KAIST

Information Processing & Storage in the Brain

Jaekyun Moon

KAIST

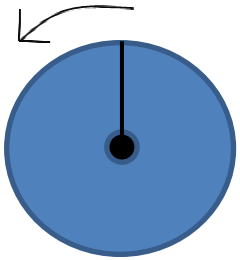
Oct 16, 2012 @ NVRAMOS

Is the doll turning clock-wise or counter-clock-wise?

Left Brain (지성적) vs Right Brain (감성적)

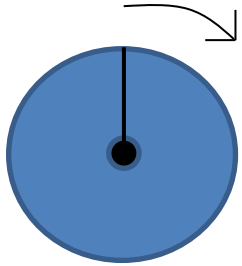
- **LEFT BRAIN FUNCTIONS (counter-clock-wise)**

  Logical,
  Deductive,
  Mathematical.



- **RIGHT BRAIN FUNCTIONS (clock-wise)**

  Visual,
  Imaginative,
  Artistic.



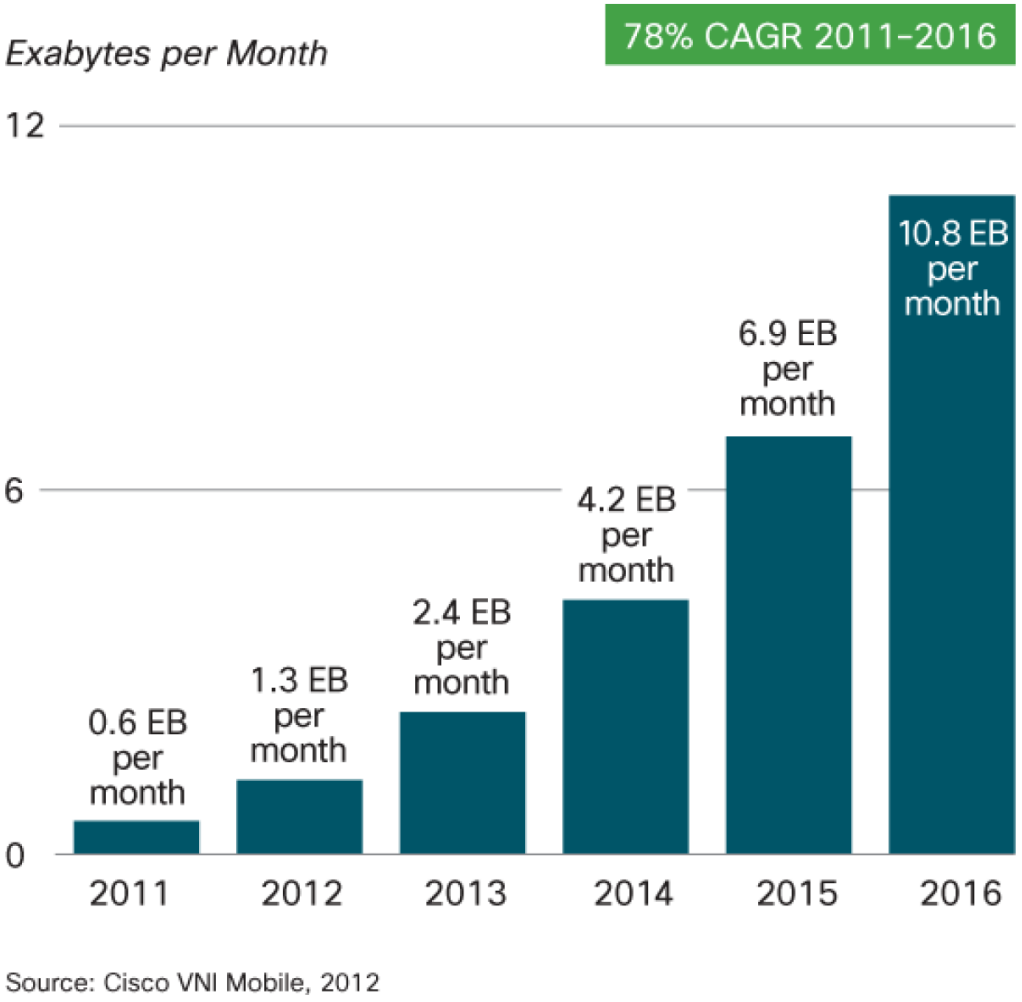
What Is Real?

- Optical illusions work because the visual system reconstructs stimuli not according to how they actually are, but by **making certain assumptions** about their properties in order to "fill in the gaps".
- The silhouette is 2D, but because almost all the objects we encounter are 3D, the visual system reconstructs it as such. And the silhouette is not actually spinning – that is one of the **assumptions made** by the visual system.

What Is Real?

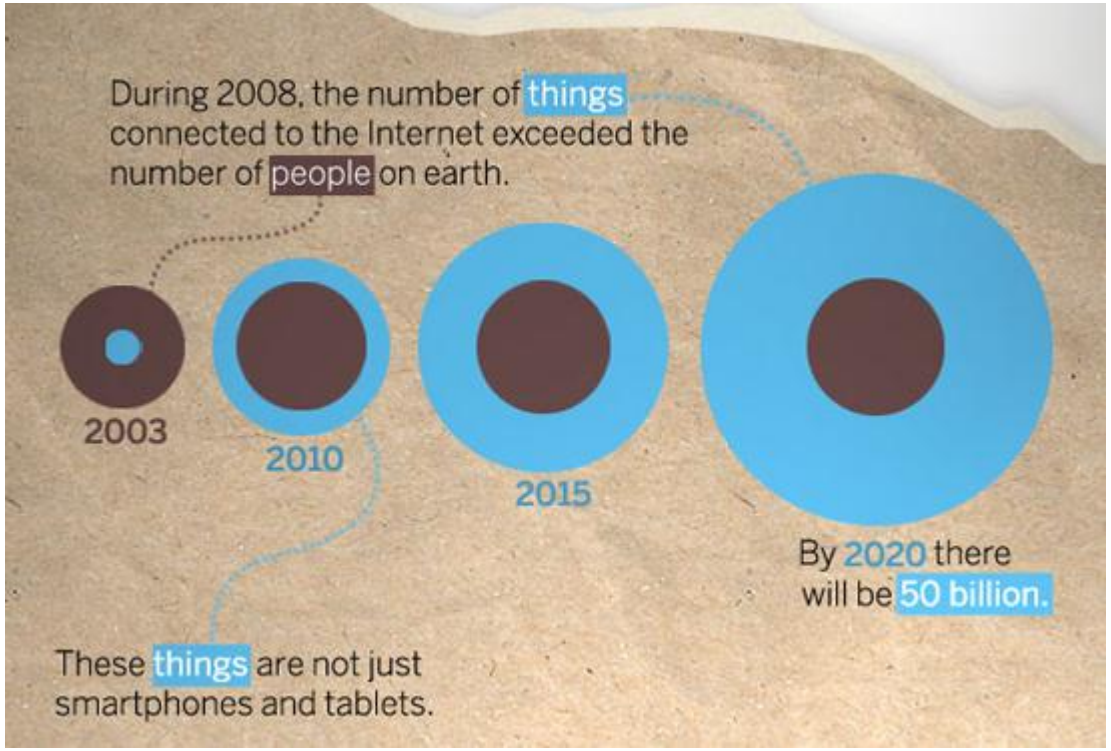
"Phantom limb" – a person who lost an arm still feels it attached to his body.

"Alien limb syndrome"- a person with cortical trauma may feel he does not have an arm and may feel the arm attached to him is someone else's.



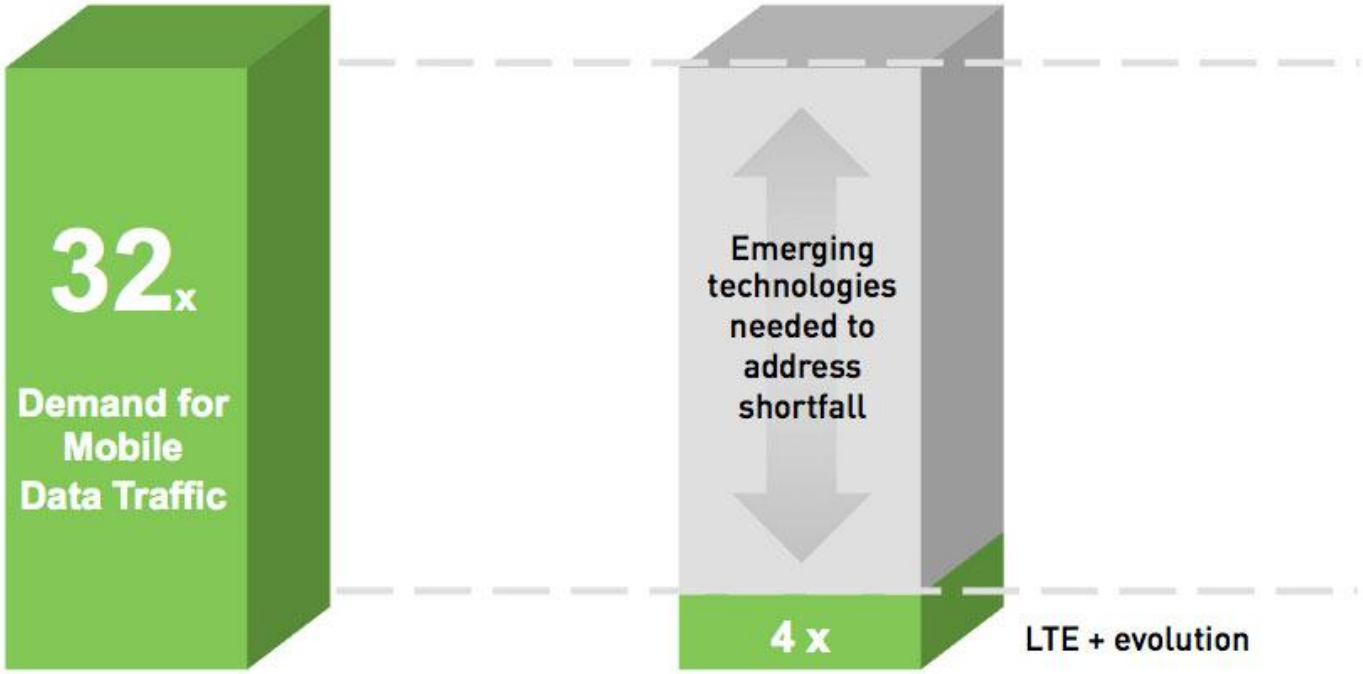
글로벌 무선 인터넷 트래픽 증가율: 연 200%

(비교: 무어의 법칙: 2x every 18 months = 연증가율 60%)



Source: Cisco

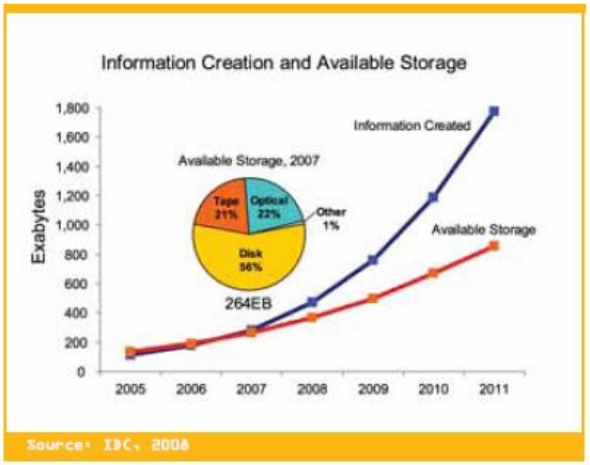
2020: 500억 사물 인터넷 (Internet of Things) 시대

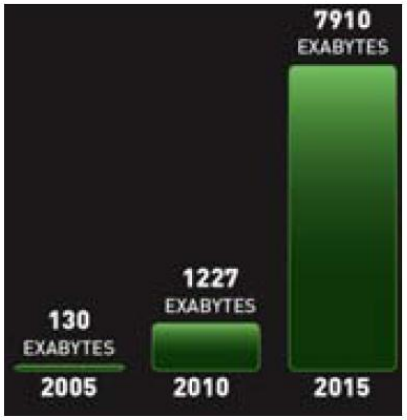


Source: Cisco VNI: Global Mobile Data Traffic Forecast 2010 = 32x Increase over 5 years

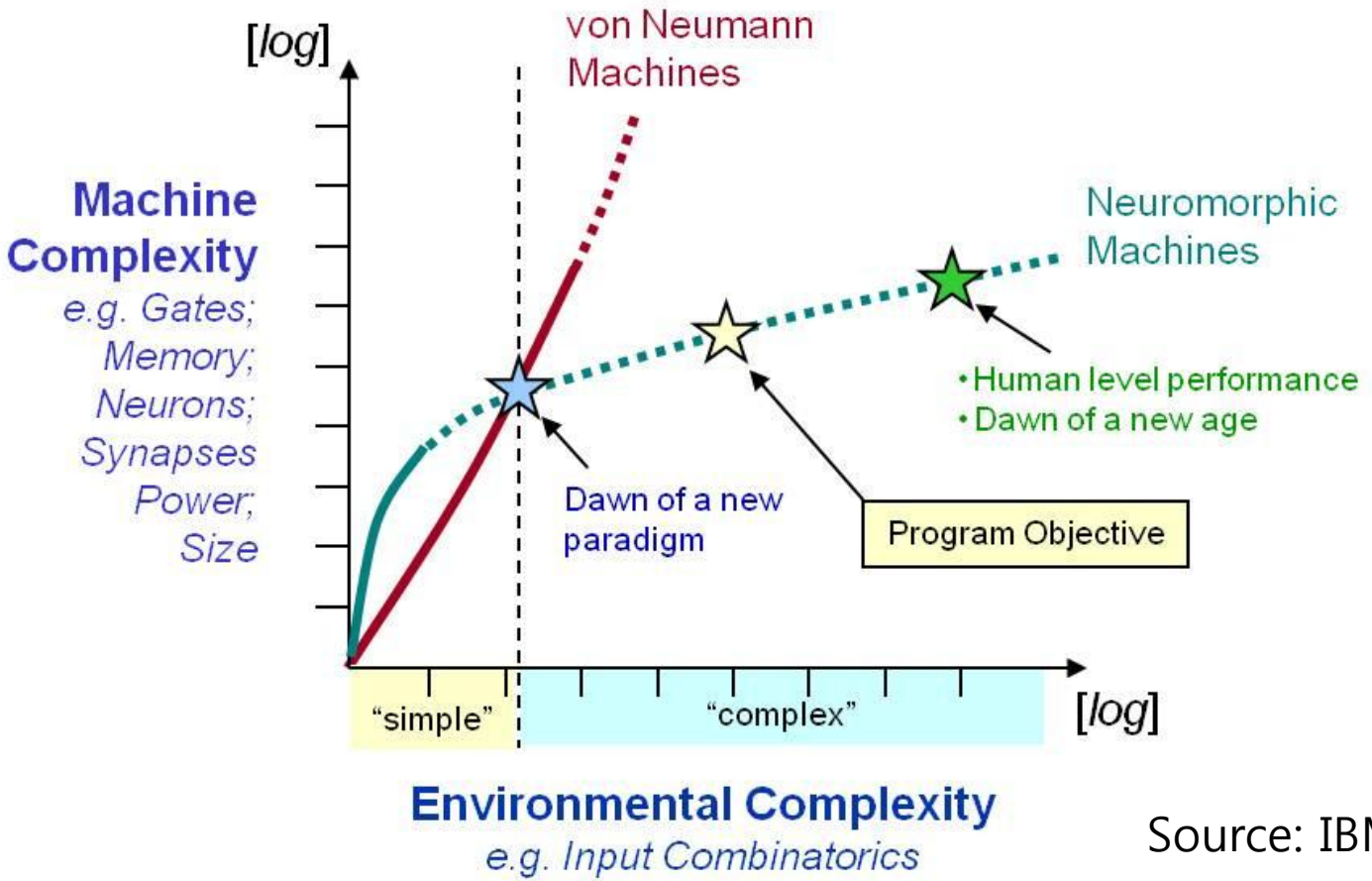
LTE 로도 폭증하는 데이터량 지원 어려움
새로운 기술 필요

The world's information is **more than doubling every two years**-with a colossal 1.8 zettabytes created and replicated in 2011, which is growing faster than Moore's Law.





(Source: IDC's Digital Universe Study, sponsored by EMC, June 2011)



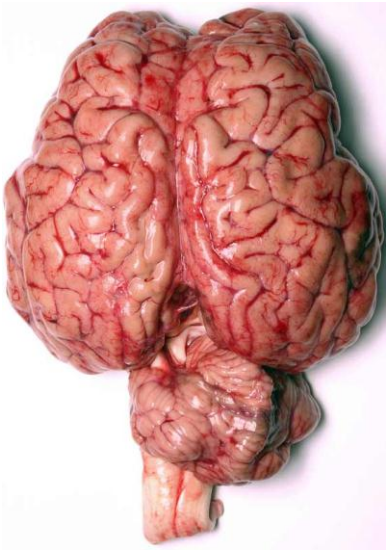
Source: IBM

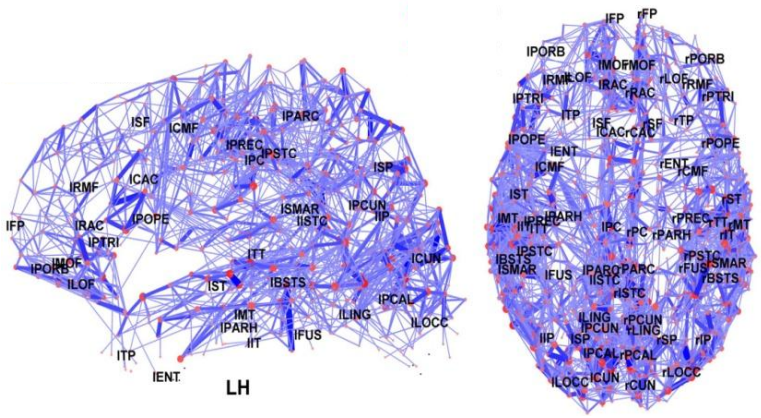
문제점: 지금까지의 IT 기술 = 폰 노이먼 구조
앞으로 필요한 기술: 뇌 모방 무한 확장 가능 시스템

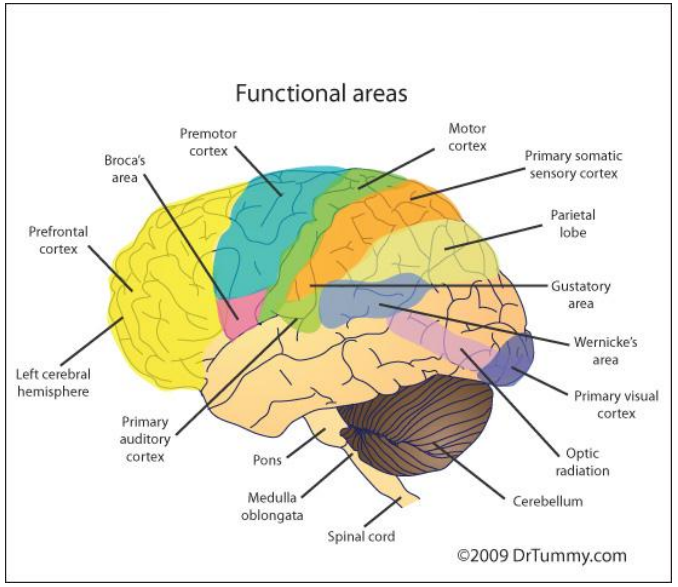
How Does the Nature Handles the Communication Issue?

Facts About the Brain

- Source of our thoughts, emotions and memories
- Monitors and controls body activities
- Fattest organ (60% fat)
- Can't tickle yourself
- 3 LBs
- 75% water
- No pain receptor
- 100 billion neurons
- ~7000 synapses/neuron
- New memory = new neuron connection
- Every thought = a unique pattern of activity in brain
- The human neocortex is a sheet of neural tissue approximately 1,000 cm2 in area and 2mm thick; Viewed under a microscope, the physical characteristics of the different regions look remarkably similar.



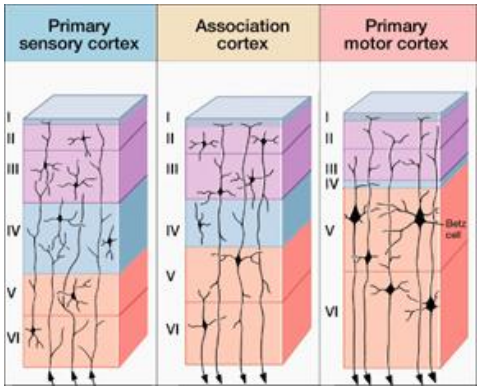


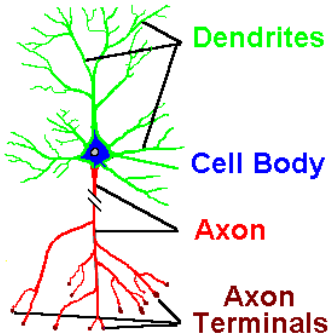


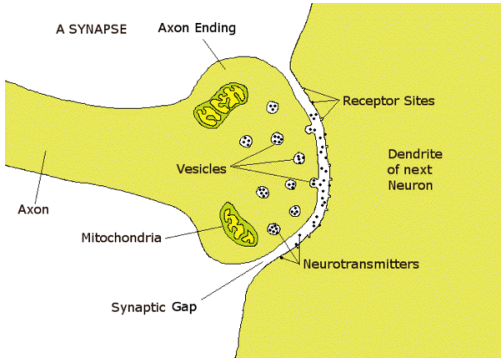
Inside the Brain…

Brain Basics

- Neurons can be viewed as arranged in columns (although connections exist across columns as well).
- **All sensations, movements, thoughts, memories, and feelings are the result of signals that pass through neurons.**
- A neuron consists of: the **cell body** (contains the nucleus), **dendrites** (that receive messages from other nerve cells) and an **axon** through which the signals pass down to another neuron.
- Neurons are connected to one another through the junction called the synapse.

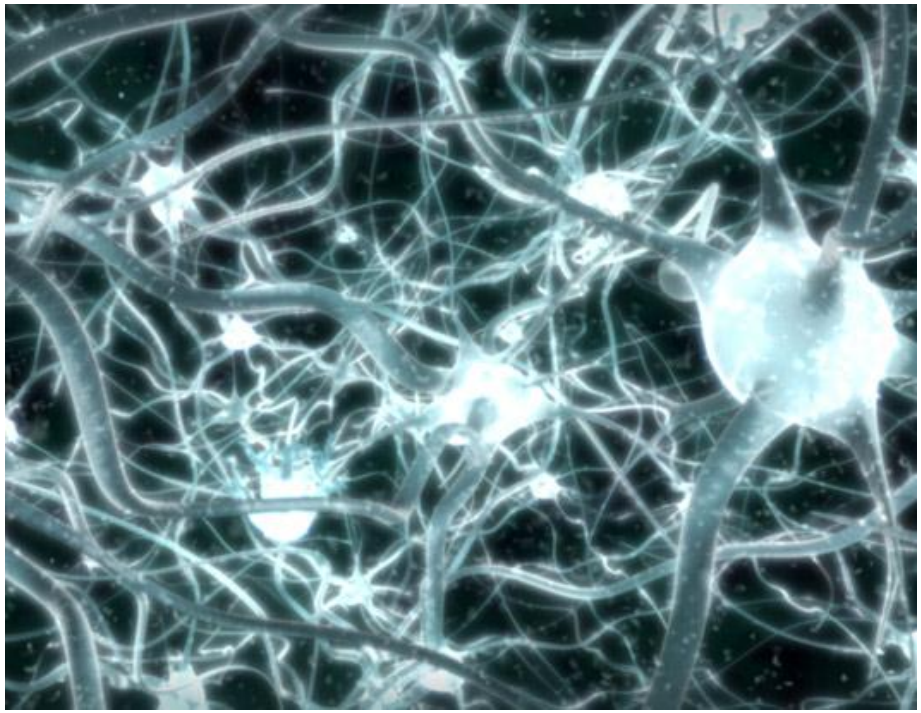






Multiple Pathways

One neuron can join up to multiple other neurons, meaning that there are thousands of different pathways connecting different areas of the brain and multiple messages can be sent down different pathways at the same time.



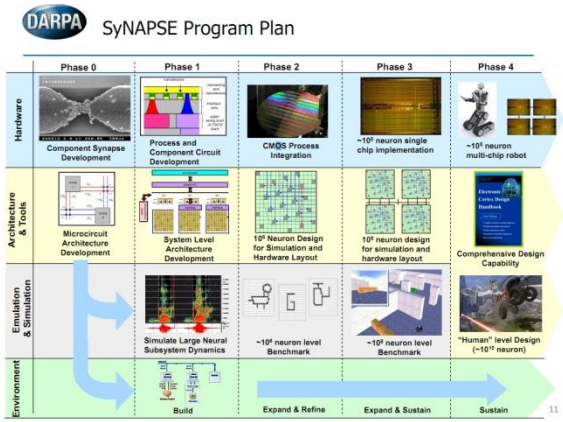
Source: Fast ForWord

Neuron Communication

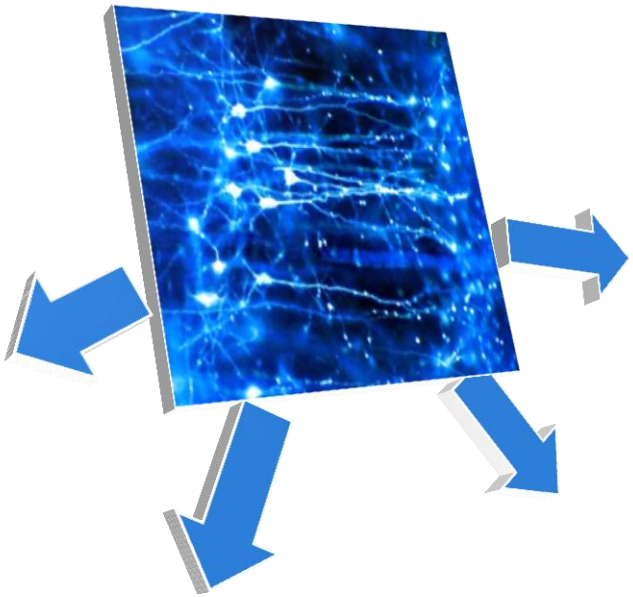
- Neuron communication is crucial (to memory, reaction, thinking, etc.)
- Neuron communication consists of electrical impulse transmission (down the axon) and chemical transmission (in the synaptic gap).
- Disconnection between neurons means loss of memory and ability to learn.

뇌 모방 IT

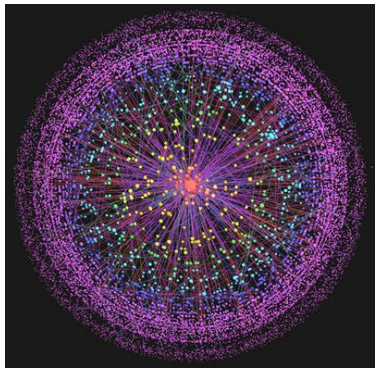
뇌 모방 프로세서



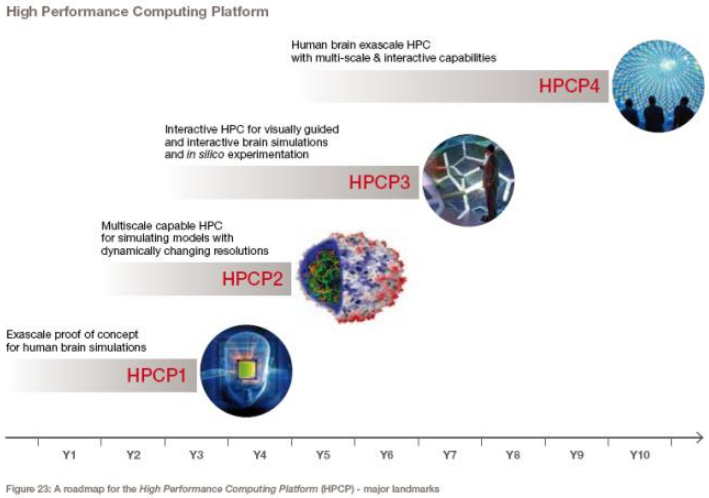
미국 DARPA SyNAPSE Project



뇌 모방 글로벌 통신/네트워크 설계 (EE KAIST)



뇌 모방 컴퓨팅



유럽 연합 FET Human Brain Project

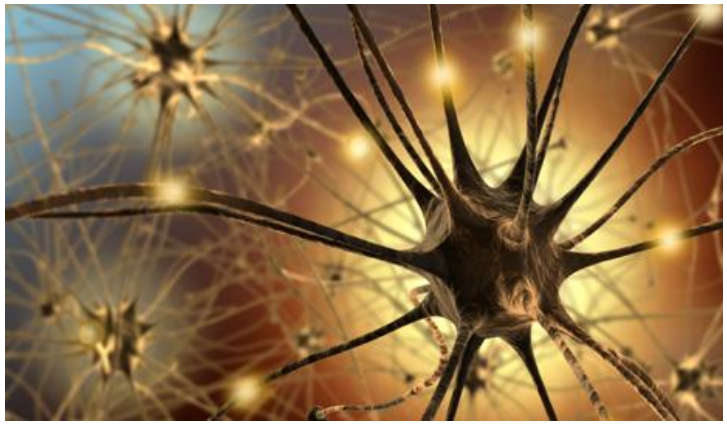
Simulation

일본 RIKEN의 K computer

Memory in Brain

- Memories are maintained in **patterns of synaptic connectivity**.
- Basic postulate of Neuroscience: **memories are stored through modifications of synaptic strengths** within neural circuits:

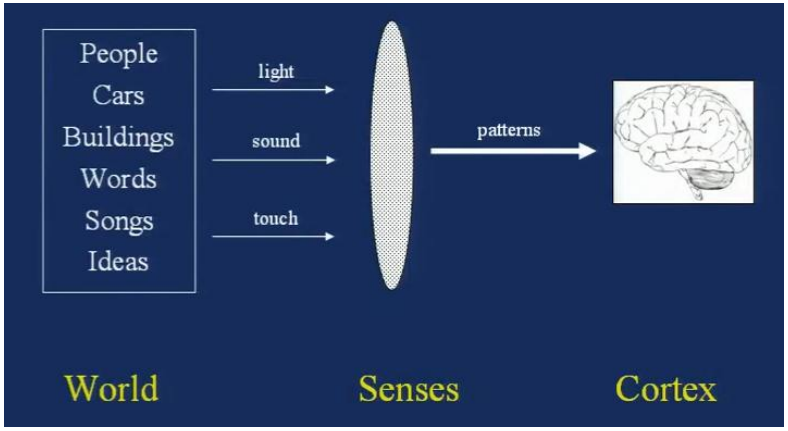
The more one practices or thinks about a piece of information stored in her brain, the more that particular synapse is used and its strength grows.

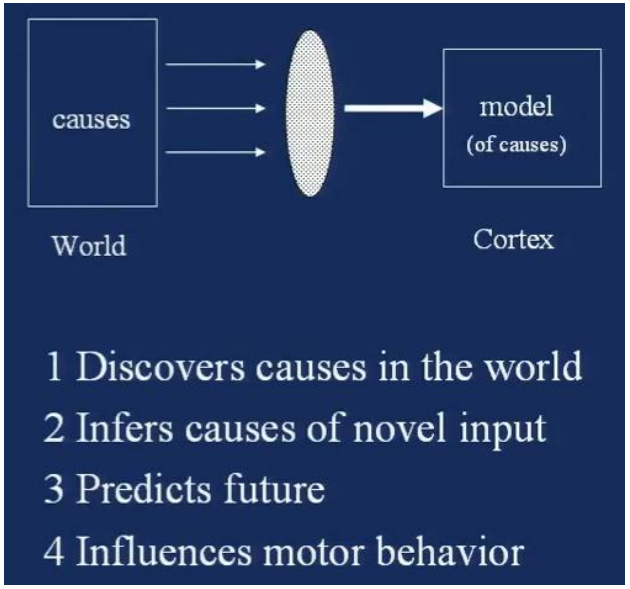


A Convincing New Theory of How Brain Works: Memory-Prediction Framework

(by Jeff Hawkins)

- The brain gets information about a very small part of the world.
- The brain develops a model of the world based on this sparse information.
- The brain makes predictions based on this model (of what is expected & what needs be done).
- It carries out these steps exceedingly well using a hierarchical structure.



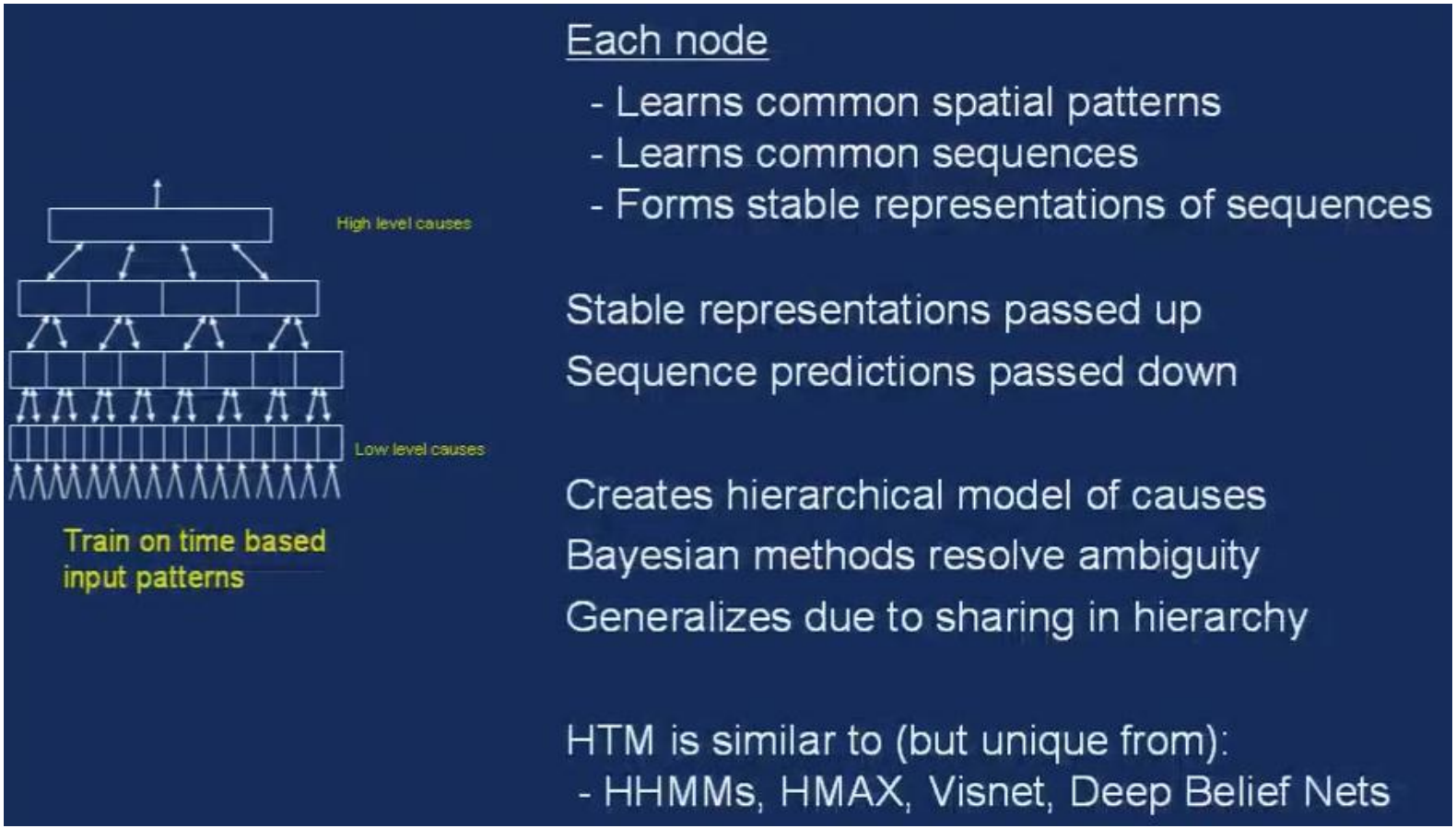


Information Processing in the Brain: Observations & Theories (due mainly to Jeff Hawkins)

- Brain processes patterns (sound, touch, sights are all inputted to cortex as **spatial-temporal sequences of patterns**).
- The brain is complex but its **structure is regular**.
- **The brain is not a fast processor, but a memory system** that stores and plays back experiences to help us predict, intelligently, what will happen next.
- The brain is a hierarchical representation system (Hierarchical Temporal Memory)
  - Matched to the inherent hierarchical structure of the world (songs, words, houses, etc.)

Hierarchical Temporal Machine

- At the lower level small details and fast-varying things are recognized.
- At levels higher up, recognized patterns do not move fast in time; presentations are more stable.
  - A running dog, a jumping dog and a carton dog are all effortlessly recognized as a dog even to by a child brain.



Source: UBC DLS Jeff Hawkins

Brain Memorizes Sequences

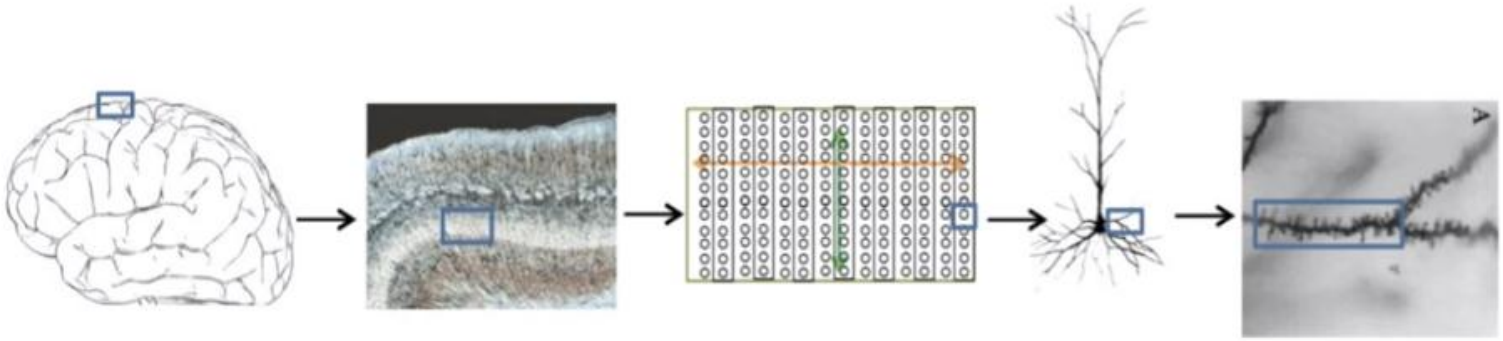
- Each HTM region **looks for** common **patterns in its input** and then learns sequences of those patterns.

- From its **memory of sequences**, each region makes **predictions** based on 3 steps:
  1) Form a sparse distributed representation of the input
  2) Form a representation of the input in the context of previous inputs
  3) Form a prediction based on the current input in the context of previous inputs

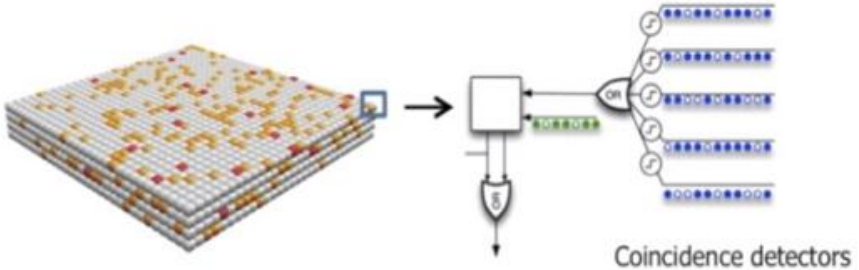
*input bits here are different from the "digital bits" we are familiar with; the bits here represent attributes

Source: Numenta

Sequence Memory, the brain's way



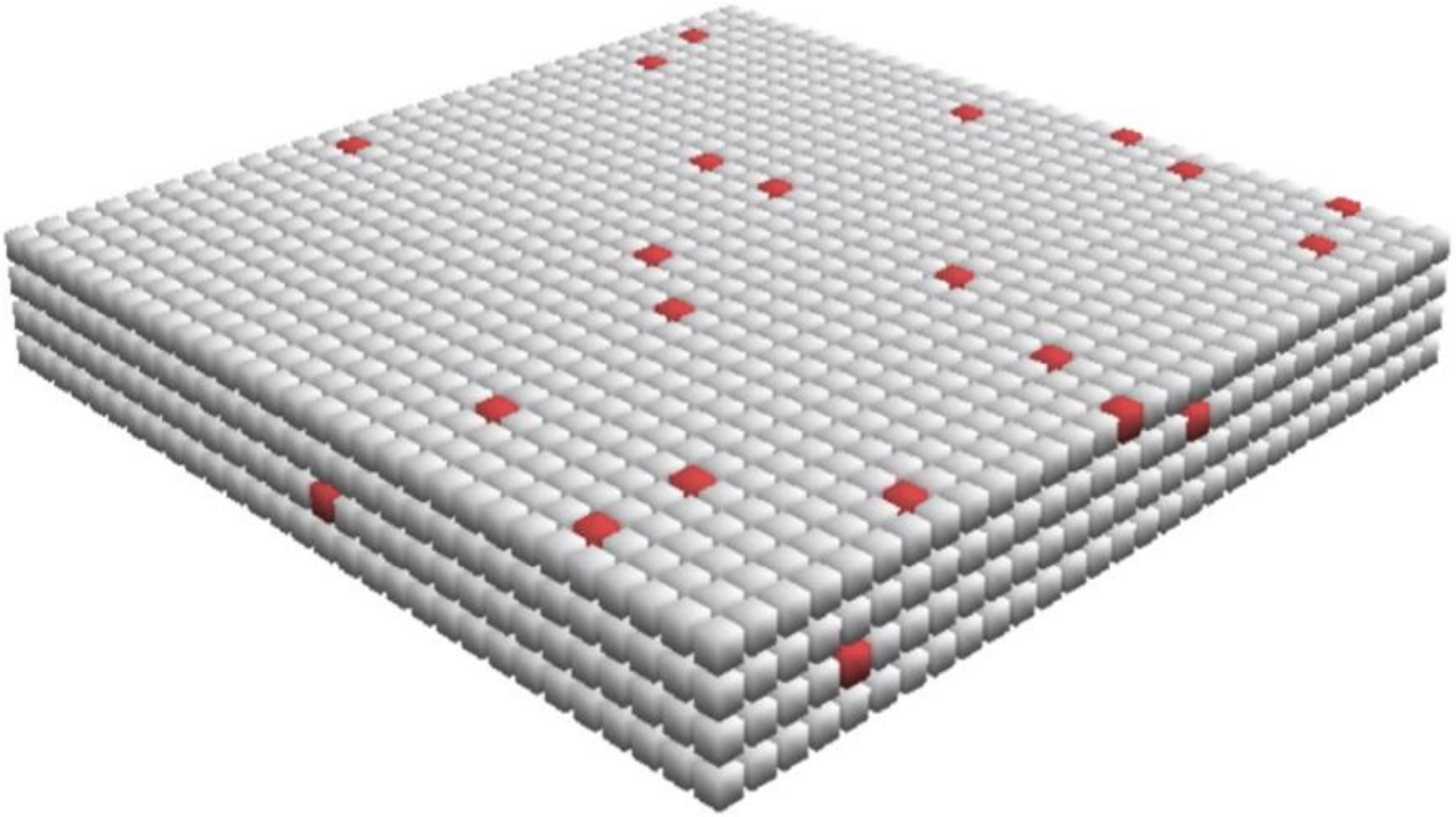
only a small
percentage of neurons
are active at one time



How does this structure learn sequences?
What makes it high-order?
What makes it online?

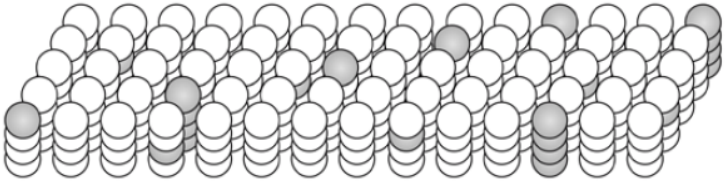
Source: Jeff Hawkins -
Modeling Data Streams Using Sparse Distributed Representations

Context information is stored with multiple cells per column



Source: Jeff Hawkins - **Modeling Data Streams Using Sparse Distributed Representations**

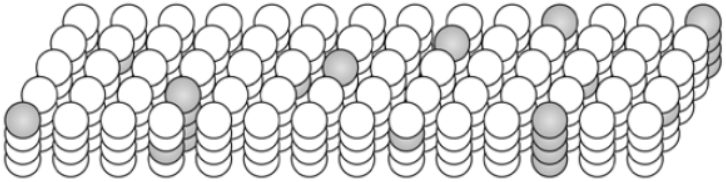
How the Context Information (Sequence) Is Stored



- Say every column has 4 cells and there are 100 columns.
- The column is considered "on" if any cell in it is on.
- An input pattern is mapped to an on-off pattern of the columns.
- If only one cell per column is active at a time, we have 4^100 ways of representing the exact same input pattern at a given time.
- Each such way represenst a different context (past history) in which the input pattern occurs.
- For a given pattern with a given context, a likely next pattern can be predicted (each cell remembers the sequence of neighboring patterns that has led to the activation of itself).

Source: Numenta

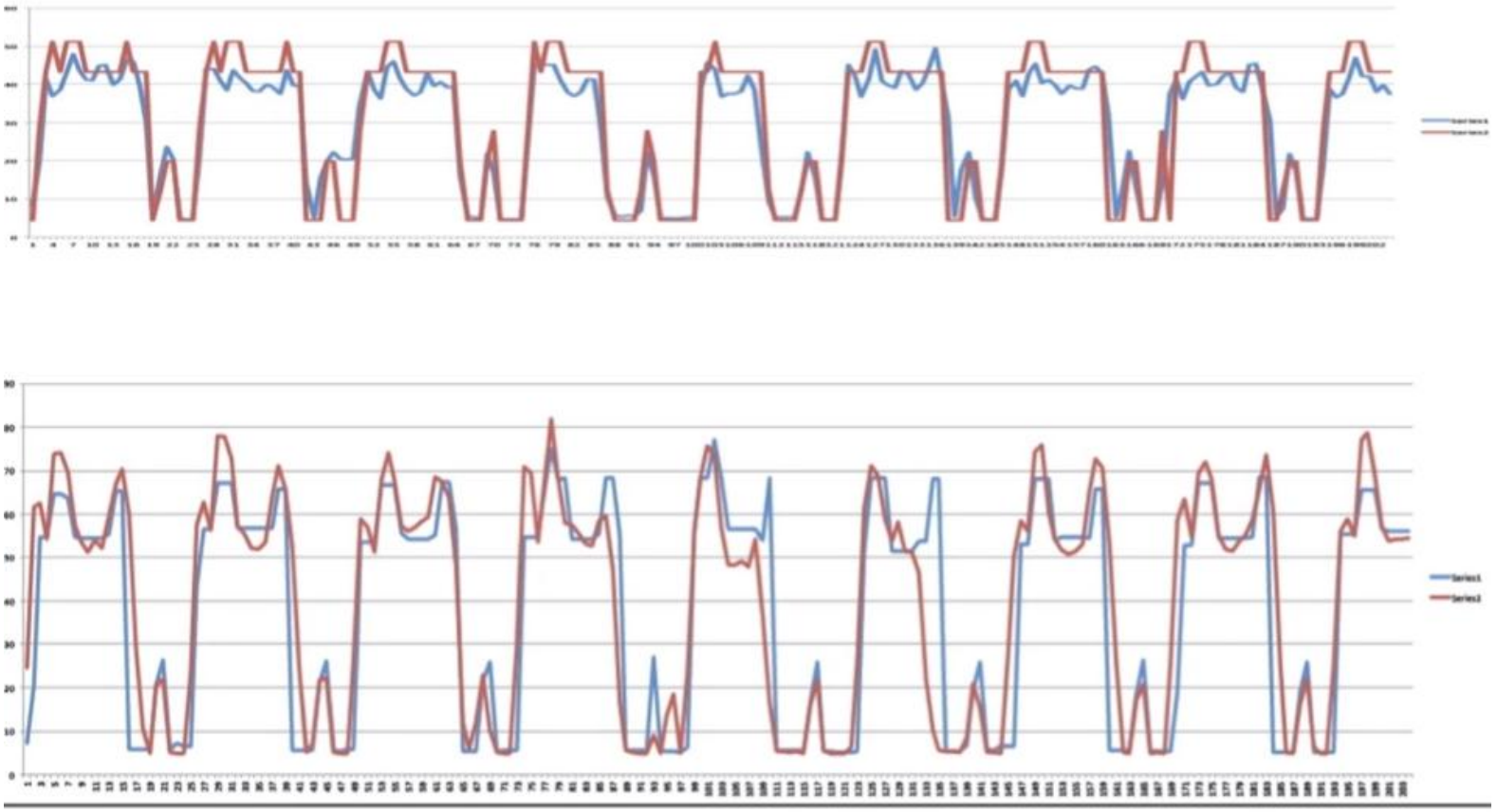
How Is the Context Information Made?



- Each cell remembers the sequence of neighboring patterns that has led to the activation of itself.
- For a given pattern with a given context, a likely next pattern can be predicted.

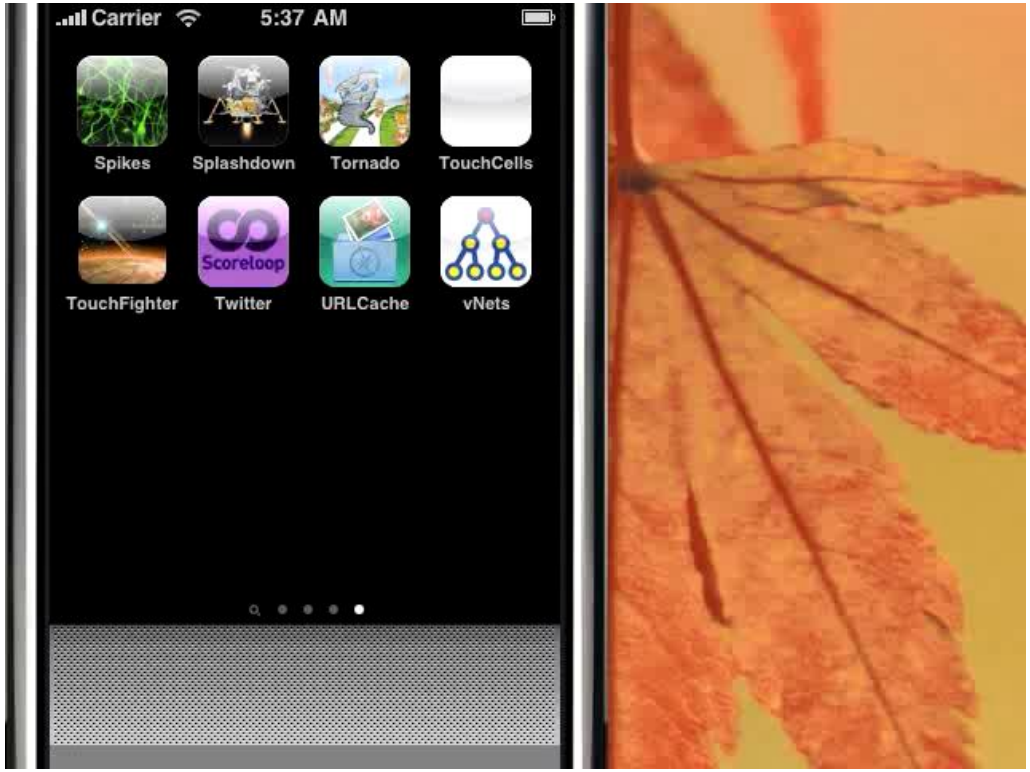
Source: Numenta

Hourly energy consumption predicted four hours in advance
Two different epochs



Source: Jeff Hawkins - **Modeling Data Streams Using Sparse Distributed Representations**

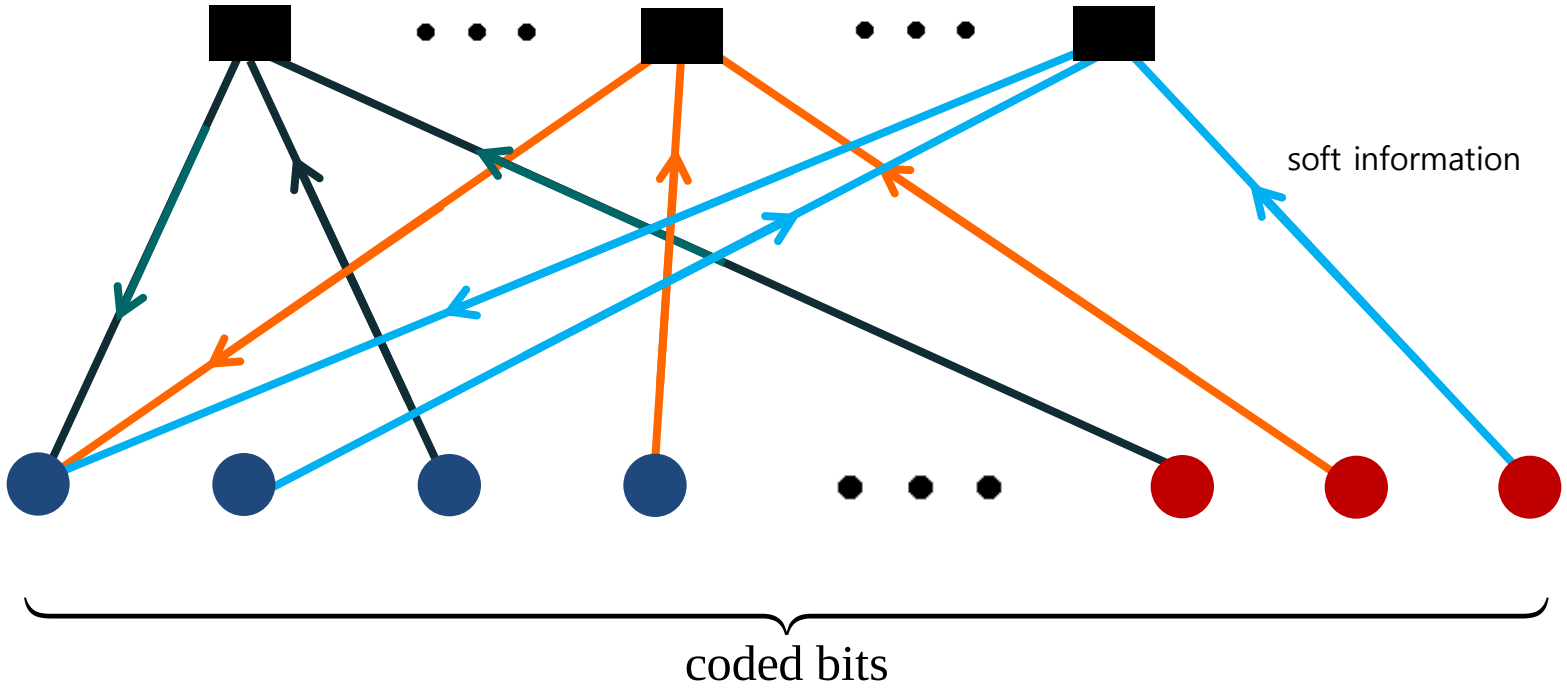
Forest Fire Detection by HTM



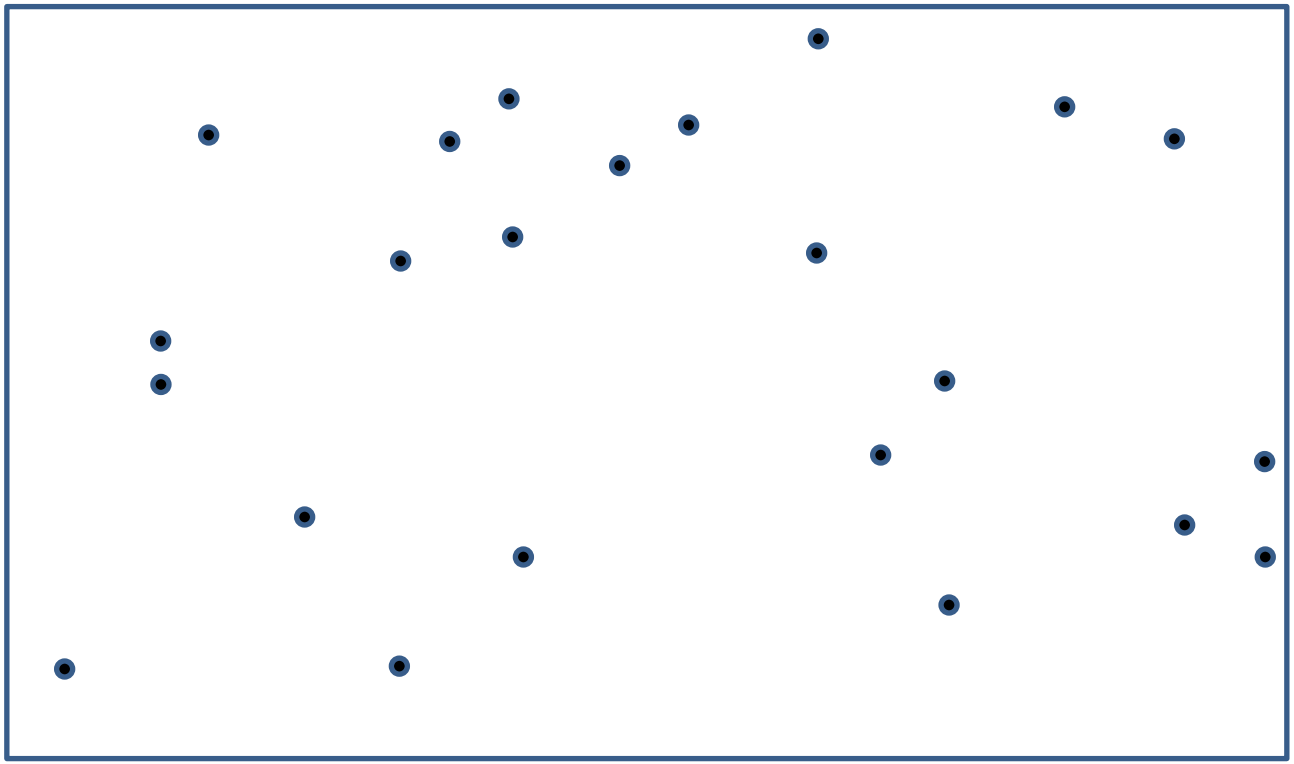
Source: Numenta

Belief-Propagation or Message-Passing Decoding of LDPC codes

A large number of simple identical processors collectively performing a highly complex task



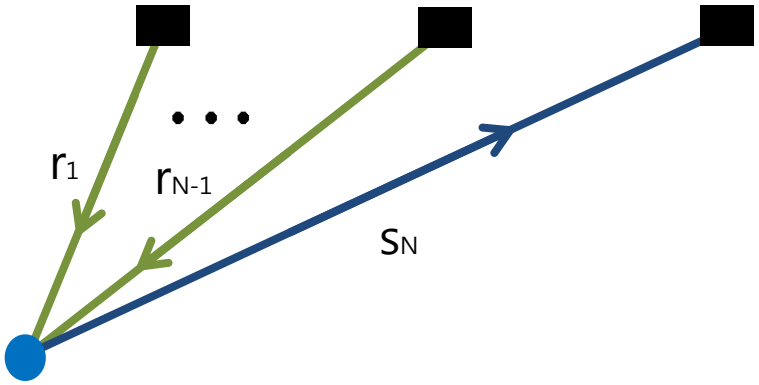
Sparse H Matrix



Mathematical Formulation of Message-Passing

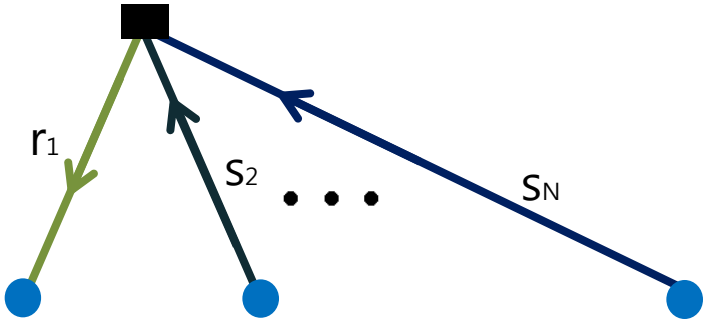
- Bit-to-Check:

$$s_N = f(r_1, r_2, \ldots, r_{N-1})$$

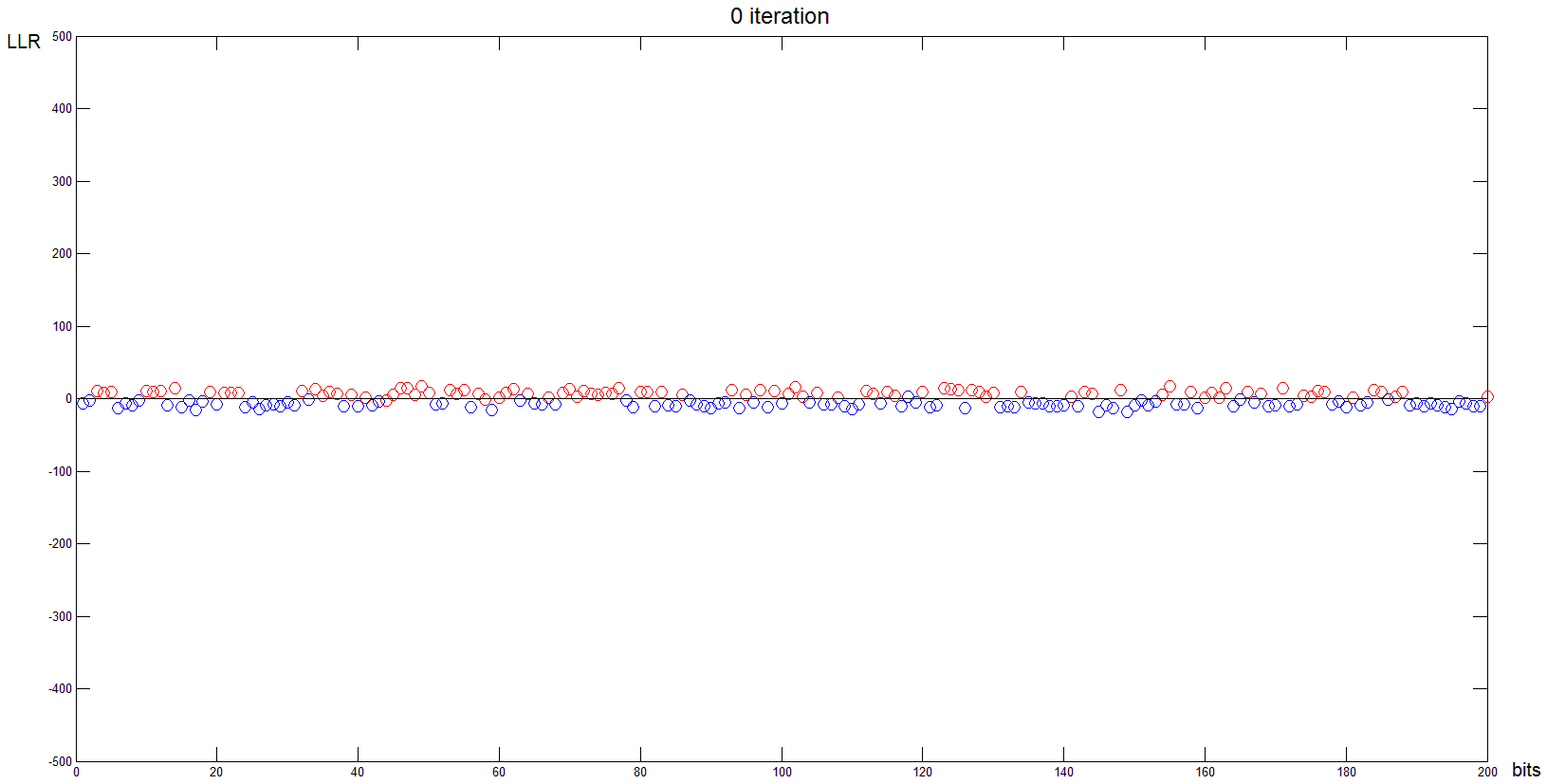


- Check-to-bit:

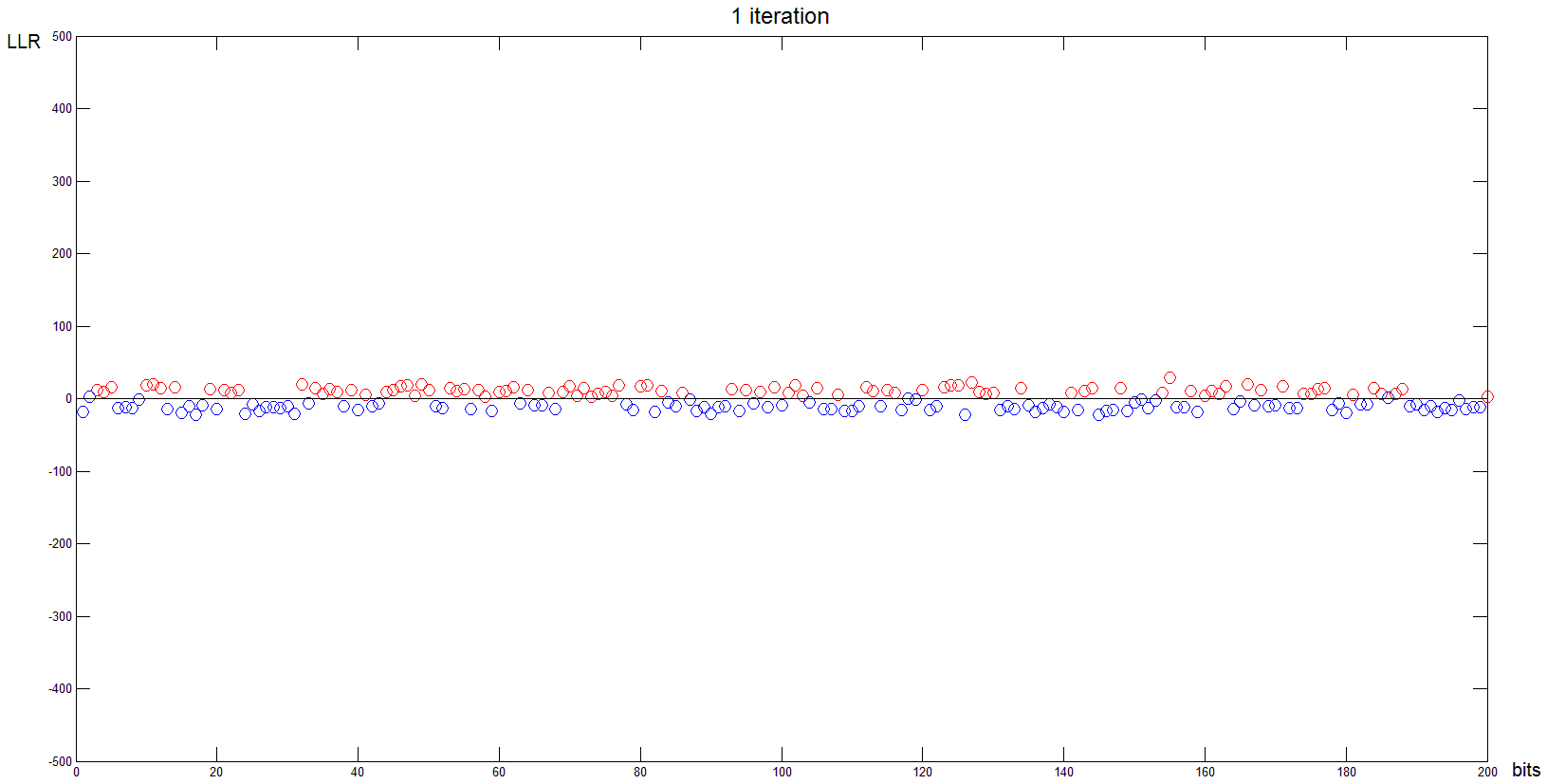
$$r_1 = g(s_2, s_3, \ldots, s_N)$$



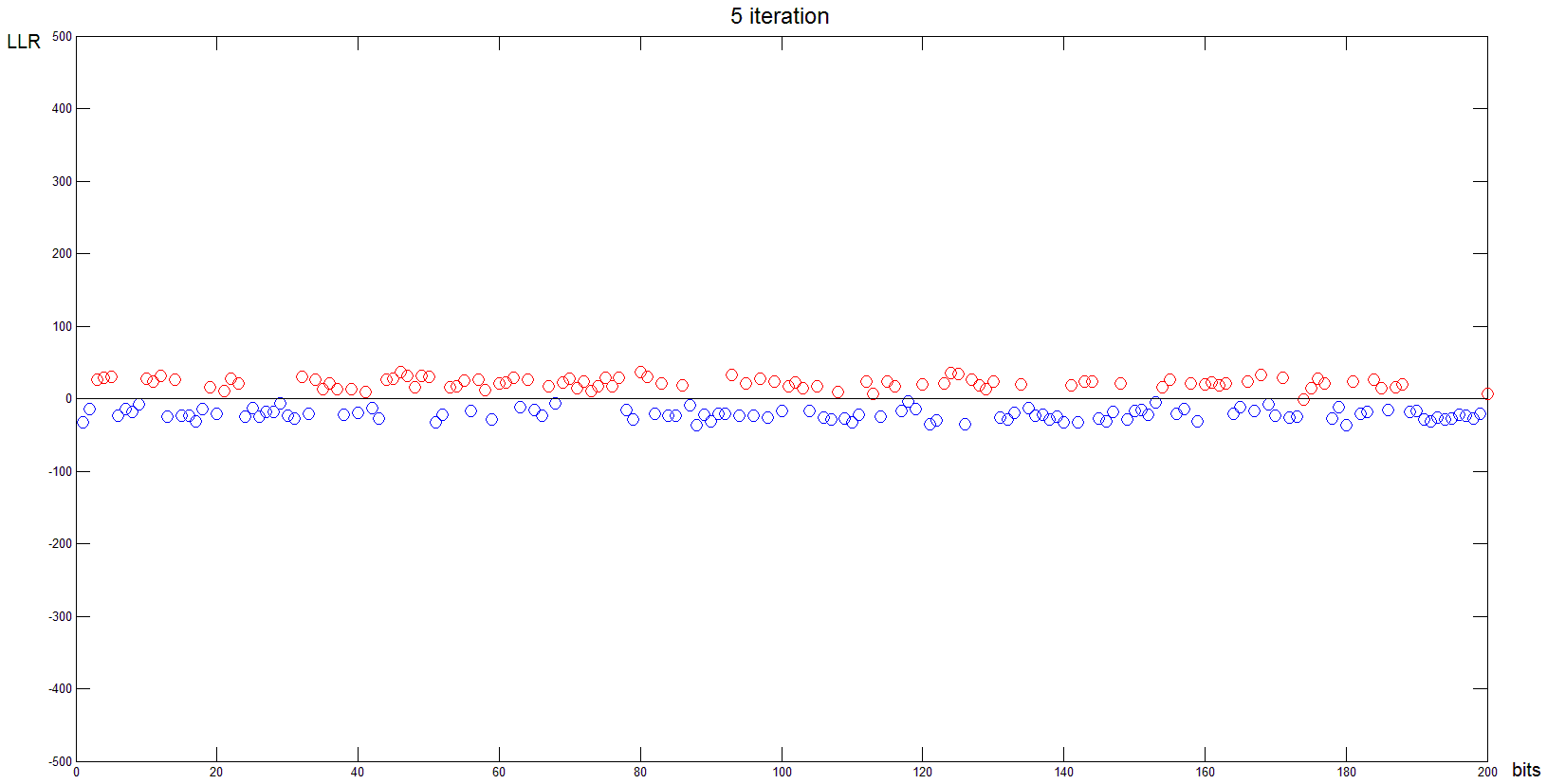
0 Iteration


0 iteration
LLR
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
20
40
60
80
100
120
140
160
180
200
bits

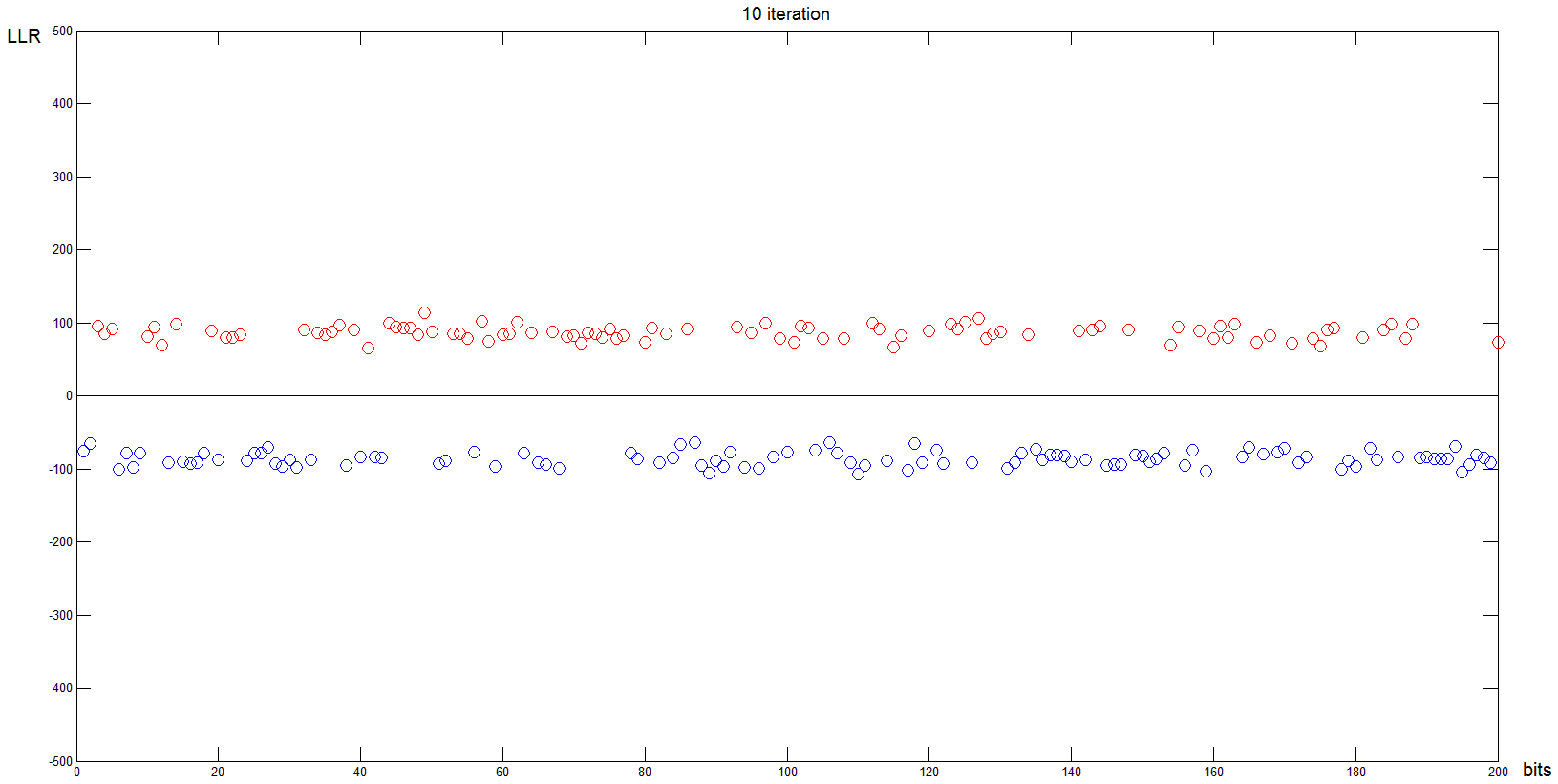
After 1 Iteration



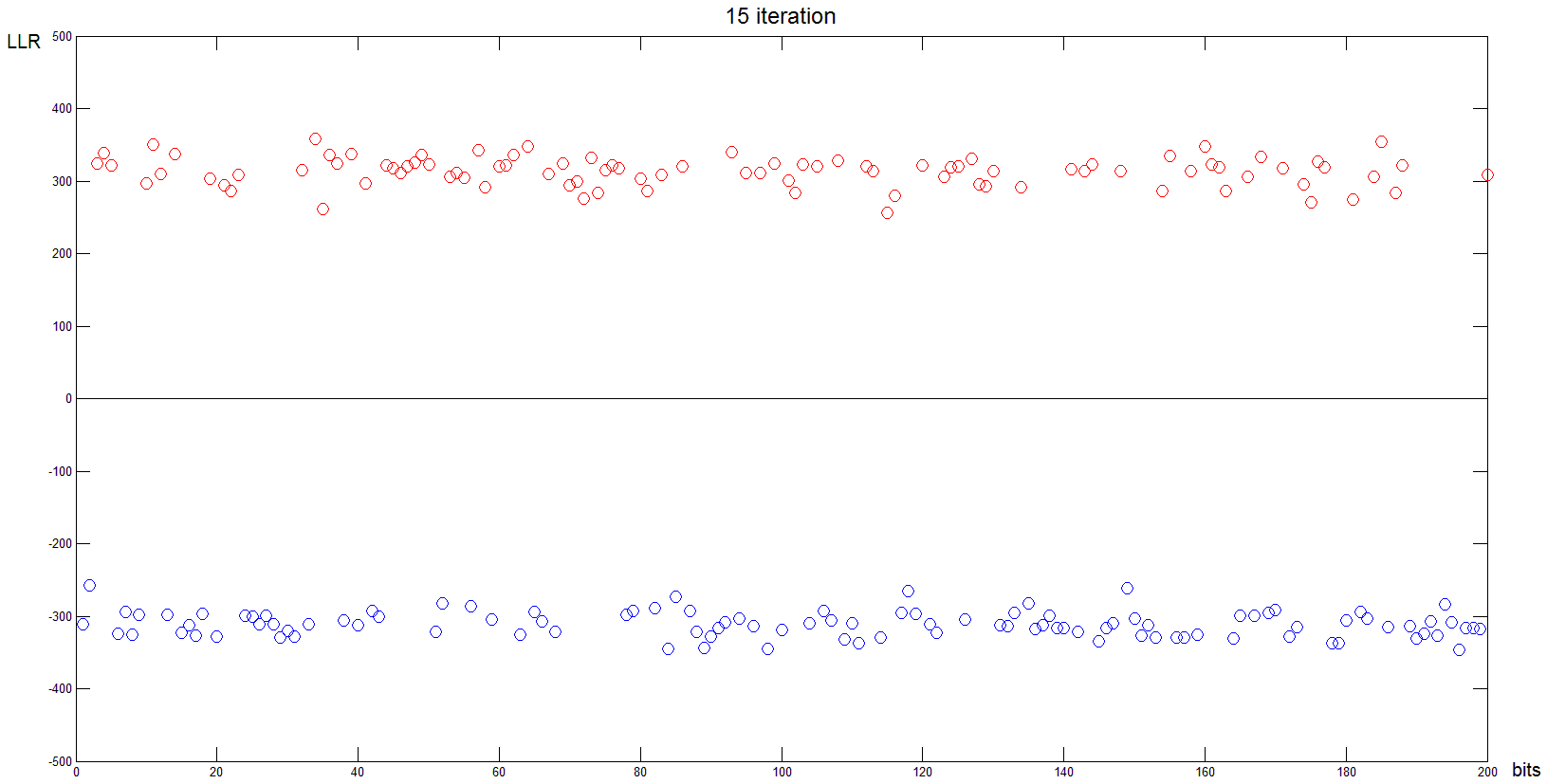
After 5 Iteration



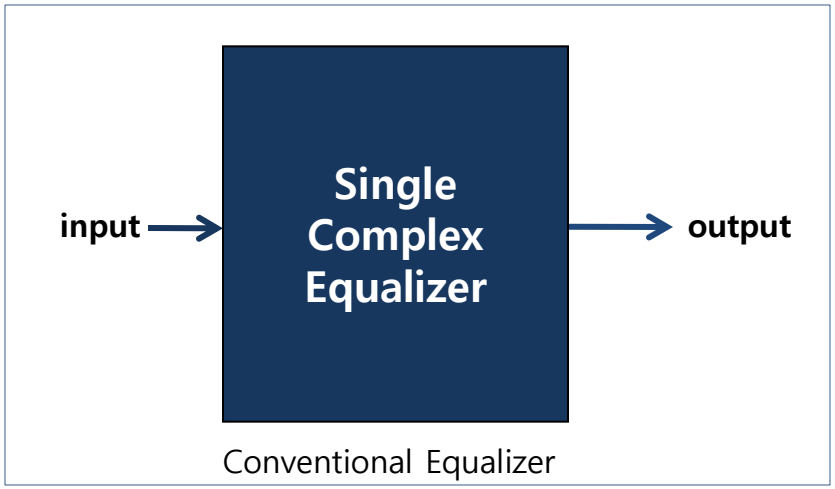
After 10 Iteration

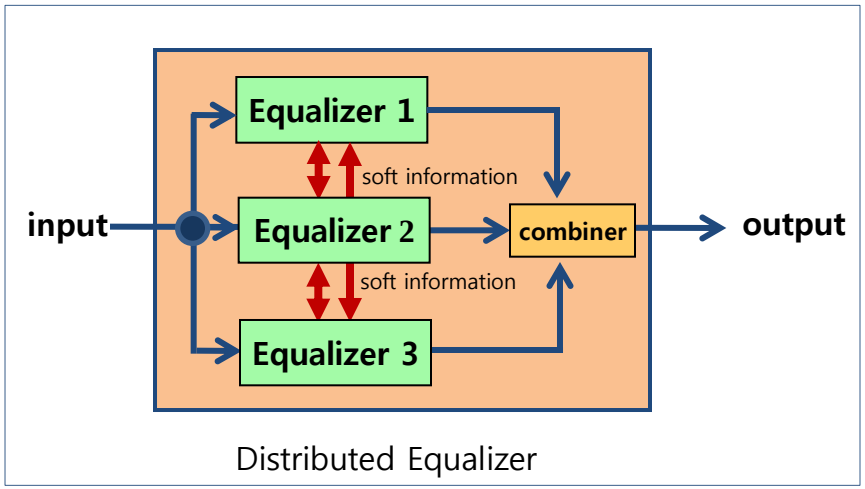


After 15 Iteration



Self-Iterating Equalization





Distributed, self-iterating equalization leading to acceptable overall hardware complexity.

Performance: h3 & time-invariant filters

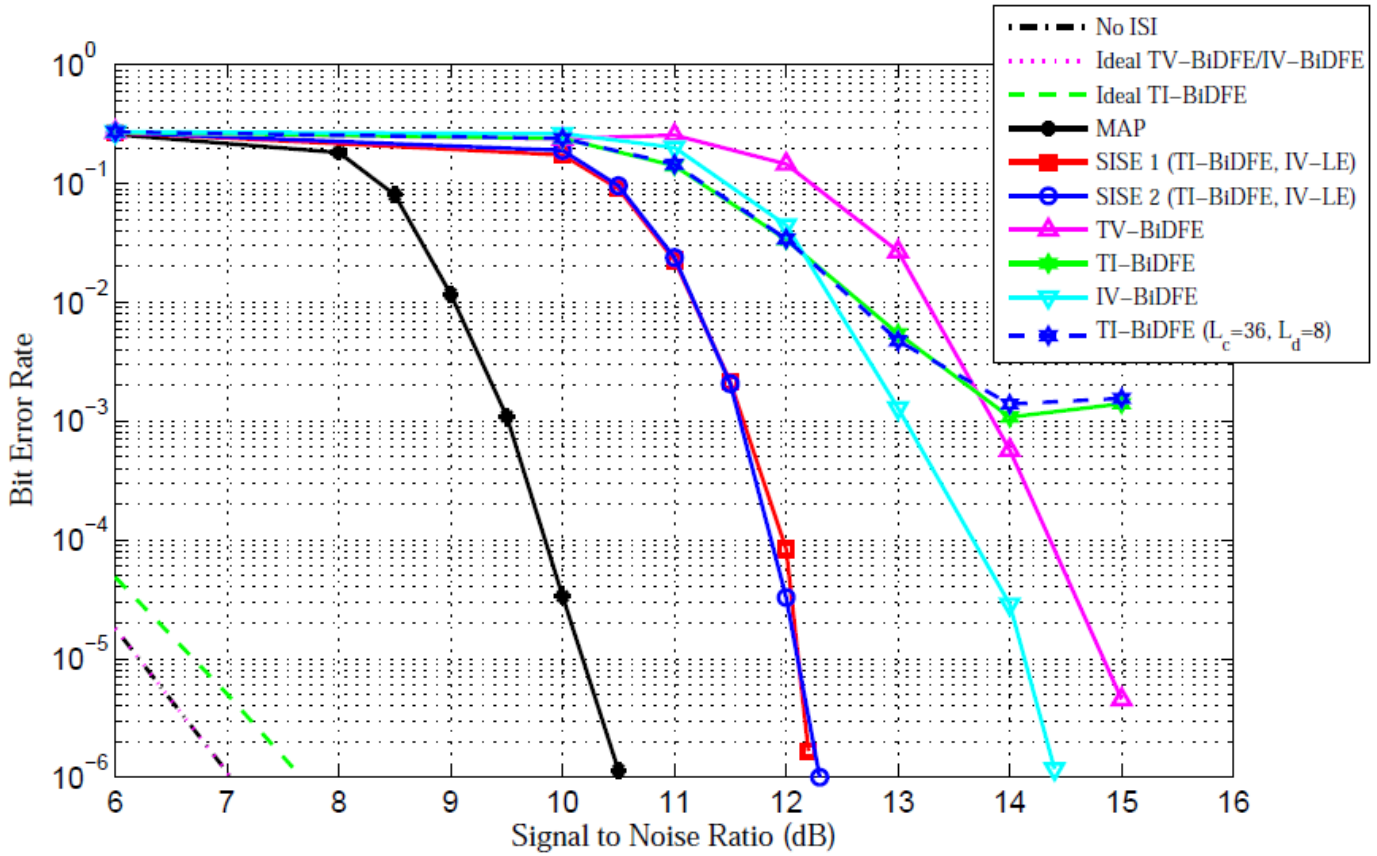


Fig. 9: BiDFE based BER Curves on the Channel $\mathbf{h_3}$ after 20 outer iterations.