The Brain That Wouldn't Die

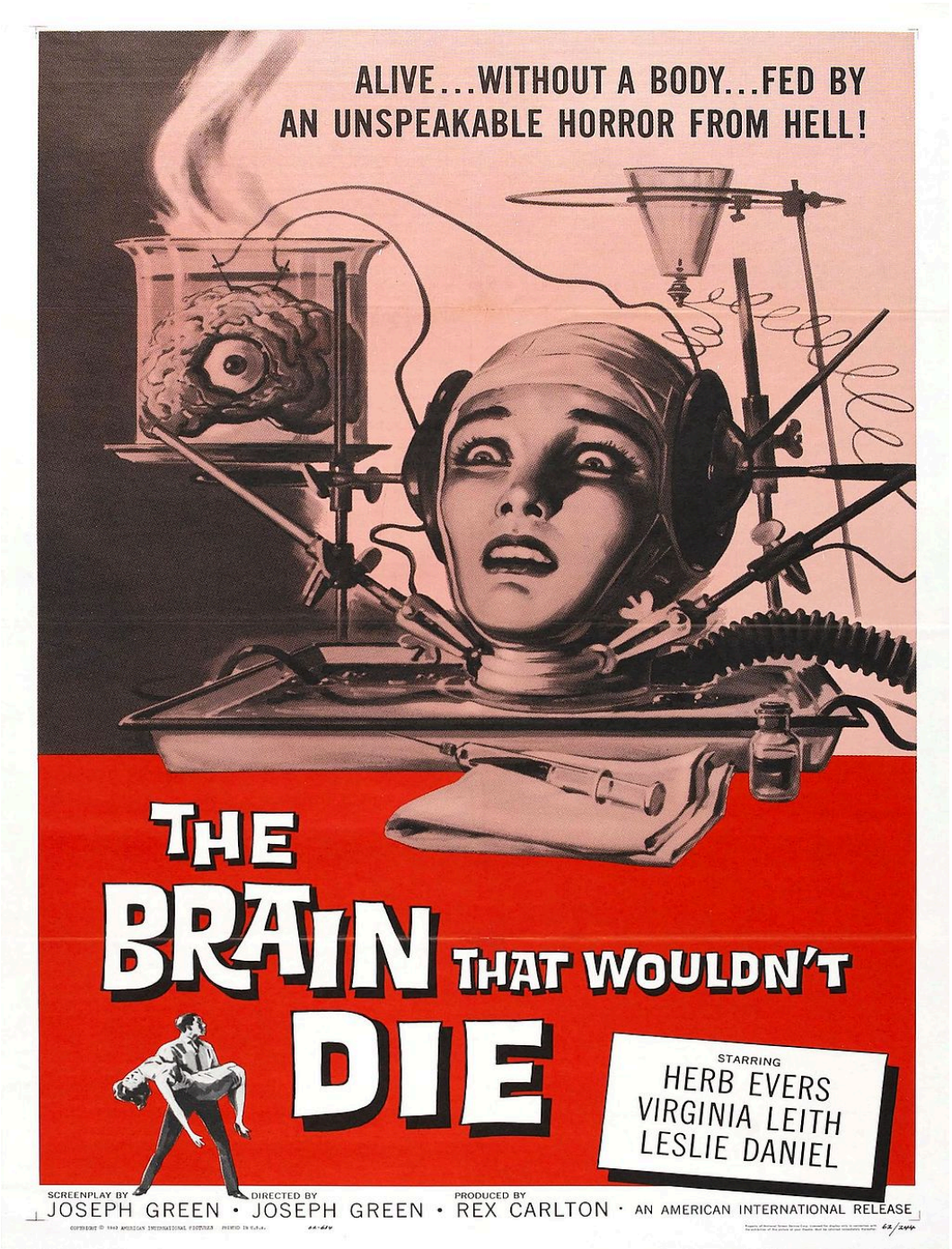
2021 한국뇌공학회 심포지엄 "디지털 브레인으로의 진화"
온라인 심포지엄, February 25, 2021

Byoung-Tak Zhang

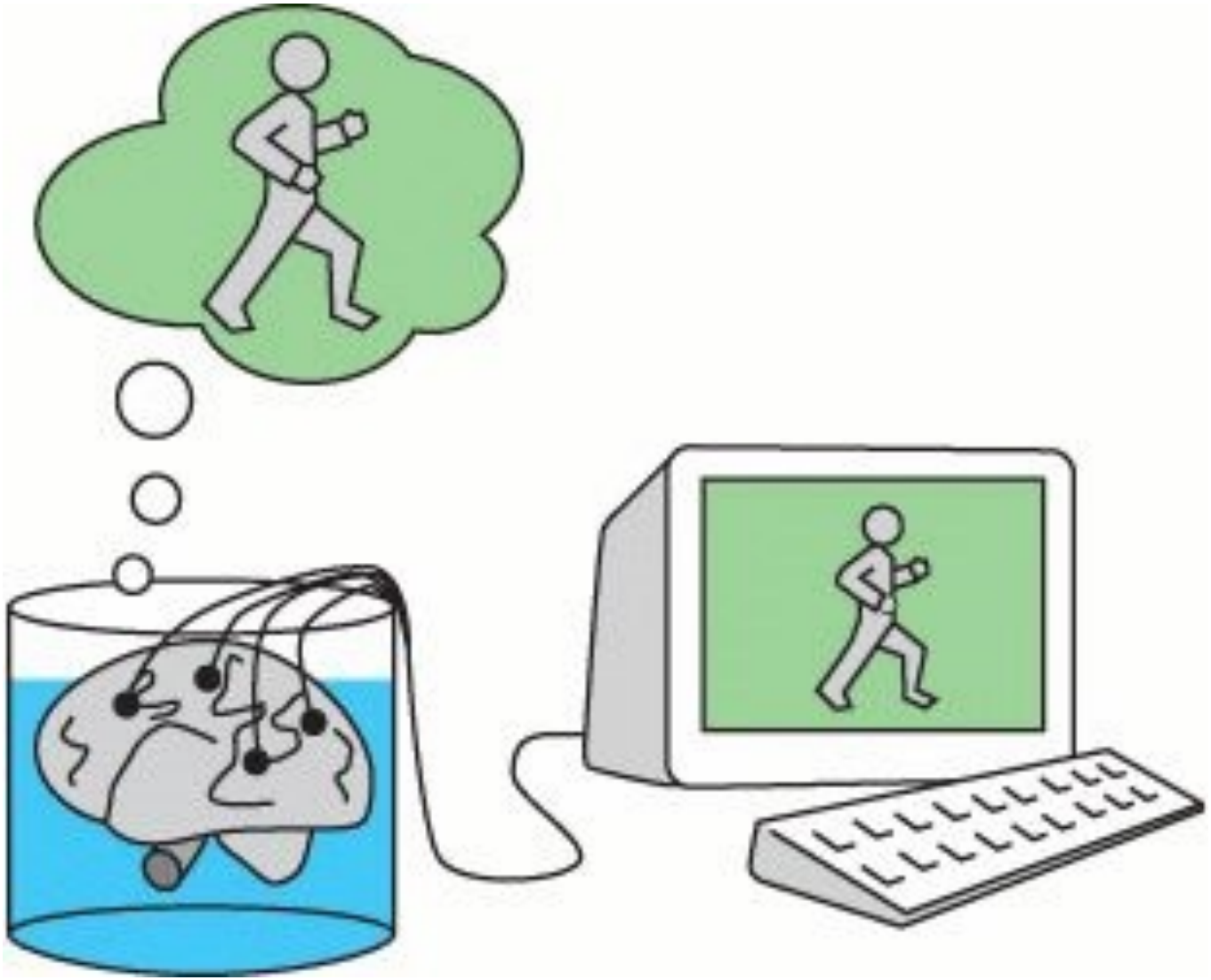
AI Institute (AIIS)
Seoul National University

Outline

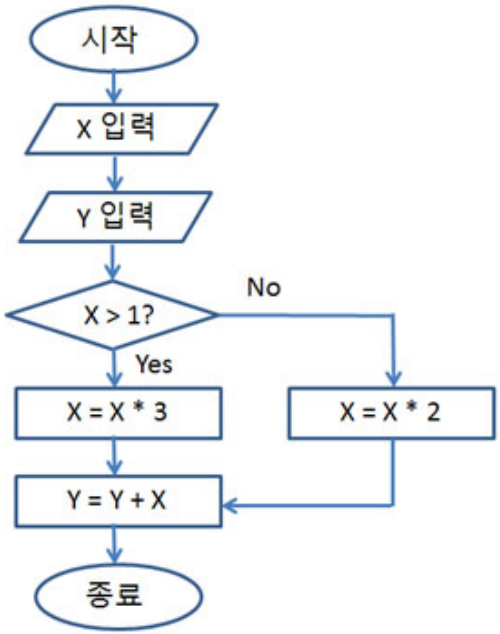
1. The Brain in a Vat


ALIVE...WITHOUT A BODY...FED BY
AN UNSPEAKABLE HORROR FROM HELL!
THE BRAIN THAT WOULDN'T DIE
STARRING
HERB EVERS
VIRGINIA LEITH
LESLIE DANIEL
SCREENPLAY BY JOSEPH GREEN · DIRECTED BY JOSEPH GREEN · PRODUCED BY REX CARLTON · AN AMERICAN INTERNATIONAL RELEASE

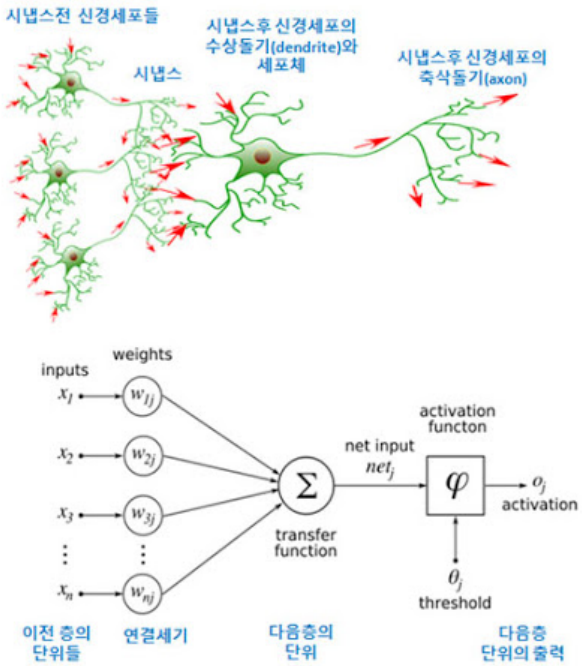
Brain in a Vat



Two Paradigms of AI



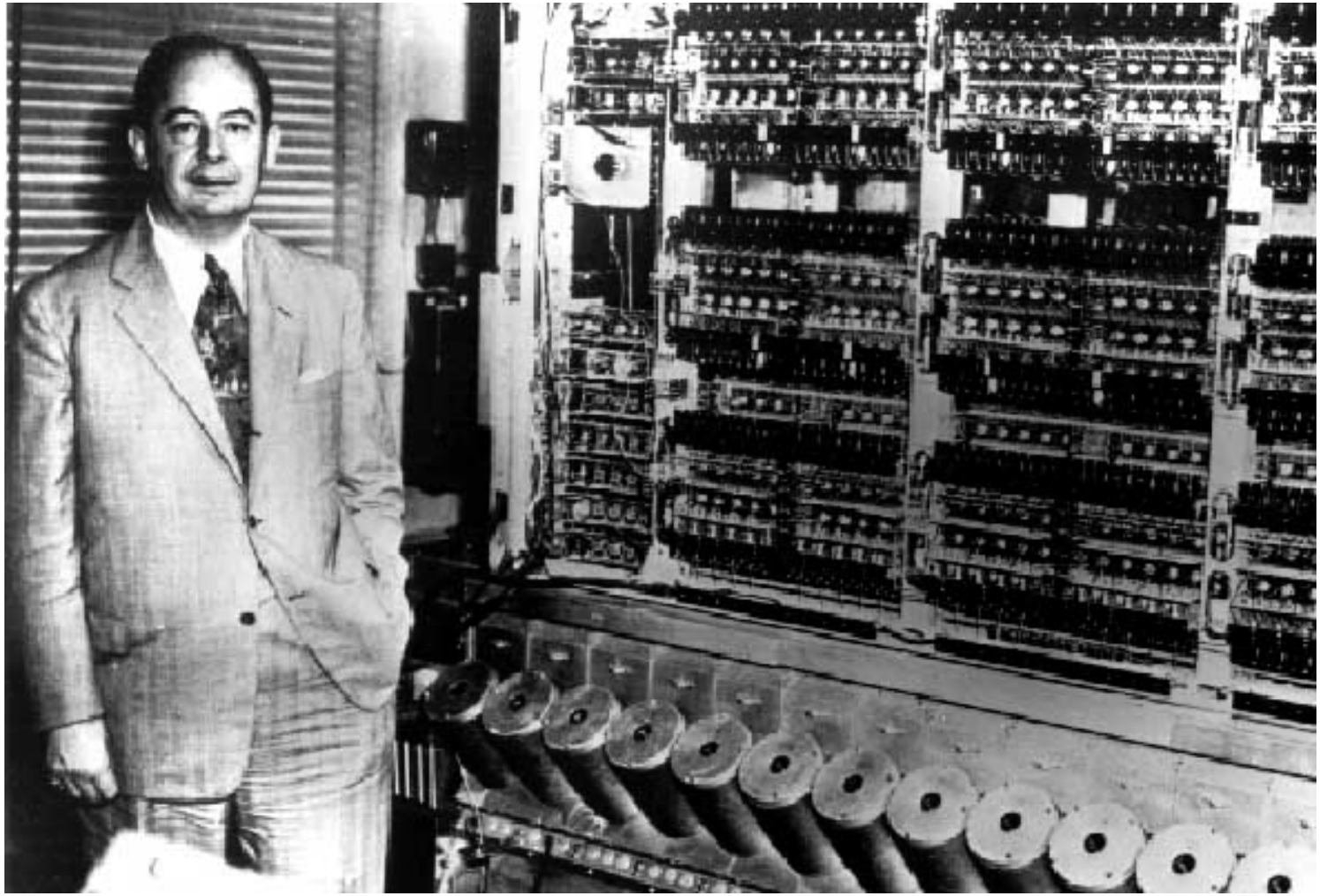
기호주의-논리규칙 모델



연결주의-뇌신경망 모델

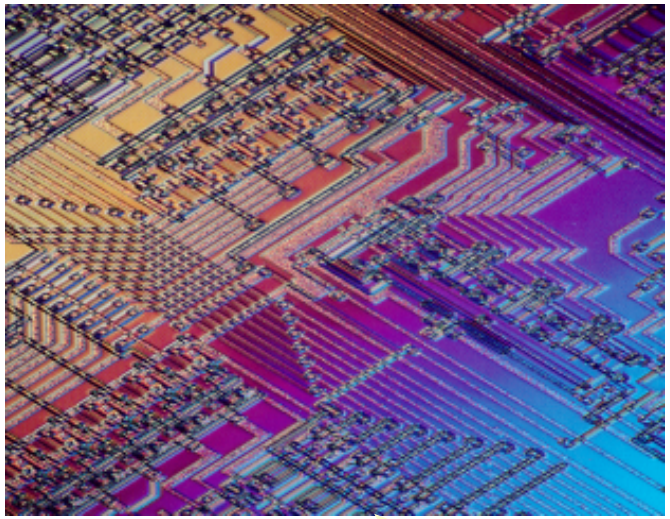
출처: http://scienceon.hani.co.kr/397536

Von Neumann's *The Computer and the Brain* (1958)



John von Neumann (1903-1957)

The Brain vs. Computer



1. 10 billion neurons
2. 60 trillion synapses
3. Distributed processing
4. Nonlinear processing
5. Parallel processing

1. Faster than neuron (10^{-9} sec)
   cf. neuron: 10^{-3} sec
3. Central processing
4. Arithmetic operation (linearity)
5. Sequential processing

History of Brain-Style Computation (1/2)

- 1943 McCulloch & Pitts Neuron
- 1948 Hixon Symposium on Cerebral Mechanisms in Behavior
- 1949 Hebbian Learning & Cell Assembly

- 1955 Session on Learning Machines (Selfridge's Pandemonium)
- 1957 Perceptron (Rosenblatt)
- 1958 The Computer and the Brain (von Neumann)
- 1960 Adalines & Madalines (Widrow)
- 1970's Kohonen, Amari, Grossberg
- 1979 First Issue of Cognitive Science Journal
- 1979 First Conference on Cognitive Science
- 1980 First Machine Learning Workshop (ML 1)

- 1982 Parallel Models of Associative Memory (Hinton & Anderson)
- 1982 Connectionist Models and Their Properties (Feldman & Ballard)
- 1982 Hopfield Network
- 1984 Kohonen Network (SOM)
- 1986 Machine Learning Journal (Langley)

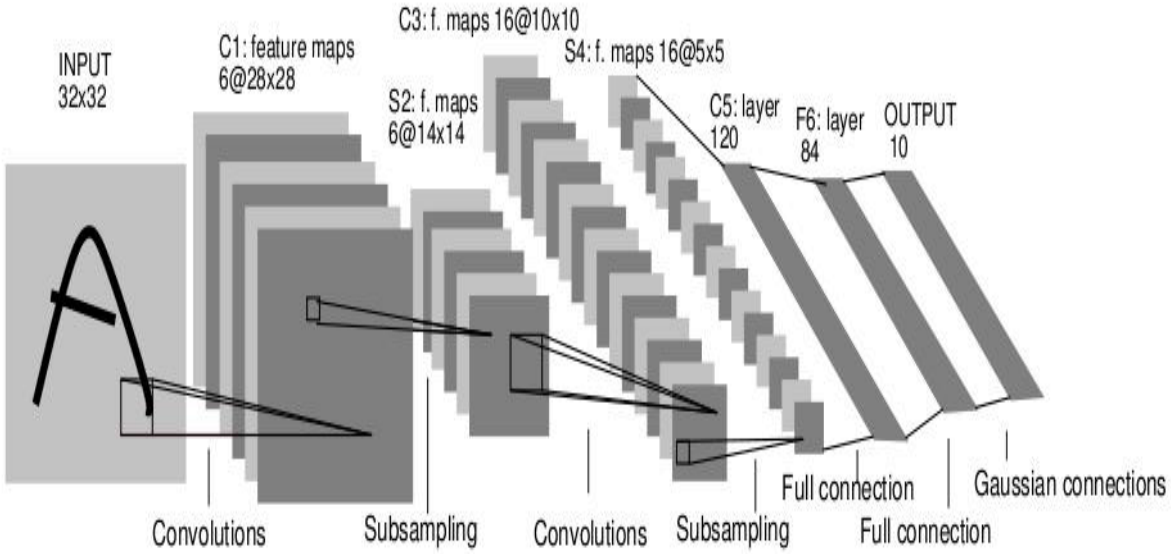
History of Brain-Style Computation (2/2)

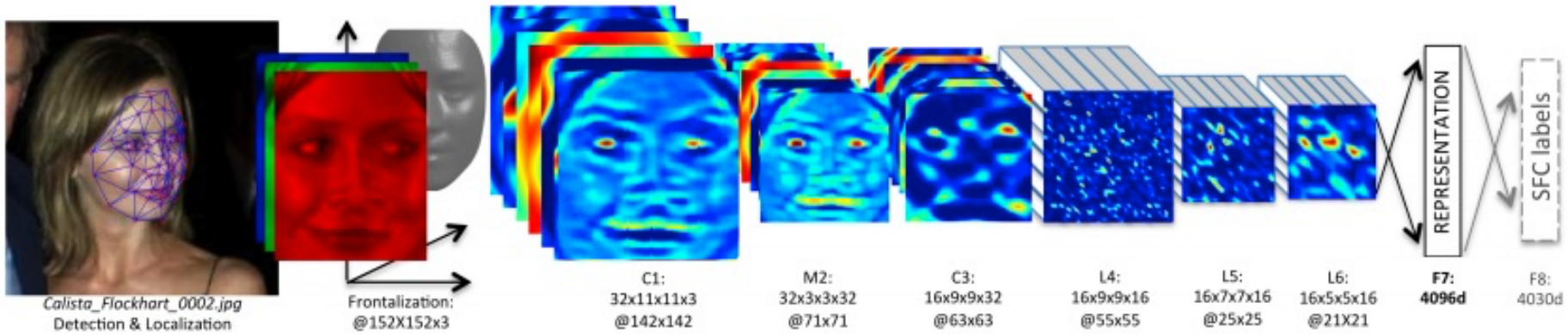
- 1986 Parallel Distributed Processing (PDP) Models (Rumelhart & McClleland)
- 1987 International Neural Network Society (INNS)
- 1988 Connectionist Models Summer School (Touretzky, Hinton, Sejnowsky)
- 1988 Bayesian Networks (Pearl)
- 1989 Neural Computation Journal (Sejnowsky)
- 1989 First Neural Information Processing Systems Conference (NIPS 1)
- 1990 Brain Style Computation: Learning and Generalization (Rumelhart)

- 1992 First Computational Neuroscience Conference (CNS)
- 1992 Support Vector Machines (Vapnik)
- 1993 First ICML Conference (ML 10, Int. Conf. on Machine Learning)
- 1995 Helmholtz Machine (Hinton, Dayan, Neal)

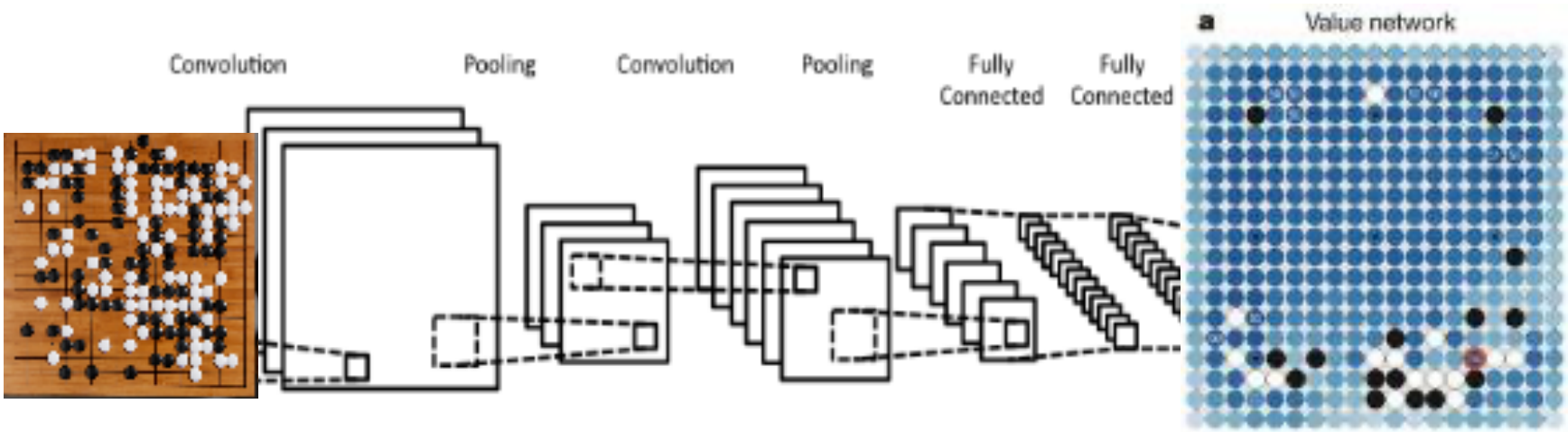
- 2002 EU FP6 Artificial Cognitive Systems
- 2006 Deep Belief Networks (DBN)
- 2006 First Computational Cognitive Neuroscience Conference (CCN)
- 2008 IBM Cognitive Computing Project (SyNAPSE)
- 2009 MIT Intelligence Initiative (I^2)

Deep Neural Networks

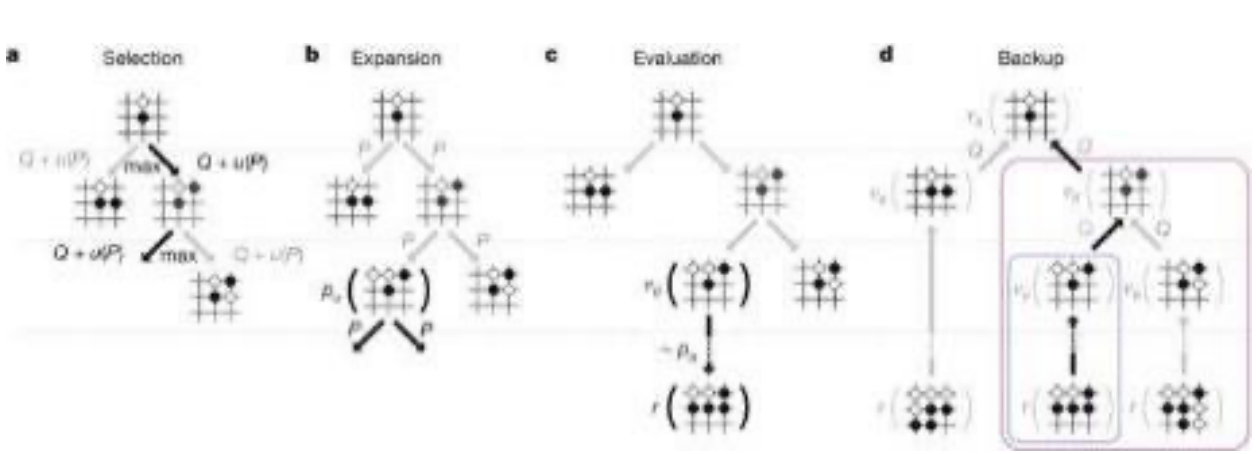


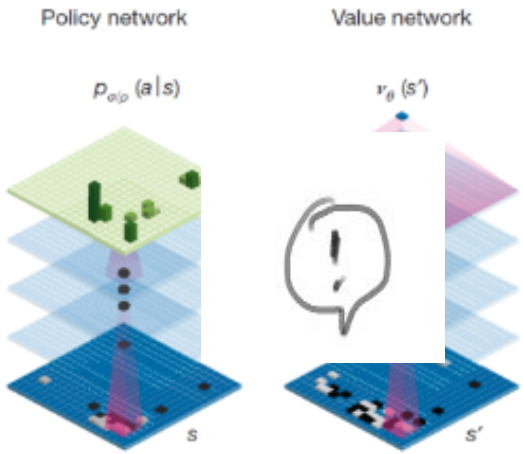


Gaming

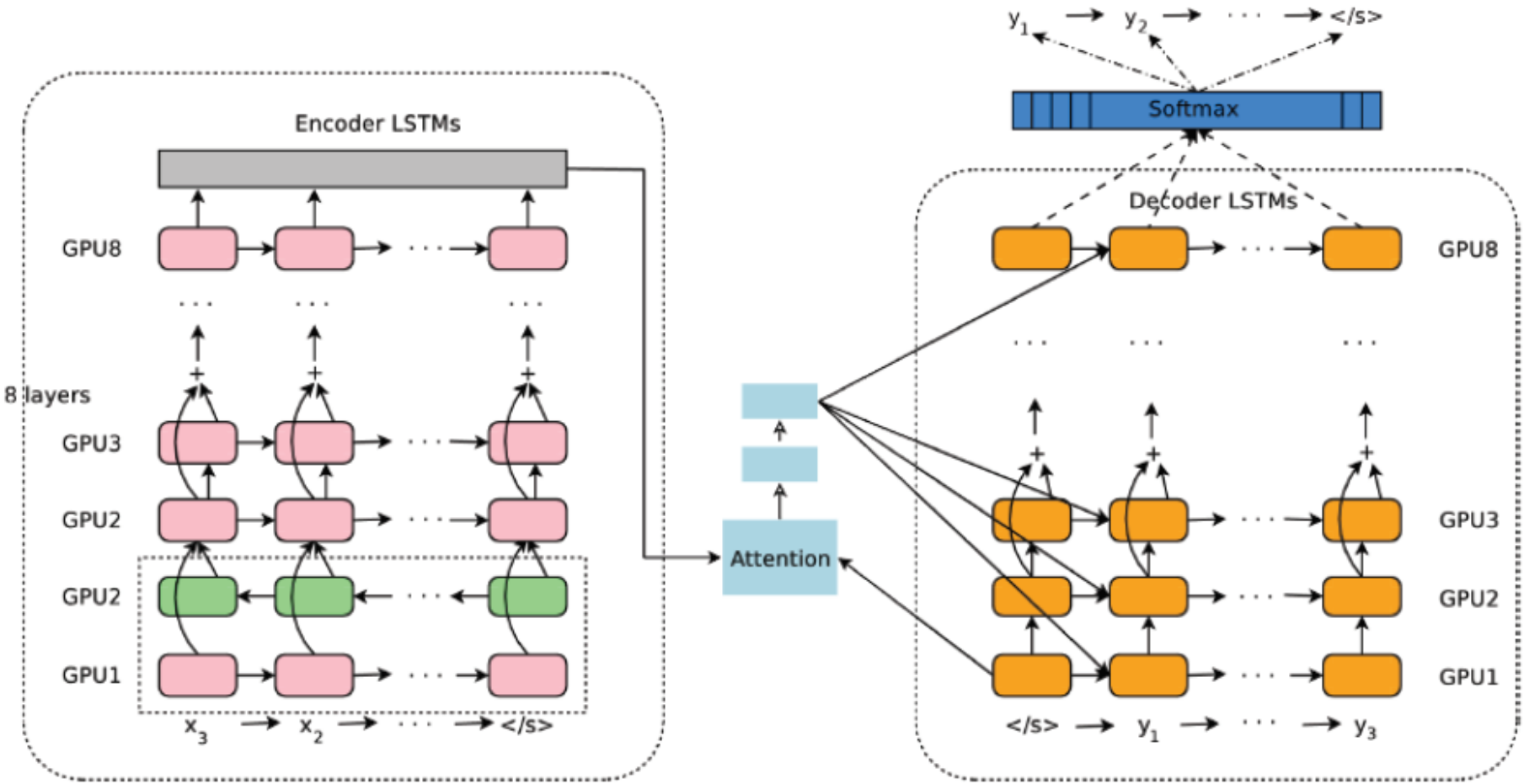


AlphaGo (Google DeepMind)





Machine Translation



Google's Neural MT

Image Synthesis

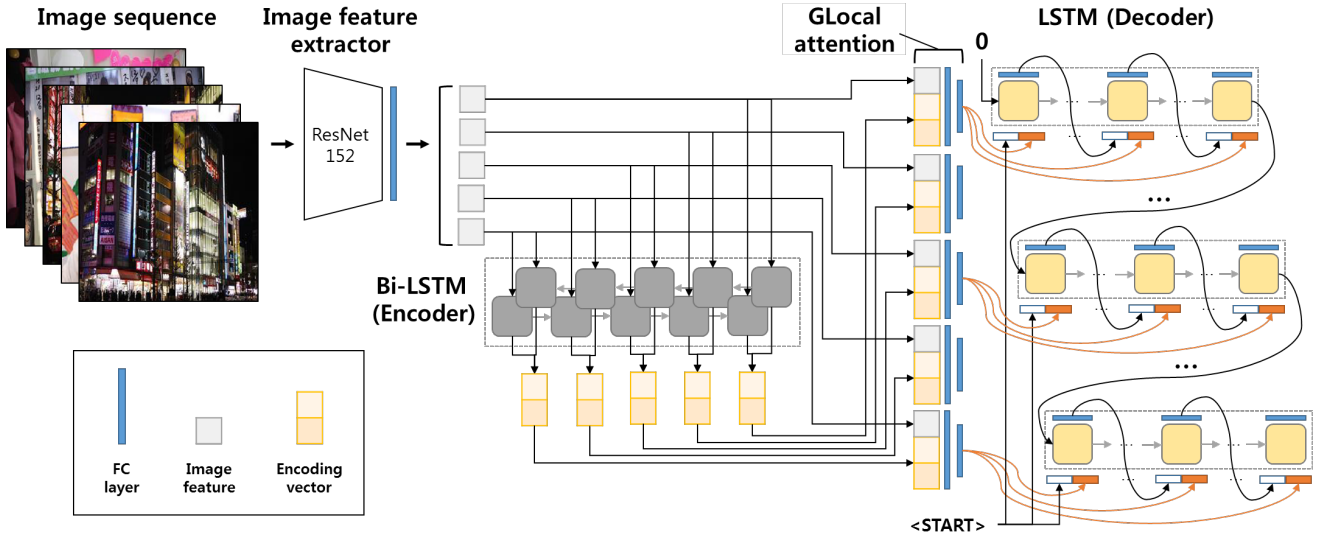
Visual Storytelling (VIST)

GLAC Net: GLocal Attention Cascading Networks for Multi-image Cued Story Generation, T. Kim et al. *NAACL 2018 Workshop on Storytelling, 2018.*

- **Visual Storytelling**
  - Visual story = photo sequence + sentence sequence

Input:					
Output:	**The local market was a lot of fun.**	**There were so many different kind of things to choose from.**	**Some of the shops looked very interesting.**	**I bought a few souvenirs for the kids**	**My favorite part was the bike ride.**

  - GLocal Attention Cascading Networks (**GLAC Net**): **1st Place in VIST Challenge**



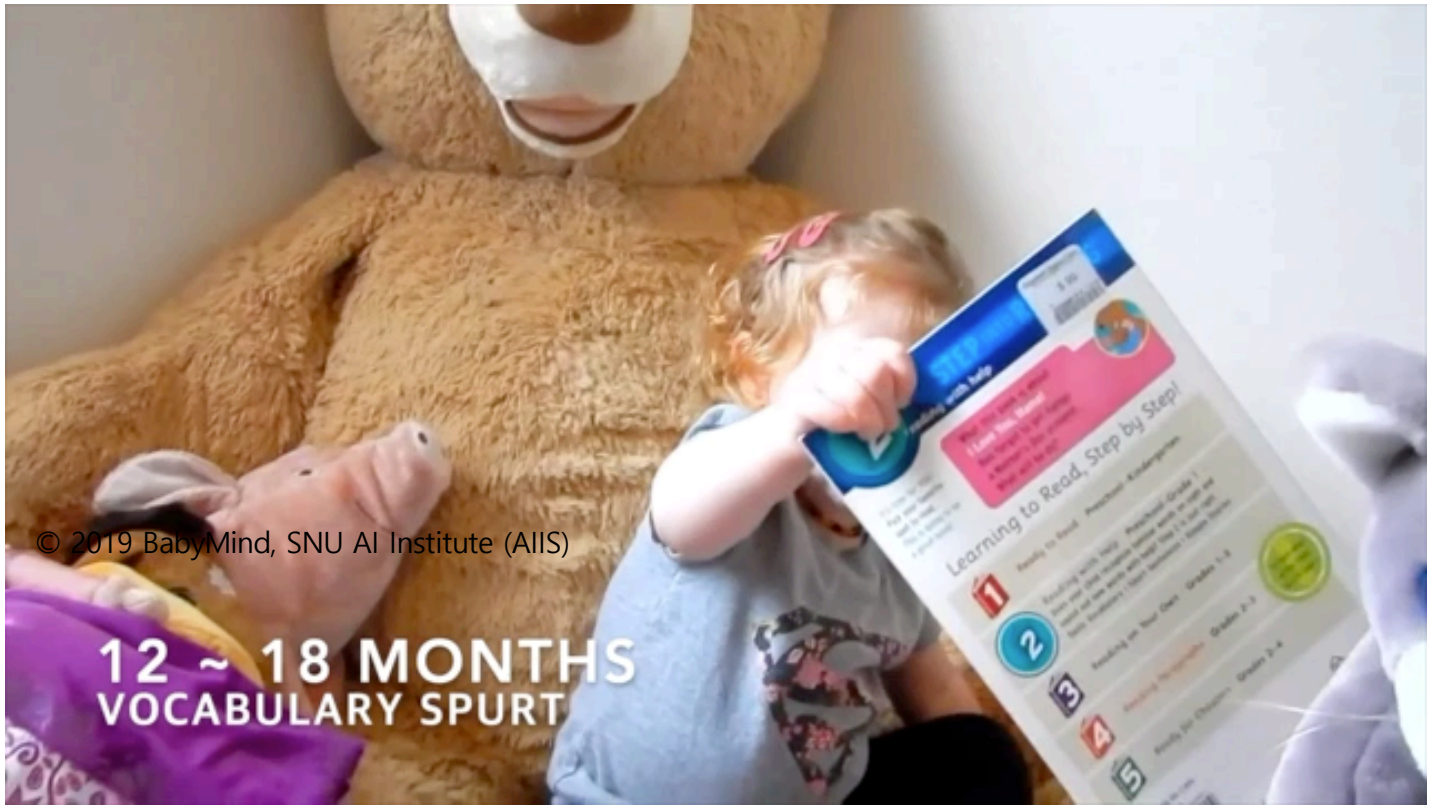
(Provocative) Question

Do deep neural networks learn like a brain?

2. The Embodied Brain in a Vat

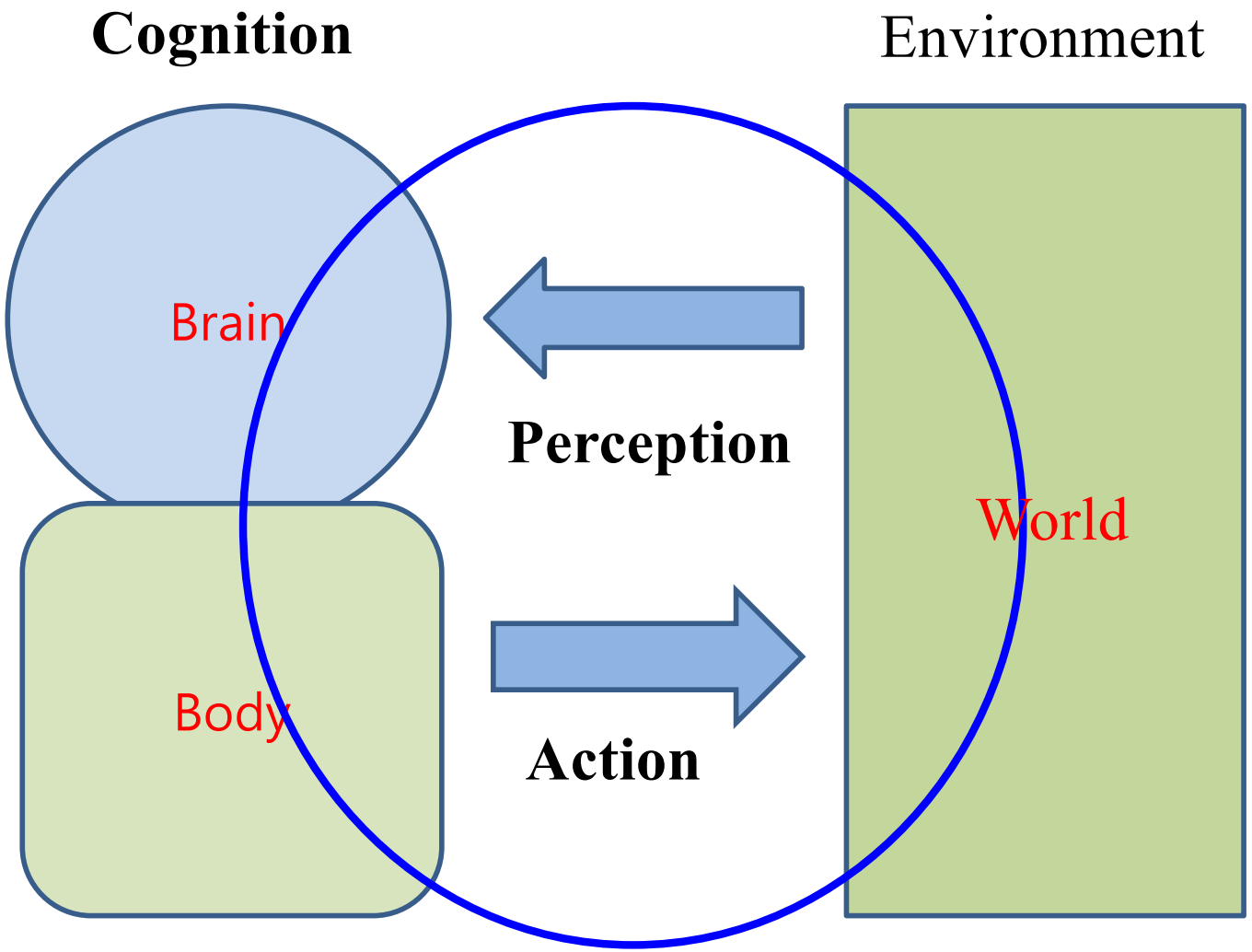
Embodied Brain

Embodied and Situated Brain



Agents in the Real World

Brain, Body, and World



[Zhang, 2008]
[Zhang, 2012 a,b,c]
[Zhang, 2018]

- **Cognition grounded by dynamic perception-action cycle**
- **Knowledge construction by interaction with the world**

Why We Need Brain-Like Intelligence?

Smart Machines

[Super Smart TV]

[Cloud & Big Data]

[Smart Watch]

[Smart Glass / VR]

[Autonomous Vehicle]

[Smart Home/Factory and IoT]

Artificial Intelligence

- Real-World
- Real-Life
- Real-Time

- Multi-Sensor Streams
- Real-Life Context
- Open-Endedness

- Non i.i.d. Big Data
- Non-Stationary
- Uncertainty

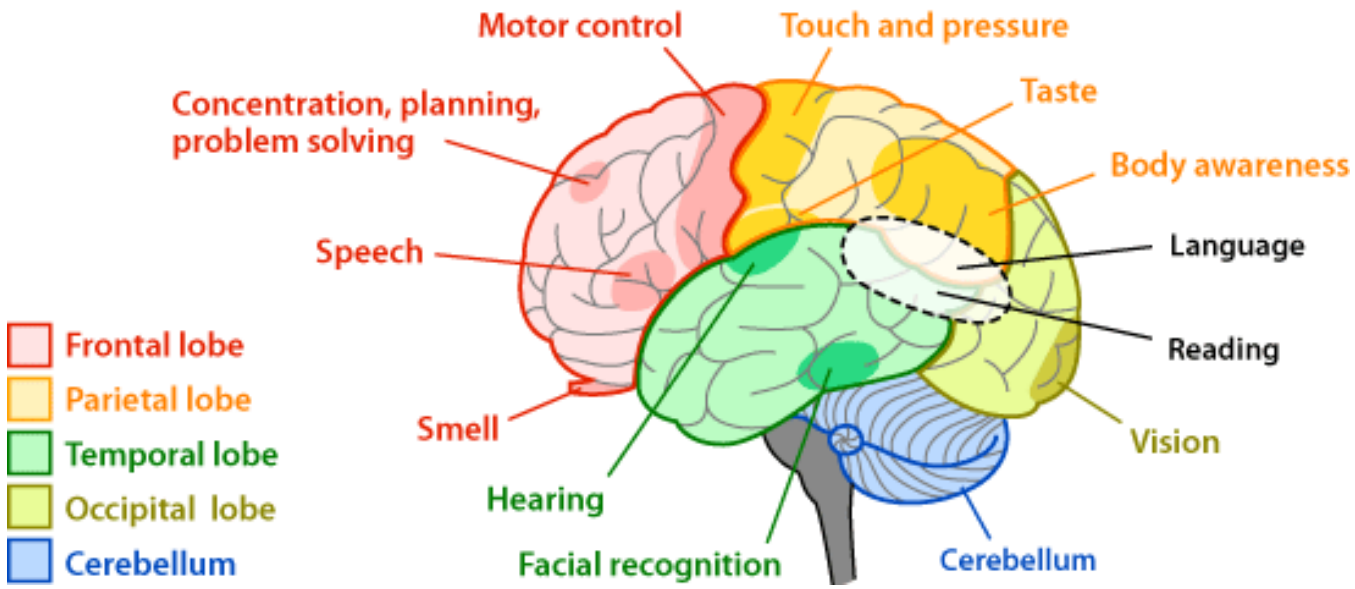
- Rapid, Flexible, Robust
- Brain-Like Cognitive AI

Brain-Like Intelligence

Brain-Like Learning

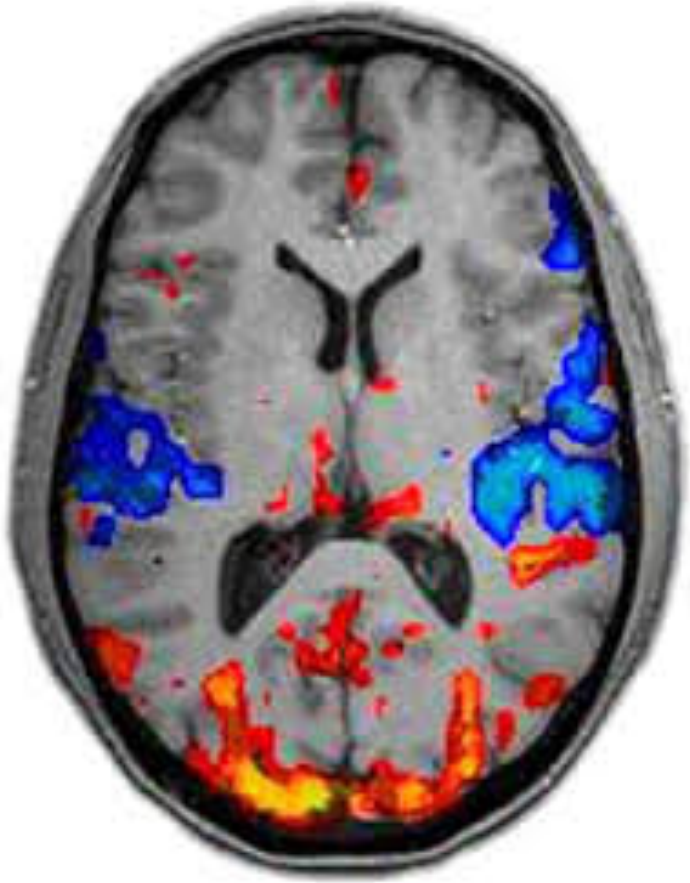
Brain-Like Computation → **Brain-Like Intelligence**

Brain Computation: Why Fast, Flexible, and Robust?



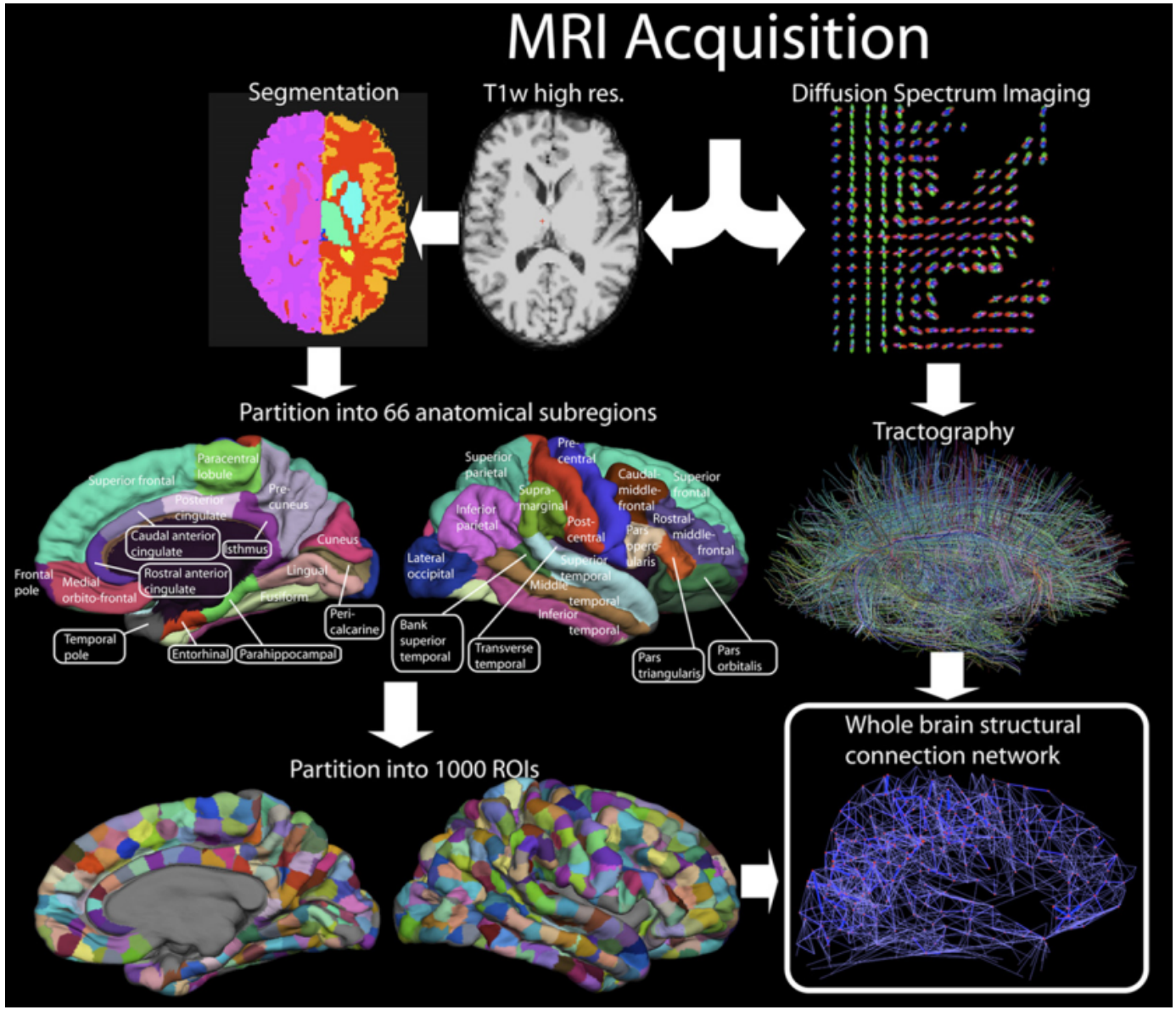
Three Levels of Analysis

- **Structural**
  - Containers & substrate
  - Representation
  - Anatomy
- **Organizational**
  - Contents & information
  - Encoding
  - Development and learning
- **Functional**
  - Computation & processing
  - Decoding
  - Behaviors



Cognitive Computing I, II, III (in Korean), B.-T. Zhang, *Communications of the Korean Institute of Information Scientists and Engineers*, **30**(1):75-111, 2012. [PDF]

Brain-Scale Structural and Functional Networks



Hagmann et al., 2010

Structural Principles: HiMACS

- **Hierarchical**
  - Layers, multiscale, deep
- **Molecular**
  - Chemical switch, distributed, massive associative
- **Aggregate**
  - Assemblies, microcircuits, cascades
- **Complex**
  - Heterogeneous, hubs, recurrent, convolutional
- **Sparse**
  - Distributed, modular, sparse population coding

Cognitive Computing I, II, III (in Korean), B.-T. Zhang, *Communications of the Korean Institute of Information Scientists and Engineers*, **30**(1):75-111, 2012. [PDF]

Organizational Principles: DevMIND

- **Developmental**
  - Growing, self-reproducing, adaptive
- **Mapping**
  - Topology-preserving map, transformation
- **Incremental**
  - Continual change, online
- **Nonequilibratory**
  - Far from equilibrium, edge of chaos, asynchronous
- **Decompositional**
  - Disassembly, reassembly, reorganization

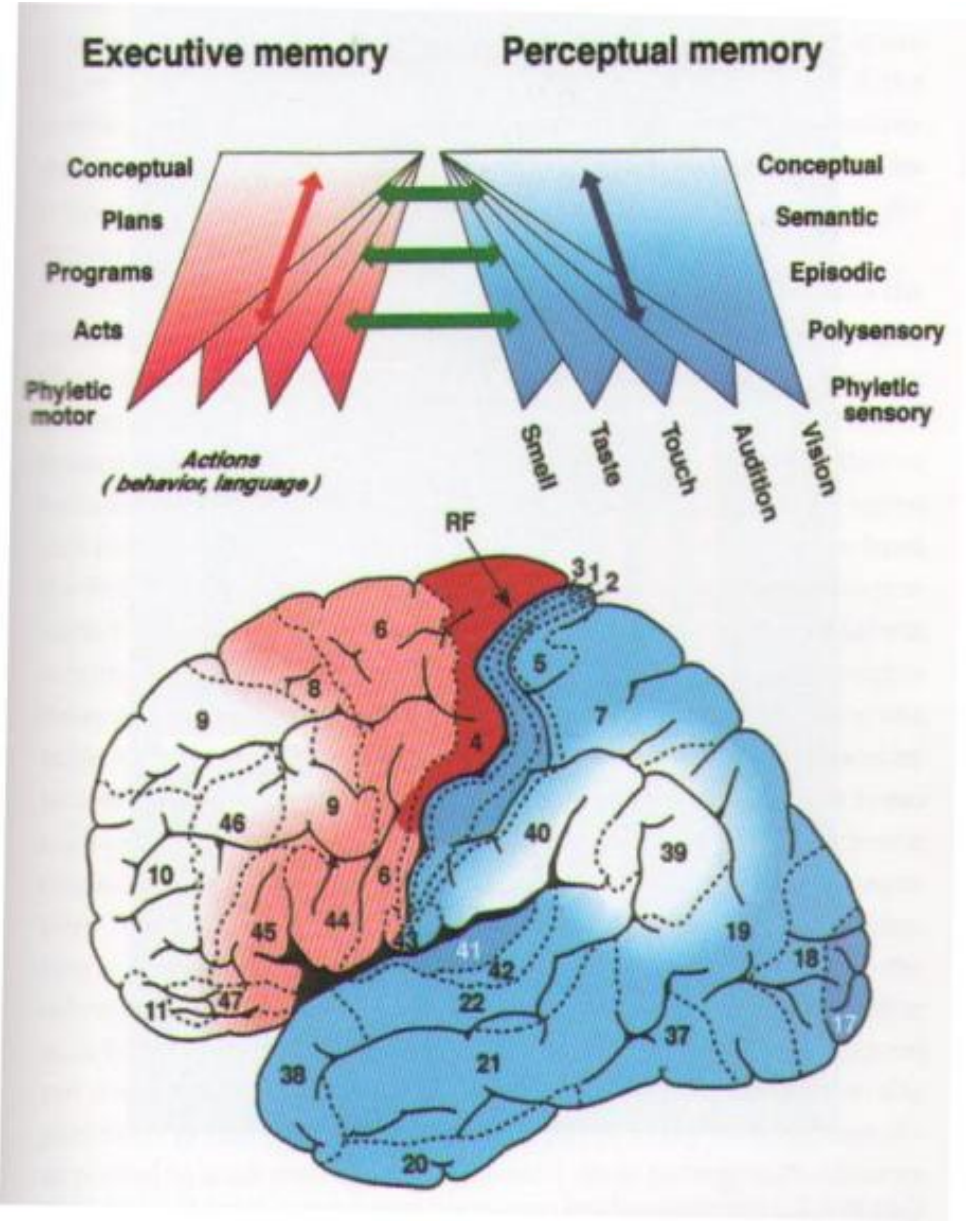
Cognitive Computing I, II, III (in Korean), B.-T. Zhang, *Communications of the Korean Institute of Information Scientists and Engineers*, **30**(1):75-111, 2012. [PDF]

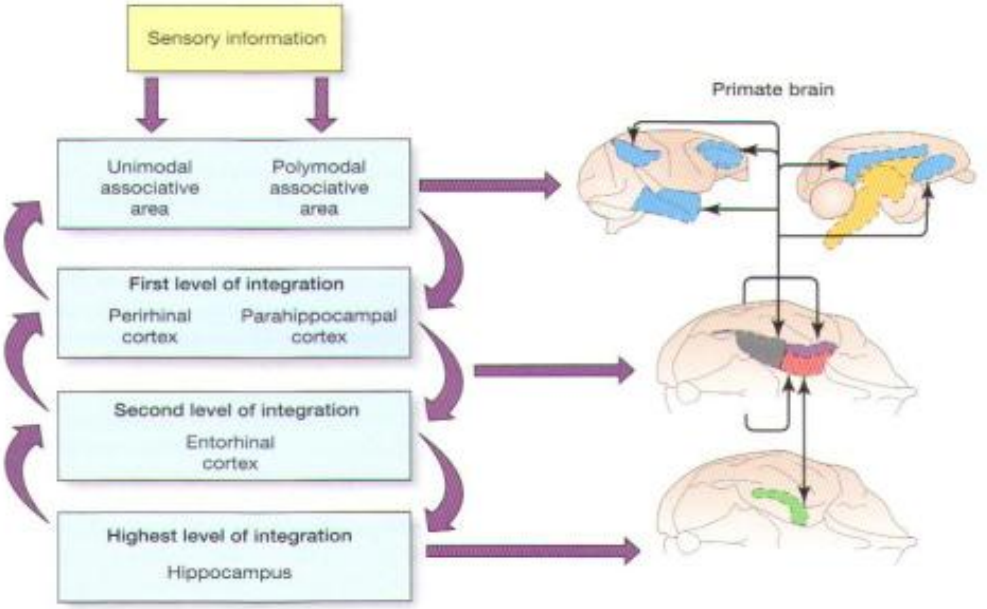
Functional Principles: DynaLIFE

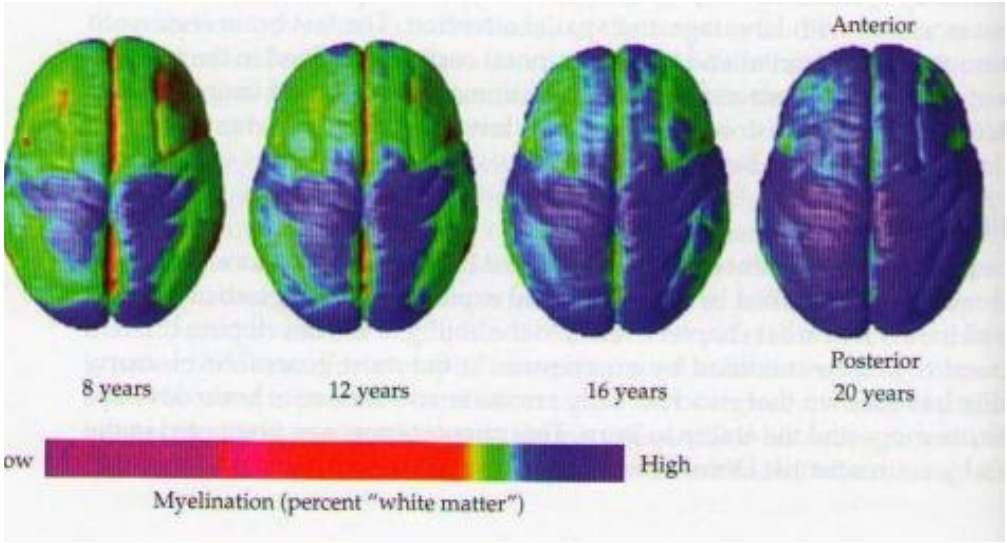
- **Dynamic**
  - Perception-action cycle, interaction, feedback
- **Long**
  - Learning continually over time
- **Integrative**
  - Spatiotemporal integration, multisensors
- **Futuristic**
  - Anticipatory, internal model, goal, desire
- **Emergent**
  - Collective, population decoding

Cognitive Computing I, II, III (in Korean), B.-T. Zhang, *Communications of the Korean Institute of Information Scientists and Engineers*, **30**(1):75-111, 2012. [PDF]

Brain as Widely Distributed, Parallel, Interactive, Overlapping, Dynamic Relational Memory Networks



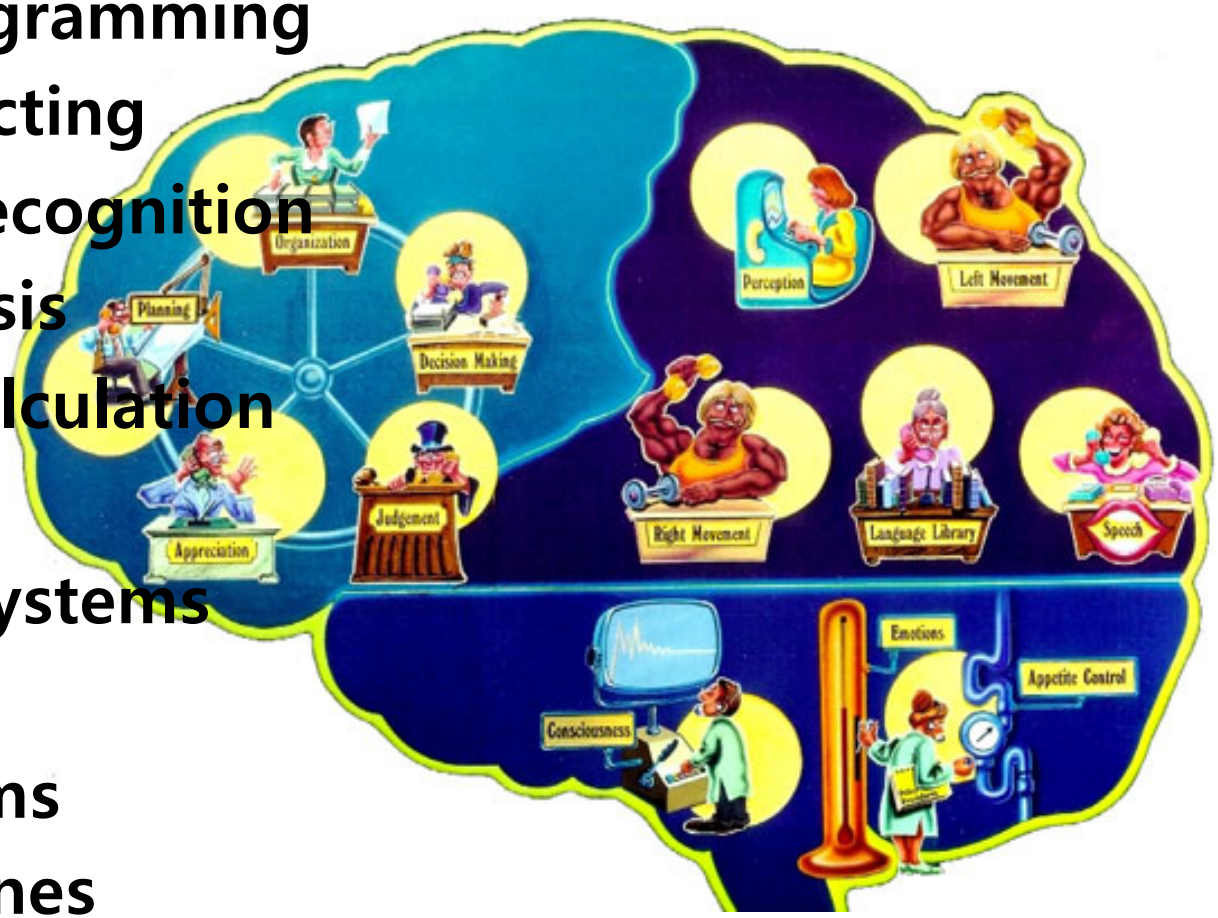




[Fuster, 2004]

Brain-Like AI

- **Organizing** vs. programming
- **Teaching** vs. instructing
- **Regeneration** vs. recognition
- **Synthesis** vs. analysis
- **Construction** vs. calculation



- Lifelong learning systems
- Growing machines
- Anticipatory systems
- Imagination machines
- Intentional systems

Cognitive Computing I, II, III (in Korean), B.-T. Zhang, *Communications of the Korean Institute of Information Scientists and Engineers*, **30**(1):75-111, 2012. [PDF]

3. Brain-Like AI

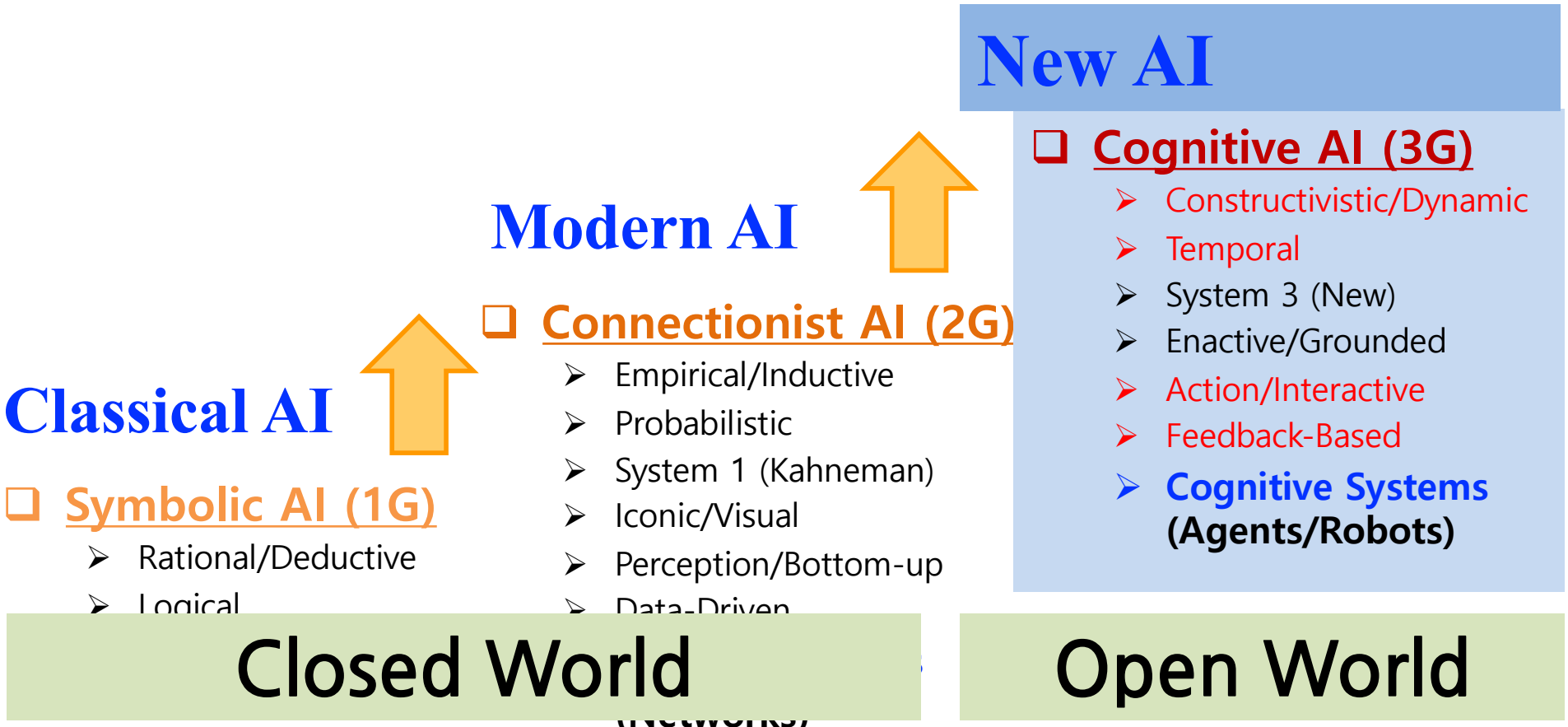
Human-Level AI and the Brain

- Human intelligence involves solving problems by sequentially acting in an uncertain world to achieve a long-term goal. *It's not just a single perception-to-action mapping.*

- Human-level AI requires goal-directed autonomous cognitive capability to *continually* perceive, plan, act, and learn about the world.

- This is exactly what the brain does best.

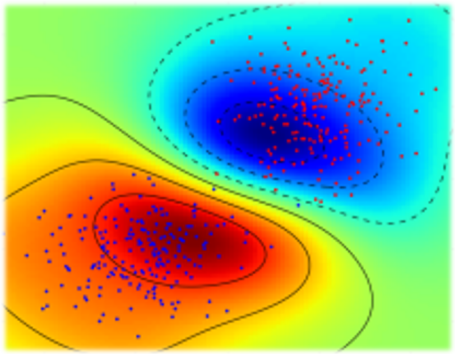
The New AI

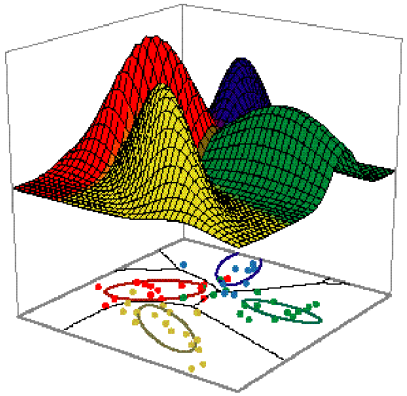


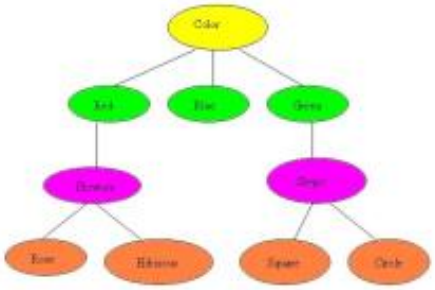
[Zhang, 2018] Human Intelligence and Machine Intelligence: Cognitive AI, *Communications of KIISE*, 36(1): 27-36, 2018.

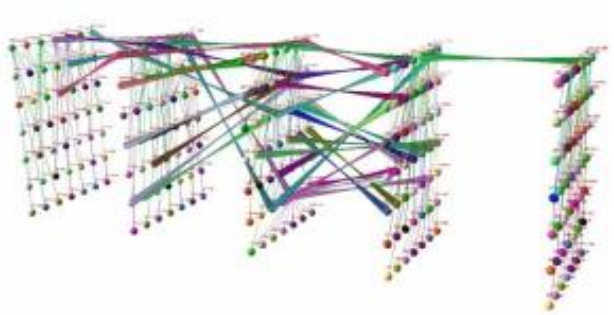
Autonomous Learning

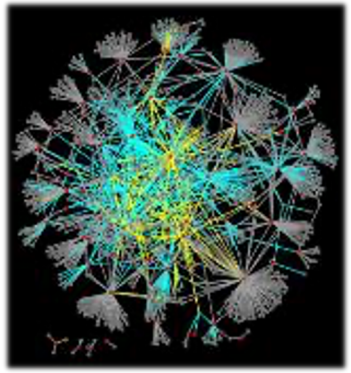
1G: Supervised Learning (1980~2000)	2G: Unsupervised Learning (2000~2020)	3G: Autonomous Learning (next generation)











- Decision Trees
- Kernel Methods
- Multilayer Perceptrons

- Deep Networks
- Markov Networks
- Bayesian Networks

- Learning by Doing
- Perception-Action Cycle
- Recursive Self-improvement

AI의 단계: L1~L6

L1	인간 프로그래밍 (Human Programming)	Tool
L2	자동 프로그래밍 (Automatic Programming)	Oracle
L3	자기 교사 (Self-teaching)	Genie
L4	자기 반성 (Self-reflection)	Sovereign
L5	인간수준 학습 (Human-Level Learning)	AGI (HLAI)
L6	초인간 학습 (Superhuman Learning)	Superintelligence

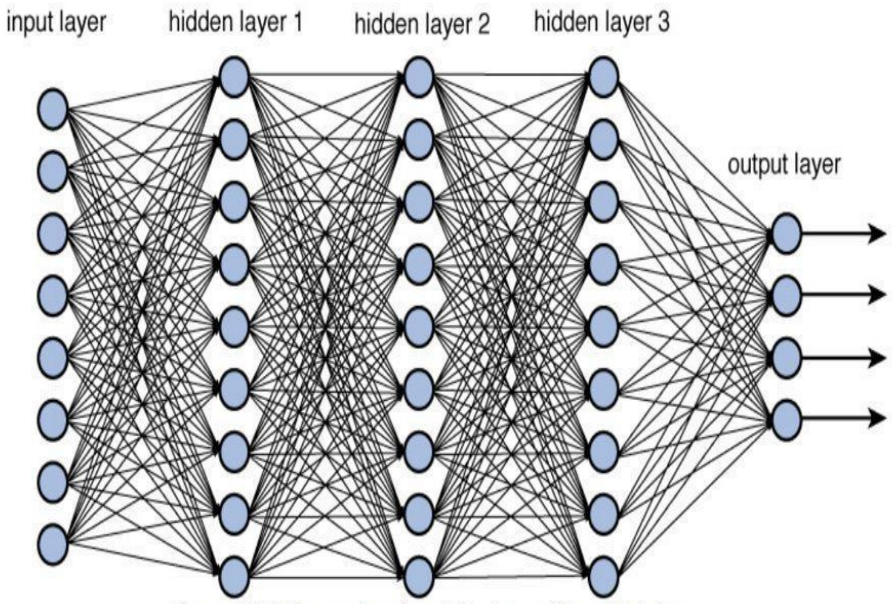
We are here

Brain-like AI

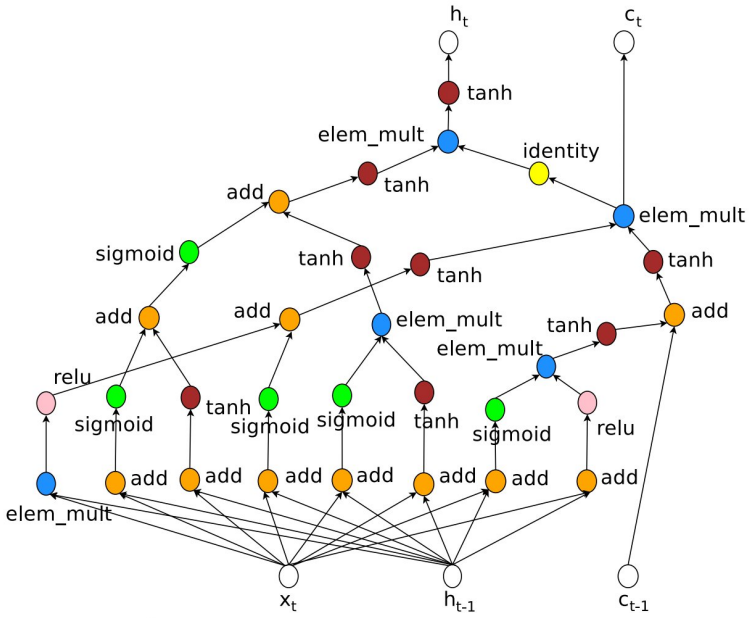
[장병탁, 인공지능의 미래-슈퍼인텔리전스, 2021-1-23]

AI Level 2

- AI가 스스로 알고리즘을 작성한다.
- 어떤 질문에도 대답해주는 오라클(Oracle)
- 자동 프로그래밍(Automatic programming)
- Automated deep learning (AutoDL)



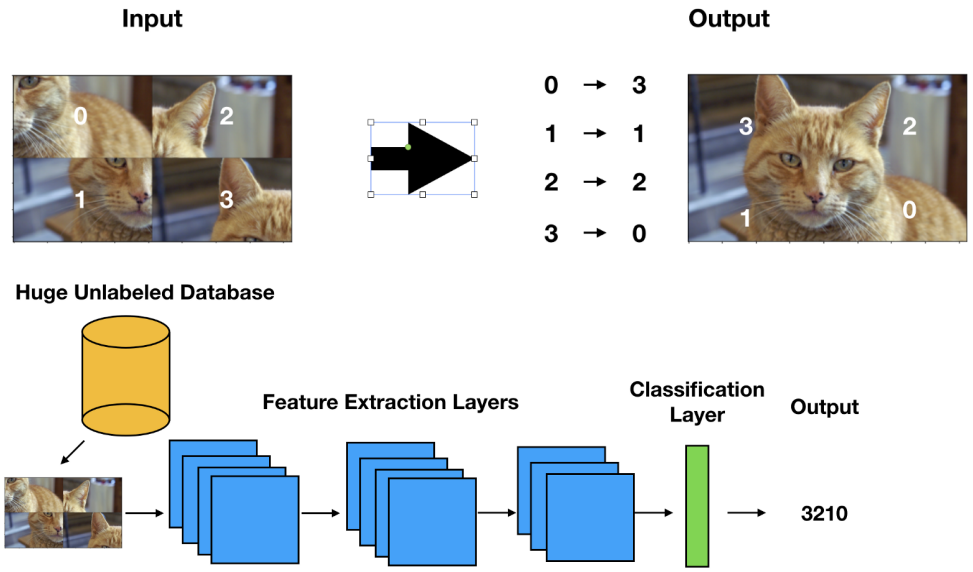
Deep Neural Networks



Neural Architecture Search

AI Level 3

- AI가 스스로 학습 데이터를 생성한다.
- 어떤 명령이든 실행하는 지니(Genie)
- 자기감독/자기교사 학습(Self-supervised learning, Self-teaching)
- 지속적 학습(Continual learning)



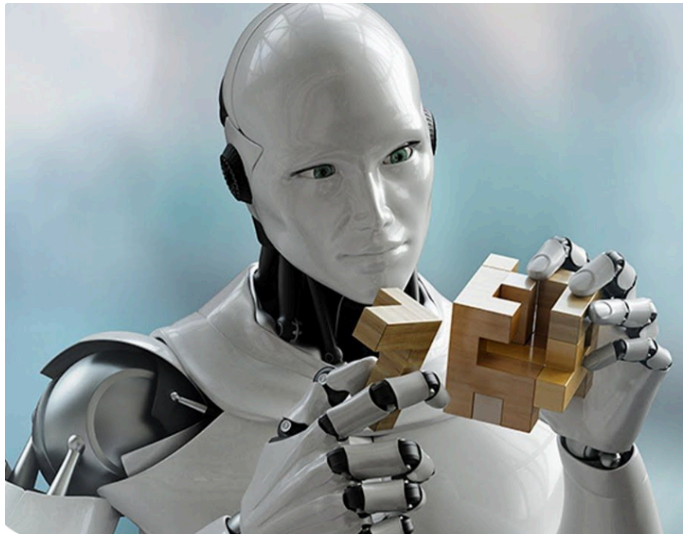
Self-supervised Learning

Self-teaching

AI Level 4

- AI가 스스로 목표함수를 수정한다.
- 자주적 개방형 작동 시스템 소버린(Sovereign)
- 자기반성 학습(Self-reflective learning)
- 재귀적 자기개선 시스템 (Recursively self-improving systems)

"Seed AI"

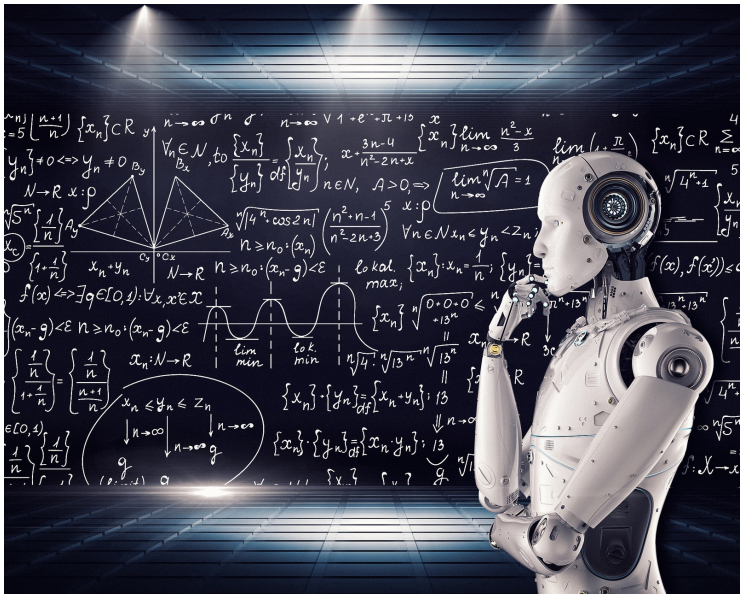


Autonomous Learning

BabyMind Project

AI Level 5

- AI가 스스로 목적과 미션을 조정한다.
- 인간수준 인공지능(Human-level AI)
- 인공일반지능(AGI)



AGI

SNU **Aupair** 홈로봇

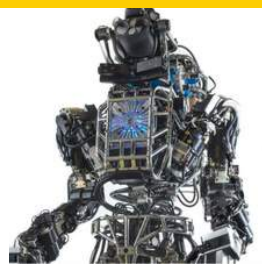
AI Level 6

- ❖ L5의 수행에 인간을 능가한다.
- ❖ 수퍼지능(Superintelligence)
- ❖ 초인간 학습 기계(Superhuman learning machines)

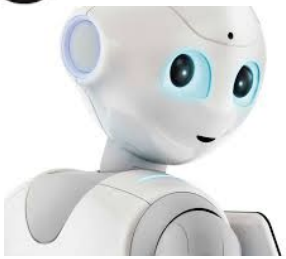
영화 Robot & Frank (2012)

4. Future of Digital Brain

Human-Level AI & Autonomous Cognitive Systems



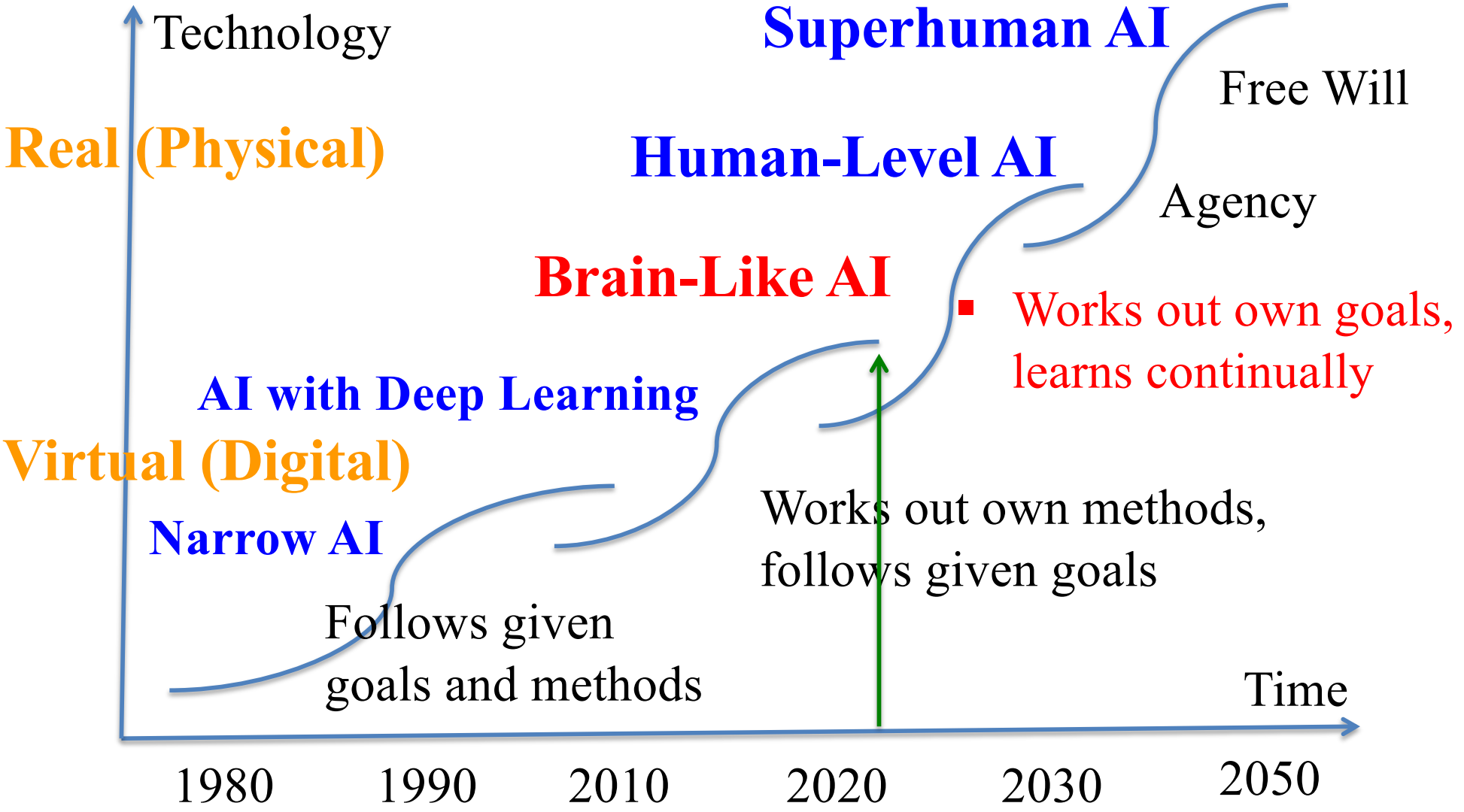
Human-Level AI



Body
(HW, Device)

Mind (SW, Data)

Future of Digital Brain



Modified from Eliezer Yudkowsky & David Wood