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Comparable Perceptual Learning With and Without Feedback in Nonstationary Context: Data and Model

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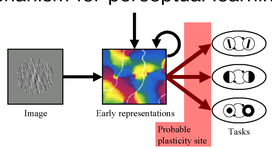
Main Ideas

- Selective reweighting is a primary mechanism for perceptual learning:

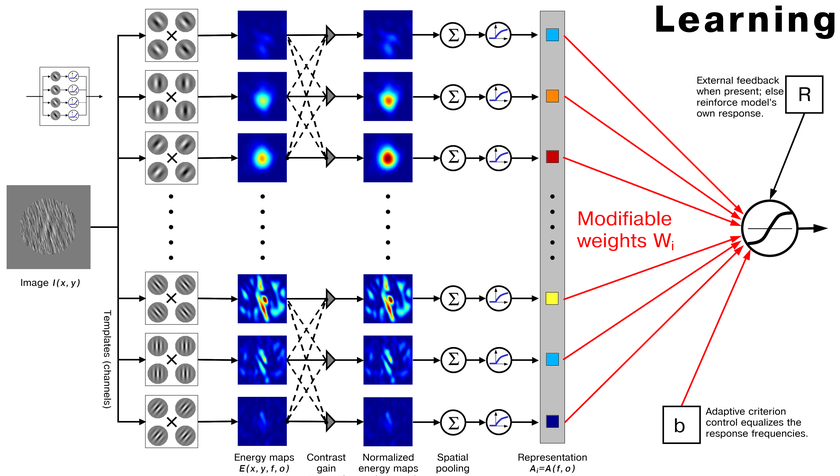


- Incremental Hebbian learning adjusts the weights guided by local task-dependent correlations:

$$\Delta W_i \propto A_i\,(R-\langle R\rangle)$$

- Self-supervised learning with no explicit feedback can be almost as efficient as externally supervised learning.
- A detailed computational model built on these principles accounts for the context-dependent learning dynamics in a non-stationary environment.

Fixed Early Representations + Hebbian Learning



Experiment Method

Orientation discrimination of peripheral Gabor targets embedded in "contexts" of filtered noise. The same targets are used throughout; the context alternates in an A-B-A-B-A schedule. The stimuli are designed to have very similar spectral content and hence activate largely overlapping representational substrate. Targets are either ***congruent*** or ***incongruent*** with the predominant noise orientation.

Observers were instructed to ignore the background and indicate the target orientation: -10^o="Left", $+10^o$="Right". 13 Ss received auditory feedback on each trial; 18 Ss received no feedback, only a short demo on day 1. 1200 trials/day, 2400 trials/epoch, ≈10000 trials total. The stimuli were presented at two equiprobable locations 5 degrees above or below fixation. Gabor spatial frequency 2 cyc/d.

Acknowledgement

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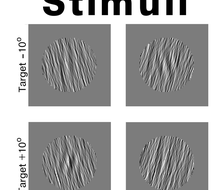
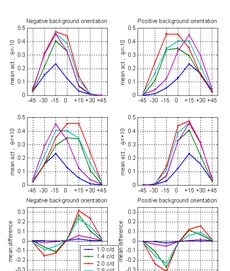
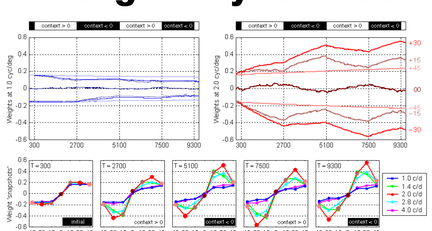
Stimuli



Three target contrasts (not shown). Context noise orientation fixed in each epoch. Alternates b/n epochs.

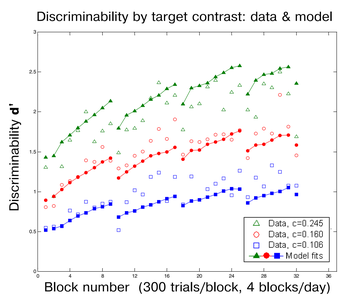


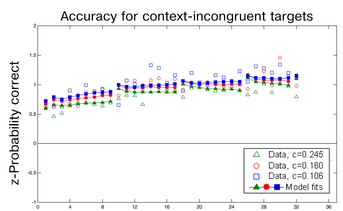
Weight Dynamics

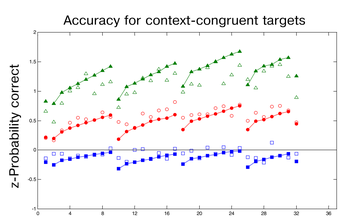


Context-Dependent Switch Costs

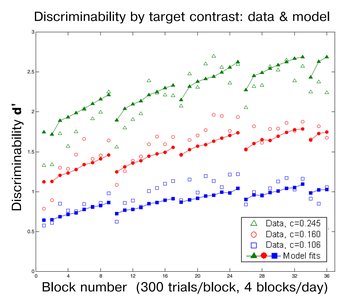
Feedback

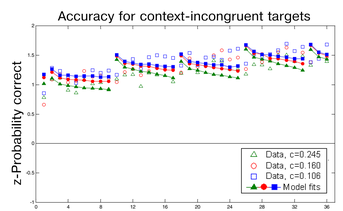


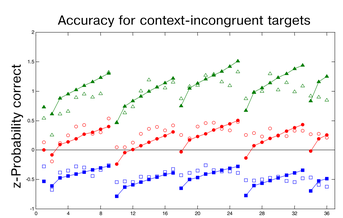




No Feedback







Summary

A fully implemented, biologically plausible model takes images as inputs and produces discrimination responses as outputs. The stimuli are first processed by standard orientation and frequency tuned units, divisively normalized. Learning occurs only in the "read-out" connections to the decision unit; the stimulus representations never change. An incremental Hebbian rule tracks the external feedback when available, or else reinforces the model's own response. An a priori bias to equalize the response frequencies stabilizes the model across switches.
The excellent quantitative fits to a challenging data set demonstrate that Hebbian channel reweighting, with no change in the early visual representations, is sufficiently powerful to account for perceptual learning. The model handles both the feedback and the no-feedback data with essentially the same parameters, demonstrating that self-supervised learning can successfully compensate for the lack of environmental feedback in perceptual tasks. The main empirical results, and their interpretation, are:

- ***Training improves performance in all conditions.*** The selective reweighting mechanism continuously "tunes in" the representational features diagnostic for the task and "tunes out" the irrelevant ones.
- ***The feedback and no-feedback data show essentially the same pattern.*** Self-supervised learning updates the weights in the right direction because the accuracy is always greater than chance.
- ***The absolute d' depends strongly on the target contrast; the temporal dynamics is largely independent of it.*** The same set of weights is applied in all cases.
- ***Partial context sensitivity: Each context change incurs a transient switch cost superimposed on the main learning curve.*** The two environments have different statistical structure. Hence the weights optimized in one context are not optimal in the other. Due to the slow learning rate, the system works with suboptimal weights after each switch until it readapts.
- ***Switch costs recur reliably for at least 5 switches and 10000 trials.*** No single set of weights exists that can maximize discriminability in both contexts.
- ***For context-congruent targets, accuracy ($P_{correct}$) decreases slightly with increasing Gabor contrast; for incongruent targets it increases greatly.*** As the congruent "channel" is compromised by noise, the system assigns greater weights to the incongruent one. Coupled with the compressive nonlinearities in the representations, this "off-channel looking" explains the counterintuitive reversal for congruent stimuli.
- ***A small but persistent response asymmetry favors the background orientation.*** The criterion control mechanism compensates for most of this natural imbalance, but not all.