ANCHOR:

A Memory-Based Model of Category Rating and Absolute Identification

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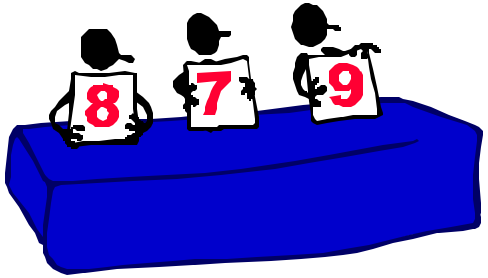
The Dynamics of Scaling

- Category rating—very widely used
- Absolute identification—theoretically important
- Testbed for the dynamics of cognition
- ACT-R magnitudes
- Detailed, precise data



Petrov & Anderson (in press)

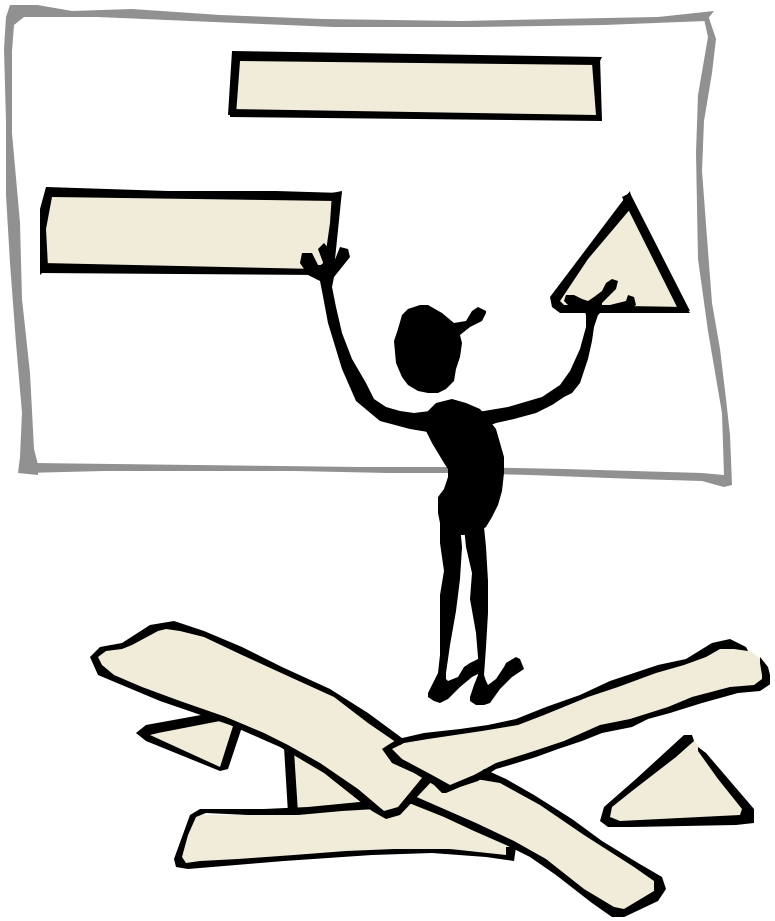
Psychological Review

- Two experiments
- Comprehensive list of empirical phenomena, operationalized
- ANCHOR model defined from the ground up
- Extensive simulations with a hierarchy of nested models
- Some mathematical analyses
- Explanation of the phenomena

Empirical Phenomena

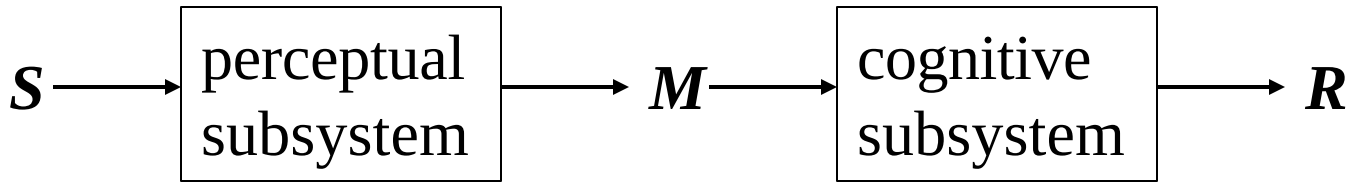
- Stevens' power law
- sequential effects at various time scales
- context effects
- non-stationary response distributions
- practice effects
- edge effects
- …

ANCHOR: Theory and Model

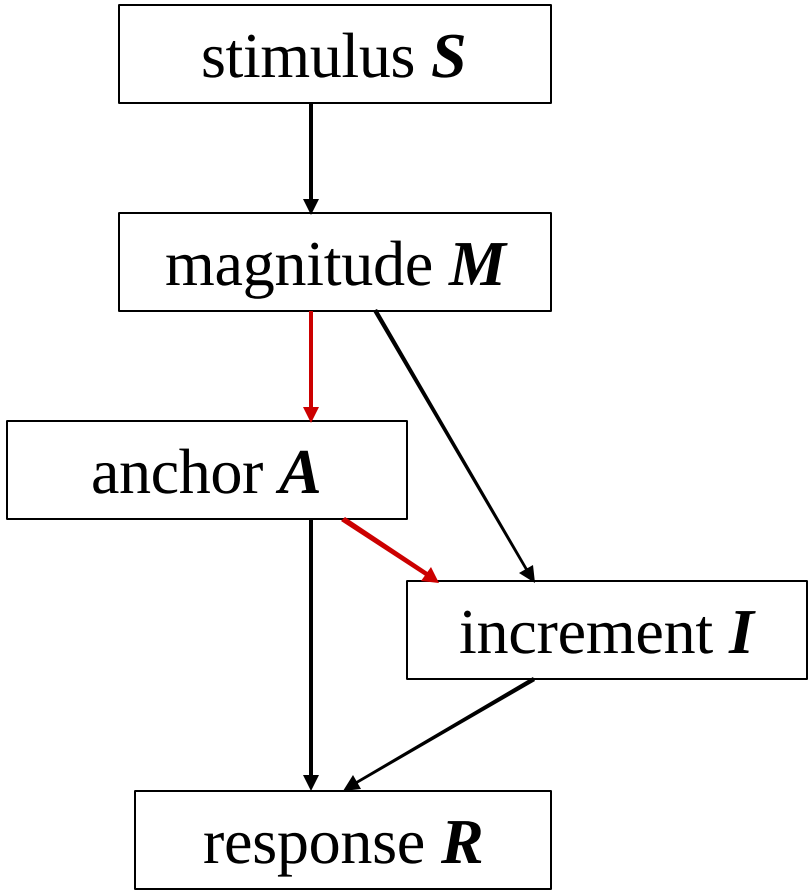


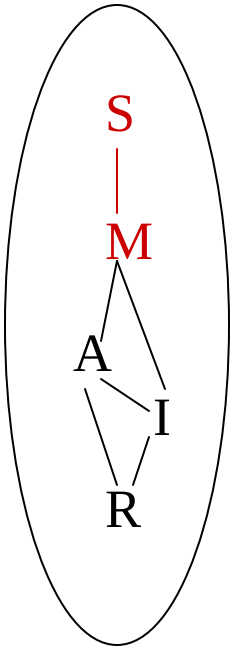
ANCHOR Principles

- Internal magnitude continuum
- Content-addressable memory anchor = <M,R> association
- Explicit correction strategies
- Obligatory learning



Dependencies among Variables



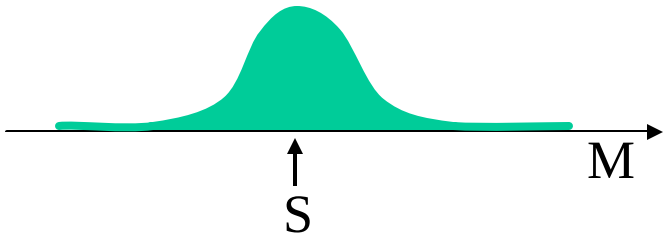


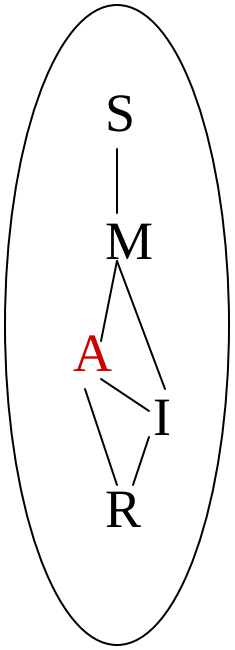
Perceptual Equation

$$M = aS^n\left(1 + k_p e_p\right)$$

multiplica-
tive noise

Each stimulus S defines a whole distribution of magnitudes.

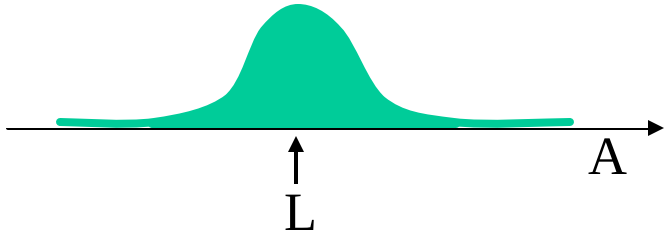


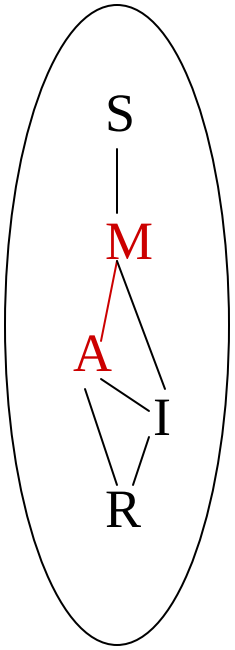


Anchor magnitudes are noisy too

$$A = L\left(1 + \overline{k_m e_m}\right)$$

multiplica-tive noise





Anchor Selection

$$G_i = \underbrace{-\left|M - A_i\right|}_{\text{similarity}} + \underbrace{HB_i}_{\text{history}}$$

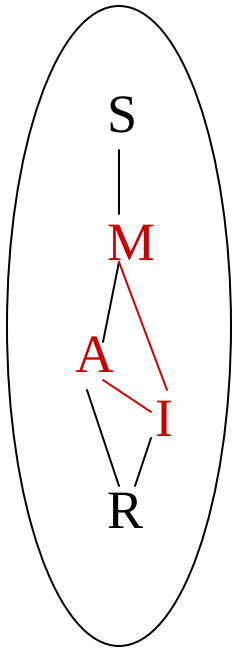
$$P_i = \frac{\exp(G_i / T)}{\sum_j \exp(G_j / T)}$$

Anchor Selection Highlights

- general memory mechanism
- stochastic (softmax rule)
- depends on the similarity b/n the target and each of the anchors
- depends on the availability
  - recency
  - strength

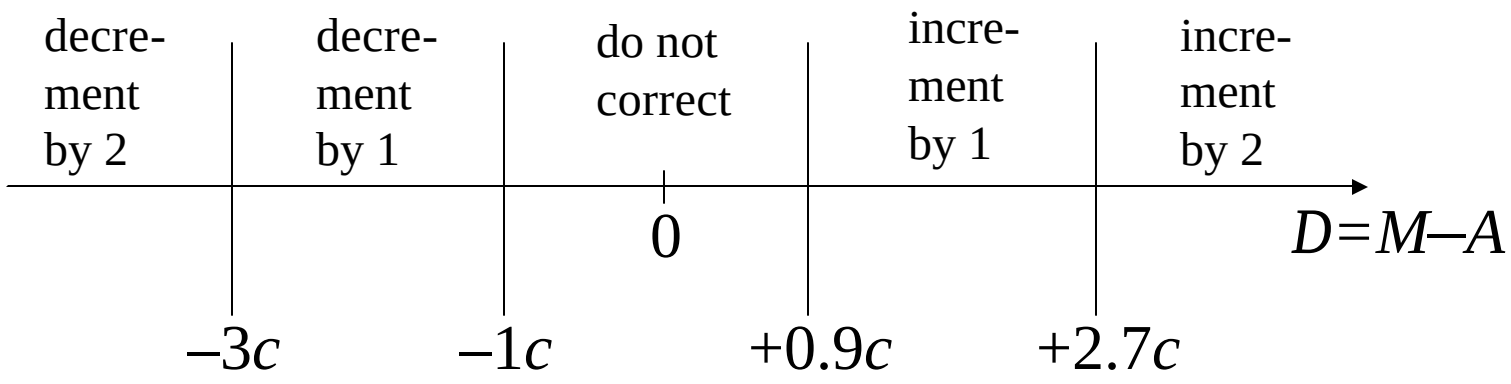
$$G_i = -\left|M - A_i\right| + HB_i$$

$$P_i = \frac{\exp(G_i / T)}{\sum_j \exp(G_j / T)}$$



Correction Mechanism

- explicit strategy
- promotes homomorphism, locally
- binds the anchors together
- redistribution of strength
- introduces prior knowledge

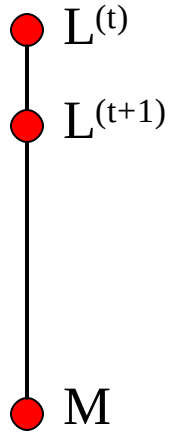


Question

The response has been produced. Is this the end of the trial?

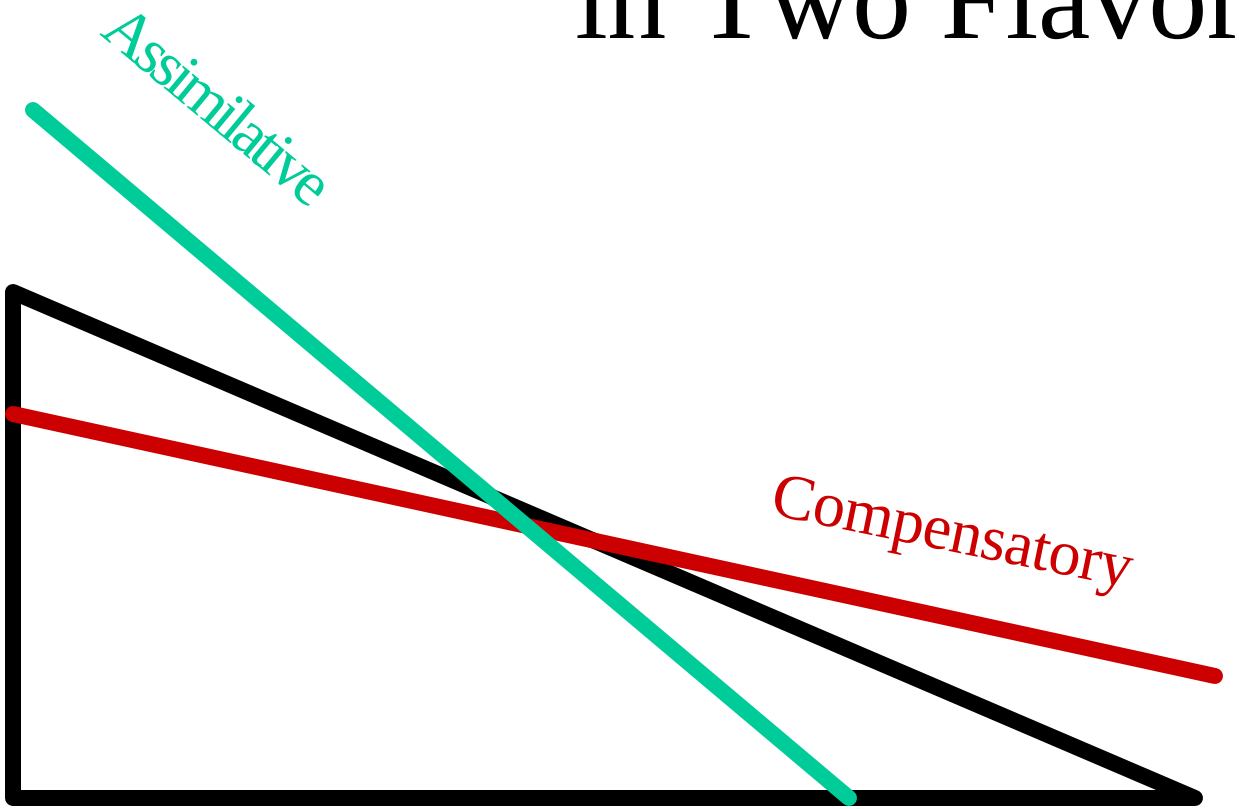
Updating the Anchor Locations

$$L^{(t+1)} = aM + (1-a)L^{(t)}$$

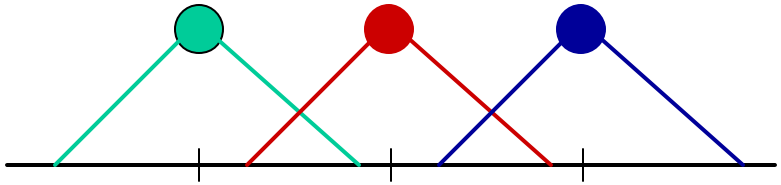


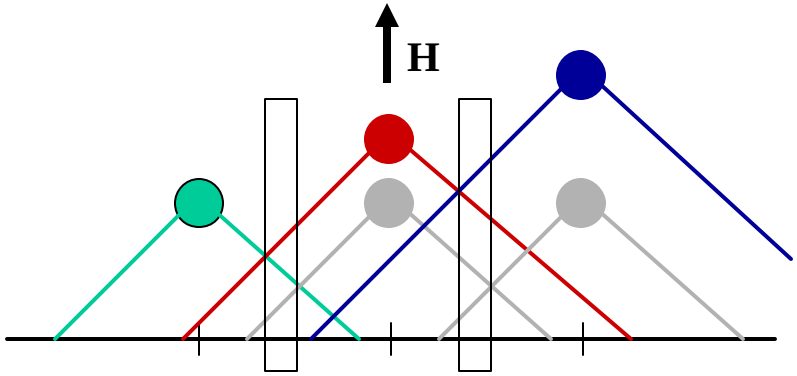
- a form of competitive learning
- consistency of responses
- anchors become weighted prototypes
- the scale unfolds as an adaptive map
- track the density → context effects

Context Effects Come in Two Flavors



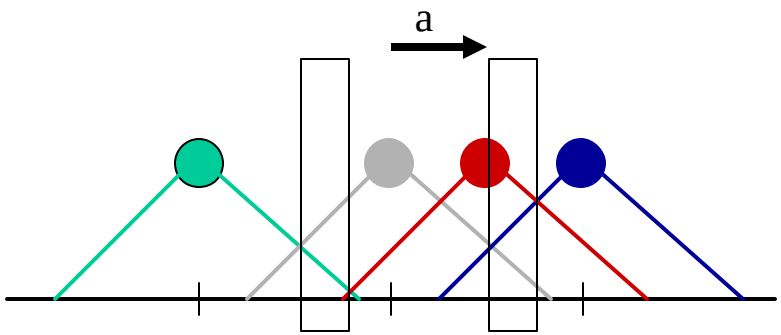
Base-level activation



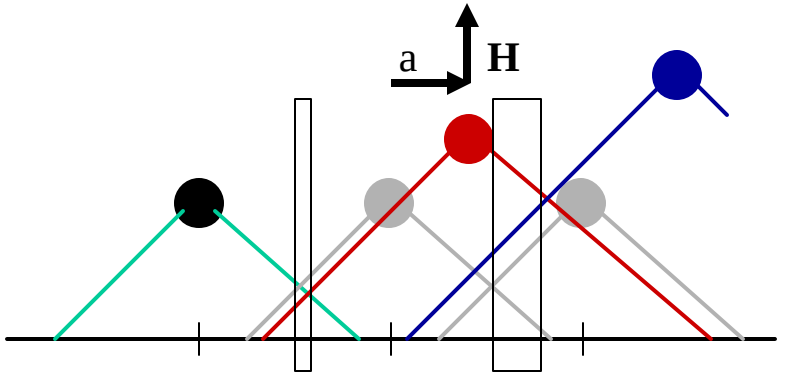


Assimilatory context effect

Competitive learning

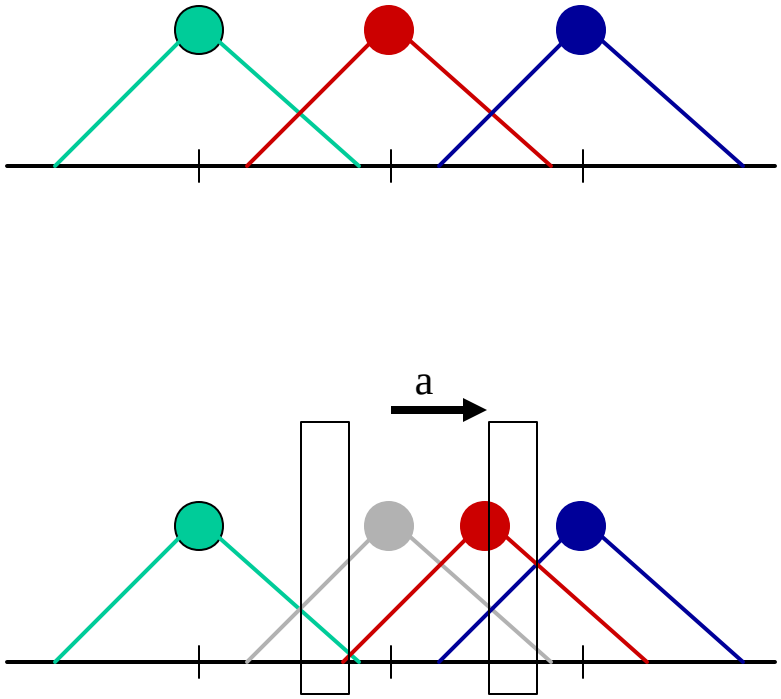


Compensatory context effect

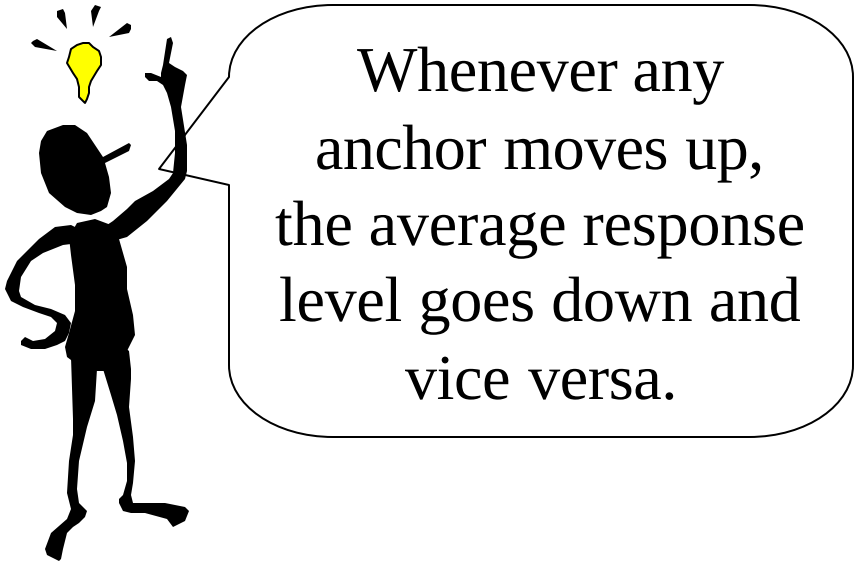


Either, depending on parameters

Inversion Rule

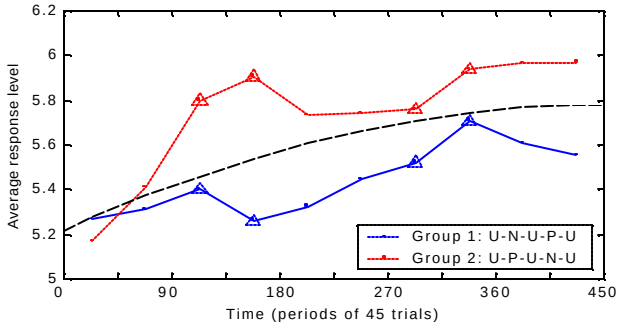


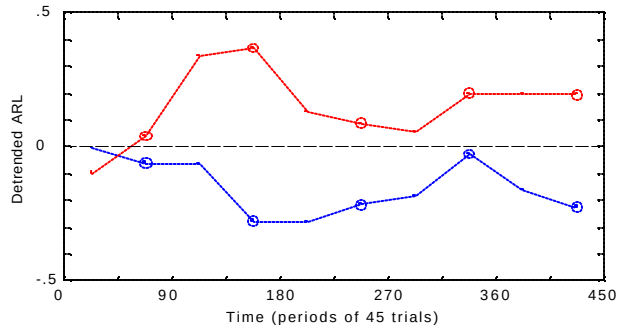
Compensatory context effect



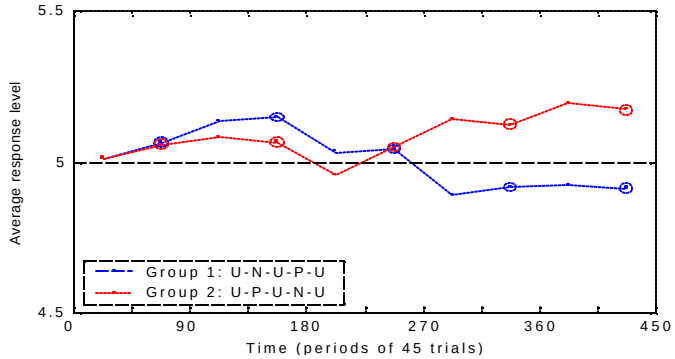
Category Rating vs Absolute Identification

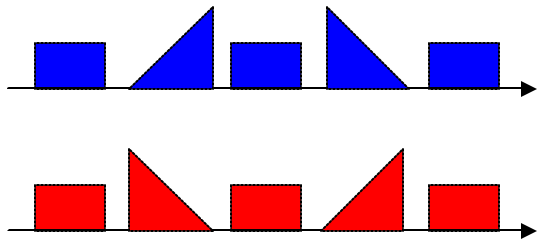
- substantial strength buildup
- substantial anchor drift



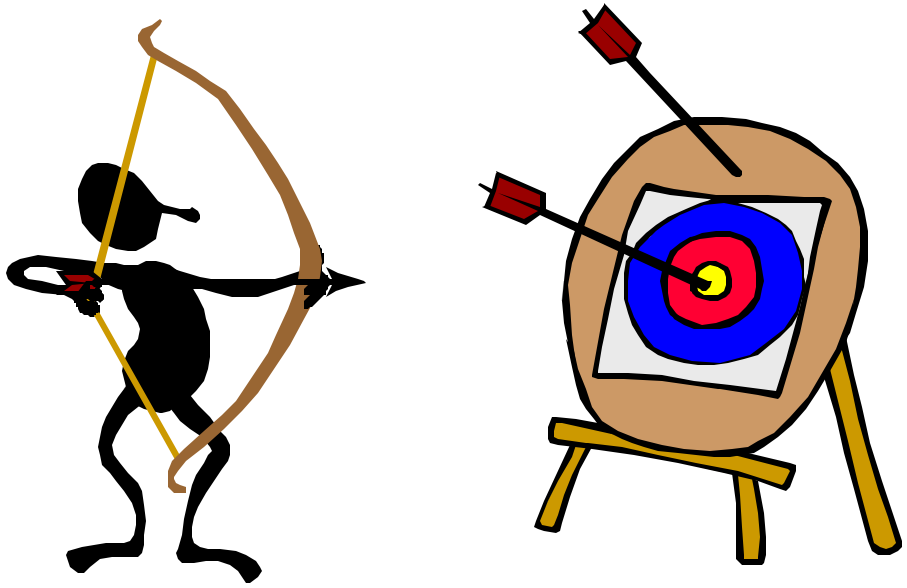


- some strength buildup
- insignificant anchor drift





Testing the Model



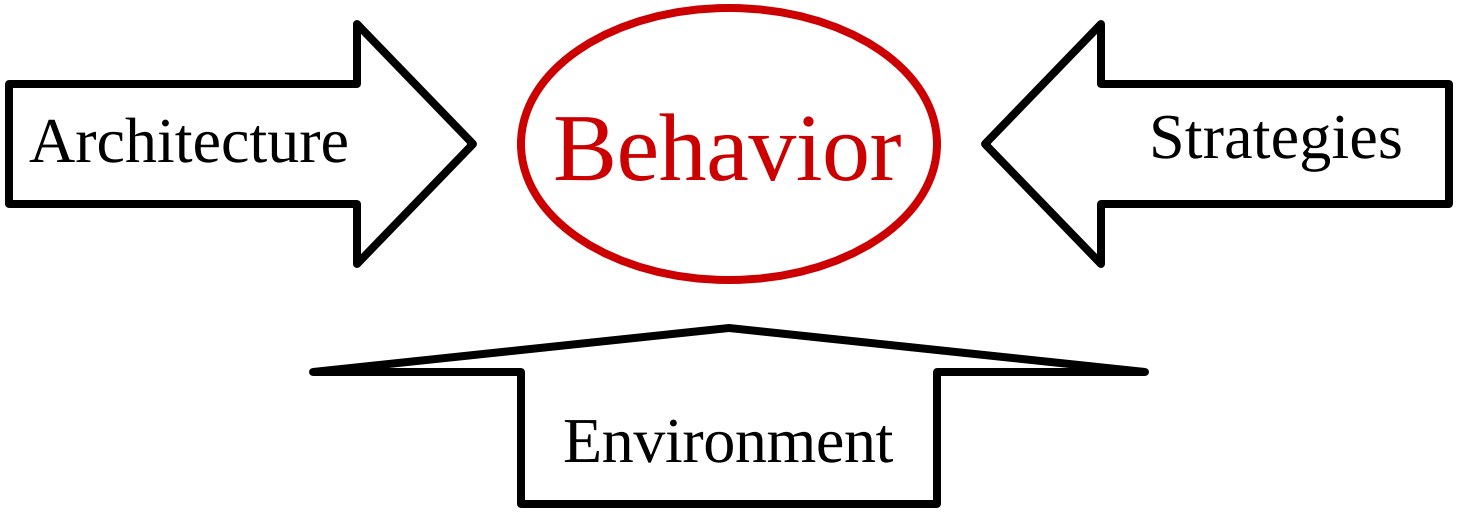
Model Fits: Category Rating

Statistic	empir	model
Overall accuracy (R^2)	0.77	0.77
Non-uniform response distrib.	1.77	1.93
Non-stationary distribution	0.55	0.21
Sequential effect (acf_{resid})	0.34	0.17
Gradual trend	0.49	0.27
Compensatory context effect	-0.21	-0.53

Model Fits: Absolute Identification

Statistic	empir	model
Transmitted information	1.68	1.57
Non-uniform response distrib.	2.40	2.50
Edge (bow) effect	+0.14	-0.31
Repetition effect	0.11	0.04
Practice effect	0.06	0.02
Assimilative context effect	+0.14	+0.11

Three Determinants of Behavior



Acknowledgements

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- Mark Steyvers
- Duncan Luce
- Jean-Claude Falmagne
- Stefan Mateeff
- Barbara Dosher
- Zhong-Lin Lu
- and many others …

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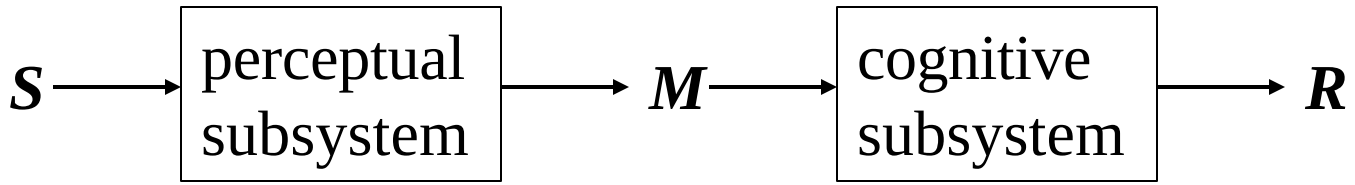
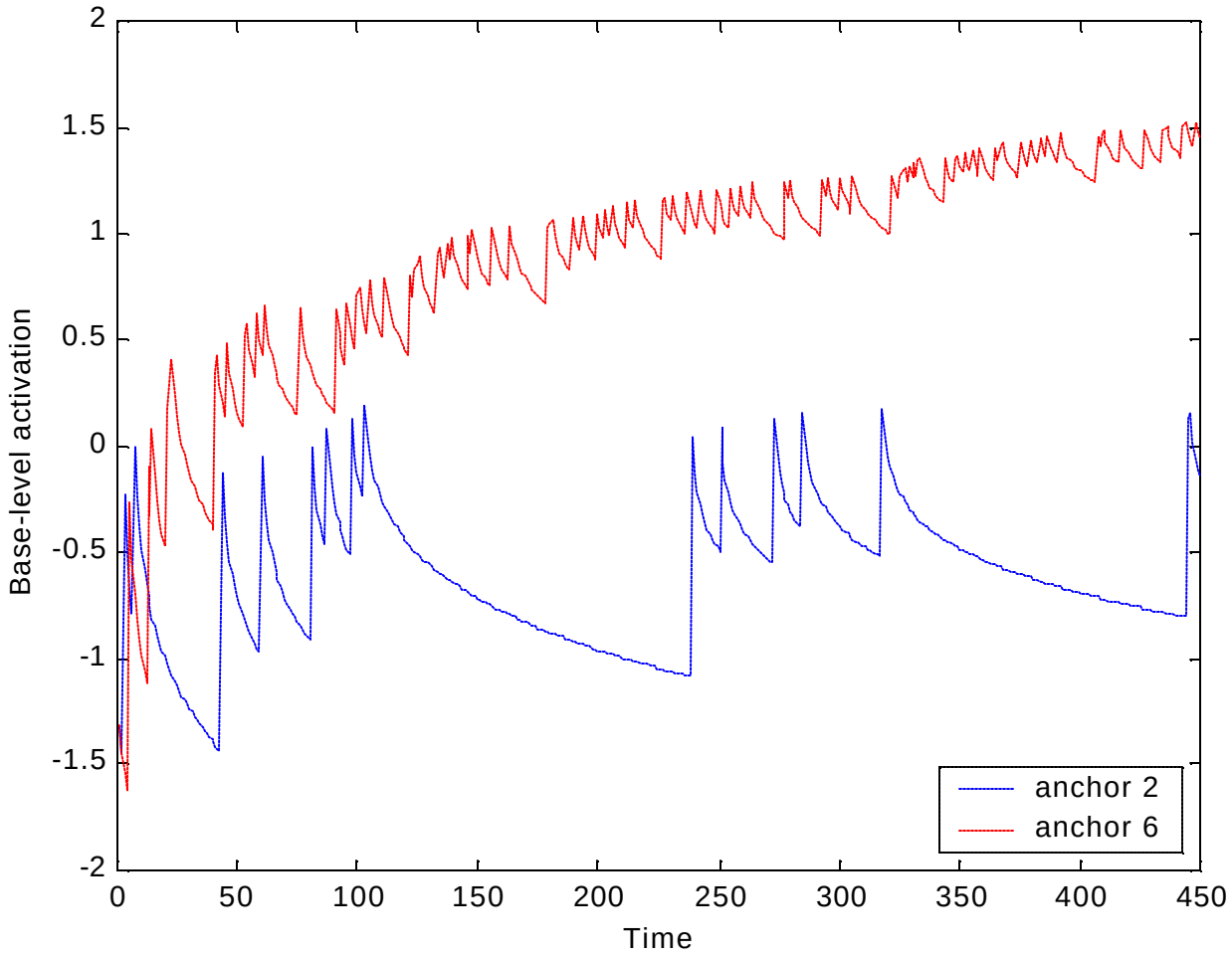


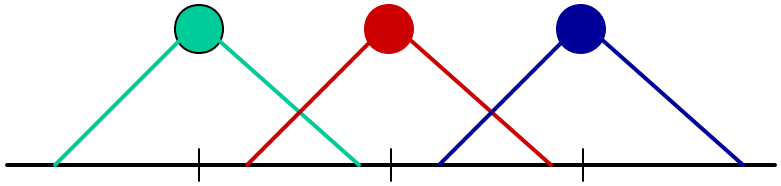
Relation to Psychophysical "Laws"

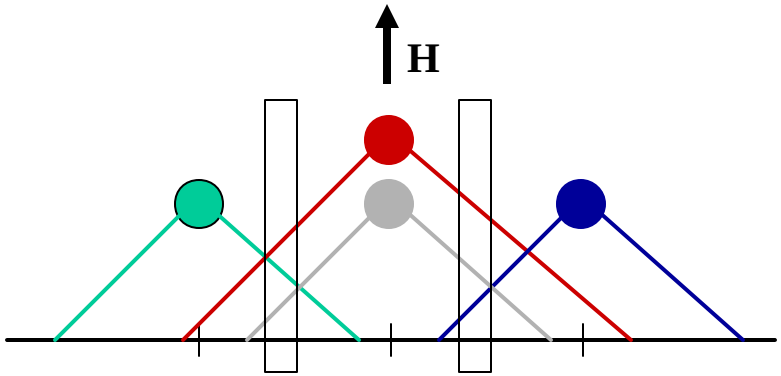
$$M = aS\left(1 + k_p e_p\right)$$

- Stevens' law: $M = aS^n$ ($n=1.0$)
- Weber's law: $dS/S = \text{const}$ ($k_p=0.04$)
- Ekman's law: $dM/M = \text{const}$

Dynamic Availability

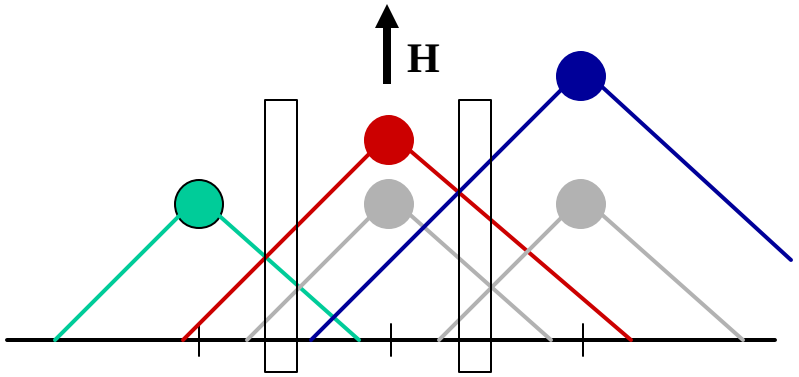






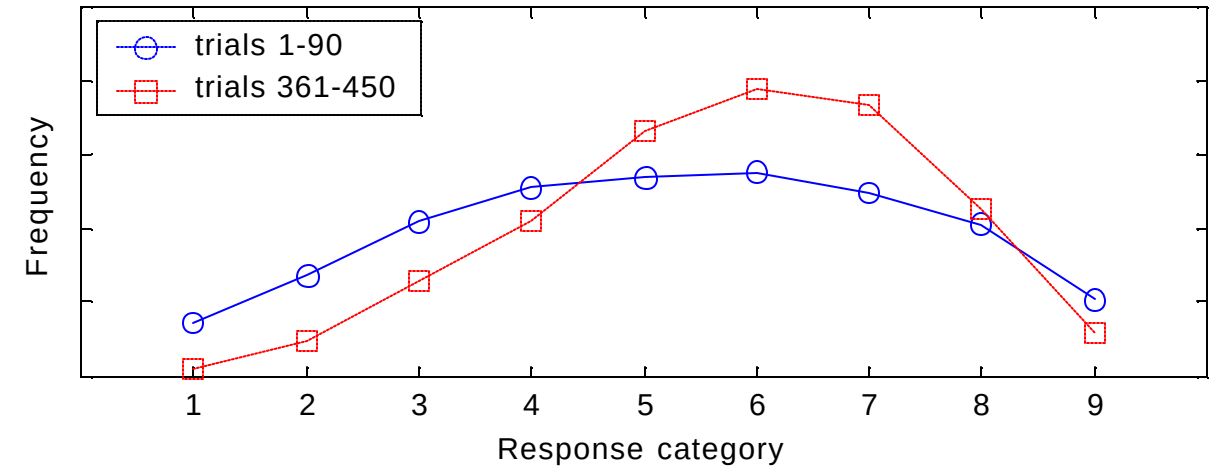
Sequential assimilation

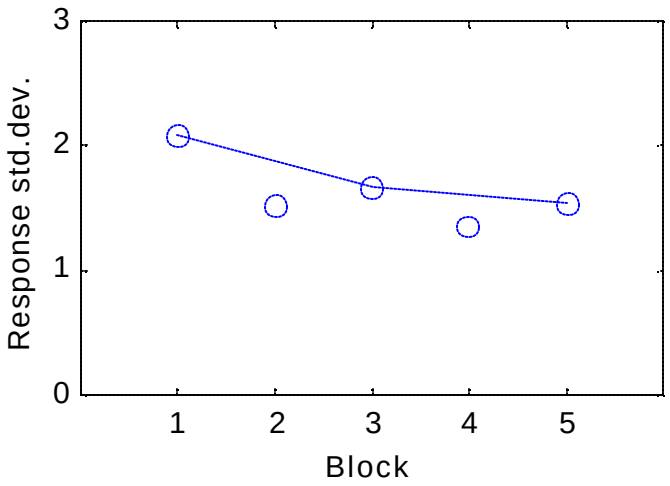
Assimilation: short- and intermediate-term

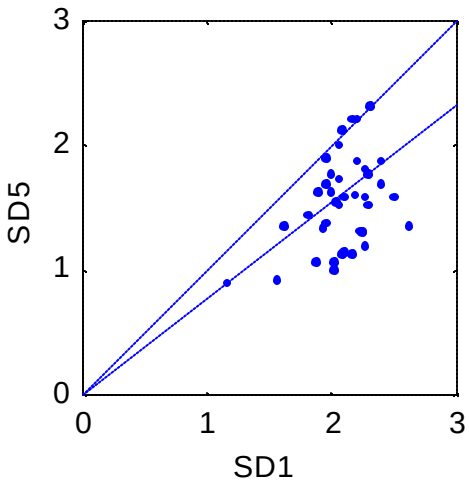


Assimilatory context effect

Nonuniformity Increases with Time



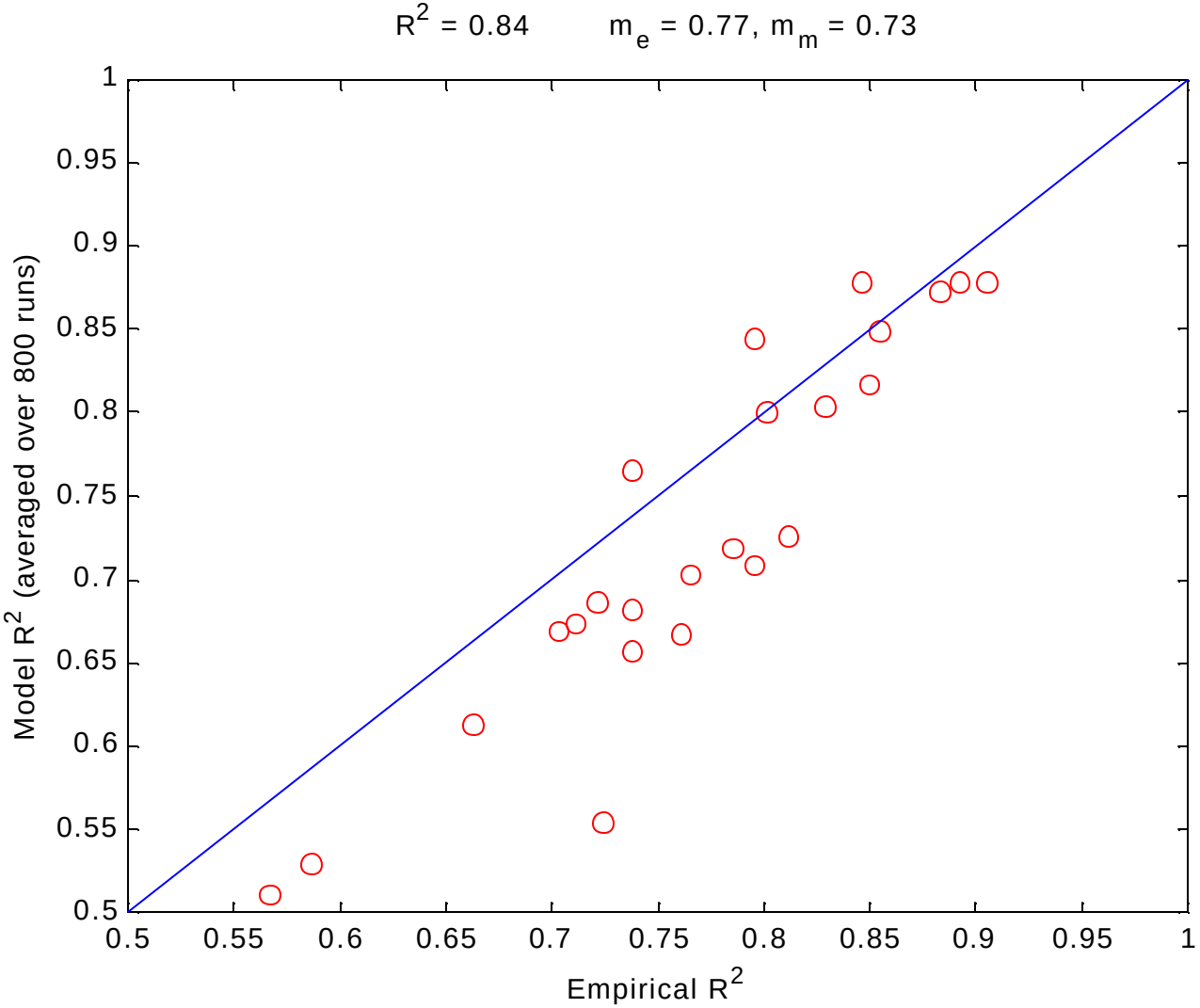




Simulation Experiments

- the basic unit of analysis is the individual
- suite of statistical measures
- 40+24 Ss $\rightarrow$ 40+24 parameter sets
- 40+24 stimulus sequences; the same that were shown to the human participants
- (40+24) x 100 runs of the model

Accuracy (R^2)



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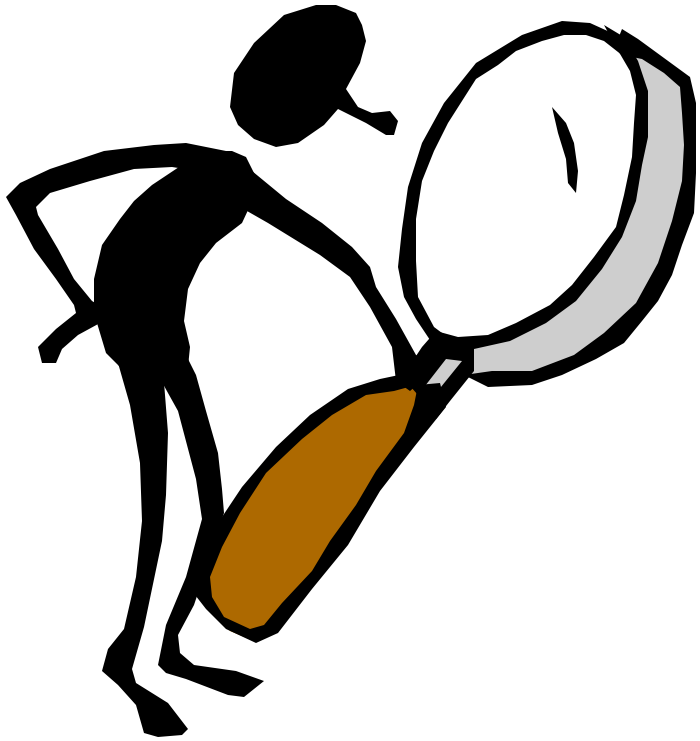
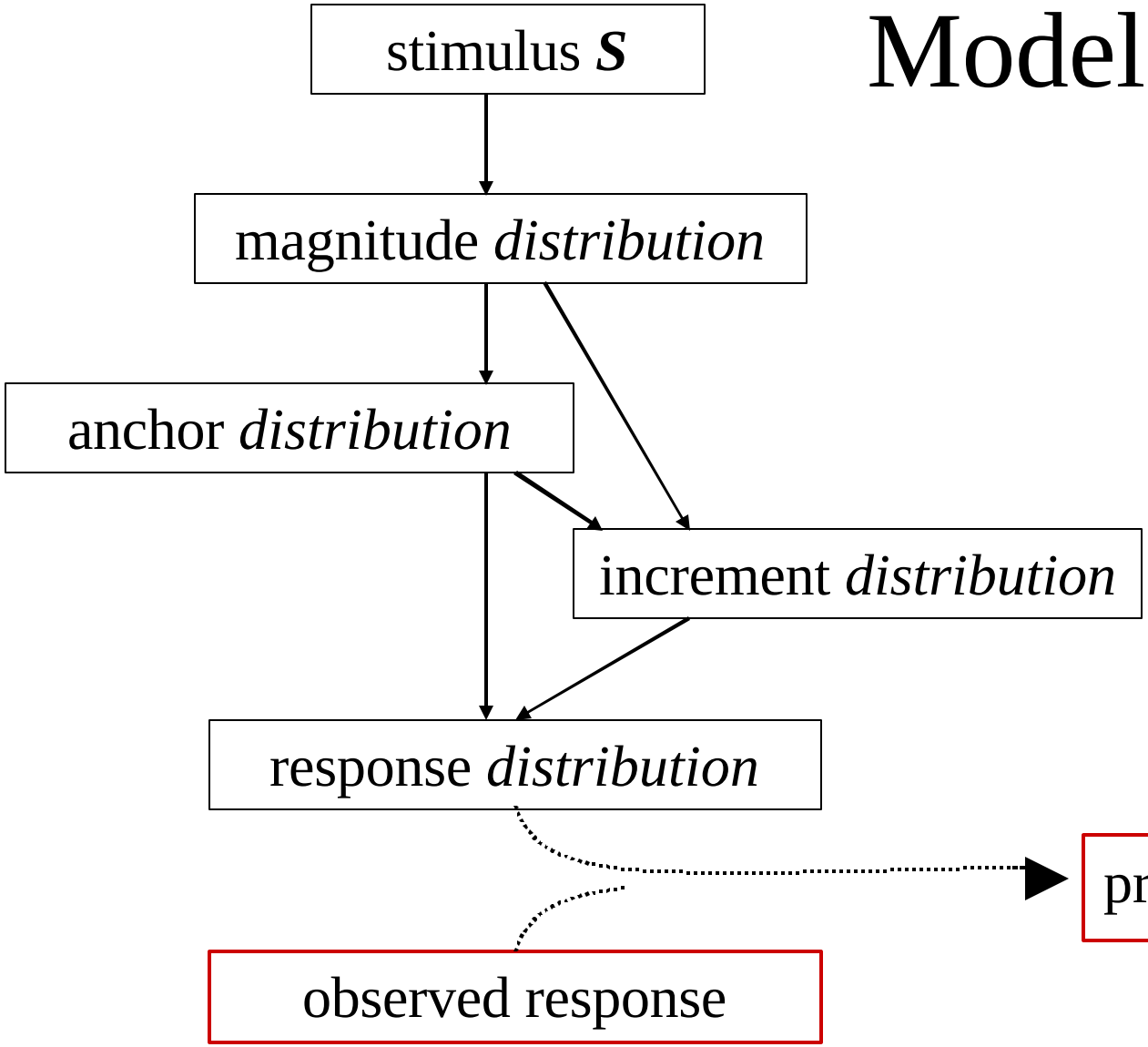
Parameter Search



Five Parameters

- memory noise k_m
- softmax temperature T
- history H
- learning rate alpha
- correction cutoff c

Model Tracing



Maximize the Log-likelihood

$$L = -\sum_{t=1}^{450} \ln\left[p_t\right]$$

where p_t is the probability that the model
produces on trial t the response that was
produced by the human participant

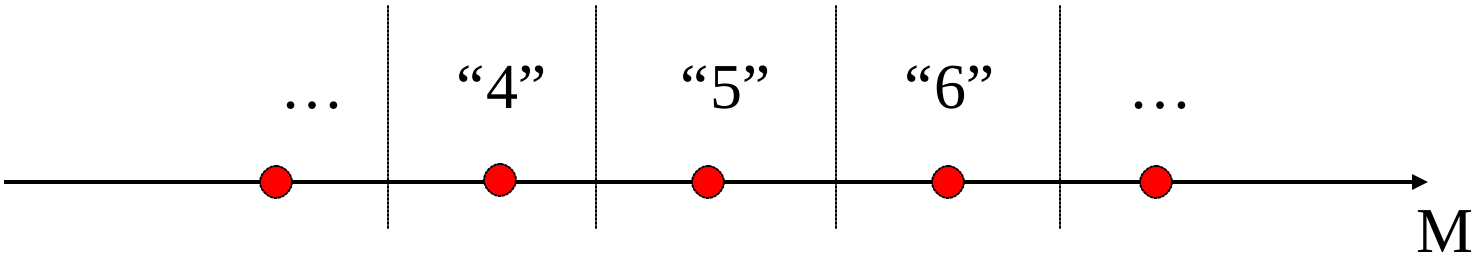
Parameter Search

- Gradient descent on L
- Individual parameter set optimized for each participant
- Reliability of the method tested on synthetic data
- Sensitivity analyses
- Discourages “fishing”

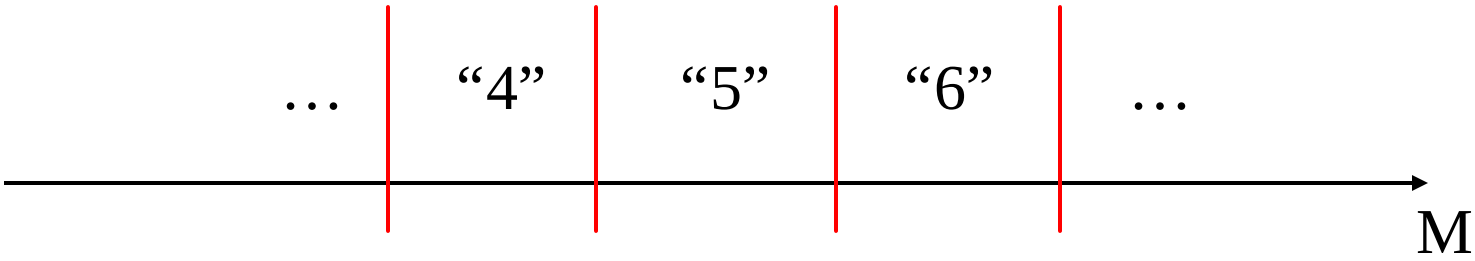
Highlights of the Talk

- Non-stationary processing
- Context effects in opposite directions
- Integration of psychophysics and memory
- Memory-based model
- Incremental learning algorithms

Prototype-based Categories



Criterion-based Categories

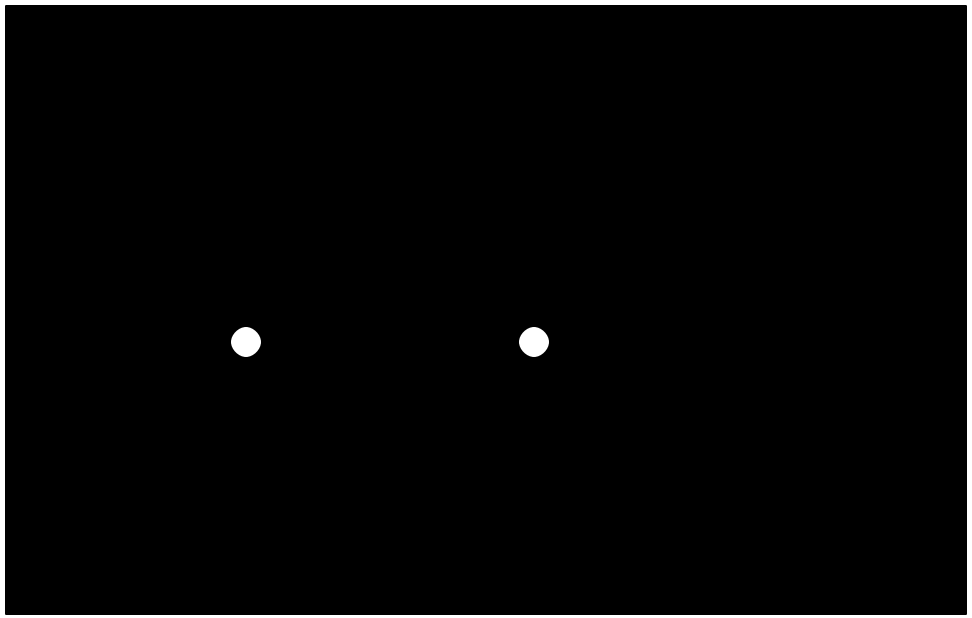


Related Tasks

- category rating
- magnitude estimation
- absolute identification

- perceptual discrimination
- categorization
- pair-associate learning

Experiments: Stimuli



distances b/n 250 and 700 pixels

9 response categories

Experiments: Details

- distances b/n 250 and 700 pixels
- randomized absolute position
- 450 trials
- 17 demo trials with feedback
- 40 category-rating participants
- 24 absolute-identification participants
- 4 sec per trial, 30 min total

Typical Data Set (CR)

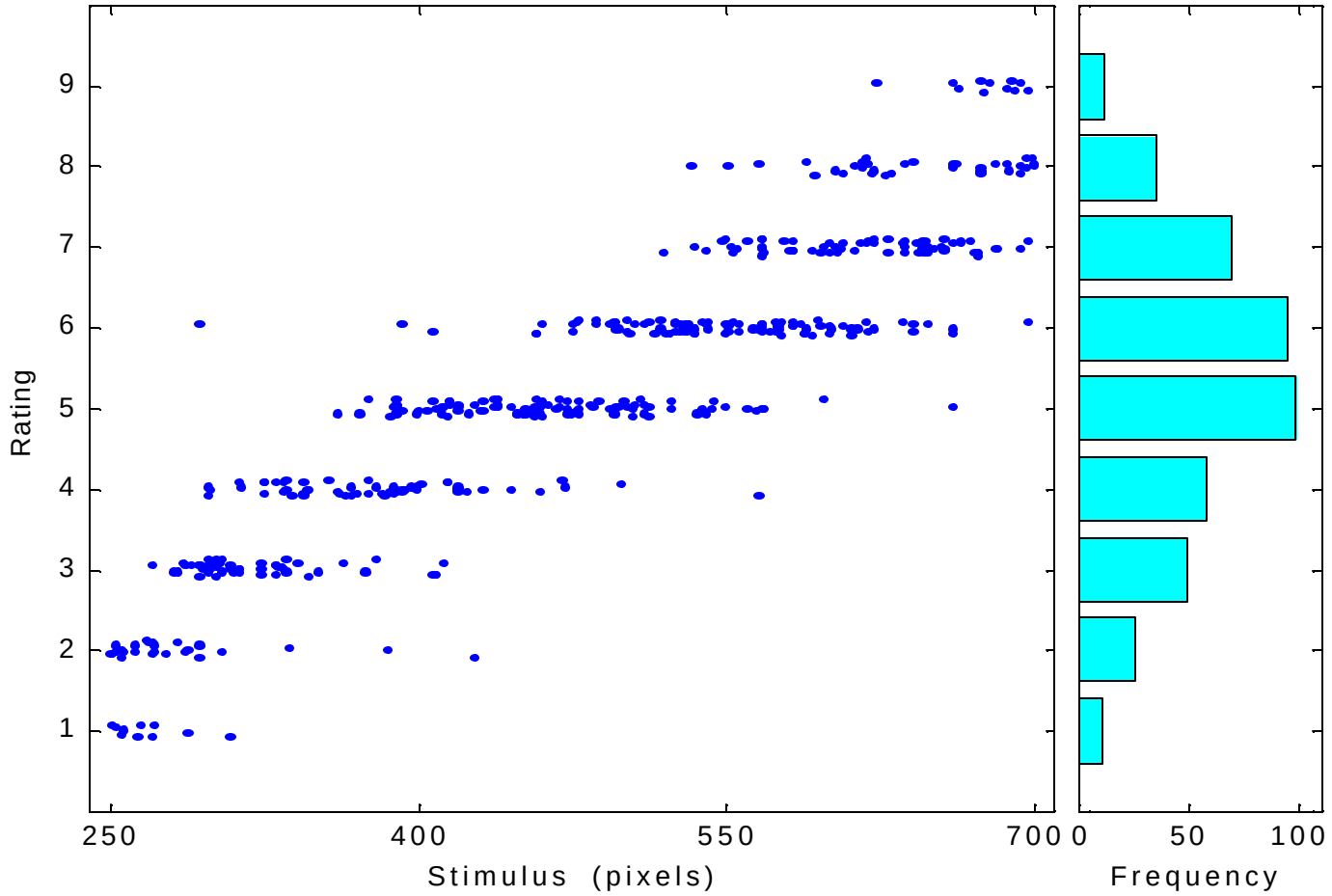
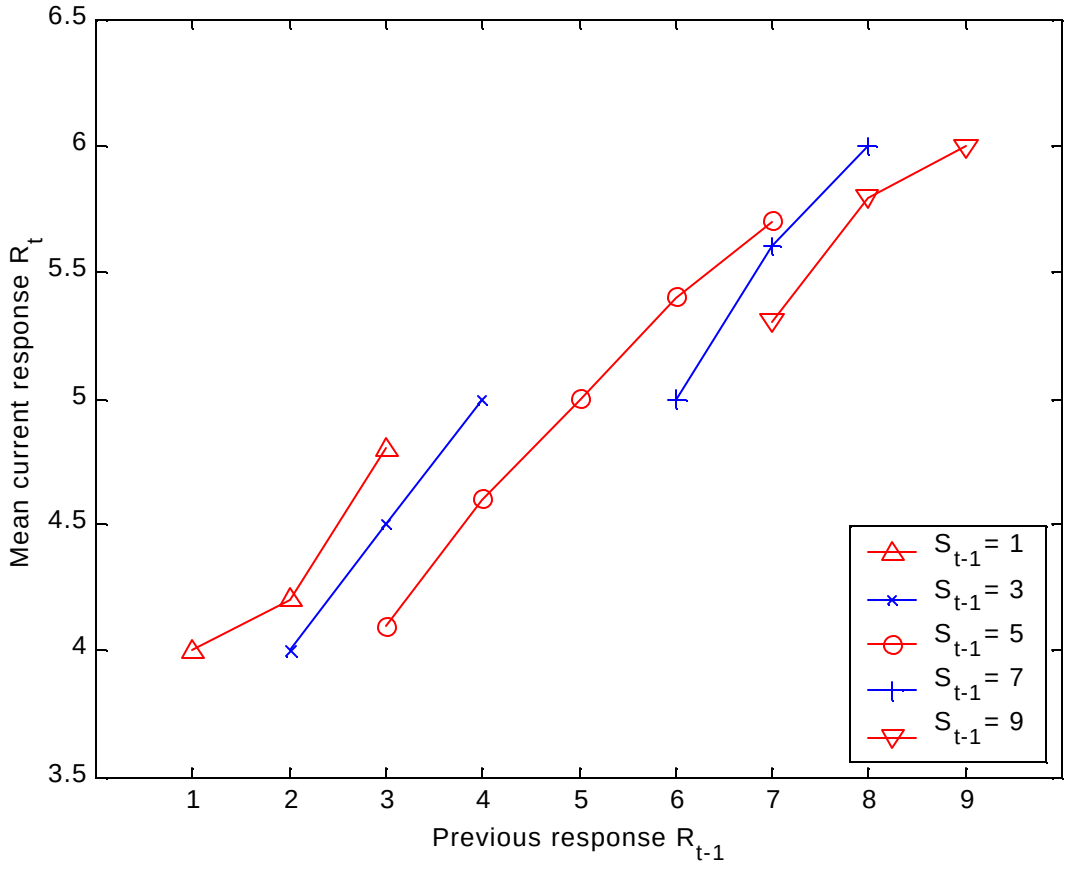


Illustration of Seqential Effects

Synthetic data modeled after real data by



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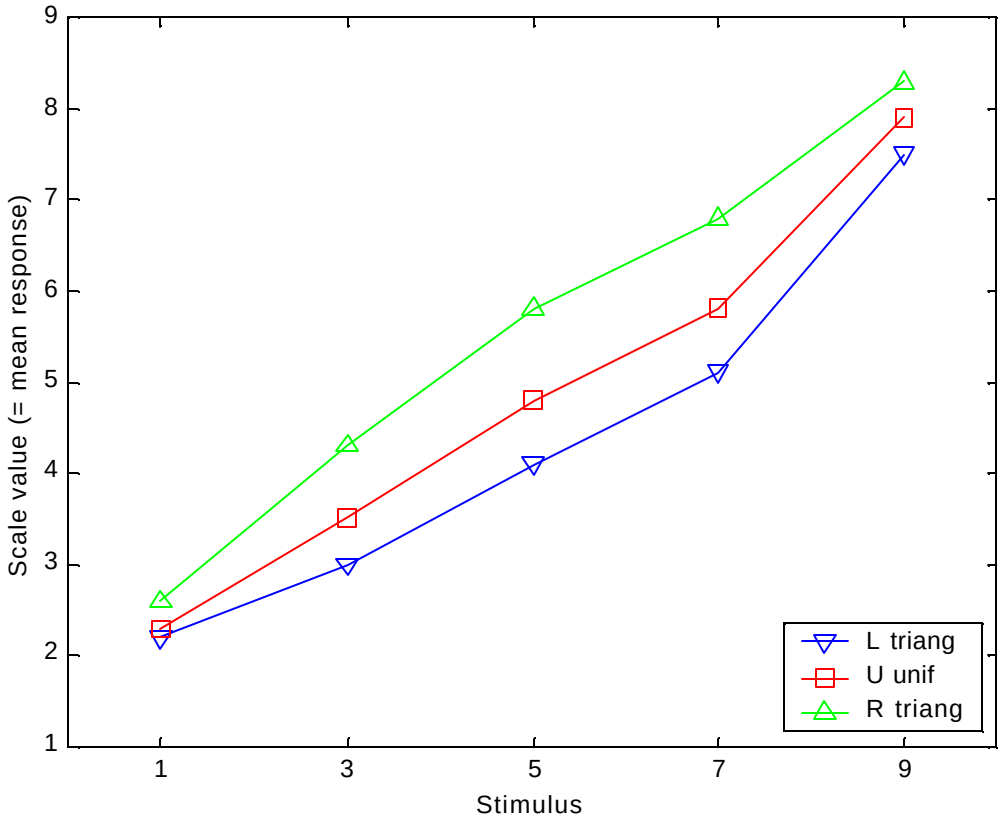
Autoregression Analyses

$$R_t = \text{const} + a.S_t + b.S_{t-1} + c.R_{t-1} + \text{err}$$

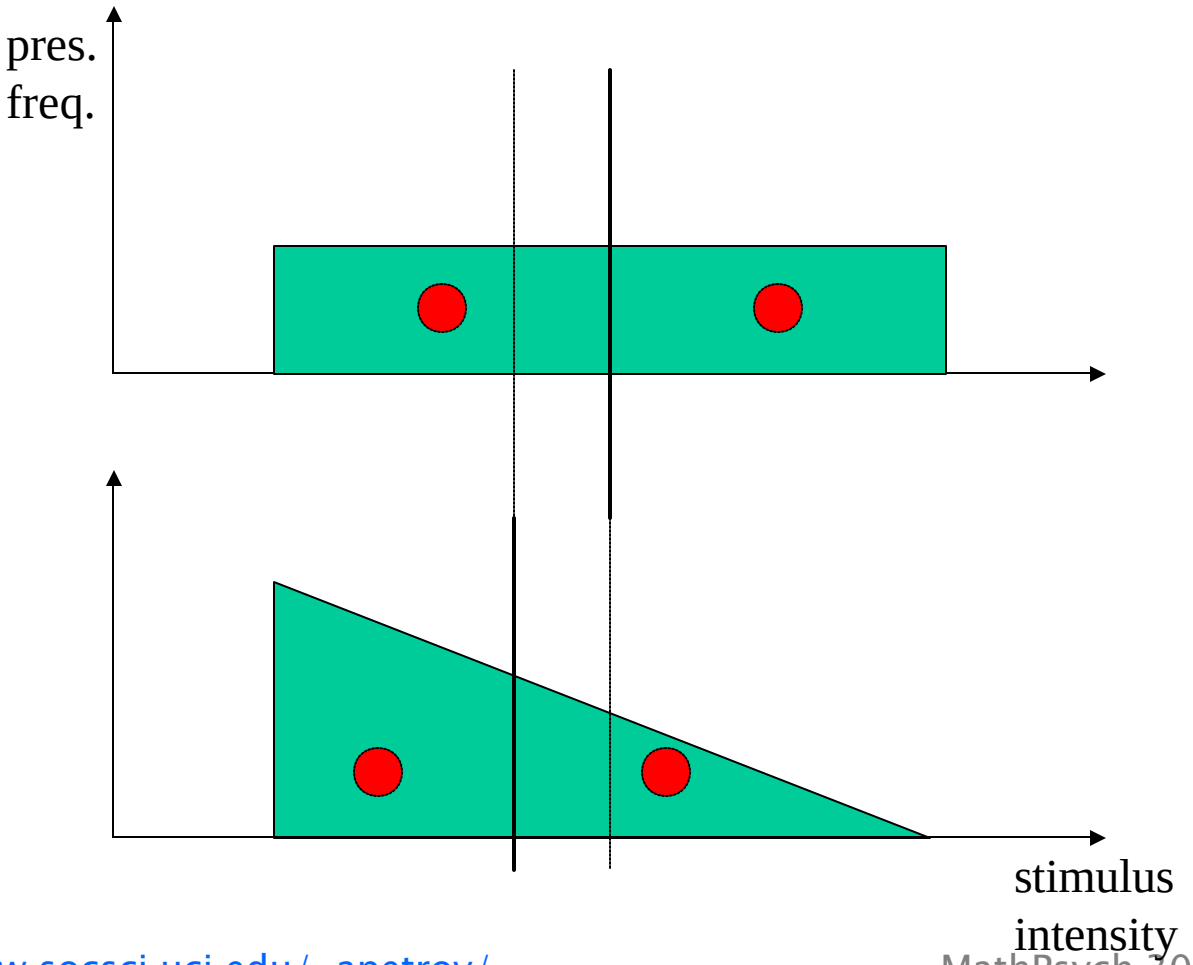
- contrast: $b < 0$
- assimilation: $c > 0$
- interaction terms can be added

Context Effects

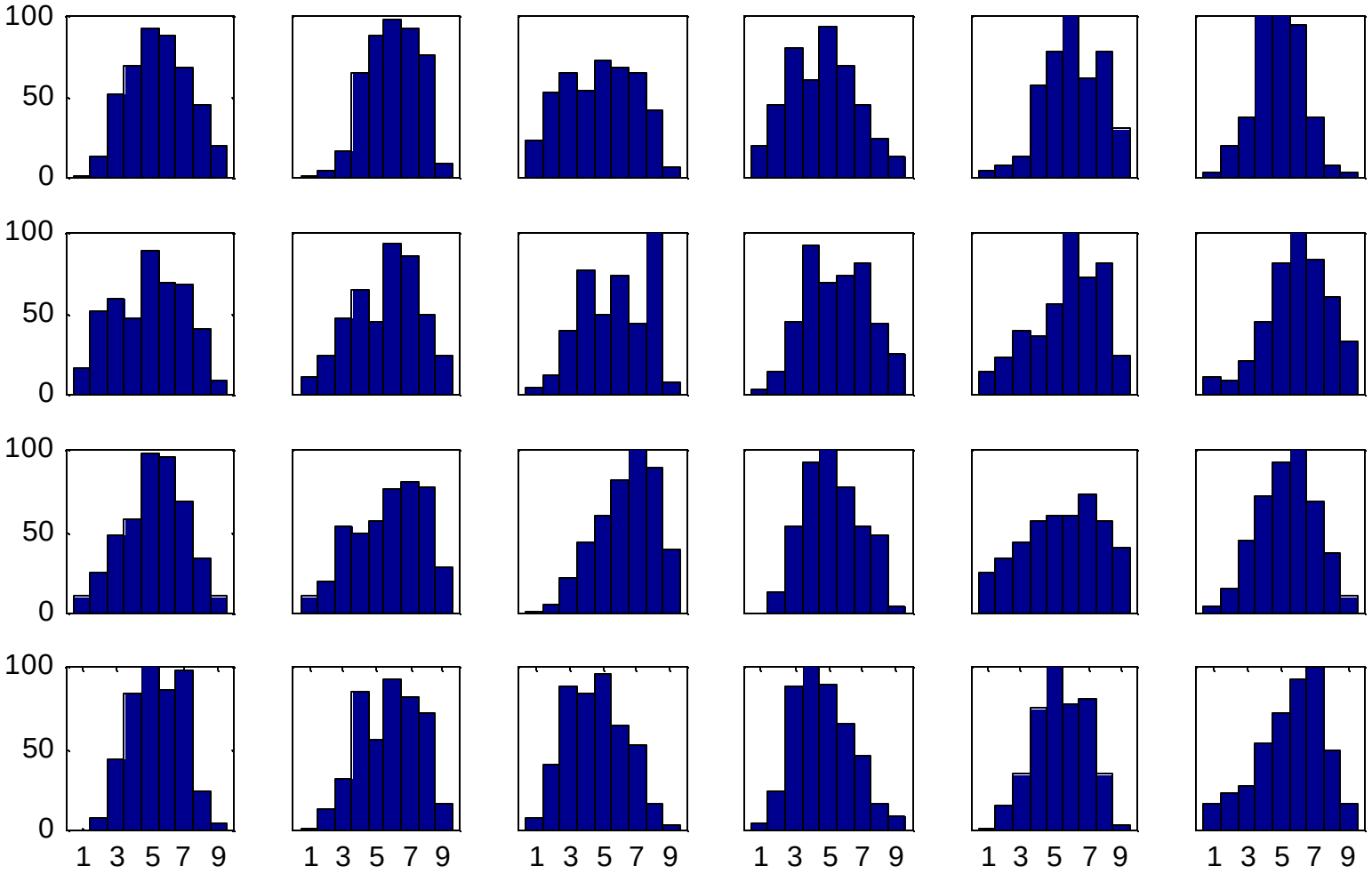
Synthetic data modeled after real



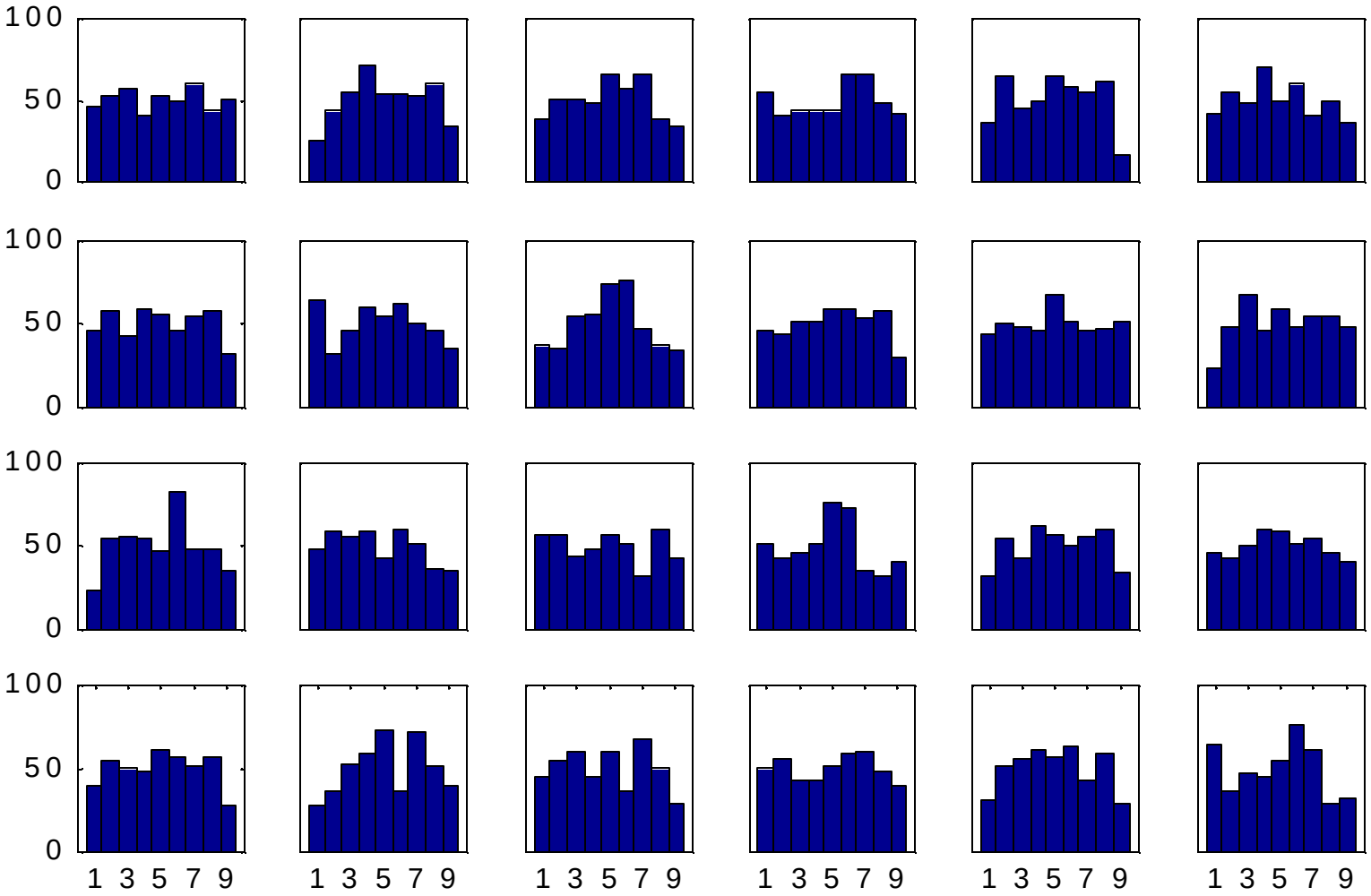
Context Effects



Response Distributions (CR)



Response Distributions (AI)



ACT-R Interpretation

- each anchor is a chunk
- retrieval via partial matching
- base-level activation determines availability

$$G_i = -\left|M - A_i\right| + HB_i$$

$$P_i = \frac{\exp(G_i / T)}{\sum_j \exp(G_j / T)}$$

Connectionist Interpretation

- pattern completion in an attractor network

OR

- winner-takes-all cluster

OR

- Kohonen network

$$G_i = -\left|M - A_i\right| + HB_i$$

$$P_i = \frac{\exp(G_i / T)}{\sum_j \exp(G_j / T)}$$

Base-Level Activation

$$B = \ln\left[\sum_{l=1}^{n} t_l^{-d}\right]$$

$$B = \ln\left[t_{last}^{-d} + \frac{n.\left(t_{life}^{1-d} - t_{last}^{1-d}\right)}{(1-d).(t_{life} - t_{last})}\right]$$

$$B = \ln\left[t_{last}^{-0.5} + \frac{2n}{(\sqrt{t_{life}} + \sqrt{t_{last}})}\right]$$

ANCHOR vs Criterion-Setting Theory

- internal magnitude M
- anchor <M,R>
- recency term in BLA
- strength term in BLA
- base-level learning
- decay of base-level act.
- anchor-location learning
- exp-weighted averaging
- correction mechanism

- central effect S_{it}
- criterion $<S_c,R>$
- response indicator traces T_r
- <no equivalent>
- tracking mechanism
- decay of T_r (response IT)
- stabilization mechanism
- decay of T_s (stimulus IT)
- lateral shift function
- reference z_0 for each criterion
- link to 2AFC tasks