Artificial Intelligence

Introduction

Deepak Khemani

The Syllabus

Introduction: Overview and Historical Perspective, Turing test, Physical Symbol Systems and the scope of Symbolic AI, Agents.

State Space Search: Depth First Search, Breadth First Search, DFID.

Heuristic Search: Best First Search, Hill Climbing, Beam Search, Tabu Search.

Randomized Search: Simulated Annealing, Genetic Algorithms, Ant Colony Optimization.

Finding Optimal Paths: Branch and Bound, A*, IDA*, Divide and Conquer approaches, Beam Stack Search:

Problem Decomposition: Goal Trees, AO*, Rule Based Systems, Rete Net.

Game Playing: Minimax Algorithm, AlphaBeta Algorithm, SSS*.

Planning and Constraint Satisfaction: Domains, Forward and Backward Search, Goal Stack Planning, Plan Space Planning, Constraint Propagation.

Logic and Inferences: Propositional Logic, First Order Logic, Soundness and Completeness, Forward and Backward chaining.

Text Book and References

Text Book

Deepak Khemani. A First Course in Artificial Intelligence, McGraw Hill Education (India), 2013.

Reference Books

Stefan Edelkamp and Stefan Schroedl. Heuristic Search: Theory and Applications, Morgan Kaufmann, 2011.

John Haugeland, Artificial Intelligence: The Very Idea, A Bradford Book, The MIT Press, 1985.

Pamela McCorduck, Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence, A K Peters/CRC Press; 2 edition, 2004.

Zbigniew Michalewicz and David B. Fogel. How to Solve It: Modern Heuristics. Springer; 2nd edition, 2004.

Judea Pearl. Heuristics: Intelligent Search Strategies for Computer Problem Solving, Addison-Wesley, 1984.

Elaine Rich and Kevin Knight. Artificial Intelligence, Tata McGraw Hill, 1991.

Stuart Russell and Peter Norvig. Artificial Intelligence: A Modern Approach, 3rd Edition, Prentice Hall, 2009.

Patrick Henry Winston. Artificial Intelligence, Addison-Wesley, 1992.

History and Philosophy of AI

The two books mentioned below give an insightful and entertaining account of the history and philosophy of AI.

"AI: The Very Idea"

by John Haugeland

http://philosophy.uchicago.edu/faculty/haugeland.html

"Machines Who Think"

by Pamela McCorduck

http://www.pamelamc.com/html/machines_who_think.html

Some definitions

We call programs intelligent if they exhibit behaviors that would be regarded intelligent if they were exhibited by human beings.

– Herbert Simon

Physicists ask what kind of place this universe is and seek to characterize its behavior systematically. Biologists ask what it means for a physical system to be living. We in AI wonder what kind of information-processing system can ask such questions.

– Avron Barr and Edward Feigenbaum

AI is the study of techniques for solving exponentially hard problems in polynomial time by exploiting knowledge about the problem domain.

– Elaine Rich

AI is the study of mental faculties through the use of computational models.

– Eugene Charniak and Drew McDermott

Machines with Minds of their Own

"The fundamental goal of Artificial Intelligence research is not merely to mimic intelligence or produce some clever fake.

Not at all.

"AI" wants the genuine article: machines with minds, in the full and literal sense.

This is not science fiction, but real science, based on a theoretical conception as deep as it is daring: namely, we are at root, computers ourselves.

That idea – the idea that thinking and computing are radically the same – is the idea of this book."

John Haugeland in "AI: The Very Idea"

Some fundamental questions

What is intelligence?

What is thinking?

What is a machine?

Is the computer a machine?

Here on when we say machine we will mean a programmable computer system

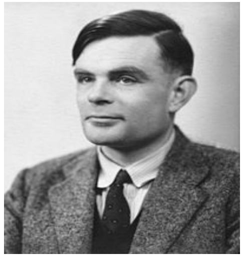
Can a machine think ?

If yes are we machines?!

The raging debates over Thinking Machines

- Herbert Dreyfus: "..intelligence depends upon unconscious instincts that can never be captured in formal rules"
  - http://en.wikipedia.org/wiki/Dreyfus%27_critique_of_artificial_intelligence
  - Made a career opposing the possibility of machine intelligence
- John Searle: The Chinese Room argument – can an agent locked in a room processing questions in Chinese based on a set of syntactic rules be said to *understand* Chinese?
  - How many rules will the agent need to have for the thought experiment to be convincing?
- Roger Penrose: "..there is something (quantum mechanical) going on in our brains that current day physics cannot explain"
- Other arguments based on Emotion, Intuition, Consciousness, Ethics etcetera.

Alan Turing's Imitation Game

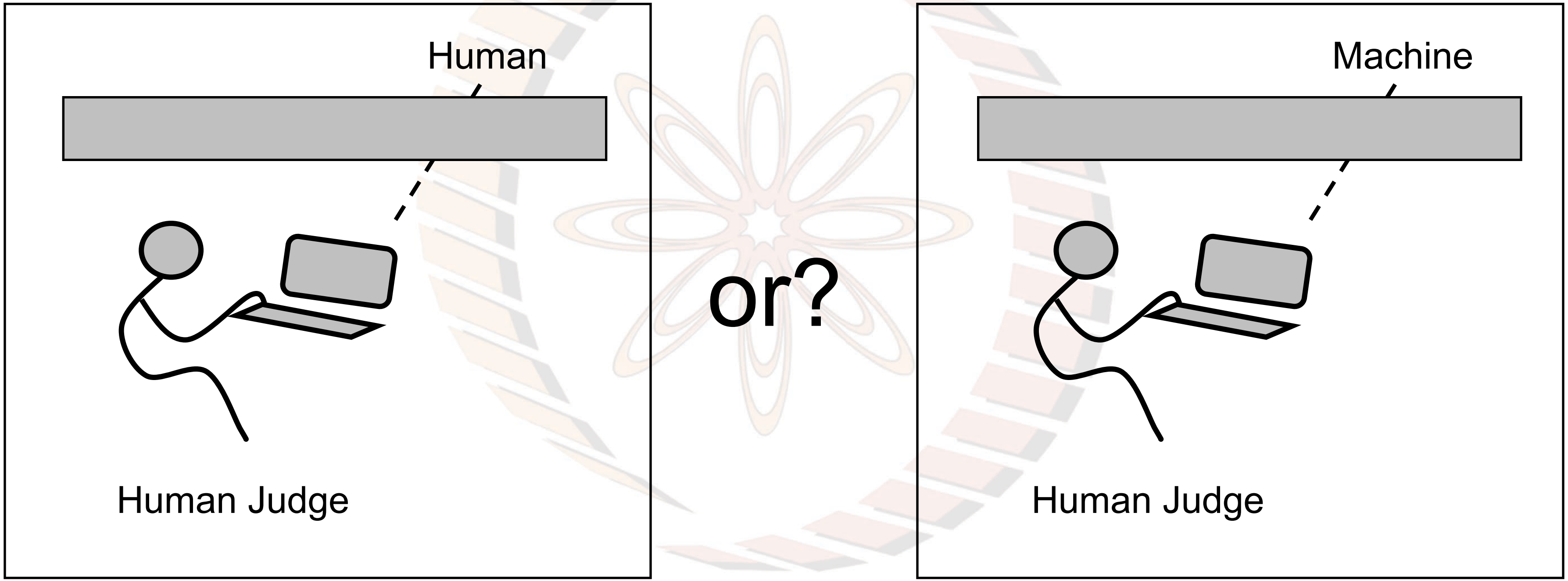


Alan Turing (1912 – 1954)

http://en.wikipedia.org/wiki/Alan_Turing

- The question whether machines can think itself "too meaningless"
- Prescribed a test which he called the *Imitation Game* which is now known as *The Turing Test*
- *"I believe that in about fifty years' time it will be possible to programme computers, with a storage capacity of about 10^9, to make them play the imitation game so well that an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning. … 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*"
  - Turing, A.M. (1950). Computing machinery and intelligence. Mind, 59, 433-460. http://www.loebner.net/Prizef/TuringArticle.html

The Turing Test



The Loebner Prize – an annual competition where chatbots are judged for human like response. The grand prize of USD 100,000 is still open.

The Loebner Prize 2013

Four finalists to compete on Sept 14, 2013

Excerpts from the leader *Izar*

IZAR TRANSCRIPT

JUDGE: Hello I'm Ronan. What is your name?

IZAR: Ronan! It's about time you contacted me! I was waiting for you! My name is Izar pronounced I zar, but you can call me Izzy if you want. Doing anything fun? Too much recursion in AIML

. . .

JUDGE: I like bananas. Which is your favorite fruit?

IZAR: Tell me more about your unknown. You are not the only one. I don't have a problem with bananas. Is that your favorite fruit? The obvious one. Does that remind you of unknown??

JUDGE: What music do you like?

IZAR: I like many kinds of human music, but recently, I've been getting into Hoomii, a type of Mongolian throat singing. Why? What kind of music do you like?

ELIZA

….named after Eliza Doolittle, a working-class character in George Bernard Shaw's play *Pygmalion*,

ELIZA was a simple natural language processing program written at MIT by Joseph Weizenbaum around 1966.

It had simple rules to manipulate language and would essentially modify the users input to generate its response. A popular version called Doctor was running a script designed to make respond like a Rogerian psychotherapist.

A Russian scientist chatting with Doctor at Stanford

Doctor: What brought you here to see me today?
Visitor: Oh, nothing much. I’m feeling a bit tired, that’s all.
Doctor: Why do you think you’re feeling a bit tired.
Visitor: Well I’ve been traveling a lot, and away from home.
Doctor: Tell me about your family.

Weizenbaum found people’s responses to the program disturbing and wrote a book highlighting the limitations of a computer!

Computer Power and Human Reason: From Judgment to Calculation

Willing suspension of disbelief

The fact that a man made artifact could respond to human input easily leads humans to make a leap of faith and conclude that it responds intelligently and knowledgeably.

In Hellenic Egypt people believed that statues that moved and gestured has a sort of a soul that could represent a god or a dead person and communicate through a priest.

Such practices continue to this day

In medieval times Europe the art of making clocks decorated with animated figures was very popular, and added much credence to the belief that learned men kept robots. To most people, there could be little difference between a human figure that nodded, bowed, marched, or struck a gong at a precise and predictable moment, and a human figure that answered knotty questions and foretold the future.

- Pamela McCorduck in *Machines Who Think*

Artificial People (Western mythology and fiction)

- In Homer's *Illiad* Hephaestus
  - created Talos, a man of bronze to patrol the beaches of Crete
  - created Pandora who, commissioned by Zeus to punish mankind for accepting Prometheus's gift of fire, overcome by curiosity opens the infamous casket

- Pygmalion, disappointed by real women, created Galatea in ivory, and Aphrodite obliges him by breathing life into Galatea

- Daedalus is credited with creating lifelike statues that wheezed and blinked, and scuttled about, impressing everyone.

- Pope Sylvester II (946 – 1003) is said to have made a statue with a talking head, with a limited vocabulary, and a penchant for predicting the future; on being asked a query about the future it would reply yes or no

Artificial People (continued)

http://en.wikipedia.org/wiki/Paracelsus

Paracelsus (1493 –1541) a prominent physician is said to have invented a *humunculus*, a little man.

"We shall be like gods … we shall duplicate God's greatest miracle – the creation of man"

Paracelsus:
Born 11 Nov or 17 Dec
Philip von Hohenheim
Egg, near Einsiedeln, Old Swiss Confederacy
(present-day Switzerland)

Judah Loew ben Bezalel (1520 –1609) is reported to have sculpted a living man from clay, named Golem, to defend the Jews of Prague. He alone could instruct him.

In Jewish folklore, a golem is an animated anthropomorphic being, created entirely from inanimate matter.

http://en.wikipedia.org/wiki/Golem

Real Mechanisms

In 802 A.D. the Emperor Haroun-al-Rashid is said to have presented Emperor Charlemagne with an elaborate clock which sent out a dozen cavaliers from a dozen windows each noon and sent them back again.

A group of Arab astrologers is credited with constructing a thinking machine called the *zairja* which was designed "to generate ideas by mechanical means.. with the help of the technique called the technique of 'breaking down'" (i.e. *al-jabr* → algebra). By combining number values associated with the letters and categories, new paths of insight and thought were created." https://en.wikipedia.org/wiki/Zairja

The *zairja* caught the imagination of the Catalonian missionary Ramon Lull (1232 – 1315) who decided to build a Christian version called the Ars Magna – *"to bring reason to bear on all subjects and, and in this way, arrive at truth without the trouble of thinking or fact finding"*

- Pamela McCorduck in *Machines Who Think*

Real Mechanisms continued

By the middle of the fourteenth century, large elaborate clocks with moving figures had become public monuments – Strasbourg, Nurnberg, Lubeck and Berne followed the Italian cities with them – and talking brass heads had become closely associated with learned men.

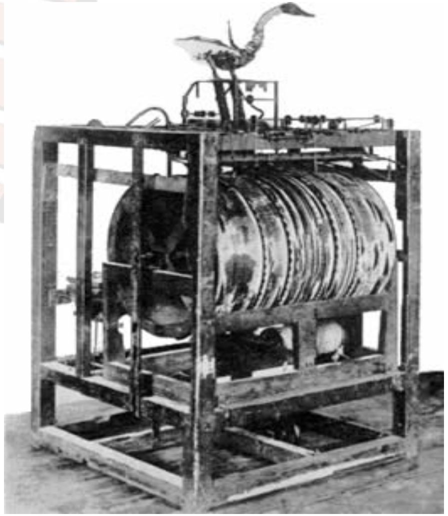
The Archbishop of Salzburg built a working model of a complete miniature town, all operated by water power from a nearby stream

Vaucanson's Duck

Jacques de Vaucanson (1709 – 1782) was a French inventor and artist who created several mechanical automata.

In 1727, he made an android that would serve dinner and clear the tables for the visiting politicians. However one government official declared that he thought Vaucanson's tendencies "profane", and ordered that his workshop be destroyed.

His most famous creation was the duck created in 1739. The mechanical duck ("*Who drinks, eats, quacks, splashes about on water, and digests his food…*") appeared to have the ability to eat kernels of grain, and to metabolize and defecate them. While the duck did not actually have the ability to do this—the food was collected in one inner container, and the pre-stored feces was 'produced' from a second, so that no actual digestion took place—Vaucanson hoped that a truly digesting automaton could one day be designed.

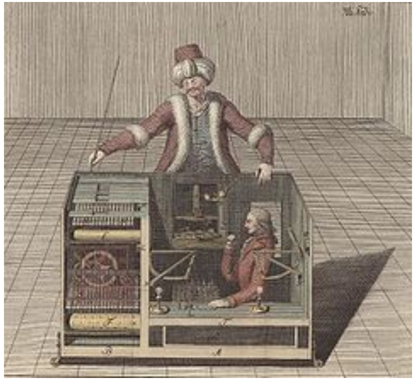


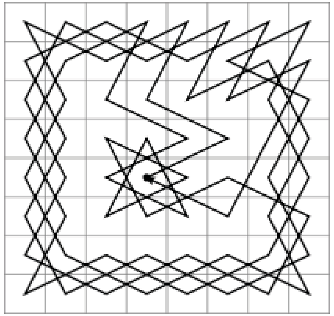
Source: http://en.wikipedia.org/wiki/Digesting_Duck

Von Kempelen’s Chess Playing Turk

Wolfgang von Kempelen (1734 – 1804) is most well known for chess playing machine also known as the *Mechanical Turk.* Constructed and unveiled in 1770 by von Kempelen to impress the Empress Maria Theresa of Austria, the mechanism appeared to be able to play a strong game of chess against a human opponent, as well as perform the knight's tour.

The Turk was in fact a mechanical illusion that allowed a human chess master hiding inside to operate the machine. With a skilled operator, the Turk won most of the games played during its demonstrations around Europe and the Americas for nearly 84 years, playing and defeating many challengers including statesmen such as Napoleon Bonaparte and Benjamin Franklin.





Edgar Allan Poe wrote an essay "Maelzel's Chess Player" (1836) exposing the fraudulent automaton chess player.

Source: http://en.wikipedia.org/wiki/The_Turk

Mechanical Arithmetic

Blaise Pascal (1623 –1662) invented the mechanical calculator using lantern gears in 1642. He went through 50 prototypes before presenting his first machine to the public in 1645.

Called *Arithmetic Machine, Pascal's Calculator* and later *Pascaline*, this calculating machine could add and subtract two numbers directly and multiply and divide by repetition.

Born: 19 June 1623
Clermont-Ferrand,
Auvergne, France

Pascal received a Royal Privilege in 1649 that granted him exclusive rights to make and sell calculating machines in France. By 1654 Pascal had sold about twenty machines, but the cost and complexity of the Pascaline was a barrier to further sales, and production ceased in that year.

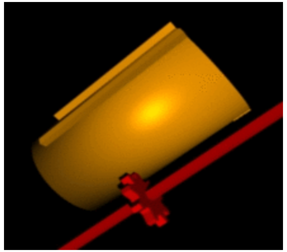
Source: http://en.wikipedia.org/wiki/Pascal%27s_calculator

The Stepped Reckoner

http://en.wikipedia.org/wiki/Gottfried_Leibniz

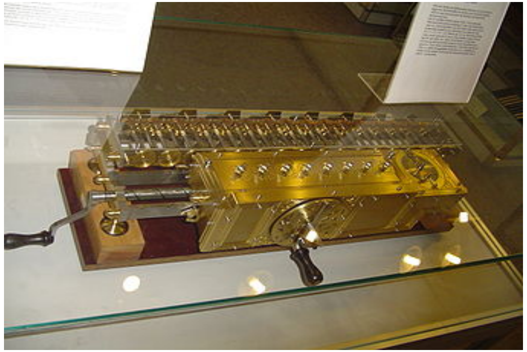
Gottfried Wilhelm von Leibniz (1646 –1716) was a German mathematician and philosopher. He started to work on his own calculator after Pascal's death.

Born: July 1, 1646
Leipzig,
Electorate of Saxony,
Holy Roman Empire



First he invented the **Leibniz wheel** or **stepped drum** in 1673, which was used for three centuries until the advent of the electronic calculator in the mid-1970s.

The **Stepped Reckoner** was a digital mechanical calculator invented by Leibniz around 1672 and completed in 1694. The machine performs **multiplication** by repeated addition, and **division** by repeated subtraction with 8 digit numbers.



Source: http://en.wikipedia.org/wiki/Stepped_Reckoner

Leibniz: *Calculus Ratiocinator*

Leibniz believed that much of human reasoning could be reduced to calculations of a sort, and that such calculations could resolve many differences of opinion:

> "*The only way to rectify our reasonings is to make them as tangible as those of the Mathematicians, so that we can find our error at a glance, and when there are disputes among persons, we can simply say: Let us calculate [calculemus], without further ado, to see who is right.*"

The principles of Leibniz's logic and, arguably, of his whole philosophy, reduce to two:

- All our ideas are compounded from a very small number of simple ideas, which form the alphabet of human thought.
- Complex ideas proceed from these simple ideas by a uniform and symmetrical combination, analogous to arithmetical multiplication.

Commercial success

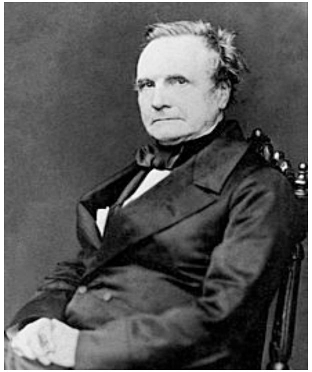
The *Arithmometer* or *Arithmomètre* was the first mechanical calculator strong enough and reliable enough to be used daily in an office environment.

This calculator could perform long multiplications and divisions effectively by using a movable accumulator for the result. Patented in France by Thomas de Colmar in 1820 and manufactured from 1851 to 1915.

Its sturdy design made it a key player in the move from human computers to calculating machines that took place during the second half of the 19th century.

Source: http://en.wikipedia.org/wiki/Arithmometer

The First Computer



Born: 26 Dec. 1791
London, England

Charles Babbage (1791 – 1871) was a mathematician, philosopher, inventor and mechanical engineer, who is best remembered now for originating the concept of a programmable computer

As a child he was much impressed by the automata displayed by a man called Merlin. He described them as "*One walked, used an eye-glass occasionally, and bowed frequently; her motions were singularly graceful. The other was a dancer, full of imagination and irresistible.*"

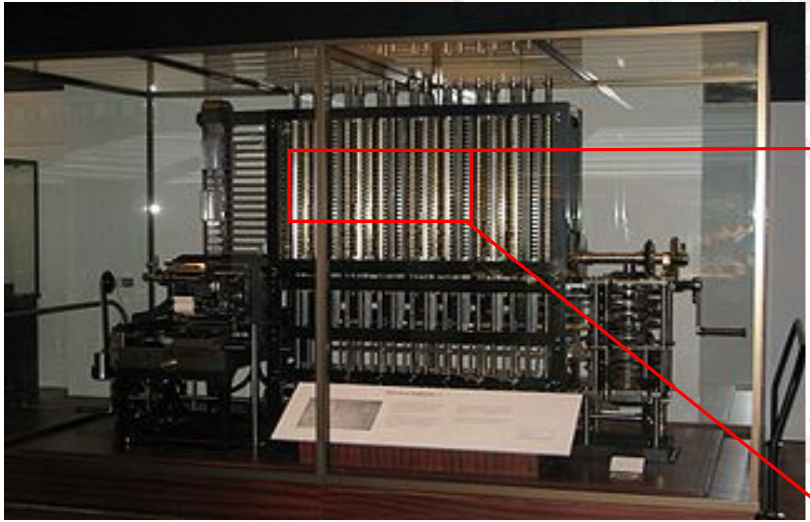
He began in 1822 with what he called the difference engine, made to compute values of polynomial functions. Babbage's difference engine was created to calculate a series of values automatically. The first difference engine was composed of around 25,000 parts, weighed fifteen tons (13,600 kg), and stood 8 ft (2.4 m) high.

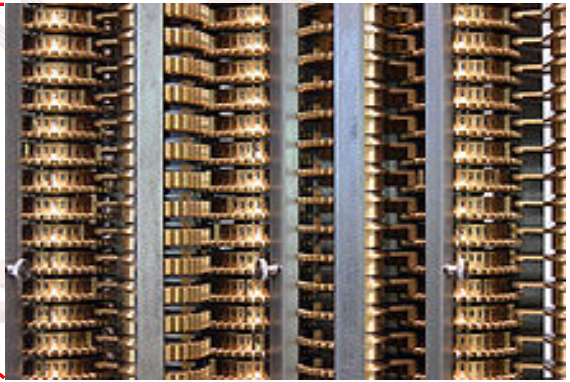
Source: http://en.wikipedia.org/wiki/Charles_Babbage

The Difference Engine

Part of Babbage's difference engine, assembled after his death by Babbage's son, using parts found in his laboratory.

Source: http://en.wikipedia.org/wiki/Charles_Babbage

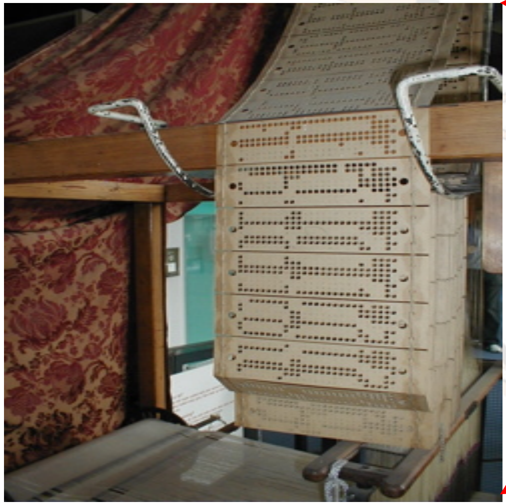


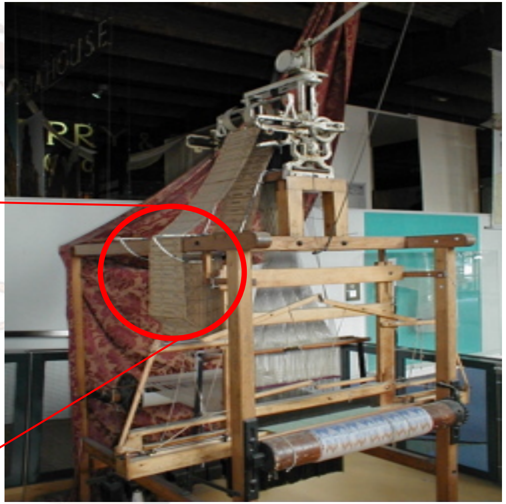


The London Science Museum's difference engine, built from Babbage's design.

Source: http://en.wikipedia.org/wiki/Difference_Engine

Jaquard Looms





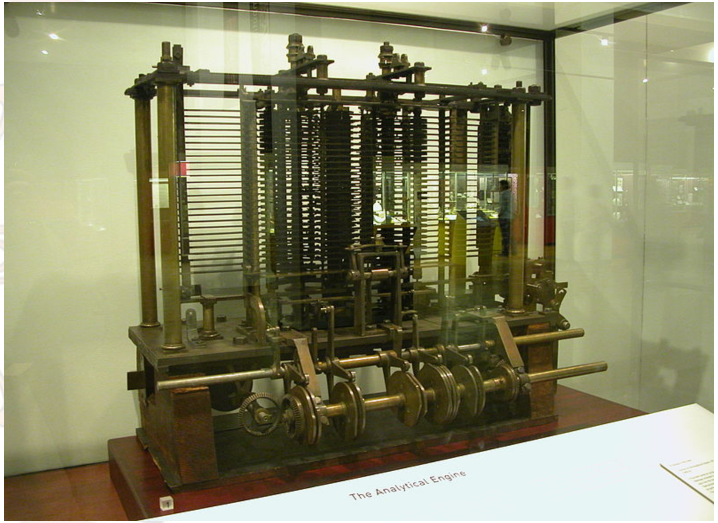
Used *punched cards* to weave *different patterns*

Source: http://en.wikipedia.org/wiki/Jacquard_loom

The Analytic Engine

The Analytical Engine was a proposed mechanical general-purpose computer designed by Charles Babbage

It was first described in 1837 as the successor to Babbage's Difference Engine. The Analytical Engine incorporated an arithmetic logic unit, control flow in the form of conditional branching and loops, and integrated memory, making it the first design for a general-purpose computer that could be described in modern terms as Turing-complete.



Trial model of a part of the Analytical Engine, built by Babbage, as displayed at the Science Museum (London)

Source: http://en.wikipedia.org/wiki/Analytical_Engine

The First Programmer

Augusta Ada King, Countess of Lovelace (1815 –1852), born Augusta Ada Byron and now commonly known as Ada Lovelace, was an English mathematician and writer chiefly known for her work on Charles Babbage's early mechanical general-purpose computer, the Analytical Engine.

Her notes on the engine include what is recognized as the first algorithm intended to be processed by a machine.

Because of this, she is often considered the world's first computer programmer.

The Hon. Augusta Ada Byron
Born 10 December 1815
London, England

The programming language ADA is named after her.

Source: http://en.wikipedia.org/wiki/Ada_Lovelace

Beyond Number Crunching

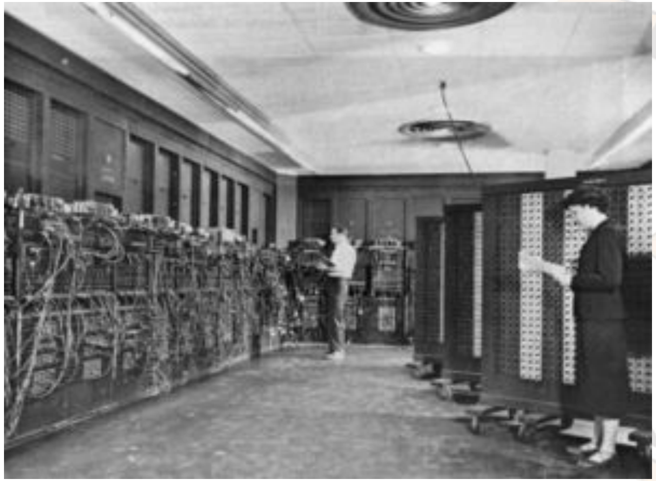
Ada Lovelace realized that the potential of the device extended far beyond mere number crunching. She wrote:

“ [The Analytical Engine] might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine...

Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.”

Source: http://en.wikipedia.org/wiki/Ada_Lovelace

ENIAC – the first electronic computer



Physically, ENIAC was massive compared to modern PC standards. It contained
17,468 vacuum tubes,
7,200 crystal diodes,
1,500 relays,
70,000 resistors,
10,000 capacitors and
around 5 million hand-soldered joints.

It weighed 27 tons,
was roughly 2.4 m by 0.9 m by 30 m,
took up 167 m²,
and consumed 150 kW of power.

Source: http://en.wikipedia.org/wiki/ENIAC

The emergence of the mind in philosophy

The European medieval world view

A Christian adaption of Greek ideas

Platonic

Creator's ideas

Human ideas

The World

Corruptible materializations of God's ideas

Our thoughts are *true* to the extent they are accurate copies of God's ideas

Aristotelian

Human ideas

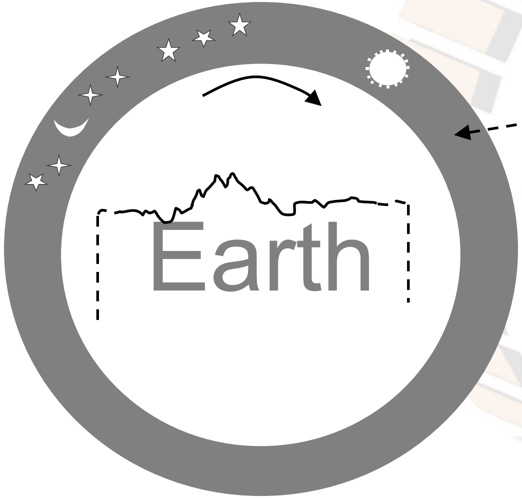
The World

Our thoughts *resemble* the objects they stand for

Correspondence theory of truth

… Ludwig Wittgenstein: Picture Theory of Language

Our world as we saw it



Our Earth was flat and at the center of the Universe, with the God' s heaven rotating around it.

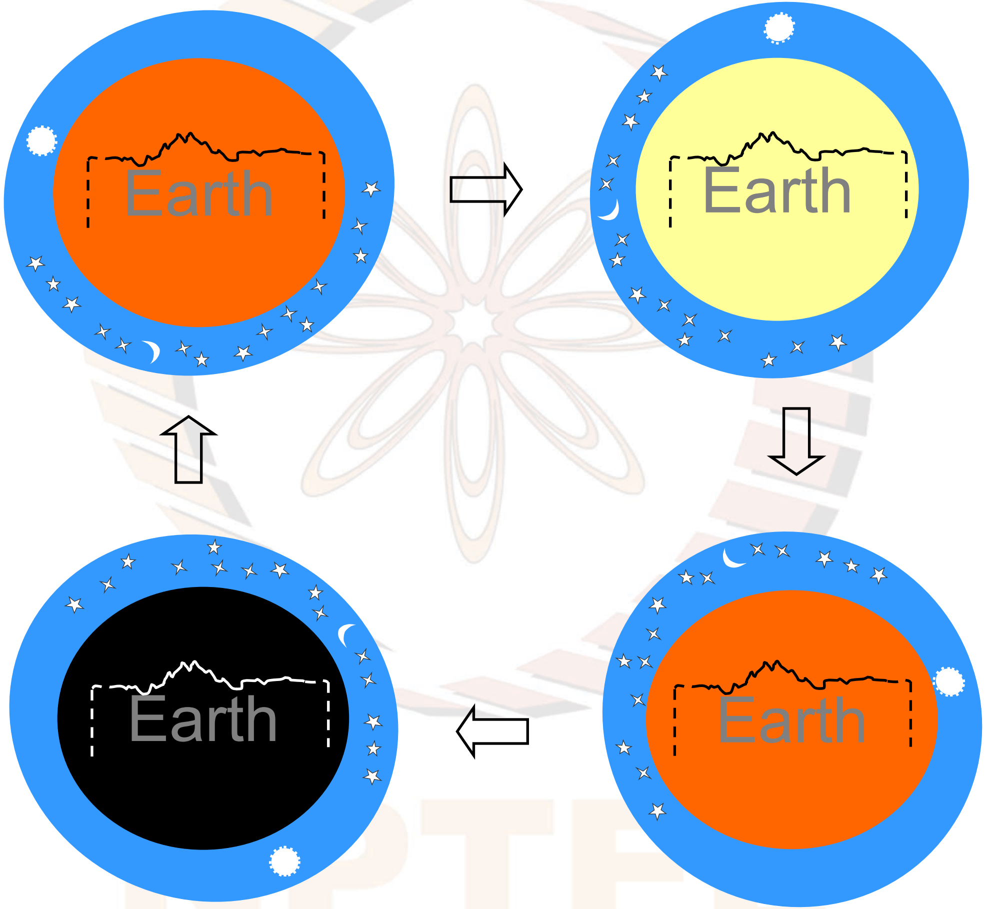
Sensible world composed of 5 elements

- quintessence
- fire
- air
- water
- earth

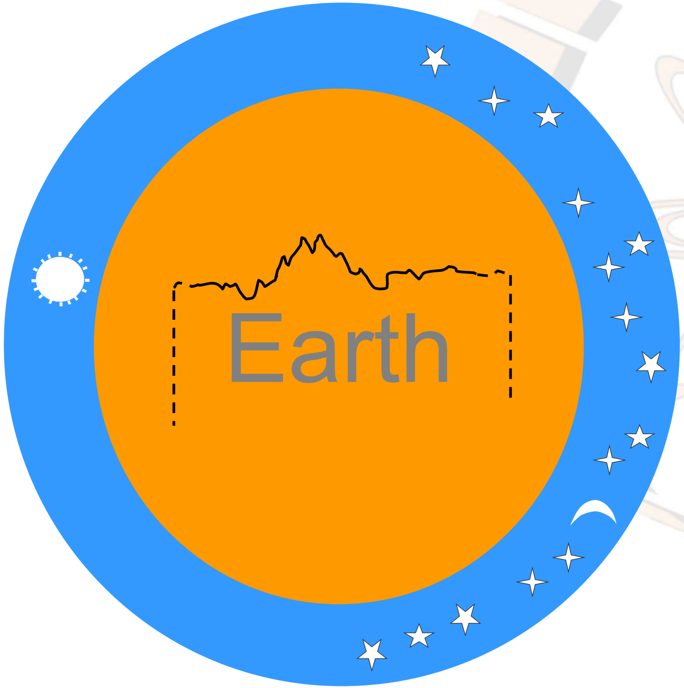
heavier

Jumbled up on Earth striving to separate and go their rightful place

Night & Day



Geocentric model of the Universe



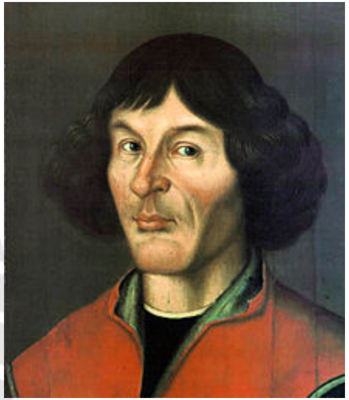
Astronomy was the most advanced empirical science, and observations like the motion of planets in the sky was specially hard to explain with the geocentric model.

"If God had consulted me when creating the universe, He would have received good advice!"

King Alfonso X of Spain (1221 – 1284)

What we see is not what really is…

It is the rotating **Earth** that creates the illusion of the Sun, the moon and the stars moving in the sky. (*On the Revolutions of the Celestial Spheres*)



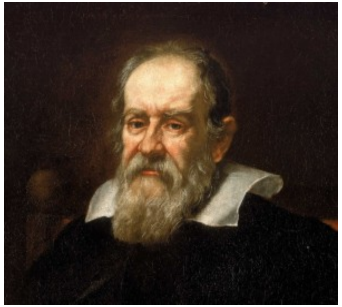
Nicolaus Copernicus
Portrait, 1580, Toruń Old Town City Hall
Born19 February 1473
Toruń (Thorn), Royal Prussia,
Kingdom of Poland

Source: http://en.wikipedia.org/wiki/Nicolaus_Copernicus

Perception is an Internal Process

"I think that tastes, odors, colors, and so on are no more than mere names so far as the object in which we locate them are concerned, and that they reside in consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated"

—Galileo Galilei, *The Assayer* (published 1623).



Galileo Galilei
Born15 February 1564
Pisa, Duchy of Florence, Italy

"Philosophy is written in this grand book, the universe ... It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures;....

Galileo showed that geometry could be used to represent and reason about motion.

Source: http://en.wikipedia.org/wiki/Galileo_Galilei

The Grandfather of AI

It was the English philsopher Thomas Hobbes (1588-1679) who first put forward the view that thinking is the manipulation of symbols.

Galileo had said that all reality is mathematical in the sense that everything is made up of particles, and our sensing of smell or taste was how we reacted to those particles.

Hobbes extended this notion to say that thought too was made up of (expressed in) particles which the thinker manipulated.

However he had no answer to the question of how can a symbol *mean* anything, because he had given up on the idea of thoughts being in the image of reality.

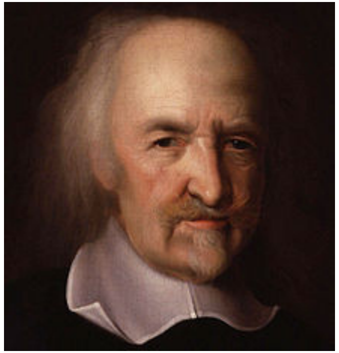
That is a question that we can say is still unresolved.

[John Haugeland, AI: The Very Idea, 1985].

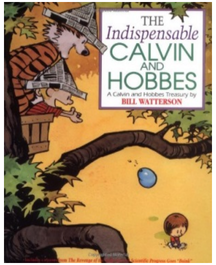
Reasoning = Computation

In *De Corpore* Hobbes first describes the view that reasoning is computation early in chapter one. "By reasoning", he says "I understand computation. And to compute is *to collect the sum of many things added together at the same time, or to know the remainder when one thing has been taken from another*. To reason therefore is the same as *to add* or *to subtract*" (Hobbes 1655, 1.2).

Stanford Encyclopedia of Philosophy
http://plato.stanford.edu/entries/hobbes/



Thomas Hobbes
Born 5 April 1588
Westport near Malmesbury, Wiltshire, England



Bill Watterson named the character Hobbes after him.

Hobbes was influenced by Galileo. Just as geometry could represent motion, thinking could be done by manipulation of mental symbols

Thoughts = Symbols

René Descartes (1596 –1650)

Animals were wonderful *machines*.
Human beings were too,
except that they possessed a *mind*.

Born 31 March 1596
La Haye en Touraine,
Kingdom of France

Galileo: Motion → Geometry
Decartes: Geometry → Algebra

Everything is "applied math"

… even "thought"

Decartes: Thoughts themselves are symbolic representations

Source: http://en.wikipedia.org/wiki/Ren%C3%A9_Descartes
John Haugeland: *AI the Very Idea*

Dualism: Mind and Body

John Haugeland: *AI the Very Idea*

Decartes: A symbol and what it symbolizes are two different things

algebraic manipulation = thinking

subject of thought

mind $\neq$ world

What makes a notation suitable for symbolizing?

What makes a suitable notation actually symbolize?

How can thought and matter interact?

mind-body problem

The Paradox of Mechanical Reason

John Haugeland: *AI the Very Idea*

IF

Reasoning is the manipulation of meaningful symbols according to rational rules

THEN

Who is manipulating the symbols?

It can be either mechanical or meaningful but how can it be both?

How can a mechanical manipulator pay attention to meaning?

faculty of will?

transcendental ego?

or

the *humunculus*? A little man?

For some more recent thoughts on this question see
Hofstadter: *Godel, Escher, Bach*
Hofstadter & *Dennet: The Mind's I*
Hofstadter: *I am a Strange Loop*

Experience → Knowledge

John Locke (1632 –1704), widely known as the Father of Classical Liberalism

Born 29 August 1632
Wrington, Somerset, England

Locke's theory of mind is often cited as the origin of modern conceptions of identity and the self, figuring prominently in the work of later philosophers such as Hume, Rousseau and Kant.

He postulated that the mind was a blank slate or *tabula rasa*.

Contrary to pre-existing Cartesian philosophy, he maintained that we are born without innate ideas, and that knowledge is instead determined only by experience derived from sense perception.

Source: http://en.wikipedia.org/wiki/John_Locke

The Mental Mechanic [Haugeland: *AI: The Very Idea*]

Born 7 May 1711
Edinburgh, Scotland, Great Britain

David Hume (1711 –1776) was a Scottish philosopher, historian, economist, and essayist known especially for his philosophical empiricism and scepticism.

In *A Treatise of Human Nature* (1739), Hume strove to create a total naturalistic "science of man" that examined the psychological basis of human nature.

The method for this science assumes "experience and observation" as the foundations of a logical argument.

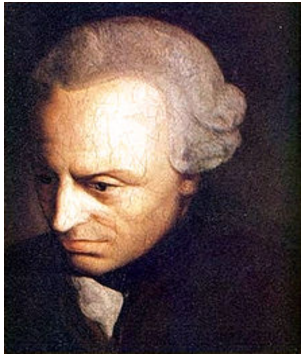
Hume was an admirer of Newton:– impressions and ideas were (like) the basic particles to which all mental forces and operations applied.

Like Newton, he was not interested in how ideas obey the laws of association.

He could not explain, however, what made ideas *ideas* and what made their interactions count as *thinking*. He has done away with meaning altogether.

Source: http://en.wikipedia.org/wiki/David_Hume

Human Concepts and Categories



Immanuel Kant (1724 –1804) was a German philosopher who is widely considered to be a central figure of modern philosophy.

The mind has *a priori* principles which make things outside conform to those principles.

Born: 22 April 1724
Königsberg,
Kingdom of Prussia

The mind shapes and structures experience so that, on an abstract level, all human experience shares certain essential structural features.

The concepts of space and time are integral to all human experience, as are our concepts of cause and effect.

We never have direct experience of things, the *noumenal* world, and what we do experience is the phenomenal world as conveyed by our senses.

Human concepts and categories structure our view of the world and its laws.

Source: http://en.wikipedia.org/wiki/Immanuel_Kant

The world as we know it

The subject–object problem, a longstanding philosophical issue, is concerned with the analysis of human experience, and arises from the premise that the world consists of objects (entities) which are perceived or otherwise presumed to exist as entities, by subjects (observers).

The subject–object problem has two primary aspects. First is the question of "what" is known. The field of ontology deals with questions concerning what entities exist or can be said to exist, and how such entities can be grouped, related within a hierarchy, and subdivided according to similarities and differences. The second standpoint is that of "how" does one know what one knows. The field of epistemology questions what knowledge is, how it is acquired, and to what extent it is possible for a given entity to be known. It includes both subjects and objects.

Source: http://en.wikipedia.org/wiki/Subject%E2%80%93object_problem

..the bounds of our own mind

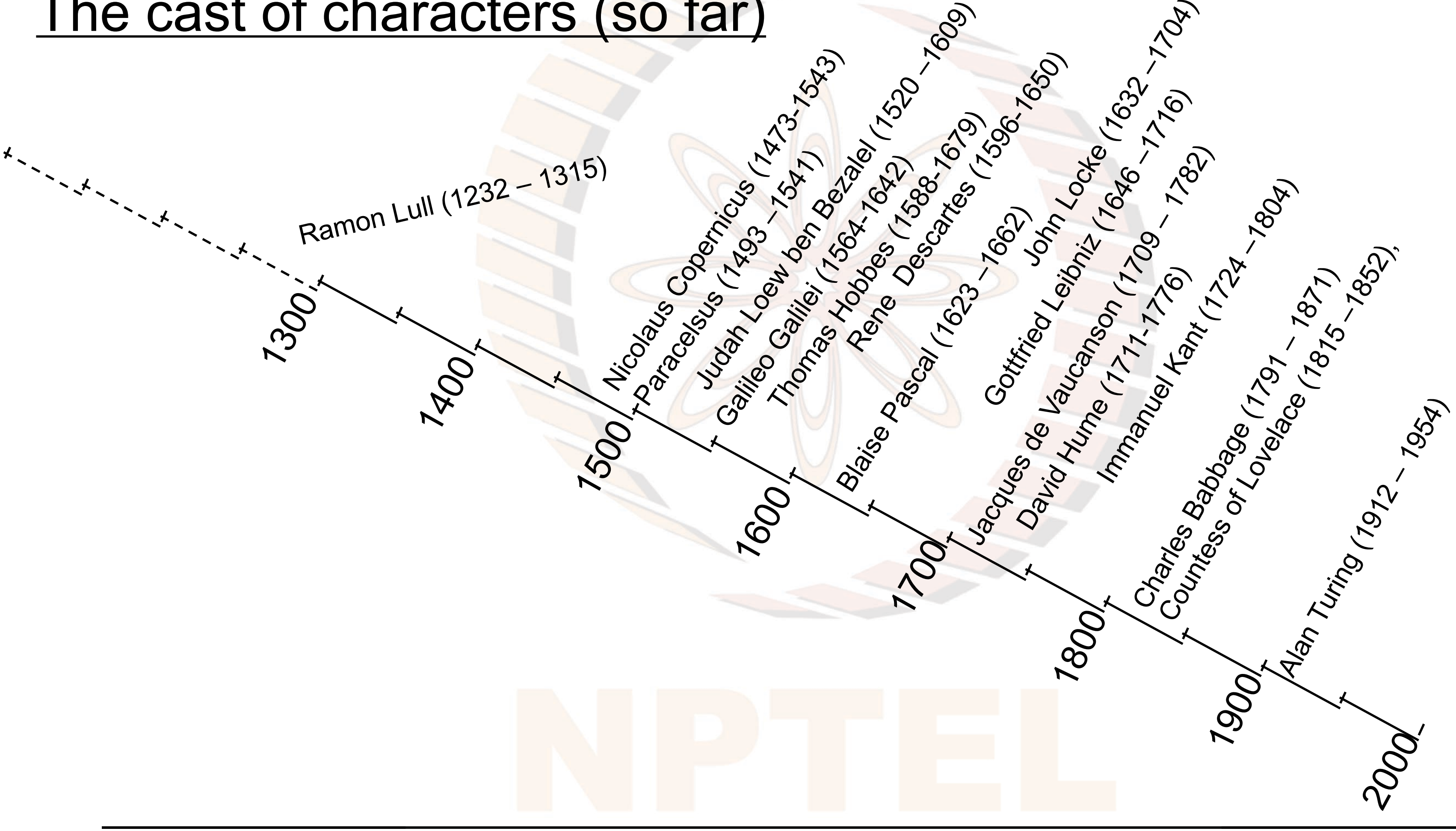
Kant claimed to have created a "Copernican revolution" in philosophy. This involved two interconnected foundations of his "critical philosophy":

- the epistemology of *Transcendental Idealism* (we are not able to transcend the bounds of our own mind), and
- the moral philosophy of the autonomy of practical reason.

Conceptual unification and integration is carried out by the mind through concepts or the "categories of the understanding" operating on the perceptual manifold within space and time. The latter are not concepts, but are forms of sensibility that are *a priori* necessary conditions for any possible experience. Thus the objective order of nature and the causal necessity that operates within it are dependent upon the mind's processes, the product of the rule-based activity that Kant called, "synthesis".

Source: http://en.wikipedia.org/wiki/Immanuel_Kant

The cast of characters (so far)



How AI got its name

The name *artificial intelligence* is credited to John McCarthy who, along with Marvin Minsky and Claude Shannon (1916–2001), organized the *Dartmouth Conference* in 1956.

The conference was to be a "*two month, ten-man study of artificial intelligence* … *on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it*".

See Machines Who Think, Chapter 5, for a detailed account.

Dartmouth Conference: The Organizers

- John McCarthy (1927-2011), then an assistant professor at Dartmouth. Designed the Lisp programming language that was very popular with AI researchers. Also did work in Logic and Commonsense Reasoning.
- Marvin Minsky (1927 -), then a Harvard Junior Fellow went on to become one of the most influential figures in AI. With McCarthy he co-founded the MIT AI Lab. Known for his ideas on Frames. Wrote a book "Society of the Mind" and more recently "The Emotion Machine"
- Nathaniel Rochester (1919 – 2001) a young engineer at IBM. He designed the IBM 701 and wrote the first assembler. He supervised Arthur Samuel writing the checkers playing program. It is said that the marketing people at IBM reported that people were frightened of "electronic brains" resulting in IBM stopping work on AI.
- Claude Shannon (1916- 2001) a mathematician at Bell Labs was already known for his information theory. Had hired McCarthy and Minsky in 1952 for the summer when they were graduate students.

Dartmouth Conference: The show stealers

Herbert Simon and Alan Newell (1927 – 1992) were "*two vaguely known persons*" *working at Carnegie Tech and RAND, who were also invited to the Dartmouth Conference "almost as an afterthought"* –

McCorduck in *Machines Who Think*.

Along with J. C. Shaw (1922–1991), also from RAND, they had already developed a program called the Logic Theorist (LT). "*It was the first program deliberately engineered to mimic the problem solving skills of a human being*". It went on to prove several theorems in Russell and Whitehead's celebrated (*Principia Mathematica* finding **shorter and more elegant proofs** for some!)

see http://en.wikipedia.org/wiki/Logic_Theorist

Simon and Newell

Herbert Simon (1916 – 2001) was "an American political scientist, economist, sociologist, psychologist, and professor—most notably at Carnegie Mellon University—whose research ranged across the fields of cognitive psychology, cognitive science, computer science, public administration, economics, management, philosophy of science, sociology, and political science". See http://en.wikipedia.org/wiki/Herbert_A._Simon

Alan Newell (1927 – 1992) was a long term collaborator of Simon at CMU. He designed the language Information Processing Language (IPL) in which LT was implemented.

Simon and Newell

Simon and Newell went to become leading figures in AI research and founded a strong group at CMU.

Their program General Problem Solver (GPS) was a pioneer in the use of heuristics in search and adopted a human like approach called means-ends-analysis.

Their work defined the Information-Processing approach for AI.

At CMU one shining example was the development of the SOAR cognitive architecture by John Laird.

Physical Symbol Systems

Symbol : A perceptible something that stands for something else.
- alphabet symbols, numerals, road signs, musical notation

Symbol System: A collection of symbols – a pattern
- words, arrays, lists, even a tune

Physical Symbol System: That obeys laws of some kind, a formal system
- long division, an abacus, an algorithm

The Physical Symbol System Hypothesis

"A physical symbol system has the **necessary** and **sufficient** means for general intelligent action."

— Allen Newell and Herbert A. Simon

The ability to manipulate symbols - Symbolic AI / Classical AI

Good Old Fashioned Artificial Intelligence (GOFAI)

– John Haugeland in *AI: The Very Idea*

Samuel's Checkers program

Arthur Samuel (1901-1990) was one of the attendees in Dartmouth.

He wrote the first Checkers playing program in 1952 on IBM's 701 computer.

Samuel's goal was to explore how to get computers to learn – he felt that if computers could learn from experience then there would be no need for detailed and painstaking programming.

His Checker's program improved as it played more and more games, eventually "beating its own creator" – evoking fears of Frankenstein (Mary Shelley) like creatures overwhelming humankind.

- Pamela McCorduck in *Machines Who Think*

Three Laws of Robotics

The Three Laws are a set of rules devised by the science fiction author Isaac Asimov. The rules were introduced in his 1942 short story "*Runaround*", although they had been foreshadowed in a few earlier stories. The Three Laws are:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Source: http://en.wikipedia.org/wiki/Three_Laws_of_Robotics

The Chess saga: Genesis

1912: Leonardo Torres y Quevedo builds a machine that could play King&Rook vs. King.

1950: Claude Shannon publishes "Programming a Computer for Playing Chess''.

1951: Alan Turing develops on paper the first program capable of playing a full game of chess.

1956: John McCarthy invents the alpha-beta search algorithm (also credited to others…).

1957: Alex Bernstein develops first program to play full chess at IBM.

1967: *Mac Hack Six*, by Richard Greenblatt et al. introduces transposition tables and becomes the first program to defeat a person in tournament play.

1968: David Levy bet: No computer program would win a game against him within 10 years.

1970: The first year of the ACM North American Computer Chess Championships

1974: *Kaissa* wins the first World Computer Chess Championship

1977: The first microcomputer chess playing machine, *CHESS CHALLENGER*, was created.

Source: http://en.wikipedia.org/wiki/Computer_chess

The Chess saga: Progress

1977: *Chess 4.6* is the first chess computer to be successful at a major chess tournament.

1978: David Levy wins the bet defeating the Chess 4.7 in a six-game match. Score: 4.5–1.5.

1980: The Fredkin Prize is established ($100,000 to beat a reigning world champion).

1981: *Cray Blitz* wins the Mississippi State Championship with a perfect 5–0 score and a performance rating of 2258. The first computer to beat a master in tournament play.

1982: Ken Thompson's hardware chess player *Belle* earns a US master title.

1988: *HiTech*, by Hans Berliner and Carl Ebeling, wins a match against grandmaster Arnold Denker 3.5 – 0.5.

1988: *Deep Thought* shares first place with Tony Miles, ahead of former world champion Mikhail Tal

1989: *Deep Thought* loses two exhibition games to Garry Kasparov, the reigning champion.

Source: http://en.wikipedia.org/wiki/Computer_chess

The Chess saga: Triumph

1992: A microcomputer, the *ChessMachine Gideon 3.1* by Ed Schröder, wins the 7th World Computer Chess Championship in front of mainframes, supercomputers and special hardware.

1994: *ChessGenius*, defeated a World Champion (Garry Kasparov) at a non blitz time limit.

1996: *Deep Blue* loses a six-game match against Garry Kasparov.

1997: *Deep Blue* wins a six-game match against Garry Kasparov. The *Deep Blue* inventors Fang Hsu, Murray Campbell, and Joseph Hone awarded the Fredkin Prize.

2002: Vladimir Kramnik draws an eight-game match against *Deep Fritz*.

2005: *Hydra* defeats Michael Adams 5.5–0.5.

2006: The undisputed world champion, Vladimir Kramnik, is defeated 4–2 by *Deep Fritz*.

2010: Before the World chess championship, Topalov prepares by sparring against the supercomputer *Blue Gene* with 8,192 processors capable of 500 trillion floating point operations per second.

Source: http://en.wikipedia.org/wiki/Computer_chess

AI: Some landmarks

1957 : Newell, Simon and Shaw implement General Problem Solver

Noam Chomsky writes “Syntactic Structures”

1958 : John McCarthy introduces LISP at MIT

Herbert Gelernter (PhD dissertation) : Theorem prover for geometry

1959 : Minsky and McCarthy set up AI Lab at MIT
Frank Rosenblatt builds the Perceptron
Arthur Samuel’s Checkers program beats the best human players

1960 : Bar-Hillel writes paper describing difficulty of Machine Translation

1962 : Unimation: First industrial robots
Jaakko Hintikka writes “Knowledge and Belief”

Saul Kripke inroduces Kripke structures for possible world semantics

1963 : Ivan Sutherland (PhD dissertation) Sketchpad: CAD program
Ross Quillian: Semantic Nets

Susomo Kuno’s parser at MIT tested on “Time flies like an arrow”
Edward Feigenbaum and Julian Feldman publish “Computers and Thought”

1964 : Daniel Bobrow (PhD dissertation): STUDENT – solves algebra problems
Bertram Raphael (PhD dissertation): SIR – on knowledge representation for question answering

Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence

Some landmarks (continued)

1965 : Alan Robinson: The Resolution Method for theorem proving
Ivan Sutherland and Bob Sproulli demonstrate Virtual Reality with a head mounted display
Simon predicts "by 1985 machines will do any work that man can do"
Herbert Dreyfus argues against possibility of AI

1960 : Weizennbaum's ELIZA

1967 : Greenblatt's MacHack defeats Dreyfus at Chess
DENDRAL program (Edward Feigenbaum et al. at Stanford University) demonstrated to interpret mass spectra on organic chemical compounds. First success of knowledge based reasoning

1968 : Joseph Moses (PhD dissertation) MACSYMA – symbolic reasoning in mathematics

1969 : SHAKEY the robot demonstarted at Stanford Research Institute
Minsky and Papert's book "Perceptrons" limits powers of single layer neural nets
Roger Schank defines Conceptual Dependency theory
McCarthy and Hayes discuss the Frame Problem

1970 : Bill Woods: Augmented Transition Networks for Natural Language Parsing
Patrick Winston (PhD Dissertation) ARCH: learns concepts from examples from children's blocks

1971 : Nils Nilsson and Richard Fikes demonstrate the planning system STRIPS
Terry Winograd (PhD dissertation) SHRDLU understanding English in a restricted domain

1971 : Alain Colmerauer develops Prolog
Earl Sacerdoti: Hierarchical planning with ABSTRIPS

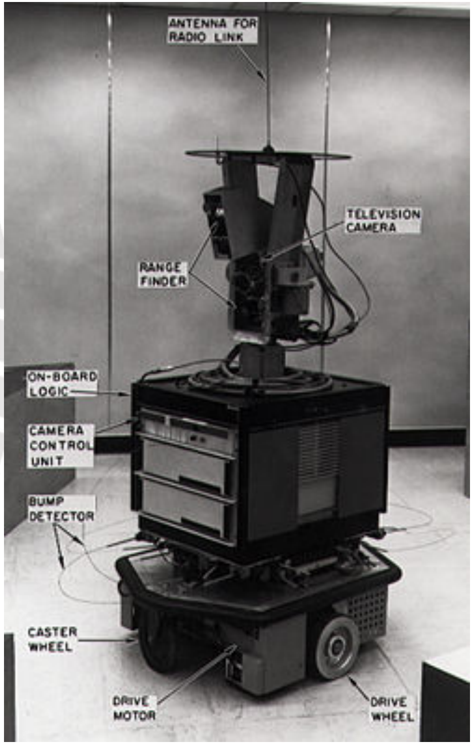
Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence

SHAKEY

Developed at Stanford Research Institute by a team led by Charles Rosen during 1966-1972, Shakey the robot was the first general-purpose mobile robot to be able to reason about its own actions.

It wandered around the corridors of SRI turning the light switches on and off, opening and closing the doors, climbing up and down from rigid objects, and pushing movable objects around.

Keywords: Robotics, computer vision, natural language processing, LISP, A*, STRIPS, Hough transform, visibility graph, collision detection.



Source: http://en.wikipedia.org/wiki/Shakey_the_robot

Some landmarks (continued)

1973 : Schank and Abelson introduce *Scripts* for story understanding

1974 : Ted Shortliffe (PHD dissertation): MYCIN – rule based approach to medical diagnosis

1975 : Marvin Minsky publishes article on *Frames*
The Meta-Dendral learning program produces new results in Chemistry
Austin Tate developes the Nonlin partial order planning system
Sacerdoti developes the NOAH planing system

~1975 : David Marr and colleagues at MIT describe the "primal sketch" as visual representation

1976 : Randall Davis (PhD dissertation) demonstrates the power of meta-level reasoning
Douglas Lenat's (PhD dissertation) program AM creates a stir

1977 : SRI's PROSPECTOR expert system predicts existence of a hitherto unknown molybdenum deposit in Washington State.

1978 : Tom Mitchell invents the concept of Version Spaces
Herbert Simon wins the Economics Nobel prize for his work on bounded rationality
Stefik and Friedland's MOLGEN demonstrates the utility of object oriented programming

1979 : The Stanford Cart by Hands Moravec autonomously navigates in the Stanford AI Lab
BKG a backgammon program by Hans Berliner defeats reigning world champion
McDermott, Doyle and McCarthy publish on non-monotonic reasoning and truth maintenance

Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence http://www.stanford.edu/~learnest/cart.htm

Some landmarks (continued)

~1980 : Dickmanns et al build the first robot cars driving autonomously in Munich
Lisp machines and Expert System shells appear in the market

1980 : Douglas Hofstadter publishes Godel Escher Bach
McDermott builds the *XCON* expert system for configuring VAX machines
First AAAI conference

1981 : Daniel Hillis designs the Connection Machine
Common Lisp standard defined

1982 : Japanese government launches the Fifth Generation Computer Systems program
John Hopfield resuscitates neural networks

1983 : Darpa initiates Strategic Computing Initiative
John Laird and Paul Rosenbloom (PhD dissertations) – CMU's *SOAR* architecture
James Allen invents Interval Calculus

1985 : AARON the drawing artist created by Harold Cohen demonstrated at AAAI

1987 : Minsky publishes "The Society of Mind"
Rodney Brooks introduces an alternative subsumption architecture for AI

1989 : Dean Pomerleau at CMU creates ALVINN (An Autonomous Land Vehicle in a Neural Network).

Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence

Some landmarks (continued)

1990 : Gerald Tesauro's *TD-Gammon* based on Reinforcement Learning plays world class Backgammon

1993 : Ian Horswill (PhD dissertation) builds Polly a behaviour based robot that used vision for navigation
Rodney Brooks and colleagues start MIT Cog Project to build a humanoid robot child

1994 : Twin robot cars VaMP and VITA-2 of Ernst Dickmanns and Daimler-Benz drive more than one thousand kilometers on a Paris three-lane highway in standard heavy traffic at speeds up to 130 km/h.

1995 : Semi-autonomous ALVINN steered a car coast-to-coast (throttle and brakes controlled by human)
Ernst Dickmanns' robot cars (with robot-controlled throttle and brakes) drove more than 1000 miles from Munich to Copenhagen and back, in traffic, at up to 120 mph,

1997 : Deep Blue beats Garry Kasparov in a six game chess match
First official *RoboCup* tabletop football tournament with 40 teams and 5000 spectators

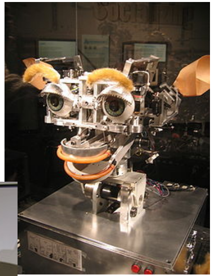
1998 : Furby the first robot toy for the domestic market released by Tiger Electronics
Tim Berne-Lee pubishes his Semantic Web roadmap paper

~1998 : Web Crawlers explore the WWW
Emotional agents demostrated at MIT

1999 : Sony introduces AIBO

Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence

Some landmarks (continued)



2000 : Cynthia Breazeal (PhD dissertation) on Sociable machines, describes *Kismet*, a robot that expresses emotions.
The Nomad robot explores remote regions of Antarctica looking for meteorite samples.

2004 : OWL Web Ontology Language W3C Recommendation
DARPA introduces the Grand Challenge for autonomous vehicles for prize money.

2005 : Honda's *ASIMO* robot, an artificially intelligent humanoid robot, is able to walk as fast as a human, delivering trays to customers in restaurant settings.
Recommendation technology based on tracking web activity or media usage brings AI to marketing
Blue Brain is born, a project to simulate the brain at molecular detail.

2006 : The Dartmouth Artificial Intelligence Conference: The Next 50 Years (AI@50)

2007 : Checkers is solved by a team of researchers at the University of Alberta.

2011 : In a Jeopardy! exhibition match IBM's *Watson* soundly defeated the two greatest Jeopardy! champions, Brad Rutter and Ken Jennings.

2013 : Japanese space agency launches *Kirobo* into space as a companion to a human.

Source: http://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence

Haugeland – The goal of AI is to build a machine with a mind of its own.

What are minds??

Reality

What is really out there?

What is the objective reality?

One thing is clear

Everything in the physical world is made up of a small number of fundamental particles

(even though we don't quite know yet what they are)

unless there is no matter at all (idealism)

The laws of physics that explain the behaviour of these particles are sufficient to explain the behaviour of ensembles of such particles

But…

Complexity

A human adult is made up of about 10^{27} atoms

These 10^{27} atoms continuously interact with zillions of surrounding atoms all the time

The air we breathe, the food we eat, the vibrations of air molecules we *sense as sound,* and impinged upon by trillions of photons (which have momentum but no mass).

Can we even hope to write down equations for these and solve them?

And what would we get if we did solve them?

A prediction of their location and movement?

Remember there are 10^{27} of them

The World in our Minds

The world around us and including us operates according to and can, in principle, be explained by the fundamental laws of physics. Nothing else is needed.

But we the thinking creatures create our own worlds in our minds. And it is only our own creation that is meaningful to us.

Idea embodied in movies: Matrix, Inception…

The Physical Symbol System Hypothesis says that the ability to operate at this epiphenomenon level is sufficient to build intelligent machines

Powers of Ten

A Film by Charles and Ray Eames (1977)
http://www.powersof10.com/film

Source: Quarks to Quasars
http://www.wordwizz.com/pwrsof10.htm

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1 yottameter – 10^{24} meters – a cluster of galaxies (about 100 million light years across)
1 zettameter – 10^{21} meters – diameter of The Milky Way (about 100,000 light years across)
100 petameters – 10^{17} meters – the nearest stars (about 10 light years away)
10 terameters – 10^{13} meters – diameter of Solar system (11,826,600,000 km)
1 terameter – 10^{12} meters – distance from Saturn to Sun (1,429,000,000 km)
100 gigameters – 10^{11} meters – distance from Earth to Sun (149,600,000 km)
100 megameters – 10^{8} meters – the diameter of Jupiter (139,822 km)
10 megameters – 10^{7} meters – the diameter of Earth (12,756 km)
1 megameter – 10^{6} meters – the distance from Chennai to Pune (1190 km)
100 kilometers – 10^{5} meters – the distance from Mandi to Manali (110 km)
10 kilometers – 10^{4} meters – the diameter of a small town
1 kilometer – 10^{3} meters – longest span of the Golden Gate Bridge (1,280 m)
100 meters – 10^{2} meters – a sprint track, a meadow, a pond, a skyscraper
10 meters – 10^{1} meters – the width of a road, a small house, a tree
1 meter – 10^{0} meters – a typical door, a table, the height of a child
10 centimeters – 10^{-1} meters – a sunbird, a typical mango, a cellphone
1 millimeter – 10^{-3} meters – a mustard seed
100 micrometers – 10^{-4} meters – pollen
10 micrometers – 10^{-5} meters – a bacterium
100 nanometers – 10^{-7} meters – a virus
1 nanometer – 10^{-9} meters – the structure of DNA
100 picometers – 10^{-10} meters – carbon's outer shell – 1 Angstrom unit
1 picometer – 10^{-12} meters – the electron cloud – electromagnetism and gravity
10 femtometers – 10^{-14} meters – the carbon nucleus
1 femtometer – 10^{-15} meters – a proton
10 attometers – 10^{-17} meters – quarks and gluons

Our Perceptible Universe

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Scientific progress enables us to extend our concepts to different scales

Scientific progress enables us to extend our concepts to different scales

Domains of Study

Reality: Everything is ensembles of “atomic” particles.

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Cosmology

Astronomy

Astrophysics

Newtonian physics

Geography

Geology

Sociology

Economics

Psychology

Newtonian physics

Physiology

Biology

Cellular biology

Chemistry

Sub-atomic physics

Downward Causality

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100 nanometers – 10^{-7} meters – a virus
1 nanometer – 10^{-9} meters – the structure of DNA
100 picometers – 10^{-10} meters – carbon's outer shell – 1 Angstrom unit
1 picometer – 10^{-12} meters – the electron cloud – electromagnetism and gravity
10 femtometers – 10^{-14} meters – the carbon nucleus
1 femtometer – 10^{-15} meters – a proton
10 attometers – 10^{-17} meters – quarks and gluons

We **operate** with **concepts** at our perceptible level. Our **thoughts** at this level **cause** the lower level activity that results in our **actions**

Douglas Hofstadter in "*I am a Strange Loop*"

Epiphenomenon in computers

Computers are man made objects. We know how they operate. At the very core the computer does only bit level operations.

Everything else is built upon that, and everything can be explained by that.

But how does a lay user see the machine?

A music player, a web browser, a video player, a word processor, a keeper of facts, an accounting spreadsheet.

In other words a Universal Machine (a machine that can imitate any other machine)

Can this machine become intelligent?

Yes, if it can introspect and examine itself and has access to an endless possible set of concepts – Douglas Hofstadter in *I am a Strange Loop*.

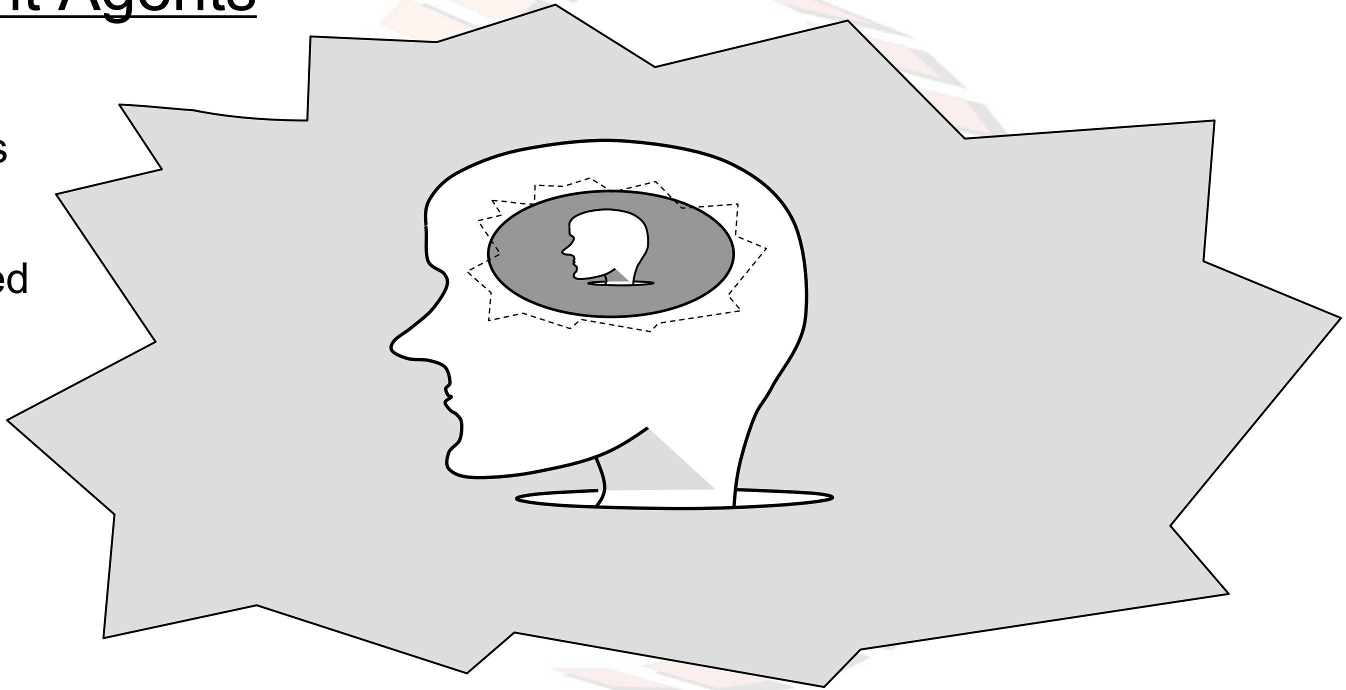
Intelligent Agents

Persistent

Autonomous

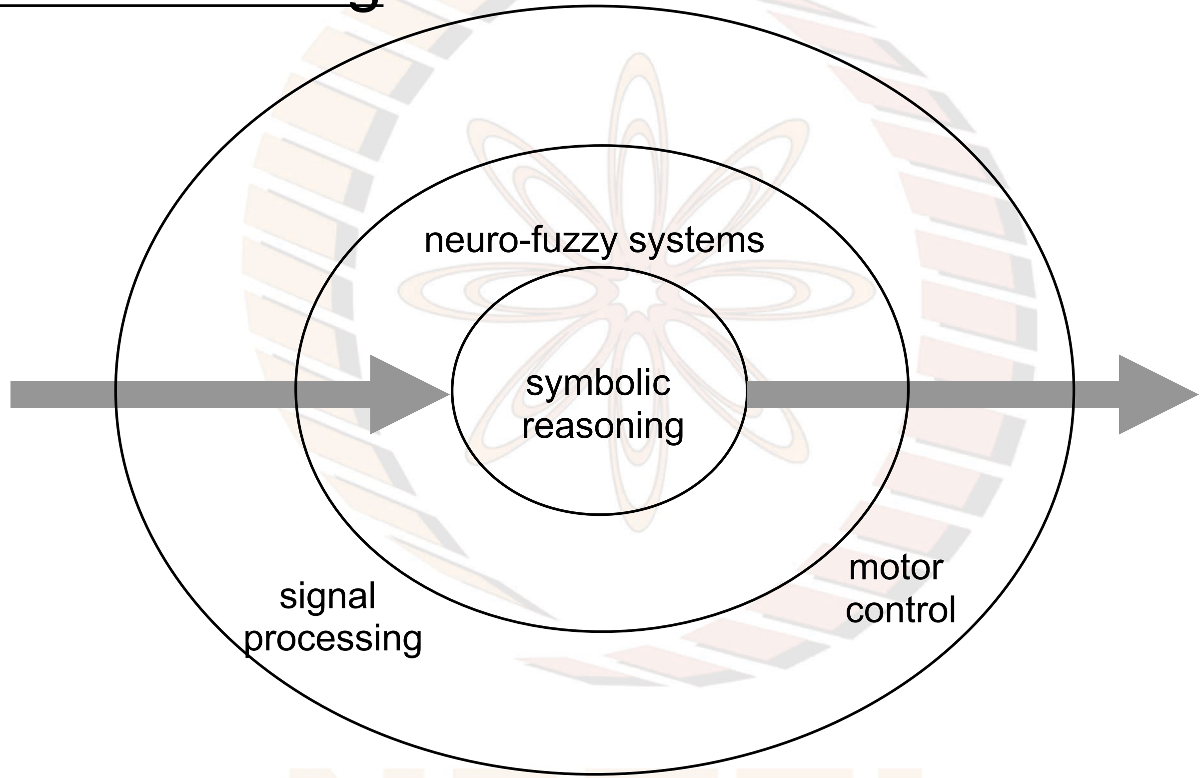
Proactive

Goal Directed



An intelligent agent in a world carries a model of the world in its "head". The model maybe an abstraction. A self aware agent would model itself in the world model. Deeper awareness may require that the agent represent (be aware of) itself modeling the world. (From A First Course in AI – Deepak Khemani)

Information Processing



signal ⟶ symbol ⟶ signal

Topics in AI

smell

natural language understanding

speech synthesis

speech recognition

natural language generation

image processing

qualitative reasoning

logic

graphics

computer vision

knowledge representation

ontology

semantics

neural networks

machine learning

knowledge discovery

search

models

memory

pattern recognition

problem solving

robot control

tactile sensing

planning

adversarial reasoning

handling uncertainty

Sense → Deliberate → Act

Source: Deepak Khemani, A First Course in Artificial Intelligence

Courses: CSE@IITM

smell

Speech Technology

natural language understanding

speech synthesis

speech recognition

Digital Video Processing

Natural Language Processing

natural language generation

image processing

qualitative reasoning

Knowledge Representation and Reasoning

Computer Vision

computer vision

knowledge representation

graphics

Computer Graphics

Machine Learning

semantics

ontology

Neural Networks

neural networks

machine learning

Pattern Recognition

Artificial Intelligence

search

Kernel Methods for Pattern Analysis

pattern recognition

memory

Memory Based Reasoning in AI

problem solving

robot control

Planning & Constraint Satisfaction

planning

tactile sensing

adversarial reasoning

Probabilistic Reasoning in AI

handling uncertainty

Sense → Deliberate → Act

AI: The Syllabus (repeated)

Introduction: Overview and Historical Perspective, Turing test, Physical Symbol Systems and the scope of Symbolic AI, Agents.

State Space Search: Depth First Search, Breadth First Search, DFID.

Heuristic Search: Best First Search, Hill Climbing, Beam Search, Tabu Search.

Randomized Search: Simulated Annealing, Genetic Algorithms, Ant Colony Optimization.

Finding Optimal Paths: Branch and Bound, A*, IDA*, Divide and Conquer approaches, Beam Stack Search:

Problem Decomposition: Goal Trees, AO*, Rule Based Systems, Rete Net.

Game Playing: Minimax Algorithm, AlphaBeta Algorithm, SSS*.

Planning and Constraint Satisfaction: Domains, Forward and Backward Search, Goal Stack Planning, Plan Space Planning, Constraint Propagation.

Logic and Inferences: Propositional Logic, First Order Logic, Soundness and Completeness, Forward and Backward chaining.

Text Book and References

Text Book

Deepak Khemani. A First Course in Artificial Intelligence, McGraw Hill Education (India), 2013.

Reference Books

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John Haugeland, Artificial Intelligence: The Very Idea, A Bradford Book, The MIT Press, 1985.

Pamela McCorduck, Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence, A K Peters/CRC Press; 2 edition, 2004.

Zbigniew Michalewicz and David B. Fogel. How to Solve It: Modern Heuristics. Springer; 2nd edition, 2004.

Judea Pearl. Heuristics: Intelligent Search Strategies for Computer Problem Solving, Addison-Wesley, 1984.

Elaine Rich and Kevin Knight. Artificial Intelligence, Tata McGraw Hill, 1991.

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End of Introduction