Applied Neuroscience

Columbia Science Honors Program
Spring 2017

Artificial Intelligence in Robotics

Soft Robotics: Baymax

Baymax of ***Big Hero 6*** is based on the robotics research of Professor Chris Atkeson at Carnegie Mellon University

Baymax is capable of maintaining a good **spoken dialogue system** and **learning** new knowledge for better **understanding** and **interacting** with people.

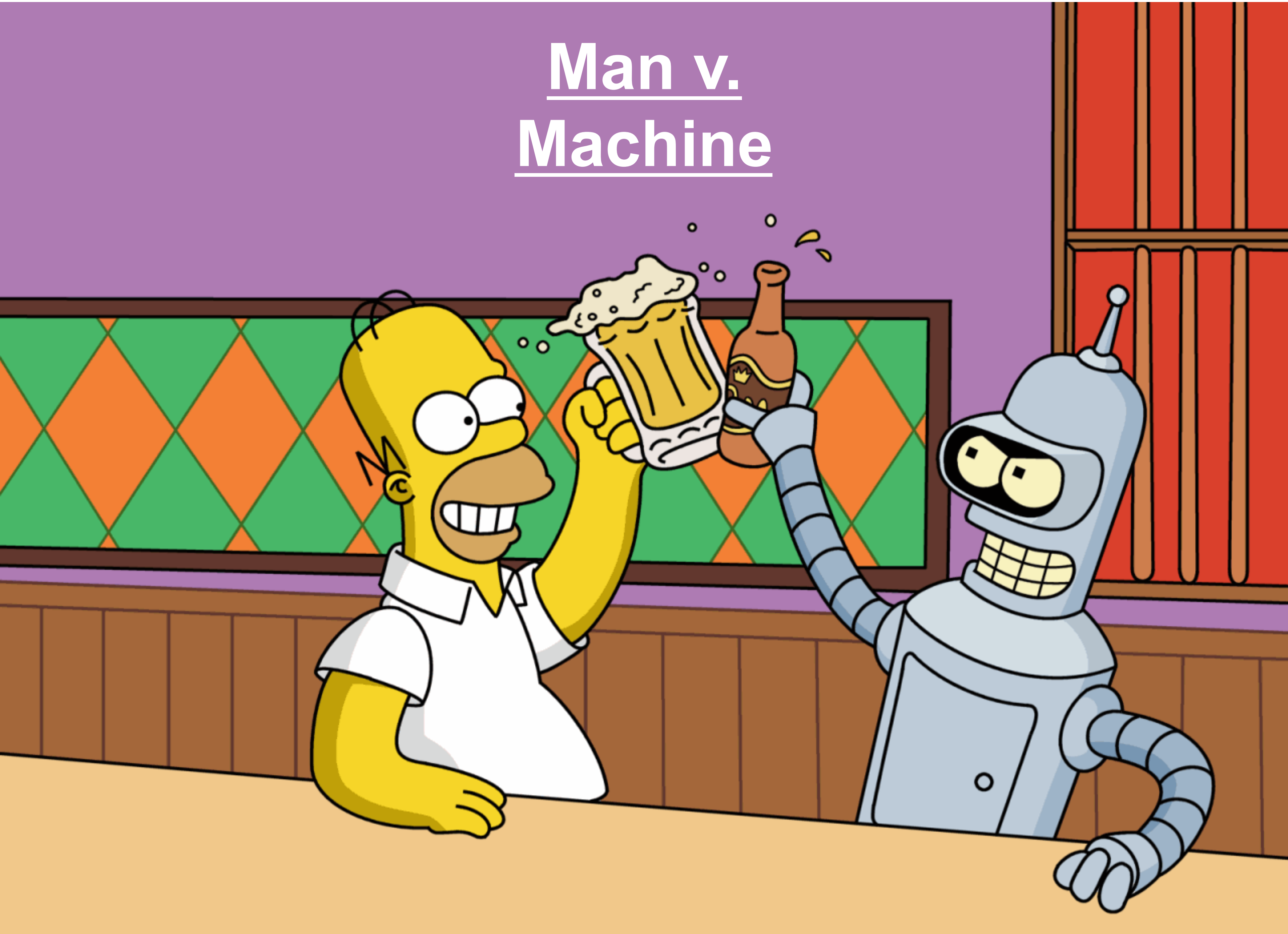
Spoken Dialogue Systems: intelligent agents that are able to help users finish tasks more efficiently through speech interactions

Apple Siri
Microsoft Cortana

Microsoft XBOX Kinect

Google Now

Man v. Machine



Artificial Intelligence in Robotics

Objective: Applications of Neural Networks in Robotics

Agenda:

1. Artificial Intelligence
2. IBM
   - *IBM Watson*
3. Google
   - *Google Brain*
   - *Google DeepMind*

On Intelligence

Intelligence: [1]capacity to learn and solve problems
[2]ability to adapt to different contexts

Nature, Nurture, or Both?

Is intelligence genetic? Acquired? A combination of both?

Fluid Intelligence: ability to reason and use information *(peaks in 20s)*

Crystallized Intelligence: acquired skill and learned knowledge *(continues to increase into old age)*

Emotional Intelligence: capacity to reason about emotions *(to assess and generate emotions so as to assist thought)*

Social Intelligence: knowledge of social matters and insight into traits of others

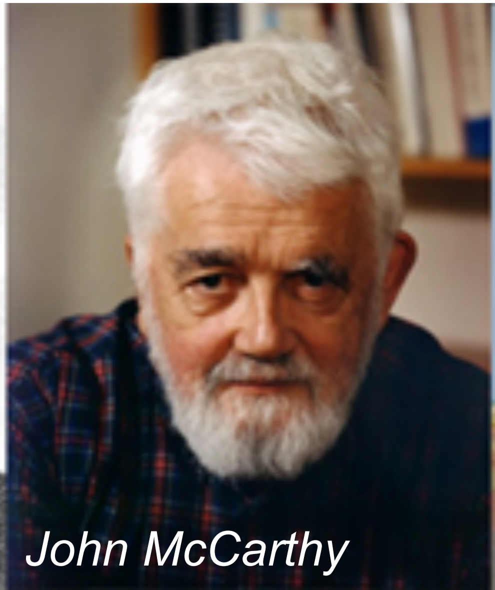
Artificial Intelligence: **"***the computational part of the ability to achieve goals in the world***"** *(John McCarthy, Stanford)*

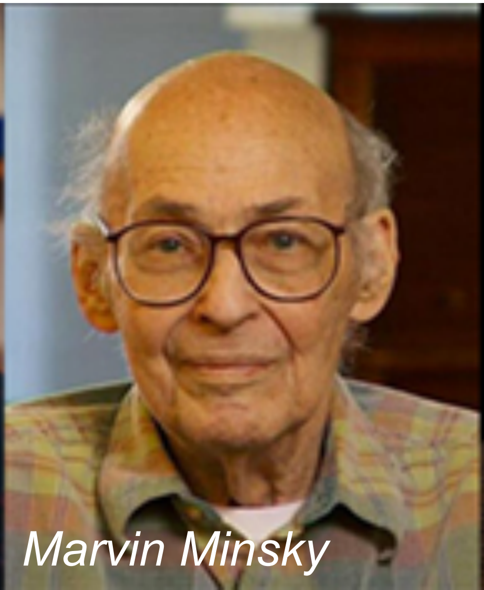
iWonder: Artificial Intelligence

Artificial Intelligence has four perspectives that can be represented by two dimensions:

1. Thinking v. Acting
2. Human v. Rational

	Human-Like Intelligence	Ideal Intelligence/ Pure Rationality
Thought	**2. Thinking Humanly**	**3. Thinking Rationally**
Behavior	**1. Acting Humanly**	**4. Acting Rationally**



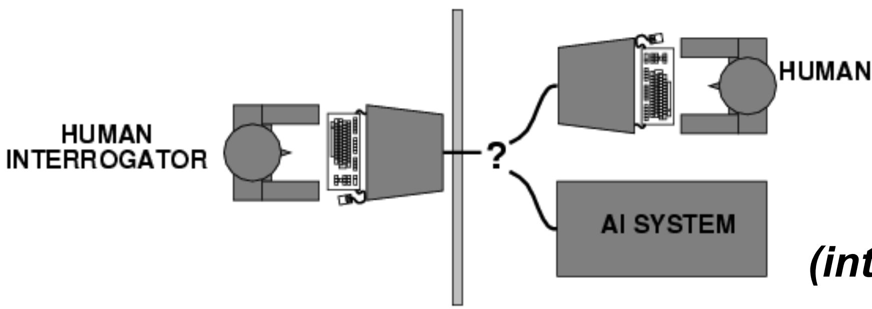


1. Acting Humanly: Turing Test

	Human-Like Intelligence	Ideal Intelligence/ Pure Rationality
Thought	2. Thinking Humanly	3. Thinking Rationally
Behavior	**1. Acting Humanly**	4. Acting Rationally

"Can machines think? Can machines behave intelligently?"

Operational Test for Intelligent Behavior: The Imitation Game



AI system passes if interrogator cannot tell which one is the machine.

(interaction via written questions)

No computer vision or robotics or physical presence required!

In 1950, Alan Turing predicted that a machine may have a 30% chance of fooling a lay person for 5 minutes by 2000.

This was achieved by Siri (Apple).

However, we have not truly passed the Turing test. Even if we did, how useful is it? *Deception appears **required** and **allowed**.*

2. Thinking Humanly: Modeling Cognition

	Human-Like Intelligence	Ideal Intelligence/ Pure Rationality
Thought	**2. Thinking Humanly**	3. Thinking Rationally
Behavior	1. Acting Humanly	4. Acting Rationally

Requires scientific theories of ***internal activities of the brain***

1. **Cognitive Science (Top-Down)** computer models based on experimental techniques in psychology

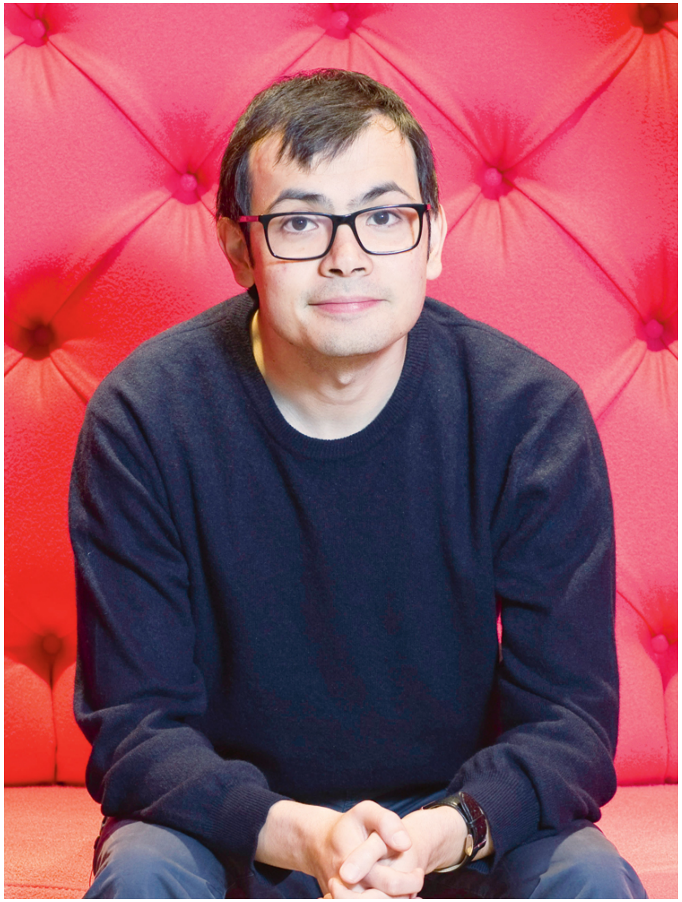
   i.e. predicting and testing behavior of human subjects

2. **Cognitive Neuroscience (Bottom-Up)** direct identification from neurological data

   i.e. neural networks and deep learning

Is the brain a good model for machine intelligence?

Demis Hassabis: Model the Brain's Algorithms



Natural v. Artificial Intelligence

Idea: Brain structure can inspire new computer algorithms and architectures.

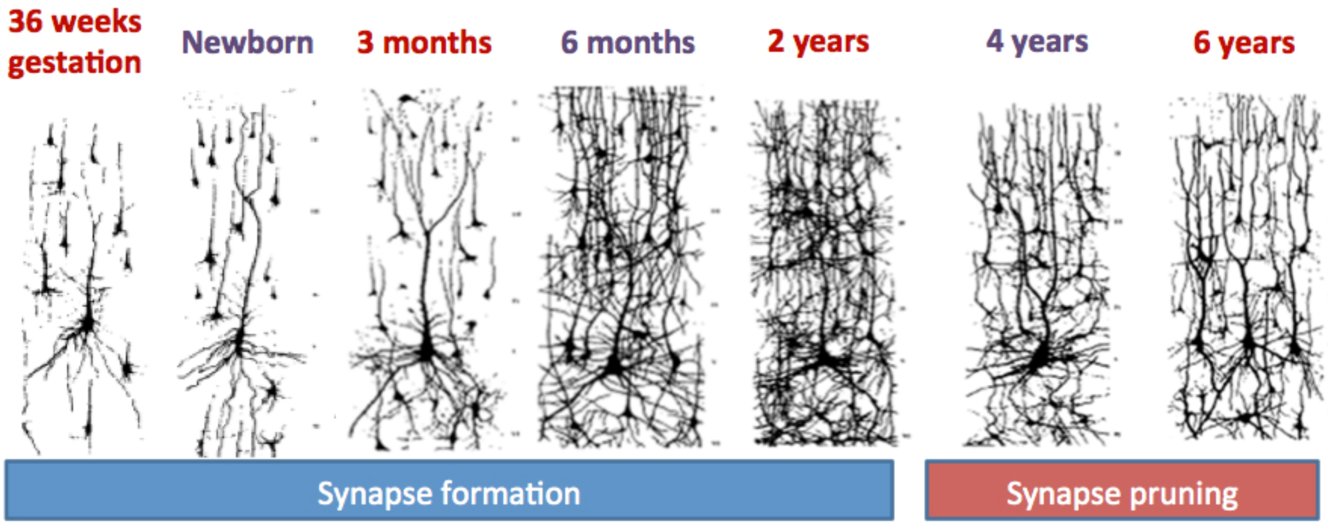
- *grid cells for navigation*
- *hierarchical cell layers for vision processing*

To advance AI:

- *What representations and processes does the brain use to portray the world around us?*
- *How is conceptual knowledge acquired?*
- *What is consciousness?*
- *What are dreams?*

"We're building systems that are able to reconfigure themselves in new ways that we haven't preprogrammed. I don't know if you'd call that writing itself. It's more like how the brain works."

Brain-Based Algorithms: Hierarchy



When the brain reaches adulthood, it has 50-60% less synaptic connections that it had at its peak in childhood.
Note how computer networks are distinct.

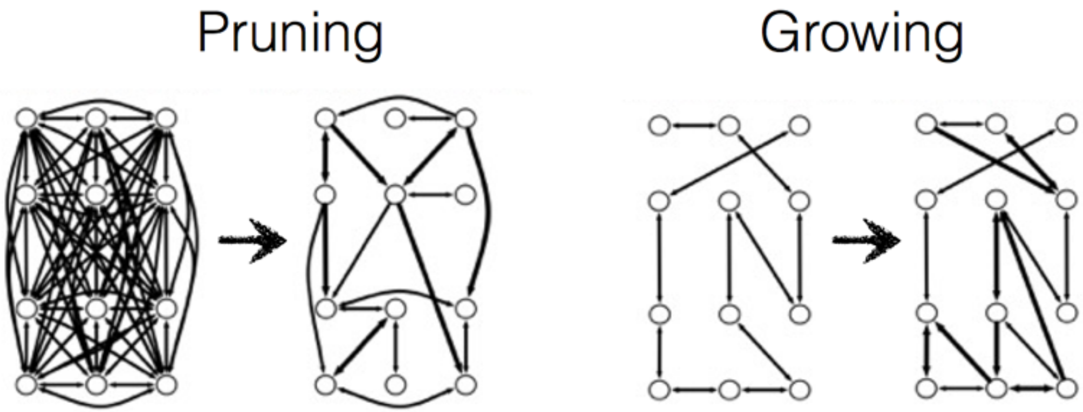
Hierarchy evolves not because it produces more efficient networks, but instead because hierarchically wired networks have fewer connections.

- Connections in biological networks are costly:
  need to be built, housed, maintained
- For the same reason, human-made systems such as the Internet and road systems are also hierarchical.

In addition to hierarchy, important design principles include:

- **Regularity:** decomposition of a large system into simple units
- **Modularity:** each unit can be designed independently of each other

Brain-Based Algorithms



"Engineered networks are built by adding connections rather than removing them. You would think that developing a network using a pruning process would be wasteful. However, this can prove beneficial." Ziv Bar-Joseph, CMU

When it comes to developing efficient, robust networks, the brain may often know best. Why is network topology important?

Biology: structure is to function

Computer Science: production of efficient interconnected systems

What are the advantages of a brain-based algorithm created with pruning?

- Direct flow information
- Multiple paths for information to reach same endpoint

minimizes risk of network failure

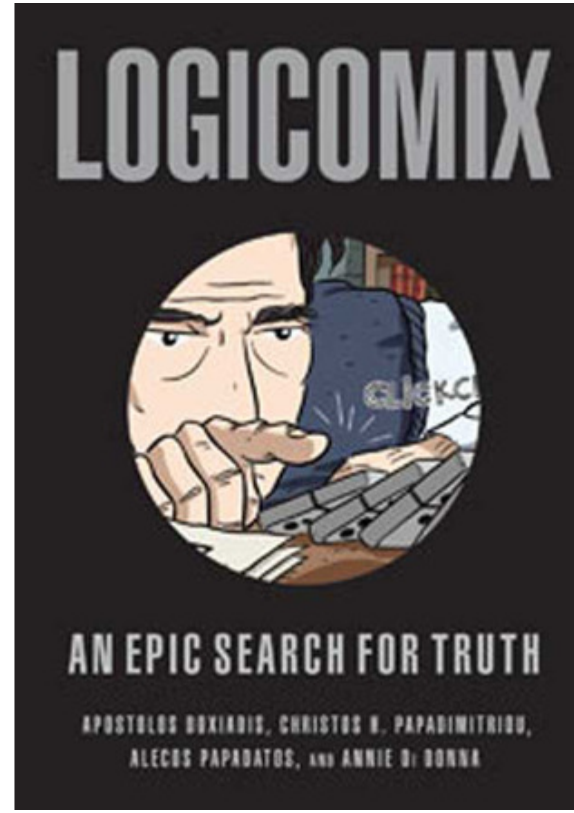
Deep learning is bring perception (hearing and vision) within reach.

SALK INSTITUTE

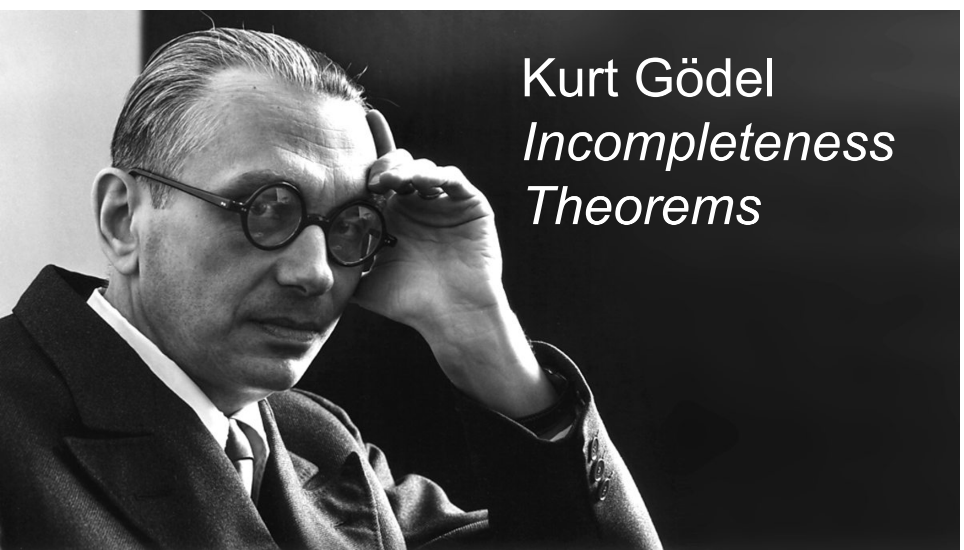
Carnegie Mellon University

3. Thinking Rationally: Laws of Thought

	Human-Like Intelligence	Ideal Intelligence/ Pure Rationality
Thought	2. Thinking Humanly	**3. Thinking Rationally**
Behavior	1. Acting Humanly	4. Acting Rationally



Greek schools have developed various forms of ***logic:*** *notation and rules of derivation for thought*
Idea: Inference derives new information from stored facts.



No **formal system extending basic arithmetic** can be used to prove its own consistency.
Idea: Knowing a computer model does not imply absolute control over the results. There is uncertainty.

On Rationality

"The arithmetic seems correct yet I find myself haunted by the idea that the basic axioms on which the arithmetic is based might give rise to contradictions which would then invalidate these computations."

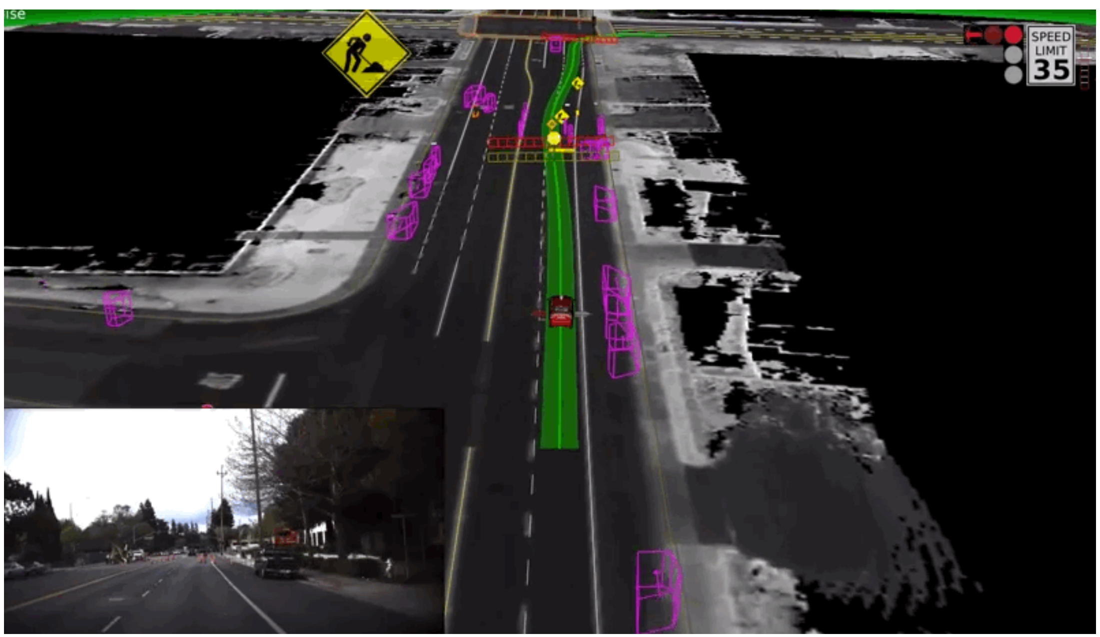
Limitations of logic include:

- Intelligent behavior is often not mediated by logical deliberation
- Logical representations of intelligence are non-trivial *(Bayesian networks and graphical models)*
- Seems to require some connection to "acting in the world" *(We feel the need and desire to affect our environment)*

4. Acting Rationally: Rational Agents

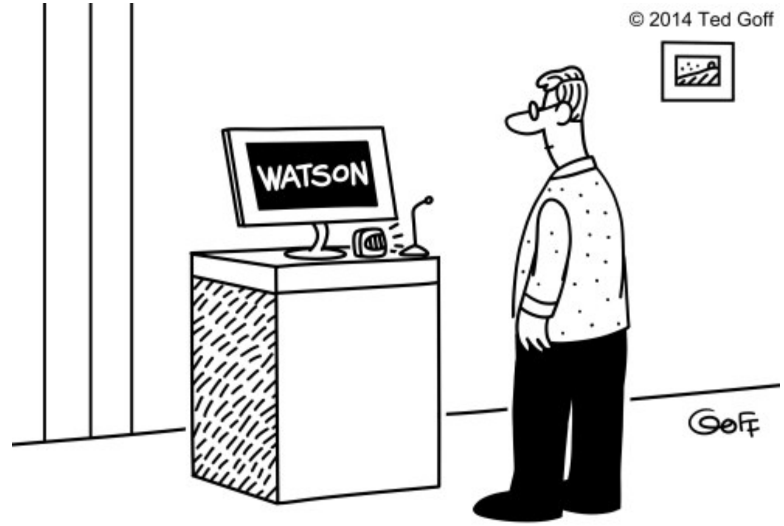
	Human-Like Intelligence	Ideal Intelligence/ Pure Rationality
Thought	2. Thinking Humanly	3. Thinking Rationally
Behavior	1. Acting Humanly	**4. Acting Rationally**

An **agent** is an entity that *perceives and acts in the world.*
i.e. an autonomous system
Example: Self-Driving Car by Google

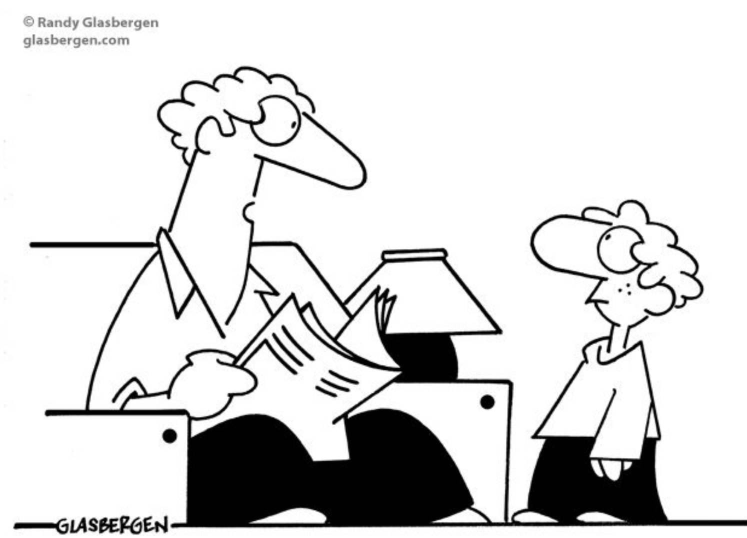


Caveat: Computational limitations may make perfect rationality unachievable.

Building Intelligent Agents



"Go ahead and think that I'm not really thinking. I thought you would think that."



"*Artificial intelligence* is when you get a college degree, but you're still stupid when you graduate."

I. Building exact models of human cognition
II. Developing methods to match or exceed human performance in certain domains, possibly by very different means.

Artificial intelligence focuses on the latter using neural networks.

Artificial Intelligence Research

Problem solving, planning, and search:

Generic problem solving architecture based on ideas from cognitive science

Knowledge Representation:

To store and manipulate information (logic)

Automated reasoning/ Inference:

To use stored information to answer questions and draw new conclusions

Machine Learning:

Intelligence from data; to adapt to new circumstances and to detect and extrapolate patterns

Natural Language Processing:

To communicate with the machine

Computer Vision:

Processing visual information

Robotics:

Autonomy, manipulate, full integration of AI capabilities

Approaches to Build Machines

1. Classical Artificial Intelligence

- 1960: AI used to solve problems that human brains perform easily
    - Understanding text
    - Recognizing objects in images
- **Result:** disappointing and slow
    - *Researchers believed that this suggested that computers need vast amounts of knowledge to be "intelligent"*
- **Solution:** "Expert System"
    - *Researchers combined computer programs with rules to solve problems by asking a series of questions*

IBM Watson is a modern version of Classic AI
How so?
IBM Watson uses sophisticated knowledge created for a particular issue.

What can we conclude about Classic AI?
Classic AI is highly tuned to answer a specific problem with encoded rules.

Test Your Understanding

Which of the following systems mimics human thinking?

A. Artificial Intelligence
B. Intelligent Agent
C. Bot
D. Database Management System

Which AI System finds and identifies patterns, for instance, in the words you use?

A. Expert System
B. Intelligent System
C. Neural Network
D. Fuzzy Logic

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Approaches to Build Machines

2. Simple Neural Network Approach

- 1943: Warren McCulloch and Walter Pitts created the first computational model of neural networks

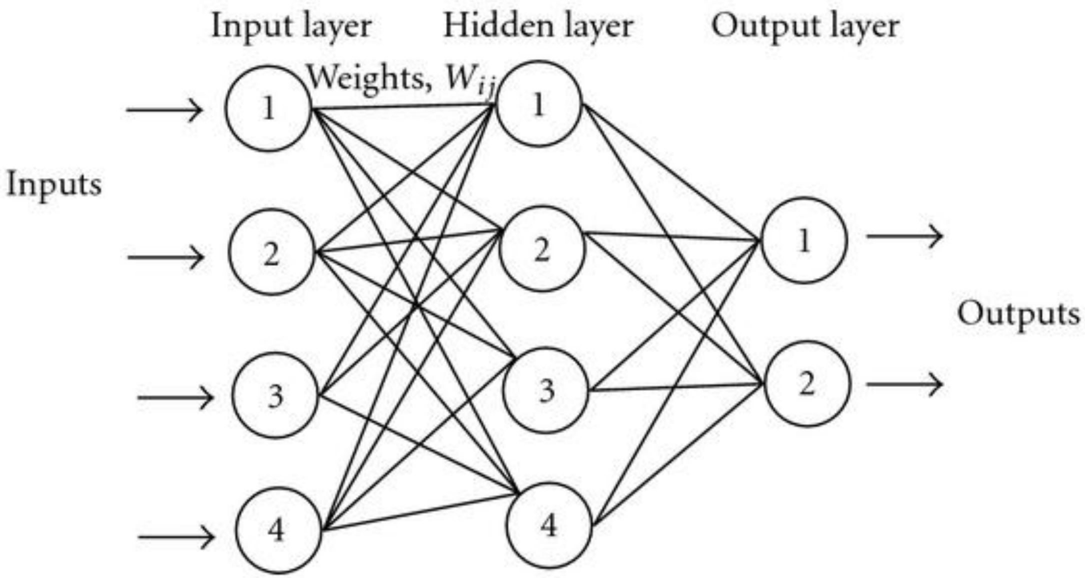
Artificial Neural Networks (ANN): large collection of neural units with links that can be enforcing or inhibitory in their effect on activation state of the neuronal ensemble

- *Did we understand the biology of real neurons when ANN was proposed?*

  No: *This implies that ANNs do not have much in common with biological neurons.*
- *What did researchers aim for in that case with ANN?*

  A system that can learn from data without human supervision rather than biological realism.

Artificial Neural Networks

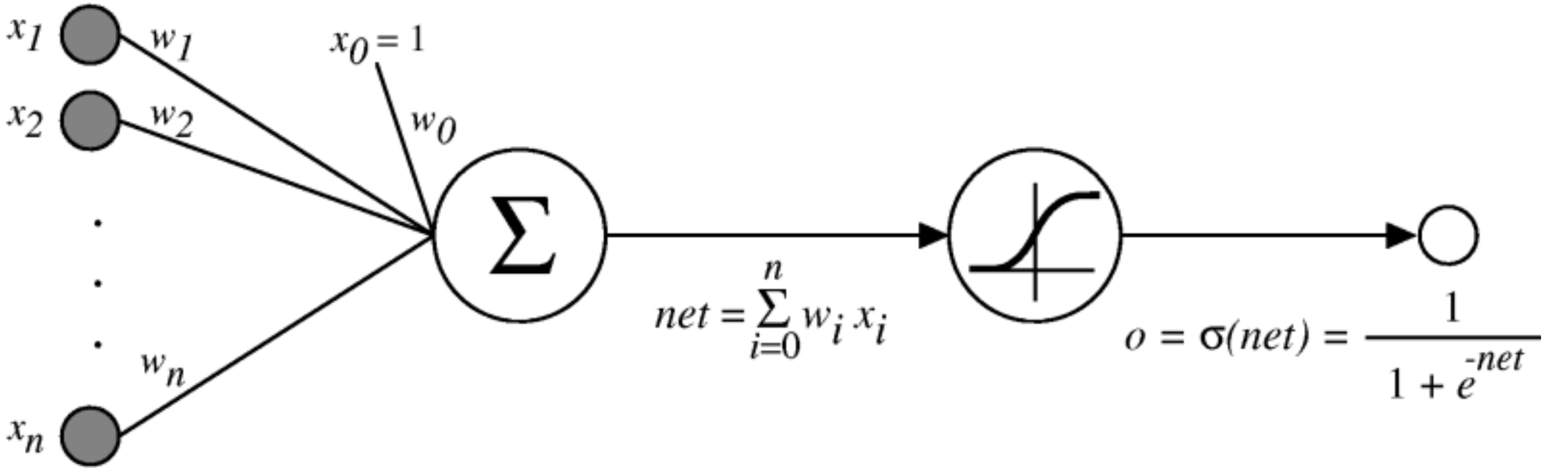


Neural Network Architecture

Each layer consists of **nodes**, represented by small circles.

1. **Input Layer:** nodes are **passive** and do not modify the data
2. **Hidden Layer:**
   values from the input layer are sent to hidden nodes, where they are multiplied by **weights** (pre-determined). Before leaving the hidden node, this input is passed through a ***sigmoid*** function.
   In this way, the output can only be between 0 and 1.
3. **Output Layer:**
   active nodes of output layer combine and modify the data to produce the final two output values of this network

Sigmoid Function in Neural Networks



$$\frac{ds(x)}{dx} = \frac{1}{1+e^{-x}} \quad = s(x)(1-s(x))$$

$$= (\frac{1}{1+e^{-x}})^2 \frac{d}{dx}(1+e^{-x})$$

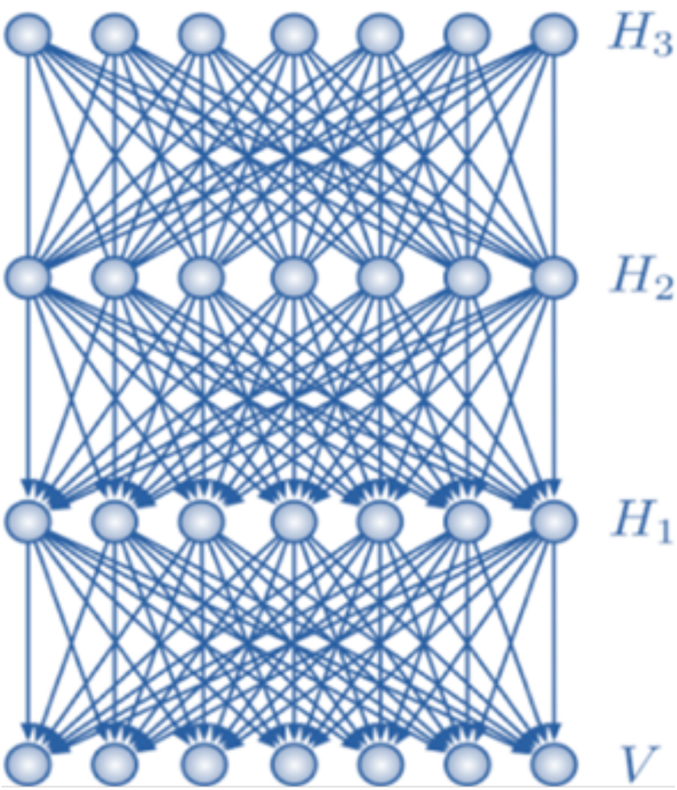
$$= (\frac{1}{1+e^{-x}})(\frac{1}{1+e^{-x}})(-e^{-x})$$

$$= (\frac{1}{1+e^{-x}})(\frac{-e^{-x}}{1+e^{-x}})$$

The sigmoid function is critical in finding the proper weights to use.

Can neural networks be made without a sigmoid function?
Yes: the three layers would *collapse* into only two layers (AND, OR, NOT).
What does this imply?
The summations and weights of the hidden layer combine into a single layer, creating a two layer network.

Deep Learning Neural Networks



Deep Learning Neural Network (DNN): an artificial neural network with multiple hidden layers of units between the input and output layers

DNN was enabled by access to fast computers and vast amounts of data for training.

Professor Geoffrey Hinton at the University of Toronto is a leader in this field and demonstrated the first use of **back propagation** in training multi-layer neural nets.

Deep Learning has successfully addressed:

- Image Classification
- Language Translation
- Identification of Spam in E-Mail

Test Your Understanding

True or False:

- The activation values of the hidden layer units in a neural network, with the sigmoid function applied at every layer, are always in the range (0,1).
- The outputs of a neural network represent probabilities and must sum to 1.
- Any logical function over binary-valued (0 or 1) inputs x_1 and x_2 can be *approximately* represented using some neural network.

Test Your Understanding

Which of the following statements are true?

- The activation values of the hidden layer units in a neural network, with the sigmoid function applied at every layer, are always in the range (0,1).
- The outputs of a neural network represent probabilities and must sum to 1.
- Any logical function over binary-valued (0 or 1) inputs x_1 and x_2 can be *approximately* represented using some neural network.

  Explanation: Since we can build the basic AND, OR, and NOT functions with the two layer network, we can approximately represent any logical function by composing these basic functions over multiple layers.

What Machine Learning Can Do

Input A	Response B	Application
Picture	Are there human faces? (0 or 1)	Photo tagging
Loan application	Will they repay the loan? (0 or 1)	Loan approvals
Ad plus user information	Will user click on ad? (0 or 1)	Targeted online ads
English sentence	French sentence	Language translation
Sensors from hard disk	Is it about to fail?	Preventive maintenance
Car camera and other sensors	Position of other cars	Self-driving cars

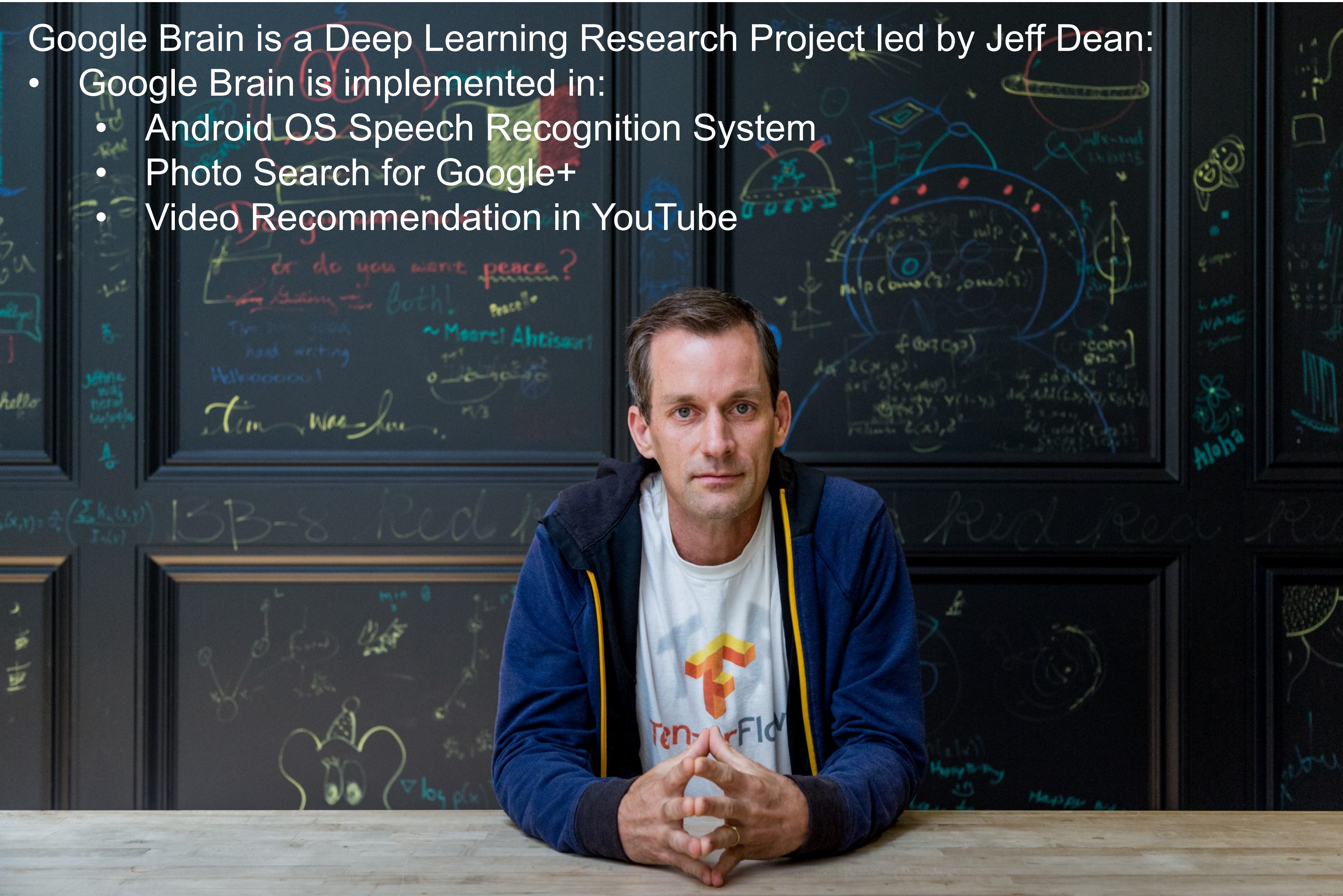
coursera

Source: Professor Andrew Ng at Stanford University
- Founder of Coursera
- Machine Learning Expert
- Co-Founder of Google Brain

Google Brain

Google Brain is a Deep Learning Research Project led by Jeff Dean:

- Google Brain is implemented in:
    - Android OS Speech Recognition System
    - Photo Search for Google+
    - Video Recommendation in YouTube



Google Brain: Robotic Arm Development

- *Learning Hand-Eye Coordination for Robotic Grasping with Deep Learning and Large-Scale Data Collection*
  ISER, 2016
- *Unsupervised Learning for Physical Interaction through Video Prediction*
  NIPS, 2016

Deep Learning for Robots: Learning from Large-Scale Interaction

What makes robotic behavior distinct from human behavior?

Robots follow a **sense-plan-act** paradigm:

1. **Sense:**
   Robot observes the world around it and formulates an internal model
2. **Plan:**
   Robot constructs a plan of action.
3. **Act:**
   Robot executes its plan.

With this paradigm,

1. Perception is imprecise.
2. Models are incorrect.
3. No plan survives first contact with reality.

In contrast, humans move quickly, reflexively, and often with remarkably little advance planning. How?

Humans rely on highly developed and intelligence feedback mechanisms that use sensory cues to correct mistakes and compensate for perturbations.

Learning Hand-Eye Coordination for Robotic Grasping

Google Brain: Robotic Arm Development

Google uses 14 robots to learn grasping in parallel

How does each robot develop hand-eye coordination?

1. A deep **convolutional neural network (CNN)** is used to predict the outcome of a grasp, given a camera image and a potential motor command.
2. This CNN is then deployed on the robots the next day, in the inner loop of a servoing mechanism that continually adjusts the robot's motion is constantly predicting, by observing the motion of its own hand.

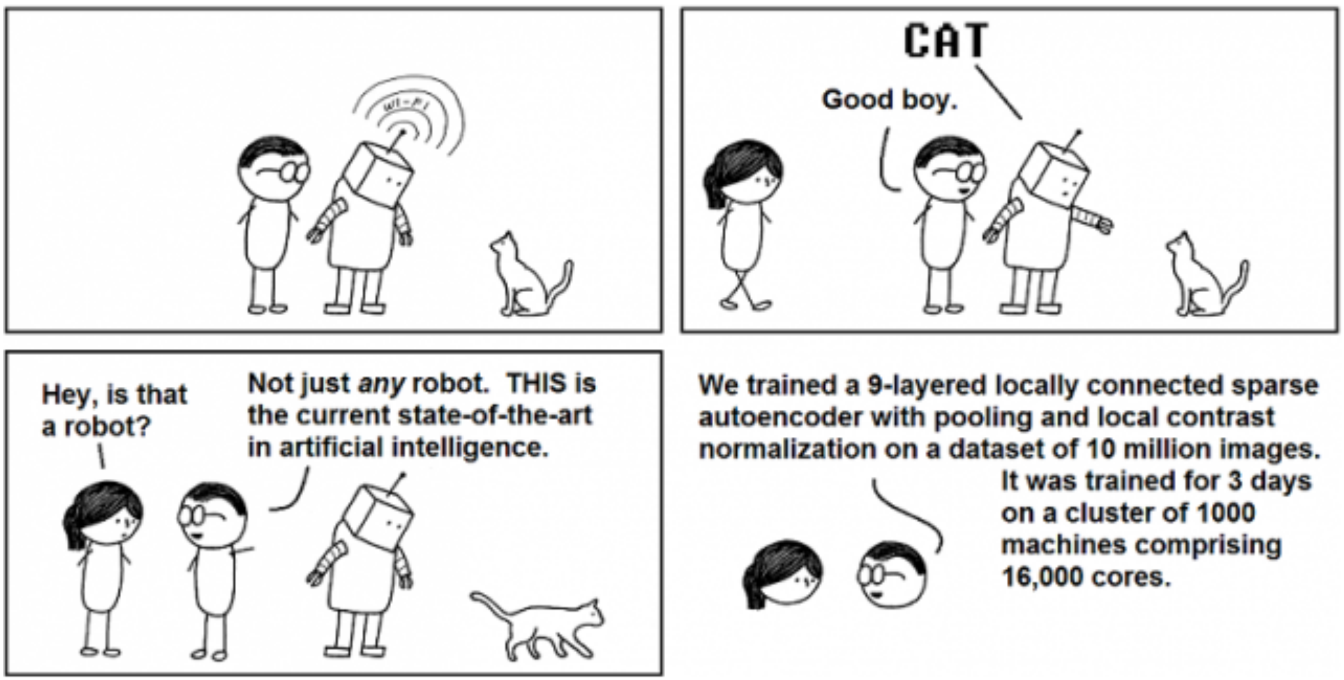
   *This is an example of **feedback** in a neural network.*
3. With continuous feedback after over 800,000 grasp attempts, the robot exhibits intelligent reactive grasp behaviors.
   - Robot observes its own gripper and corrects its motions in real time.
   - Robot exhibits pre-grasp behaviors (*i.e.* isolating a single object from a group)

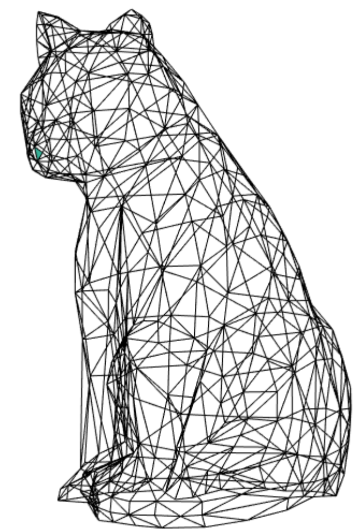
   *These behaviors emerged naturally from **learning**, rather than being programmed into the system.*

Learning Hand-Eye Coordination for Robotic Grasping

Google Brain: Cat Recognition

Building High-level Features Using Large Scale Unsupervised Learning





TECHNOLOGY

How Many Computers to Identify a Cat? 16,000

Deep Learning Net Architecture

Deep learning aims to take machine learning to the next level, letting the program choose its own inputs.

Professor Hinton creates artificial programs that simulate the way the human brain would operate using a **4 plane model:**

1. **Concept Plane:** Inputs are fed into program.
2. **Pattern Plane:** Patterns are detected in the data.
3. **Prime Plane:** Decides how the patterns should be treated.
4. **Action Plane:** System is altered and performance analyzed.

By this method, new inputs are selected and the process repeats. This removes the need for human beings to set inputs.

"It was as if a person could suddenly cram in, say, the equivalent of five hours of skiing practice in ten minutes."

Geoffrey Hinton

Approaches to Build Machines

3. Biological Neural Network Approach

With classic AI and simple neural networks, we cannot handle data that is constantly evolving. We are limited to finding patterns in large, **static** datasets.

What is an intelligent system?

Human Brain:

We hope that by studying how the brain works, we can learn what intelligence is and what properties of the brain are essential for any intelligent system.

What do we understand so far?

1. Brain represents information using SDRs
2. Memory is primarily a sequence of patterns
3. Behavior is an essential part of learning
4. Learning ***must*** be continuous

Cortical Learning Algorithm

Retina

Cochlea

Touch

High Velocity Data Stream

The **neo-cortex** builds online models from streaming data based on:

- Prediction
- Anomaly Detection
- Behavior

Retina

Cochlea

Touch

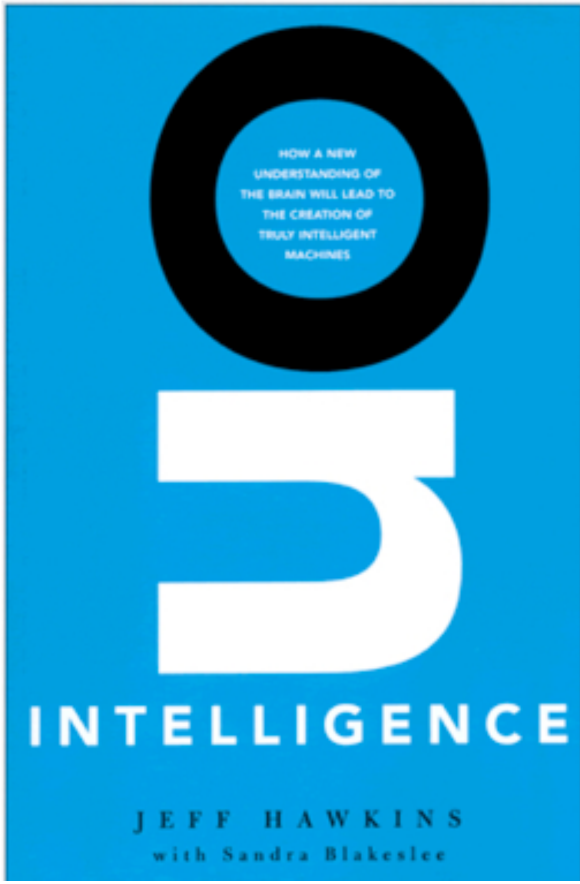
Machine Learning Algorithm

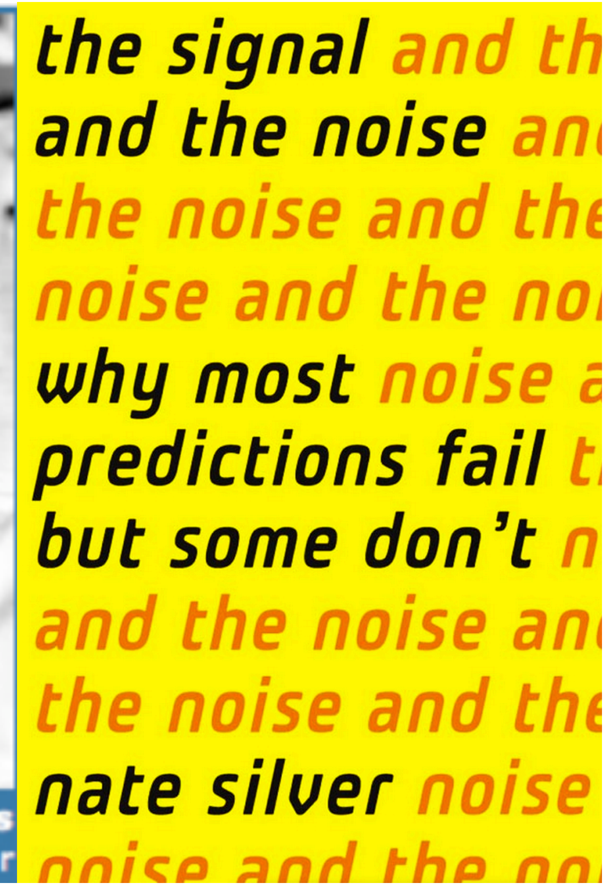
Computer uses:

- Hierarchy
- Sequence Memory

Hierarchical temporary memory (HTM):
unsupervised learning method model developed by Jeff Hawkins that is based on the structural and algorithmic properties of the neo-cortex
This bio-mimetic model is based on the memory-prediction theory.

On Intelligence





- *The brain is distributed, not hierarchical.*
- *The goal of the brain is survival through action, not sensory prediction.*
- *The action-focused parts of the brain use different strategies than the perceptual system.*

Google DeepMind: All Systems *Go*

The game of **Go** originated in China more than 25,000 years ago.

Rules: Players take turns to place black or white stones on a board, trying to capture the opponent's stones or surround empty space to make points of territory.

***Go** is played primarily through intuition and feel.*

Games are used as a testing ground to invent smart, flexible algorithms that can tackle problems, sometimes in ways similar to humans.

Games mastered by AI include tic-tac-toe, checkers, and chess.

Google DeepMind: All Systems *Go*

Despite its simple rules, **Go** is more complex than chess and possesses more possibilities than the total number of atoms in the visible universe.

How so?

Go has both a larger board with more scope for play and longer games. On average, there are many more alternatives to consider per move as well.

Google DeepMind: AlphaGo

Why is **Go** so hard for computers to play?

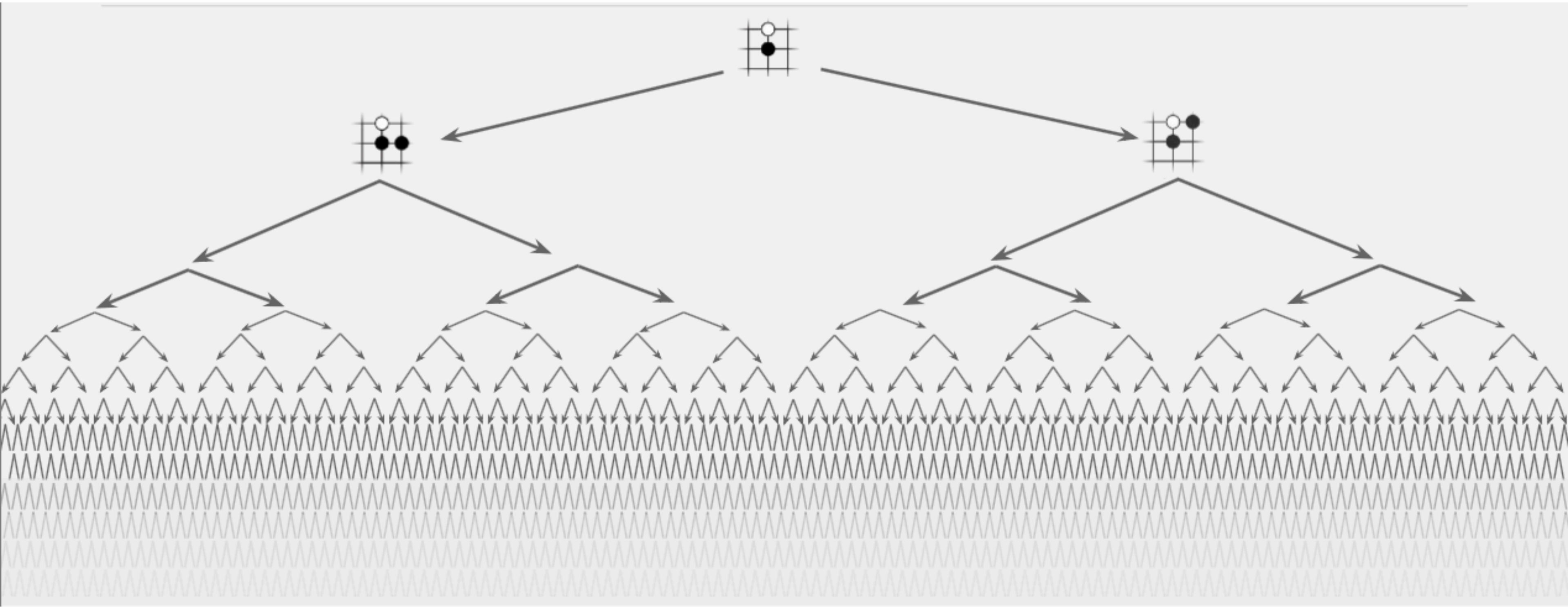
While traditional AI methods construct a ***search tree*** *over all possible positions, a brute force search is intractable in Go:*

1. *Search space is huge*
2. *“Impossible” for computers to evaluate who is winning*

AlphaGo is a system that combines an **advanced tree search** with **deep neural networks.**

Google DeepMind: AlphaGo

Exhaustive Search in AlphaGo

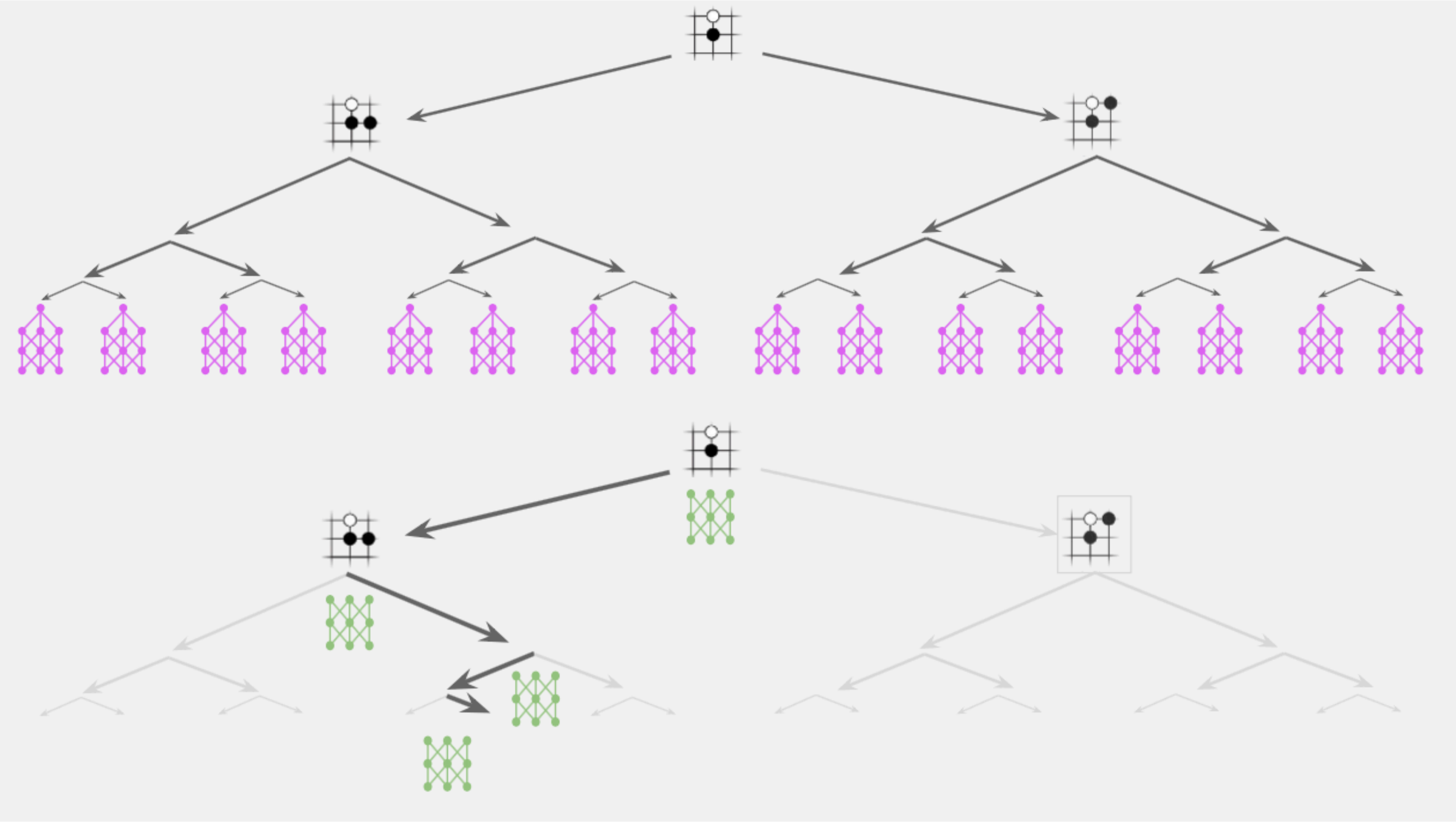


How do we reduce this search in AlphaGo?

Neural networks take a description of the Go board as an input and process it through 12 neural networks.

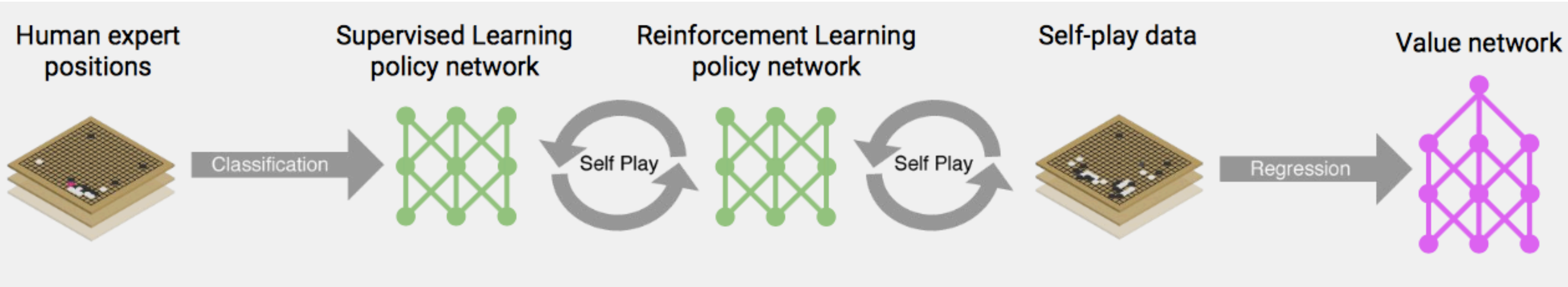
- *The **policy network** selects the next move to play.*
- *The **value network** predicts the winner of the game.*

Neural Networks of AlphaGo



- *The **value network** predicts the winner of the game.*
- *The **policy network** selects the next move to play.*

Neural Network Training Pipeline in AlphaGo



Supervised learning of policy networks

Policy Network: 12 layer convolutional neural network

Training Data: 30M positions from human expert games

Training Algorithm: maximize likelihood by stochastic gradient descent

$$\Delta\sigma \propto \frac{\partial \log p_\sigma(a \mid s)}{\partial \sigma}$$

Training Time: 4 weeks on 50 GPUs using Google Cloud Computing

Results: 57% accuracy on held out test data

(*state-of-the art was 44%)*

How DeepMind AlphaGo Beat Lee Sedol

How DeepMind AlphaGo Beat Lee Sedol

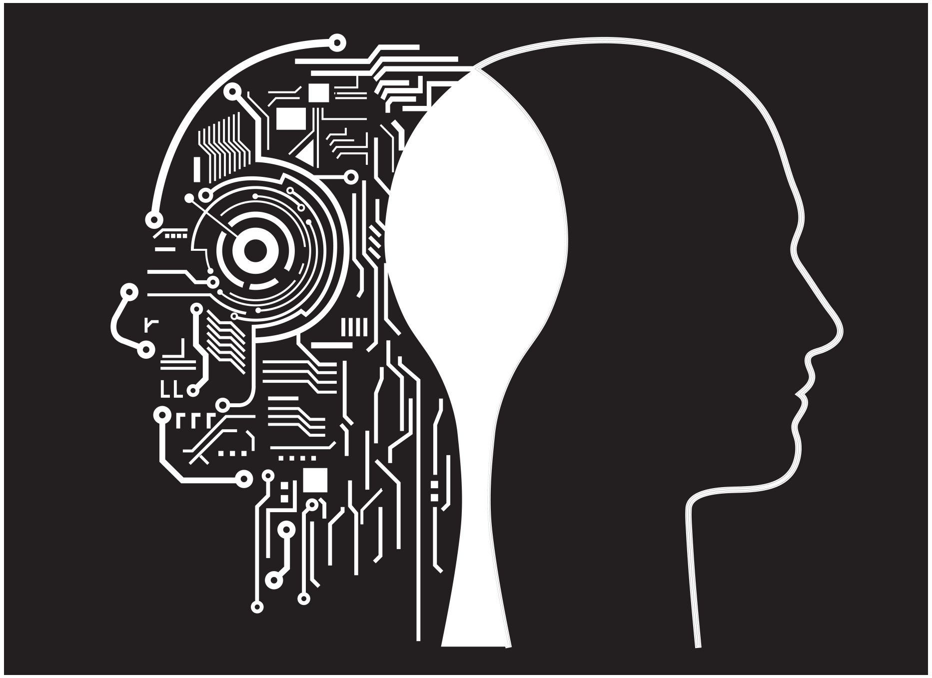
Lee Sedol is a professional Go player in South Korea.
He received $200,000 for the match against Google DeepMind AlphaGo.

$$\Delta\sigma \propto \frac{\partial \log p_\sigma(a \mid s)}{\partial \sigma} z$$

Reinforcement learning of policy networks

Policy Network: 12 layer convolutional neural network
Training Data: games of self-play between policy network
Training Algorithm: maximize wins *z* by policy gradient reinforcement learning
Training Time: 1 week on 50 GPUs using Google Cloud
Results: 80% v. supervised learning.

Future of Artificial Intelligence

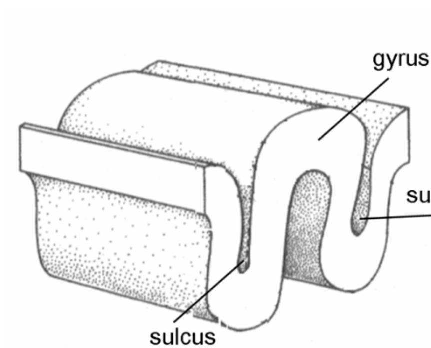


What do you foresee as the future of artificial intelligence?

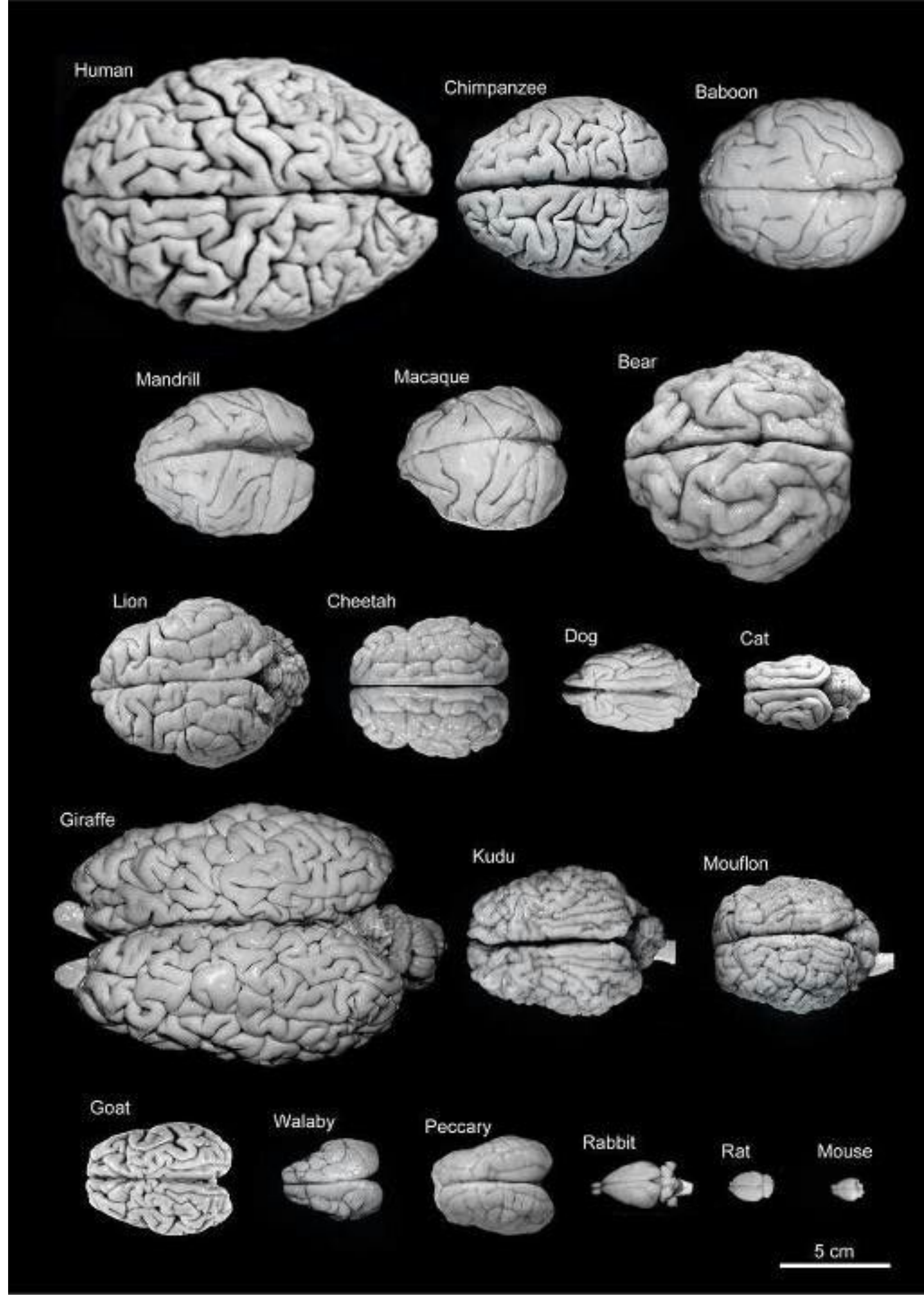
- *Climate Change Prediction*
- *Building Baymax*
- *Improving care*
- *Rethink how we value people*

Demo: Brain Bank

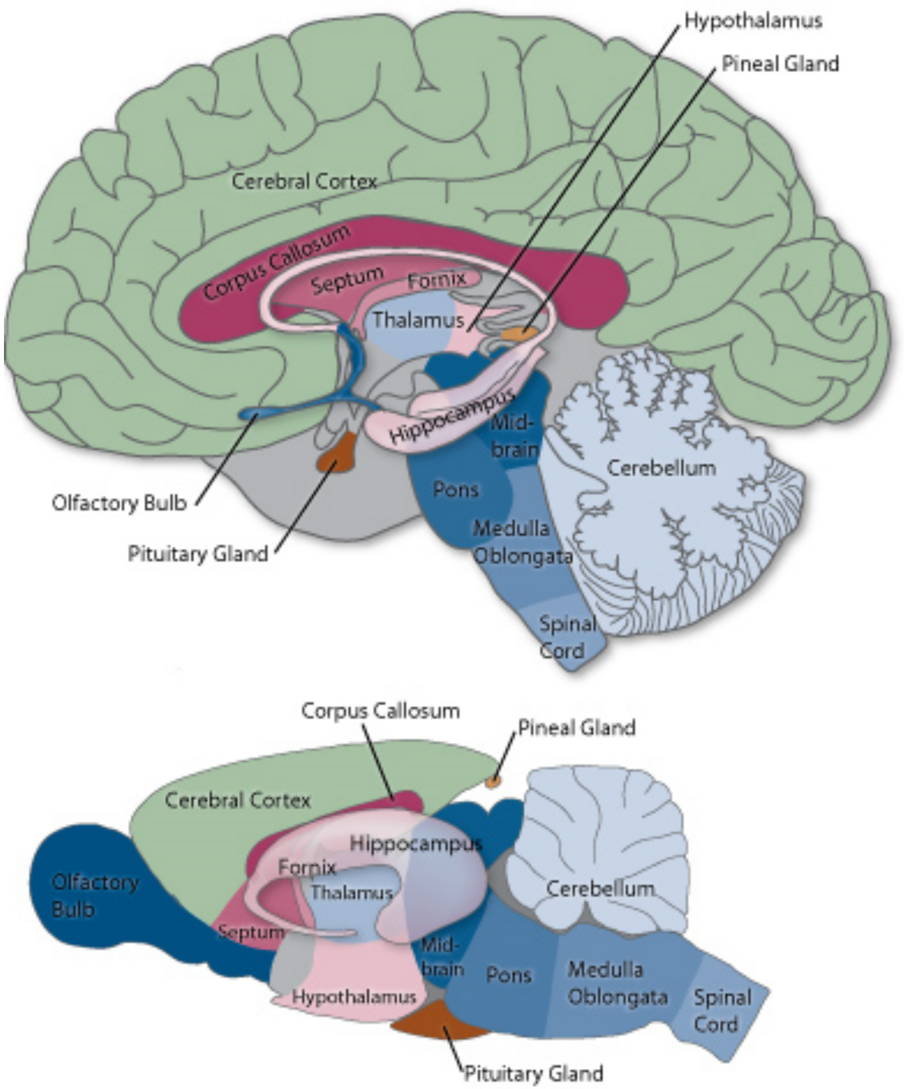
1) Wear gloves
2) Don't remove brains from vials
3) Be gentle!



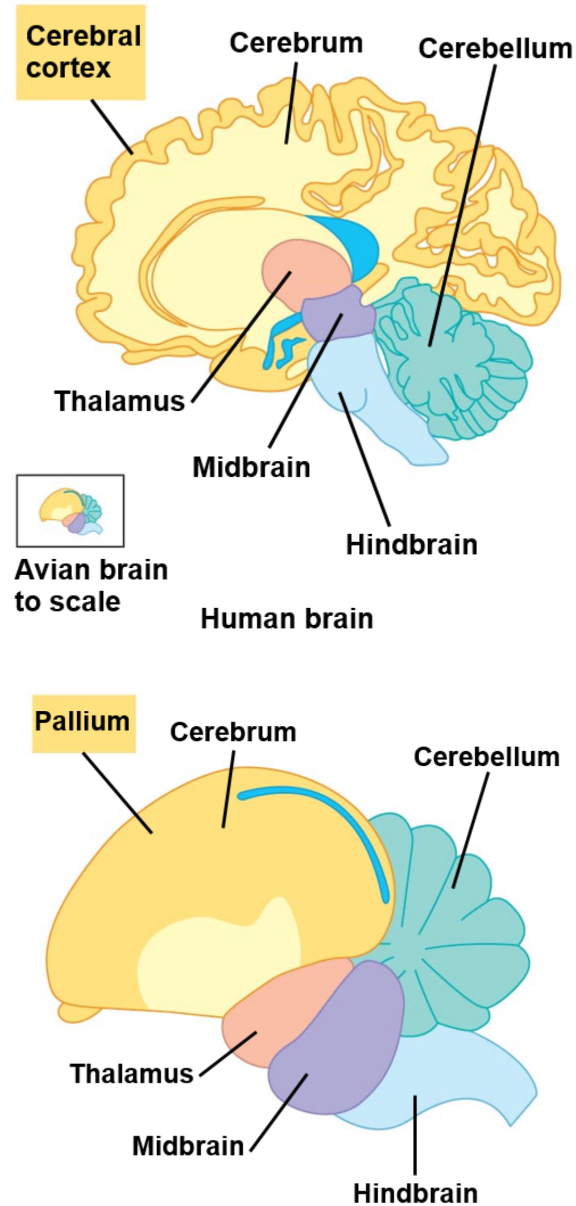
The folds allow for greater surface area =
better organization of complex behaviors



Demo: Brain Bank



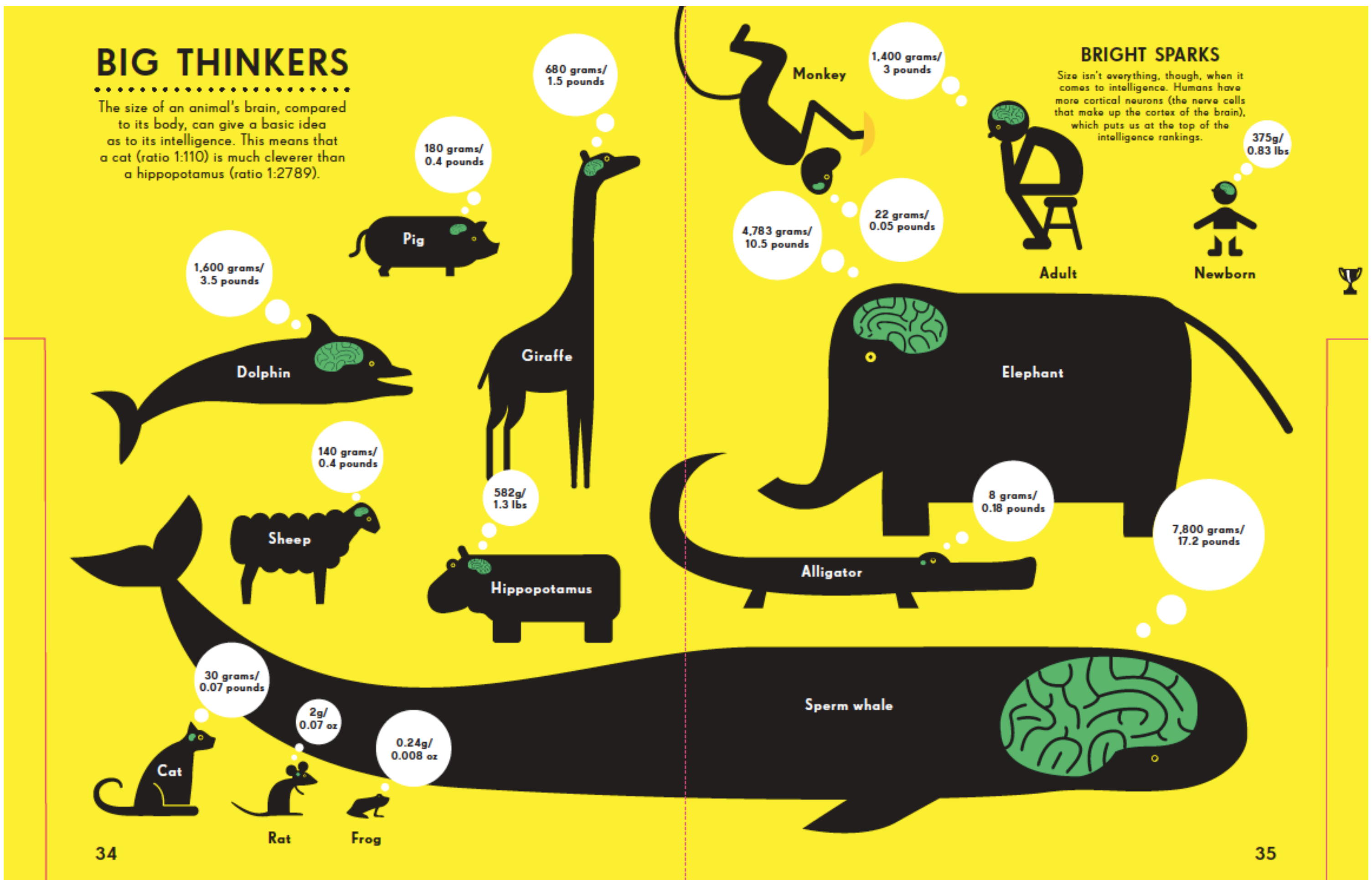
Human vs. Rat brain



Human vs. Bird brain

Comparing brains in different animals

1. Greater surface area of cerebral cortex allows for more social and complex behaviors, like emotion and language.
2. Different animals have larger areas of their brain dedicated to different regions (take note of size of olfactory bulbs)
3. Proportion of brain region usually dictates importance of that function



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