



Artificial Intelligence & Quantum Computing



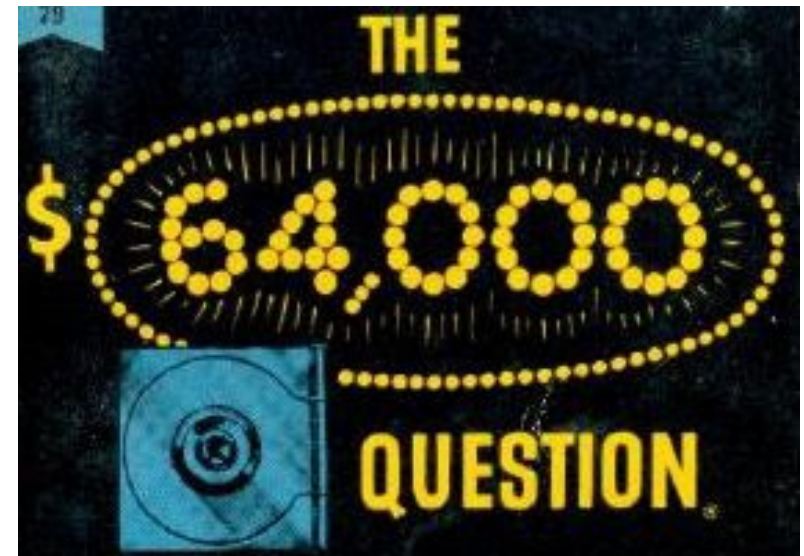
**Universiteit
Leiden**
The Netherlands

Aske Plaat
18 september 2018

Discover the world at Leiden University

Outline

- Why is there so much interest in AI?
- What is AI?
- What is QML?
- Will QML be the next disruptor?



Setting the scene



**Why is there so much
interest in AI?**

Buying Books

The image is a screenshot of the Amazon.com homepage. At the top, there is a navigation bar with the Amazon logo, navigation links like 'Aske's Amazon.com', 'Today's Deals', 'Gift Cards', 'Sell', and 'Help', and a search bar. To the right of the search bar are links for 'Hello, Aske Your Account', 'Try Prime', 'Wish List', and 'Cart'. Below the navigation bar is a large banner for 'Amazon Fashion' featuring 'TOP RUNNING SHOES' with a pair of blue and green sneakers. Below the banner is a 'New For You' section with a 'See more' link and a row of book covers: 'The Rational Male', 'Celia Imrie', 'Elon Musk', and 'Global Asset Allocation'. To the right of the 'New For You' section is an 'Amazon Gift Cards' advertisement with the text 'Any Occasion. No Expiration.' and a 'Shop now' link.

amazon.com

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Amazon Fashion

TOP RUNNING SHOES

STANDOUTS FROM NEW BALANCE AND MORE

New For You See more

THE RATIONAL MALE
FRIVOLETTE MEDICINE

Celia Imrie
Not Quite

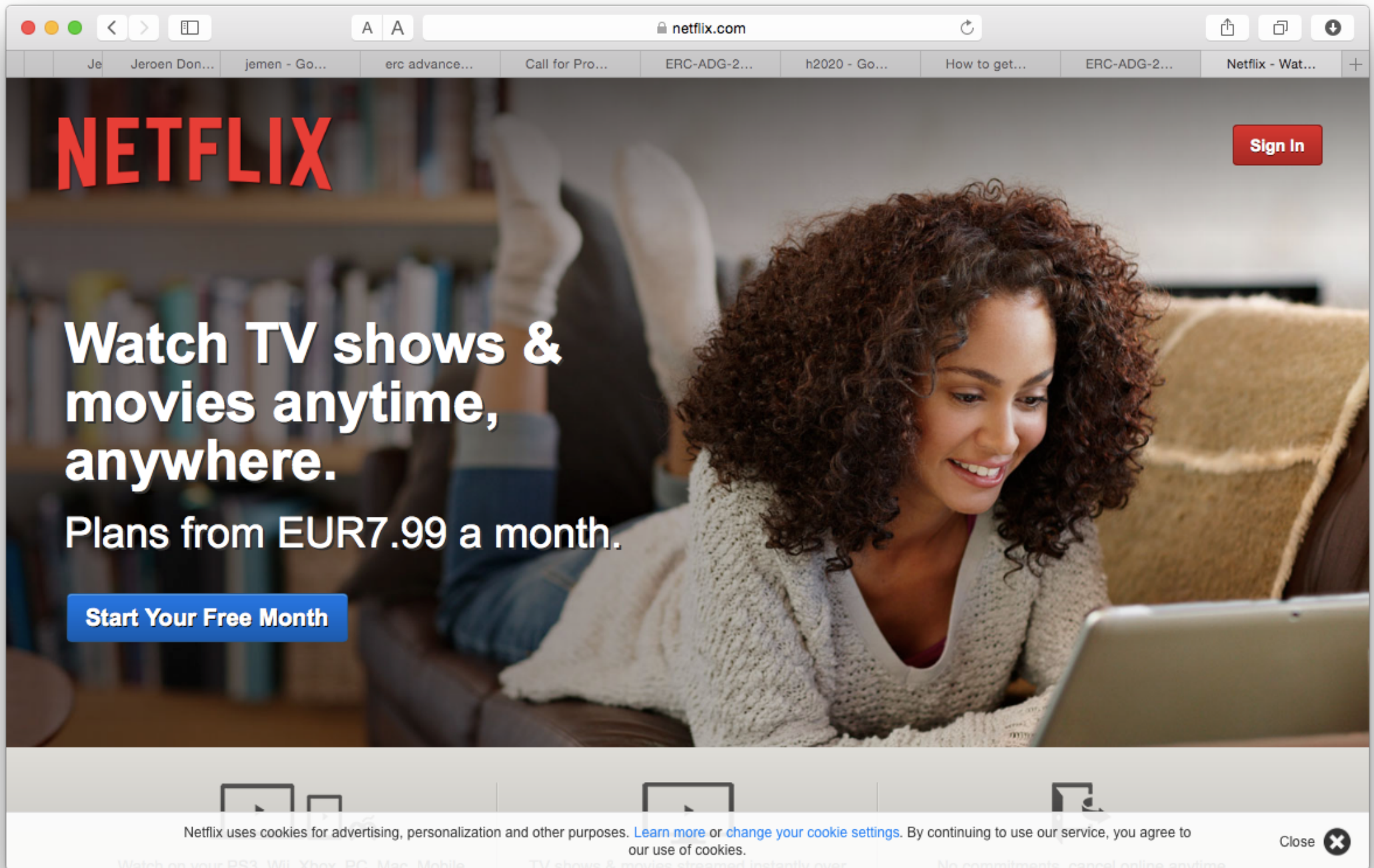
ELON MUSK
Tesla, SpaceX, and the Quest for a Fantastic Future

GLOBAL ASSET ALLOCATION
A SURVEY OF THE WORLD'S TOP INVESTMENT STRATEGIES

Amazon Gift Cards
Any Occasion. No Expiration.
> Shop now

kindle fire
Make a wish...
congratulations

Watching Movies



The image shows a browser window displaying the Netflix homepage. The browser's address bar shows 'netflix.com'. The page features the Netflix logo in red, a 'Sign In' button, and a main headline: 'Watch TV shows & movies anytime, anywhere. Plans from EUR7.99 a month.' Below this is a blue button that says 'Start Your Free Month'. At the bottom, there is a cookie consent banner with a 'Close' button.

NETFLIX

Sign In

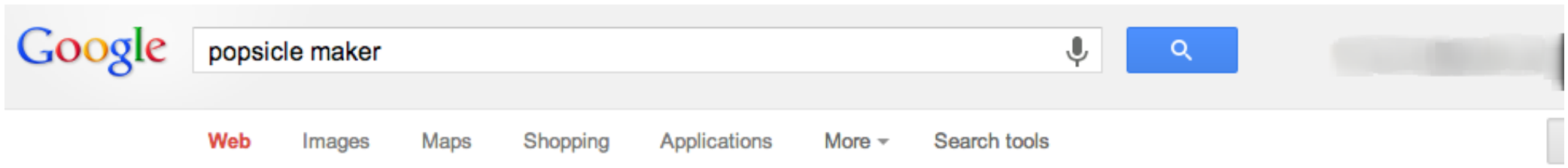
Watch TV shows & movies anytime, anywhere.

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Netflix uses cookies for advertising, personalization and other purposes. [Learn more](#) or [change your cookie settings](#). By continuing to use our service, you agree to our use of cookies. Close

Surfing the Web



About 1,410,000 results (0.40 seconds)

Ad related to **popsicle maker** ⓘ

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www.amazon.com/popsicle-molds - ★★★★★ 566 seller reviews

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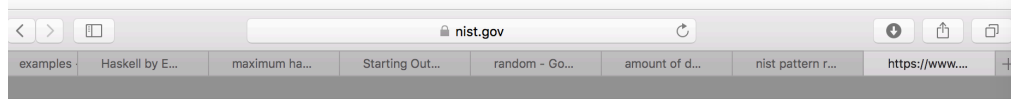
[Zoku Quick Pop Maker | Williams-Sonoma](#)

www.williams-sonoma.com/products/zoku-quick-pop-maker/ ▾

Now you can create your own customized frozen pops, including cream-filled varieties, in as little as seven minutes. Simple and easy to use, our freezer ensures ...

[Zoku | Quick Pop Maker](#)

Pattern Recognition



Comparing human and machine face recognition

Face Recognition Algorithms Surpass Humans

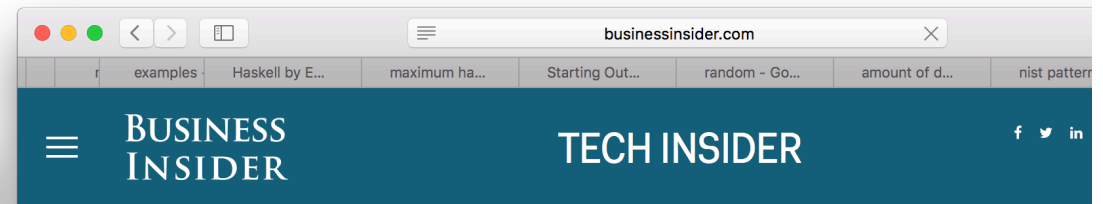
Alice J. O'TOOLE, P. Jonathon PHILLIPS, Fang JIANG, Janet AYYAD, Nils PENARD,
and Hervé ABDI*

Abstract—There has been significant progress in improving the performance of computer-based face recognition algorithms over the last decade. Although algorithms have been tested and compared extensively with each other, there has been virtually no work comparing the accuracy of computer-based face recognition systems with humans. We compared seven state-of-the-art face recognition algorithms with humans on a face-matching task. Humans and algorithms determined whether pairs of face images, taken under different illumination conditions, were pictures of the same person or of different people. Three algorithms surpassed human performance matching face pairs prescreened to be “difficult” and six algorithms surpassed humans on “easy” face pairs. Although illumination variation continues to challenge face recognition algorithms, current algorithms compete favorably with humans. The superior performance of the best algorithms over humans, in light of the absolute performance levels of the algorithms, underscores the need to compare algorithms with the best current control—humans.

Index Terms—face and gesture recognition, performance evaluation of algorithms and systems, human information processing

I. INTRODUCTION

An increase in security concerns worldwide has focused public attention on the accuracy of computer-based face recognition systems for security applications. How accurate must a face recognition algorithm be to contribute to these applications? Over the last decade, academic computer vision researchers and commercial product developers have improved the performance of automated face recognition algorithms on a variety of



iPhone SE 16GB

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Microsoft built technology that's better than a human at understanding a conversation



Matt Weinberger

Oct. 18, 2016, 9:00 AM

33,562



FACEBOOK



LINKEDIN



TWITTER



How to track your vehicle on the...

(TechieFans)

Saved By The Bell: Then and Now

(All Things Celeb)

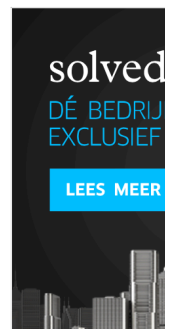
The 10 Coolest Gadgets For Men

(nicerest.info)

30 Creepy Places You Didn't Know...

(GeekVIP)

Sponsored Links



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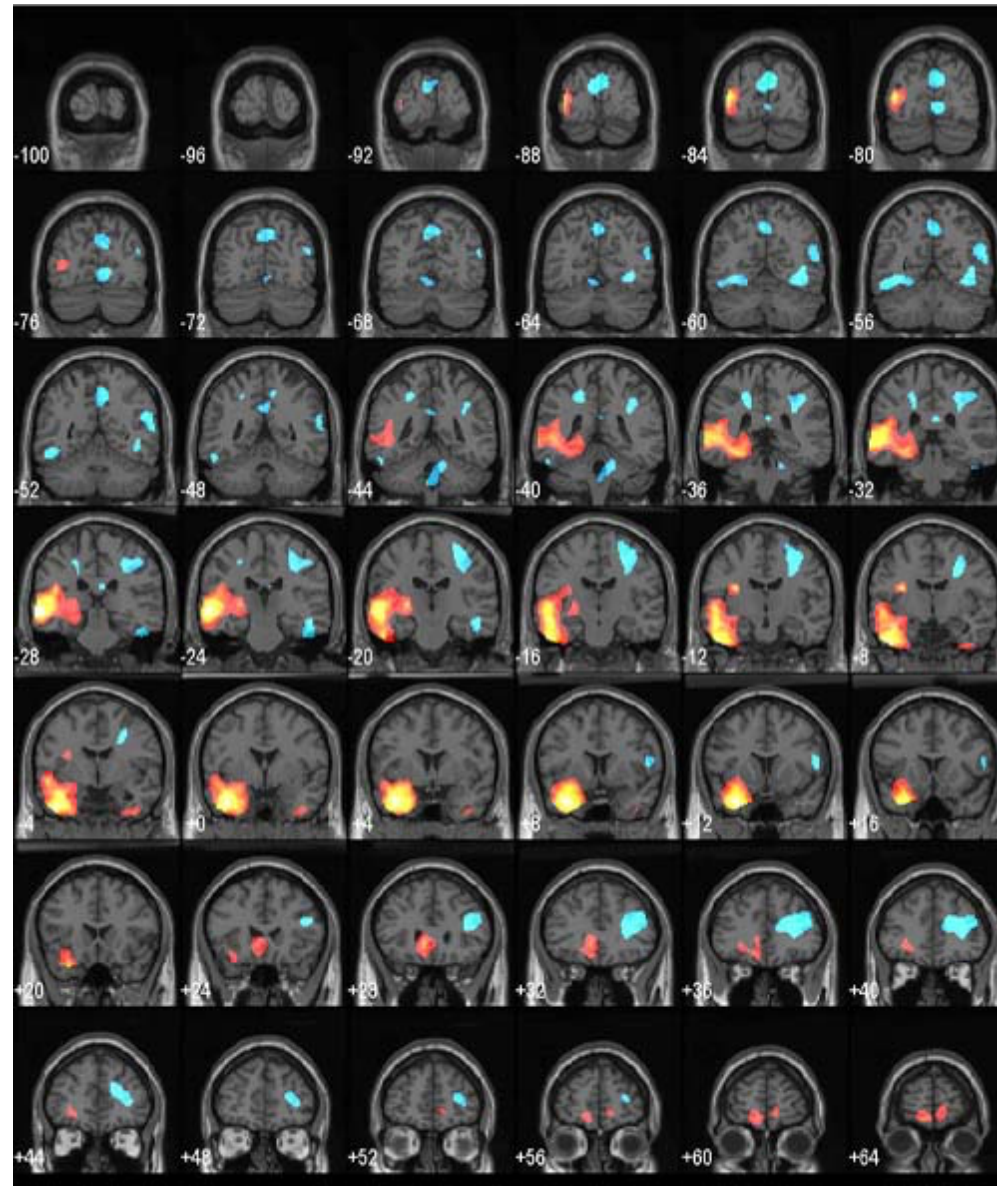


A pe
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Princ

In December 2015,
Microsoft Chief Scientist
of Speech Xuedong
Huang told Business
Insider that "in the next



Medical Diagnosis



Intelligent Assistants



Sorry, I didn't get that

Self-driving cars



Game Playing



Google

amazon



Alibaba.com



ebay

腾讯
Tencent

DeepMind

D E Shaw & Co

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IBM

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Inside China's Ministry of Truth

Trump in trouble

Who are the Niger Delta Avengers?

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Motorcycles that fly

March of the machines

A SPECIAL REPORT ON ARTIFICIAL INTELLIGENCE



DOUBLE ISSUE

DECEMBER 19, 2016

Puppet of the Year

TIME

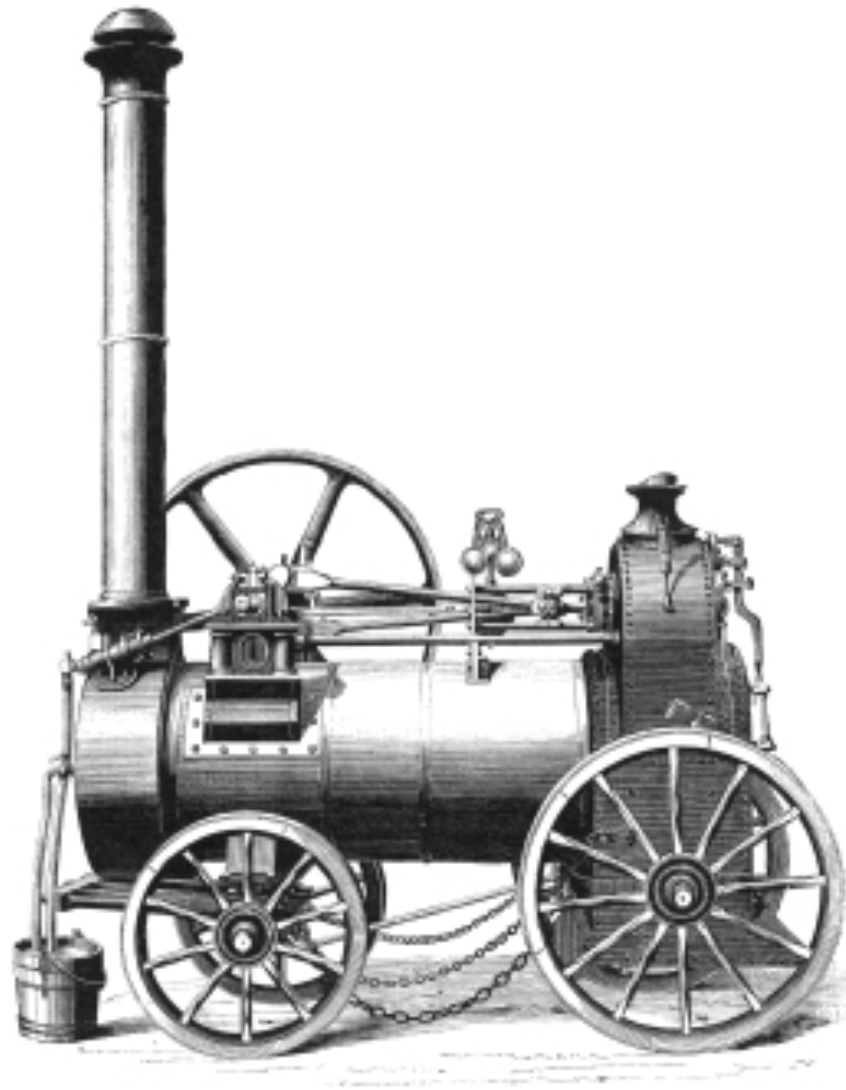
DONALD
TRUMP
TRAITOR IN CHIEF



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time.com

Disruption



What is Artificial Intelligence?



Is Deep Blue Intelligent?



To be intelligent...

- problem solving
- memory
- creativity
- emotion
- consciousness
- self-awareness



To be...

- problem solving
- memory
- creativity
- emotion
- consciousness
- self-awareness



To act...

The Turing Test

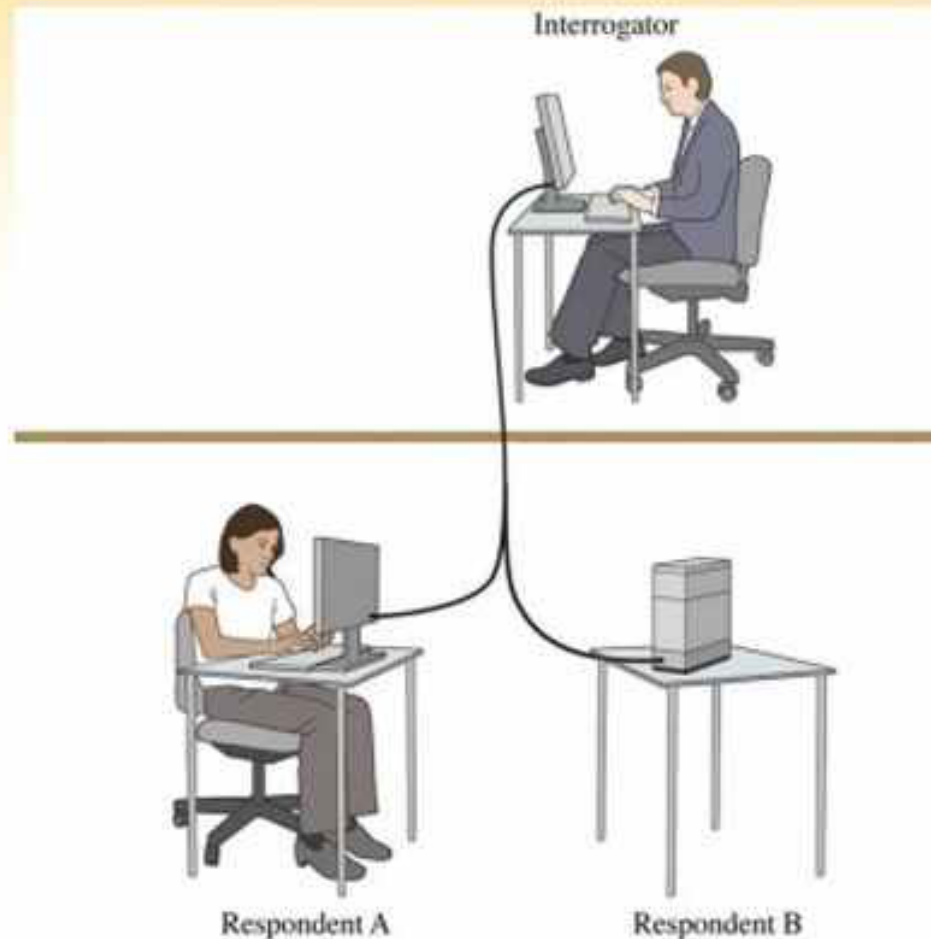
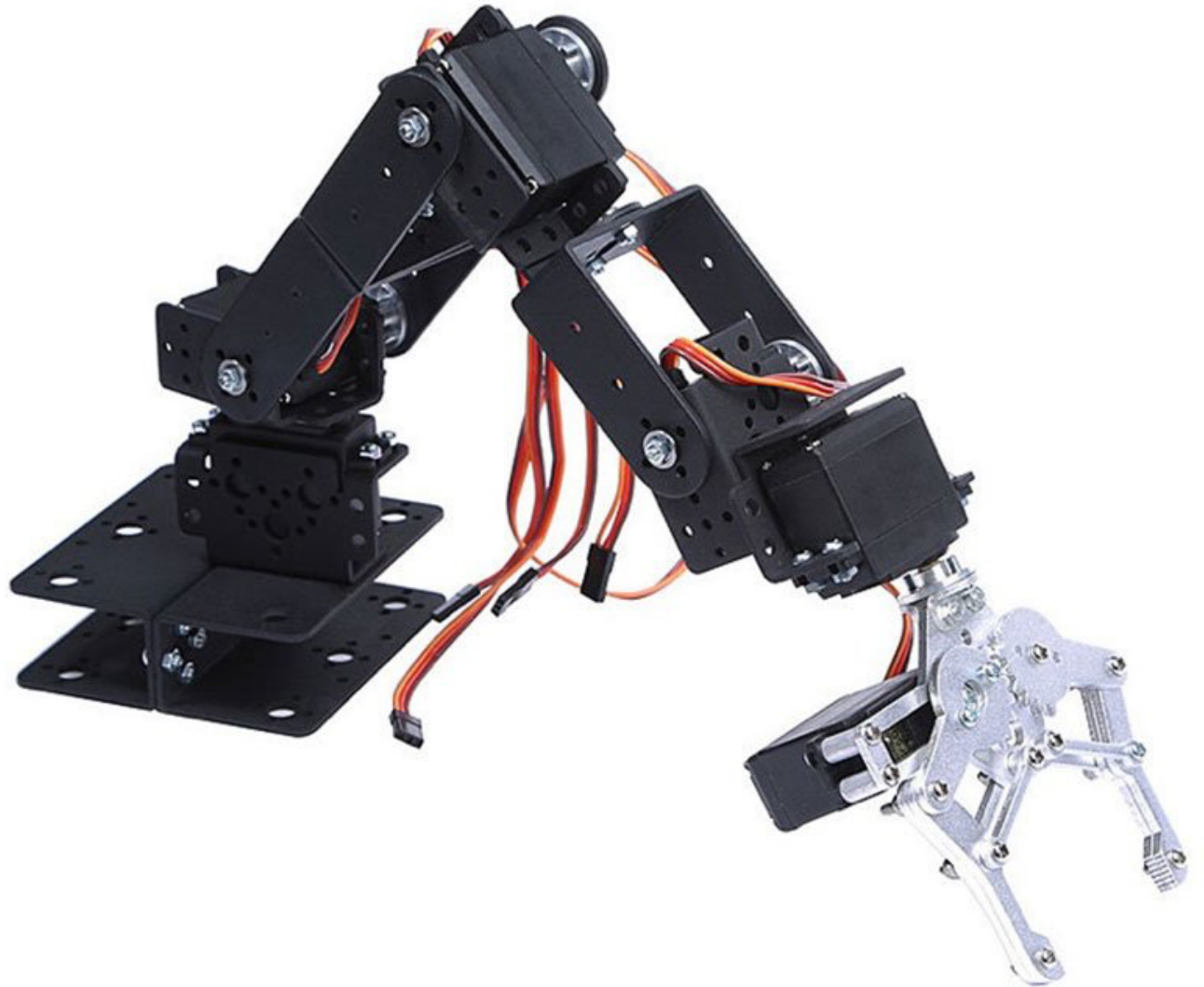


Figure 13.2

In a Turing test, the interrogator must determine which respondent is the computer and which is the human

Acting Intelligent

- sensing
- **adaptation**
- actuating

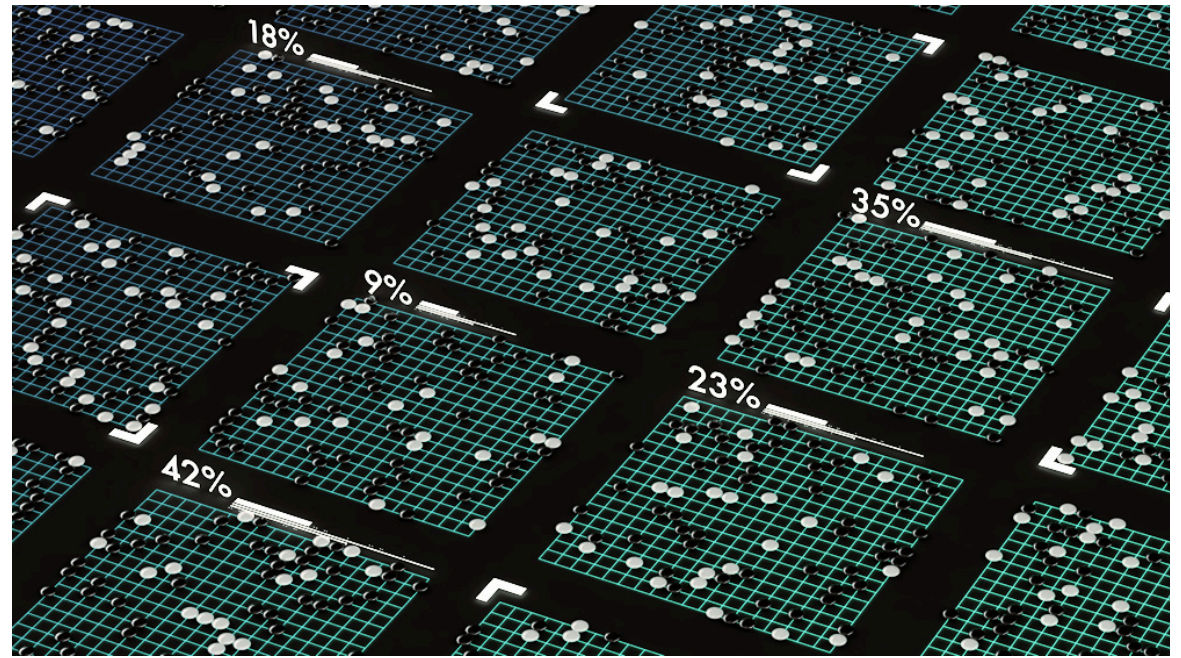
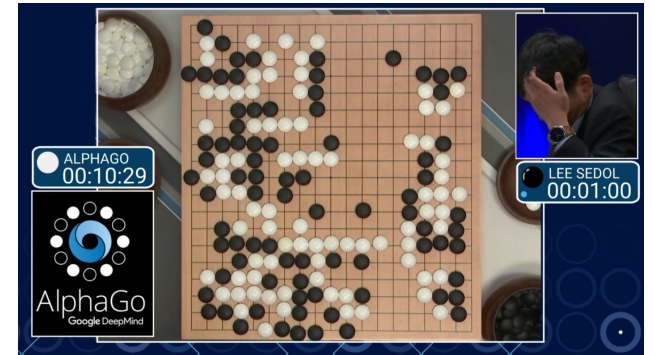


Adaptation

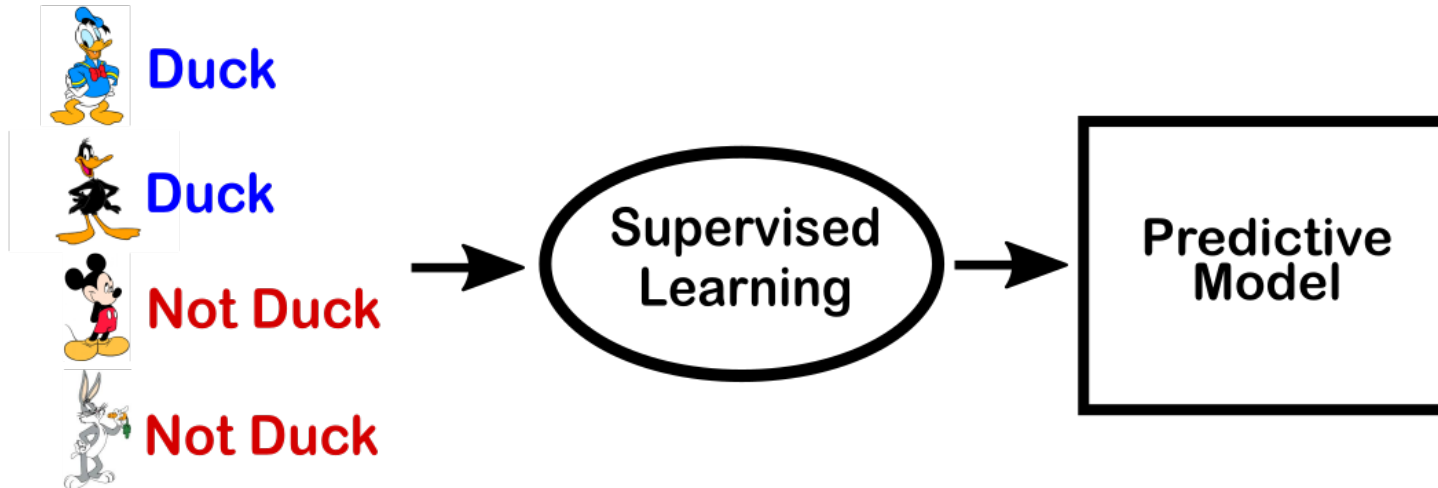
- logical reasoning
- memory
- learning/generalization

Machine Learning

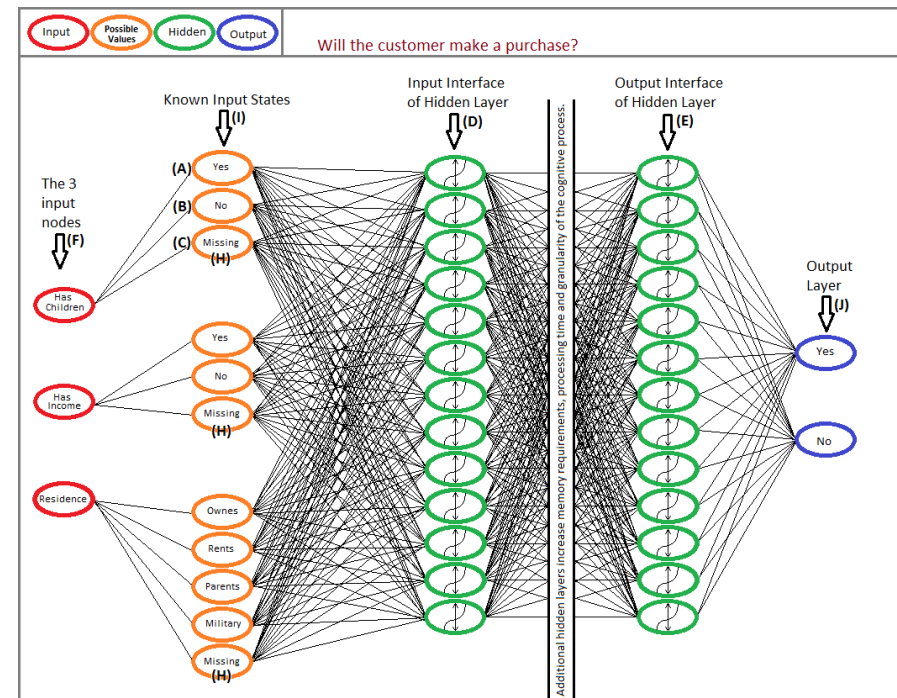
- logical reasoning
- memory
- **learning/generalization**



Supervised Learning

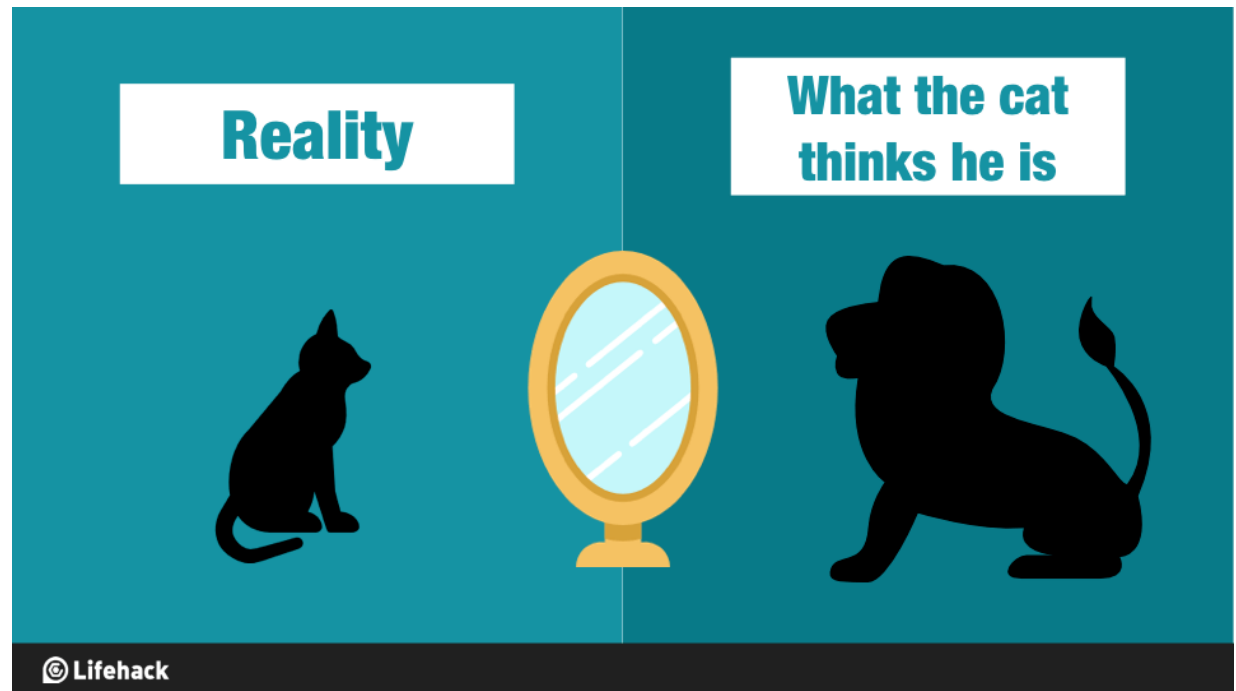


- learning = generalization = approximating a mapping



No hard-to-define concepts

- Self awareness
- emotion
- consciousness
- creativity



Yes clear problem domains



Yes clear problem domains



What technology is behind the AI breakthroughs?



AI

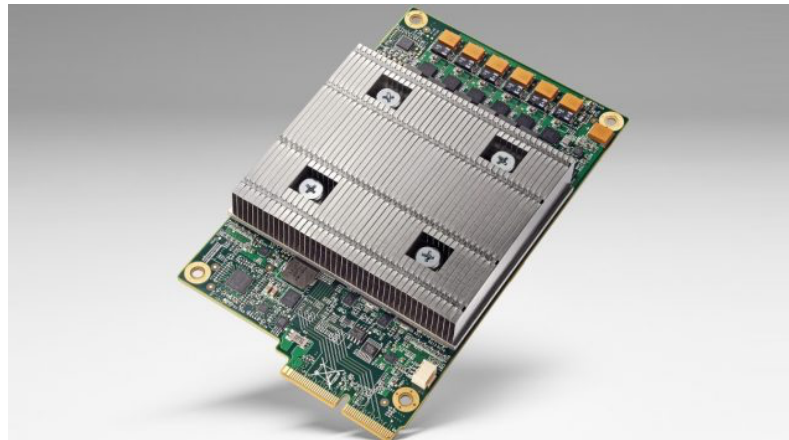
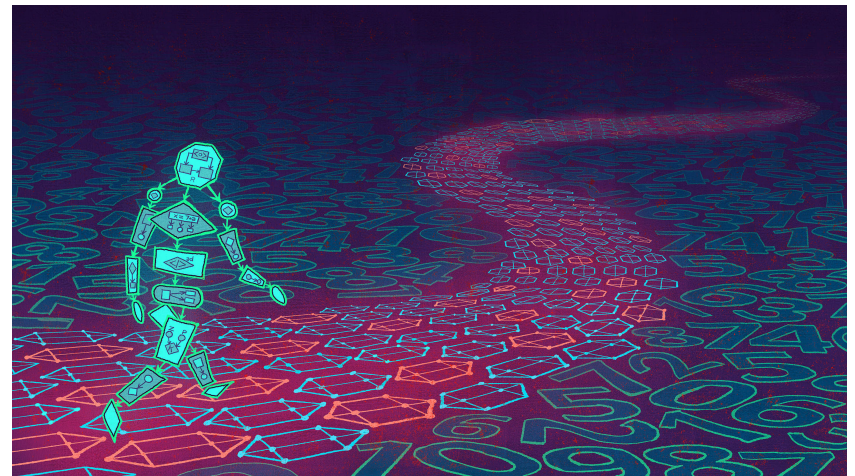


OpenML

1. Algorithm

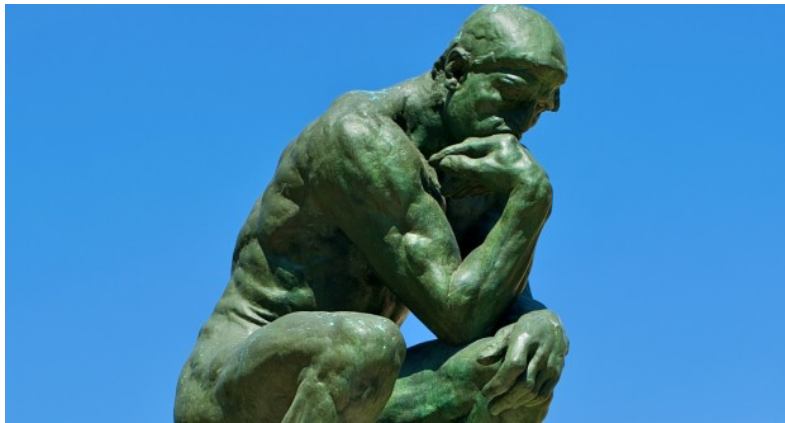
2. Data

3. Speed



1. Algorithms

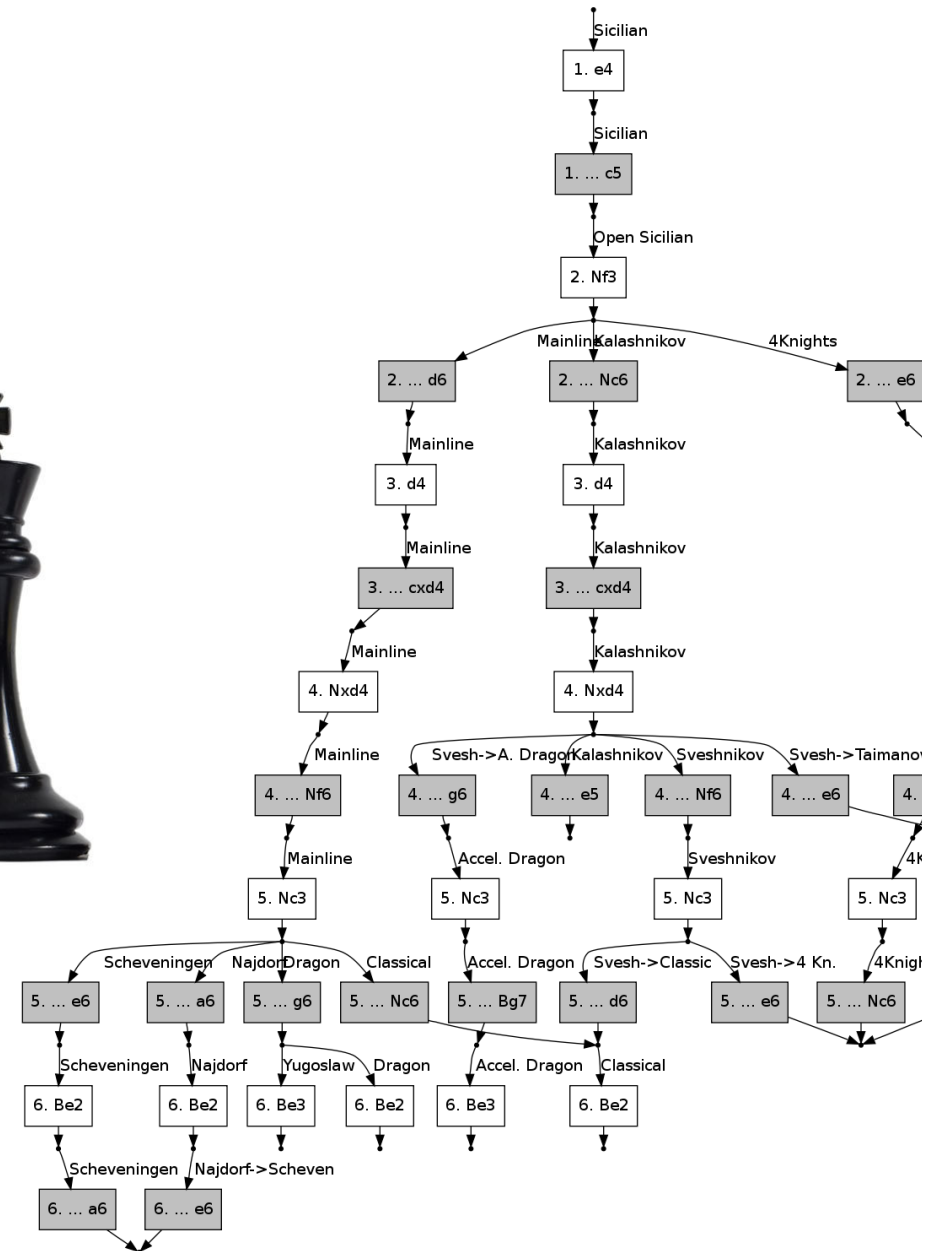
Symbolic



Connectionist

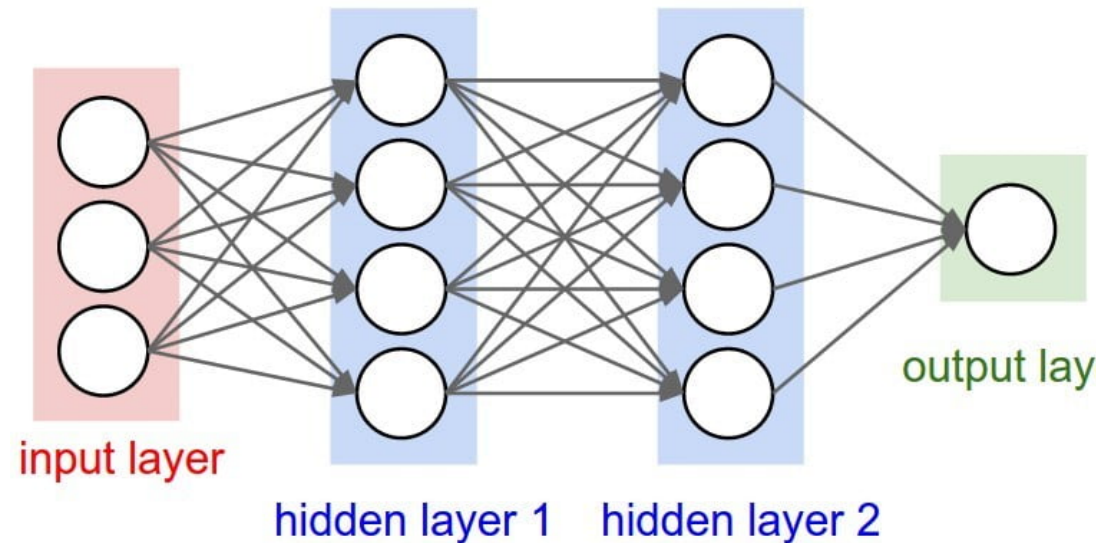
Symbolic

- Philosophy, logic, system 2
- Top down
- Expert systems
- Ontologies, resolution,
- Agents, Planning
- Tabular Q Learning, SVM, PCA
- Markov Decision Problems, Mcts

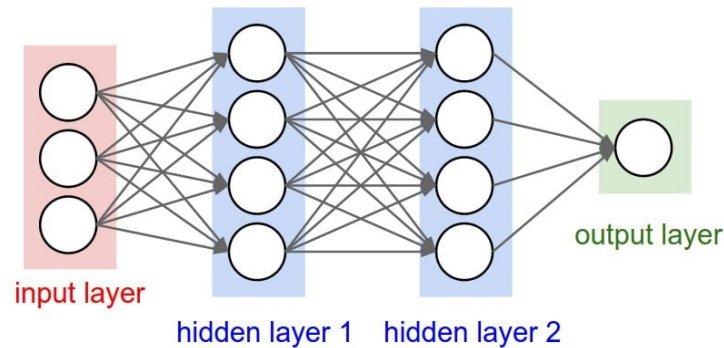


Connectionist

- Biology, neural net, evolutionary, robotics, life, system 1
- Generalization, function approximators
- Perceptrons
- Deep Learning
- Bottom up
- CNN, RNN, LSTM
- Skips Resnet, Regularization
- Batch normalization vanishing gradients



Issues



- A net is a function mapping input on output
- In theory a one hidden layer net is a sufficient function approximator
Many layers work better in practice
- Learning a function is generalizing example states, optimization of underconstrained multidimensional problem. Many more parameters than examples
- Regularization tricks to get convergent learning
- Works great in practice, no satisfactory theory of deep learning

Notable Successes

- Symbolic reasoning: Chess



- Agent simulations: Emergent Social Norms, Negotiation

- Evolutionary Optimization in Industry



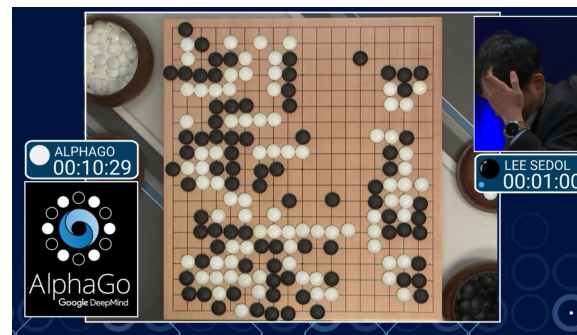
- Deep Convolutional Nets: Image recognition



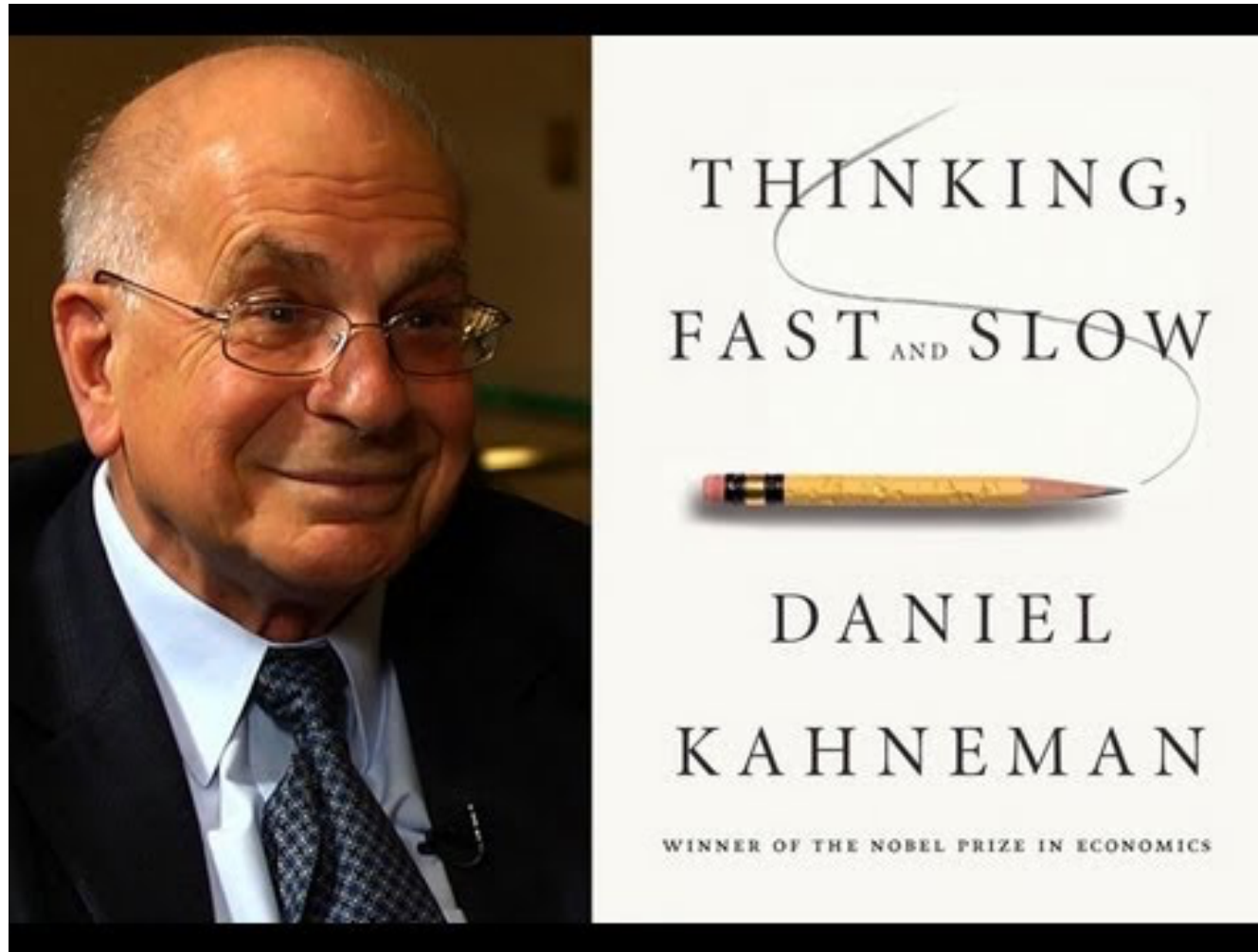
- Recurrent Nets: Speech recognition



- Search+Net: Go



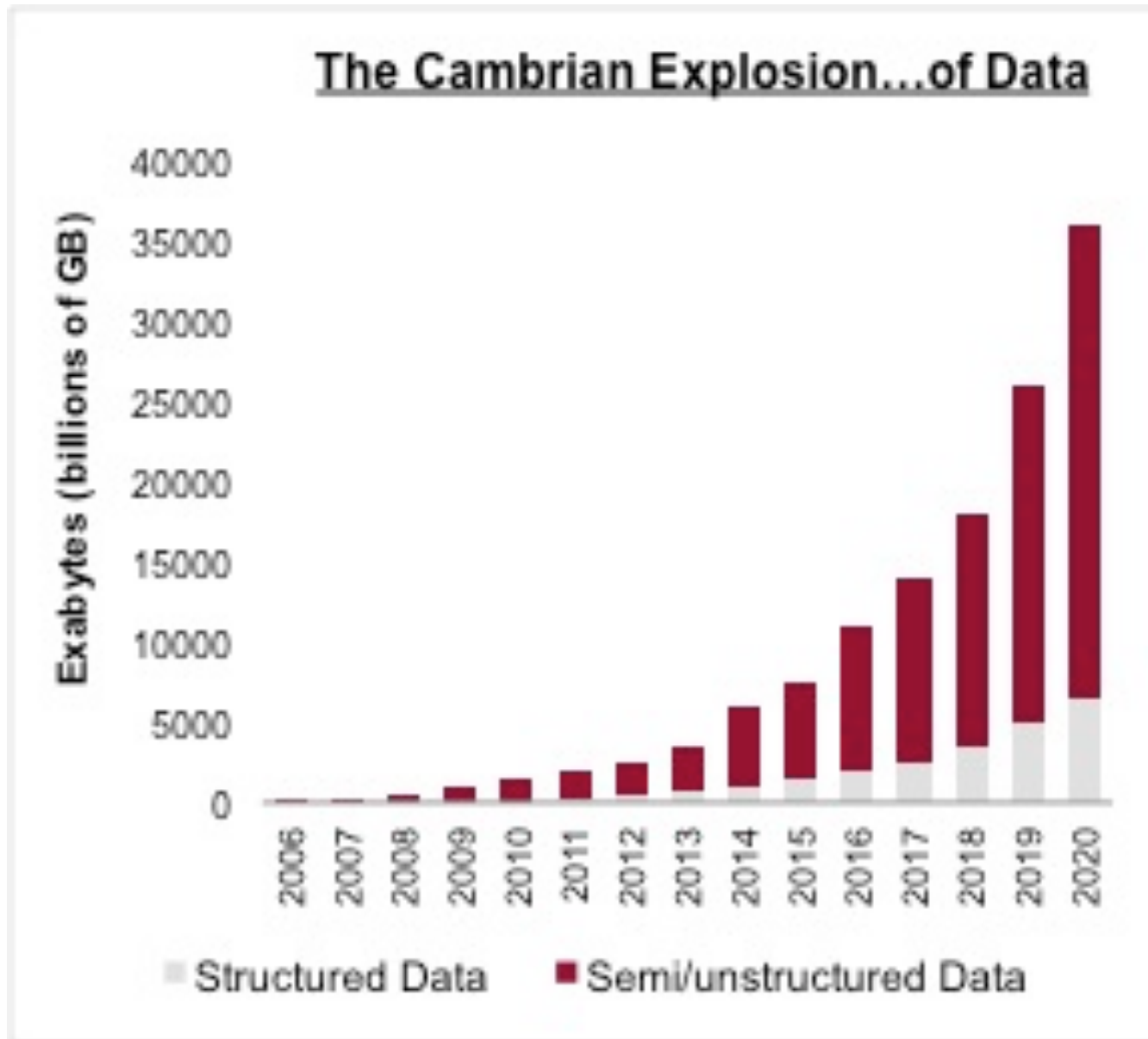
Kahneman



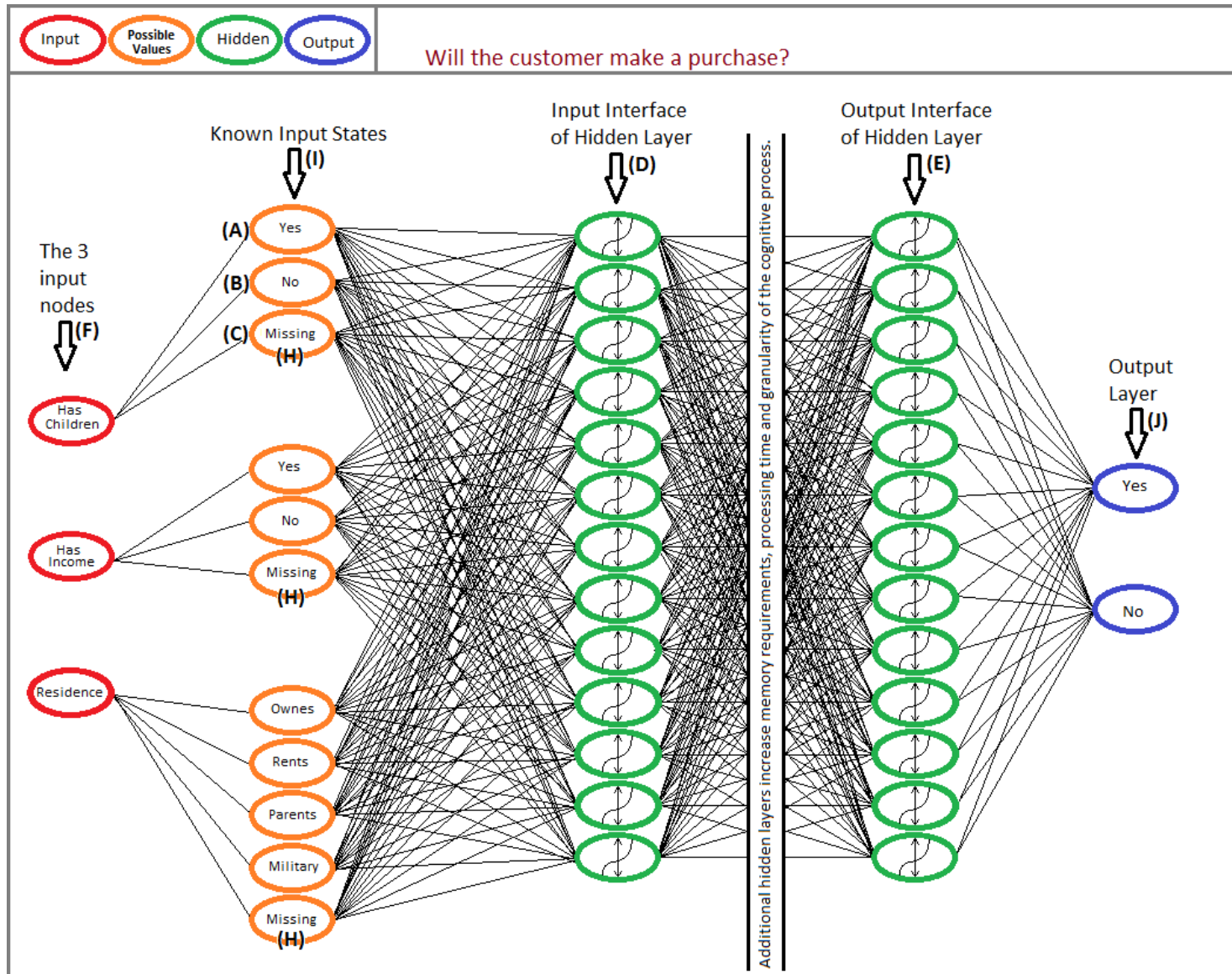
1: reflex. 2: reasoning

2. The Importance of Data for AI

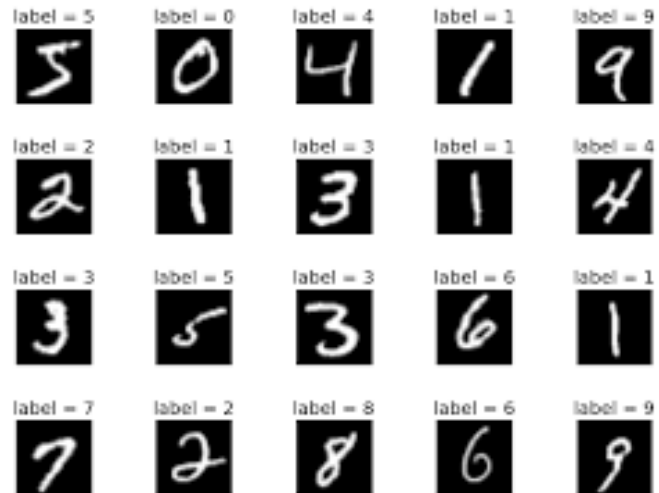
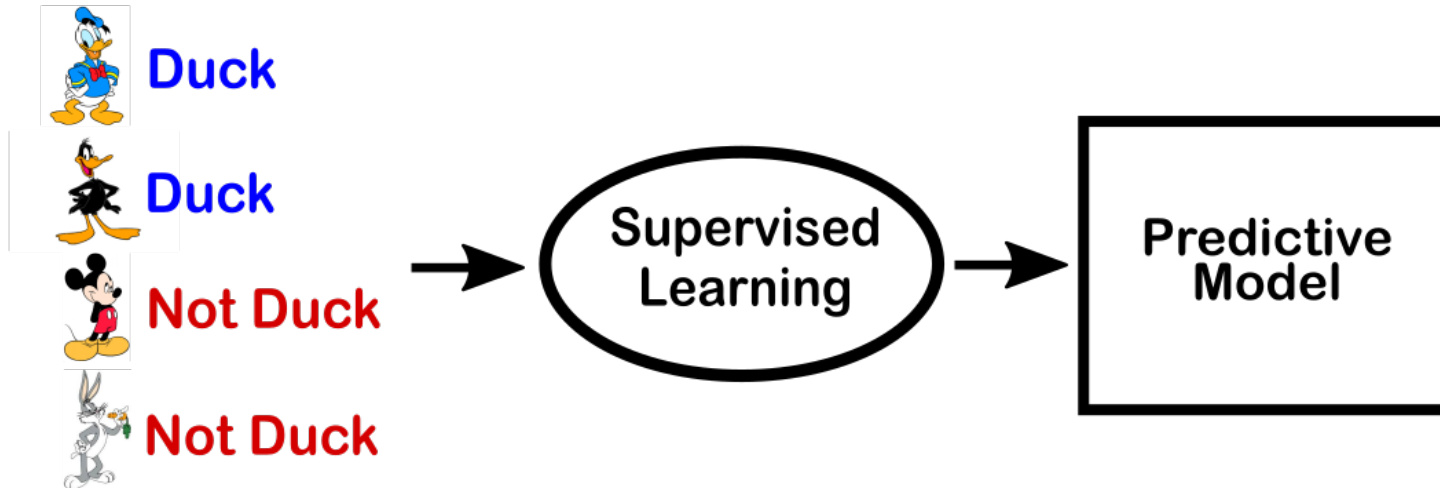
Data



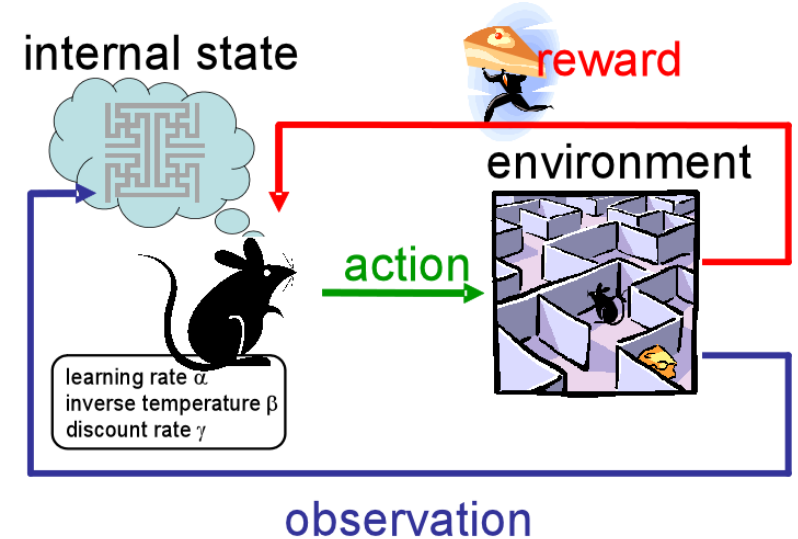
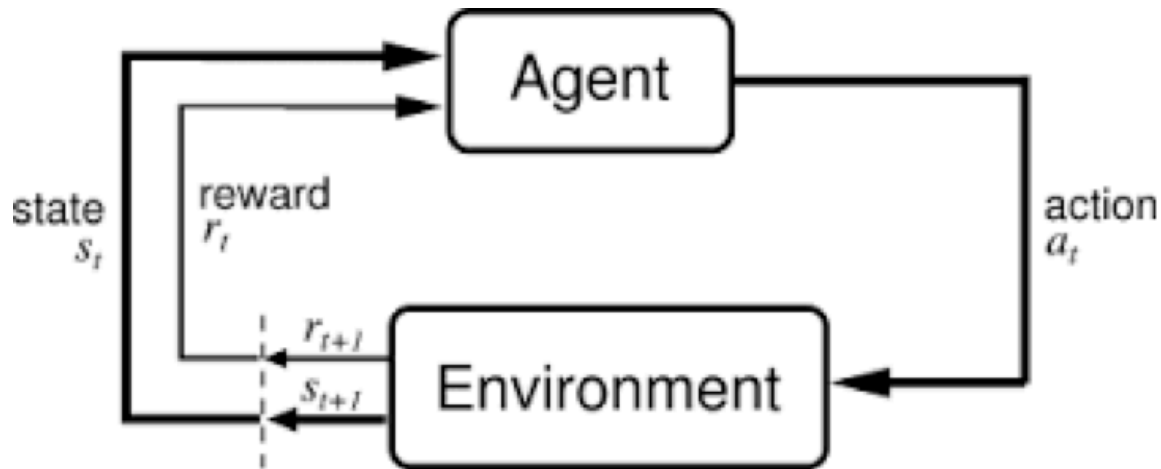
Function Approximator Generic Mapper



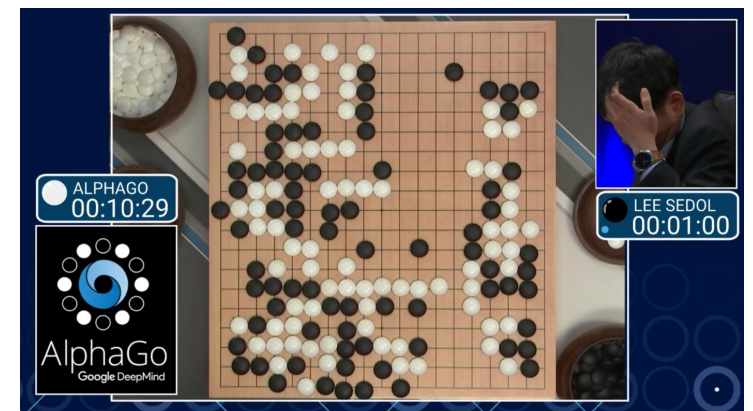
Supervised Learning



Reinforcement Learning

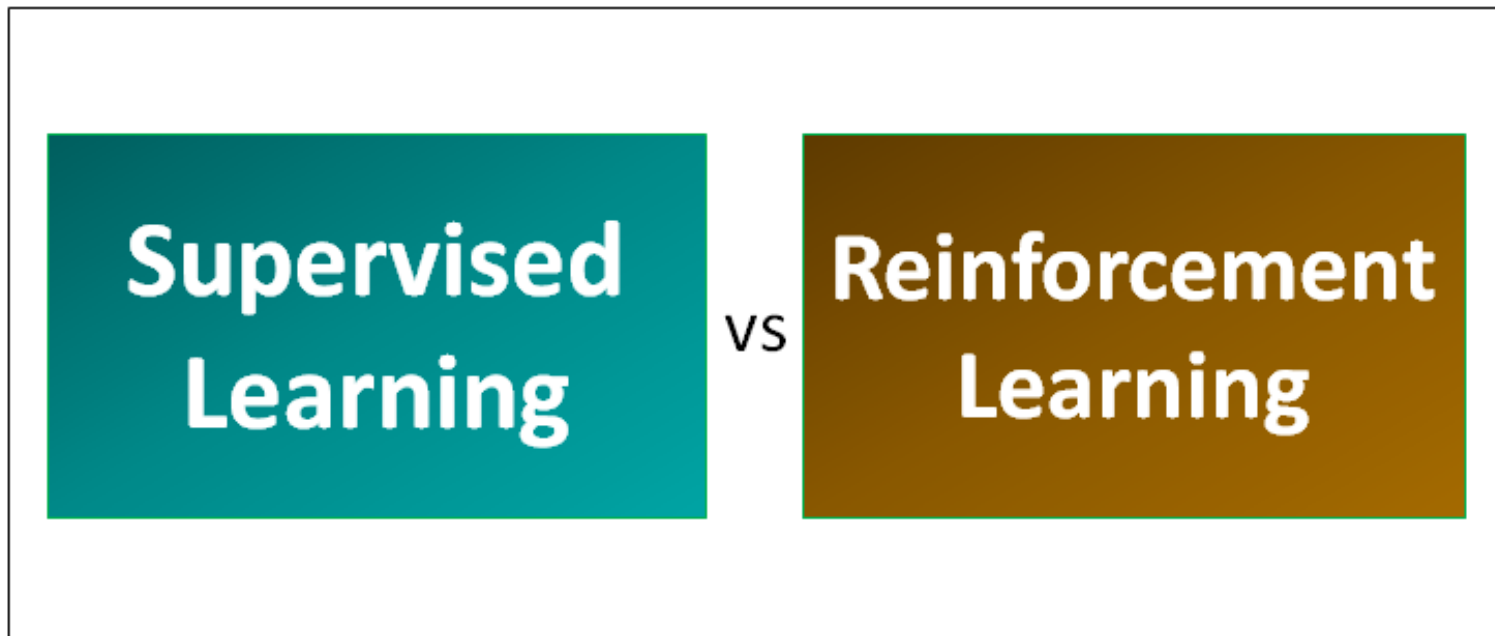


- Internal states have no reward, only actions leading to other states
Rewards must be derived
- symbolic
chess: alphabeta search + eval of hand coded features
- connectionist
backgammon: NN of hand coded features
atari: Deep Q-learning features DQN
- symbolic + connectionist
go: MCTS search generating training examples for DQN

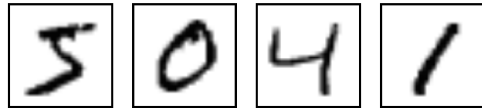


Supervised / Reinforcement

- Supervised Learning: EXPLICIT big data
- Reinforcement Learning: IMPLICIT big data



Data

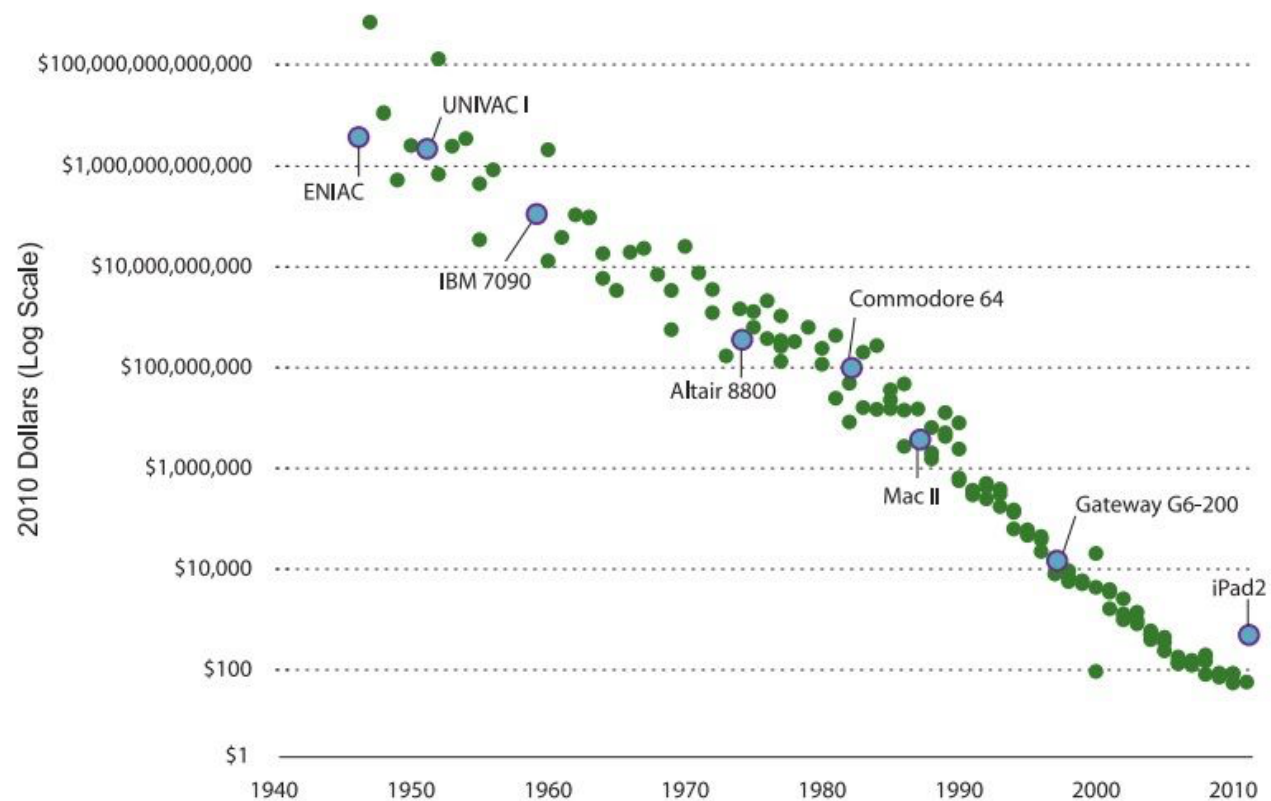


- **Supervised learning** uses big labelled data sets
- Consumer
- **Connectionist generalizes** data into theory
- Image, Speech recognition
- Preference “recognition”
- **Reinforcement learning** uses simulators to generate examples
- Producer
- **Symbolic** generates data from theory
- **Planning** in Games, Markov
- Agent Simulators

3. The Importance of Speed for AI

3. Speed

Cost of Computing Power Equal to an iPad 2

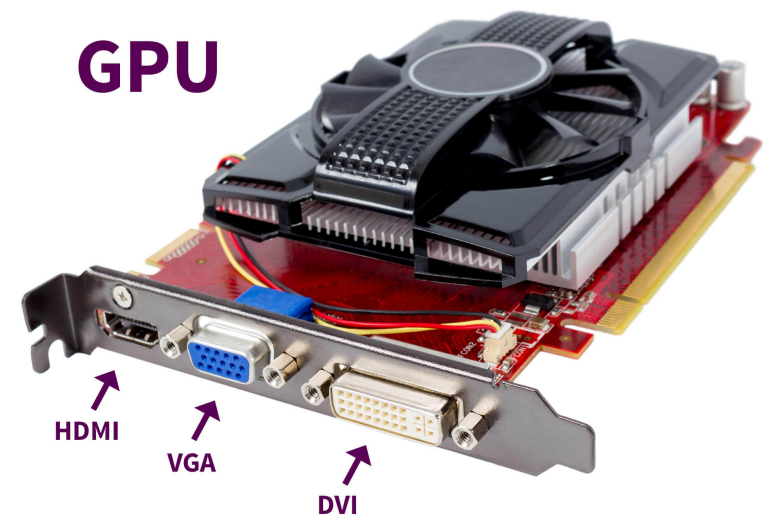


Note: The iPad2 has computing power equal to 1600 million instructions per second (MIPS). Each data point represents the cost of 1600 MIPS of computing power based on the power and price of a specific computing device released that year.

Source: Moravec n.d..

Speed

- Matrix operations : GPU (highly parallel matrix ops)
- Software packages: Theano, Torch, Tensorflow, Python
- Open source



Interlude: Benchmarks

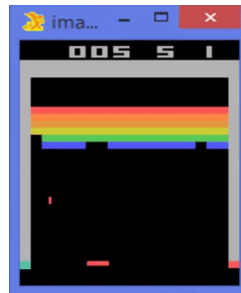
deep supervised learning



continuous domain



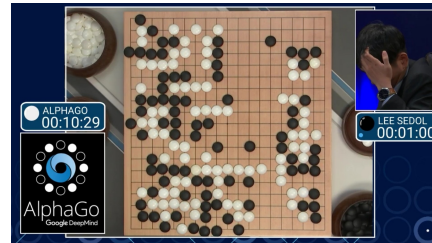
deep reinforcement learning



imperfect information/multi agent



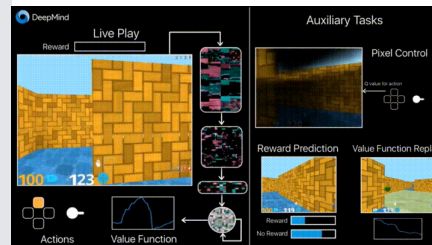
MCTS+DQN



imperfect information



deep Q-learning



imperfect information/cooperation

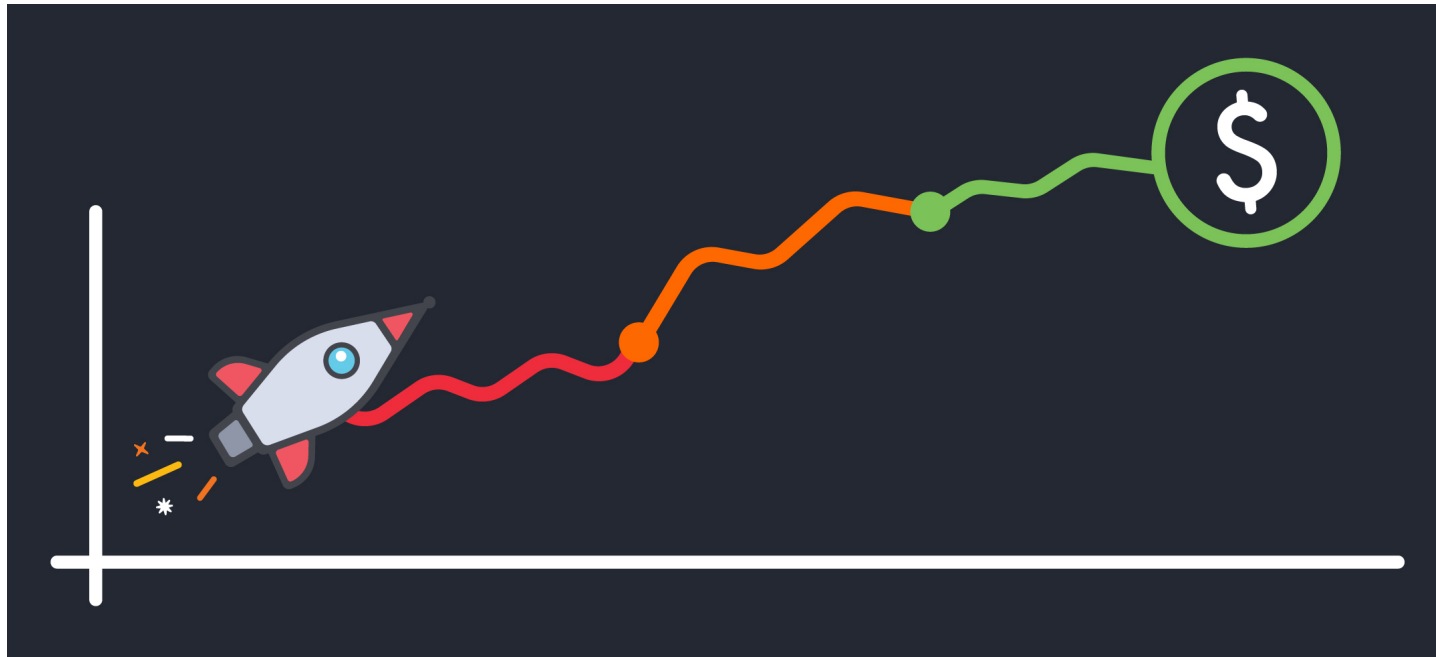


Summary

1. Algorithms: Symbolic & Connectionist
2. Data: Supervised explicit & Reinforcement implicit
3. Speed: Matrix operations on GPUs & Open Source

Need for Speed

- If intelligence is learning to solve large combinatorial problems
- Then Machine Learning converts compute power into intelligence



Future AI?

- Present AI
 - Approximated some complex problems better than humans.
Image & Speech Recognition, Recommendation, Game playing
- Future AI
 - Autonomous systems: cars, Search and rescue, Space exploration
 - Medical diagnosis, Algorithmic trading
 - Profiling: security, insurance
 - Efficient logistics, humanitarian aid
 - Efficient, sustainable production



Challenges in ML

- Domains with:
 - Sparse inputs
 - Imperfect information
 - Delayed credit assignment
 - Large branching factors
- Learning:
 - Transfer learning/
model lifting
 - Imitation
 - Life long learning
 - Hierarchical
 - Metalearning
 - Robust/1 pixel problem

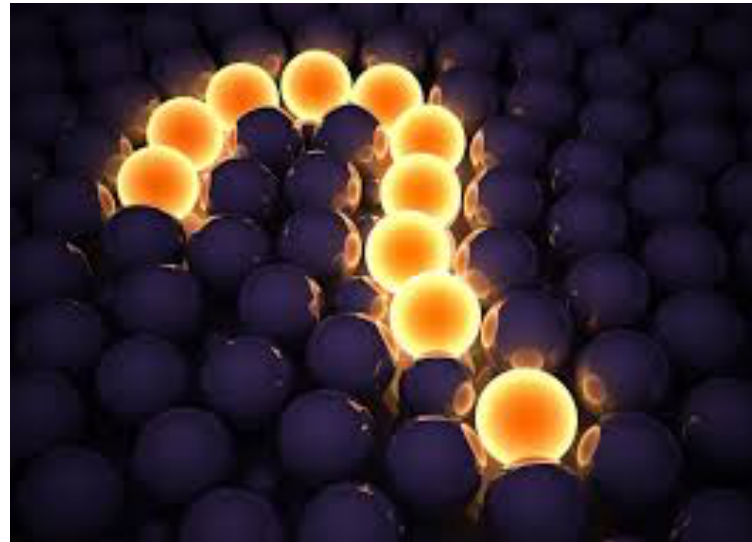
Challenges in ML

- Domains with:
 - Sparse inputs
- Learning:
 - Transfer learning/
model lifting

**If we have all the compute power in the world,
Will these challenges be solved?**

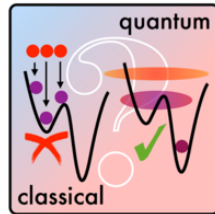
- Delayed credit assignment
- Large branching factors
- Efficiency
- Hierarchical
- Metalearning
- Robust/1 pixel problem

What is QML?

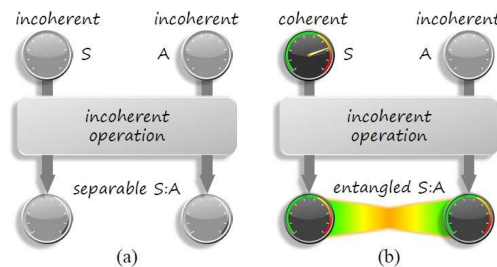


1. Algorithms

- Annealing
- Superposition
- Entanglement
- Coherence
- Stochasticity

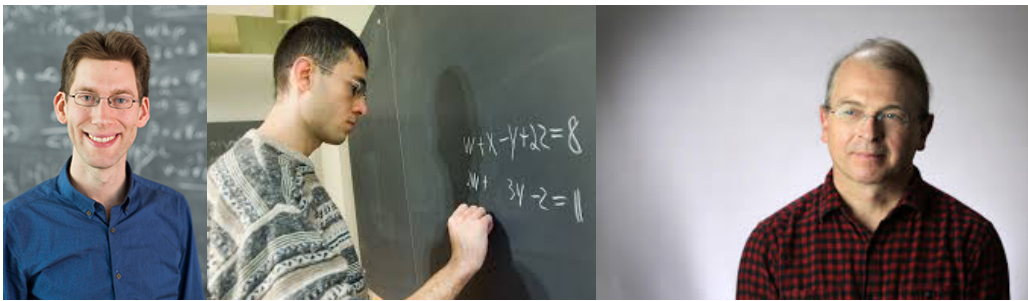


$$\frac{1}{\sqrt{2}}|\text{cat}\rangle + \frac{1}{\sqrt{2}}|\text{cat}\rangle$$



3. Speed

- Exponential search spaces of large problems appear a good match to quantum's inherent parallelism (superposition)
- Intelligence through fast learning
- HHL or Dwave as qGPU

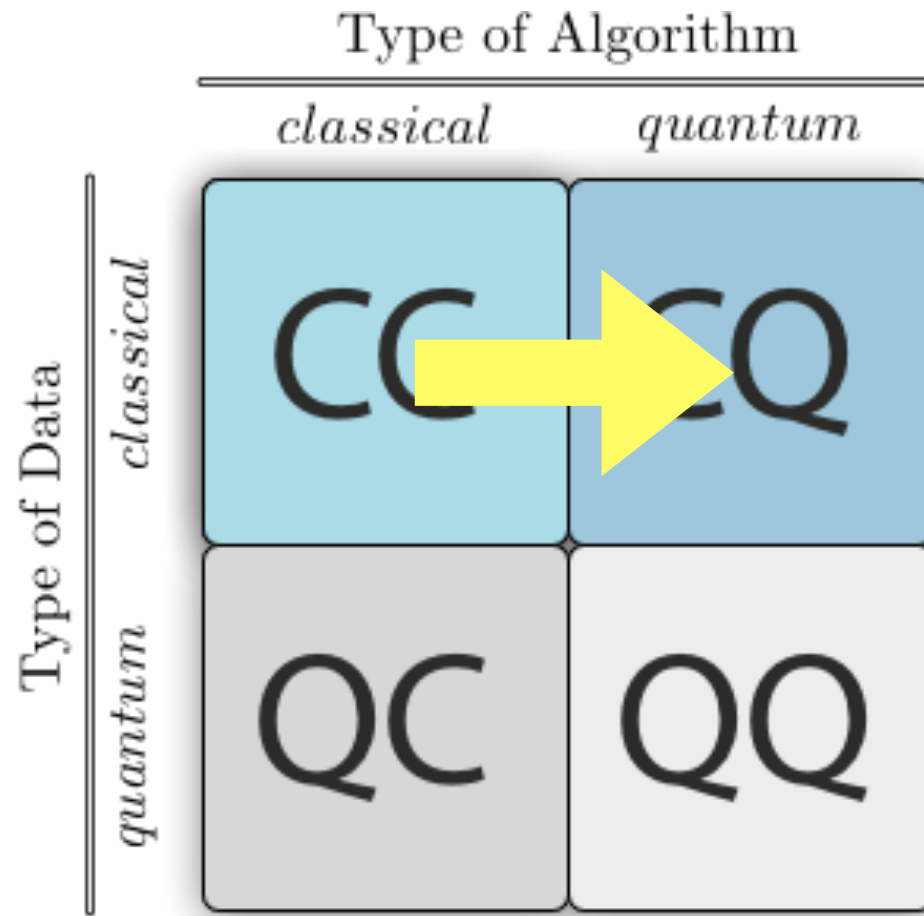


2. QML & classical data

- Quantum Recommender System for your books ar ads
- Quantum Image Recognition in your car
- Quantum Go
- Faster, better qML on classical data



Quadrant



Quantum ML Algorithms

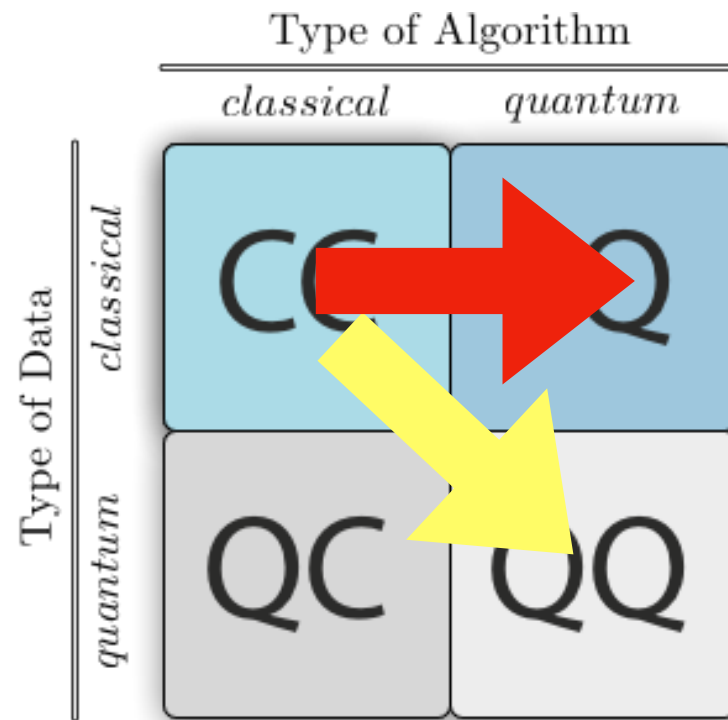
- qSearch [Grover 1996]
- qPrincipal Component Analysis [Lloyd, Mohseni, Rebentrost 2013]
- qSupport Vector Machine [Rebentrost, Mohseni, Lloyd, 2013]
- qBayesian Network [Tucci 2012, Moreira, Wichert 2018]
- qHidden Markov Model [Clark, Huang, Barlow, Beige 2014, Cholewa, Gawron, Glomb, Kurzyk 2015, Srinivasan, Gordon, Boots 2017]
- qMatrix Operations, qBLAS [Harrow, Hassidim, Lloyd 2009, Le Gall 2012, Zhang, Zhang, Xue 2018, Shao 2018]
- qNeural Network [Schuld, Sinayskiy, Petruccione 2014, Neukart 2013, Ricks, Ventura 2004, Dorozhinsky, Pavlovsky 2018, Farhi, Neven 2018]
- qAnnealing [Behrman, Steck, Moustafa 2016, Li, Felice, Rohs, Lidar 2018]

Reviews (selection)

- [Schuld, Sinayskiy, Petruccione 2014]
- [Adcock, Allen, Day, Frick et al 2015]
- [Dunjko, Briegel 2018]
- [Arunachalam, De Wolf 2017]
- [Biamonte, Wittek, Pancotti, Rebentrost, Wiebe, Lloyd 2017]

2. The Data Problem

- Decoherence
- Supervised learning: get data in
- Transfer learning: get weights out



Observation

- Classical ML -> classical algorithms to achieve generalization
- QML: we are mimicing low level classical algorithms (NN, BLAS)
Go for 3. Speed
- Runs into problems, such as decoherence, errors
- We could focus on high level goals: generalization
use quantum effects as opportunity
Go for 1. Algorithms



qFuture for AI?

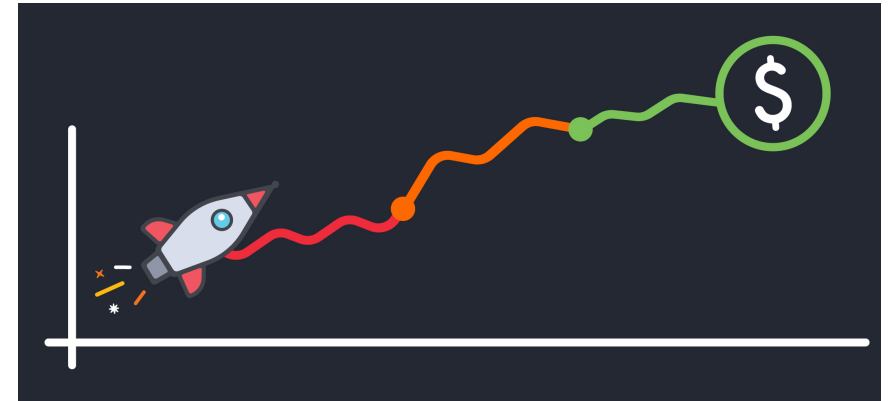
- Transfer learning - decoherence problem
- Life long learning - decoherence problem
- One shot learning - superposition
- Imperfect information - stochasticity
- Delayed credit assignment - entanglement
- Large problem spaces - superposition/annealing
- “quantum intelligence” - ???

$$\frac{1}{\sqrt{2}}|\text{cat}\rangle + \frac{1}{\sqrt{2}}|\text{dog}\rangle$$



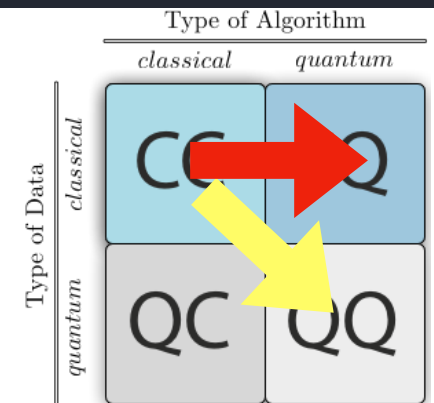
Options for a QML agenda

- speed up current AI
(such as quantum deep learning)



- speed up & work on future ML challenges
(such as quantum meta learning)

- work on higher level AI approaches
(such as entanglement and superposition for “new kinds of quantum intelligence: reasoning+generalization”)
symbolic -> connectionist -> quantum

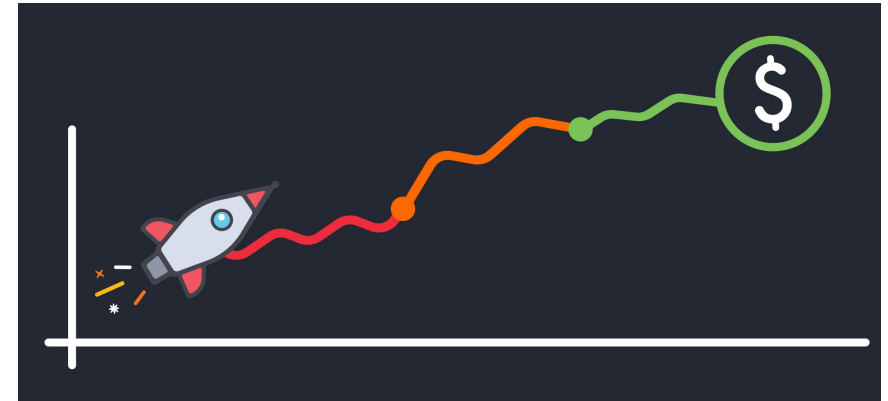


QML = fast NN?



QML agenda

- Go from 3. speeding up the past symbolic/connectionist learning



- To making new future quantum learning 1. Algorithms



Conclusion

- AI is hot. It has been cold
- Intelligence: Behaviorist approach. Intelligence is learning is generalization
- Breakthroughs in specific applications not in general approaches; Benchmarks work
- 1. Algorithms, 2. Data, 3. Speed
- Combination of two schools: symbolic and connectionist
- Copying classic AI in Q or new approaches to intelligence?
- QML: collaborate & understand quantum computing and AI communities



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Limitations

- New developments in learning (imperfect information, transfer learning)
- Behavioral kind of intelligence. No emotion, no self awareness, no consciousness, no creativity
- AI. The semblance of intelligence by approximating large combinatorial spaces using machine learning

qFuture for AI?

- “QML” has focused on quantum versions of existing classical symbolic and connectionist ML algorithms
AI as solving large combinatorial problems

- (Data remains a problem)

$$\frac{1}{\sqrt{2}}|\text{cat}\rangle + \frac{1}{\sqrt{2}}|\text{dog}\rangle$$

- QML could focus on list of Challenges in ML (sparse inputs, transfer learning, etc)
- Or QML could focus on its defining qualities (superposition, decoherence, entanglement) to “solve” learning/generalization

