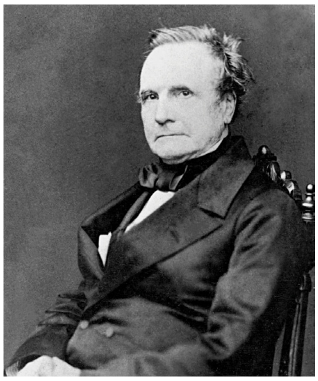
1936
The Turing Machine

Learning Outcomes addressed in this section are listed below.

1.7	develop algorithms to implement key lent chosen solutions
1.12	compare the positive and negative impacts of computing on culture and society
1.13	identify important computing developments that have taken place in the last 100 years and consider emerging trends that could shape future computing technologies
1.14	explain when and what machine learning and AI algorithms might be used in certain contexts
1.18	recognise the diverse roles and careers that use computing technologies
2.5	use pseudo code to outline the functionality of an algorithm
2.8	apply basic search and sorting algorithms and describe the limitations and advantages of each algorithm



Charles Babbage

When other Learning Outcomes are addressed, for instance in classroom activities or through related online resources, the LO is numbered.

The birth of Computer Science and Machine Learning can be traced back to many ideas and early prototypes, such as Babbage's calculating machine in the early 19th century or Hollerith's punch card system from the end of the 19th century. There is however a strong case that Alan Turing's machine laid the foundations for the development of Computer Science and Machine Learning.

In 1936, Alan Turing invented a mathematical model of a universal machine, which later became known as a Turing Machine.

The operation of the machine is a simple concept.

Despite its apparent simplicity, a Turing Machine can be constructed to solve any given computer algorithm.[1] It is in this sense, the first concept of a universal, all-purpose, computing machine. It provides computer science with a firm scientific foundation, since it offers a model of computation which can be tested against real world applications.

Classroom Activity

To demonstrate an algorithm on the Turing Machine with an unplugged version of the addition of two numbers.

A Turing Machine can, in theory, execute any algorithm a modern computer can execute. The Turing Machine, shown below, consists of an infinitely long paper tape comprising an infinite number of cells. A read/write head points to a particular cell at any given time. There are only 3 operations that can be performed on the tape:

1. Read the value
2. Write a new value (0,1, BLANK)
3. Move the read/write head to the next cell.

The # symbol in the diagram below will be interpreted in this case as ADD. The machine itself is oblivious to the symbol, as the algorithm is deciding that # in this case means addition. An example of the steps of an algorithm to perform 2 + 3 are outlined below. The values, 2 and 3, are bookended by blanks. **We want to end our execution of the algorithm with five 1's in a row, bookended by BLANKs.**

Demonstrate the operation of the pseudocode below to students before assigning roles.

How to explain the importance of the Turing Machine? Visit runestone academy

Use the classroom unplugged activity below to perform the addition of 1 + 2 on a Turing Machine.

LO 1.3–1.8, **1.13**
LO 2.5

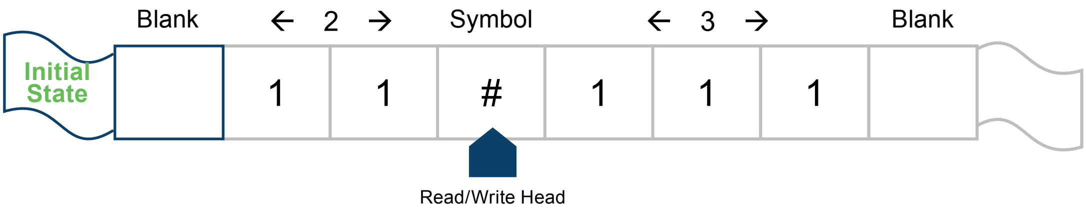
Learn how to assemble another unplugged algorithm.

An unplugged punch card lesson, with video demonstration. From the teachinglondoncomputing website.

LO 1.7
LO 2.8

1 Sipser (2006) *Introduction to the Theory of Computation* Thomson Course Technology, USA.

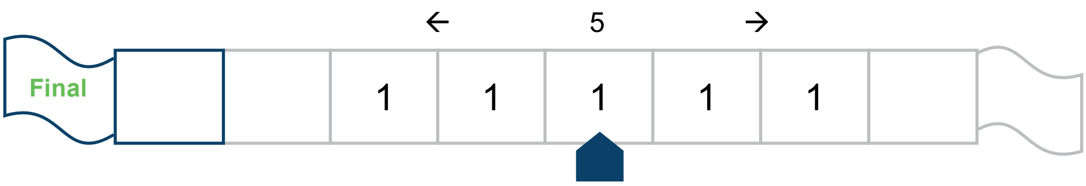
1. Draw a representation of the infinite tape on a whiteboard (or any display board). The initial state is shown below.



2. Move LEFT; Read the value;
   REPEAT until the value == BLANK {
   Write 0;
   Move LEFT;
   Read the value;
   }

3. Move RIGHT; Write a BLANK;
   Move RIGHT; Read the value;

4. REPEAT until the value == 1 {
   Write 1;
   Move RIGHT;
   Read the value;
   }



The classroom activity requires 3 students to execute individual operations at the whiteboard. Another group, which could be the rest of the class, ensure the steps of the algorithm are carried out correctly. They are the control unit.

The 3 people with specific individual roles are:

The READER

The role is to read the value in the cell where the read/write head is pointing. The Reader must read out the value from the whiteboard as instructed, even if the algorithm is operating incorrectly.

The WRITER

The role is to write a value into the cell where the read/write head is pointing. The state of the Turing machine will be updated by the writer on the whiteboard.

The read/write HEAD

The role is to re-draw the position of the read/write head on the whiteboard, according to the instructions issued by the control unit. The head can be represented by the shape shown in the example, or any similar symbol that is appropriate.

The challenge is to carry out the addition of any two natural numbers. For example, 2+1 or 2+5 or 3+3.

A further challenge, at an appropriate stage of the course, could be to program the algorithm in Python or JS with a suitable UI, to carry the out the addition of any two user-defined natural numbers.

Turing Machine Addition Activity

The activity addresses a range of LOs.

In particular:

- Computational Thinking LOs in Strand 1 (**LO 1.1–1.10**)
- Computers and Society LOs in Strand 2 (**LO 1.13–1.14**)
- Algorithm LOs in Strand 2 (**LO 2.5–2.7**)

Watch a video showing basic arithmetic on the Turing machine. The algorithm for addition is in the first minute.

Explain how it is different to the algorithm in the classroom activity.

Brain Buster

Alan Turing was also fascinated by such a machine's ability to think

"The original question, "Can machines think?", I believe too meaningless to deserve discussion. Nevertheless I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted."

Computing Machinery and Intelligence. Turing (1950)

After reading the quote in the Brain Buster, was Alan Turing's belief correct? **Facilitate a walking debate or TPSS activity.**

LO 1.13, 1.14

What is Artificial Intelligence (AI)?

Humans have been thinking about AI for many centuries. The term Artificial Intelligence was only coined in 1955 by John McCarthy as: "the science and engineering of making intelligent machines." The following year, 1956, it was founded as an area of academic research during a workshop in Dartmouth College.[2] The goal of AI is to teach computers to do things that humans do, only better. One of those key things is learning. Machine Learning is therefore in some ways a subset of AI, but it has grown so rapidly in the early 21st century that some people argue it has outgrown AI.

Alan Turing was also famous for the Turing test.

Can you tell the AI from the human in these short breakthrough phone calls released at a Google IO event in 2018?

What do you think the T in the abbreviation CAPTCHA stands for?

Machine Learning (ML) Algorithms

There are 2 broad categories of ML: supervised and unsupervised. For example, let's consider items needing to be sorted into waste and recyclables. Supervised learning would require humans to examine the categorisation performed by the algorithm and tell the algorithm, using labels, which items have been incorrectly sorted. An unsupervised algorithm will identify patterns in both the input and output, perhaps correlating existing categorisation, with statistical analysis, to sort the items. Both systems improve, but in different ways.

2 https://en.wikipedia.org/wiki/History_of_artificial_intelligence

The following links give 3 examples of each of the 2 main categories of Machine Learning.

Supervised Learning uses training (input) data and if certain outputs are incorrect, the algorithm is notified not to output this in future. It relies on good data and some feedback.

Unsupervised Learning allows the algorithm to spot patterns and decide itself which outputs are most useful. It does not rely on feedback.

Within these categories there are five popular schools of machine learning algorithms[3]:

1. **SYMBOLISTS**

This is closely related to mathematical thinking. They believe all intelligence can be reduced to manipulating symbols. By combining pre-existing knowledge with new data, and incorporating it into the machine, new learning will take place.

2. **CONNECTIONISTS**

This is related to neuroscience. They believe that strengthening connections between neurons/logic gates will improve the machine's learning and similarly eliminating connections that cause errors in outputs. By looking at the output and comparing it to the correct output, the connections that require modification can be identified. This is known as backpropagation.

3. **EVOLUTIONARIES**

This is related to evolution by natural selection. The concept of genetic programming is very strong where the best programs are merged together evolving into better programs. The less successful programs are disposed of creating a constantly evolving structure capable of new learning.

4. **BAYESIANS**

This is related to a theorem in probability called Bayes Theorem. Bayesians, using probability, combine new evidence with existing beliefs to infer new ideas. Learning itself, they believe, is uncertain knowledge.

5. **ANALOGISERS**

By comparing two things which have similarities, perhaps other characteristics are similar. For example if two patients share symptoms, perhaps they have the same underlying illness. By remembering the correct situations, and combining those things that are similar, new learning can be achieved.

Learning Opportunity: The types and uses of Machine Learning

Watch an in-depth video on the categories and uses of Machine Learning.

Now examine and discuss when machine learning and AI algorithms might be used in certain contexts.

LO 1.14

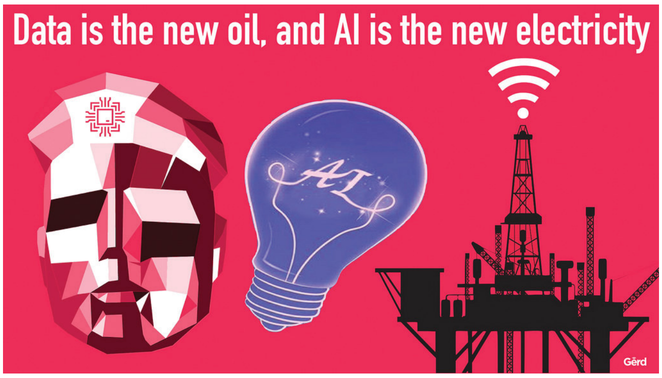
3 Domingos (2015) *The Master Algorithm* Penguin Books

What is Driving the AI and Machine Learning Expansion?

AI and Machine Learning systems have been around for decades yet the self-driving car, for example, has only become a possibility in the second decade of the 21st century. Why? Why this seemingly sudden explosion.

- Have humans become better at designing algorithms?
- Is a computer's processing of the real world now approximating a human's?
- Are there more quantities of useful data available to humans and computers?
- Is the rapid expansion going to continue? What are the emerging trends?

Predicting future trends and technologies is extremely difficult.



In 1973, the invention of wifi and radio technology made mobile phones possible.

How difficult would it have been back then, to predict the future technologies available 40 years later in 2013? In 40 years time how will technology shape our world? What trends will underpin that technology.

"The bits explosion is not over. We are in the middle of it. But we don't know whether it will be destructive or enlightening. The time for deciding who will control the explosion may soon be past. Bits are still a new phenomenon — a new natural resource whose regulatory structures and corporate ownership are still up for grabs. The legal and economic decisions being made today, not just about bits but about everything that depends on bits, will determine how our descendants will lead their lives. The way the bits illuminate or distort the world will shape the future of humanity." [4]

Data, Algorithms and Processing Power

Take the Crash Course on AI and Machine Learning.

Facilitate a discussion around the rapid expansion of AI technologies, and the reasons behind the expansion.

LO 1.13, 1.14

One trend being widely predicted is the area of quantum computing. Watch a short video on Quantum Computing.

Classical versus Quantum Computers... a 10 minute explanation.

LO 1.13, 1.14

4 Abelson, Ledeen, Lewis (2008) Blown to Bits Addison-Wesley.