comp4620/8620: Advanced Topics in AI
Foundations of Artificial Intelligence

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Abstract: Motivation

The dream of creating artificial devices that reach or outperform human intelligence is an old one, however a computationally efficient theory of true intelligence has not been found yet, despite considerable efforts in the last 50 years. Nowadays most research is more modest, focussing on solving more narrow, specific problems, associated with only some aspects of intelligence, like playing chess or natural language translation, either as a goal in itself or as a bottom-up approach. The dual, top down approach, is to find a mathematical (not computational) definition of general intelligence. Note that the AI problem remains non-trivial even when ignoring computational aspects.
Abstract: Contents

In this course we will develop such an elegant mathematical parameter-free theory of an optimal reinforcement learning agent embedded in an arbitrary unknown environment that possesses essentially all aspects of rational intelligence. Most of the course is devoted to giving an introduction to the key ingredients of this theory, which are important subjects in their own right: Occam’s razor; Turing machines; Kolmogorov complexity; probability theory; Solomonoff induction; Bayesian sequence prediction; minimum description length principle; agents; sequential decision theory; adaptive control theory; reinforcement learning; Levin search and extensions.
Background and Context

- Organizational
- Artificial General Intelligence
- Natural and Artificial Approaches
- On Elegant Theories of
- What is (Artificial) Intelligence?
- What is Universal Artificial Intelligence?
- Relevant Research Fields
- Relation between ML & RL & (U)AI
- Course Highlights
Organizational – ANU Course COMP4620/8620

- Lecturer: Marcus Hutter, Assistant: Sultan Javed Majeed
- Where: Australian National University
- Register with ISIS or Wattle or Admin or Lecturer.
- Course is based on: book “Universal AI” (2005) by M.H.
- Literature: See course homepage
- Course Homepage: More/all information available at http://cs.anu.edu.au/courses/COMP4620/
**Artificial General Intelligence**

What is (not) the goal of AGI research?
- Is: Build general-purpose *Super-Intelligences*.
- Not: Create AI software solving specific problems.
- Might ignite a technological *Singularity*.

What is (Artificial) Intelligence?

What are we really doing and aiming at?
- Is it to build systems by trial&error, and if they do something we think is smarter than previous systems, call it success?
- Is it to try to mimic the behavior of biological organisms?

We need (and have!) theories which can guide our search for intelligent algorithms.
“Natural” Approaches

copy and improve (human) nature

Biological Approaches to Super-Intelligence

- Brain Scan & Simulation
- Genetic Enhancement
- Brain Augmentation

Not the topic of this course
“Artificial” Approaches

Design from first principles. At best inspired by nature.

Artificial Intelligent Systems:

- Logic/language based: expert/reasoning/proving/cognitive systems.
- Economics inspired: utility, sequential decisions, game theory.
- Cybernetics: adaptive dynamic control.
- Information processing: data compression ≈ intelligence.

Separately too limited for AGI, but jointly very powerful.

Topic of this course: Foundations of “artificial” approaches to AGI
There is an Elegant Theory of ... 

Cellular Automata $\Rightarrow$ ... Computing

Iterative maps $\Rightarrow$ ... Chaos and Order

QED $\Rightarrow$ ... Chemistry

Super-Strings $\Rightarrow$ ... the Universe

Universal AI $\Rightarrow$ ... Super Intelligence
What is (Artificial) Intelligence?

Intelligence can have many faces \(\Rightarrow\) formal definition difficult

- reasoning
- creativity
- association
- generalization
- pattern recognition
- problem solving
- memorization
- planning
- achieving goals
- learning
- optimization
- self-preservation
- vision
- language processing
- motor skills
- classification
- induction
- deduction
- ...

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<th>What is AI?</th>
<th>Thinking</th>
<th>Acting</th>
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<tbody>
<tr>
<td>humanly</td>
<td>Cognitive Science</td>
<td>Turing test, Behaviorism</td>
</tr>
<tr>
<td>rationally</td>
<td>Laws Thought</td>
<td>Doing the Right Thing</td>
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Collection of 70+ Defs of Intelligence
http://www.vetta.org/
definitions-of-intelligence/

Real world is nasty: partially unobservable, uncertain, unknown, non-ergodic, reactive, vast, but luckily structured, ...
What is Universal Artificial Intelligence?

- Sequential **Decision Theory** solves the problem of rational agents in uncertain worlds if the environmental probability distribution is known.

- Solomonoff’s theory of **Universal Induction** solves the problem of sequence prediction for unknown prior distribution.

- Combining both ideas one arrives at

  
  A Unified View of Artificial Intelligence

  =

  Decision Theory = Probability + Utility Theory

  +

  Universal Induction = Ockham + Bayes + Turing

**Group project:** Implement a Universal Agent able to learn by itself to play TicTacToe/Pacman/Poker/…  [www.youtube.com/watch?v=yfsMHtmGDKE](http://www.youtube.com/watch?v=yfsMHtmGDKE)
Relevant Research Fields

(Universal) Artificial Intelligence has interconnections with (draws from and contributes to) many research fields:

- computer science (artificial intelligence, machine learning),
- engineering (information theory, adaptive control),
- economics (rational agents, game theory),
- mathematics (statistics, probability),
- psychology (behaviorism, motivation, incentives),
- philosophy (reasoning, induction, knowledge).
Relation between ML & RL & (U)AI

Universal Artificial Intelligence
Covers all Reinforcement Learning problem types

Statistical Machine Learning
Mostly i.i.d. data
classification, regression, clustering

RL Problems & Algorithms
Stochastic, unknown, non-i.i.d. environments

Artificial Intelligence
Traditionally deterministic, known world / planning problem
Course Highlights

• Formal definition of (general rational) Intelligence.

• Optimal rational agent for arbitrary problems.

• Philosophical, mathematical, and computational background.

• Some approximations, implementations, and applications.
  (learning Tic Tac Toe, PacMan, simplified Poker from scratch)

• State-of-the-art artificial general intelligence.
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