AI Introduction
The Turing Test, 1950

“Can machines think?”

Q: Please write me a sonnet on the subject of the Forth Bridge.
A: Count me out on this one. I never could write poetry.
Q: Add 34957 to 70764.
A: (Pause about 30 seconds and then give as answer) 105621.
What can computer do better than Human?
Computer Vision
Autonomous Driving

**Look — no driver**

**Video camera**
Detects traffic lights, oncoming vehicles and other obstacles

**Lidar**
A rotating sensor on the roof scans 200ft in all directions to create a 3D map of its surroundings

**Radar**
Three sensors at the front and one at the back work out the positions of nearby objects

**Position estimator**
A sensor on the left rear wheel measures the car’s movements so that its position can be mapped with accuracy
Handwriting Recognition
“This movie should have NEVER been made. From the poorly done animation, to the beyond bad acting. I am not sure at what point the people behind this movie said "Ok, looks good! Lets do it!" I was in awe of how truly horrid this movie was.”

Positive or Negative ?
Le premier ministre a lancé une autre piste – sans l'expliquer et beaucoup des experts présents à la conférence environnementale n'ont pu le faire - : la mobilisation d'une partie des gains financiers perçus sur le parc nucléaire français. "Pendant toute la durée de vie restante de nos centrales, et tout en assurant une sécurité maximale, a déclaré Jean-Marc Ayrault, notre parc nucléaire sera mis à contribution sans rupture d'approvisionnement."

The Prime Minister has launched another track - without explaining and many experts at the environmental conference could not do - : the mobilization of some of the financial gains earned on the French nuclear fleet. "Throughout the remaining life of our plants, and while ensuring maximum security, said Jean-Marc Ayrault, our nuclear fleet will be involved without supply disruption."
Virtual Assistants
Dialog System

2016 ten breakthrough technology from MIT technology review
Chat bot
Tutor robot
...

10
Humans versus Machines

1997: Deep Blue (chess) 2011: IBM Watson (Jeopardy!) 2016: AlphaGo
Stephen Hawking warns artificial intelligence could end mankind

By Rory Cellan-Jones
Technology correspondent

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Elon Musk: AI Is Going to Happen. Let’s Prepare For It

"It’s definitely going to happen. So if it’s going to happen, what’s the best way for it to happen?"

BY ESI TOWNSEND Staffreporter, Inc.com @Esi. Townsend

TODAY’S MUST READS

1. Speaking Points That Make You Sound, Like, Totally Unprofessional

2. How Playing the Long Game Made Elizabeth Holmes a Billionaire

3. 5 Holy Knicknacks to Celebrate Pope Francis’s Visit

4. Inside the Mind of Facebook’s Sheryl Sandberg

5. Take a Video Tour of Facebook’s Frank Gehry-Designed New York City Office

NICK BOSTROM
SUPERINTELLIGENCE
Paths, Dangers, Strategies
1956: Dartmouth workshop, John McCarthy coined “AI”
1960: checkers playing program, Logical Theorist
1966: ALPAC report cuts off funding for translation
1974: Lighthill report cuts off funding in UK
1970-80s: expert systems (XCON, MYCIN) in industry
1980s: Fifth-Generation Computer System (Japan); Strategic Computing Initiative (DARPA)
1987: collapse of Lisp market, government funding cut
1990-: rise of machine learning
2010s: heavy industry investment in deep learning
???
Many AI Applications

... Web search
Speech recognition
Handwriting recognition
Machine translation
Information extraction
Document summarization
Question answering
Spelling correction
Image recognition
3D scene reconstruction
Human activity recognition
Autonomous driving
Music information retrieval
Automatic composition
Social network analysis
...

... Product recommendation
Advertisement placement
Smart-grid energy optimization
Household robotics
Robotic surgery
Robot exploration
Spam filtering
Fraud detection
Fault diagnostics
AI for video games
Financial trading
Dynamic pricing
Protein folding
Medical diagnosis
Medical imaging
...

14
Characteristics of AI Tasks

**High societal impact** (affect billions of people)

**Diverse** (language, games, robotics)

**Complex** (really hard)
Two sources of complexity

**Computational Complexity**
- Most AI problems are NP-hard
- Go – $361^{200}$ trajectories that a player would have to consider to play optimally.

**Information Complexity**
- Translate a sentence
- Classify a bird from image
Resources

Computation (time/memory)  Information (data)
Big Data + Hardware + Machine Learning Algorithm

**AlphaGo (2016)**
- 30 million training data
- Tensor Processing Unit
- Deep & Reinforcement Learning

**NVIDIA Self-Driving (2016)**
- Vision data by driving tens of thousands miles
- NVIDIA GPU, Deep Learning

**Google Translation**
- Billions of translation data
- IBM’s linguistic approach fails
How do we solve tackle these challenging AI tasks?
Real-world task
Real-world task

Modeling

Formal task (model)

Algorithms

Program
Algorithms (example)

• Formal task:
  • Input: list $L = \{x_1, \ldots, x_n\}$ and a function $f : X \to \mathbb{R}$
  • Output: $k$ highest-scoring elements

• Example ($k = 2$):
  • $L : A \ B \ C \ D$
  • $f : 3 \ 2 \ 7 \ 1$

• Two algorithms:
  1. Scan through to find the largest, scan through again to find the second largest, etc.
  2. Sort $L$ based on $f$, return first $k$ elements
Modeling (example)

• Real-world task:
  • Input: 20 billion web pages, a keyword query
  • Output: 10 most relevant web pages

• Modeling:
  • \( L = \) list of web pages
  • \( f(x) = 10 \times \text{QueryMatch}(x) + 3 \times \text{PageRank}(x) \)

• Formal task:
  • Input: list \( L = \{x_1, \ldots, x_n\} \) and a function \( f : X \rightarrow \mathbb{R} \)
  • Output: \( k \) highest-scoring elements
Modeling and algorithms

- Separate **what** to compute (**modeling**) from **how** to compute it (**algorithms**) => Advantage: division of labor

- What do we learn?
  - Type of models...
  - Art of modeling...
  - Developing Algorithms...
Summary so far

• Applications of AI: high-impact, diverse

• Challenges: computational/information complexity

• Paradigm: modeling + algorithms
Reflex

"Low-level intelligence"  "High-level intelligence"
Sentiment Analysis

• Input: movie review

  “Shows moments of promise but ultimately succumbs to cliches and pat storytelling.”

• Output: sentiment

  \textit{POSITIVE} or \textit{NEGATIVE}
Reflex-based Models

• Input: $x$, a document or sentences
• Output: $f(x)$, a simple function of $x$

• Example: model $f$ is a set of simple rules
  • If $x$ contains “clichés”, return NEGATIVE.
  • If $x$ contains “promise”, return POSITIVE.
Reflex-based Models: Linear model

• Use scores to capture nuances...
• Output $f$ is determined based on scores
  • Set score = 0
  • If $x$ contains “clichés”, score = score - 10.
  • If $x$ contains “promise”, score = score + 5.
  • …
  • If score > 0, return POSITIVE.

• More generally...
  • Key idea: linear classifier
  • $f(x) = \text{sign}(w_1 \phi_1(x) + w_2 \phi_2(x) + \cdots)$
  • $f(x) = \sigma(w \cdot \phi(x))$

• How about “not bad”?
Machine learning approach

**Training examples**

“... excellent script ...” => positive
“... succumbs to cliches ...” => negative
“... pat storytelling ...” => negative

**Learning algorithm**

Simple Program with Parameters = [3.2, 1.2, ...]
Machine Learning

• **Key idea: generalization**
  • Learning algorithm maximizes accuracy on *training* examples.
  • But we only care about accuracy on future *test* examples.
  • How to *generalize* from training to test?
Low-level intelligence  
High-level intelligence  

Search problems  
Markov decision processes  
Adversarial games  

Reflex  
States  

"Low-level intelligence"  
"High-level intelligence"
Text Reconstruction

• Chinese is written without spaces:

是 什 4 意思

• Arabic omits (some) vowels:

مَكْتَبَة

• Remove vowels and spaces from an English phrase:

rtfclntllgnc
State-based Models

• Solutions are represented as paths through a graph
State-based Models

Key idea: state

• A state captures all the relevant information about the past in order to act optimally in the future
State-based Models

• **Search problems**: you control everything

• **Markov decision processes**: against nature (e.g., Blackjack)

• **Adversarial games**: against opponent (e.g., chess)
Pac-Man

What kind of model is appropriate for playing Pac-Man against ghosts that move into each valid adjacent square with equal probability?

1. Search problem
2. Markov decision process
3. Adversarial game
Goal: maximize distance travelled by robot

Markov decision process (MDP):
• States: positions (4 possibilities) for each of 2 servos
• Actions: choose a servo, move it up/down
• Transitions: move into new position (unknown)
• Rewards: distance travelled (unknown)
Deep reinforcement learning

Playing Atari [Google DeepMind, 2013]:

• Just use a neural network for $\hat{Q}_{\text{opt}}(s, a)$
• Last 4 frames (images) => 3-layer NN => keystroke
• $\epsilon$-greedy, train over 10M frames with 1M replay memory
• https://www.youtube.com/watch?v=V1eYniJ0Rnk
• Supervised learning: on human games
• Reinforcement learning: on self-play games
• Evaluation function: convolutional neural network (value network)
• Policy: convolutional neural network (policy network)
• Monte Carlo Tree Search: search / lookahead
"Low-level intelligence"  "High-level intelligence"

Reflex  States  Variables

Search problems  Markov decision processes  Constraint satisfaction problems
Adversarial games  Bayesian networks
Question: how can we color each of the 7 provinces \{red, green, blue\} so that no two neighboring provinces have the same color?
Map coloring

(one possible solution)
Constraint Satisfaction Problem (CSP)

Three sculptures (A, B, C) are to be exhibited in rooms 1, 2 of an art gallery.

The exhibition must satisfy the following conditions:
• Sculptures A and B cannot be in the same room.
• Sculptures B and C must be in the same room.
• Room 2 can only hold one sculpture.
Event scheduling

Setup:

• Have $E$ events and $T$ time slots
• Each event $e$ must be put in exactly one time slot
• Each time slot $t$ can have at most one event
• Event $e$ allowed in time slot $t$ only if $(e, t) \in A$
Variable-based Models

- **Constraint satisfaction problem**: hard constraints (e.g., map coloring, scheduling)

- **Bayesian networks**: soft dependencies (e.g., tracking cars from sensors)
Topic modeling

**Question:** given a text document, what topics is it about?

**Probabilistic program: latent Dirichlet allocation**

Generate a distribution over topics \( \alpha \in \mathbb{R}^K \)

For each position \( i = 1, \ldots, L \):

- Generate a topic \( Z_i \sim p(Z_i | \alpha) \)
- Generate word \( W_i \sim p(W_i | Z_i) \)
"Low-level intelligence"

Reflex

Search problems
Markov decision processes
Adversarial games

States

Constraint satisfaction problems
Bayesian networks

Variables

Logic

"High-level intelligence"
Question

You get extra credit if you write a paper and you solve the problems.
You didn’t get extra credit, but you did solve the problems.
Did you write a paper?
Yes or No
Knowledge representation and reasoning

All students work hard.
John is a student.
Therefore, John works hard.

Variable-based models would explicitly represent all the students – this is inefficient

Need expressive power of logic to represent this ...
Modeling is often expressed as optimization problems, which provides a mathematical specification of what we want to compute.
Problem: predicting exam score $y$

- $x$: # of hours studying
- $y$: exam score
- Assume $y = w x$
- $w$ is a **learning parameter** we need to estimate (learn) from training data

- $D_{\text{train}}$: set of pairs $\{(x_1, y_1), \ldots, (x_n, y_n)\}$
- $f: w \in \mathbb{R}$ that minimizes the squared error $F(w) = \sum_{i=1}^{n} (x_i w - y_i)^2$
- Example:
  \[
  \{(2,4)\} \Rightarrow 2 \\
  \{(2,4),(4,2)\} \Rightarrow ?
  \]
Optimization

• Models are optimization problems:
  $$\min_{x \in C} F(x)$$

• Discrete optimization: x is a discrete object
  $$\min_{x \{abcd,xyz\}} \text{Length}(x)$$
  Algorithmic tool: dynamic programming

• Continuous optimization: x is a vector of real numbers
  $$\min_{x \in \mathbb{R}} (x - 5)^2$$
  Algorithmic tool: gradient descent
Summary

• Applications of AI: high-impact, diverse

• Challenges: computational/information complexity

• Paradigm: modeling + algorithms

• Models: learning + [reflex, states, variables, logic]