Theoretical aspects
  – Mathematical formalizations, properties, algorithms

Engineering aspects
  – The act of building (useful) machines

Empirical science
  – Experiments
What's involved in Intelligence?

A) Ability to interact with the real world
to perceive, understand, and act
- speech recognition and understanding (natural language)
- image understanding (computer vision)

B) Reasoning and Planning
- modeling the external world
- problem solving, planning, and decision making
  ability to deal with unexpected problems, uncertainties

C) Learning and Adaptation
- Lots of data. Use to train statistical models.
- We are continuously learning and adapting.
- We want systems that adapt to us!
AI leverages from different disciplines

philosophy
e.g., foundational issues (can a machine think?), issues of knowledge and believe, mutual knowledge

psychology and cognitive science
e.g., problem solving skills

neuro-science
e.g., brain architecture

computer science and engineering
e.g., complexity theory, algorithms, logic and inference, programming languages, and system building.

mathematics, statistics, and physics
e.g., statistical modeling, continuous mathematics, statistical physics, and complex systems.
Obtaining an understanding of the human mind is one of the final frontiers of modern science.

**Founders:**
- George Boole, Gottlob Frege, and Alfred Tarski
  - formalizing the laws of human thought
- Alan Turing, John von Neumann, and Claude Shannon
  - thinking as computation
- John McCarthy (Stanford), Marvin Minsky (MIT), Herbert Simon and Allen Newell (CMU)
  - the start of the field of AI (1956)
History of AI:
The gestation of AI 1943-1956
(See Russell & Norvig)

1943 McCulloch and Pitts
  – McCulloch and Pitts’ model of artificial neurons
  – Minsky’s 40-neuron network

1950 Turing’s “Computing machinery and intelligence”

1950s Early AI programs, including Samuel’s checkers program, Newell and Simon’s Logic theorist

1956 Dartmouth meeting: Birth of “Artificial Intelligence”
  – 2-month Dartmouth workshop; 10 attendees
  – Name was chosen. AI
1957 Herb Simon (CMU):

It is not my aim to surprise or shock you – but the simplest way I can summarize is to say that there are now in the world machines that think, that learn, and that create. 😊

1958 John McCarthy’s LISP (symbol processing at core)

1965 J.A. Robinson invents the resolution principle, basis for automated theorem. General reasoning procedure.

Limited intelligent reasoning in microworlds
(such as the “blocks world” --- a toy robotics domain)
The Blocks World

Requires:
--- Vision
--- Reasoning/Planning
--- Manipulation
--- Acting/Robotics

“A Microworld”
“Brainy, Yes, but Far From Handy”
New York Times 09/01/14
Making dexterous hands with human-level touch and sensing still a real challenge. Link.

Stacking blocks may seem like an easy task for a human, but robots have long struggled with such fine control. HDT’s Adroit manipulator uses force-sensing and vision to accomplish the delicate task.

Dynamic human touch — for example, when a finger slides across a surface — could distinguish ridges no higher than 13 nanometers, or about 0.0000005 of an inch. Individual molecules...
1) Weizenbaum’s ELIZA ("fools" users)

Capturing general knowledge is hard.

2) Difficulties in automated translation

See Babelfish

Syntax and dictionaries are not enough
Consider going from English to Russian back to English.
Early effort…

“The spirit is willing but the flesh is weak.”

“The vodka is good but the meat is rotten.”

Natural language processing (NLP) is hard.
(Ambiguity! Context! Anaphora resolution.)
3) Cars climbing up trees (at CMU)...
   Road sides look like parallel lines.
   But, unfortunately, so do trees!

   *Computer vision is hard.*
   *(Ambiguity! Context! Noisy pixels.)*

4) Limitations of perceptrons discovered
   Minsky and Papert (1969)
   Can only represent linearly separable functions
   Neural network research almost disappears

   *Machine learning is hard.*

5) Intractability of inference. NP-Completeness (Cook 72)
   Intractability of many problems attempted in AI.
   Worst-case result....

   *Machine reasoning is hard.*
History of AI

Knowledge based systems (1969-79)

Intelligence requires knowledge

Knowledge-based systems (lots of knowledge with limited but fast reasoning)
(Feigenbaum)

versus

general “weak” methods (a few basic principles with general reasoning)
(Simon and Newell)

Some success: *Expert Systems*

- Mycin: diagnose blood infections (medical domain)
- R1: configuring computer systems
- AT&T phone switch configuration

Knowledge in rules of form:
If symptom_1 & symptom_3 then disease_2 (with certainty .8)
Expert Systems
Very expensive to code. ($1M+)
   Response: Try to learn knowledge from data.
Weak with uncertain inputs / noisy data / partial information
   Response: Incorporate probabilistic reasoning
Brittle! (fail drastically outside domain)

Leads to 1980 -- 1995:
--- General foundations reconsidered
--- Foundations of machine learning established (e.g. computational learning theory; PAC learning; statistical learning)
--- Foundations of probabilistic formalisms: Bayesian reasoning; graphical models; mixed logical and probabilistic formalisms.

From 1995 onward:
--- Data revolution combined with statistical methods
--- Building actual systems
--- Human world expert performance matched (and exceeded) in certain domains
Several success stories with high impact …
Machine Learning

In ’95, TD-Gammon.

World-champion level play by Neural Network that learned from scratch by playing millions and millions of games against itself! (about 4 months of training. Temporal-Difference learning.)

(initial games hundreds of moves)

Has changed human play.

Remaining open question: Why does this NOT work for, e.g., chess??
A mathematical conjecture (Robbins conjecture) unsolved for 60 years!

The Robbins problem was to determine whether one particular set of rules is powerful enough to capture all of the laws of Boolean algebra.

Mathematically:
Can the equation not(not(P) )= P be derived from the following three equations?

[1]  (P or Q) = (Q or P)
[2]  (P or Q) or R = P or (Q or R),
[3]  not(not(P or Q) or not(P or not(Q))) = P.

First creative mathematical proof by computer.
Contrast with brute-force based proofs such as the 4-color theorem.

[An Argonne lab program] has come up with a major mathematical proof that would have been called creative if a human had thought of it. New York Times, December, 1996

Robbins Conjecture

The Proof:

7. \( p + q + p + q = q \) \([\text{Robbins' Axiom}]

10. \( p + q + p + q + q = p + q \)

11. \( p + q + p + q + q = p + q \)

29. \( p + q + p + q + q = q \)

54. \( p + q + p + 2q + p + q + r + q + q = r \)

217. \( p + q + p + 2q + p + q + q + r + r + r = q + r \)

674. \( p + q + p + 2q + p + q + q + r + r + q + q + q + q = r \)

6736. \( 3p + 3q + 3p + 3q + 3p + 3q + 3p + 3q = 3p + p \)

8855. \( 3p + 3p = 3p \)

8865. \( 3p + 3q + 3p + 3q + 3p + 3q = 3p + p + 2q \)

8870. \( 3p + 3p = p \)

8870. \( 3p + 3p + 3p + q + q + q = q \)

8871. \( 3p + 3p + 2p = 2p \)

A Baker's Dozen: The key steps in proving the Robbins conjecture, as reported by EQP, an automated theorem-proving program developed by William McCune and colleagues at Argonne National Laboratory. (See Box, "Substitue Teacher" page 63 for details.)

Quantitative threshold for creativity?
1997: Deep Blue beats the World Chess Champion

I could feel human-level intelligence across the room

Gary Kasparov, World Chess Champion (human...)

Deep Blue had Kasparov in deep thought (CNN)

VS.
Deep Blue vs. Kasparov

Game 1: 5/3/97: 
Kasparov wins

Game 2: 5/4/97: 
Deep Blue wins

Game 3: 5/6/97: 
Draw

Game 4: 5/7/97: 
Draw

Game 5: 5/10/97: 
Draw

Game 6: 5/11/97: 
Deep Blue wins

The value of IBM’s stock increased by $18 Billion!

We’ll discuss Deep Blue’s architecture, when we cover multi-agent search.

Note: when training in self-play, be careful to randomize!
On Game 2

Game 2 - Deep Blue took an early lead. Kasparov resigned, but it turned out he could have forced a draw by perpetual check.

Interestingly, if Kasparov had been playing a human he would most likely not have resigned!

This was real chess. This was a game any human grandmaster would have been proud of.

Joel Benjamin
grandmaster, member Deep Blue team
Kasparov on Deep Blue

1996: Kasparov Beats Deep Blue

“I could feel --- I could smell --- a new kind of intelligence across the table.” (CNN)

1997: Deep Blue Beats Kasparov

“Deep Blue hasn't proven anything.” 😊

Current strongest play: Computer-Human hybrid
May, '97 --- Deep Blue vs. Kasparov. First match won against world-champion. "intelligent creative" play. 200 million board positions per second!

Kasparov: ... still understood 99.9 of Deep Blue's moves.

Deep Blue considers **60 billion boards per move!** Human?

Around 10 to 20 lines of play. Hmm…

**Intriguing issue:** How does human cognition deal with the search space explosion of chess? Or how can humans compete with computers at all?? (What does human cognition do? Truly unknown…)
Concepts (briefly)

(more details with multi-agent search)

--- Minimax search on game tree to get optimal move
(large tree $\geq 10^{80}$ chess)

Size tree: $b^d$ ($b$ --- average branching; $d$ --- depth)

alpha-beta pruning: $b^{(d/2)}$ [key technique]

--- Board evaluation or utility function when
you can’t search to the bottom

--- Board eval is linear weighted some of features; can
be trained via learning

--- Chess complexity?

$O(1)$ (formally speaking…)
From Robocup to Warehouse Automation

Kiva Systems $700M
2005 Autonomous Control: DARPA GRAND CHALLENGE

October 9, 2005
Stanley and the Stanford Racing Team were awarded 2 million dollars for being the first team to complete the 132 mile DARPA Grand Challenge course (Mojave Desert). Stanley finished in just under 6 hours 54 minutes and averaged over 19 miles per hours on the course.

Sebastian Thrun: Google's driverless car (2011)

Cornell team stuck due to malfunctioning GPS.

http://www.youtube.com/watch?v=bp9KBrH8H04
**A* algorithm**
Covered in search and problem solving.

Path Planning Overview
Path planning is the basic process by which our vehicle decides on what path to take through the world. The A.I. uses the world model created by the sensors, the GPS waypoints provided during the race by DARPA, and a road following algorithm to pick a best path.

Road Following
The road following algorithm uses color differences, shadowing, and edge-detection algorithms to detect the sides of a road (if there is a road) and then decides if the road is turning, going straight, which direction, how sharply, etc. The road following algorithm uses input from most of the vehicle sensors, and provides the A.I. with probable road characteristics.
Cornell: 4th!
Also, in historic

1st autonomous driverless car collision. Rear-ended by MIT car!

2007 Darpa Urban Challenge
Winner: CMU Tartan Racing's Boss

The Urban Challenge will pit driverless vehicles against one another on city streets. Robots will have to handle traffic, intersections, rules of the road and other robots. The challenge is a high-stakes competition that plays out on a world stage. The prize is $2M, but the payoff for driver safety is much greater. This competition will be held November 3, 2007.

The Urban Challenge is third in a series of autonomous vehicle competitions designed to catalyze robotic technology development. On October 8, 2005, Carnegie Mellon's "Sandstorm" and "Highlander" crossed the finish line of DARPA Grand Challenge after successfully completing a 132-mile course through the Nevada desert, coming in second and third place respectively.

http://www.tartanracing.org/blog/index.html#26
Watson defeats the two greatest Jeopardy! champions

http://www.youtube.com/watch?v=dr7IxQeXr7g
Watson

Multi-layer neural networks, a resurgence!

a) Winner one of the most recent learning competitions

b) Automatic (unsupervised) learning of “cat” and “human face” from 10 million of Google images; 16,000 cores 3 days; multi-layer neural network (Stanford & Google).

c) Speech recognition and real-time translation (Microsoft Research, China).

Aside: see web site for great survey article “A Few Useful Things to Know About Machine Learning” by Domingos, CACM, 2012.
Start at min. 3:00. Deep Neural Nets in speech recognition.
**Other promising ongoing efforts**

1) Intelligent autonomous assistants, e.g., iPhone’s Siri
(still a long way to go 😊) Integrated, autonomous agents.
Google Glass will be the next step. Location / context aware;
rich sensing, vision and speech understanding and generation.

2) Fully self-driving car (Google; assisted driving Mercedes and BMW
--- the cost of a car is becoming software and sensors Incredibly
more lines of code in a Mercedes than in a Boeing 747.)

2) Google translate. Reaches around 70% of human translator
performance. Almost fully a purely statistical approach.

Not clear yet how far one can go without a real understanding of the
semantics (meaning). But with Big Data, statistical methods already
went much further than many researchers had considered possible
only 10 years ago.
Course Administration

What is Artificial Intelligence?

Course Themes, Goals, and Syllabus
Setting expectations for this course

Are you going to build real systems and robots?  
NO...

Goal:  
Introduce the conceptual framework and computational techniques that serve as a foundation for the field of artificial intelligence (AI).
• Structure of intelligent agents and environments.
• Problem solving by search: principles of search, uninformed (“blind”) search, informed (“heuristic”) search, and local search.
• Constraint satisfaction problems: definition, search and inference, and study of structure.
• Adversarial search: games, optimal strategies, imperfect, real-time decisions.
• Logical agents: propositional and first order logic, knowledge bases and inference.
• Uncertainty and probabilistic reasoning: probability concepts, Bayesian networks, probabilistic reasoning over time, and decision making.
So far, we discussed

Artificial Intelligence and characteristics of intelligent systems.

Brief history of AI

Major recent AI achievements

Reading: Chapter 1 Russell & Norvig