Maintaining stable perception during active exploration

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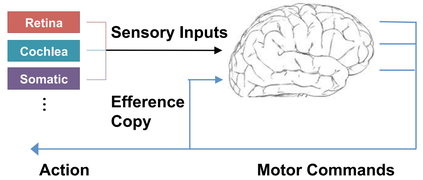
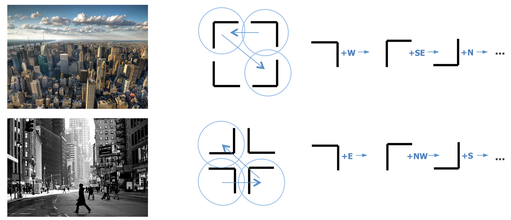
Overview

1. Cortex builds a sensorimotor model

- **Most sensory changes are rapid and due to our own behavior …but our perception of the world is amazingly stable**
- **We know the cortex receives a copy of motor commands**





We learn the structure of the world from sensorimotor sequences through active exploration (Gibson 1988; Bushnell and Boudreau 1993)

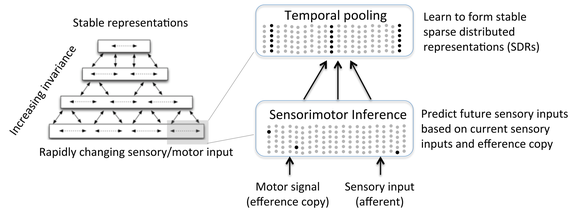
2. How do we learn a sensorimotor model?

Basic Approach

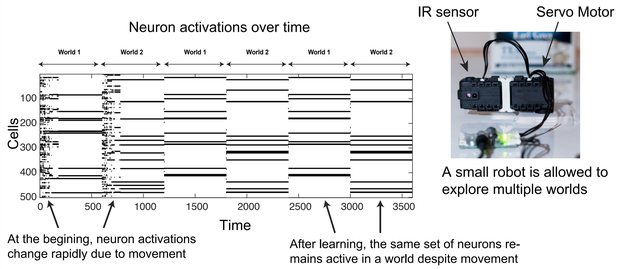
Predictable transitions lead to invariant representations

A. Learn predictive model of sensorimotor changes
B. Learn stable representations of predicted changes

Hierarchical Temporal Memory (HTM)



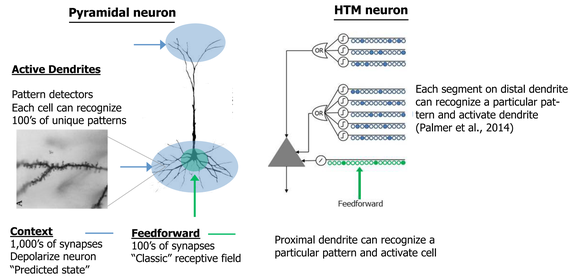
3. Experimental results



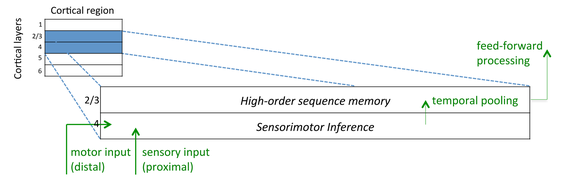
4. Summary

- **We asked the question: how can the cortex build a sensorimotor model of the world?**
- **We proposed a biologically detailed model of sensorimotor inference.**
- **We built and tested the model on a robotic testbed as well as artificial scenarios.**

Neural implementation

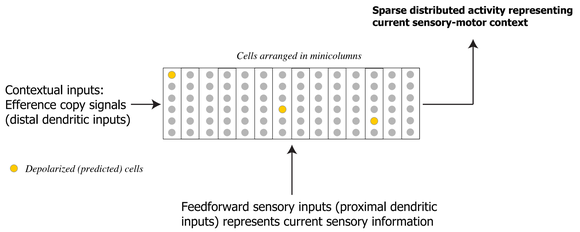


Cortical circuits underlying sensorimotor inference



Algorithm details

Sensorimotor inference layer predicts future sensory inputs

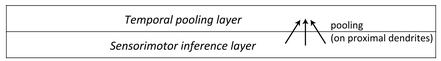


Activation and learning rules:

If any cell in a column is predicted, only the predicted cells fire
- Reinforce active dendritic segments of an active cell using a Hebbian-like rule

If no cell in a column receving feedforward inputs is predicted, all cells in the column fire
- Form a new dendritic segment with connections to a subset of the distal input

Temporal pooling layer forms stable representations



Activation and learning rules:

If input was predicted, keep the currently active columns active

If input was unpredicted, activate columns based on proximal dendritic inputs

For all active columns, reinforce their proximal dendrites using a Hebbian-like rule

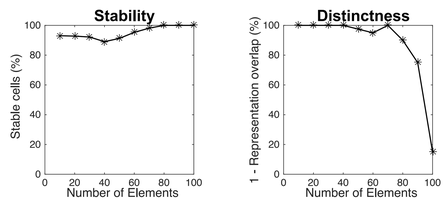
Note: related ideas were proposed as "temporal association rules" (Isik et al. 2012) or "Foldiak's trace rule" (Foldiak 1991).

Scaling experiments: single small level

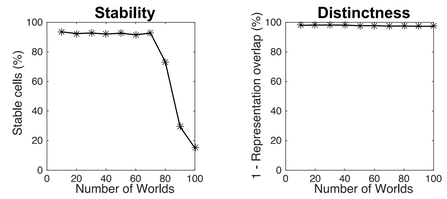
Model performance metrics:

Stability indicates whether the same cells are active each time the same world is seen.
Distinctness indicates whether cells that are active in a world are different from cells active in other worlds.

2 worlds, increasing number of elements



10 elements, increasing number of worlds

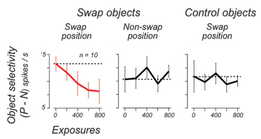


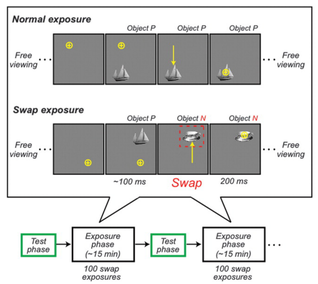
Model parameters: 1024 mini-columns, 2% active at any time

Related experiments

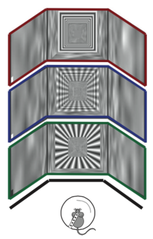
Temporal Pooling in area IT of awake, behaving macaque (Li & Dicarlo 2008)

If two objects consistently swapped identity across saccades, then after sufficient experience in this altered visual world, IT neurons associates the neural representations of those objects viewed at different positions into a single representation.

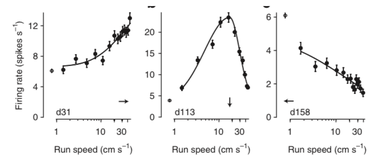




Motor action related signals in sensory cortex (Saleem et al., 2013)



Tuning of V1 neurons for run speed in the dark



References

[1] Bushnell E and Boudreau R (1993) Child Develop 64:1005-1021
[2] Crapse TB and Sommer MA (2008) Nat Rev Neurosci 9(8): 587-600
[3] Foldiak P (1991) Neural Comput. 3: 194-200
[4] Gibson (1988) Annu Rev Psychol 39: 1988
[5] Hawkins J and Blakeslee S, On Intelligence (2004), Henry Holt and Company
[6] Holtmaat A and Svoboda K (2009) Nat Rev Neurosci. 10:647-58
[7] Isik L, Leibo JZ and Poggios T (2012) Front Comput Neurosci. 6: 37.
[8] Li N and Dicarlo JJ (2008) Science 321: 1502-1507
[9] Palmer et al., (2014) Nat Neurosci 17: 383-390
[10] Ringach et al., (2002) J Neurosci 22:5639-5651
[11] Saleem et al., Nat Neurosci 2013; 16:1864-9
[12] Sherman S and Guillery R., (2013) Functional Connections of Cortical Areas: A New View from the Thalamus. MIT press
[13] Wurtz RH (2013) Scholarpedia 8(10): 12335

Acknowledgements

We thank Scott Purdy, Jay Gokhale, Alex Lavin, Ryan McCall for helpful discussions on the algorithm, and Ian Danforth for providing us the robot to test the algorithm.

Our code is open source

We believe in open research, full transparency, and producing high-quality software. Numenta's research and algorithm code is part of the open-source project Numenta Platform for Intelligent Computing (NuPIC). A fast growing project, NuPIC currently has 2,800 "Stars" on Github, 730 forks, and over 1,200 members on three mailing lists.

The core NuPIC algorithm code is used in commercial applications.

We would love to have you involved. For full details please see http://github.com/numenta or contact one of the authors.

NuPIC
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Star 2,821