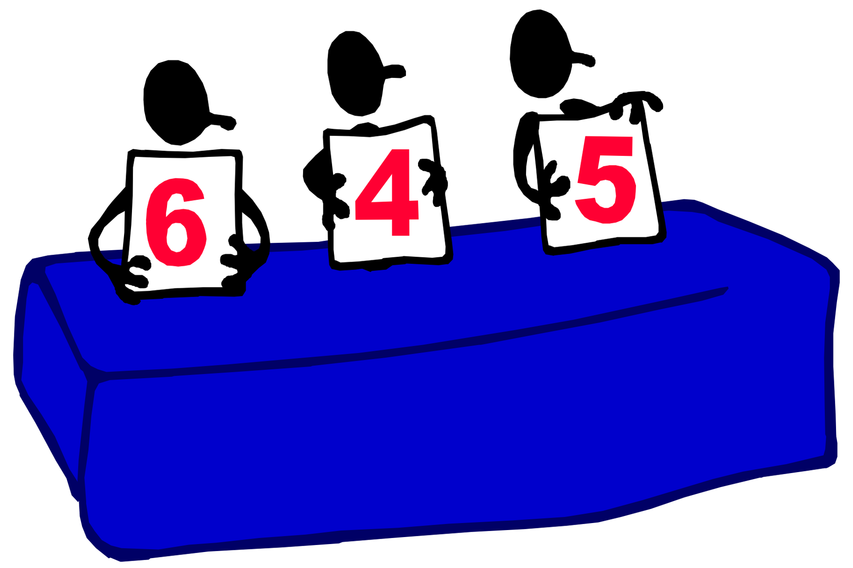

Non-Stationary Response Distribution: A Telltale Sign of the Dynamics of Category Rating

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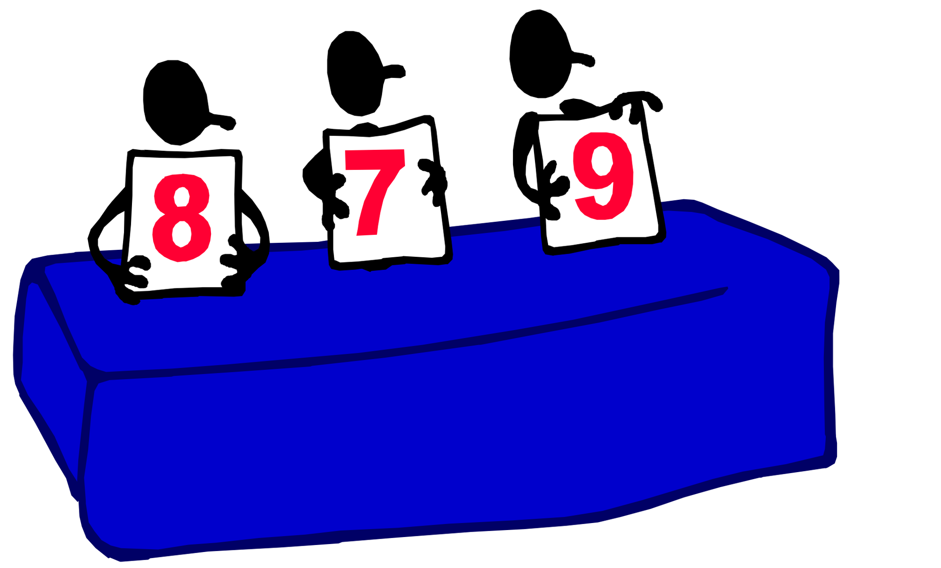


Motivation

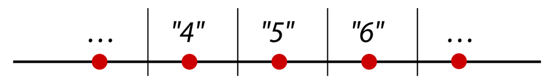
- -- Category rating is very widely used.
- -- Absolute identification is theoretically important.
- -- **Testbed for the dynamics of cognition.**
- -- A number of well-established empirical regularities.
- -- Integration of psychophysics and memory.
- -- Continuous magnitudes in the ACT-R architecture.
- -- Detailed, precise data are very easy to collect.

Main Ideas

-- Internal magnitude continuum

S → [perceptual subsystem] → *M* → [cognitive subsystem] → *R*

-- Prototype-based categories



-- Each *anchor* is an <*M*,*R*> association

-- Content-addressable memory

A set of anchors compete to match the perceived magnitude ***M*** of the target stimulus ***S***. Anchor selection is probabilistic and sensitive to similarity, frequency, and recency. One anchor is selected on each trial and provides a reference point in the vicinity of the target, thereby converting the global scaling problem into a local comparison problem.

-- Explicit correction strategies

People are aware of the unreliablity of their "first gueses" and adopt explicit correction strategies. For instance, if the anchor magnitude is greater than the target magnitude, the observer may respond one category higher than the response associated with the anchor.
These explicit corrections have far reaching consequences:
- they introduce prior knowledge about numbers (and scaling in general),
- they generate novel responses not currently represented in memory,
- they promote homomorphism between stimuli and responses,
- they stabilize the dynamics of the system in the absence of feedback.

-- Incremental learning

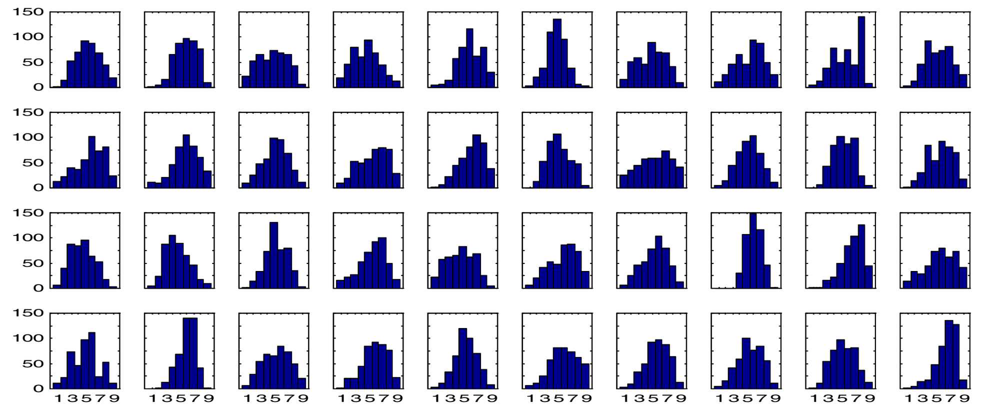
Two learning mechanisms continuously update the *locations* and *base-level activations* of the anchors, tracking the statistics of the environment and giving rise to sequential, context, transfer, and other dynamic effects.

-- The scale unfolds as an adaptive map

A system built on these principles converges reliably to a coherent global scale starting with a single arbitrarily placed anchor.

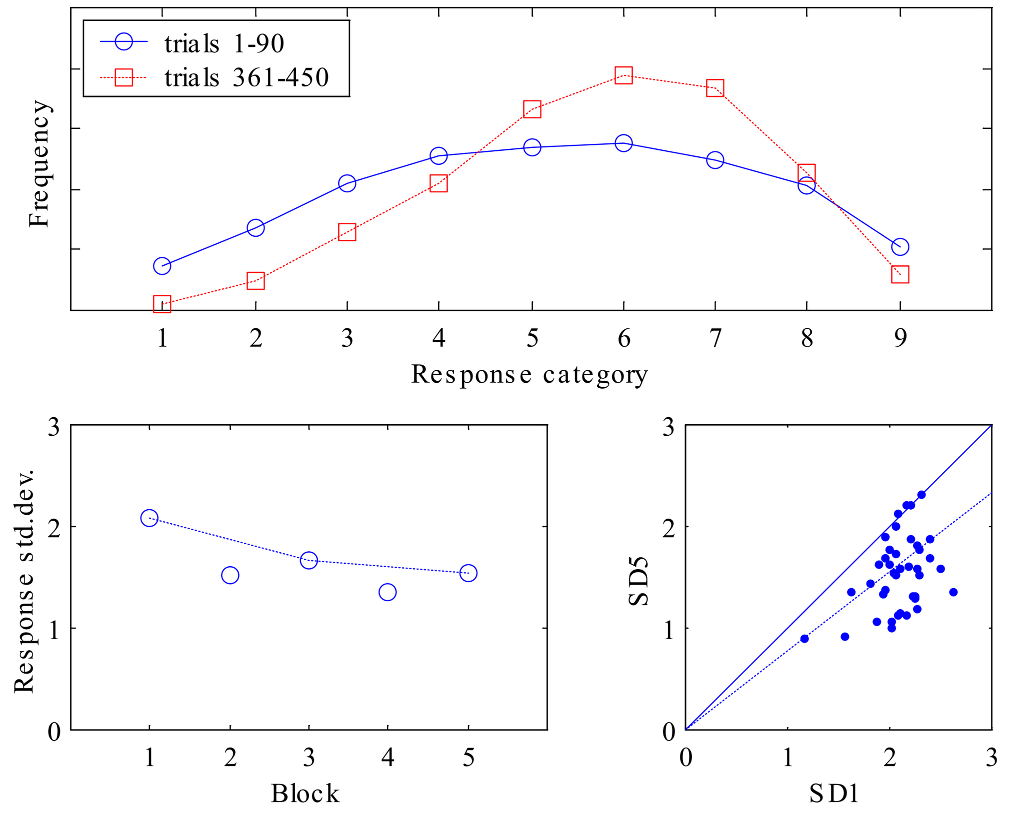
-- ANCHOR: A dynamic process model

Non-Uniform Responses



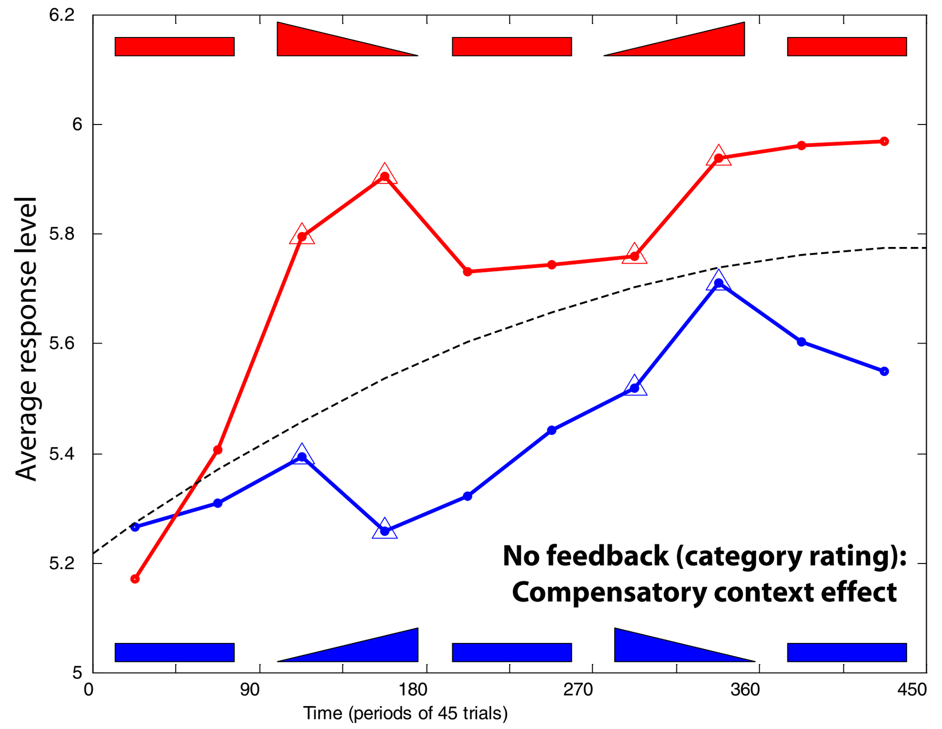
Response histograms for 40 individual observers who rated lengths of lines on a 9-point scale. The response distribution is consistently non-uniform despite the uniformity of the stimulus distribution. Note the generic unimodal shape.

Non-Stationary Responses

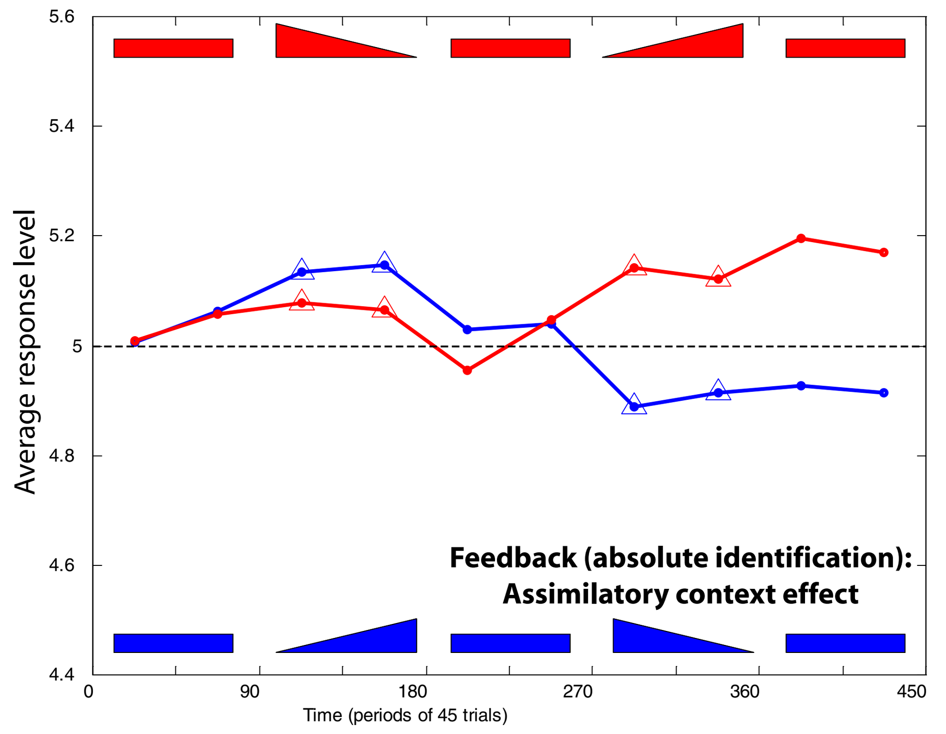


The response distribution becomes progressively less uniform over time. The overall response histogram is significantly more peaked during the last experimental block (red line on top) than during the first block (blue line). The standard deviation of responses decreases steadily both in the group average (bottom left) and in the individual data (bottom right). These slow trends (and other sequential effects not shown here) indicate that category rating is a dynamic process driven by a gradually evolving internal state.

Context Effects

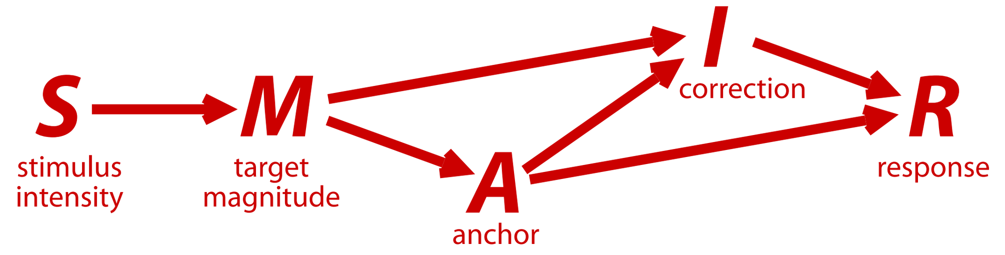


The average response level (ARL) changes over time -- both endogenously and due to external factors such as the relative presentation frequencies of the stimuli. The stimulus distribution was manipulated within and between subjects in a category-rating experiment without feedback. Rectangular and triangular distributions skewed in different directions alternated in blocks of 90 trials each as schematized above. Group 1 (red, 20 Ss) had a *low context* early and a *high context* late in the presentation sequence; counterbalanced Group 2 (blue, 20 Ss). The spontaneous gradual upward drift of the average response levels in both groups is one more manifestation of the non-stationarity of responses. There is **compensatory context effect** as well -- the ARL goes up when short stimuli dominate and down when long stimuli dominate. There are also transfer effects to subsequent uniform blocks. The ANCHOR model accounts for all phenomena.



The context effect reverses direction in an analogous absolute-identification experiment. With feedback, the ARL goes down when short stimuli dominate and up when long stimuli dominate the presentation schedule. Activation learning in ANCHOR induces assimilaiton while competitive learning induces compensation under skewed stimulus distributions. As competitive learning is silenced by external feedback, the model predicts both kinds of context effects.

ANCHOR Model



Perceptual Magnitudes: $M = \underbrace{aS^n}_{\text{Consistent with Stevens' law}}(1 + \underbrace{k_p\varepsilon_p}_{\text{Multiplicative perceptual noise. Consistent with Weber's law}})$

Anchor Magnitudes: $\underbrace{A_i}_{\text{Current magnitude of anchor } i} = \underbrace{L_i}_{\text{Current location of anchor } i}(1 + \underbrace{k_m\varepsilon_m}_{\text{Multiplicative memory noise}})$

Probabilistic Anchor Selection:

Goodness score of anchor *i*: $G_i = \underbrace{-|M - A_i|}_{\text{Similarity to the current target}} + \underbrace{HB_i}_{\text{Base-level activation of anchor } i \text{ reflecting the frequency and recency of use of response "}i\text{"}}$

Probability of selecting anchor *i*: $P_i = \dfrac{\exp(G_i/T)}{\Sigma_j \exp(G_j/T)}$ The selection-noise parameter *T* controls the degree of randomness.

Explicit Corrections

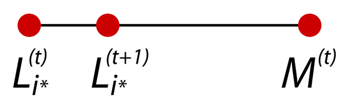
An introspective report of a trial might go like this:
"I see the stimulus... It looks like a 7... No, it's too short for a 7; I'll give it a 6."

decre-ment by 2	decre-ment by 1	do not correct	incre-ment by 1	incre-ment by 2
	−3c	−1c 0 +0.9c	+2.7c	$\Delta = M - A$

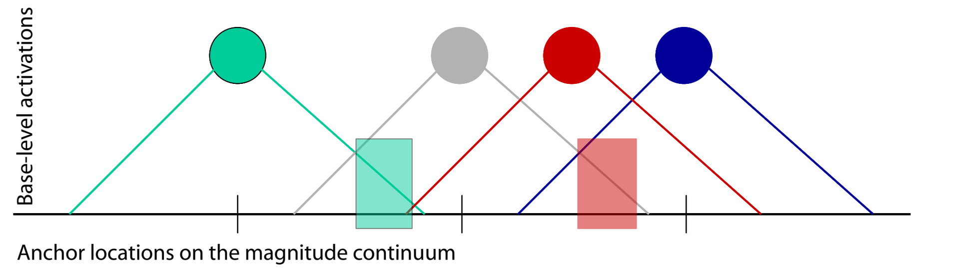
The anchor retrieved from memory establishes a reference point near the target and converts the global scaling problem into a local comparison problem. An explicit correction strategy then increments or decrements the anchor response depending on the discrepancy Δ between the target magnitude *M* and the anchor magnitude *A*. These occasional corrections have far-reaching consequences. They **introduce ordinal relations and enforce the stimulus-response homomorphism** that is so essential for scaling. They **introduce prior knowledge** and stabilize the dynamics of the system, especially in the absence of feedback. The correction mechanism endows ANCHOR with the ability to **generate novel responses** not currently represented in memory. It also **explains the gradual drift of the average response levels** -- upward corrections occur more frequently than downward ones.

Competitive Learning

$$\underbrace{L_{i^*}^{(t+1)}}_{\text{New location of anchor } i^*} = (1-\alpha)\underbrace{L_{i^*}^{(t)}}_{\text{Old location of anchor } i^*} + \alpha \underbrace{M^{(t)}}_{\text{Current target is averaged in}}$$



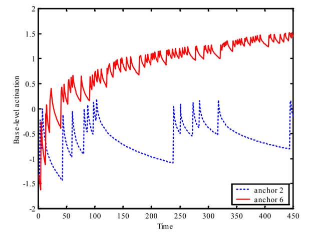
The target magnitude M is averaged into one of the anchors at the end of each trial. When feedback is provided, it designates the correct anchor; otherwise the own response serves as the best available estimate. The **anchor magnitudes thus become weighted prototypes** of the stimuli classified in the respective categories. The anchor magnitudes track the stimulus density and **the scale unfolds as an adaptive map** constrained by the ordering imposed by the correction mechanism. If the stimulus distribution changes, the anchors shift accordingly.

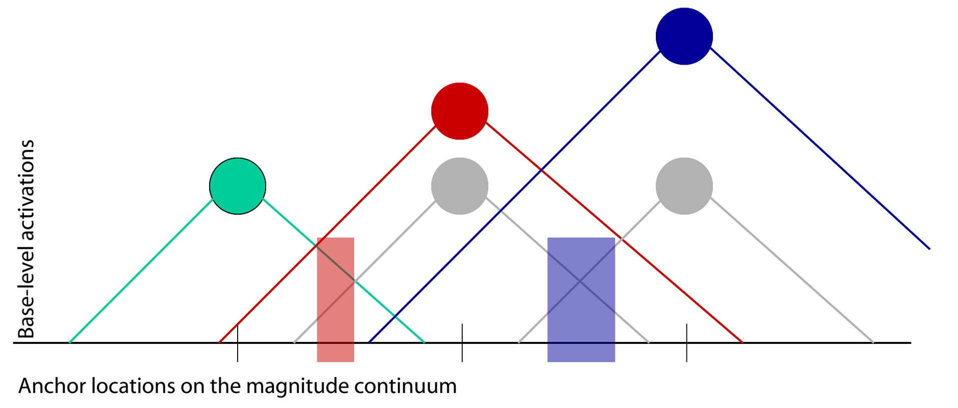


Competitive learnig leads to a compensatory context effect under skewed stimulus distributions. If disproportionately many long stimuli are averaged in, for instance, the anchors tend to shift to rightwards as illustrated in the figure. As a result, an area of the continuum formerly labeled "2" is now labeled "*1*," and an area formerly labeled "*3*" is now labeled "*2*." The average response level thus shifts away from the heavy end of the distribution. External feedback silences this mechanism.

Activation Learning

General memory mechanism motivated by priming, sequential assimilation, base-rate effects and many other phenomena. Used in the ACT-R architecture:
-- sharp transient peak immediately after use,
-- gradual decay in the absence of use,
-- gradual buildup of strength with frequent use.
Tracks the response frequency and recency.





Activation learnig always leads to assimilative context and sequential effects.

Summary

We propose a theory bridging the gap between psychophysics and memory. Two behavioral experiments consolidate the scattered literature on category rating and absolute identification and uncover novel phenomena. The response distributions are noticeably non-stationary and non-uniform even when the stimulus distributions are stationary and uniform. The context effect induced by skewed stimulus distributions reverses direction depending on the presence or absence of feedback.

An adaptive memory-based model called **ANCHOR** accounts for these and various other dynamic phenomena. A set of anchors compete to match the perceived magnitude of the target stimulus. An explicit correction strategy corrects most (but not all) memory fluctuations. Incremental competitive learning updates the location of the anchors and activation learning updates their availability. The response scale unfolds as an adaptive map from a single arbitrarily placed anchor. The correction strategy generates novel responses and enforces the local consistency of the stimulus-response mapping whereas competitive learning consolidates this local consistency into a global homomorphism.

As ANCHOR reinforces its own responses during category rating without feedback, its dynamic stability depends vitally on the correction mechanism. The central peak in the response distribution emerges from this controlled self-reinforcing activation dynamics. Under skewed stimulus distributions, activation learning induces assimilation while competitive learning induces compensation. The direction of the overall context effect depends on the relative strength of these competing tendencies. Interestingly, as competitive learning is silenced by external feedback, the context effect reverses direction during absolute identification exactly as in the behavioral data.

References:

Petrov, A. A. & Anderson, J. R. (2005). The dynamics of scaling: A memory-based anchor model of category rating and absolute identification. ***Psychological Review***. http://www.socsci.uci.edu/~apetrov/pub/biganchor/
(For the abstract associated with this poster, see Petrov (2004) in the *Abstracts of the Psychonomic Society*, *9*, 4097. http://www.socsci.uci.edu/~apetrov/pub/psnom04/)