



Drawing of neurons in the pigeon cerebellum -Santiago Ramón y Cajal in 1899

HTM 101

A quick guide to key concepts in HTM and NuPIC

Chandan Maruthi and Jeff Fohl
NuPIC Open Source Community

What is Numenta?

Numenta is a company that researches and develops machine intelligence technologies based on biological learning principles. It was founded in March 2005. Jeff Hawkins is the Co-Founder of Numenta and Donna Dubinsky is the CEO and Co-Founder. Jeff also founded Palm and Handspring which built handheld computing devices. Numenta has built technology called Hierarchical Temporal Memory (HTM), which is a detailed computational framework based on principles of the neocortex. Numenta also supports the NuPIC open source community where this technology has been made open source through an AGPL license.

What is NuPIC?

NuPIC, or the Numenta Platform for Intelligent Computing, is an open source implementation of Hierarchical Temporal Memory (HTM) written in C++ and Python. Parts of HTM theory have been implemented, tested, and used in applications, and other parts of HTM theory are still being developed. Today the HTM code in NuPIC can be used to analyze streaming data. It learns the time-based patterns in data, predicts future values, and detects anomalies.

What is NuPIC good for?

NuPIC can be used to learn patterns in time-based data streams. It can then make predictions and detect anomalies on the continuously streaming data in real time.

A few examples that have these characteristics are:

- Tracking server performance and monitoring for anomalies.
- Geospatial tracking for finding anomalies in vehicle driving patterns.
- Power consumption monitoring.
- Natural language prediction and anomaly detection.

What is HTM?

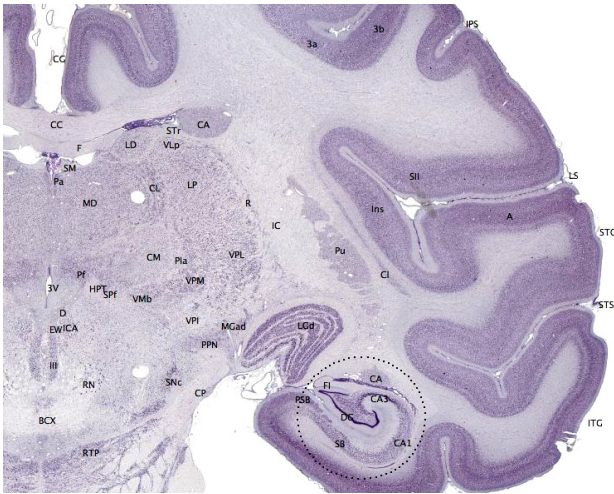
HTM is an acronym for Hierarchical Temporal Memory. It is a theoretical framework that models the way information is processed by the neocortex. The theory maintains that the neocortex processes information in a generalized way. For instance, areas of the neocortex that perceive visual information are not profoundly different from areas that perceive other types of information such as auditory, touch, or smell. The theory also states that the neocortex is organized into many regions, each of which learns through exposure to temporal streams of information. These regions are connected in vast and deep hierarchies. Theoretically, this time-based hierarchical memory structure is what gives rise to what we call “intelligence” in the mammalian brain.

What are all these neuroscience terms?

Cerebral Cortex and Neocortex

The cerebral cortex is the brain's outer layer of neural tissue found in humans and other mammals. The Neocortex is a part of the cerebral cortex. It is made up of six layers, labelled from the outer in, I to VI.

In humans, the neocortex is involved in higher functions such as sensory perception, generation of motor commands, spatial reasoning, conscious thought and language.



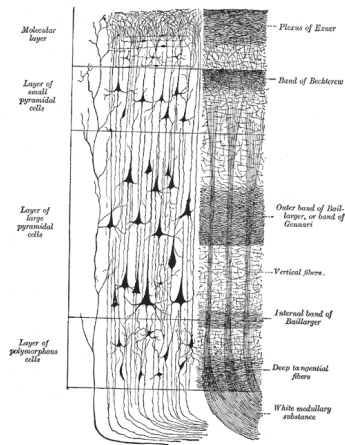
Cross section of a macaque brain, the darker outer layer surrounding the brain is the cerebral cortex. https://en.wikipedia.org/wiki/Cerebral_cortex

Cortical layers

The neocortex is organized into 6 layers, from outside to inside. Current HTM theory holds that the function of each of these layers are:

- Layer I: Consists of connections between regions of the neocortex
- Layers II & III: Learns high-order sequences
- Layer IV: Learns sensory-motor transitions
- Layer V: Recalls motor sequences
- Layer VI: Attention

NuPIC currently only covers the activity of Layers II & III. Active research is being done to model layers IV, V, and VI.



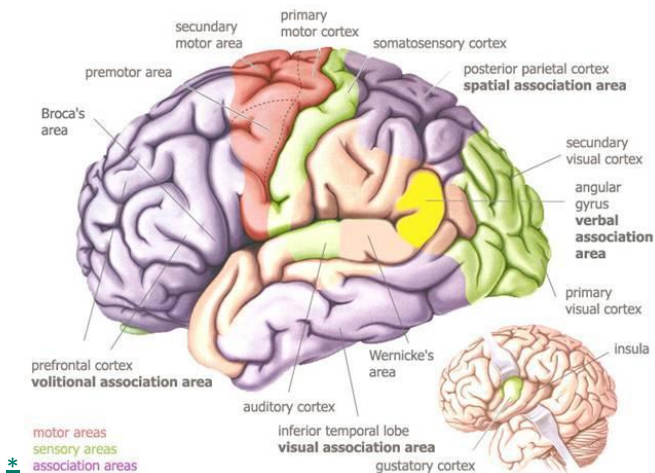
How can I find out more?

https://en.wikipedia.org/wiki/Cerebral_cortex#Layered_structure

Cortical regions

Different regions of the brain are considered to play key roles in different functions. This has been possible by studying activity in different parts of the brain when different types of stimulus is provided.

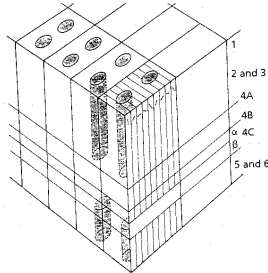
In HTM theory, a "region" is a collection of columns of neurons. This unit can then be connected to other regions in a hierarchical manner.



<http://www.webmd.com/brain/picture-of-the-brain>

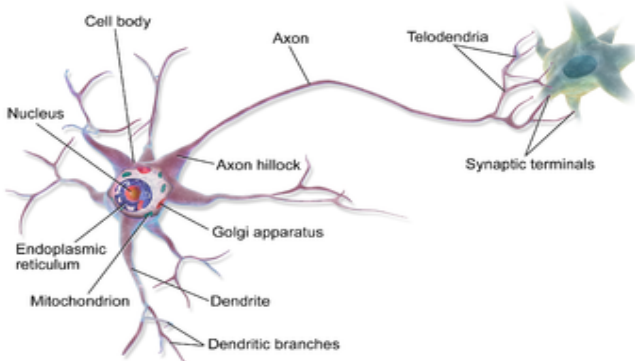
Columns

HTM theory holds that each region is in turn organized into mini columns of neurons, stacked vertically. Each of the neurons share certain connections with other regions, allowing each neuron in the column to be exposed to the same input.



How can I find out more? https://en.wikipedia.org/wiki/Cortical_minicolumn

Neuron



<https://en.wikipedia.org/wiki/Neuron>

A neuron is a type of biological cell. The neocortex is made up of billions of neuron cells. A neuron typically has 3 key parts: dendrites, cell body, and axons. Dendrites are cell extensions that bring electrical information to the cell body from other neurons. If a neuron cell receives enough electrical information, then it send this information forward through its axons to the dendrites of other cells. The signals between neurons occur via synaptic connections. Thus, neurons connect to each other to form neural networks. Which captures information/data and knowledge that is used to exhibit intelligence.

Dendrite

A dendrite is a branch-like structure of the neuron that receives information from other neurons. A neuron might have several thousand dendrites. Dendrites can either be proximal (meaning near) or distal (meaning far). Proximal dendrites gather signals from feedforward sources (information being fed up the hierarchy), and distal dendrites are usually connected to nearby active neurons in the same region.

How can I find out more?

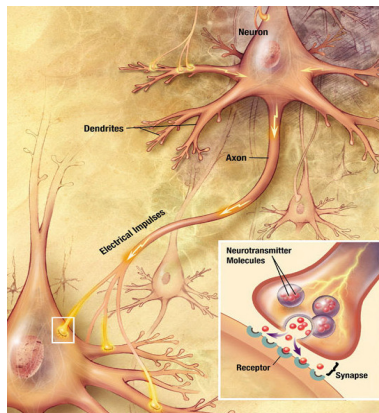
<https://en.wikipedia.org/wiki/Dendrite>

Axon

An axon is a long, slender projection of a neuron, an axon typically conducts electrical impulses away from the neuron's cell body. The function of the axon is to transmit information to different neurons, muscles and glands. Myelinated axons are covered in a myelin sheet. This sheet acts as an insulation and allows the axon to send electrical information over longer distances in the brain.

Synapse

A synapse is the point at which a neuron connects to another neuron. The vast majority of synapses are between the axon of one neuron and the dendrite of another neuron, thus allowing information to flow throughout the network of neurons.



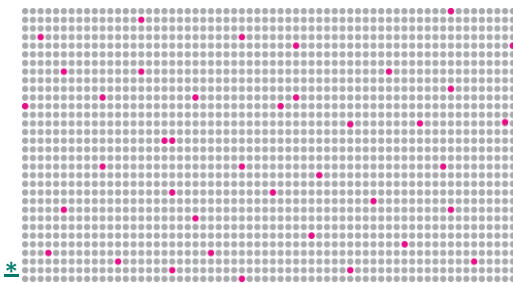
<https://en.wikipedia.org/wiki/Synapse>

What are the principles of HTM?

1. Sparse Activation: Cortical columns are sparsely activated. Which means that at any point of time only a small subset (less than 2%) of the columns are active. This property is mathematically beneficial as it allows for a lot of information to be represented.
2. Sequence Memory: Representing Input in the context of previous Inputs: Every input is recorded with a context of the previous input. This steps allows for learning to occur and the information is used to make predictions of future inputs.
3. Prediction: Every input is computed to make a prediction of a future input. The accuracy of these predictions is used to improve the learning. By the nature of the Cortical learning algorithms they are continuously learning.

What is an SDR?

SDR stands for Sparse Distributed Representation. SDRs are the data format of HTMs, SDRs are inspired by the neocortex where neurons are sparsely activated. The mathematical benefit of a sparse representation is that the combination of a large number of neurons along with the sparse nature of the activation allows for a very large capacity, allowing and allows us to remember a lot of information. Further, the neurons columns are semantic in nature. So a single bit not appearing in the representation does not change the meaning of the representation. This is very important in the real world, as real world data is highly noisy and a robust representation allows better identification of incomplete data.



A visual illustration of a sparse representation

<https://github.com/numenta/nupic/wiki/Sparse-Distributed-Representations>

What is an encoder?

An encoder translates different kinds of data into SDRs, which HTMs can work with. For example, a developer might write an encoder to translate audio signal

into a stream of SDRs. A good encoder will capture the semantics of the data type in the SDR using overlapping bits for semantically similar values.

What is the Spatial Pooling?

Spatial poolingThe spatial pooler is a stage in the processing of information in an HTM system. It learns 'Spatial' patterns are learned (as opposed to be time-based patterns). An example would be a shape, an image, a word, or a sound. The output of spatial pooling is a sparse distributed representation or SDR.

What is the Temporal Memory?

The Temporal Memory is a stage in the processing of information in an HTM system that is concerned with learning sequences, or time-based patterns. While a word might be considered a spatial pattern, a sentence of words would be a temporal pattern. Note that the concept of Temporal Memory has been undergoing significant evolution, and this definition is likely to change soon.

What is a classifier?

A classifier as the word suggest classifies a given input value into a set of known classes. In HTMs a classifier is used to map a predicted sparse representation or SDR to a predicted value, usually matching the input data.

What is the OPF?

The OPF is an acronym for “Online Prediction Framework”. It is a software framework for working with and deriving predictions from online learning algorithms, including (but not limited to) HTM. The OPF can assist in the development of applications that take input data and feeds it through encoders, models, and metrics and store or report the resulting predictions or metric results.

How can I find out more?

<https://github.com/numenta/nupic/wiki/Online-Prediction-Framework>

How can I get involved?

Probably the best way to get involved is through becoming a NuPIC community member. You can read about what is involved in that here: <https://github.com/numenta/nupic/wiki/Contributing-to-NuPIC>

References

<https://github.com/numenta/nupic>

<https://en.wikipedia.org/wiki/Neuron>

<https://en.wikipedia.org/wiki/Brain>

<https://en.wikipedia.org/wiki/Neocortex>

<http://www.webmd.com/brain/picture-of-the-brain>