Short introduction to neuromorphic systems and research trend

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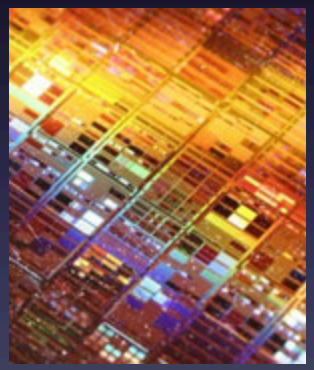
Outline

Brain

- What attributes inspire AI researchers?
- Comparison with computer



Neuromorphic engineering

- What is neuromorphic engineering for? (definition included)
- Research trend
- Where to go?

The brain is able to

- easily capture hidden structure (pattern) of given data,
- store the structure in an invariant form, which causes us to recognize any new examples including the structure (pattern),

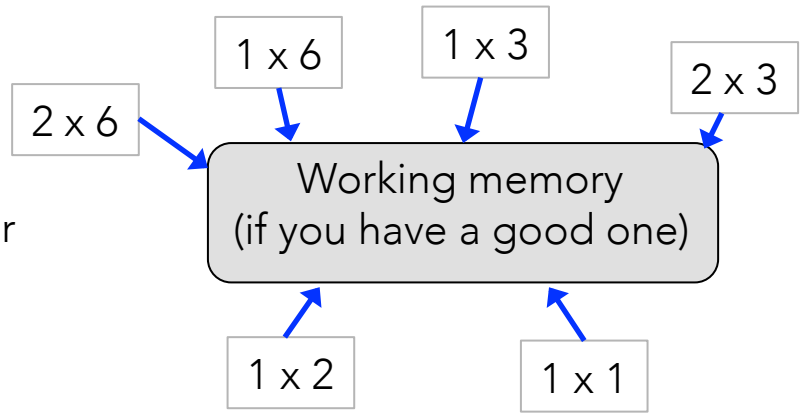
$7 \times 8 =$

$120 \times 136 =$

Multiplication table

x	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45
6	6	12	18	24	30	36	42	48	54
7	7	14	21	28	35	42	49	56	63
8	8	16	24	32	40	48	56	64	72
9	9	18	27	36	45	54	63	72	81

You need a pen and paper otherwise. ☺



The brain is able to

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- base arithmetic on memory
  - in fact, the brain is a memory system not a processor!


Aha! I now remember.

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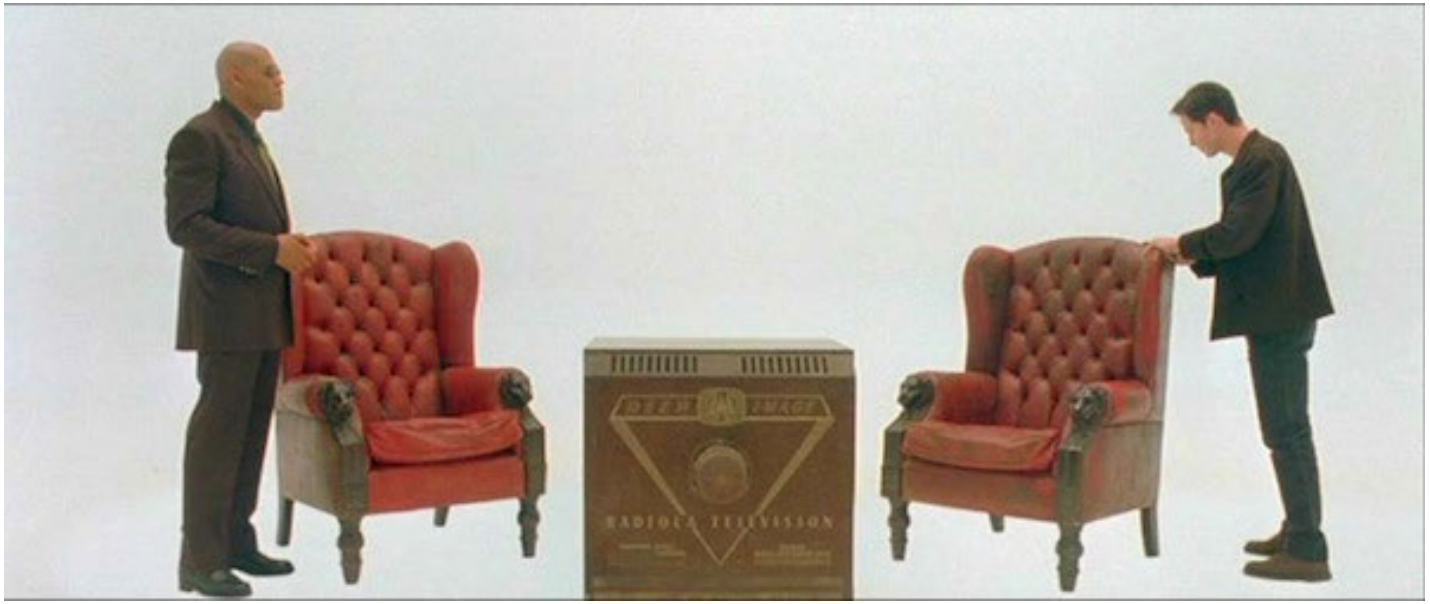
- address the memory under given circumstances (content addressable memory)
- let a piece activate the whole in auto-associative manner.

There is perhaps a single general algorithm for learning in the entire neocortex



Neo: This… this isn't real?
Morpheus: What is real. How do you define real? If you're talking about what you can feel, what you can smell, what you can taste and see, then real is simply electrical signals interpreted by your brain. This is the world that you know.

There is perhaps a single general algorithm for learning

See with your tongue!
Physiology Today

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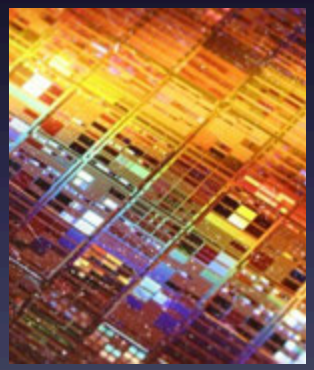
- be trained with a universal algorithm.

Brain

- What attributes inspire AI researchers?
- Comparison with computer



Neuromorphic engineering

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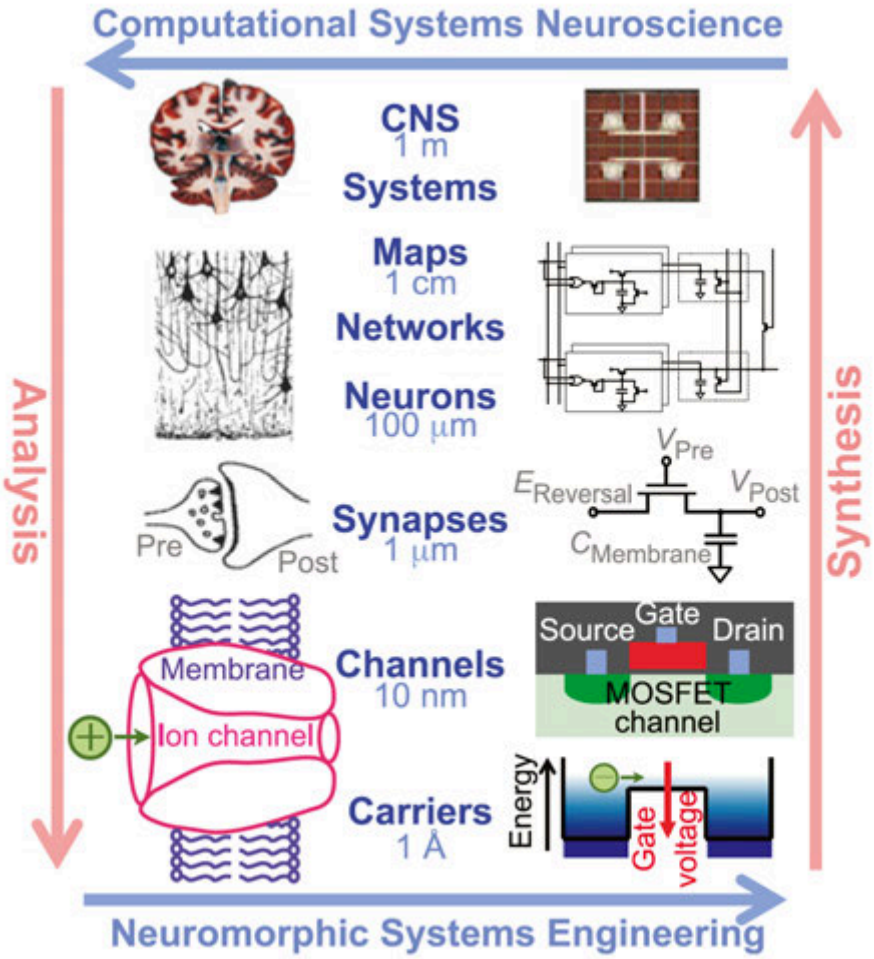
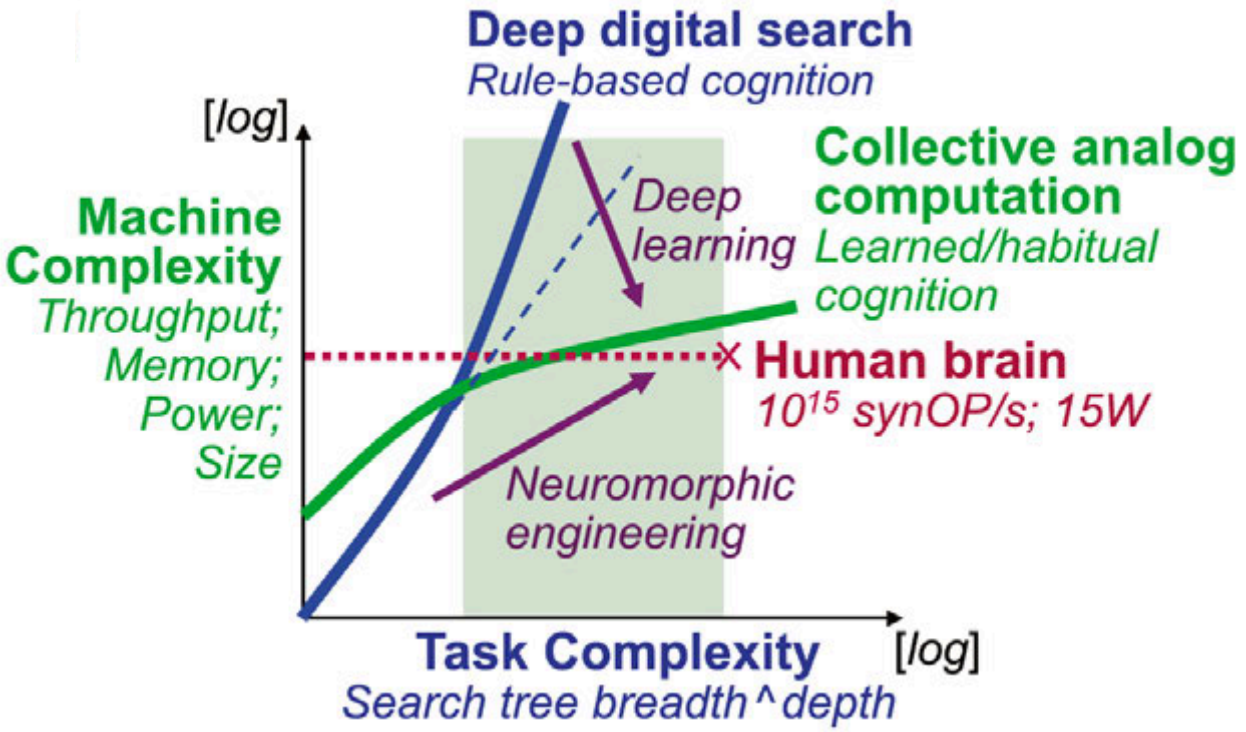
Neumorphic engineering aims at synthesis of artificial spiking neural network using analog CMOS technology



Cauwenberghs, PNAS 110, 15512 (2013)

But now it includes non-spiking neural network (e.g. deep neural network) powered by analog nonvolatile memory

Required computing performance astronomically increases with task complexity



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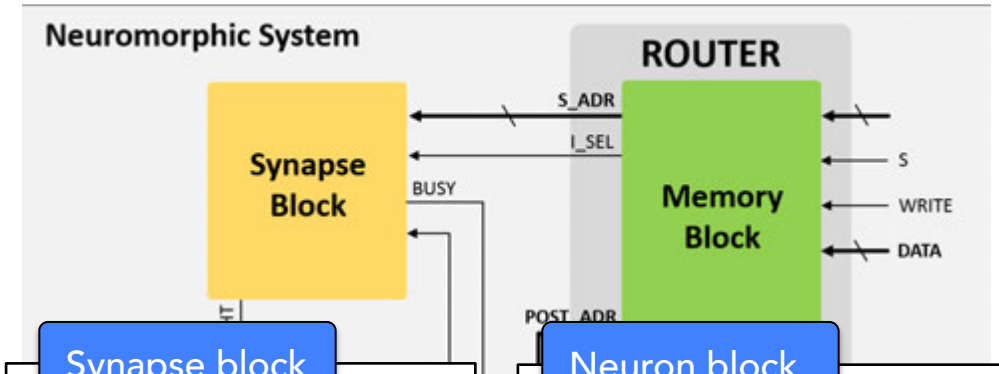
Work breakdown structure: neuromorphic system

Algorithm

Online learning algorithm

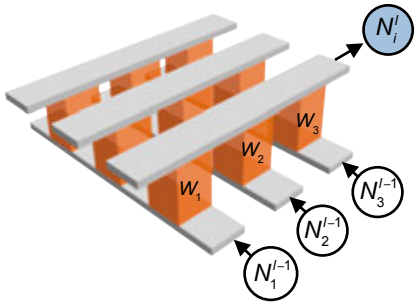
Neural Network Architecture

Neuron/synapse/routing block design



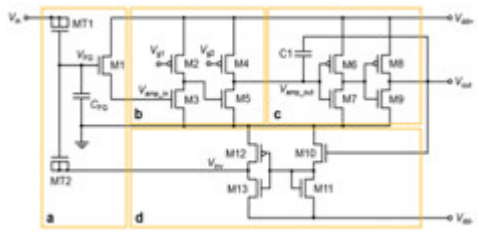
Synapse block

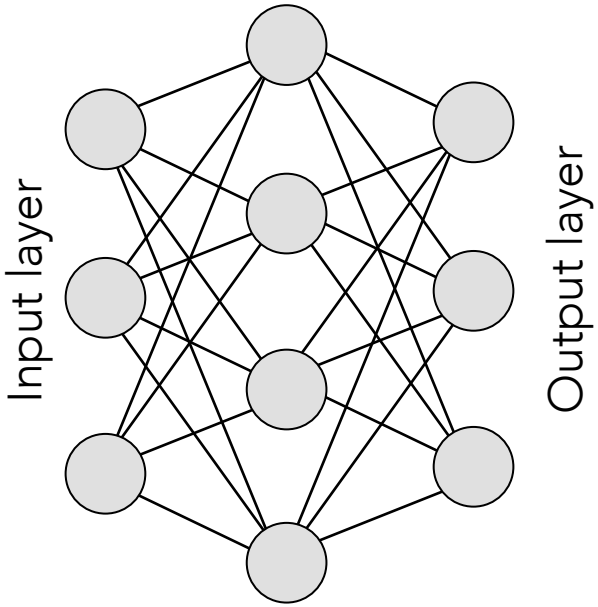
Massive weight storage



Neuron block

Memory writing voltage driver design



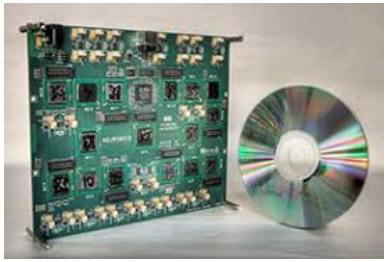


Strategies for neuromorphic engineering

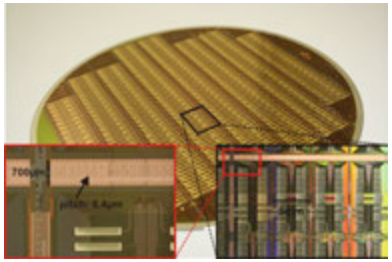
Software strategies
Virtual neural networks
Deep learning 

Hardware strategies				
Dedicated CMOS circuits (digital)	Physical neural networks (analog)/ Dedicated CMOS circuits (digital)			
ASIC (e.g. TPU)	Training with the aid of computers		Standalone training	
	Circuit components		Circuit components	
	SRAM  IBM TrueNorth	Analog VLSI	SRAM  Loihi Intel	Analog VLSI
No standalone neuromorphic systems			Standalone	
Offline learning only			Online learning	

Research trend



Neurogrid 2009 (Stanford)
Analog, sub-threshold
1M neurons, 4B synapses
100 pJ (energy/connection)



BrainScaleS 2012 (Heidelberg)
Analog, above-threshold
4M neurons, 1B synapses
100 pJ (energy/connection)

TrueNorth 2014 (IBM)
Fully digital
1M neurons, 256M synapses
25 pJ (energy/connection)

Loihi 2017 (Intel) On-chip learning
Fully digital
131,072 neurons, 130M synapses

Neo^{2}C chip 2018, On-chip learning
Fully digital
1,024 neurons, 204,800 synapses/core

Must-to-do list to boost the technology

- Development of neural network description languages
- User-friendly interface between neuromorphic chip and computer
- Algorithm development platform

- Improvement of hardware towards lower power consumption and larger neural networks

Challenges

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Thank you!