# An Introduction to Perceptual Learning

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## Perceptual Learning - Definition

- Perceptual learning (PL) is the improvement in performance on a variety of simple sensory tasks, following practice.
  - PL is implicit (procedural) –
    - no conscious awareness of changes
    - progresses even in absence of reward
    - Unfolds automatically on repeated exposures
  - Some characteristics
    - Improvement tends to persist over weeks and months making it different than sensitization, habituation and priming.
    - Is often specific for the exact task trained

## Prerequisites of Models of PL

- It must describe the way the sensory world is represented by neuronal activity in the sensory areas of the brain.
- It must describe the changes that occur in the sensory pathways when PL occurs.

## A Practical Problem

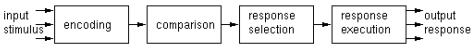
- How can primary circuits undergo repeated changes that result from leaning, but simultaneously be able to operate in tasks that have already been learned?

## Main Models

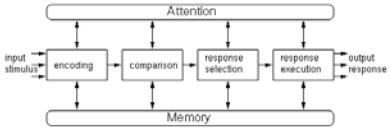
- Feedforward Network
- Recurrent Network
- Reverse Hierarchy
- Early Selection
- Late Selection

## Digression – Information Processing

- Simple linear information processing (IP) model.

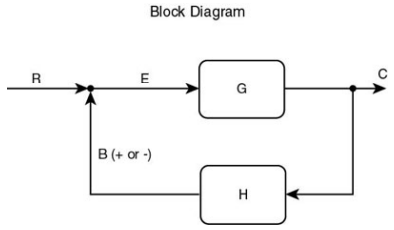



- Slightly more complex with attention and memory added in.

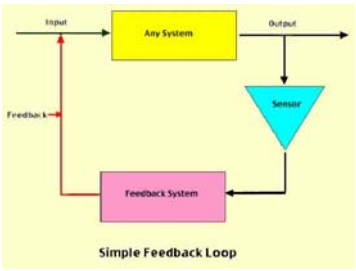


## What about feedback?

- Basic or simple feedback from the output back to the input.



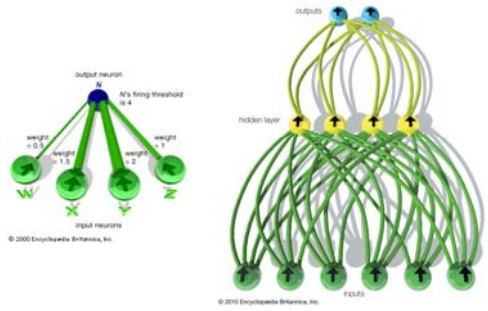

## IP Feedback with a sensor




## Back to PL – Feedforward

- First attempts to understand begin with feedforward:
  - System does move in one direction
  - Based on a limited number of input units it yields specific read-outs that improve very specifically and quickly during training.
  - Main drawback is that it relies on a teaching signal – yes/no – correct/incorrect.

## Feedforward Weighting - Hebbian




## Reverse Hierarchy

- The theory that easy conditions guide the learning of difficult ones.
- Improvement begins at higher cortical levels and proceeds to lower-levels if necessary.

## Early Selection Theory

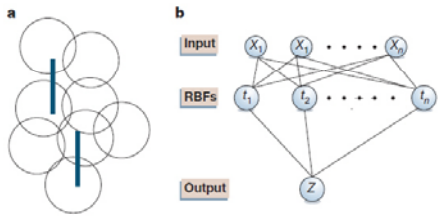
- In PL, irrelevant signals should be eliminated as early as possible during cortical information processing.
- Thus, PL might change processing at rather "early" stages of cortical signal processing.
  - In talking about efferent fibers, here in the auditory system, "Similar to the situation in the visual system, noise is eliminated at an early level; hence loss of efferent feedback (to the cochlea) degrades auditory perception in noise."

## Late Selection Theory

- In PL, irrelevant signals should be eliminated at a relatively late stage of cortical information processing, leaving the peripheral cortices unchanged.
- Selection of the most suitable (salient) features is done at late stages in processing.
  - "PL seems to improve elimination of external noise, and it does this by retuning the internal templates."

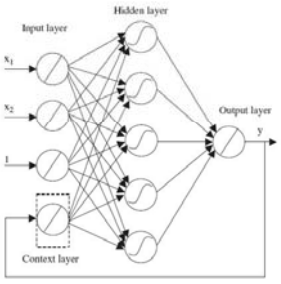
## Early model by Poggio for hyperacuity

- Network underlying training of hyperacuity or Vernier Acuity

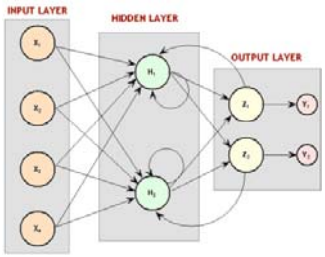



## Let's add in some feedback – but where?

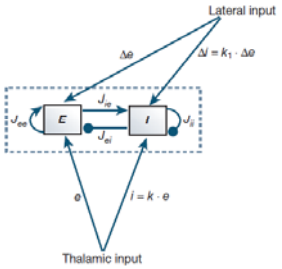
- Feedback can be from the output layer to the input layer directly.




## Feedback might be to the hidden layer



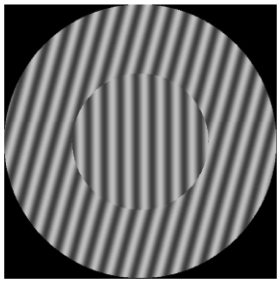

## Or it might be exclusively within a layer between excitatory and inhibitory sites.




## No teaching signal needed

- A fundamental feature of this system of Adini is that it does not require a feedback teaching signal.
- Characteristics from practice:
  - Changes in orientation tuning occur if during training the (E)excitatory cells influence are weakened slightly. Then the orientation of those cells becomes sharper.
  - If both the (E)excitatory and (I)inhibitory influences are weakened in a balanced way this leads to the "tilt illusion".
  - "Although recurrent networks provide a more realistic setting as a substrate for PL, training them to produce an optimal performance on a task is in general an unsolved problem."

## Tilt Illusion



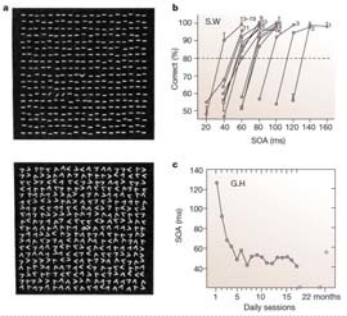
## A few limitations

- If a subject is trained on a discrimination task at one location in space, the improvement in performance is relatively specific for that location and does not transfer to other locations in the same sensory map.
- This may work up to about $8^0$ away but there is no transfer across the midline!
- Learning on one task only shows transfer to another task to the degree that both tasks have elements in common.

## Time-Course work

- General
  - Initial period of fast learning
  - Later period much slower learning but it does continue
- Possible Mechanisms
  - Early phase: new cells/units are added to the intermediate layer.
  - Later phase: architecture of the network is fixed but the parameters adapt to their optimal levels.
  - In a complex network both phases may overlap with each other.

## Time-Course – Texture Discrimination




## Time-Course – The role of sleep

- "New experimental data have broadened the evidence that consolidation of improvement achieved through PL requires sleep. Both sleep and restful waking facilitate auditory tone learning."

## How hard do you need to work to get changes?

- The amount of PL is proportional to the number of trials taken.
  - In low level discrimination only no reward is needed.
  - "Although learning can occur in the absence of feedback, feedback can facilitate learning."

## Longevity of changes

- "A striking long-term stability of the improvement in performance is observed in certain tasks." (Karni and Sagi) Later – "up to three years"
- A dilemma as yet unexplained: "Obviously, neurons in these areas are constantly responding to a continuous stream of sensory inputs that should, with time, wipe out specific traced produced by training."
- Related dilemma: "Even luminance contrast training improves through training, and generalizes across orientations. This finding is surprising given the fact that humans should be overtrained for contrast detection through everyday life, especially under low illuminances."

## Top-Down / Attention Influences

- In most instances of PL the subject must attend to the trained stimulus for improvement to occur. – This is evidence of top-down influences on learning.
- "The role of cortical feedback is little understood, but increasing evidence for attentional influences at early stages suggests that feedback may be involved in transmitting this kind of cognitive control."
- "To prevent interference of learning one task with performance in other tasks, the changes achieved on early levels have to be activated, in a task-dependent way, by top-down signals."

## Some Real-World Findings

- Improvement achieved through PL generalizes more for complex tasks than for simpler ones.
  - "Playing action video games indeed seems to generalize to other tasks, and in visual search, both specific features and a global search strategy are learned."
  - "Visual training through reading text seems to modify the way people perceive printed words: reading-related training improved perception of words but not of non-words."
  - "Moreover, the size of the visual span expands through training, with an associated increase in maximum reading speed."
  - "These results encourage the use of PL in visual rehabilitation."

## Implications for us

- Is the term "Perceptual Learning" to become the next term used for VT?
  - What benefits would accrue if it did?
  - What negatives might follow?
- We should understand this emerging field as it may:
  - Help make explicit the reasons for our successes and failures and add to our evidence-base.
  - It may open up doors to collaboration and funding that might stay closed if we don't become informed and reach out across fields.

## Thanks.

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