Queen Mary
University of London

# ECS629U/759P: Artificial Intelligence

Simon Dixon

School of Electronic Engineering and Computer Science

Queen Mary University of London

Acknowledgements: Geraint Wiggins, Karen Shoop, John Bigham, et al.

# Module Overview

Queen Mary University of London

- Topic 1: Introduction to Artificial Intelligence
  - What is AI? Background, history and future of AI
- Topic 2: Rational Agents
  - Computational entities that exhibit intelligent behaviour
- Topics 3-5: Problem Solving, Search and Games
  - Representing problems and solving them via search
  - Local vs global search
  - Adversarial search and strategy games

# Module Overview

Queen Mary University of London

- Topics 6-7: Learning Systems
  - Classification with decision trees: the ID3 algorithm
  - Neural networks
- Topics 8-10: Knowledge Representation and Reasoning
  - Formal logic as a representation language
  - Automated reasoning
  - Reasoning with uncertainty

# Module Overview

Queen Mary University of London

- Learning and Teaching
  - Lectures
    - 3 hours of lectures each week (including week 7; no lectures week 4)
  - Tutorials
    - 8 sets of supporting exercises in tutorial sessions each week from week 5 (incl. week 7)
  - Individual course work assignments
    - 2 pieces of assessed practical programming work
  - Getting help
    - Questions during (and after) lectures
    - My office hours (Tue 4pm and Wed 2pm in ENG E407) - please mail to confirm
    - Ask the demonstrator (Brice Denoun) in tutorials

# Module Overview

Queen Mary University of London

- Assumed knowledge
  - Data structures and algorithms (trees, graphs, stacks, queues, priority queues)
  - Some logic and probability
  - Programming with RECURSION
- Assessment
  - course work
    - two items
    - done individually (ON YOUR OWN)
    - each counts for 12.5% of module total (i.e., 25% in total)
  - unseen examination:
    - duration 2 hours and 30 minutes
    - answer 4 questions, with no choice
    - counts for 75% of module total

# Recommended books

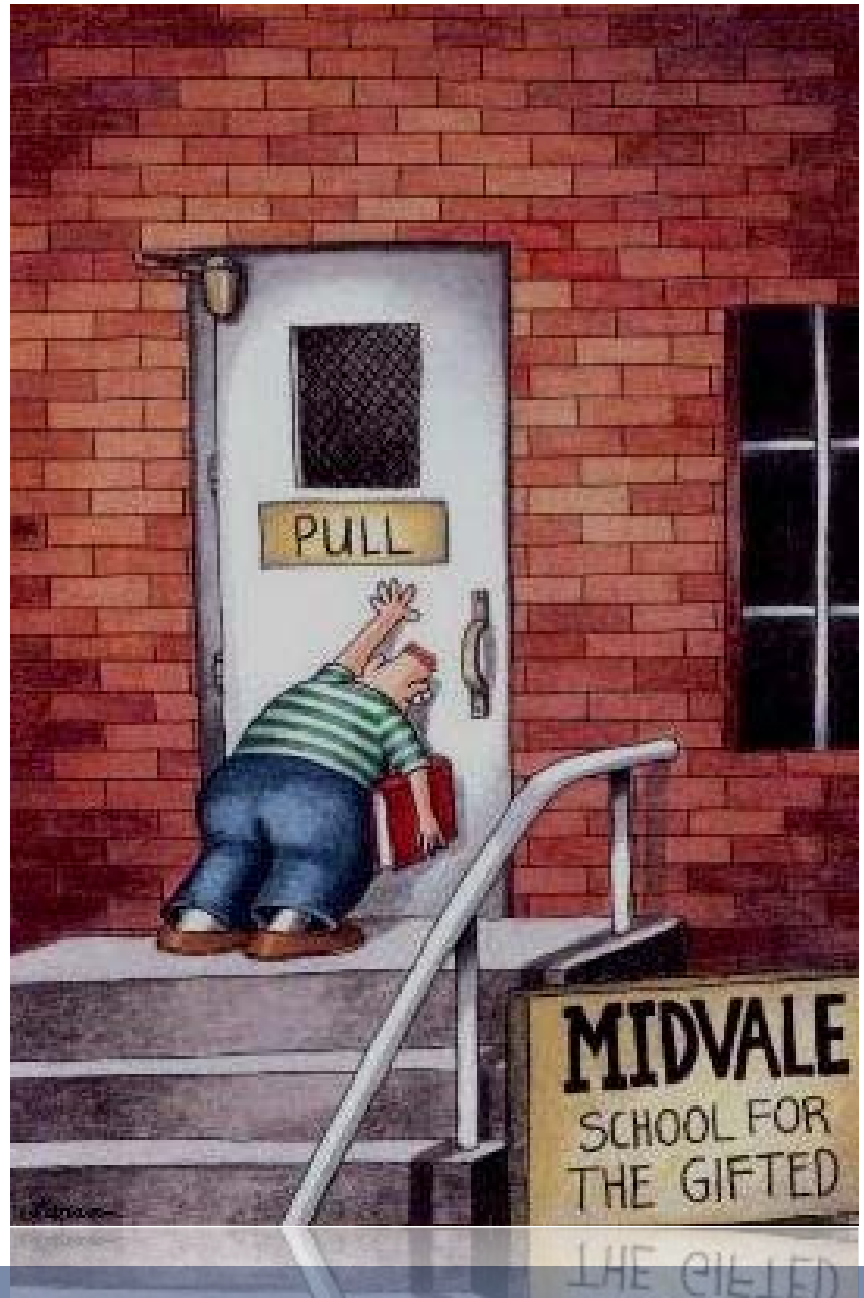
Queen Mary University of London

- Stuart Russell and Peter Norvig
  **Artificial Intelligence: A Modern Approach**
  Prentice Hall, 1995, 2003, 2009
  - The text book (more like an encyclopedia)
- George F. Luger
  **Artificial Intelligence: Structures and Strategies for Complex Problem Solving**
  6th edition, Addison Wesley, 2007
  - Another popular AI text; earlier editions by Luger and Stubblefield
- Ian Goodfellow, Yoshua Bengio and Aaron Courville
  **Deep Learning**
  MIT Press, 2016, www.deeplearningbook.org
  - Extra reading for personal interest

# What is Intelligence?

Queen Mary University of London

- What is meant by human intelligence?
  - exams, education, perform well in intelligence (IQ) tests
  - skills – languages, chess, mathematical reasoning
  - cognition: perception, memory, judgement and reasoning
  - volition: the will, purpose, choice
  - emotion: affective intelligence
  - speed, efficiency and creativity of information processing



# What is Intelligence?


Queen Mary University of London

- What might make computers smart...clever....intelligent... intellectual?
  - Beat human at chess ✓ *IBM's Deep Blue beat Gary Kasparov in 1997*
  - Discover mineral fields ✓ *PROSPECTOR closely matched human experts in 1978*
  - Diagnose disease ✓ *MYCIN diagnosed 68% of cases acceptably in 1975*
  - Hold a convincing conversation, social interaction ✗ *Turing "test"*

# What is Artificial Intelligence?

Queen Mary University of London

- Marvin Minsky
  - "The science of making machines do things that would require intelligence if done by men."
- Eugene Charniak
  - "The study of mental faculties through the use of computational models."
- John L. Gordon
  - "The aim of Artificial Intelligence is to create intelligent machines and through this, to understand the principles of intelligence. At the moment, we can settle for creating less stupid machines."
- Unknown
  - "The set of things a computer can't do (yet)."

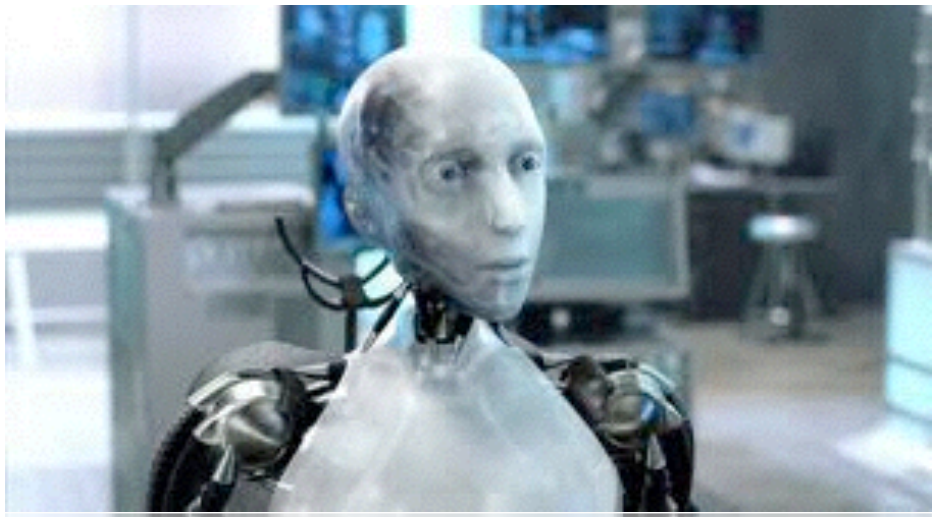
# Two kinds of Artificial Intelligence

Queen Mary University of London

- Weak AI
  - Machines can be made to act *as though* they were intelligent
- Strong AI
  - Machines that act intelligently and have real, *conscious* minds

*real*

*fictional*



# Four categories of AI

Queen Mary University of London

| | |
|---|---|
| **Thinking Humanly** | **Thinking Rationally** |
| **Acting Humanly** | **Acting Rationally** |

# Acting Humanly

Queen Mary
University of London

| | |
|---|---|
| **Thinking Humanly** | **Thinking Rationally** |
| **Acting Humanly** | **Acting Rationally** |

# Acting Humanly

Queen Mary University of London

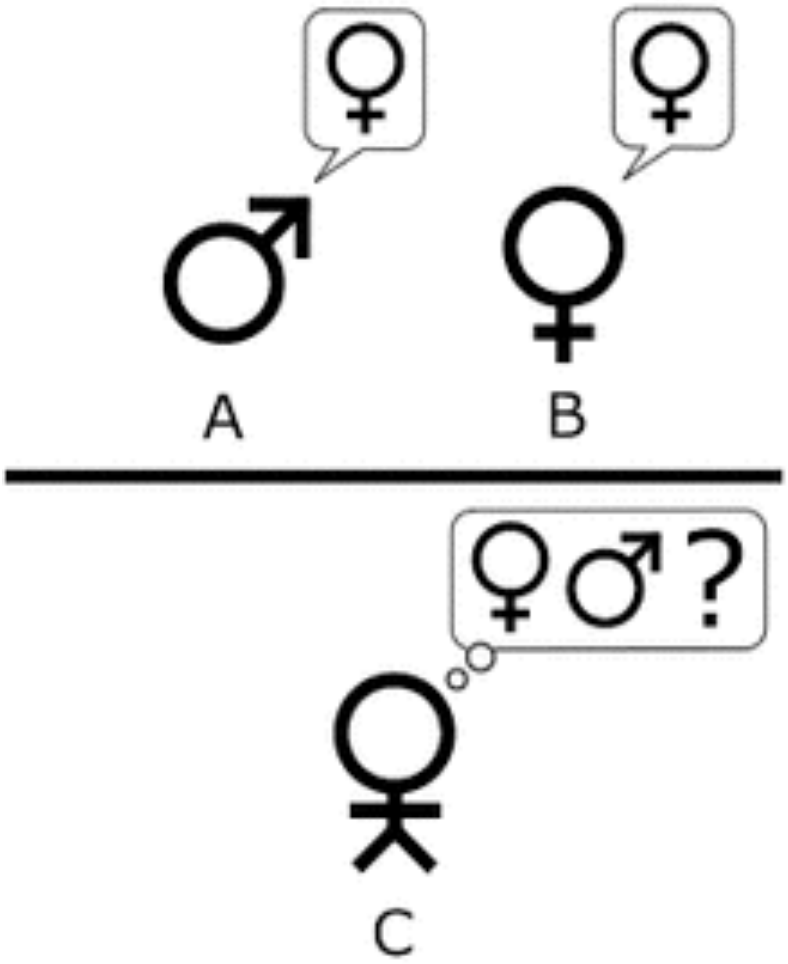
| Thinking Humanly | Thinking Rationally |
| --- | --- |
| **Acting Humanly** | Acting Rationally |

- In 1950, Alan Turing's paper "Computing machinery and intelligence"
  - Instead of asking if machines can think, ask whether they can pass a behavioural intelligence test
- Links:
  - www.turing.org.uk
  - www.alanturing.net

# The Imitation Game

Queen Mary University of London

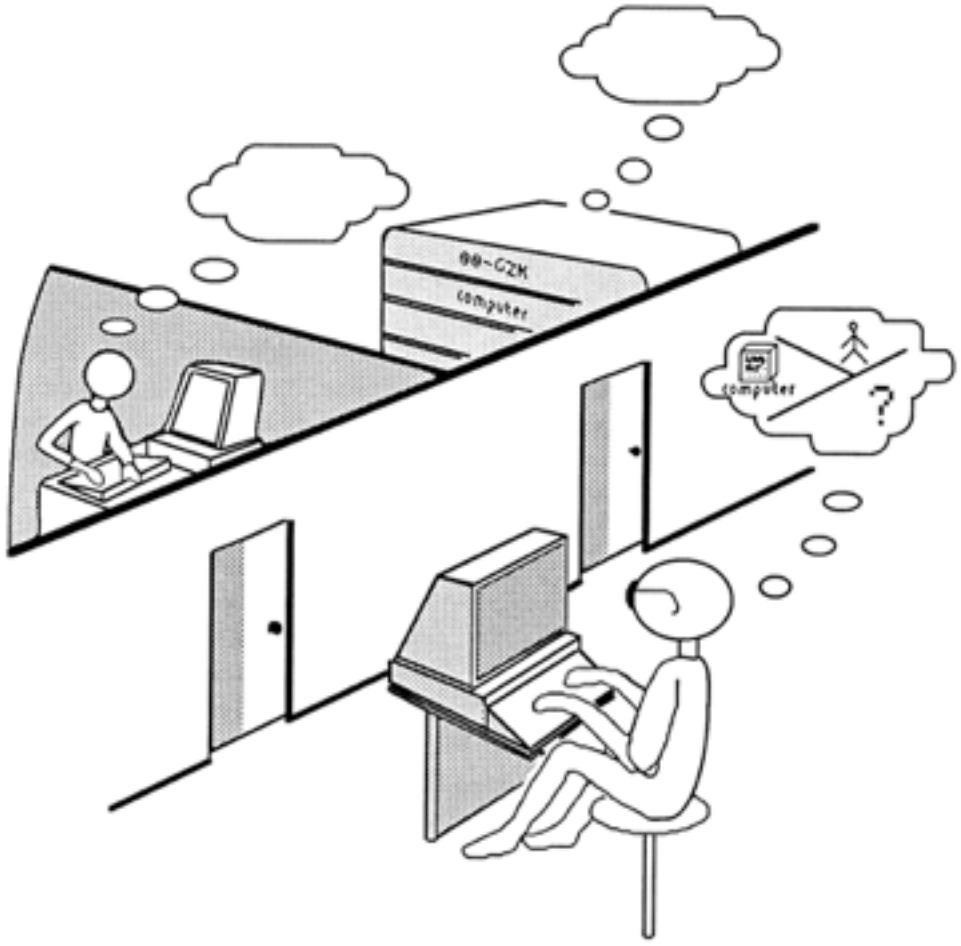
- Turing asked the question "Can machines think?"
  - but because "think" is an ill-defined term, he proposed a thought experiment instead: **The Imitation Game**
  - based on Victorian parlour game where an interrogator guesses the gender of an unseen person



# The Imitation Game

Queen Mary University of London

- Turing asked the question "Can machines think?"
  - but because "think" is an ill-defined term, he proposed a thought experiment instead: **The Imitation Game**
  - based on Victorian parlour game where an interrogator guesses the gender of an unseen person
- In Turing's Game, the human interrogator must decide if an unseen chat partner is human or a computer



# The Imitation Game

Queen Mary University of London

- To convince the interrogator of its intelligence, the computer must
  - understand and generate language
  - know about the world
  - reason about the world
  - learn about the dialogue and the interrogator
  - combine all this knowledge and reasoning instantaneously

# The Imitation Game

Queen Mary University of London

- Turing's paper is usually interpreted as though he is proposing a test for intelligence
  - The Turing Test
- However, he doesn't actually say that in his paper
  - Another interpretation is that this is a thought experiment intended to demonstrate that you can't answer the question "is a machine thinking?"
- Loebner prize for first success
  - See Guardian article for more info

# Thinking Humanly

Queen Mary University of London

**Thinking Humanly**

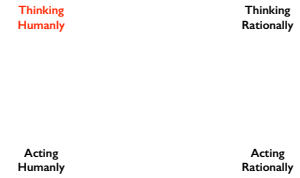
**Thinking Rationally**

**Acting Humanly**

**Acting Rationally**

# Thinking Humanly

Queen Mary University of London




- To build a machine that thinks like a human we must first know how we think, e.g.,
  - through introspection (thinking about how we do it – unscientific)
  - through psychological experiments (proper science)
- A precise theory of mind can be expressed as a computer program:
  - similar I/O and timing behaviour to humans is evidence that similar mechanisms to the program are operating in humans
  - compare trace of reasoning steps of program to that of humans, e.g., the "General Problem Solver" (Newell and Simon, 1961)

# Cognitive Science & the AI Diaspora

Queen Mary University of London

- Cognitive science unites
  - computer models from AI
  - experimental techniques from psychology

  to try to construct precise and testable theories of how the mind works.
- Now a distinct subject from AI
  - Indeed, what once was a unified subject is now a collection of specialised sub-fields, e.g.
    - machine vision
    - natural language processing
    - automated reasoning
    - etc.

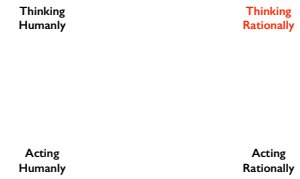
# Thinking Rationally

Queen Mary University of London

| | |
|---|---|
| Thinking Humanly | Thinking Rationally |
| Acting Humanly | Acting Rationally |

# Thinking Rationally

Queen Mary University of London




- Aristotle's syllogisms provided patterns for argument structure that always gave correct conclusions from correct premises, e.g.,

  Socrates is a man

  All men are mortal

  ∴ Socrates is mortal

- Precursor of formal logic that provides a precise notation for statements about things in the world and relations between them.

# "Laws" of Thought

Queen Mary University of London

- By 1965, programs existed that could solve soluble logical problems, given enough time
- Logicist tradition in AI hopes to build on such programs to create intelligent systems
  - logicist emphasis in Russell & Norvig
- Emphasis is on correct inferences. However,
  - formalising knowledge into logic is not easy, especially if that knowledge is uncertain
  - soluble in principle but, in practice, time and memory are limited
  - some problems are *undecidable,* or only *semi-decidable*

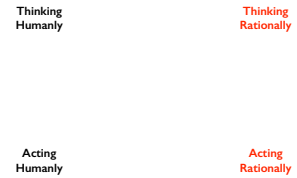
# Thinking and Acting Rationally

Queen Mary University of London

| | |
|---|---|
| **Thinking Humanly** | **Thinking Rationally** |
| **Acting Humanly** | **Acting Rationally** |

# Thinking and Acting Rationally

Queen Mary University of London




- To act rationally means
  - to act so as to achieve one's goals, given one's beliefs
- An agent is something that *acts* (i.e. does things) in the world
  - to do so usefully it also needs to *perceive* the world
- AI can be viewed as the study and construction of rational agents
  - many connections to economics and control theory
- What is the impact of self-consciousness, emotions, desires, love of music, fear of dying, etc ... on human intelligence?

# Rational Agents in AI

Queen Mary University of London

- Extends laws of thought approach:
  - one way to act rationally is to reason logically that a particular action will achieve one's goals and then to perform it
- But acting rationally goes further:
  - when no action is provably correct but some action must be taken
  - when logical reasoning is unnecessary (reflex actions, e.g., pulling hand away from hot stove)
  - not all cognitive skills are purely logical (e.g., visual perception, language comprehension)

# Rational Agents in AI

Queen Mary University of London

- Cognitive skills used in Turing's Imitation game are necessary for rational action (but are they sufficient?)
  - communicating effectively helps an agent get by in a complex society
  - being able to represent knowledge and reason with it enables good decision-making in a wide variety of situations
  - learning about how the world works enables agents to generate more efficient strategies for dealing with it
- This approach sums up AI, because
  - it generalises thinking rationally, which is useful but not always necessary
  - it is scientifically easier than reproducing human thought or human behaviour
  - it equates AI with rational behaviour (clearly defined), rather than human intelligence (much harder to define)

# Origins of AI as a research field

Queen Mary University of London

- Philosophy
  - logic, methods of reasoning, mind as physical system, foundations of learning, language, rationality
- Mathematics
  - formal representation and proof, algorithms, computation, decidability, tractability, probability
- Psychology
  - adaptation, phenomena of perception and motor control, experimental techniques (psychophysics, etc.)
- Linguistics
  - knowledge representation, grammar
- Neuroscience
  - physical substrate for mental activity
- Control theory
  - stability, simple optimal agent designs, homeostatic* systems

* ***Homeostasis:*** *The ability or tendency of an organism or cell to maintain internal equilibrium by adjusting its physiological processes.*

# A Brief History of AI

Queen Mary University of London

- McCulloch and Pitts (1943)
  - proposed model of artificial neurons characterised as either on or off; switched on in response to stimulation of sufficient number of neighbouring neurons
  - showed that any computable function is computable by some network of connected neurons; logical connectives implemented by simple net structures
- Early 1950s
  - Christopher Strachey wrote first working AI program for Ferranti Mark 1 computer: draughts
  - Claude Shannon & Alan Turing wrote chess programs (1950ish)
  - Marvin Minsky & Dean Edmonds built first neural network (SNARC) (1951)

# Early Enthusiasm

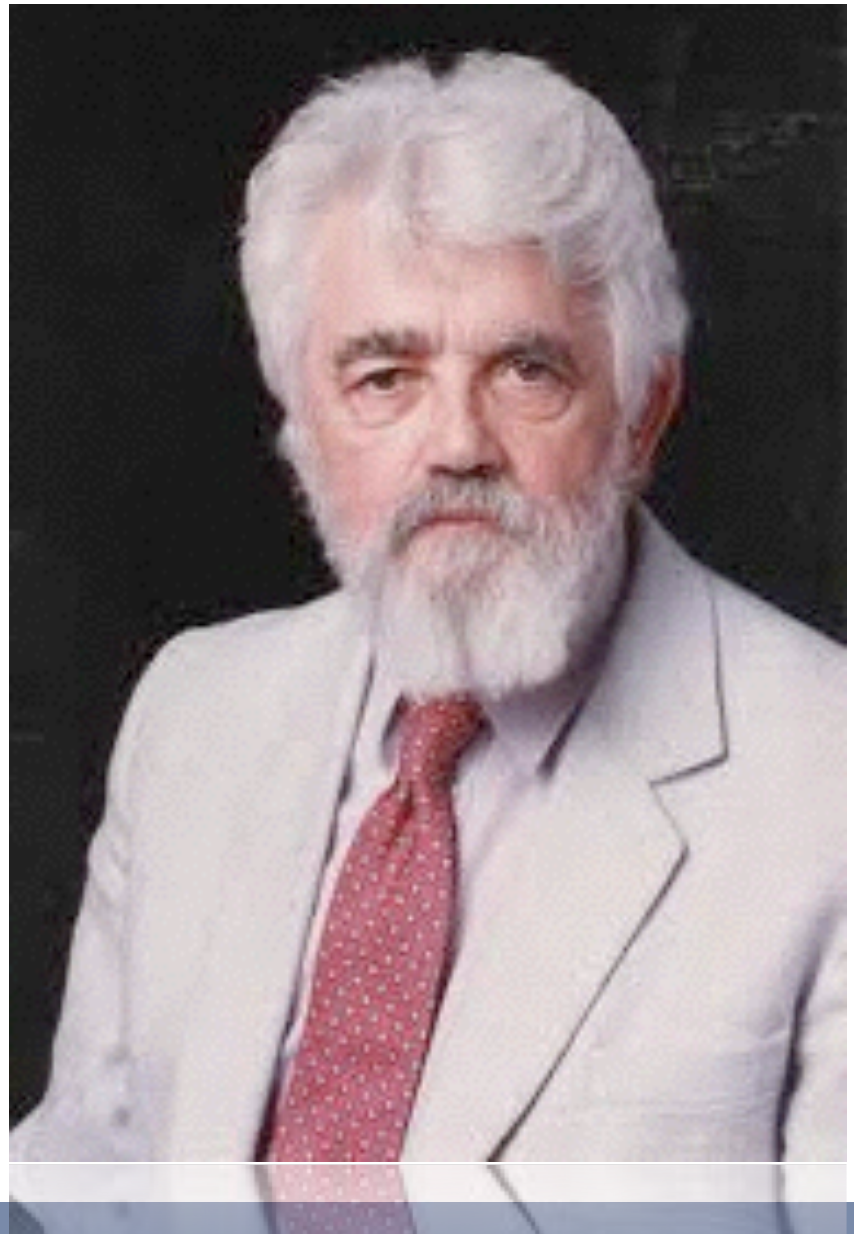
Queen Mary University of London

- 1952 Arthur Samuel's checkers (draughts) program
  - wrote a program to play checkers that reached tournament level
  - disproved idea that computers could not do more than they are told since the program quickly learned to beat its creator
- 1956 conference at Dartmouth College, New Hampshire
  - John McCarthy coined phrase "Artificial Intelligence"
  - Newell and Simon presented a reasoning program (Logic Theorist) that could prove theorems (from Newton's Principia Mathematica)

# Early Enthusiasm

Queen Mary University of London

- 1958 John McCarthy
  - defined high-level symbolic language LISP
    - still used in AI programming in USA
  - invented time-sharing operating systems to enable better access to scarce and expensive computing resources
  - hypothesised the *Advice Taker*, a complete AI system that used knowledge to search for solutions to problems
  - stressed representation and reasoning in formal logic



# Early Enthusiasm

Queen Mary University of London

- 1963–1968 Marvin Minsky's "microworlds"
  - solved closed-form integration problems from first-year calculus courses
  - solved geometric analogy problems from IQ tests
  - solved algebra story problems (e.g., if my father were twice as old as I am now...)
  - More interested in getting programs to work than in theory (cf McCarthy)

# A Dose of Reality (Maybe)

Queen Mary University of London

- 1966–1974, the wildly optimistic predictions for AI failed to materialise
  - programs only worked for simple examples, e.g., Weizenbaum's ELIZA program apparently engages in serious conversations but actually just borrows and manipulates sentences typed in by humans. (http://www-ai.ijs.si/eliza/eliza.html)
  - problems with scalability weren't properly understood
  - Minsky and Papert's book "Perceptrons" (1969) showed that single layer neural networks were incapable of representing XOR
  - general purpose problem solving methods were too weak to solve problems in complex domains
  - UK National Research Council cut AI funding after Lighthill Report (1973)

# A Dose of Reality (Maybe)

Queen Mary University of London

- 1966–1974, the wildly optimistic predictions for AI failed to materialise
  - programs only worked for simple examples, e.g., Weizenbaum's ELIZA program apparently engages in serious conversations but actually just borrows and manipulates sentences typed in by humans. (http://www-ai.ijs.si/eliza/eliza.html)
  - problems with scalability weren't properly understood
  - Minsky and Papert's book "Perceptrons" (1969) showed that single layer neural networks were incapable of representing XOR
  - general purpose problem solving methods were too weak to solve problems in complex domains
  - UK National Research Council cut AI funding after Lighthill Report (1973)

# Coming of Age

Queen Mary University of London

- The maturing of AI came through the development of knowledge-based systems that use:
  - knowledge more suited to making larger reasoning steps
  - more problem-specific domain knowledge
  - narrow area of expertise
  - rules obtained from expert practitioners
- Older AI technology is now part of mainstream computer science
- There is also more emphasis on
  - building on existing theories rather than proposing brand new ones
  - basing claims on rigorous theorems or hard experimental evidence rather than intuitions
  - showing relevance to real world applications rather than toy examples

# Recent events

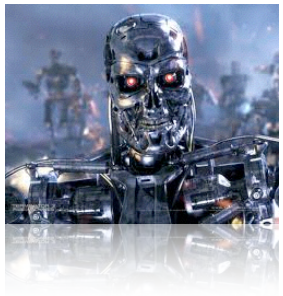
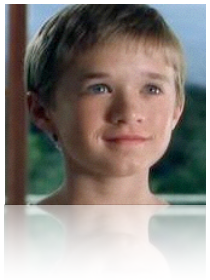
Queen Mary University of London

- The ups and downs of AI have resulted in changes to both content and methodology of AI research
- Recent years have seen a boom in data-driven solutions using deep learning technologies for:
  - Automatic speech recognition
  - Image recognition
  - Natural language processing
  - Recommendation systems
  - Bioinformatics
- AI research is flourishing, with major industry players (Google, Microsoft, IBM, Apple, Facebook, etc.) taking the lead

# AI in Fact and Fiction

Queen Mary University of London

- AI in Entertainment
  - Movies
    - Metropolis (1927)
    - 2001: A Space Odyssey (1968)
    - Bladerunner (1982)
    - The Terminator (1984)
    - AI (2001)
    - I, Robot (2004)
  - TV
    - Star Trek: The Next Generation (Lieutenant Commander Data; 1987-94)
    - Battlestar Galactica (The Cylons; 1978, 2004-5)

# AI in Fact and Fiction

Queen Mary University of London

- Books
  - Do Androids Dream of Electric Sheep (1968) by Philip K.Dick
  - Neuromancer (1984) by William Gibson (coined term "cyberspace")
  - Hyperion (1989) by Dan Simmons
  - Cryptonomicon (1997) by Neal Stephenson (nanotechnology)
  - The Diamond Age (1998) by Neal Stephenson (early wifi, cryptography)
  - Thinks... (2001) by David Lodge
- Robot pets
  - Tamagotchi

# AI in Fact and Fiction

Queen Mary University of London

- Video Games
  - Halo
    - Non Player Characters with real time perceptions of their environment
    - Knowledge of the state of the world, as last perceived
    - Emotions based on events
    - Decision making capability

# AI in Fact and Fiction

Queen Mary University of London

- Video Games
  - Halo
    - Non Player Characters with real time perceptions of their environment
    - Knowledge of the state of the world, as last perceived
    - Emotions based on events
    - Decision making capability
  - Black and White
    - Characters learn from feedback from player
    - Emergent unscripted behaviour

# AI in Fact and Fiction

Queen Mary University of London

- Video Games
  - Halo
    - Non Player Characters with real time perceptions of their environment
    - Knowledge of the state of the world, as last perceived
    - Emotions based on events
    - Decision making capability
  - Black and White
    - Characters learn from feedback from player
    - Emergent unscripted behaviour
  - The Sims
    - Toggle "free will" on and off
    - Agents climb peaks of a "happiness landscape"

# AI in Fact and Fiction

Queen Mary University of London

- Strategy game successes
  - (3D) Noughts and Crosses
  - Connect-4
  - Othello/Reversi
  - Checkers (Chinook, 1994; fully solved 2007)
  - Backgammon (TD Gammon, 1995)
  - Scrabble (MAVEN, 1986-1998)
  - Poker (Polaris, 2008)
  - Go (AlphaGo, 2016)
  - Bridge (Jack, WBridge5, ??)

# Artificial Intelligence Futures

Queen Mary University of London

- Everyday applications
  - cars – cruise control, fuel injection, driverless cars
  - planes – autopilots and lower-level control systems
  - lawnmowers & vacuum cleaners
  - washing machines
  - environmental control – light, thermostats, etc.
- Large scale applications
  - military strategy planning – Desert Storm
  - prevention of mid-air collisions between planes
  - disaster recovery services – 9/11
  - Deep Space 1 – remote agent experiment

# The Robocup Challenge

Queen Mary University of London

- Design a team of robots that can play soccer against other robots
  - this clip is from 2011

# The Big Questions

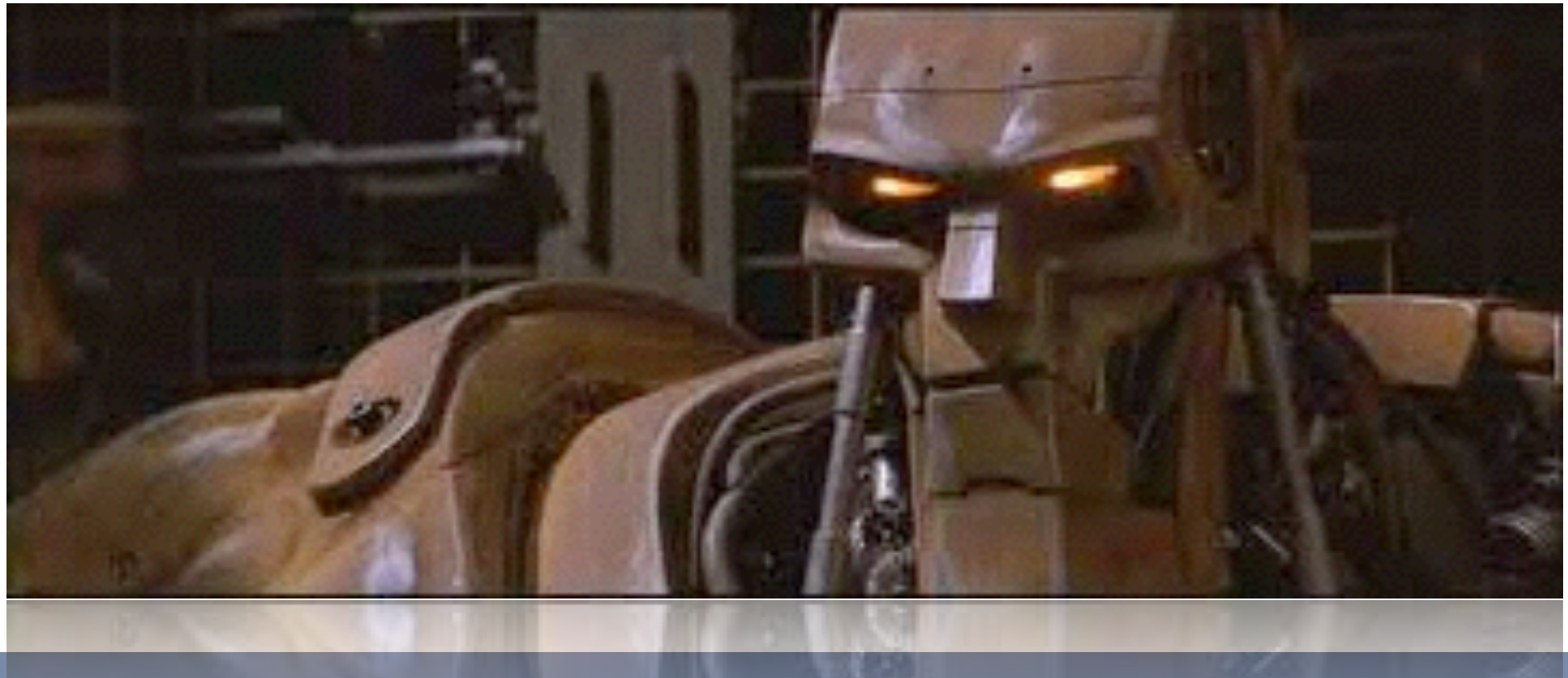
Queen Mary University of London

- What is AI, really?
  - Can machines really be said to think?
  - What does an intelligent system look like?
  - Does an AI need—and can it have—emotions and consciousness?
- Can we ever achieve AI, even in principle?
  - How will we know if we've done it?
  - If we can do it, should we?

# A warning?

Queen Mary University of London

- In many sci-fi stories, the robots take over
- But we can always unplug...



# Past **Exam**ple Question

Queen Mary University of London

*Note that I do NOT ask the same questions every year!*

- Q1a (2016): The Turing Test has been proposed as a test for computational intelligence. Explain what the test is, and describe what capabilities an AI system would need in order to pass the test. [9 marks]

- Answer A: During the test, a human participant will have a text conversation with either a human or a computer, and no participants knows whether it is a computer or a human. Another human participant observes the conversation while not knowing the identity of either of the "speaker". The observer shall decide if each of the speaker is a human or a computer. To pass the test, an AI system

*How many marks does this answer deserve?*

# Past **Exam**ple Question

Queen Mary University of London

- Q1a (2016): The Turing Test has been proposed as a test for computational intelligence. Explain what the test is, and describe what capabilities an AI system would need in order to pass the test. [9 marks]

- Answer B: The Turing Test is based on a Victorian game in which the player had to decide the gender of two people by asking them questions without seeing them. In the Turing Test a person has to guess if it is talking to a computer or another person by asking questions, obviously the person who is "playing" can't see the interlocutors. In order to pass this test, the computer would have to think as a human, it would have to give plausible answer to the questions asked, answers that have rational and humane factors. The system would have to have to have a good way to make sense of language (linguistics), in order to understand what was asked, a way of delivering output, i.e. answering, and a good manner of formulating answers as a human would.