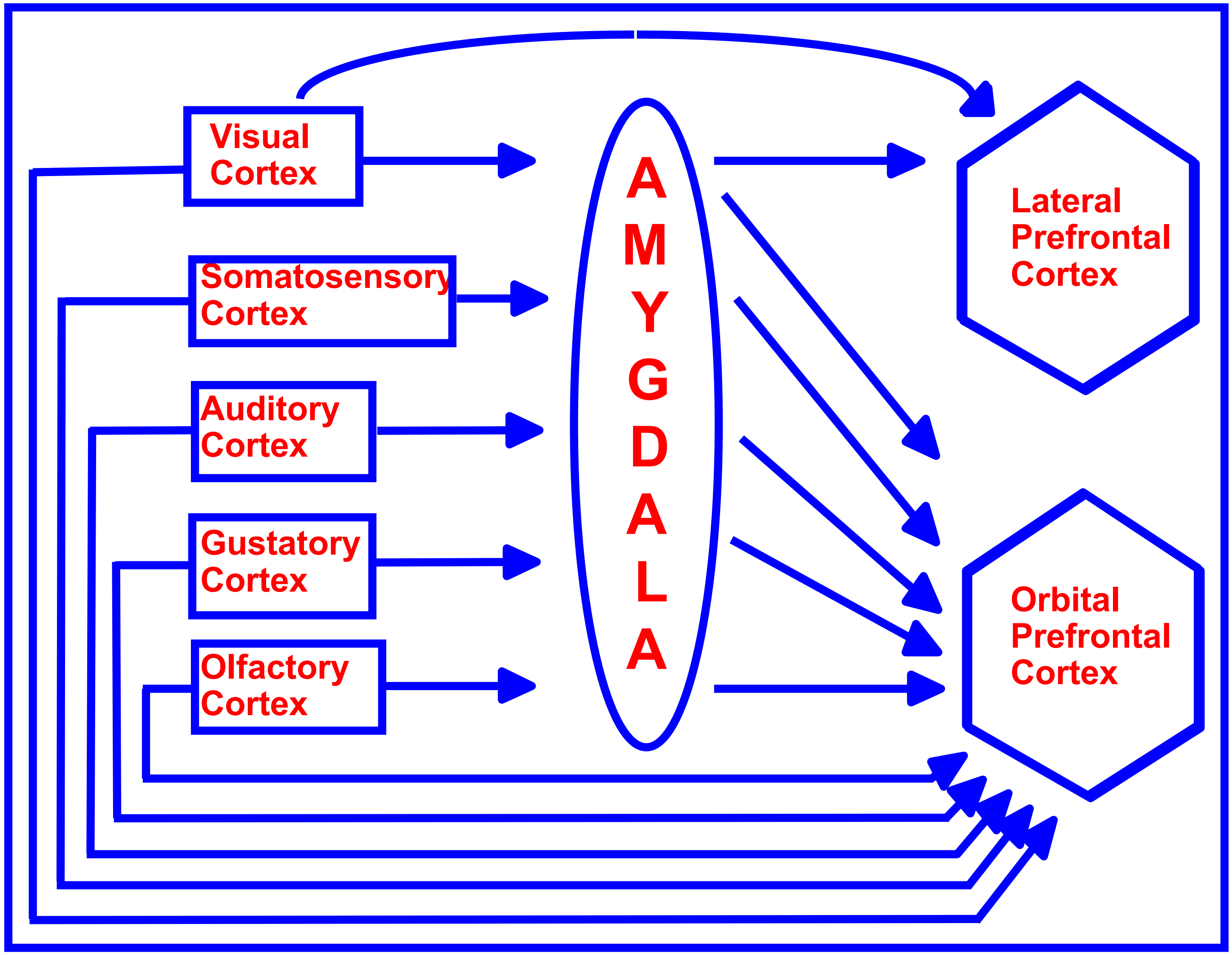
Object and value contingent release of actions



INTERPRETATION OF CogEM ANATOMY



COGNITIVE-EMOTIONAL ANATOMY



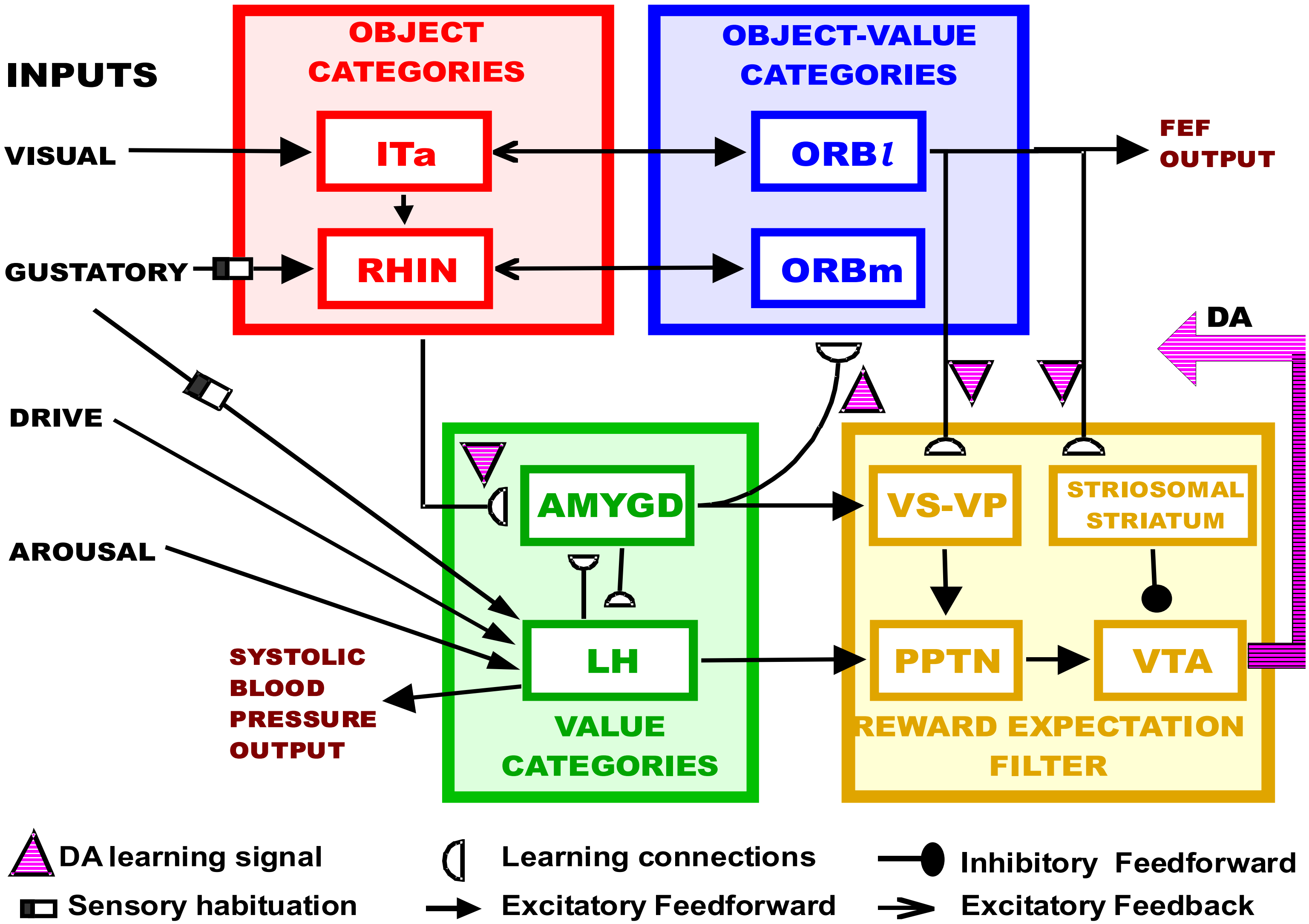
Barbas, 1995

MOTIVATOR

Matching Objects To Internal Values Triggers Option Revaluations

A model of needs-based evaluation of goal options

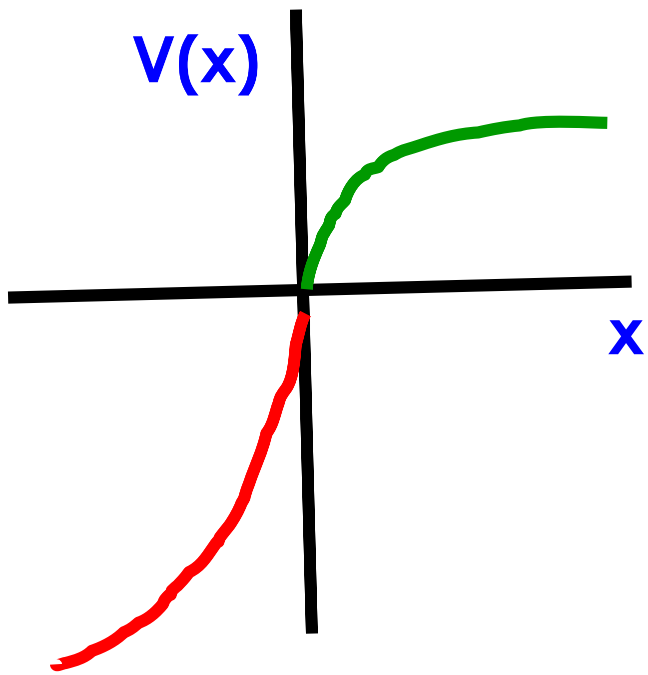
Grossberg, Dranias, Bullock (2008, *Beh. Neurosci.*, *Brain Res.*)



NEURAL EXPLANATION OF PROSPECT THEORY VALUE FUNCTION

Value function V(x) converts event x into subjective value

- concave for positive changes or gains
- convex for negative changes or losses
- marginal value decreases with larger magnitudes
- steeper for losses than for gains



OPPONENT EMOTIONS

Pleasure vs. Pain

Hunger vs. Satiety

Fear vs. Relief

Desire vs. Frustration

Enable adaptive responses to environmental contingencies

ANTAGONISTIC REBOUND

Pleasure vs. Pain

Hunger vs. Satiety

Fear vs. Relief

Desire vs. Frustration

Offset of a fearful cue causes a wave of relief

Offset of a negative event causes a positive *REBOUND*

Use relief as positive motivation to learn escape from a fearful cue

ANTAGONISTIC REBOUND

Pleasure vs. Pain

Hunger vs. Satiety

Fear vs. Relief

Desire vs. Frustration

Removal of food during eating causes frustration

Offset of a positive event causes a negative *REBOUND*

Use frustration as negative motivation to respond to cause of food removal

OPPONENT PROCESSING

How are ON and OFF reactions generated at the drive representations?

Through a

GATED DIPOLE

OPPONENT PROCESS

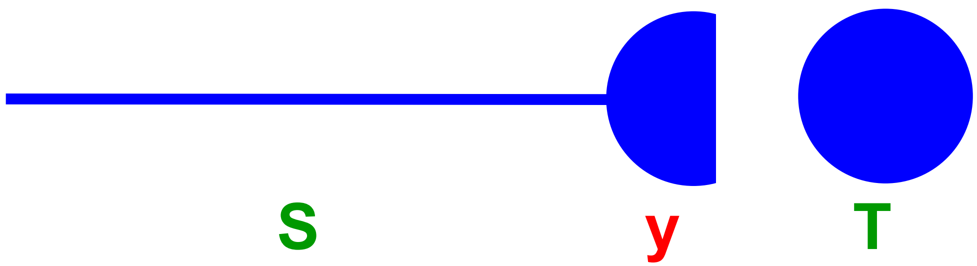
Grossberg, 1972

UNBIASED TRANSDUCER

S = input
T = output
T = SB

B is the gain

Suppose T is due to release of chemical transmitter y at a synapse:



RELEASE RATE: $T = S\,y$ (mass action)

ACCUMULATION: $y \cong B$

MTM: TRANSMITTER ACCUMULATION AND RELEASE

Transmitter y cannot be restored at an infinite rate:

$$T = S\,y$$

$$y \cong B$$

Differential Equation:

$$\frac{d}{dt}y = A\,(B - y) - S\,y$$

Accumulate

Release

Transmitter y tries to recover to ensure unbiased transduction

What if it falls behind?

Evolution has exploited good properties of slow recovery

MINOR MATHEMATICAL MIRACLE!

At equilibrium:

$$0 = \frac{dy}{dt} = A(B - y) - Sy$$

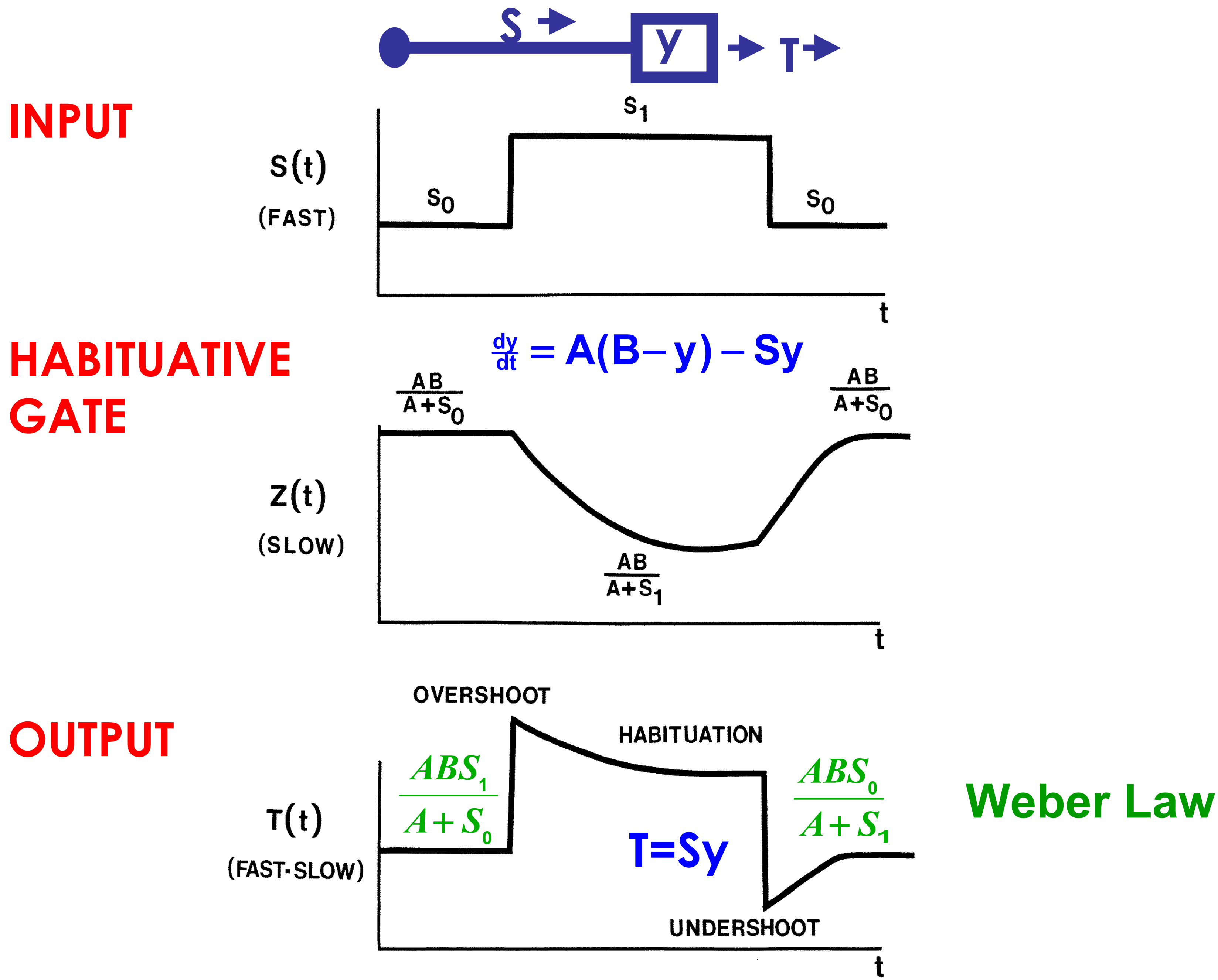
Transmitter y decreases when input S increases:

$$y = \frac{AB}{A + S}$$

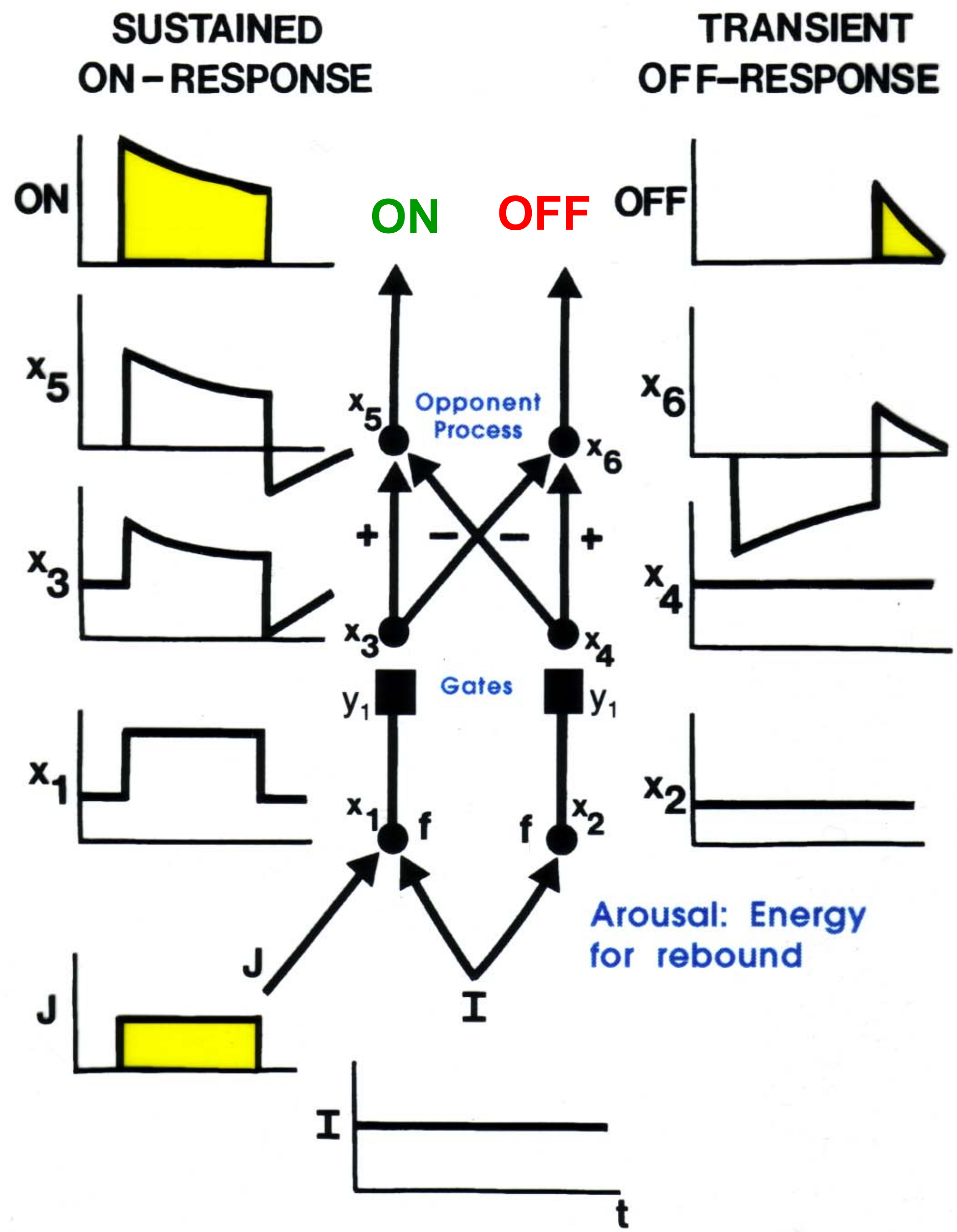
However, output Sy increases with S!

$$Sy = \frac{ABS}{A + S} \qquad \text{(gate, mass action)}$$

HABITUATIVE TRANSMITTER GATE



NONRECURRENT GATED DIPOLE



MAIN IDEA:
HABITUATIVE GATE
sets an
AFFECTIVE ADAPTATION LEVEL
against which future choices are evaluated

Habituative gate = Medium term memory

Grossberg, 1968, PNAS

Confirming neural data and models:

Visual cortex: Depressing synapses, Abbott et al., 1997

Somatosensory cortex: Dynamic synapses, Markram et al., 1997

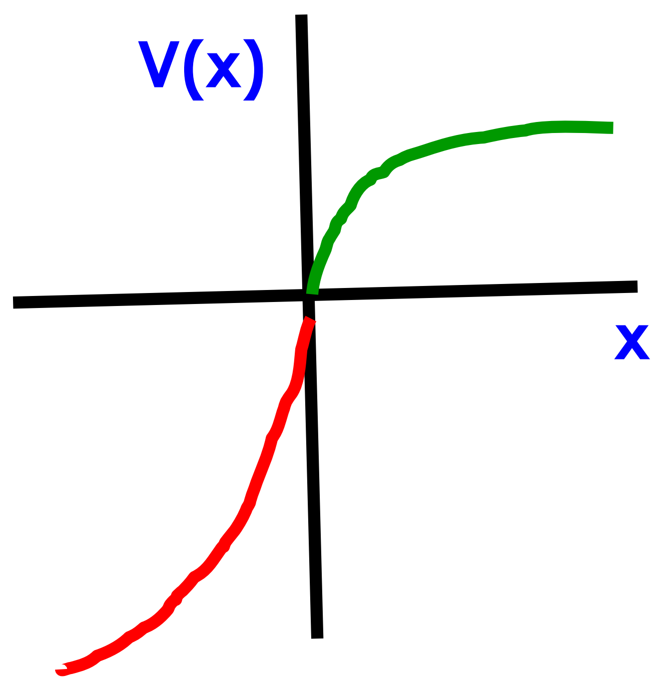
e.g., FRAMING EFFECT

Preferences depend on whether outcomes of choices are stated positively or negatively

NEURAL EXPLANATION OF PROSPECT THEORY VALUE FUNCTION

Value function V(x) converts event x into subjective value

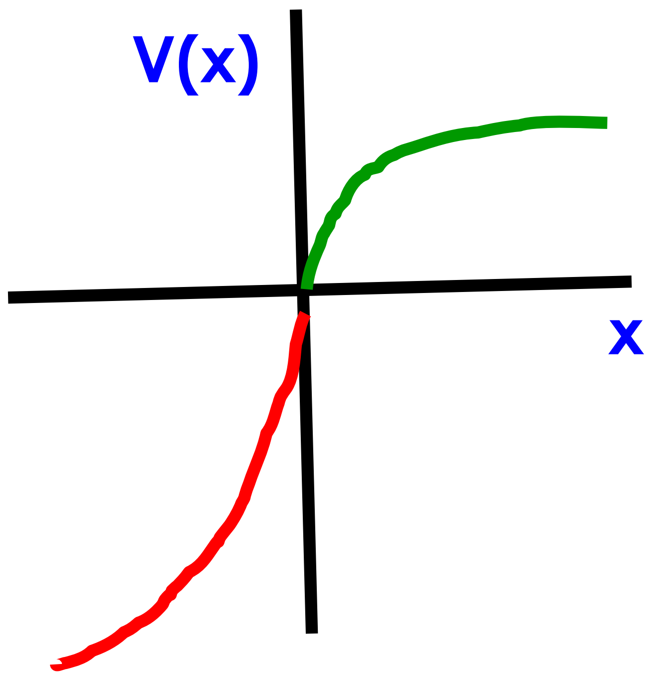
concave for positive changes or gains
convex for negative changes or losses
marginal value decreases with larger magnitudes
steeper for losses than for gains



TO DISCONFIRM

ON RESPONSE, OFF REBOUND MUST BE BIGGER

Is this true in a gated dipole?



ON-RESPONSE TO PHASIC ON-INPUT

$S_1 = f(I+J)$ $\qquad$ $S_2 = f(I)$

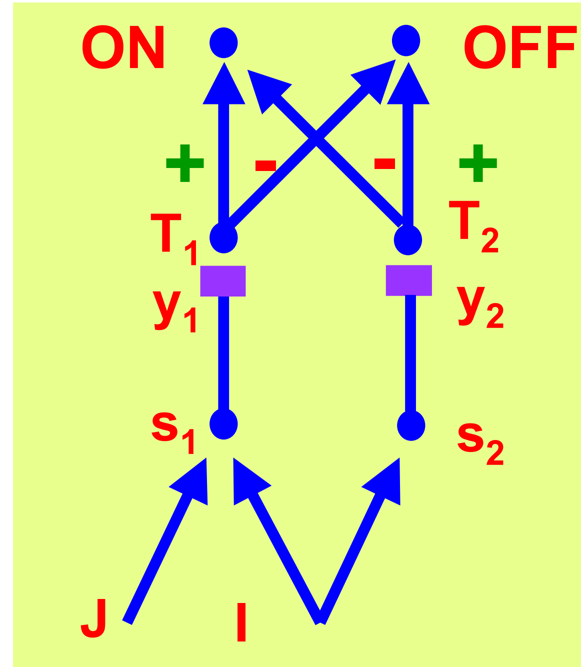
$$y_1 = \frac{AB}{A + S_1} \qquad y_2 = \frac{AB}{A + S_2}$$

$$T_1 = S_1 y_1 = \frac{ABS_1}{A + S_1} \qquad T_2 = S_2 y_2 = \frac{ABS_2}{A + S_2}$$

$$ON = T_1 - T_2 = \frac{A^2 B(f(I+J) - f(I))}{(A + f(I))(A + f(I+J))}$$

Cf. Prospect Theory

Affective Adaptation Level (Weber Law)



OFF-REBOUND DUE TO PHASIC INPUT OFFSET

Shut off J (Not I!). Then: $S_1 = f(I)$ and $S_2 = f(I)$

$$y_1 \cong \frac{AB}{A + f(I + J)} < y_2 \cong \frac{AB}{A + f(I)}$$

y_1 and y_2 are SLOW

$$T_1 = S_1 y_1 \qquad T_2 = S_2 y_2$$

$$T_1 < T_2$$

$$\text{OFF} = T_2 - T_1 = \frac{ABf(I)(f(I + J) - f(I))}{(A + f(I))(A + f(I + J))}$$

Note Affective Adaptation Level of remembered previous input

Arousal sets sensitivity of rebound: $\frac{\text{OFF}}{\text{ON}} = \frac{f(I)}{A}$

Why is the rebound transient?

OFF-REBOUND DUE TO PHASIC INPUT OFFSET

Shut off J (Not I!). Then: $S_1 = f(I)$ and $S_2 = f(I)$

$$y_1 \cong \frac{AB}{A + f(I + J)} < y_2 \cong \frac{AB}{A + f(I)}$$

y_1 and y_2 are SLOW

$$T_1 = S_1 y_1 \qquad T_2 = S_2 y_2$$

$$T_1 < T_2$$

$$\text{OFF} = T_2 - T_1 = \frac{ABf(I)(f(I + J) - f(I))}{(A + f(I))(A + f(I + J))}$$

Arousal sets sensitivity of rebound: $\frac{\text{OFF}}{\text{ON}} = \frac{f(I)}{A} > 1$

Not in underaroused people!

NOVELTY RESET: REBOUND TO AROUSAL ONSET

Disconfirmed expectations (novel events) cause reset

Novel events are arousing!

Why is this adaptive?

Novelty-triggered rebounds enable us to respond adaptively to changing environmental conditions

NOVELTY RESET: REBOUND TO AROUSAL ONSET

Disconfirmed expectations (novel events) cause reset

Novel events are arousing!

We do not get punished to prevent all bad behaviors

Often, our desired goal objects just do not happen

e.g., go to oasis looking for coconuts. No more coconuts! Why don't we keep going until we starve to death?

How does the non-occurrence of coconuts extinguish the motivation to look for them in the oasis?

The non-occurrence of coconuts is unexpected

Unexpected events cause an arousal burst

Arousal burst causes a frustrative rebound whose negative conditioned reinforcer learning competitively cancels the positive conditioned reinforcer learning that controls approach in the gated dipole

NOVELTY RESET: REBOUND TO AROUSAL ONSET

Disconfirmed expectations (novel events) cause reset

Novel events are arousing!

Novelty-triggered rebounds can also lead to irrational behaviors

e.g. PARTIAL REINFORCEMENT ACQUISITION EFFECT

Why an animal or human may work harder to get intermittent (partial) reward than continuous reward

On a learning trial when reward is unexpected but does occur:

The unexpected reward triggers a rebound
This negative-to-positive rebound can add to the direct effect of receiving reward

A higher total amount of effective reward is generated than during continuous reward when there is no disconfirmation

NOVELTY RESET: REBOUND TO AROUSAL ONSET

Disconfirmed expectations (novel events) cause reset

Novel events are arousing!

Equilibrate to I and J: $S_1 = f(I+J)$ $S_2 = f(I)$

$$y_1 = \frac{AB}{A + S_1} \qquad y_2 = \frac{AB}{A + S_2}$$

Keep phasic input J fixed; increase arousal I to $I^* = I + \Delta I$:

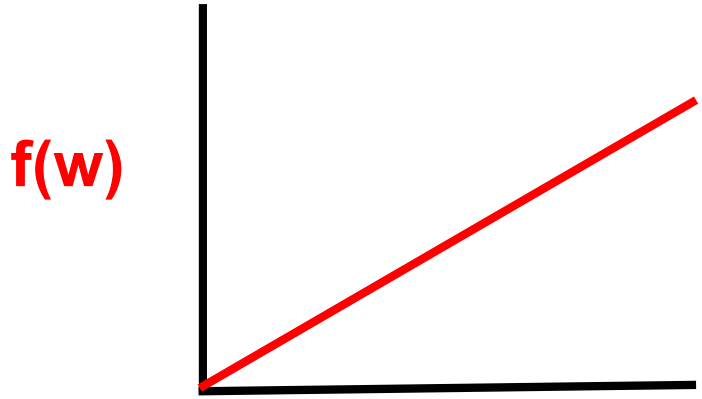
OFF reaction if $T_1 < T_2$

$$OFF = T_2 - T_1 = f(I^*+J)\, y_2 - f(I^*)\, y_1$$

$$= \frac{AB(f(I^*) - f(I^*+J)) - B(f(I^*)f(I+J) - f(I)f(I^*+J))}{(A + f(I))(A + f(I+J))}$$

How to interpret this complicated equation?

NOVELTY RESET: REBOUND TO AROUSAL ONSET



$f(w) = Cw$: Linear signal

More novelty implies ΔI is bigger!

$$\text{OFF} = \frac{ABJ(\Delta I - A)}{(A + I)(A + I + J)}$$

$$\Delta I = I^* - I$$

OFF > 0 only if there is enough novelty: $\Delta I > A$

OFF response increases with J:
If a given cell has a greater effect on a mismatched expectation, then it is reset more vigorously

Selective reset of dipole field by unexpected event

GATED DIPOLES IN PERCEPTION AND COGNITION

REINFORCEMENT

Shock on → Fear

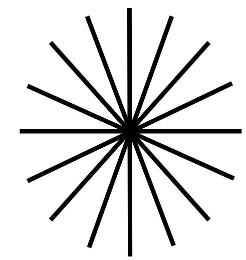
Estes & Skinner

Shock off → Relief

Denny

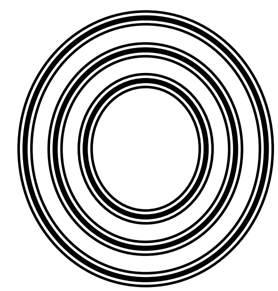
PERCEPTION

Picture on → Percept



Picture off → Negative Aftereffect

Helmholtz; MacKay



COGNITION learn to push lever when blue light turns off

Blue light feature detector on-cell

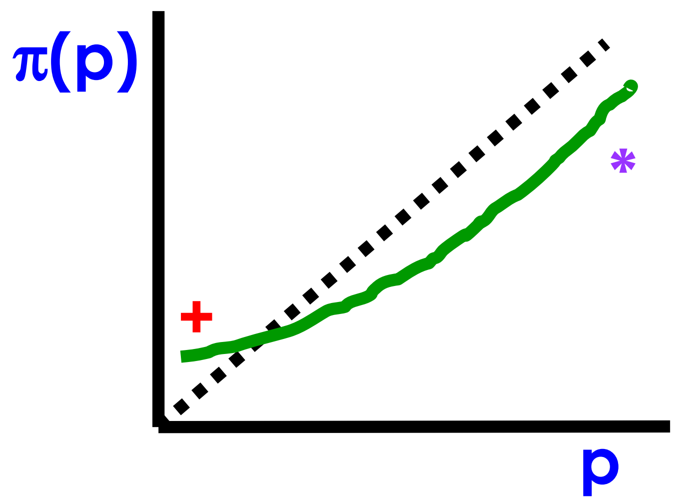
Offset of light activates rebound in off-cell, which triggers movement

---

LOGIC true vs. false

HOW TO EXPLAIN PROSPECT THEORY DECISION WEIGHT?

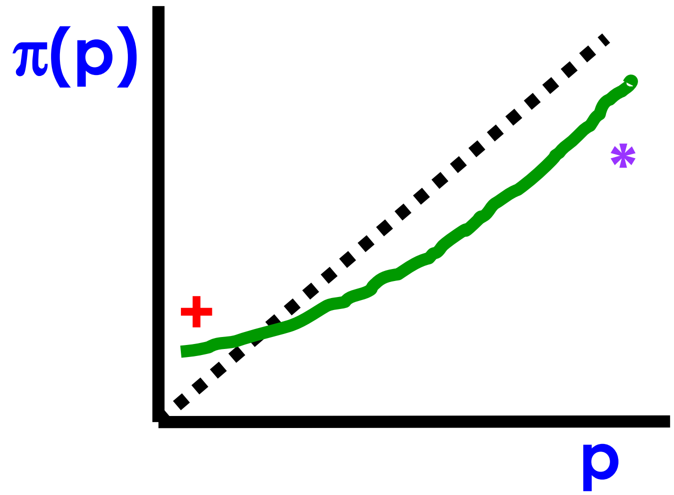
Decision weight function $\pi(p)$ converts event with probability p into a decision weight that multiplies value of a risky alternative



Subcertainty and subproportionality
e.g., small probabilities (+) are overweighted
large probabilities (*) are underweighted

1. RARE EVENTS ARE MORE UNEXPECTED:

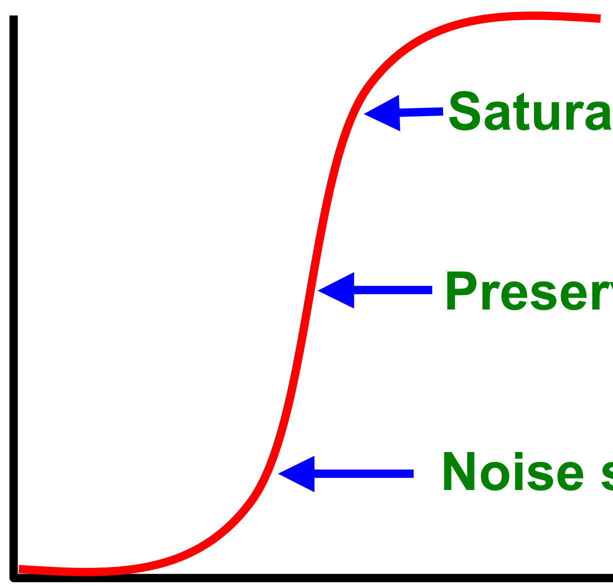
Cause bigger rebounds (ΔI is bigger)
and are instated with more activity In STM (+)



Subcertainty and subproportionality
e.g., small probabilities (+) are overweighted
large probabilities (*) are underweighted

Cf., Gambler's fallacy

SIGMOID SIGNAL FUNCTION
Distributed Processing and Noise Suppression



HYBRID SIGNAL:

Saturates pattern: every signal is bounded
Slower-than-linear

Preserves pattern and normalizes
Approximately linear

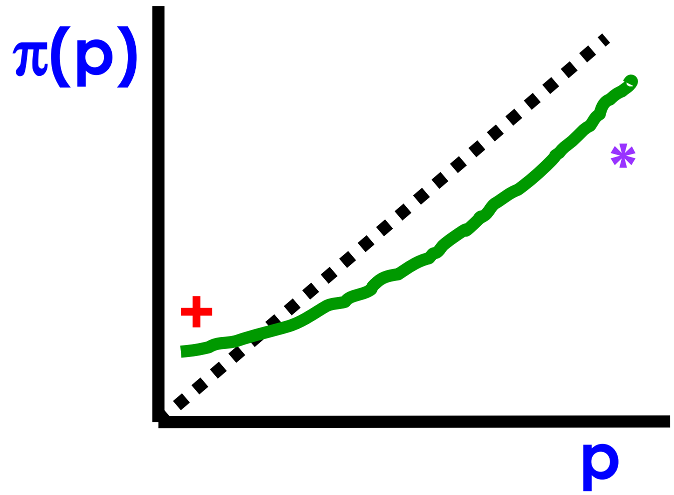
Noise suppression and contrast-enhancement
Faster-than-linear

The faster-than-linear part suppresses noise and starts to contrast-enhance the pattern

As total activity normalizes, the approximately linear range is reached and tends to store the partially contrast-enhanced pattern

2. SIGMOID SIGNAL FUNCTIONS:

Help to cause subcertainty and subproportionality

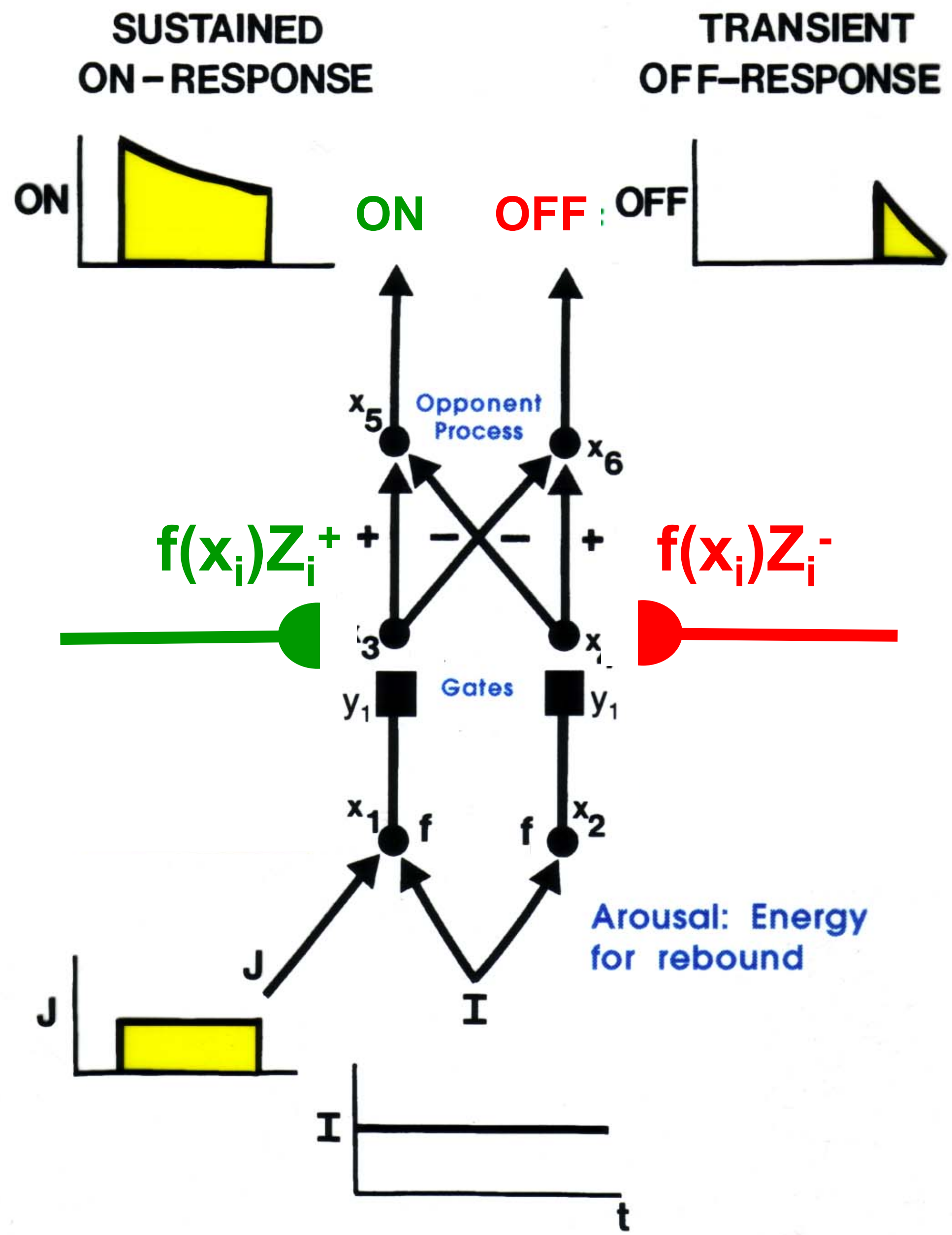


Subcertainty and subproportionality

e.g., small probabilities (+) are overweighted

large probabilities (*) are underweighted

GATED DIPOLE + CONDITIONED REINFORCER LEARNING



REFLECTION EFFECT: RISK AVERSION

Choices involving gains tend to choose less risky alternative
Choices involving losses tend to choose riskier alternative

Problem 1

A. A sure win of $3000
B. An 80% change to win $4000

Problem 2

C. A sure loss of $3000
D. An 80% change to lose $4000

Most people prefer A to B and D to C

A>B D>C

REFLECTION EFFECT: RISK AVERSION

Choices involving gains tend to choose less risky alternative

Choices involving losses tend to choose riskier alternative

Consider two alternatives a_1 and a_2

$J_i^+ = f(x_i)Z_i^+$, $J_i^- = f(x_i)Z_i^-$, $i = 1,2$.

Sample a_1, let habituation occur, then sample a_2; preference is independent of sampling order. Then

$$a_2 - a_1 = K_1[(A+I)((J_2^+ - J_2^-) - (J_1^+ - J_1^-)) + J_2^+J_1^- - J_1^+J_2^-]$$

where $K_1 = AB/(A+I+J_1^-)(A+I+J_2^-)$

Suppose that a_1 and a_2 are equally valued:

Then $D = J_1^+ - J_1^- = J_2^+ - J_2^-$

Then $a_2 - a_1 = K_1[J_2^+J_1^- - J_1^+J_2^-] = K_1[(J_2^- + D)J_1^- - (J_1^- + D)J_2^-]$

$$a_2 - a_1 = K_1D(J_1^- - J_2^-)$$

Suppose that a_2 is riskier than a_1 : $J_1^- < J_2^-$.

Then a_2 less than a_1 (less risky alternative chosen) only if

D is positive; i.e., alternatives are favorable (involve gains)

PREFERENCE REVERSALS

Psychophysical data: Gutowski, 1984; Gutowski and Chechile, 1986

For favorable alternatives, preference reversal favors the less risky alternative

For unfavorable alternatives, preference reversal favors the riskier alternative

Suppose that a_1 and a_2 are NOT equally valued:

Let $J_1^+ - J_1^- = D_1$ and $J_2^+ - J_2^- = D_1 + D_2$

Suppose that a_2 is riskier than a_1 : $J_1^- < J_2^-$.

A *preference reversal* occurs if $(a_2 - a_1)D_2 < 0$;

e.g., choose a_2 over a_1 but value a_1 more.

Note that $a_2 - a_1 = K_1[(A+I + J_1^-)D_2 + (J_1^- - J_2^-)D_1]$

Suppose a_2 is riskier: $(J_1^- - J_2^-) < 0$.

Then $a_2 - a_1$ can be positive or negative only if $D_1D_2 > 0$.

Choose less risky a_1 if both D_1 and D_2 are positive (favorable)

Choose riskier a_2 if both D_1 and D_2 are negative (unfavorable)

GENERAL THEMES OF THIS TALK

How understanding human cognition, emotion, and decision making can impact economic theory

How emotions impact decisions

Decision making under risk

e.g., Prospect Theory Kahneman & Tversky

How a mathematical understanding of cooperative-competitive dynamics can impact economic theory

voting paradox Condorcet, Arrow

market equilibria Nash

preferences: do we know what we like?

totalitarian, socialist, democratic trends

the rich get richer

GENERAL THEMES OF THIS TALK

How adaptive behaviors that are selected by evolution can cause irrational decisions when they are activated by certain environments

Part of the “human condition”!

GENERAL THEMES OF THIS TALK

How adaptive behaviors that are selected by evolution can cause irrational decisions when they are activated by certain environments

Part of the "human condition"!

…a bigger theme:

TRENDS IN SCIENCE AND TECHNOLOGY THAT LOOK TO NEURAL NETWORK RESEARCH

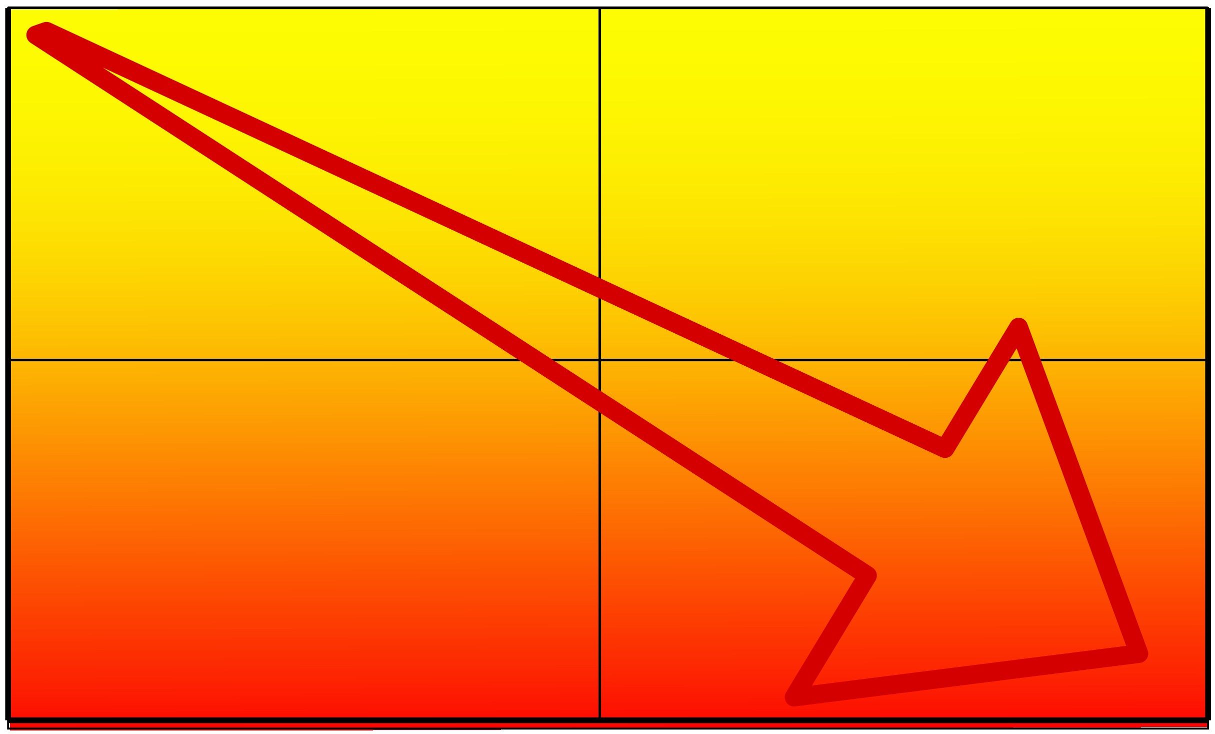
WORLD

CONTROL

EXTERNAL (SUPERVISED) | AUTONOMOUS (UNSUPERVISED)

STATIONARY

NON-STATIONARY



GENERAL THEMES OF THIS TALK

How adaptive behaviors that are selected by evolution can cause irrational decisions when they are activated by certain environments

Vs. BAYESIAN approaches:

No Bayes needed

The designs help to explain how the brain adapts autonomously in real time to a changing world where they may be no priors

Not a world in which Bayes is comfortable…