# Richard Feynman, Data-Intensive Science and the Future of Computing

TONY HEY

# Feynman and Computation

# Parallel Computing without Computers

Feynman and Oppenheimer at Los Alamos, 1942

# Feynman's Computational Toolkit

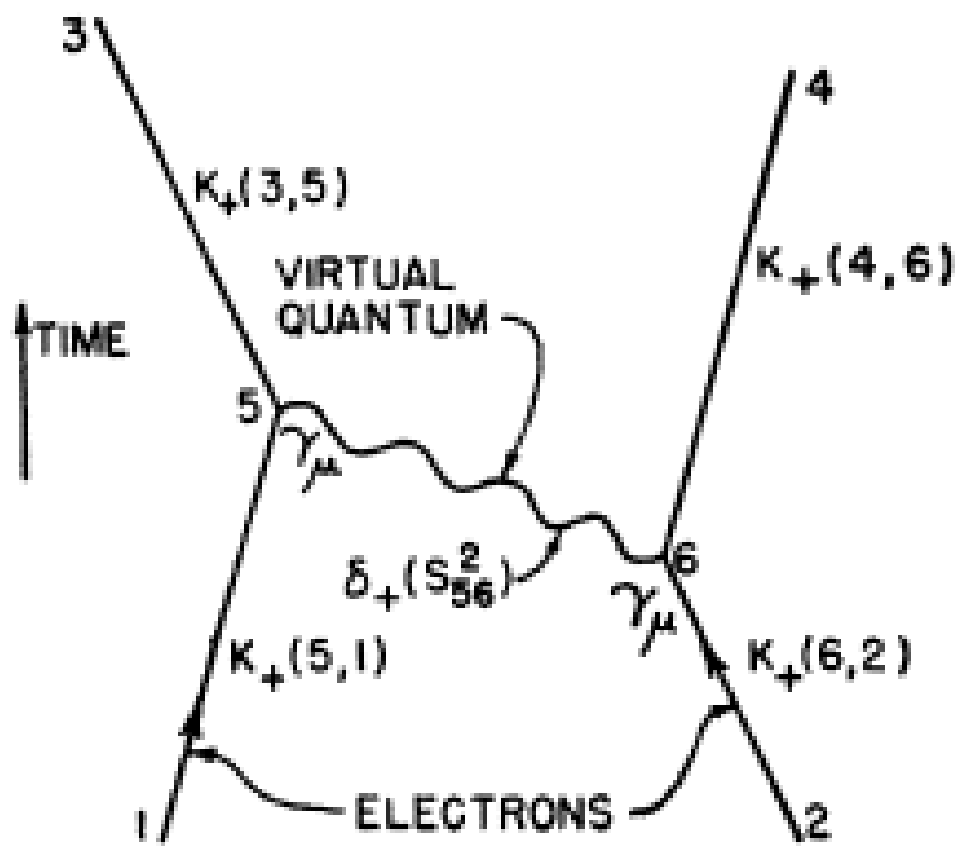



FIG. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.

First Published Feynman Diagram

**"Like the silicon chips of more recent years, the Feynman diagram was bringing computation to the masses"**

**Julian Schwinger**

# Caltech: Four Kings and the Joker

Carl Anderson, Murray Gell-Mann, Max Delbruck, Richard Feynman, George Beadle, 1969

# Physics of Computation Conference, MIT 1981

# Simulating Physics with Computers

- Can a universal classical computer simulate physics *exactly*?
- Can a classical computer *efficiently* simulate quantum mechanics?

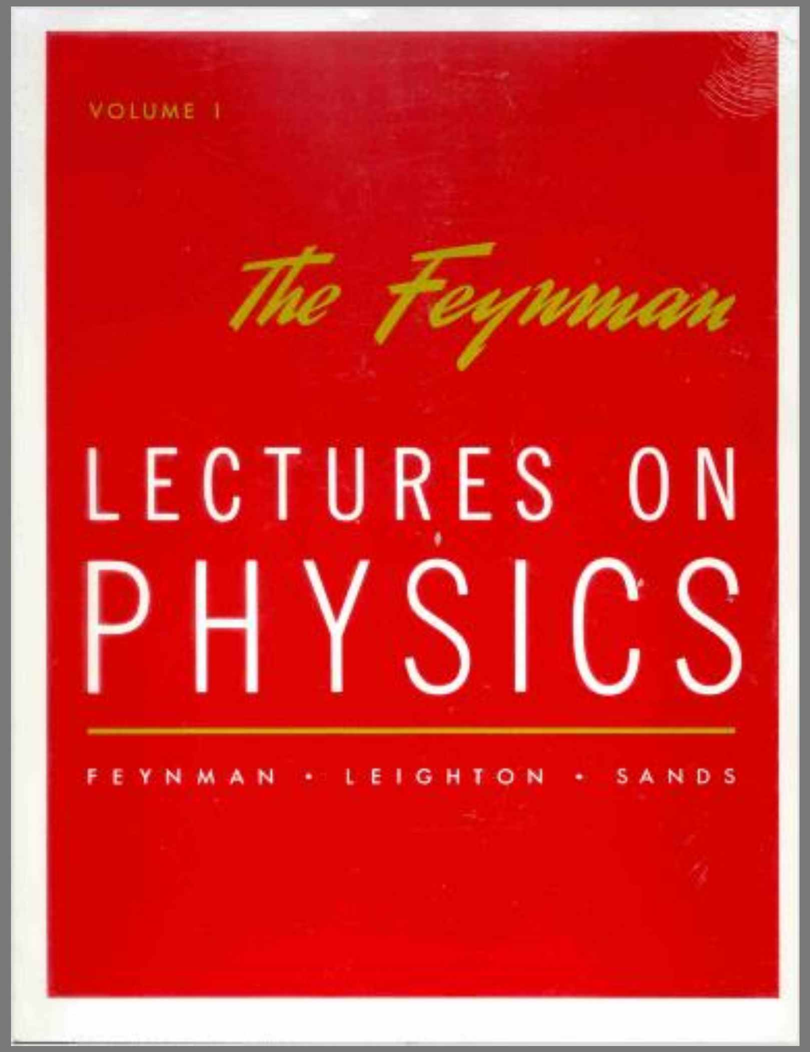
"I'm not happy with all the analyses that go with just classical theory, because Nature isn't classical, dammit, and if you want to make a simulation of Nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem!"

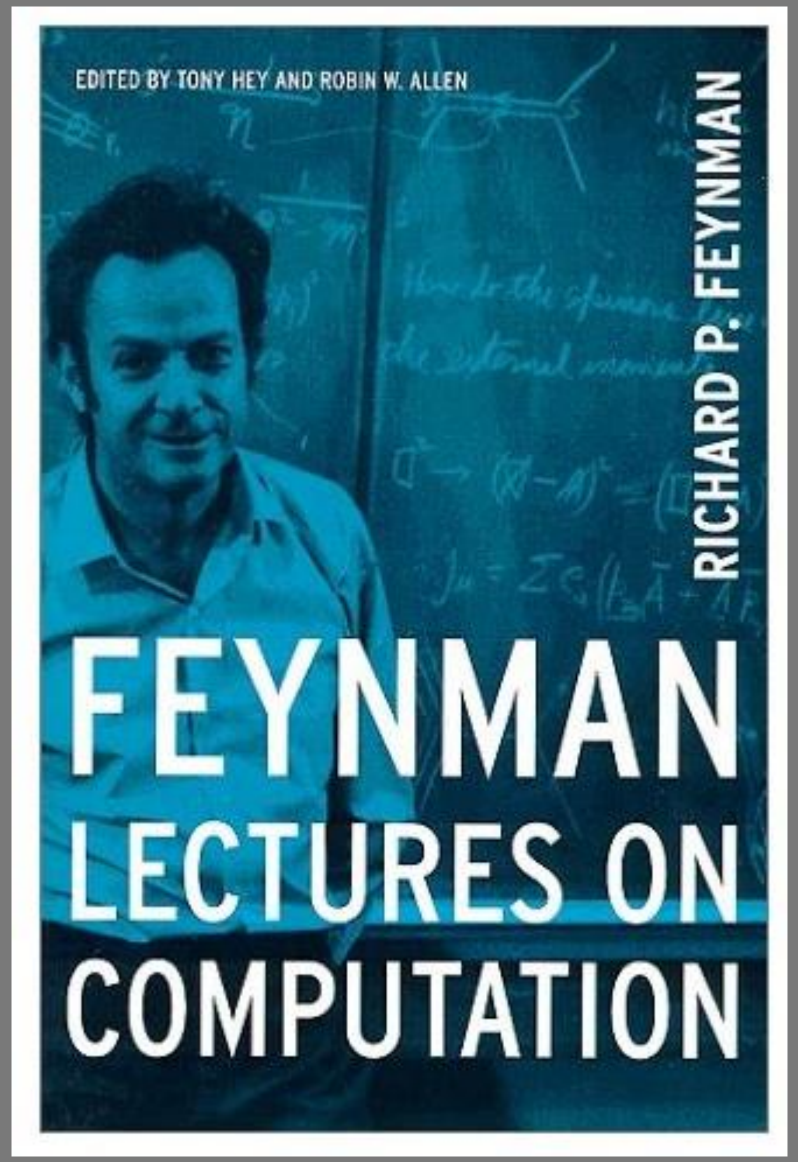
"How can we simulate the quantum mechanics?….Can you do it with a new kind of computer - a quantum computer? It is not a Turing machine, but a machine of a different kind."

R P Feynman 1981

# Fundamental Limits to Computation

- Feynman is famous for his Lectures on Physics but from 1981 to 1985 he lectured on computing
- Examined the fundamental limits to computation arising from:
  - Mathematics
  - Noise
  - Thermodynamics
  - Engineering in Silicon
  - Quantum Mechanics
- Complete set of reversible logic gates – CN, CNN, Fredkin, …

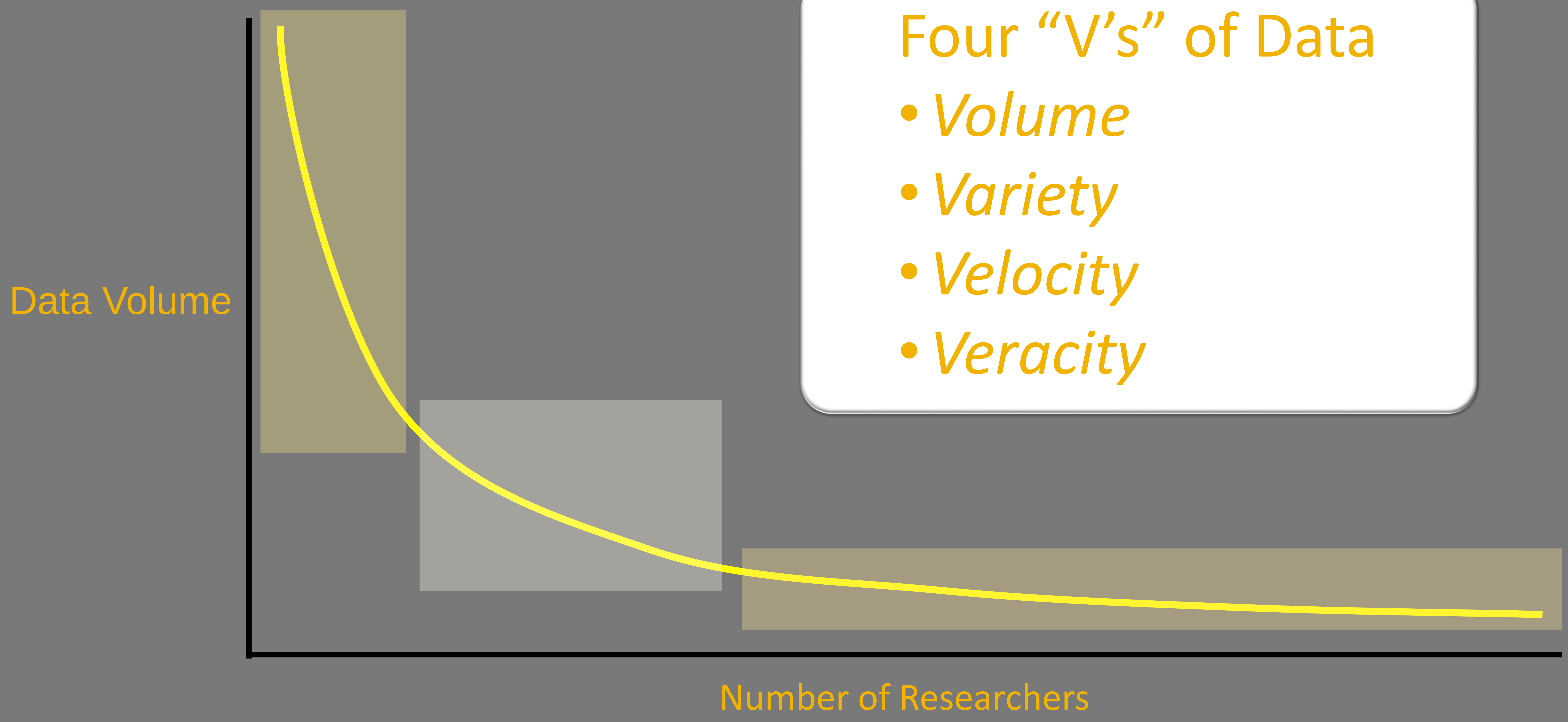


# Data-Intensive Science

Jim Gray, Turing Award Winner

# Much of Science is now Data-Intensive




Four “V’s” of Data

- *Volume*
- *Variety*
- *Velocity*
- *Veracity*

## ‘The Long Tail of Science’

# The Fourth Paradigm: Data-Intensive Science

Thousand years ago – **Experimental Science**

Description of natural phenomena

Last few hundred years – **Theoretical Science**

Newton's Laws, Maxwell's Equations…

Last few decades – **Computational Science**

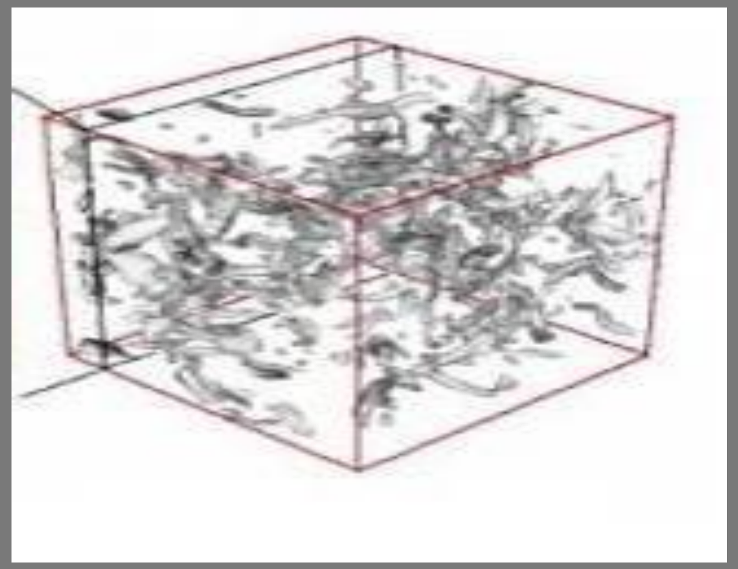
Simulation of complex phenomena

Today – **Data-Intensive Science**

Scientists overwhelmed with data sets from many different sources

- Data captured by instruments
- Data generated by simulations
- Data generated by sensor networks
- Data generated by satellites

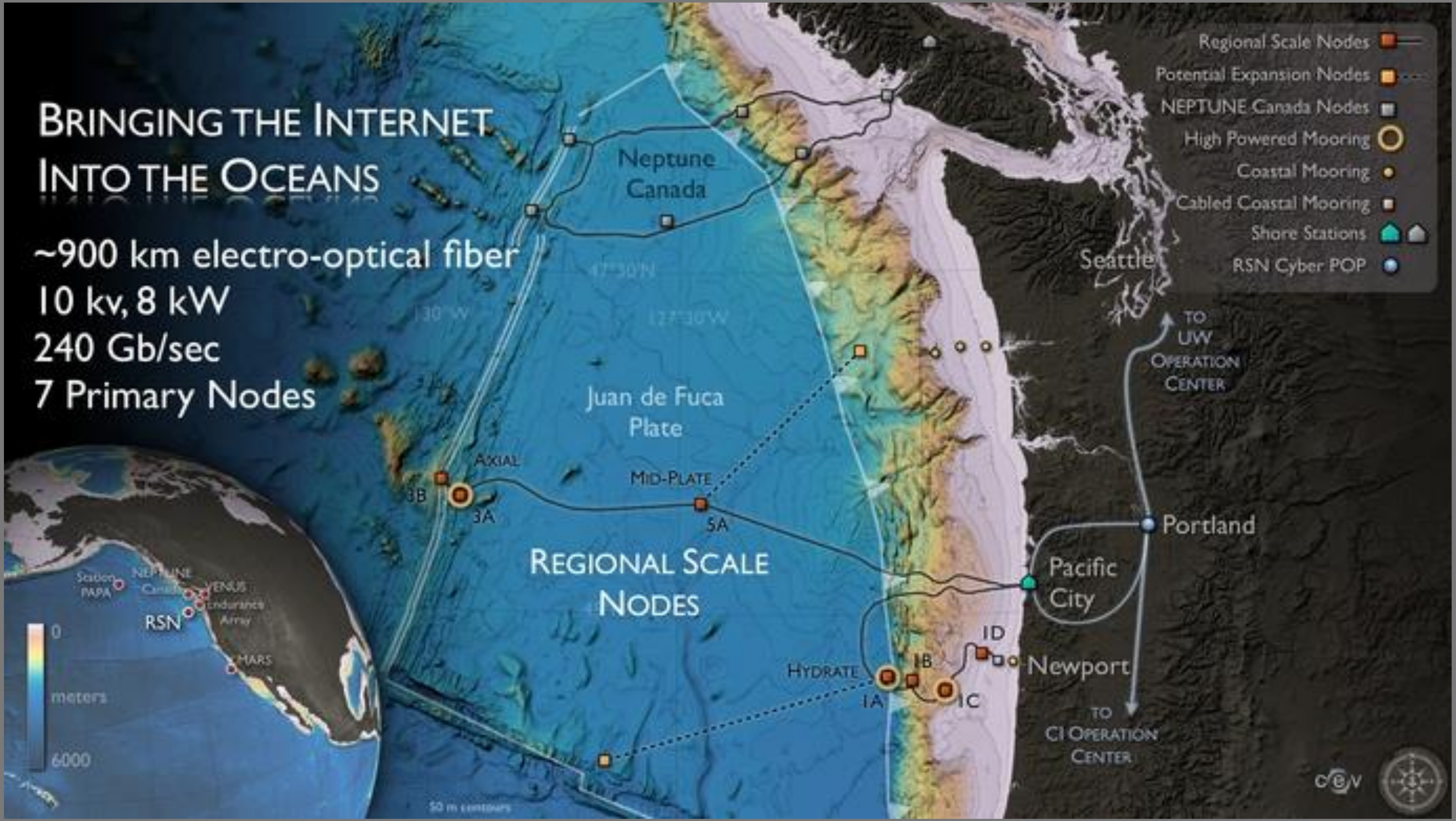
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - K\frac{c^2}{a^2}$$



eScience is the set of tools and technologies to support data federation and collaboration

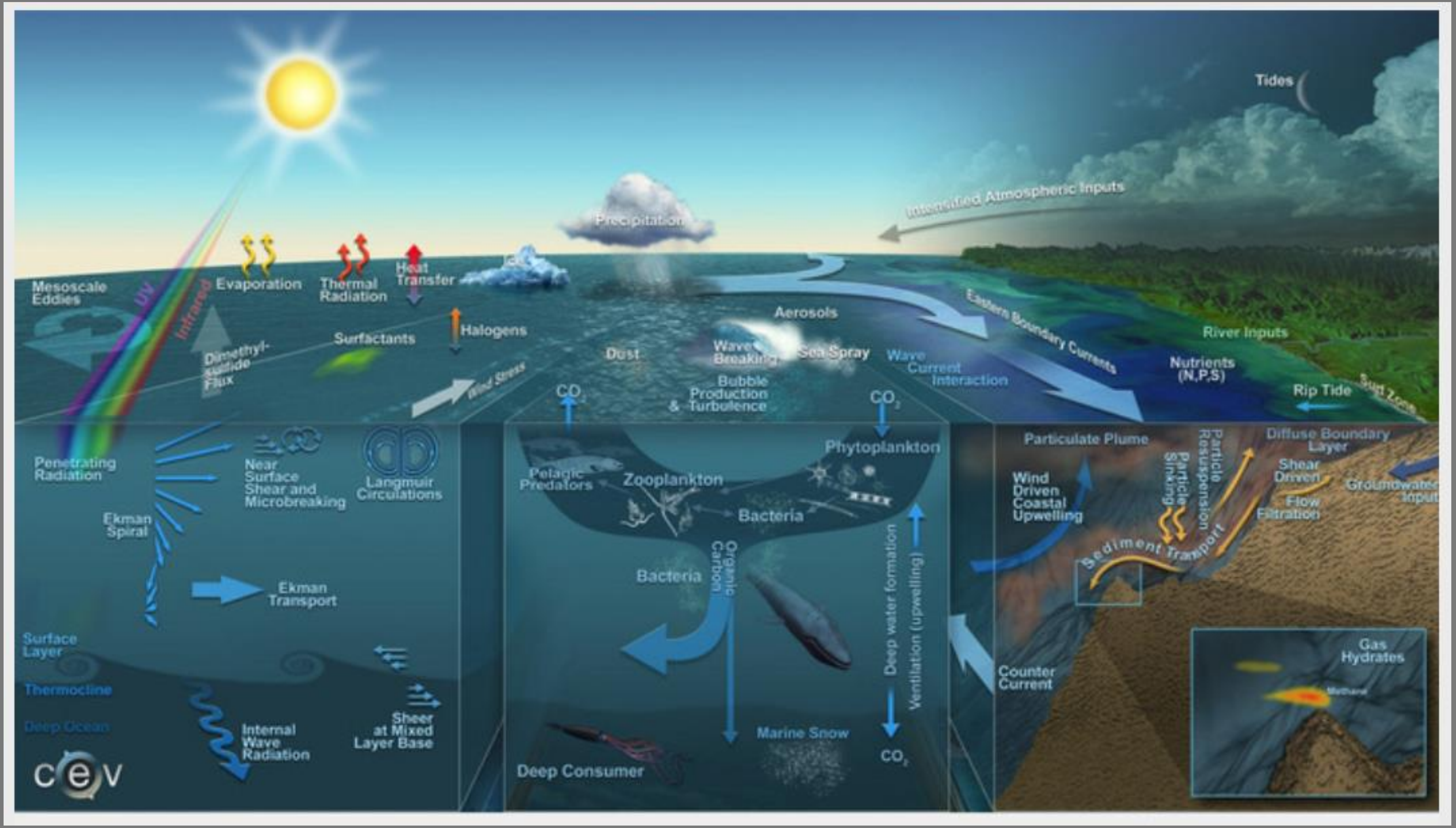
***With thanks to Jim Gray***

# NSF's Ocean Observatory Initiative

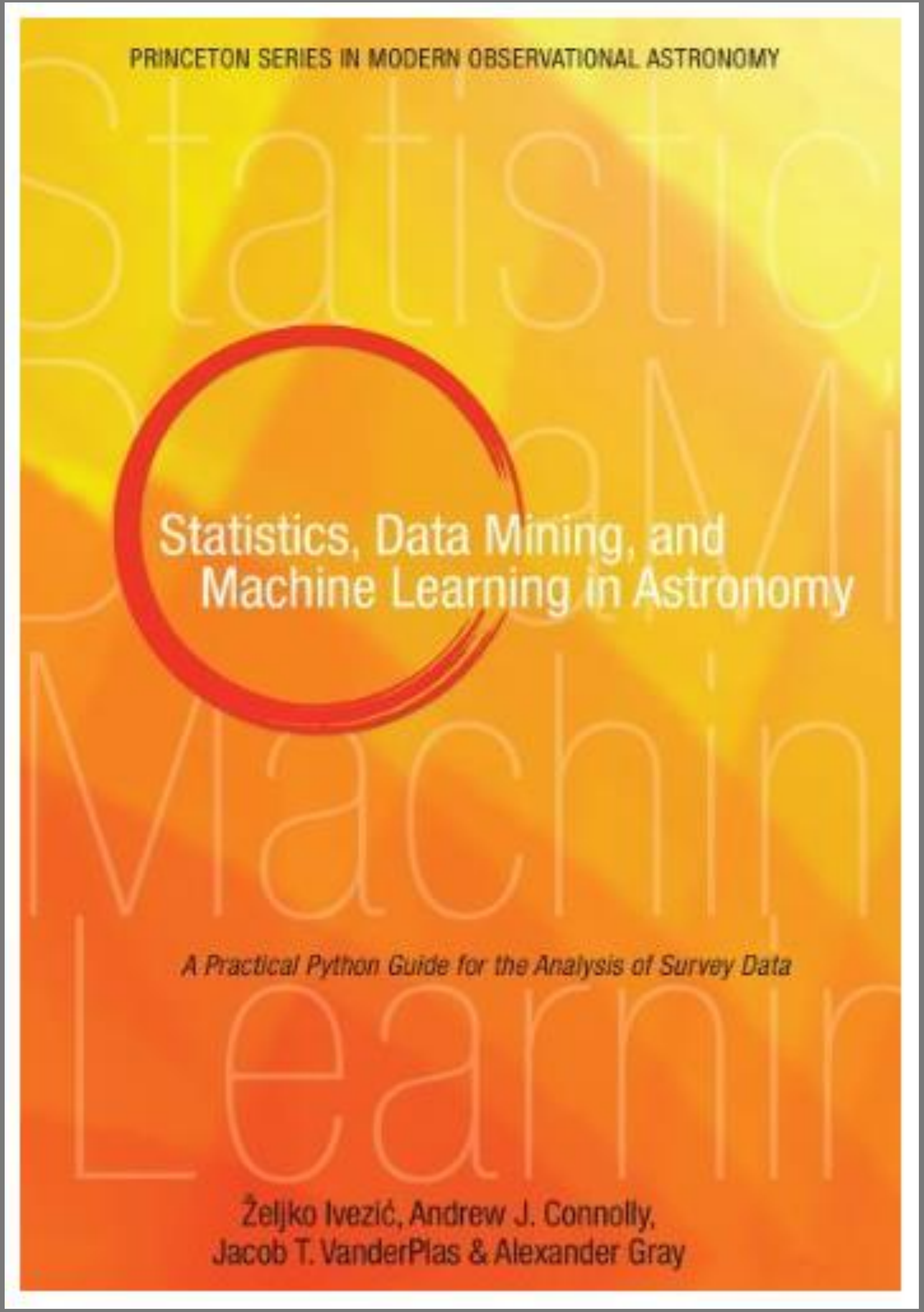



Slide courtesy of John Delaney

# Oceans and Life




Slide courtesy of John Delaney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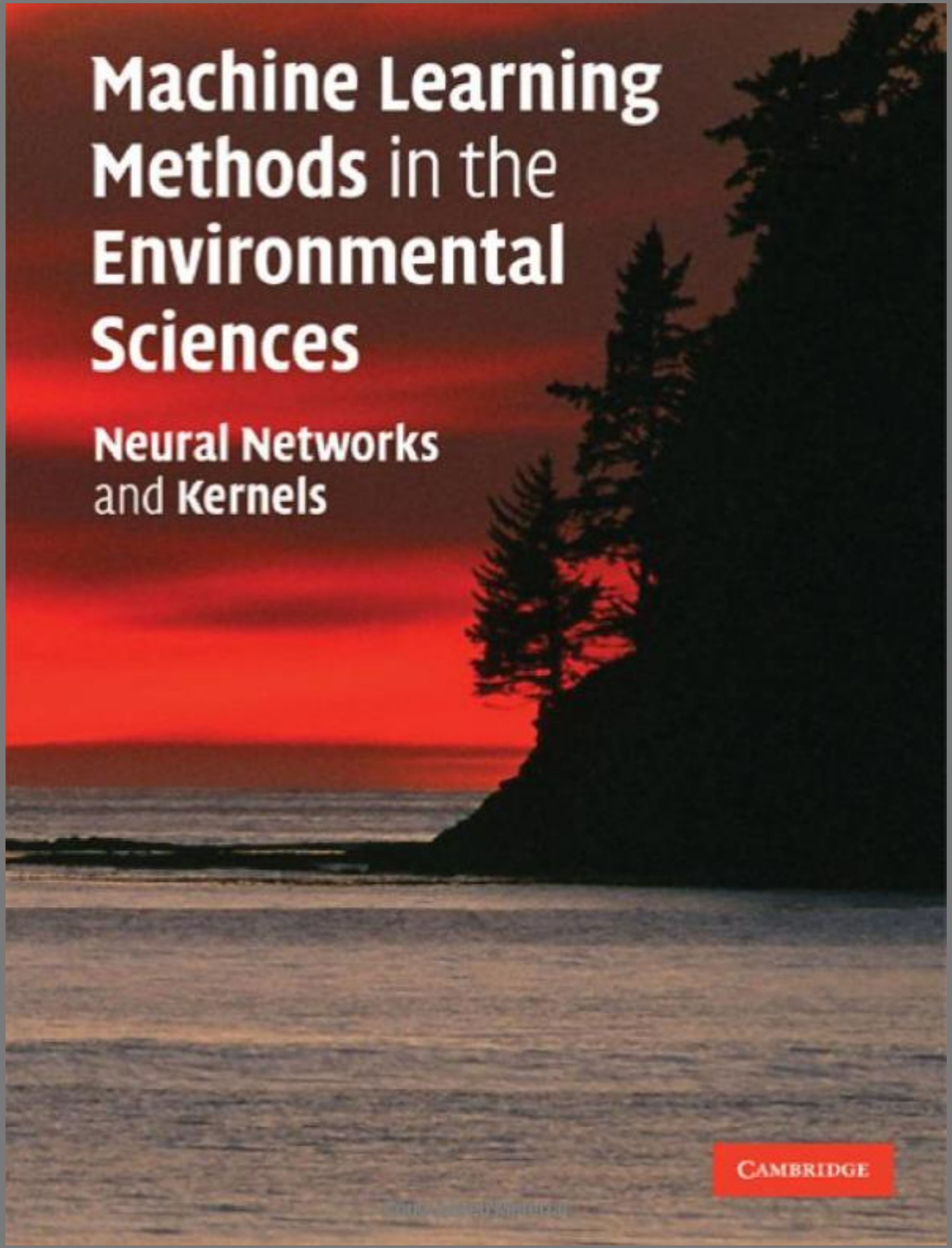

Machine Learning
Methods in the
Environmental
Sciences
Neural Networks
and Kernels
CAMBRIDGE

# Machine Learning wins the Higgs Challenge

- Winner Gábor Melis, a graduate in software engineering and mathematics, developed an algorithm that is an ensemble of deep neural networks trained on random subsets of data provided with very little feature engineering and no physics knowledge

- Runner-up Tim Salimans, who has a PhD in Econometrics and works as a data science consultant, developed a solution he describes as a combination of a large number of boosted decision tree ensembles

- A Special High Energy Physics meets Machine Learning Award was presented to Tianqi Chen and Tong He of Team Crowwork. Their XG Boost algorithm was an excellent compromise between performance and simplicity, which could improve tools currently used in high-energy physics.


Winners of the Higgs Machine Learning Challenge: Gábor Melis and Tim Salimans (top row), Tianqi Chen and Tong He (bottom row).

# The Third Age Of Computing

## ‘Computers For Embodiment’

‘Every 30 years there is a new wave of things that computers do. Around 1950 they began to model events in the world (*simulation*), and around 1980 to connect people (*communication*). Since 2010 they have begun to engage with the physical world in a non-trivial way (*embodiment*)’

Butler Lampson

# 1973: The Miracle of Xerox PARC

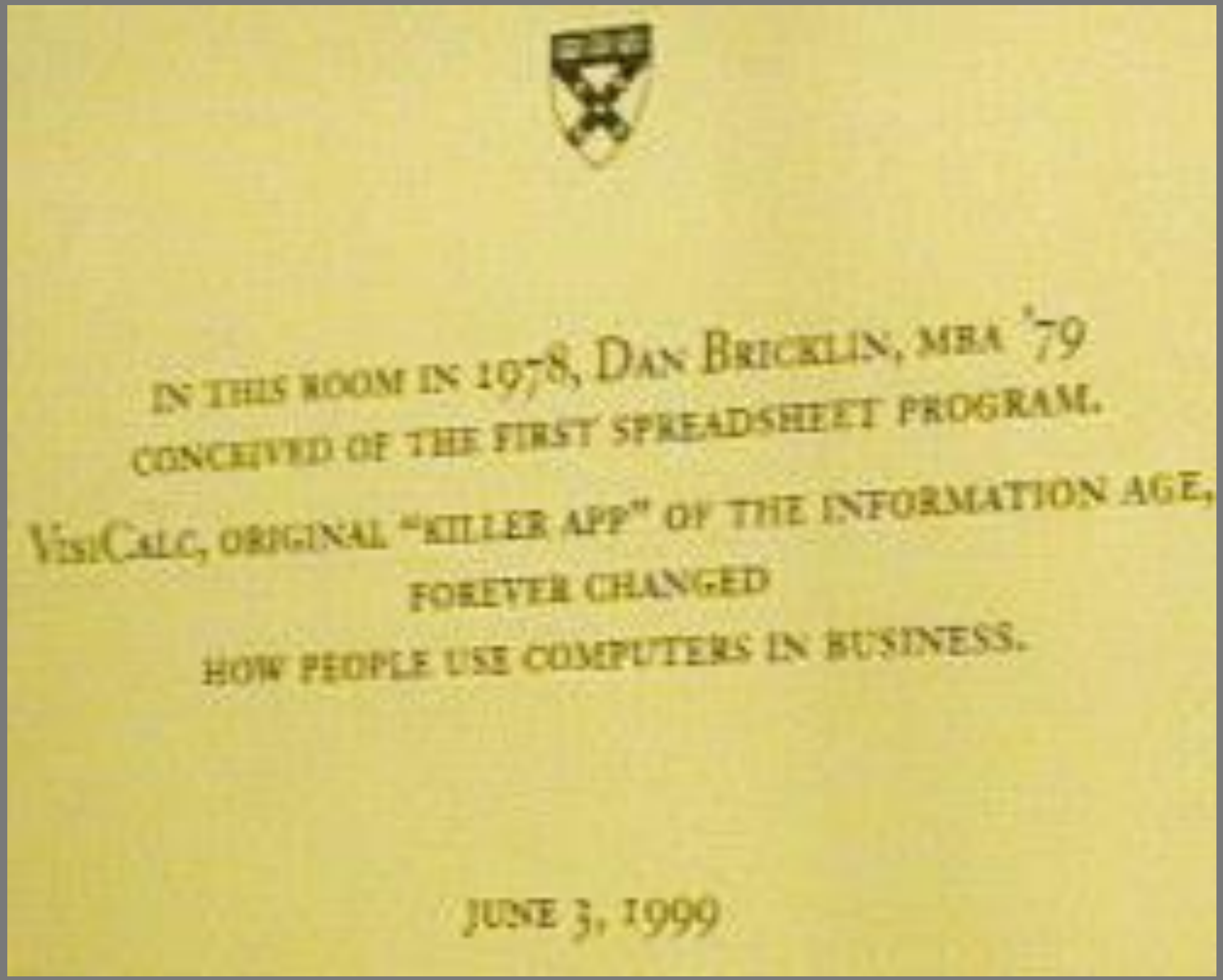
The Alto

- WYSIWYG Word Processor
- Ethernet
- WIMP interface
- Laser printer

Chuck Thacker and Butler Lampson

# 1976: The 'Killer App' for the PC

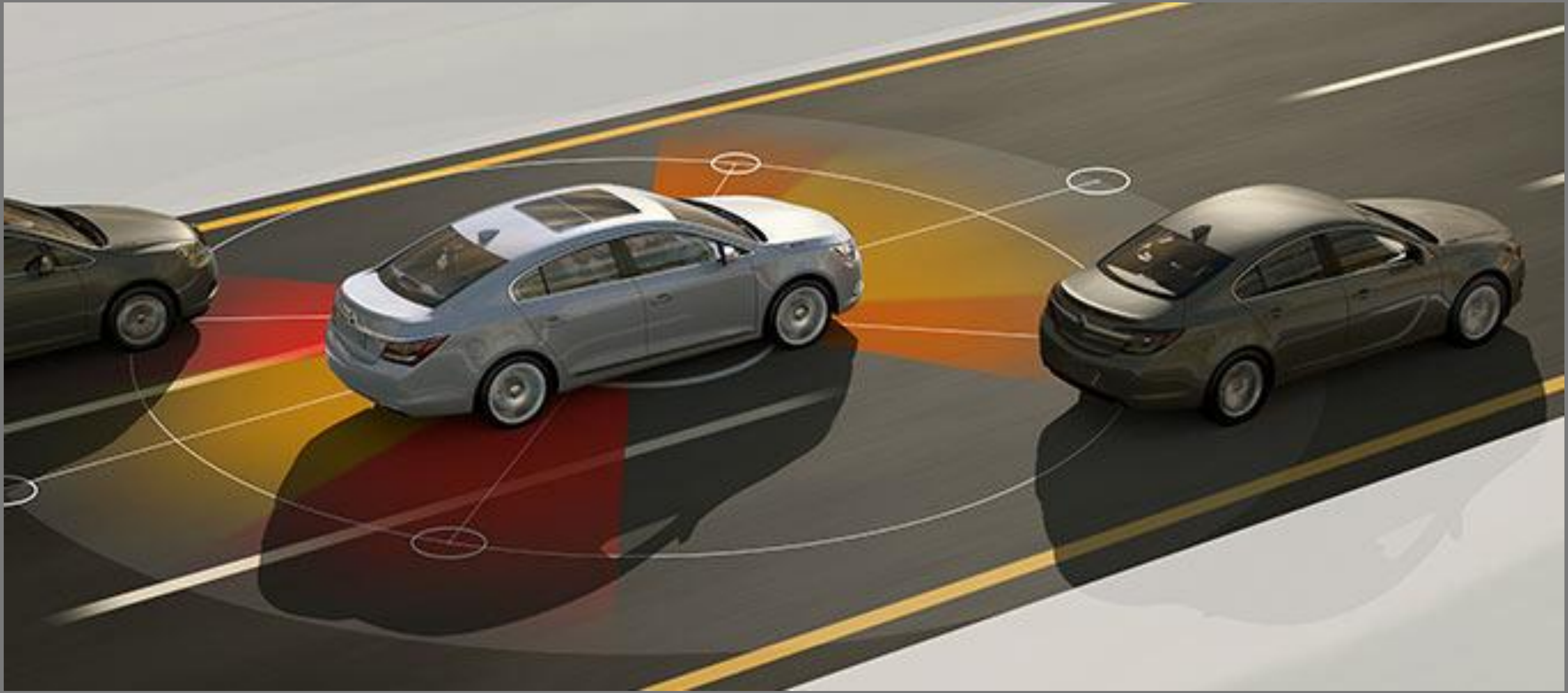
Commemorative plaque on the wall of Aldrich 108 in Harvard Business School



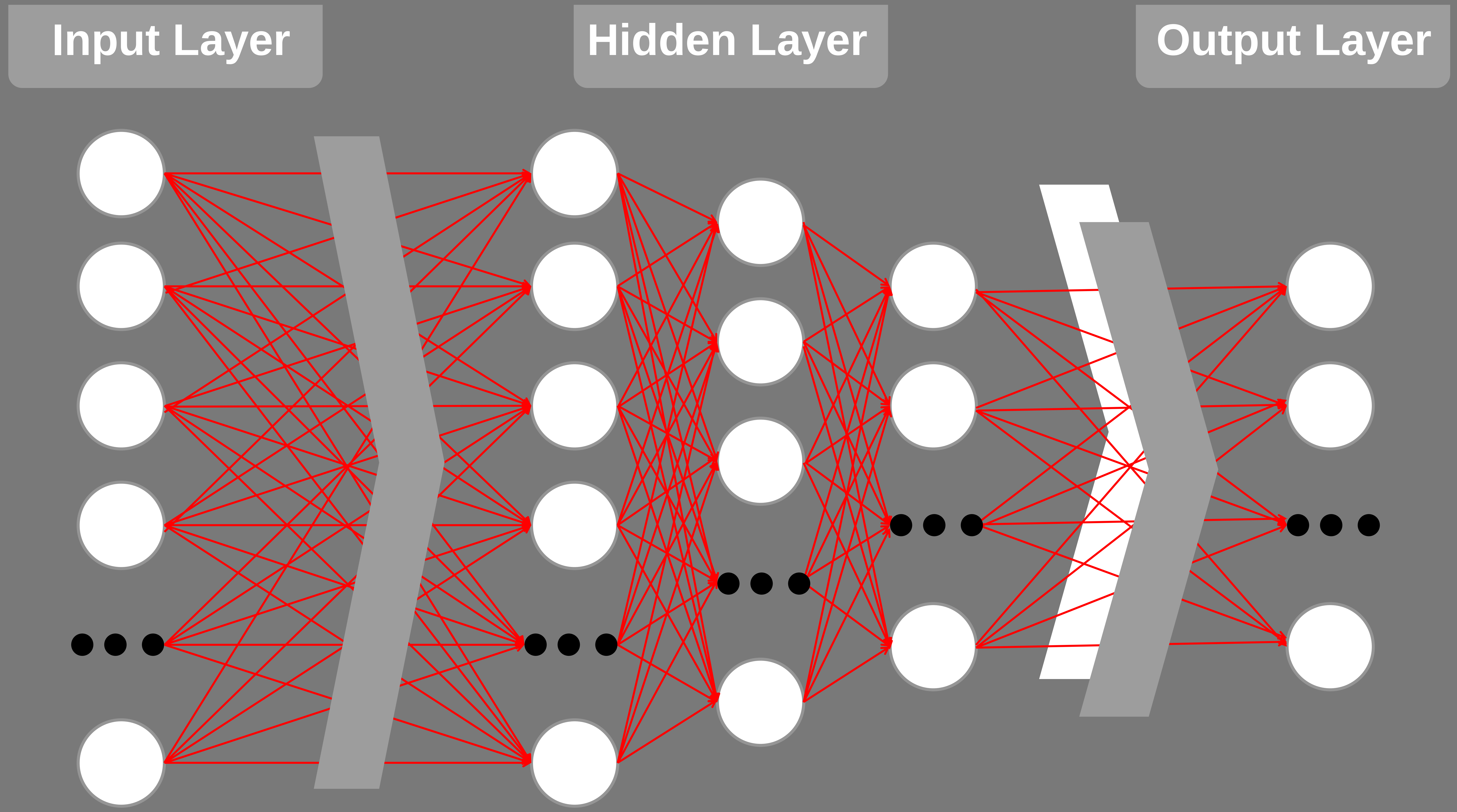

Dan Bricklin, inventor of the spreadsheet

# Social Computing

# Smart Cars



# Artificial Neural Networks and Machine Learning

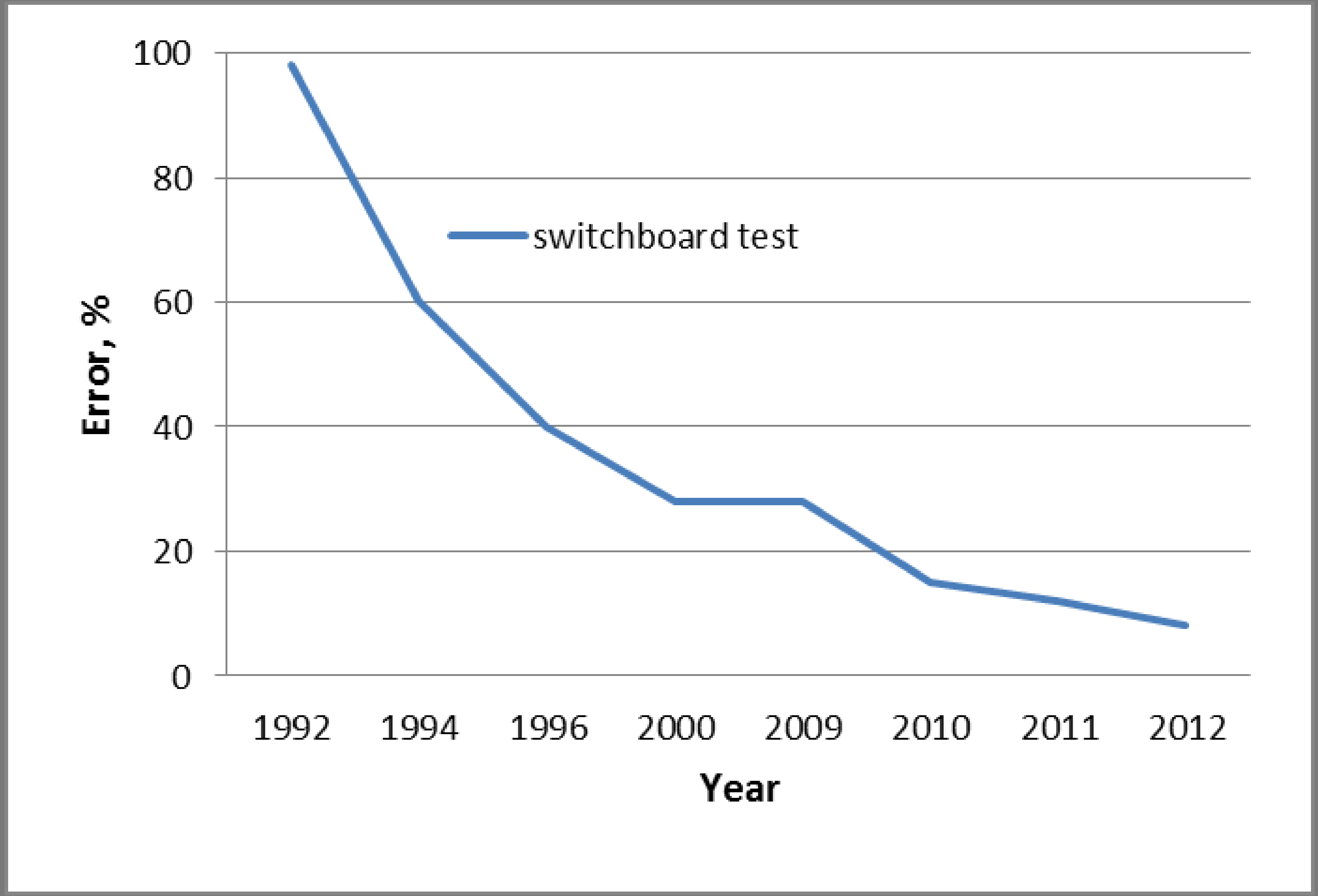


# Machine Learning

Deep Neural Networks are now exciting the whole of the IT industry since they enable us to:

- Building computing systems that improve with experience
- Solve extremely hard problems
- Extract more value from Big Data
- Approach human intelligence

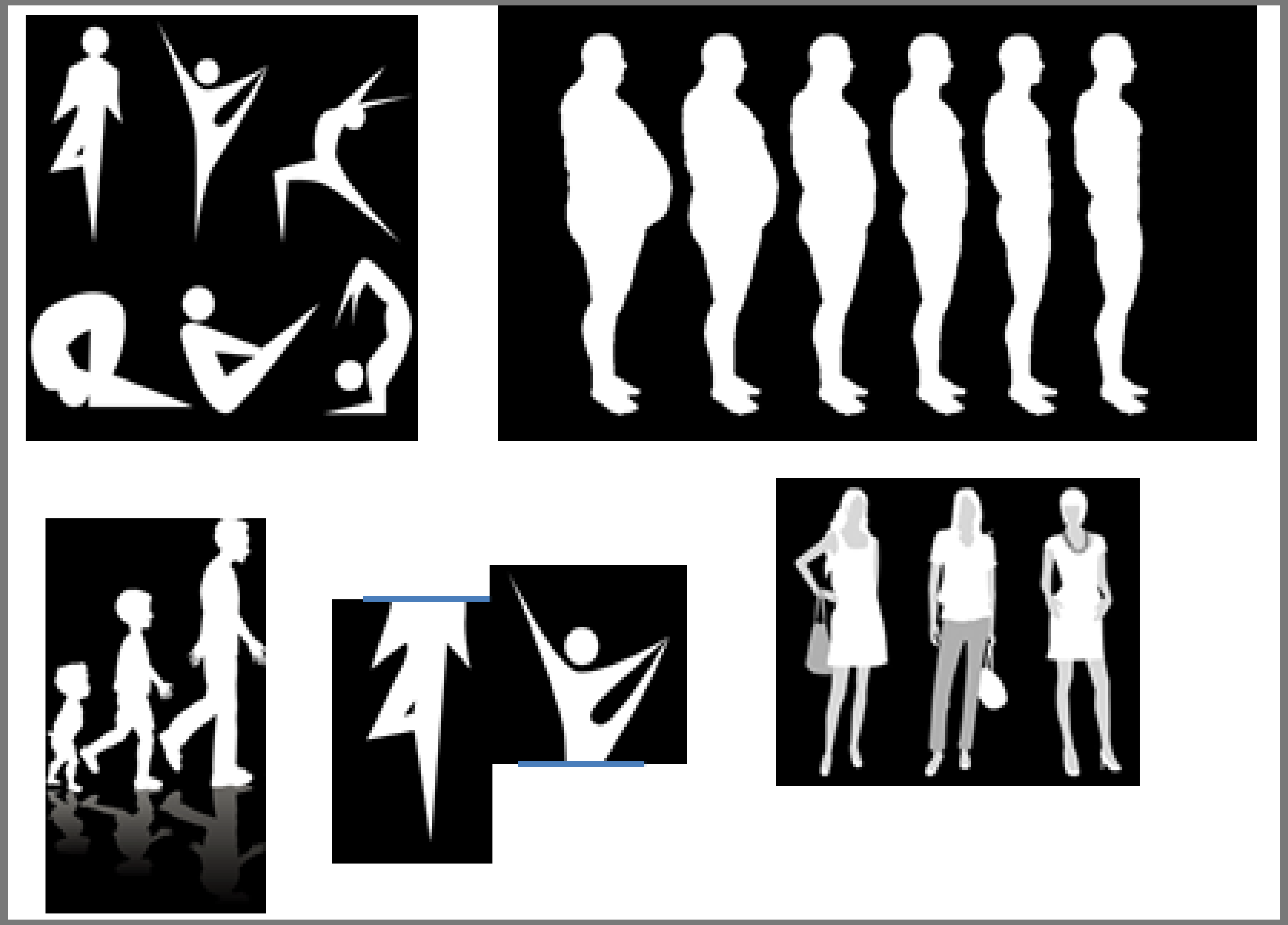
  e.g. natural language processing




- Change in the Word Error Rate (WER) with time for the NIST “Switchboard” data.
- Dramatic improvement made in the last few years using Deep Neural Networks

# Computer Vision and Machine Learning

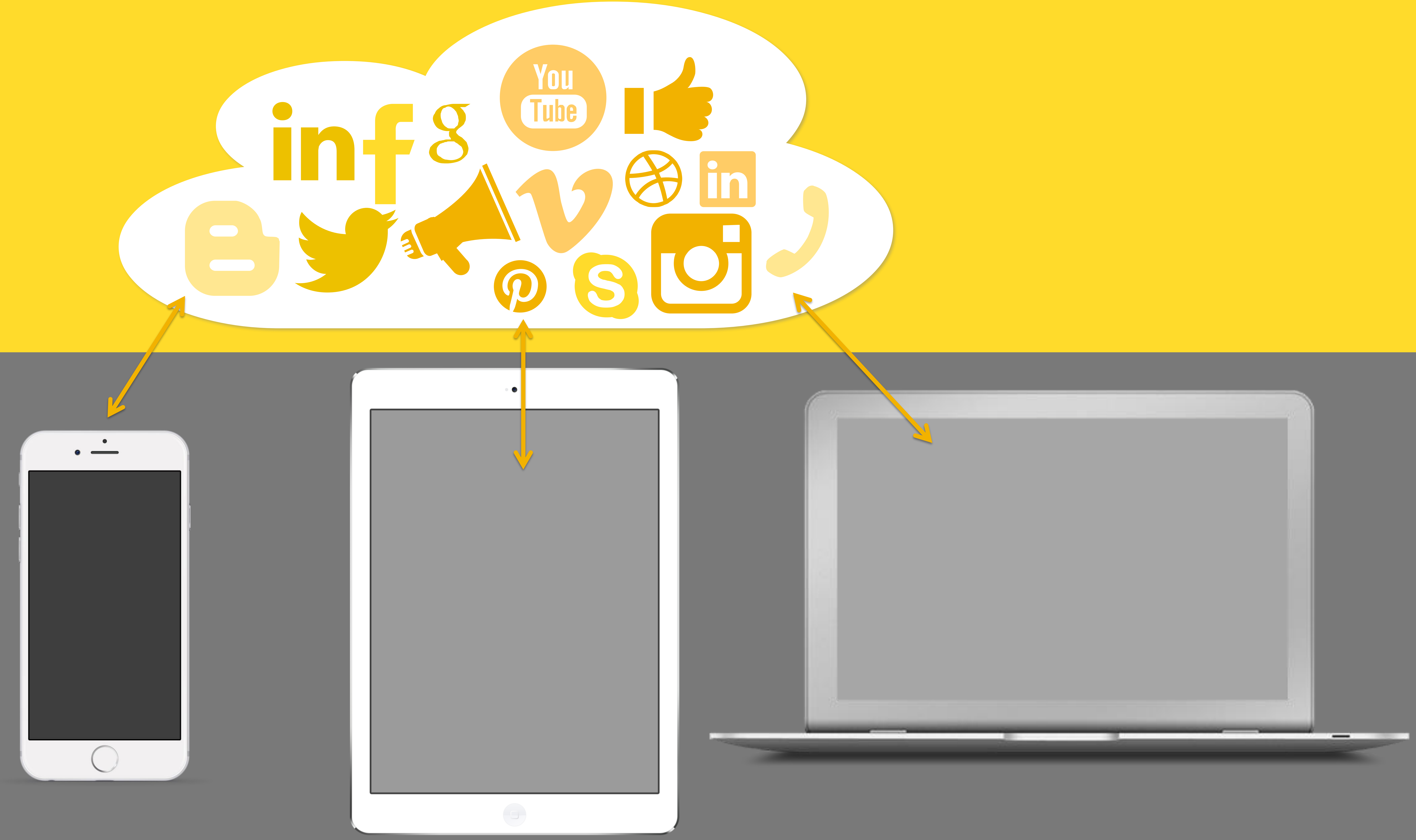
Images from the Kinect 3D camera



Learns from a training set containing millions of synthetically generated images

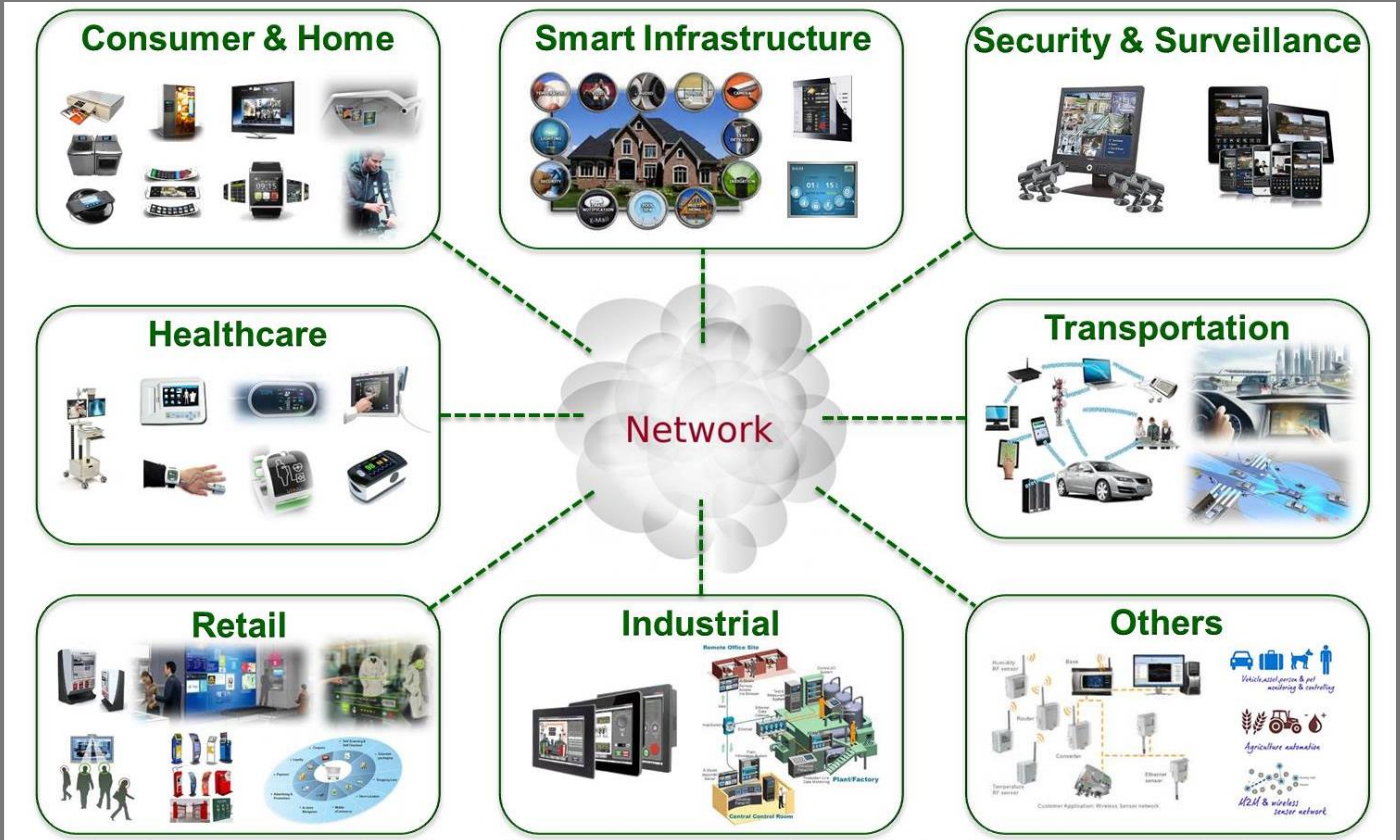
# Master Chief and Cortana

# The Cloud Transforms Mobile Devices

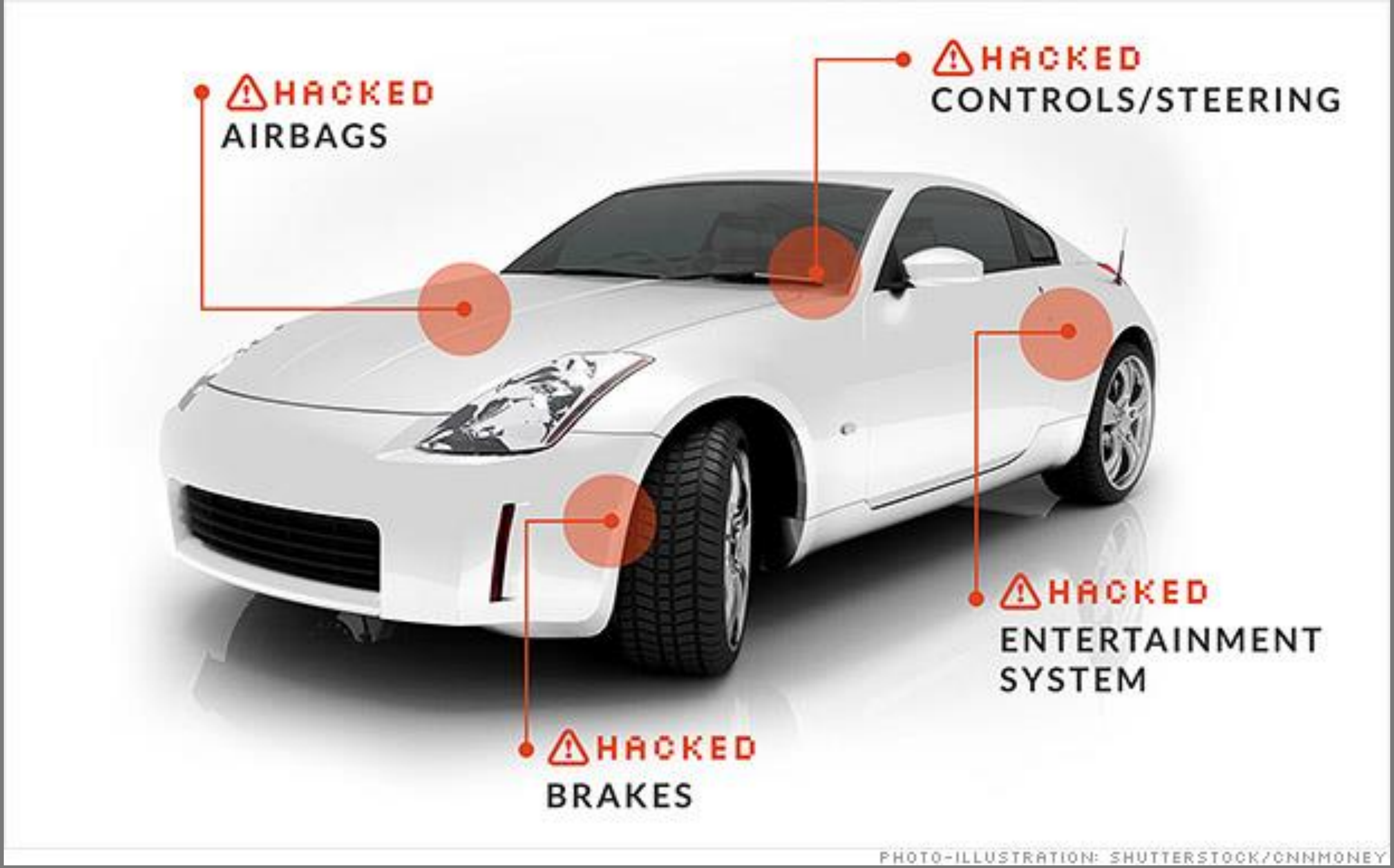


# ‘Intelligence’ everywhere …

# The Internet of Things



# Car Hacking



HACKED
AIRBAGS
HACKED
CONTROLS/STEERING
HACKED
ENTERTAINMENT SYSTEM
HACKED
BRAKES
PHOTO-ILLUSTRATION: SHUTTERSTOCK/CNNMONEY

# Artificial Intelligence: Weak or Strong AI?

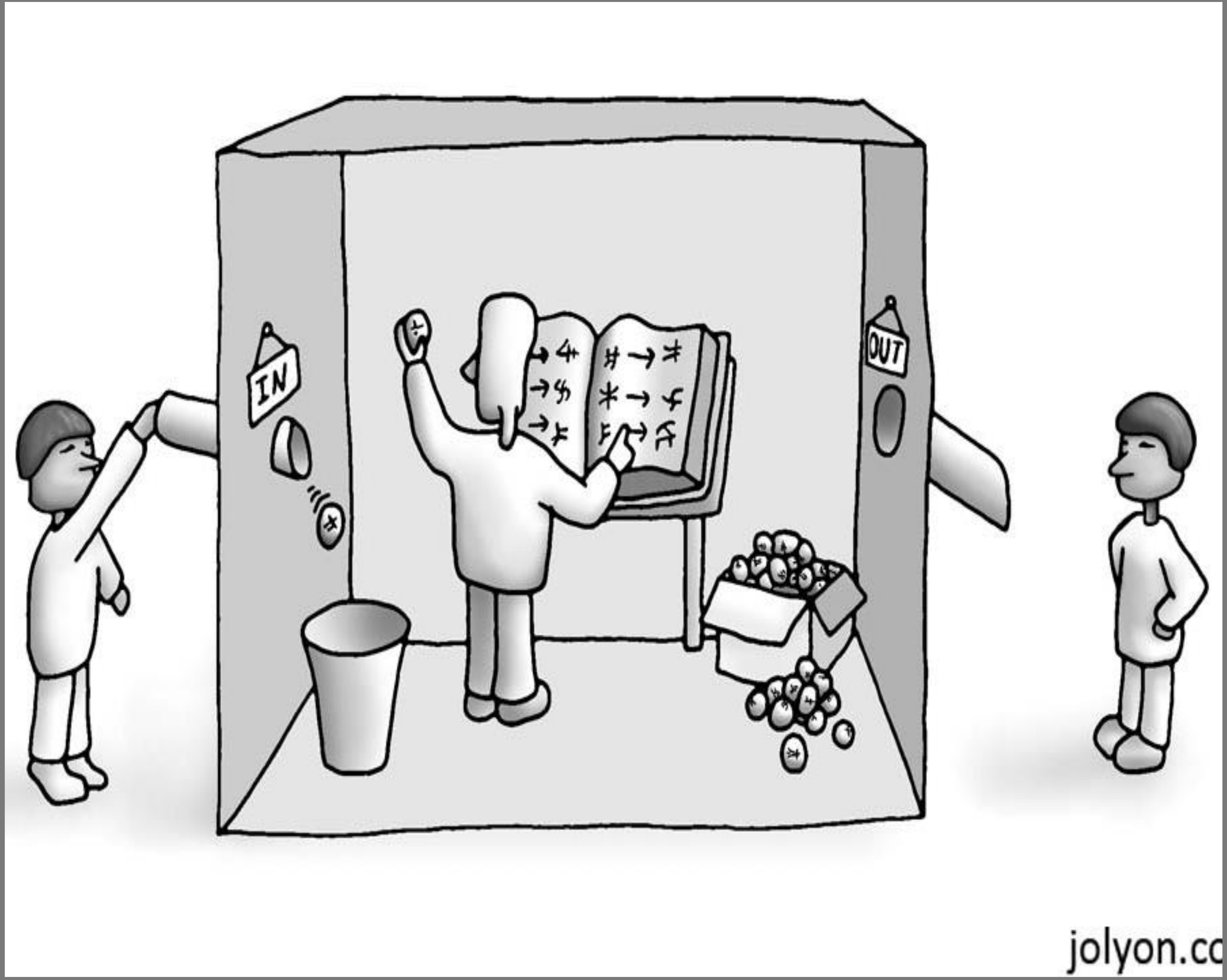
‘The assertion that machines could act as if they were intelligent is called weak AI hypothesis by philosophers, and the assertion that machines that do so are actually thinking (not just simulating thinking) is called the strong AI hypothesis’

Stuart Russell & Peter Norvig, 2010

# Computer Chess

# IBM Watson and Jeopardy!

# John Searle's Chinese Room

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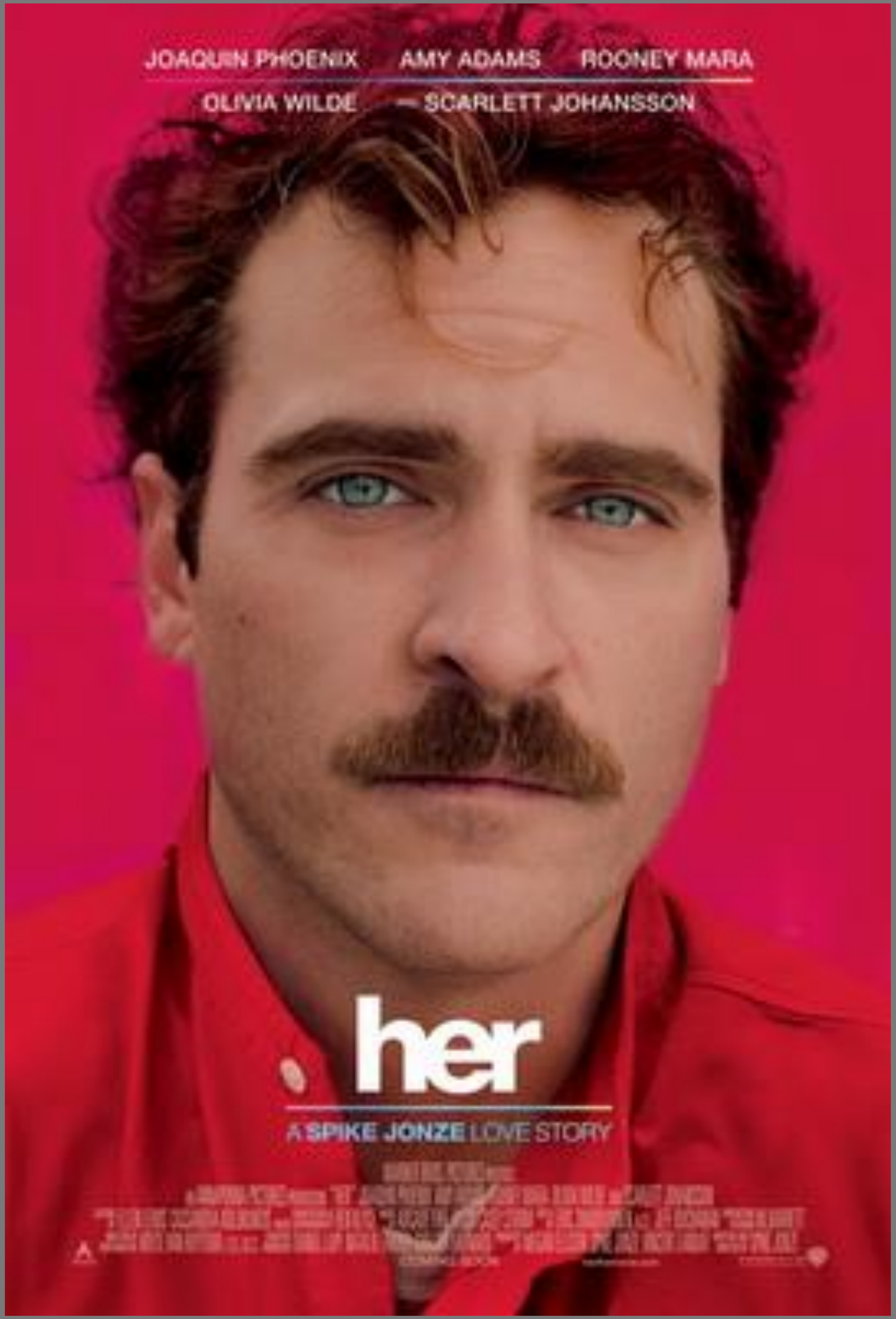
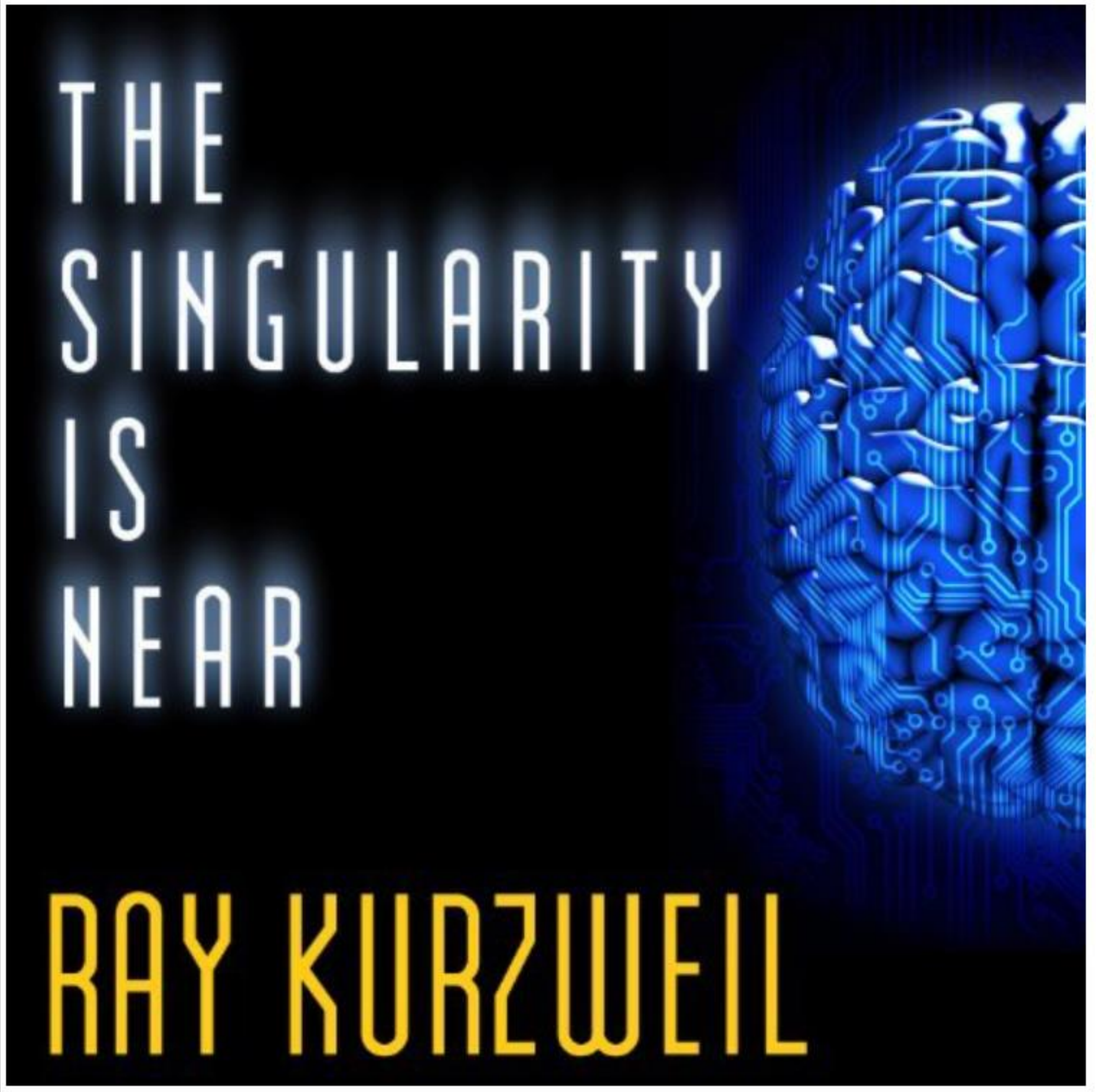

JOAQUIN PHOENIX
AMY ADAMS
ROONEY MARA
OLIVIA WILDE
SCARLETT JOHANSSON
her
A SPIKE JONZE LOVE STORY

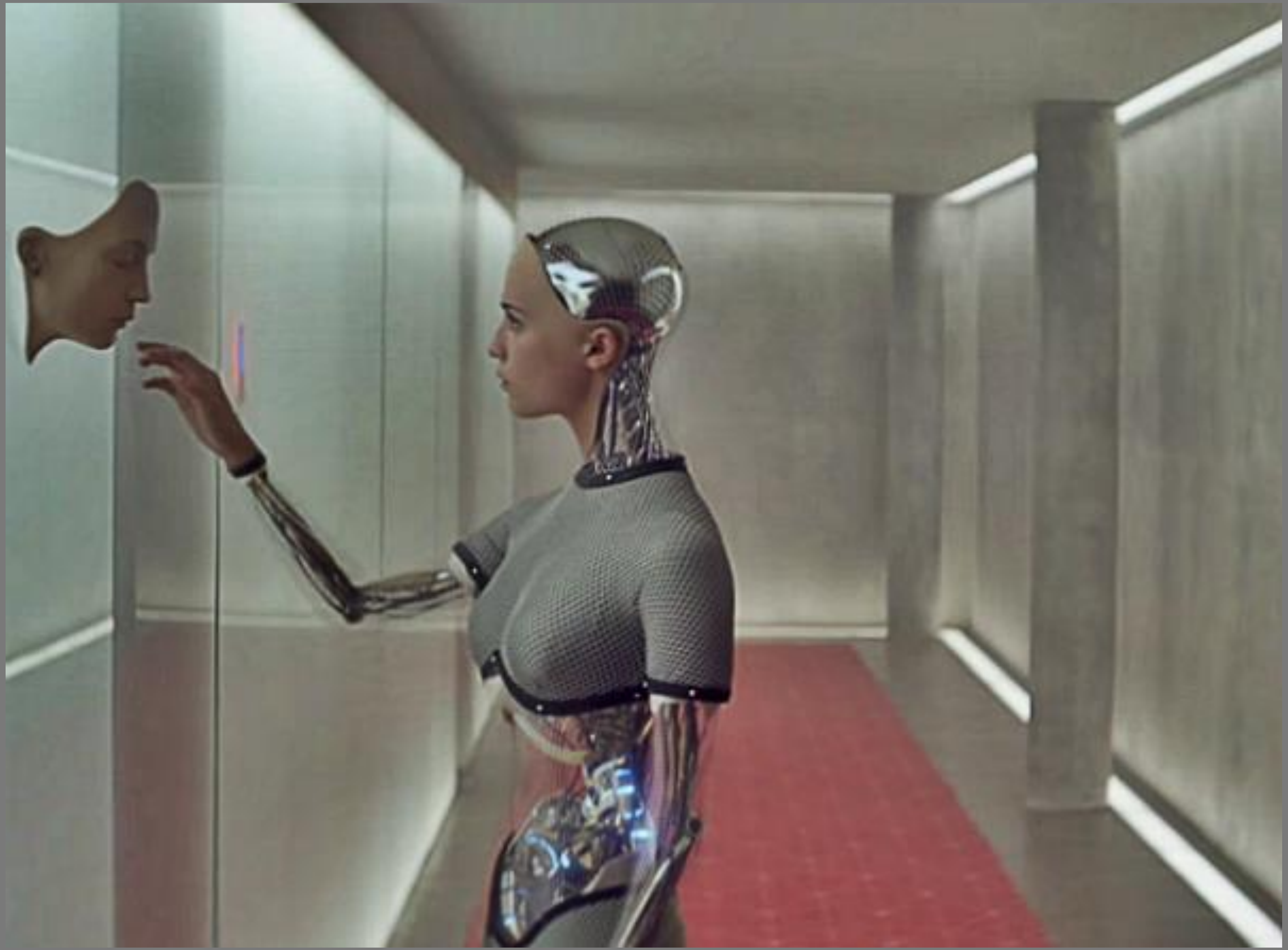
# A Fourth Age of Computing …



# … or Feynman's dumb file clerk?

'The inside of a computer is as dumb as hell but it goes like mad!'

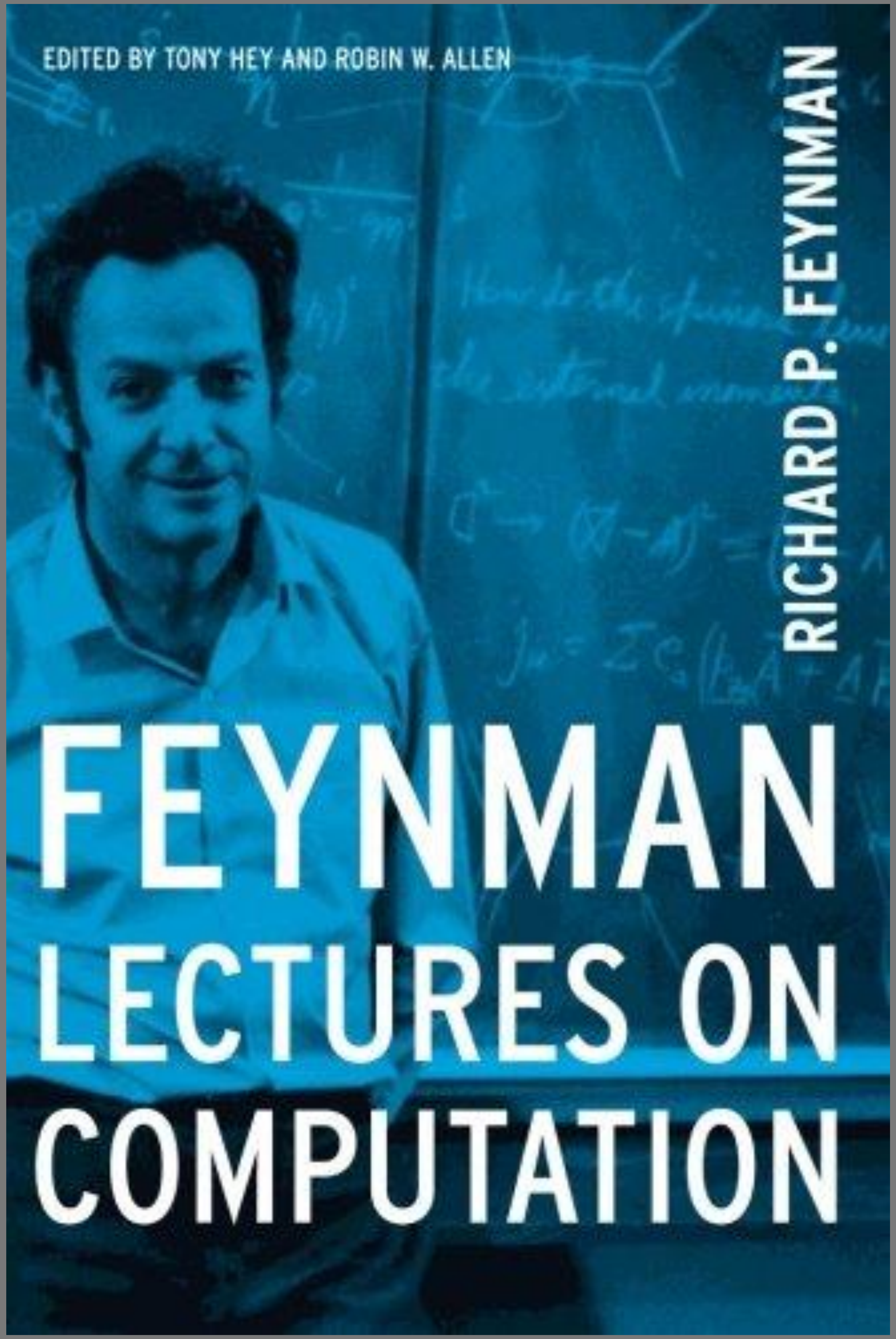
# Sentient Computers – The Singularity?



**Ex Machina**

'Human consciousness is just about the last surviving mystery'

Daniel Dennett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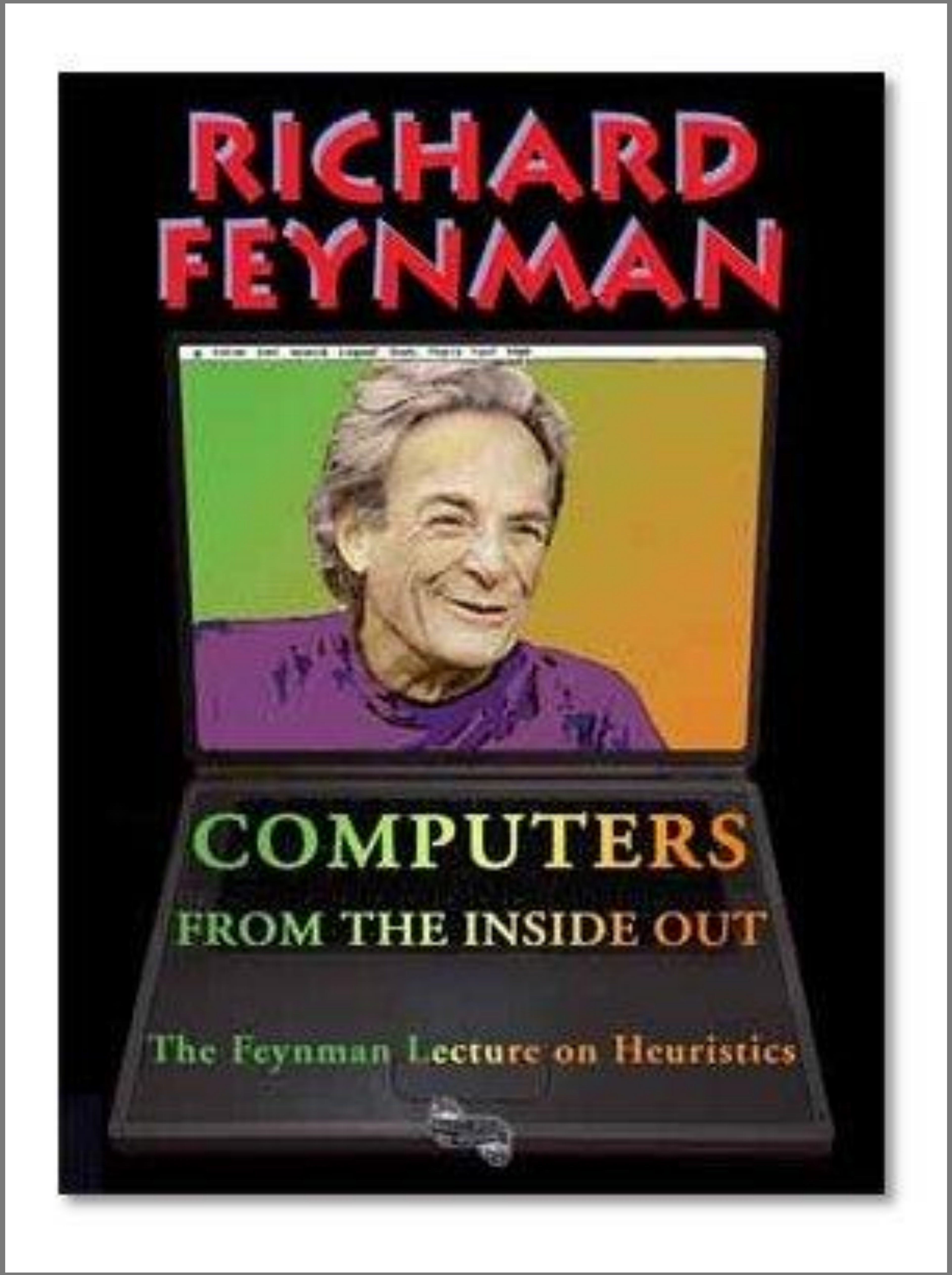
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