University of Chinese Academy of Sciences

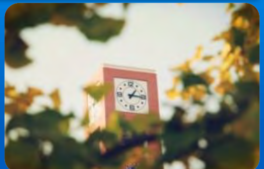
# Machine Learning and AI-IC

## *Applications of AI-ICs*

Chun-Zhang Chen, Ph.D.

June 28 - July 2, 2021



中国科学院大学2021年夏季

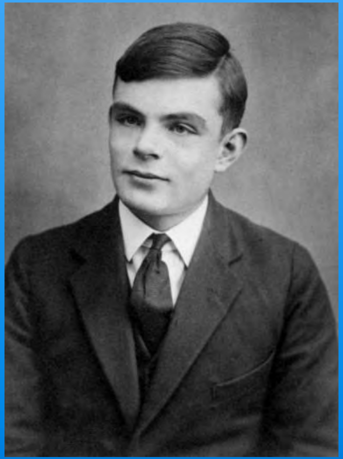
# Definition/Classification of AI

- What is AI? Merriam-Webster Dictionary:
  - "An area of computer science that deals with giving machines the ability to seem like they have human intelligence"
  - "The power of a machine to copy intelligent human behavior"
- How AI is classified?
  - Artificial Weak/Narrow Intelligence (**ANI**)
    - Focuses on improvement of individual ability, *e.g.* Siri
  - Artificial General Intelligence (**AGI**)
    - On humankind, human's brains, *e.g.* TrueNorth
  - Artificial Superintelligence (**ASI**)
    - Smarter than human brains, including innovation, recognition and social

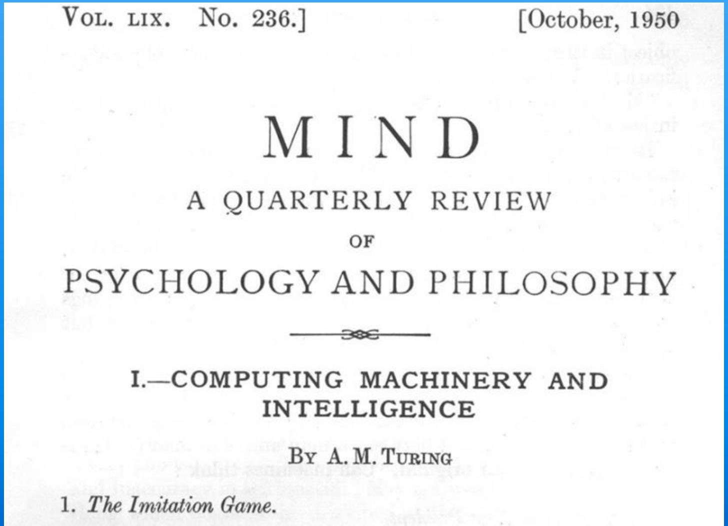
# Alan Turing and AI

the "Nobel Prize of computing"

- ACM: A.M. Turing's Award By Year (since 1966)
- Turing is widely considered to be *the father of theoretical computer science and artificial intelligence*.



Turing aged 16



VOL. LIX. No. 236.] [October, 1950

MIND

A QUARTERLY REVIEW

OF

PSYCHOLOGY AND PHILOSOPHY

I.—COMPUTING MACHINERY AND INTELLIGENCE

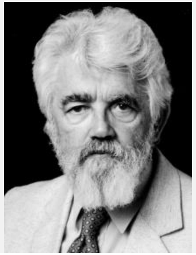
BY A. M. TURING

1. *The Imitation Game.*

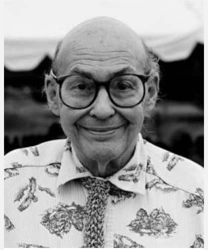
# The Birth of AI (1952-56)

- John McCarthy (Stanford)
- Marvin Minsky (MIT)
- Trenchard More (IBM ret'd)
- Ray Solomonoff (London)
- Oliver Selfridge (MIT)

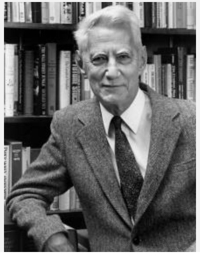
## Dartmouth Summer Research Project on Artificial Intelligence 1956



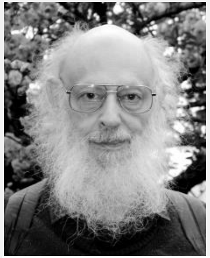
**John McCarthy,** *"AI" 1955*



**Marvin Minsky,** *MIT AI Lab*



**Claude Shannon,** *MIT Boolean alg.*



**Ray Solomonoff,** *Inductive Inference*

**Allen Newell, Turing 1975**

**Herbert Simon,** Nobel78,Turing75

**Arthur Samuel, "ML" 1959**

**Oliver Selfridge,** *Machine Perc.*

**Nat Rochester** *(IBM 701);* **Trenchard More**

**Julian Bigelow,** *IAS/MANIAC*

Source: https://en.wikipedia.org/wiki/Dartmouth_workshop

# The Past 60+ Years of AI

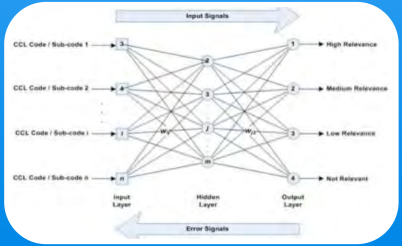
**"The First Wave of AI (1956-76)"**


*The Golden Years of AI (1956-74); H. Simon & A. Newell 1975 Turing*


**"Winter Seasons of AI (1976-05)"**

*PC Market ; IBM-Deep Blue 1997 & Jeopardy 2011*

**DNN Algorithm, Backpropagation *(1986)*;**




**Next Step:**
***BP? Capsule?***

# Machine Learning and AI-IC

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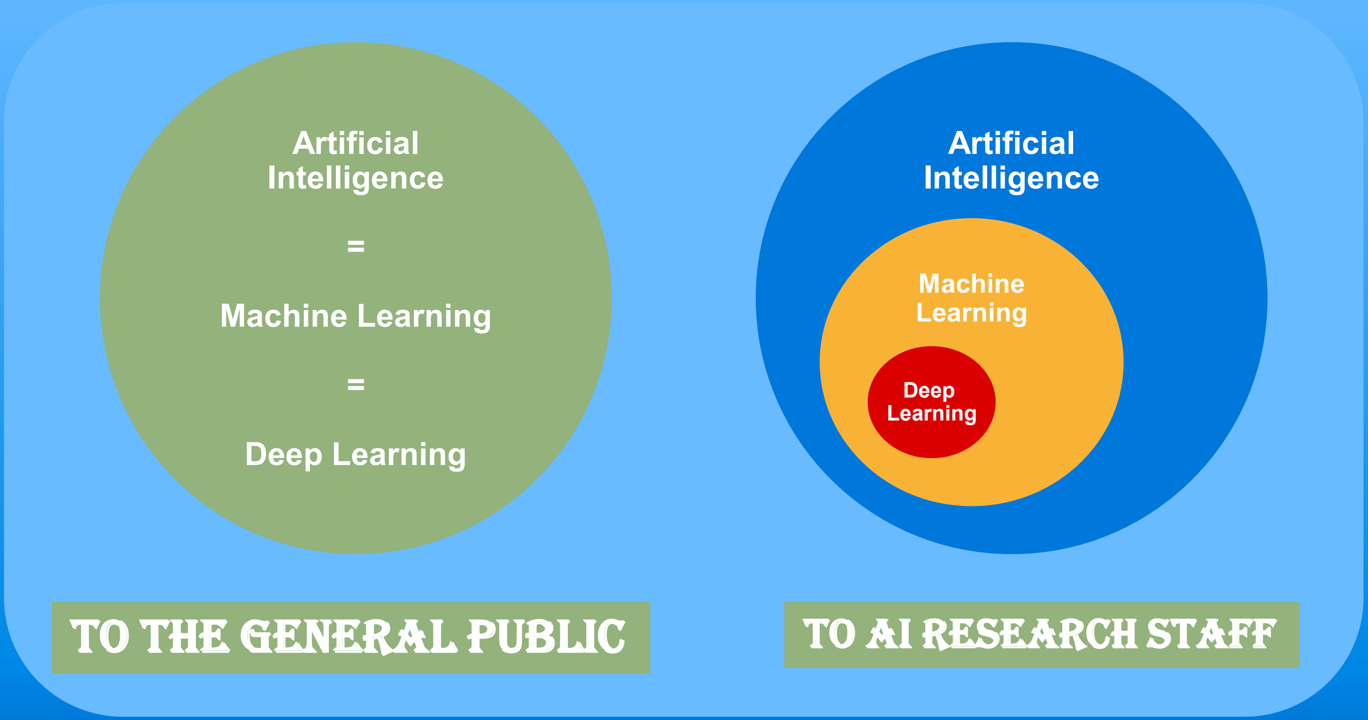
- **Machine Learning Methods**
- **Machine Learning and Deep Learning**
- **CPU and GPU in AI-IC**
- **Applications of AI-IC**
- **Discussion**

# Views of AI/ML/DL

*Can AI Replace Human Beings?*




**ML: Schools? Algorithms?**

# Schools of Machine Learning

- Symbolic *(e.g. Frank Rosenblatt, 1957)*
  - *logicism, aka logicism, psychology, or computerism*
- **Connectionism** *(e.g. Geoffrey Hinton, 1986 Nature)*
  - *Aka bionicsism or physiologism*
- Actionism
  - *Aka evolutionism or cybernetics*
- **Probabilistic Graphical Models**
  - *E.g. Bayes network, Random mean forest*

# Key Aspects of ML, Algorithms

- **Types of ML Algorithm**
  - Supervised learning
  - Semi-supervised learning
  - Unsupervised learning
  - Reinforcement learning

- Regression, KNN, SVM, Boosting (Ada, X-G), Decision Tree, Random Forest etc.
- Clustering (e.g. K-means, GMM), Dimensionality Reduction, PCA, ICA, etc.

# Machine Learning and AI-IC

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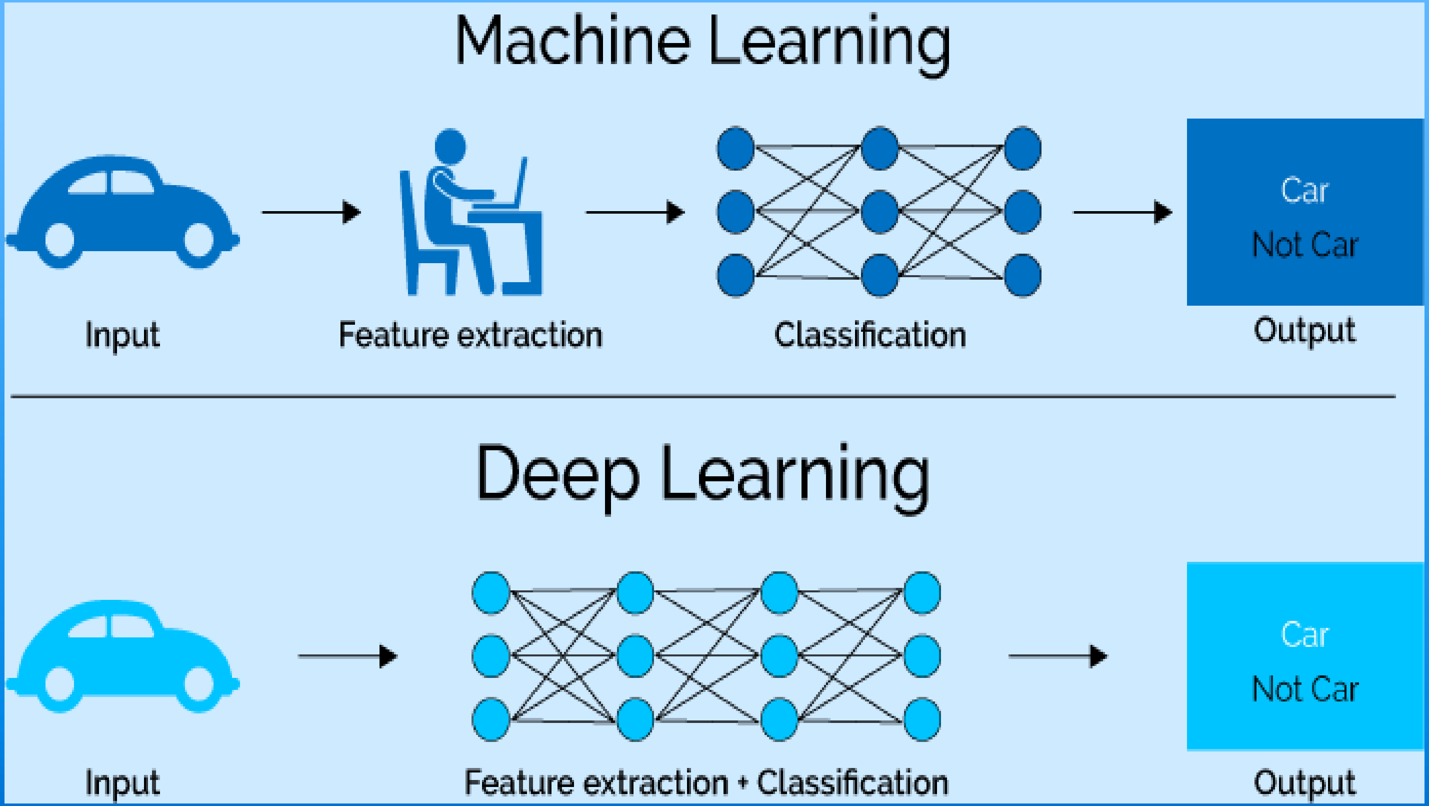
# Comparison of Learning Flow in ML and DL



# Types of Deep Learning Algorithms

- Artificial Neural Network
  - *ANN,*
    - *Artificial Neural Network*
  - FNN,
    - Feedforward Neural Network
  - CNN,
    - Convolutional Neural Network
    - *Cellular Neural/Nonlinear Network*
  - RNN,
    - Recurrent Neural Network
    - LSTM, modified RNN
    - Transformer(s) from Google
  - GAN,
    - Generative Adversarial Network

# 2018 ACM A.M. Turing Award



- Yoshua Bengio,
  - Professor at the University of Montreal and Scientific Director at Mila, Quebec's Artificial Intelligence Institute
- Geoffrey Hinton,
  - VP & Engineering Fellow of Google, Chief Scientific Adviser of The Vector Institute, and Univ. Prof. Emeritus at Univ. Toronto
- Yann LeCun,
  - Professor at New York University and VP and Chief AI Scientist at Facebook

ACM DL DIGITAL LIBRARY

# ML/DL Applications

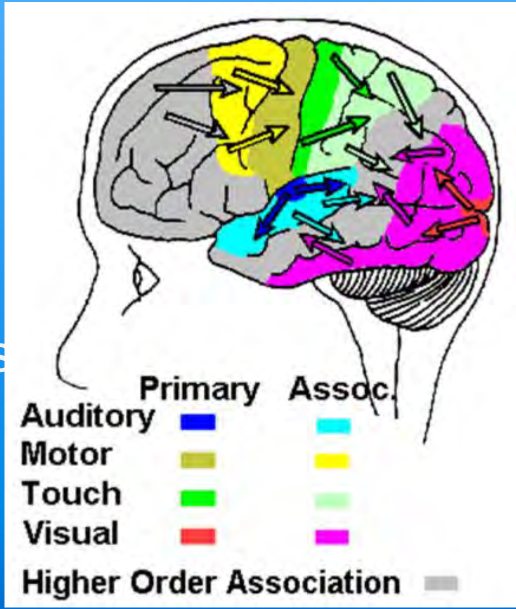
- **ML Applications**
  - Image Recognition. One of the most common uses of machine learning
  - Speech Recognition.  SR the translation of spoken words into text.
  - Medical Diagnosis. ML provides methods, techniques, and tools that can help solving diagnostic...
  - Statistical Arbitrage.
- **DL Applications**
  - Self-driving cars
  - Deep Learning in Healthcare
  - Voice Search & Voice-Activated Assistants
  - Automatic Colorization of Black and White Images.
  - Automatically Adding Sounds To Silent Movies
  - Automatic Machine Translation

# In Human Cerebrum

- Functional areas
  - Frontal lobe
    - Thinking/plan/short mem.
  - Parietal lobe
    - Touch/smell/taste
  - Occipital lobe
    - Visual activity
  - Temporal lobe
    - Memories

- Under cerebral cortex

  *(Primary, Association)*
  - Auditory,
  - Motor,
  - Touch,
  - Visual,
  - High order as



# Neurons and Synapses (Neural Network)

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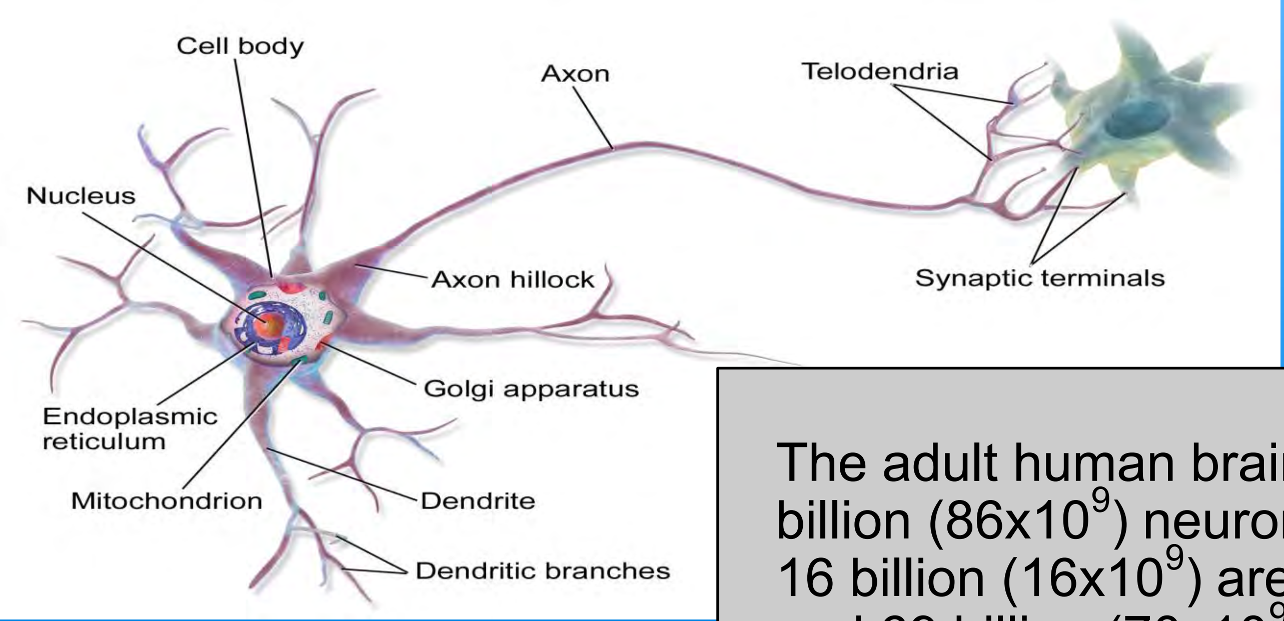
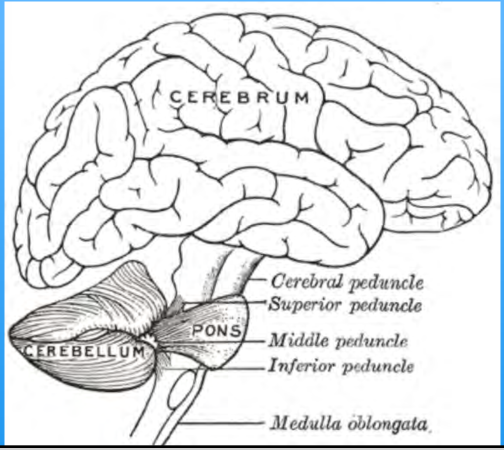
- Human brain: Cerebrum, Cerebellum




The adult human brain contains about 85-86 billion ($86 x 10^9$) neurons,[38][39] of which 16 billion ($16 x 10^9$) are in the cerebral cortex and 69 billion ($70 x 10^9$) in the cerebellum.[39]

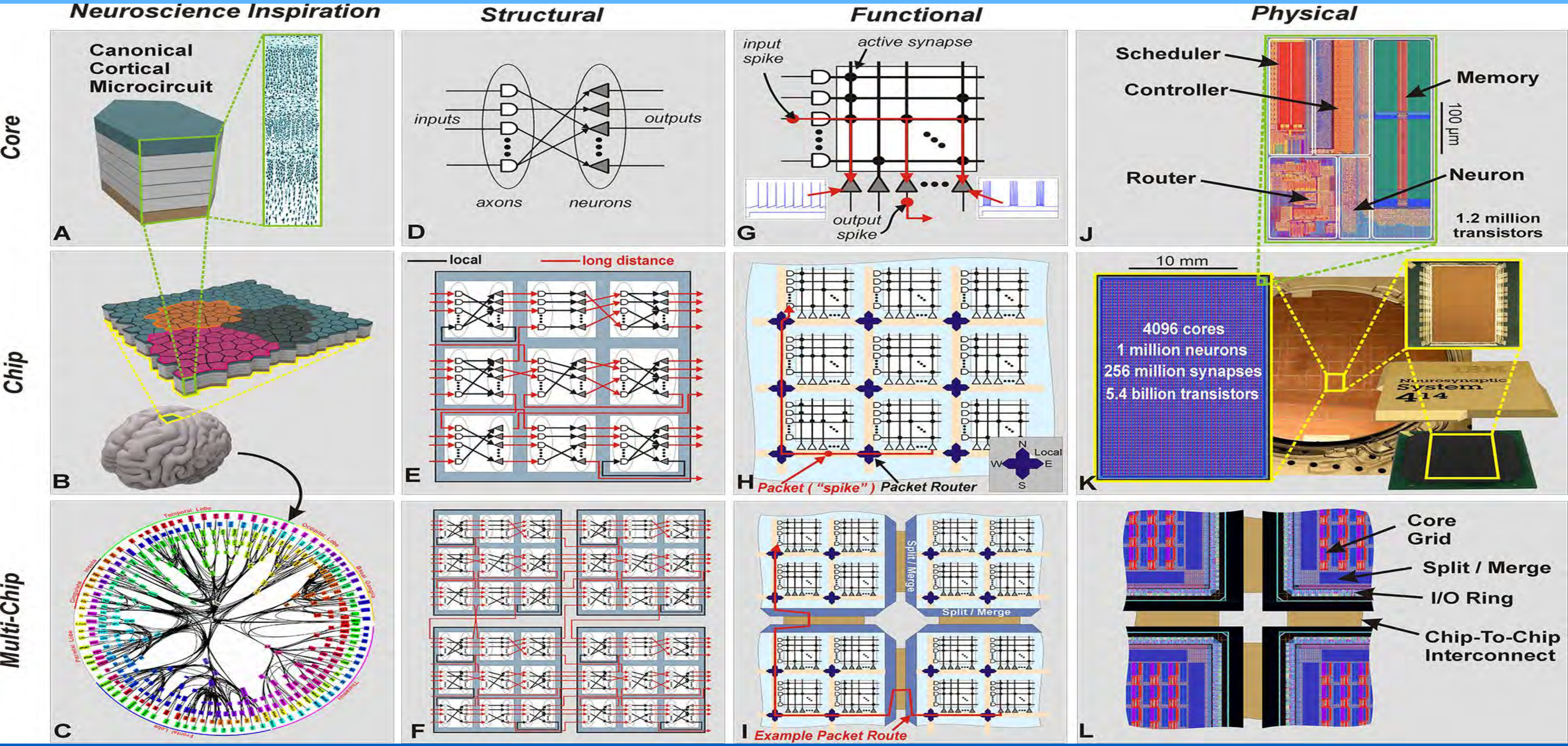
# Machine Learning and AI-IC

- Machine Learning Methods
- Machine Learning and Deep Learning
- CPU and GPU in AI-IC
- Applications of AI-IC
- Discussion

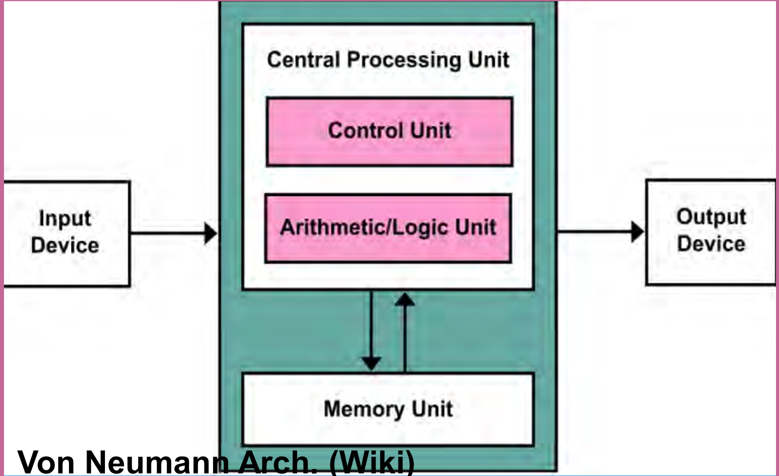
# Neuromorphic AI-IC, IBM 2014

- **A neuromorphic CMOS IC, TrueNorth chip**
  - Many cores, 4096 cores, simulating a total >$10^6$ neurons
  - The programmable synapses is >$268 \times 10^6$ ($2^{28}$)
- **Contains $5.4 \times 10^9$ transistors (Sg28nm)**
  - At low T, 70 mW, about 1/10,000$^{th}$ of conventional MPU
- **Application**
  - SyNAPSE 16 chips for DARPA

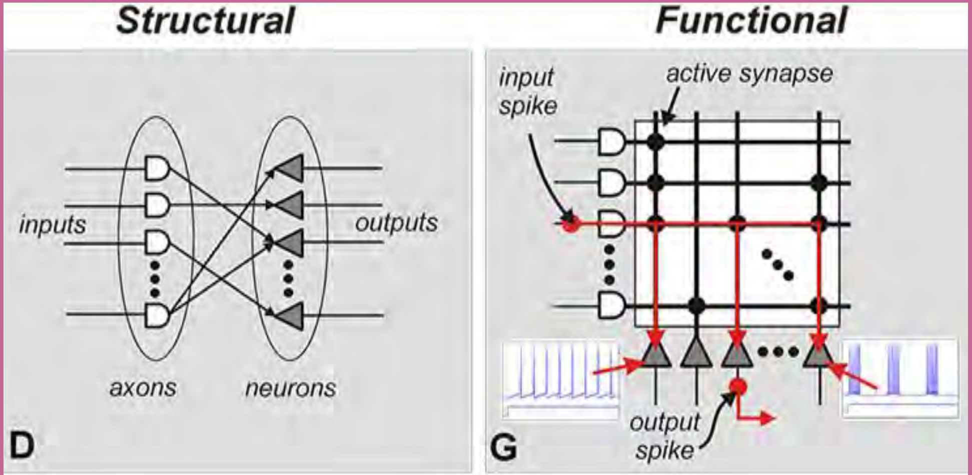
# IBM SyNAPSE Project and TrueNorth Chip



# CPU and von Neumann Bottleneck




Von Neumann Arch. (Wiki)

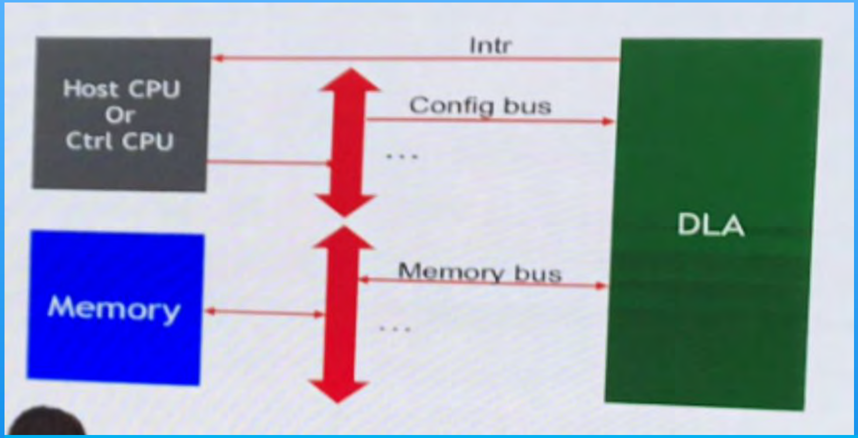



**Von Neumann Computing**
**Serial Computing**
**Separate Memory**
**High Precision**

**Neuromorphic Computing**
**Highly Parallel**
**In Memory Computing**
**Tolerance to Low Precision**

# GPU for Deep Learning

- Nvidia, 1999 GeForce 256: "*the world's first GPU*"
- a "single-chip processor with integrated transform, lighting, triangle setup/clipping, & rendering engines"
- GPU for DL and EC

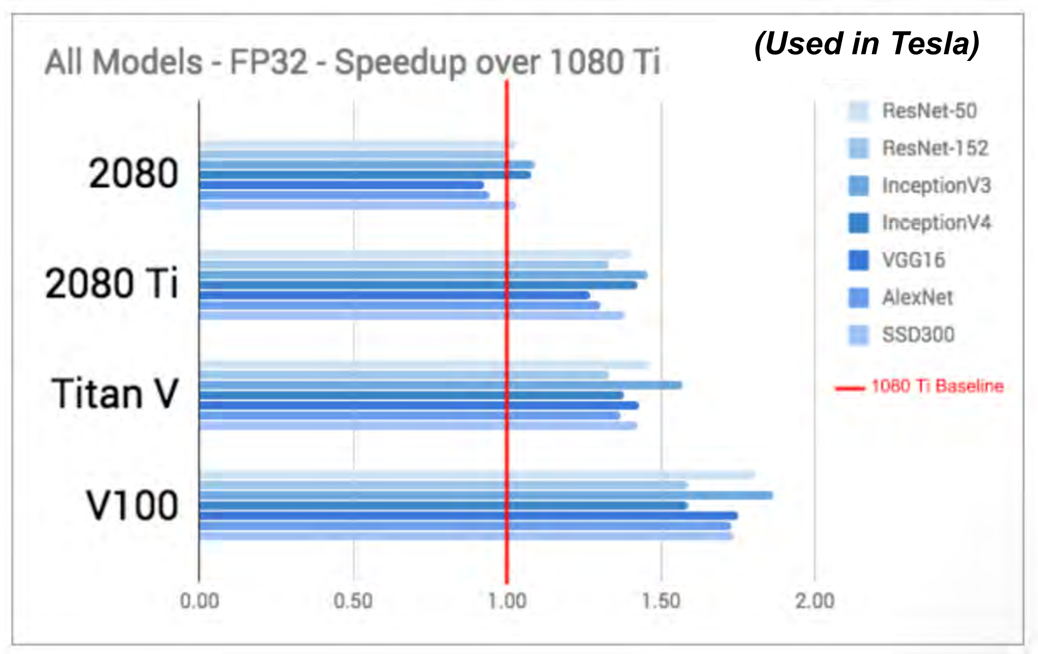



**Nvidia DLA (Deep Learning Accelerator)**
***"DL Solution for Edge Computing"***
(SiFive-RISC-V, 03/29/19 Shanghai)

# GPU Benchmarks for DL

- ResNet-50
- ResNet-152
- Inception-V3
- Inception-V4
- VGG16
- AlexNet
- SSD300

- GPU tested/used in *Tesla*

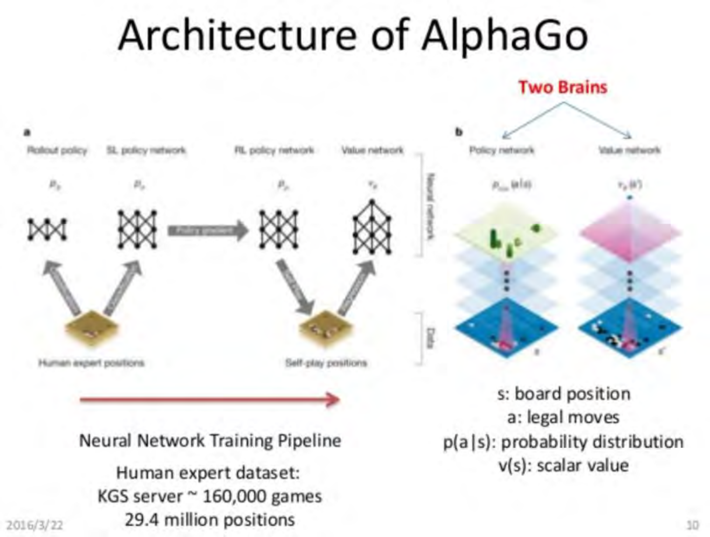


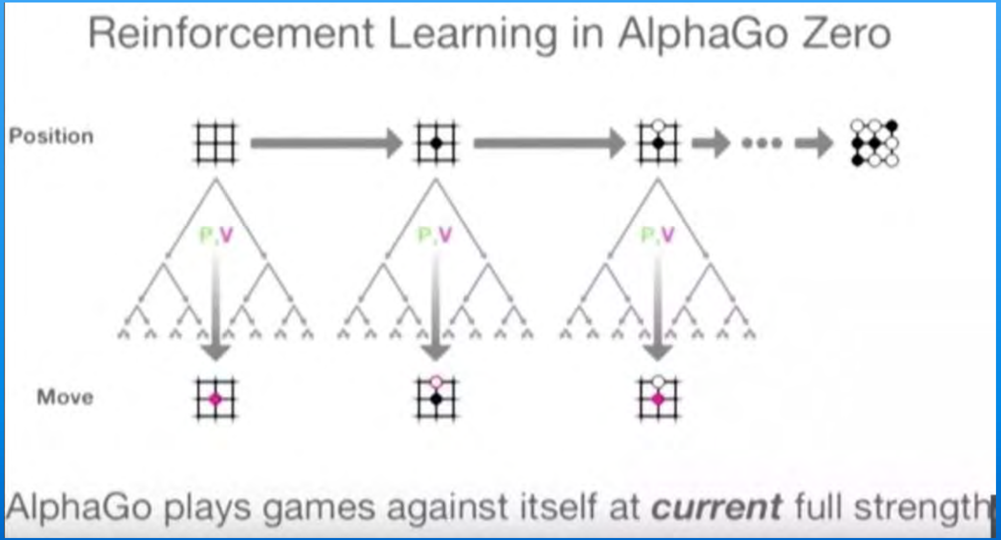
# GPU from AMD

- Acquisition of ATI in 2006
  - CPU chips: *A4, A6, A8*
  - *Fusion* chip (CPU+GPU)
  - *Llano* (Accelerated) APU

# AI-IC in AlphaGo/AlphaGo Zero

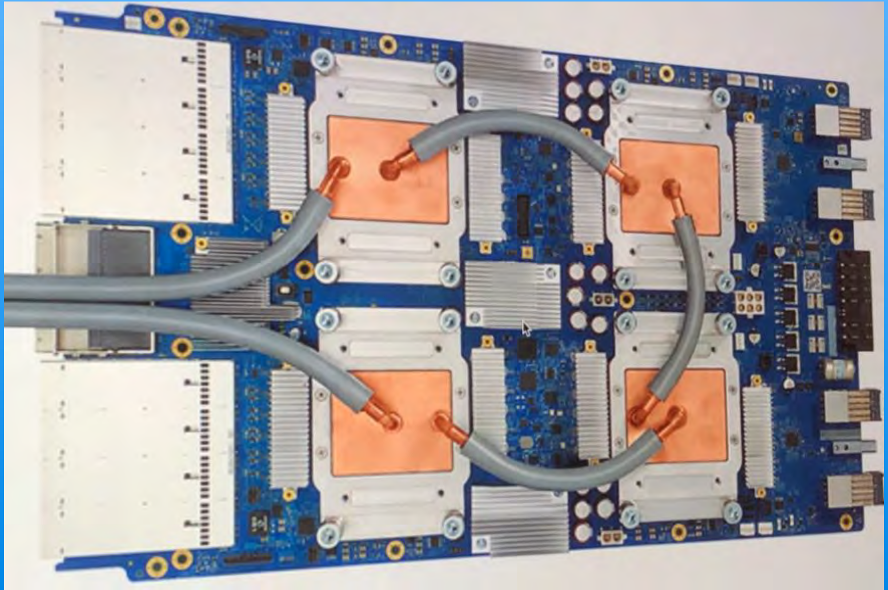
- Architecture based on CPU + GPU
  - AlphaGo (Oct. 15; Mar. 16; Mar. 17)
  - AlphaGo Zero (10/19/17)



# TPU used in AlphaGo for ML

- Can be accessed from Cloud
- 2018 Edge TPU: IoT EC
- TPU in AlphaGo 2016 (Lee Sedol)
  - 2016 Gen1: CISC 8-bit, PCIe 3.0, 28nm, ≤331 $mm^2$,
  - 2017 Gen2: 4x16GB HBM 4x600GB/s, 180TFLOPS→ 11.5PFLOPS
  - 2018 Gen3: 2x of Gen2, 1024 chips per pod, 28nm, 700MHz, 40W

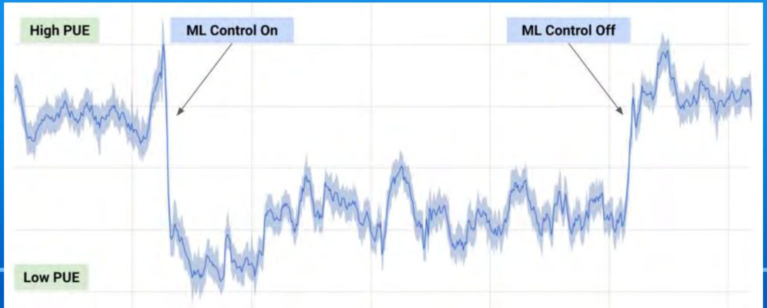


*2018, TPU 3.0, 100 PFLOPS, Google*

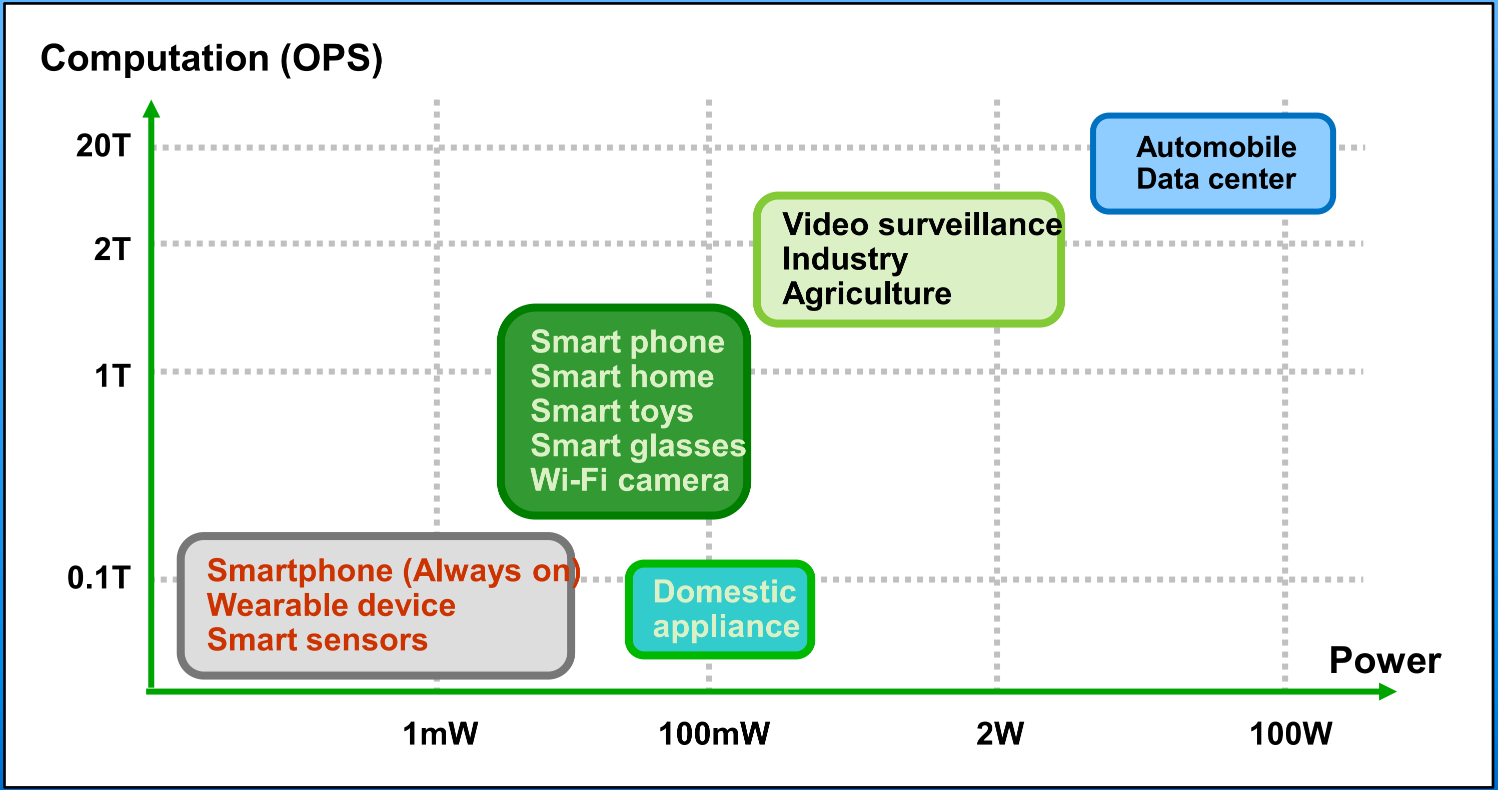
*AlphaGo, AlphaStar, AlphaZero, AlphaFold*

# TPU used in TensorFlow

- TPU (announced at Google I/O, Mtn View) )
  - TPU 1.0 (05/20/16); TPU 2.0 (05/23/17); TPU 3.0 (5/8-5/10/18)
- TensorFlow, ASIC (CPU+GPU)
  - https://www.tensorflow.org/
  - Feb 15, 2017, **TensorFlow 1.0** [09/27/16 → 11/06/16 → 02/15/17]
  - Nov 04, 2018, **TensorFlow 2.0**
- DeepMind,

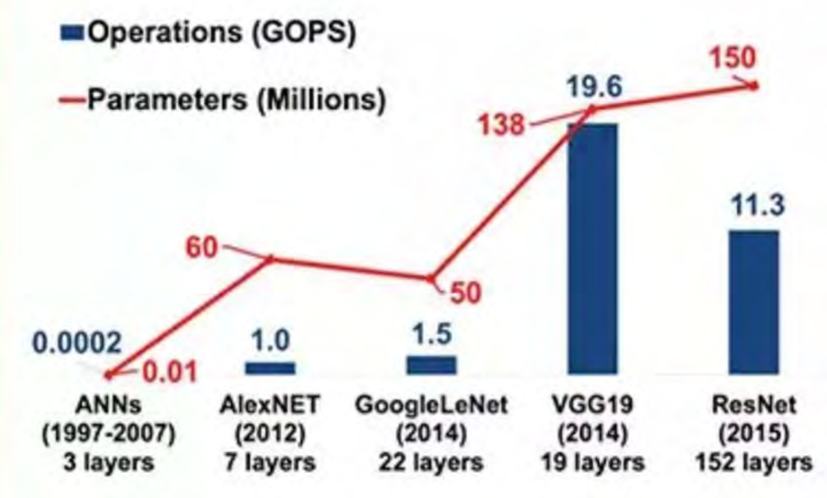


# Computation Needs vs Power Limits

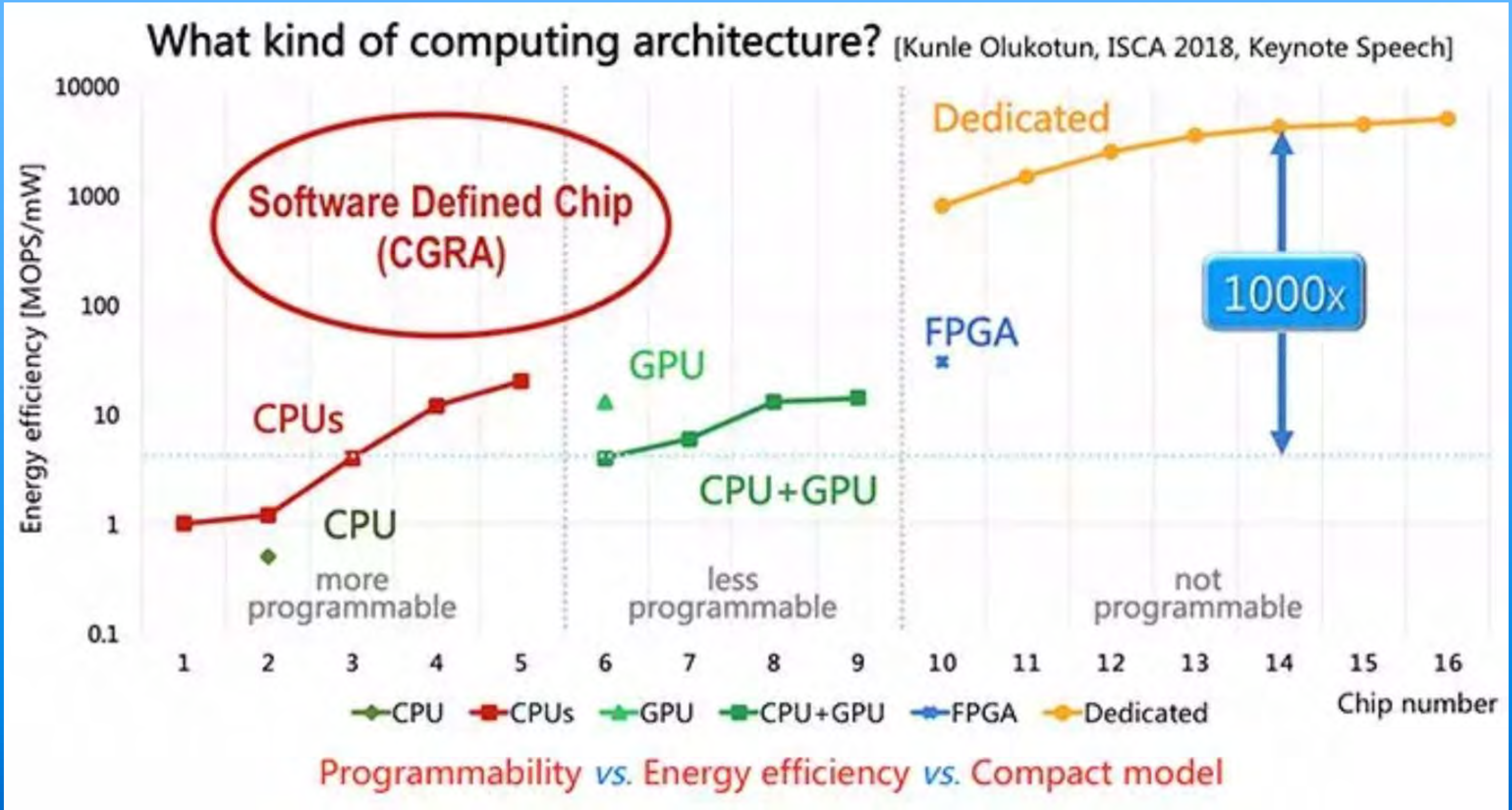


# Features of AI-IC

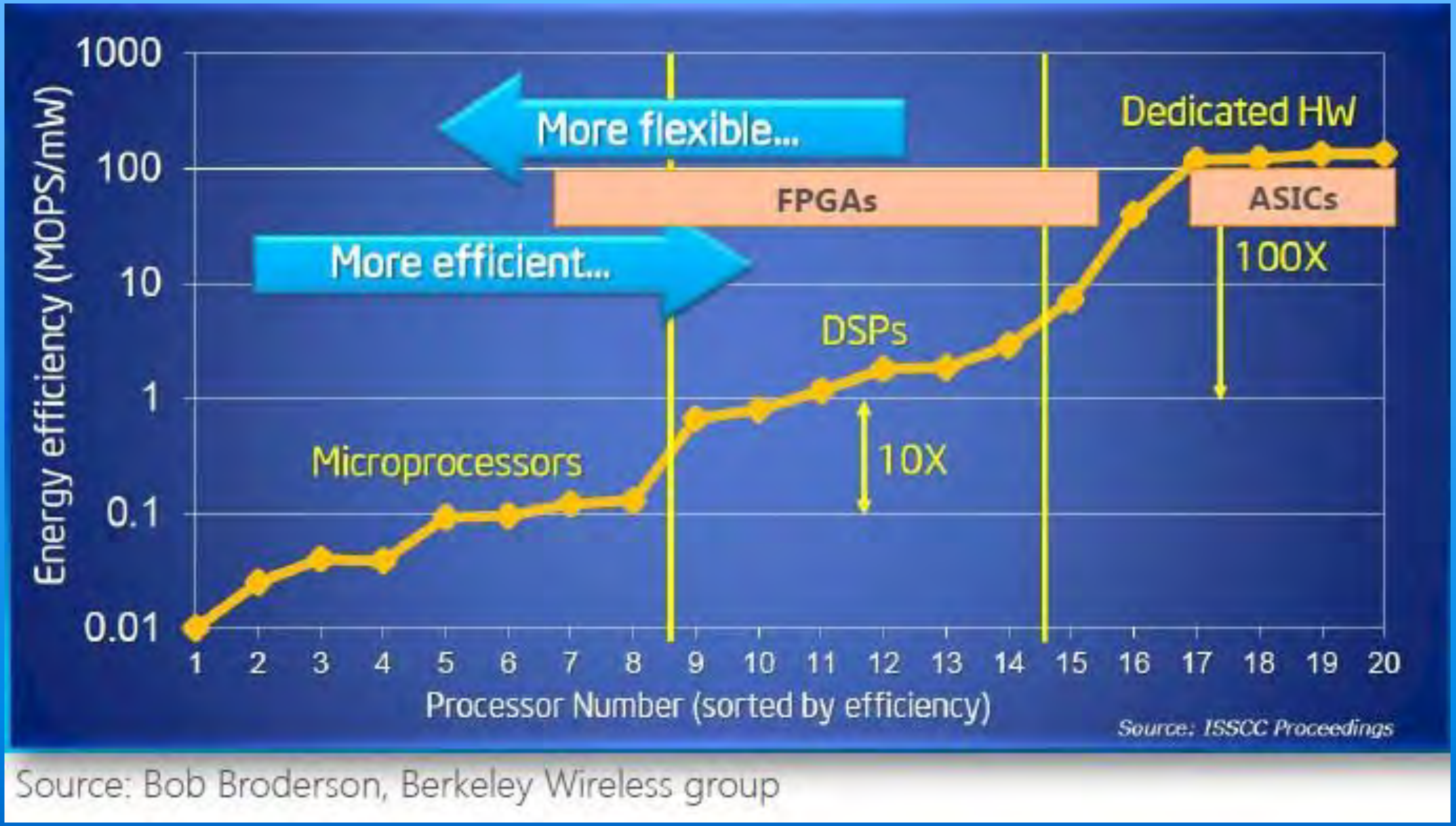
- Requirements for an AI-Chip
  - Programmability
  - **High Energy Efficiency**
  - Common use for DL
- CNN becomes most popular
  - Pattern (LeNet)
  - Image (AlexNet)
  - Vision (LRCN net)
- To meet **Edge Computing** with high Energy Efficiency
- OPS and Parameters



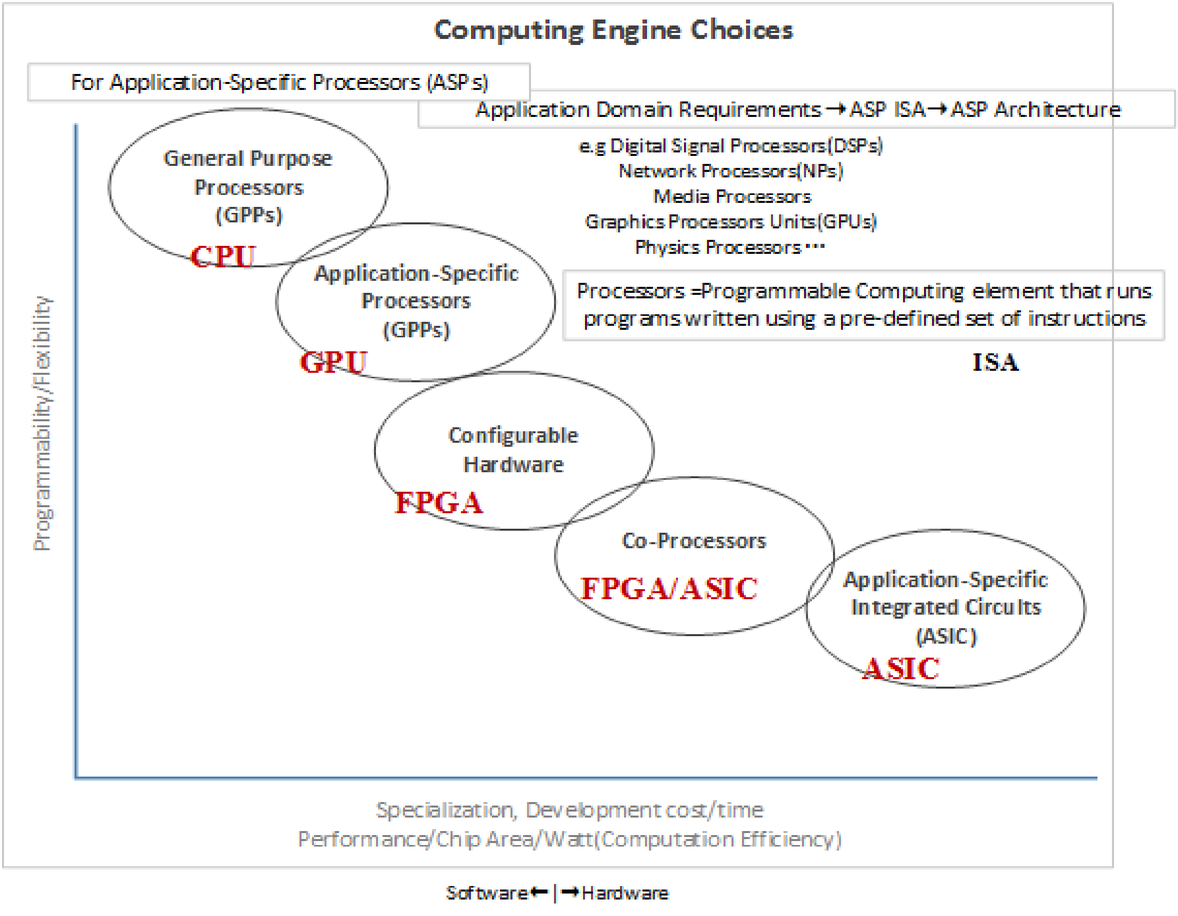
# Progress of Energy Efficiency (OPS/W)



# Comparison of Energy Efficiency (Processors)



# Comparison of Computing Engines' Flexibility



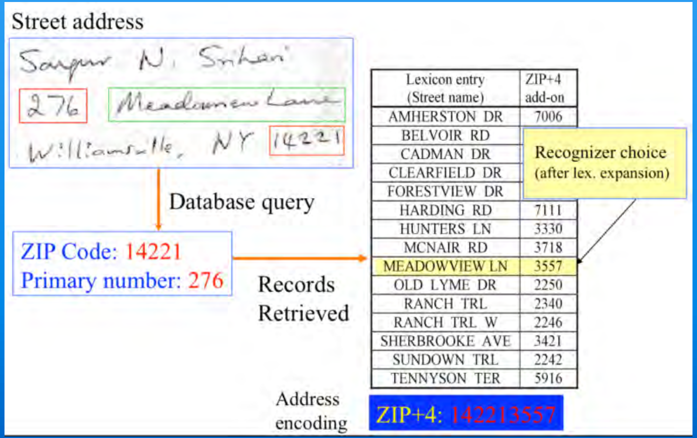
# Machine Learning and AI-IC

# Applications of ML and HW

- Biomedical informatics
- **Computer vision**
- Customer relationship management
- Data mining
- Email filtering
- Inverted pendulum
- **Natural language processing (NLP)**
  - Automatic ...
  - translation ...
- **Pattern recognition**
  - Facial recognition system

**AlexNet**
**VGG**
**ResNet**

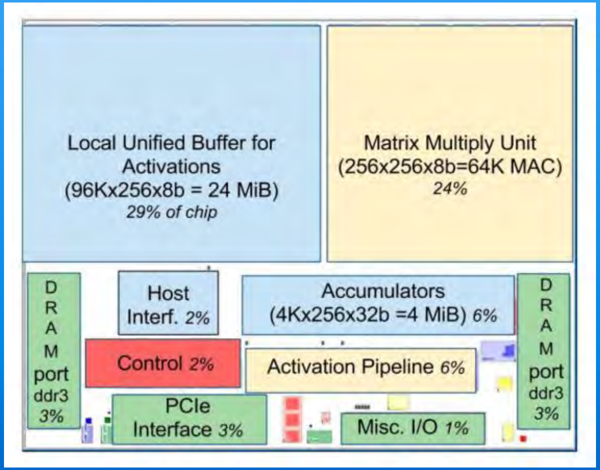
- Handwriting recognition
- Image recognition
- Optical character recognition
- Speech recognition
- Recommendation system
- Search engine
- Social engineering

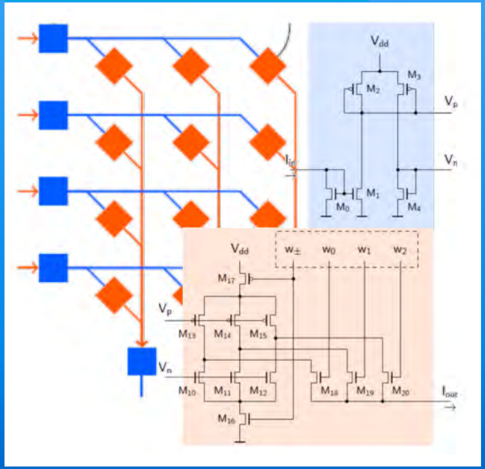


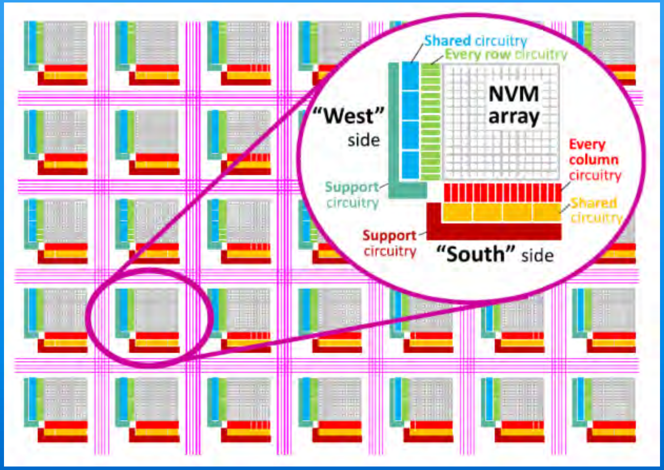
# New Hardware for Inference and Training

- Digital
  - GPU,TPU,FPGA etc.
  - 10-$10^3$ speedup
  - Power hungry, large
- Analog
  - Neuromorphic
- Beyond-Si
  - RRAM, STT etc.
  - >$10^3$ speedup
  - Small footprint, E efficient

*Ref. Mohanty et al. IEDM 2017*





# Apple Chip A Series

| Year | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Generation | A11 | A12 | A13 | A14 | A15? |
| Process, nm | 10 | 7 | N7 | 5 | |
| Chip area, $mm^2$ | 1.83 | 5.8 | 1.16 | | |
| TOPS | **0.6** | **5** | **6** | **11** | |

# WSE by Cerebras

|  | Cerebras WSE | Largest GPU | Cerebras Advantage |
|---|---|---|---|
| Chip size | 46,225 $mm^2$ | 815 $mm^2$ | 56.7 X |
| Cores | 400,000 | 5,120 | 78 X |
| On chip memory | 18 Gigabytes | 6 Megabytes | 3,000 X |
| Memory bandwidth | 9 Petabytes/S | 900 Gigabytes/S | 10,000 X |
| Fabric bandwidth | 100 Petabits/S | 300 Gigabits/S | 33,000 X |

# WSE by Cerebras, CS-1

## Cerebras CS-1: A 15 RU System for Training and Inference in the Data Center

- Accelerates all deep learning models: CNN, RNN, LSTM, etc.
- Powered by an array of 400,000 Cerebras' AI optimized processor cores
- 18 GB on chip memory —> 3,000 times more than a graphics processing unit
- > 9PB/s on-die memory bandwidth-> 10,000 more than a graphics processing unit
- 100 Pb/s total interconnect bandwidth-->33,000 times more than a graphics processing unit
- System IO: 12 x 100 GbE
- System power: 20 KW;
- Programed with TensorFlow, PyTorch, Mxnet, Caffé2, Theano, CNTK

**More Compute than Up To 1,000 GPUs**

1/40th the space, 1/50th the power

# Cerebras WSE-2

- WSE Gen1 16nm, Aug 2019
- WSE Gen2 7nm, Q3 2021
  - 850,000 AI Cores
  - 2,600B transistors, 56 mTr/$mm^2$
  - Memory 40GB, 20 PB/s
  - Fabric 220 Pb/s

# WSE-2 vs Largest GPU



| IC | **WSE** | ***WSE-2*** | **Nvidia A100** |
|---|---|---|---|
| Area | 46,255mm$^2$ | *46,255mm$^2$* | 826mm$^2$ |
| Transistors | 1.2 trillion | *2.6 trillion* | 54.2 billion |
| Cores | 400,000 | *850,000* | 6,912 + 432 |
| On-chip memory | 18GB | *40GB* | 40MB |
| Memory bandwidth | 9PB/s | *20PB/s* | 1,555GB/s |
| Fabric bandwidth | 100Pb/s | *220Pb/s* | 600GB/s |
| Fabrication process | 16nm | *7nm* | 7nm |

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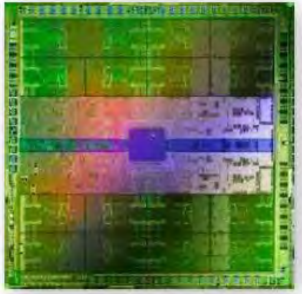
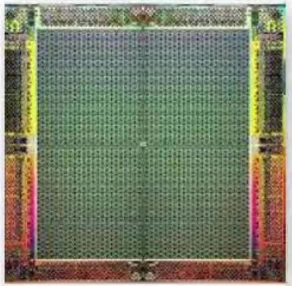
# Hardware Acceleration Platforms



- CPU, 1X
- GPU, FPGA, ASIC, Beyond CMOS

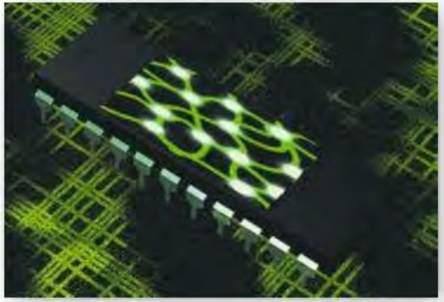


**GPU**
**10 – 30 X**



**FPGA**
**10 – 50 X**


**CMOS ASIC**
**$10^2$ – $10^3$ X**



**Beyond CMOS**
**>$10^3$ X**

# Comparison of AI-Chip Features

*GPU, FPGA, ASIC, Neuromorphic*

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| Type / Feature | GPU | FPGA | ASIC | Brain-inspired |
|---|---|---|---|---|
| Customization | General | Semi-custom | Customized | Neuromorphic |
| Programma-bility | No | Easy | Difficult | No |
| App scenario | Cloud train. | Acc., D Ctr, Infer. | Widely used | Comp. recog. Envir. |
| Vendor | Nvidia | Xilinx, Altera | Google, Cambricon | IBM |
| Advantages | Peak comp., mature | Perf. Power, prog., fast | Av. Perf., power, size | Power, comm., recog |
| Disadv. | Effic., prog., power | Cost, peak comp. | NRE, R&D cycle, risk | Immature |