Artificial intelligence

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"AI" redirects here. For other uses, see Ai.
For other uses, see Artificial intelligence (disambiguation).

Artificial intelligence (AI) is the intelligence of machines and the branch of computer science that aims to create it. Textbooks define the field as "the study and design of intelligent agents," where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. John McCarthy, who coined the term in 1956, defines it as "the science and engineering of making intelligent machines."

The field was founded on the claim that a central property of humans, intelligence—the sapience of Homo sapiens—can be so precisely described that it can be simulated by a machine. This raises philosophical issues about the nature of the mind and limits of scientific hubris, issues which have been addressed by myth, fiction and philosophy since antiquity. Artificial intelligence has been the subject of optimism but has also suffered setbacks and, today, has become an essential part of the technology industry, providing the heavy lifting for many of the most difficult problems in computer science.

AI research is highly technical and specialized, deeply divided into subfields that often fail to communicate with each other. Subfields have grown up around particular institutions, the work of individual researchers, the solution of specific problems, longstanding differences of opinion about how AI should be done and the application of widely differing tools. The central problems of AI include such traits as reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects. General intelligence (or "strong AI") is still a long-term goal of (some) research.

History

Main articles: History of artificial intelligence and Timeline of artificial intelligence

Thinking machines and artificial beings appear in Greek myths, such as Talos of Crete, the golden robots of Hephaestus and Pygmalion's Galatea. Human likenesses believed to have intelligence were built in every major civilization: animated statues were worshipped in Egypt and Greece and humanoid automatons were built by Yan Shi, Hero of Alexandria, Al-Jazari and Wolfgang von Kempelen. It was also widely believed that artificial beings had been created by Jābir ibn Hayyān, Judah Loew and Paracelsus. By the 19th and 20th centuries, artificial beings had become a common
feature in fiction, as in Mary Shelley's *Frankenstein* or Karel Čapek's *R.U.R. (Rossum's Universal Robots)*. Pamela McCorduck argues that all of these are examples of an ancient urge, as she describes it, "to forge the gods". Stories of these creatures and their fates discuss many of the same hopes, fears and ethical concerns that are presented by artificial intelligence.

Mechanical or "formal" reasoning has been developed by philosophers and mathematicians since antiquity. The study of logic led directly to the invention of the programmable digital electronic computer, based on the work of mathematician Alan Turing and others. Turing's theory of computation suggested that a machine, by shuffling symbols as simple as "0" and "1", could simulate any conceivable act of mathematical deduction. This, along with recent discoveries in neurology, information theory and cybernetics, inspired a small group of researchers to begin to seriously consider the possibility of building an electronic brain.

The field of AI research was founded at a conference on the campus of Dartmouth College in the summer of 1956. The attendees, including John McCarthy, Marvin Minsky, Allen Newell and Herbert Simon, became the leaders of AI research for many decades. They and their students wrote programs that were, to most people, simply astonishing: computers were solving word problems in algebra, proving logical theorems and speaking English. By the middle of the 1960s, research in the U.S. was heavily funded by the Department of Defense and laboratories had been established around the world. AI's founders were profoundly optimistic about the future of the new field: Herbert Simon predicted that "machines will be capable, within twenty years, of doing any work a man can do" and Marvin Minsky agreed, writing that "within a generation ... the problem of creating 'artificial intelligence' will substantially be solved".

They had failed to recognize the difficulty of some of the problems they faced. In 1974, in response to the criticism of England's Sir James Lighthill and ongoing pressure from Congress to fund more productive projects, the U.S. and British governments cut off all undirected, exploratory research in AI. The next few years, when funding for projects was hard to find, would later be called an "AI winter".

In the early 1980s, AI research was revived by the commercial success of expert systems, a form of AI program that simulated the knowledge and analytical skills of one or more human experts. By 1985 the market for AI had reached over a billion dollars. At the same time, Japan's fifth generation computer project inspired the U.S and British governments to restore funding for academic research in the field. However, beginning with the collapse of the Lisp Machine market in 1987, AI once again fell into disrepute, and a second, longer lasting AI winter began.

In the 1990s and early 21st century, AI achieved its greatest successes, albeit somewhat behind the scenes. Artificial intelligence is used for logistics, data mining, medical diagnosis and many other areas throughout the technology industry. The success was due to several factors: the incredible power of computers today (see Moore's law), a
greater emphasis on solving specific subproblems, the creation of new ties between AI and other fields working on similar problems, and above all a new commitment by researchers to solid mathematical methods and rigorous scientific standards.\[38\]

[] Problems

The general problem of simulating (or creating) intelligence has been broken down into a number of specific sub-problems. These consist of particular traits or capabilities that researchers would like an intelligent system to display. The traits described below have received the most attention.\[11\]

[] Deduction, reasoning, problem solving

Early AI researchers developed algorithms that imitated the step-by-step reasoning that humans use when they solve puzzles, play board games or make logical deductions.\[39\] By the late 1980s and '90s, AI research had also developed highly successful methods for dealing with uncertain or incomplete information, employing concepts from probability and economics.\[40\]

For difficult problems, most of these algorithms can require enormous computational resources — most experience a "combinatorial explosion": the amount of memory or computer time required becomes astronomical when the problem goes beyond a certain size. The search for more efficient problem solving algorithms is a high priority for AI research.\[41\]

Human beings solve most of their problems using fast, intuitive judgments rather than the conscious, step-by-step deduction that early AI research was able to model.\[42\] AI has made some progress at imitating this kind of "sub-symbolic" problem solving: embodied agent approaches emphasize the importance of sensorimotor skills to higher reasoning; neural net research attempts to simulate the structures inside human and animal brains that gives rise to this skill.

[] Knowledge representation

Main articles: Knowledge representation and Commonsense knowledge

Knowledge representation\[43\] and knowledge engineering\[44\] are central to AI research. Many of the problems machines are expected to solve will require extensive knowledge about the world. Among the things that AI needs to represent are: objects, properties, categories and relations between objects;\[45\] situations, events, states and time;\[46\] causes and effects;\[47\] knowledge about knowledge (what we know about what other people know);\[48\] and many other, less well researched domains. A complete representation of "what exists" is an ontology\[49\] (borrowing a word from traditional philosophy), of which the most general are called upper ontologies.

Among the most difficult problems in knowledge representation are:
**Default reasoning** and the **qualification problem**

Many of the things people know take the form of "working assumptions." For example, if a bird comes up in conversation, people typically picture an animal that is fist sized, sings, and flies. None of these things are true about all birds. John McCarthy identified this problem in 1969 as the qualification problem: for any commonsense rule that AI researchers care to represent, there tend to be a huge number of exceptions. Almost nothing is simply true or false in the way that abstract logic requires. AI research has explored a number of solutions to this problem.

The breadth of **commonsense knowledge**

The number of atomic facts that the average person knows is astronomical. Research projects that attempt to build a complete knowledge base of commonsense knowledge (e.g., Cyc) require enormous amounts of laborious ontological engineering — they must be built, by hand, one complicated concept at a time. A major goal is to have the computer understand enough concepts to be able to learn by reading from sources like the internet, and thus be able to add to its own ontology.

The subsymbolic form of some **commonsense knowledge**

Much of what people know is not represented as "facts" or "statements" that they could actually say out loud. For example, a chess master will avoid a particular chess position because it "feels too exposed" or an art critic can take one look at a statue and instantly realize that it is a fake. These are intuitions or tendencies that are represented in the brain non-consciously and sub-symbolically. Knowledge like this informs, supports and provides a context for symbolic, conscious knowledge. As with the related problem of sub-symbolic reasoning, it is hoped that situated AI or computational intelligence will provide ways to represent this kind of knowledge.

### Planning

Main article: Automated planning and scheduling

Intelligent agents must be able to set goals and achieve them. They need a way to visualize the future (they must have a representation of the state of the world and be able to make predictions about how their actions will change it) and be able to make choices that maximize the utility (or "value") of the available choices.

In classical planning problems, the agent can assume that it is the only thing acting on the world and it can be certain what the consequences of its actions may be. However, if this is not true, it must periodically check if the world matches its predictions and it must change its plan as this becomes necessary, requiring the agent to reason under uncertainty.

Multi-agent planning uses the cooperation and competition of many agents to achieve a given goal. Emergent behavior such as this is used by evolutionary algorithms and swarm intelligence.
[[ Learning

Main article: Machine learning

Machine learning[61] has been central to AI research from the beginning.[62] Unsupervised learning is the ability to find patterns in a stream of input. Supervised learning includes both classification and numerical regression. Classification is used to determine what category something belongs in, after seeing a number of examples of things from several categories. Regression takes a set of numerical input/output examples and attempts to discover a continuous function that would generate the outputs from the inputs. In reinforcement learning[63] the agent is rewarded for good responses and punished for bad ones. These can be analyzed in terms of decision theory, using concepts like utility. The mathematical analysis of machine learning algorithms and their performance is a branch of theoretical computer science known as computational learning theory.

[[ Natural language processing

Main article: Natural language processing

Natural language processing[64] gives machines the ability to read and understand the languages that humans speak. Many researchers hope that a sufficiently powerful natural language processing system would be able to acquire knowledge on its own, by reading the existing text available over the internet. Some straightforward applications of natural language processing include information retrieval (or text mining) and machine translation.[65]

[[ Motion and manipulation

ASIMO uses sensors and intelligent algorithms to avoid obstacles and navigate stairs.

Main article: Robotics

The field of robotics[66] is closely related to AI. Intelligence is required for robots to be able to handle such tasks as object manipulation[67] and navigation, with sub-problems of localization (knowing where you are), mapping (learning what is around you) and motion planning (figuring out how to get there).[68]

[[ Perception
Main articles: Machine perception, Computer vision, and Speech recognition

**Machine perception**[^69] is the ability to use input from sensors (such as cameras, microphones, sonar and others more exotic) to deduce aspects of the world. **Computer vision**[^70] is the ability to analyze visual input. A few selected subproblems are speech recognition[^21], facial recognition and object recognition.[^22]

### Social intelligence

Main article: Affective computing

![Kismet](image)

*Kismet*, a robot with rudimentary social skills

Emotion and social skills[^22] play two roles for an intelligent agent. First, it must be able to predict the actions of others, by understanding their motives and emotional states. (This involves elements of *game theory*, *decision theory*, as well as the ability to model human emotions and the perceptual skills to detect emotions.) Also, for good human-computer interaction, an intelligent machine also needs to *display* emotions. At the very least it must appear polite and sensitive to the humans it interacts with. At best, it should have normal emotions itself.

### Creativity

Main article: Computational creativity

![TOPIO](image)

*TOPIO*, a robot that can play table tennis, developed by TOSY.

A sub-field of AI addresses *creativity* both theoretically (from a philosophical and psychological perspective) and practically (via specific implementations of systems that generate outputs that can be considered creative). A related area of computational research is *Artificial Intuition* and *Artificial Imagination*. 

[^69]: "Machine perception" is the ability to use input from sensors (such as cameras, microphones, sonar and others more exotic) to deduce aspects of the world. Computer vision is the ability to analyze visual input. A few selected subproblems are speech recognition, facial recognition and object recognition.
[^70]: Computer vision is the ability to analyze visual input. A few selected subproblems are speech recognition, facial recognition and object recognition.
[^71]: "Facial recognition" is the ability to identify or verify a person’s identity by analyzing or comparing a person’s facial biometric data, typically using the face as the biometric characteristic for automatic identification or verification.
[^21]: "Speech recognition" is the ability of a machine to convert spoken language into computer-executable text.
[^22]: "Emotion and social skills" play two roles for an intelligent agent. First, it must be able to predict the actions of others, by understanding their motives and emotional states. (This involves elements of *game theory*, *decision theory*, as well as the ability to model human emotions and the perceptual skills to detect emotions.) Also, for good human-computer interaction, an intelligent machine also needs to *display* emotions. At the very least it must appear polite and sensitive to the humans it interacts with. At best, it should have normal emotions itself.
[^23]: "Creativity" is the ability of a system to produce or respond in an innovative or original manner.
[^24]: "Artificial Intuition" and "Artificial Imagination" are related areas of computational research that deal with the ability of machines to simulate human-like decision-making and creative thought processes.
[] General intelligence

Main articles: Strong AI and AI-complete

Most researchers hope that their work will eventually be incorporated into a machine with general intelligence (known as strong AI), combining all the skills above and exceeding human abilities at most or all of them. A few believe that anthropomorphic features like artificial consciousness or an artificial brain may be required for such a project.

Many of the problems above are considered AI-complete: to solve one problem, you must solve them all. For example, even a straightforward, specific task like machine translation requires that the machine follow the author's argument (reason), know what is being talked about (knowledge), and faithfully reproduce the author's intention (social intelligence). Machine translation, therefore, is believed to be AI-complete: it may require strong AI to be done as well as humans can do it.

[] Approaches

There is no established unifying theory or paradigm that guides AI research. Researchers disagree about many issues. A few of the most long standing questions that have remained unanswered are these: should artificial intelligence simulate natural intelligence, by studying psychology or neurology? Or is human biology as irrelevant to AI research as bird biology is to aeronautical engineering? Can intelligent behavior be described using simple, elegant principles (such as logic or optimization)? Or does it necessarily require solving a large number of completely unrelated problems? Can intelligence be reproduced using high-level symbols, similar to words and ideas? Or does it require "sub-symbolic" processing?

[] Cybernetics and brain simulation

Main articles: Cybernetics and Computational neuroscience
There is no consensus on how closely the brain should be simulated.

In the 1940s and 1950s, a number of researchers explored the connection between neurology, information theory, and cybernetics. Some of them built machines that used electronic networks to exhibit rudimentary intelligence, such as W. Grey Walter's turtles and the Johns Hopkins Beast. Many of these researchers gathered for meetings of the Teleological Society at Princeton University and the Ratio Club in England. By 1960, this approach was largely abandoned, although elements of it would be revived in the 1980s.

[[ Symbolic

Main article: Good old fashioned artificial intelligence

When access to digital computers became possible in the middle 1950s, AI research began to explore the possibility that human intelligence could be reduced to symbol manipulation. The research was centered in three institutions: CMU, Stanford and MIT, and each one developed its own style of research. John Haugeland named these approaches to AI "good old fashioned AI" or "GOFAI".

Cognitive simulation

Economist Herbert Simon and Alan Newell studied human problem solving skills and attempted to formalize them, and their work laid the foundations of the field of artificial intelligence, as well as cognitive science, operations research and management science. Their research team used the results of psychological experiments to develop programs that simulated the techniques that people used to solve problems. This tradition, centered at Carnegie Mellon University would eventually culminate in the development of the Soar architecture in the middle 80s.

Logic based

Unlike Newell and Simon, John McCarthy felt that machines did not need to simulate human thought, but should instead try to find the essence of abstract reasoning and problem solving, regardless of whether people used the same algorithms. His laboratory at Stanford (SAIL) focused on using formal logic to solve a wide variety of problems, including knowledge representation, planning and learning. Logic was also focus of the work at the University of Edinburgh and elsewhere in Europe which led to the development of the programming language Prolog and the science of logic programming.

"Anti-logic" or "scruffy"

Researchers at MIT (such as Marvin Minsky and Seymour Papert) found that solving difficult problems in vision and natural language processing required ad-hoc solutions – they argued that there was no simple and general principle (like logic) that would capture all the aspects of intelligent behavior. Roger Schank described their "anti-logic" approaches as "scruffy" (as opposed to the "neat" paradigms at CMU and Stanford). Commonsense knowledge bases (such as
Doug Lenat’s Cyc) are an example of "scruffy" AI, since they must be built by hand, one complicated concept at a time.\[86\]

Knowledge based

When computers with large memories became available around 1970, researchers from all three traditions began to build knowledge into AI applications.\[87\] This "knowledge revolution" led to the development and deployment of expert systems (introduced by Edward Feigenbaum), the first truly successful form of AI software.\[85\] The knowledge revolution was also driven by the realization that enormous amounts of knowledge would be required by many simple AI applications.

[] Sub-symbolic

During the 1960s, symbolic approaches had achieved great success at simulating high-level thinking in small demonstration programs. Approaches based on cybernetics or neural networks were abandoned or pushed into the background.\[88\] By the 1980s, however, progress in symbolic AI seemed to stall and many believed that symbolic systems would never be able to imitate all the processes of human cognition, especially perception, robotics, learning and pattern recognition. A number of researchers began to look into "sub-symbolic" approaches to specific AI problems.\[29\]

Bottom-up, embodied, situated, behavior-based or nouvelle AI

Researchers from the related field of robotics, such as Rodney Brooks, rejected symbolic AI and focused on the basic engineering problems that would allow robots to move and survive.\[89\] Their work revived the non-symbolic viewpoint of the early cybernetics researchers of the 50s and reintroduced the use of control theory in AI. These approaches are also conceptually related to the embodied mind thesis.

Computational Intelligence

Interest in neural networks and "connectionism" was revived by David Rumelhart and others in the middle 1980s.\[90\] These and other sub-symbolic approaches, such as fuzzy systems and evolutionary computation, are now studied collectively by the emerging discipline of computational intelligence.\[91\]

[] Statistical

In the 1990s, AI researchers developed sophisticated mathematical tools to solve specific subproblems. These tools are truly scientific, in the sense that their results are both measurable and verifiable, and they have been responsible for many of AI's recent successes. The shared mathematical language has also permitted a high level of collaboration with more established fields (like mathematics, economics or operations research). Stuart Russell and Peter Norvig describe this movement as nothing less than a "revolution" and "the victory of the neats."\[38\]

[] Integrating the approaches
Intelligent agent paradigm

An intelligent agent is a system that perceives its environment and takes actions which maximizes its chances of success. The simplest intelligent agents are programs that solve specific problems. The most complicated intelligent agents are rational, thinking humans. The paradigm gives researchers license to study isolated problems and find solutions that are both verifiable and useful, without agreeing on one single approach. An agent that solves a specific problem can use any approach that works — some agents are symbolic and logical, some are sub-symbolic neural networks and others may use new approaches. The paradigm also gives researchers a common language to communicate with other fields—such as decision theory and economics—that also use concepts of abstract agents. The intelligent agent paradigm became widely accepted during the 1990s.

Agent architectures and cognitive architectures

Researchers have designed systems to build intelligent systems out of interacting intelligent agents in a multi-agent system. A system with both symbolic and sub-symbolic components is a hybrid intelligent system, and the study of such systems is artificial intelligence systems integration. A hierarchical control system provides a bridge between sub-symbolic AI at its lowest, reactive levels and traditional symbolic AI at its highest levels, where relaxed time constraints permit planning and world modelling. Rodney Brooks' subsumption architecture was an early proposal for such a hierarchical system.

Tools

In the course of 50 years of research, AI has developed a large number of tools to solve the most difficult problems in computer science. A few of the most general of these methods are discussed below.

Search and optimization

Main articles: Search algorithm, Optimization (mathematics), and Evolutionary computation

Many problems in AI can be solved in theory by intelligently searching through many possible solutions. Reasoning can be reduced to performing a search. For example, logical proof can be viewed as searching for a path that leads from premises to conclusions, where each step is the application of an inference rule. Planning algorithms search through trees of goals and subgoals, attempting to find a path to a target goal, a process called means-ends analysis. Robotics algorithms for moving limbs and grasping objects use local searches in configuration space. Many learning algorithms use search algorithms based on optimization.

Simple exhaustive searches are rarely sufficient for most real world problems: the search space (the number of places to search) quickly grows to astronomical numbers. The result is a search that is too slow or never completes. The solution, for many problems, is to use "heuristics" or "rules of thumb" that eliminate choices that are
unlikely to lead to the goal (called "pruning the search tree"). Heuristics supply the program with a "best guess" for what path the solution lies on.\[100]\]

A very different kind of search came to prominence in the 1990s, based on the mathematical theory of optimization. For many problems, it is possible to begin the search with some form of a guess and then refine the guess incrementally until no more refinements can be made. These algorithms can be visualized as blind hill climbing: we begin the search at a random point on the landscape, and then, by jumps or steps, we keep moving our guess uphill, until we reach the top. Other optimization algorithms are simulated annealing, beam search and random optimization\[101]\...Evolutionary computation uses a form of optimization search. For example, they may begin with a population of organisms (the guesses) and then allow them to mutate and recombine, selecting only the fittest to survive each generation (refining the guesses). Forms of evolutionary computation include swarm intelligence algorithms (such as ant colony or particle swarm optimization)\[102]\ and evolutionary algorithms (such as genetic algorithms\[103]\ and genetic programming\[104]\\[105]\).

**Logic**

Main articles: Logic programming and Automated reasoning

Logic\[106\] was introduced into AI research by John McCarthy in his 1958 Advice Taker proposal. Logic is used for knowledge representation and problem solving, but it can be applied to other problems as well. For example, the satplan algorithm uses logic for planning\[108\] and inductive logic programming is a method for learning.\[109\]

Several different forms of logic are used in AI research. Propositional or sentential logic\[110\] is the logic of statements which can be true or false. First-order logic\[111\] also allows the use of quantifiers and predicates, and can express facts about objects, their properties, and their relations with each other. Fuzzy logic,\[112\] is a version of first-order logic which allows the truth of a statement to be represented as a value between 0 and 1, rather than simply True (1) or False (0). Fuzzy systems can be used for uncertain reasoning and have been widely used in modern industrial and consumer product control systems. Default logics, non-monotonic logics and circumscription\[51\] are forms of logic designed to help with default reasoning and the qualification problem. Several extensions of logic have been designed to handle specific domains of knowledge, such as: description logics;\[45\] situation calculus, event calculus and fluent calculus (for representing events and time); causal calculus; belief calculus; and modal logics.\[48\]

**Probabilistic methods for uncertain reasoning**

Main articles: Bayesian network, Hidden Markov model, Kalman filter, Decision theory, and Utility theory.
Many problems in AI (in reasoning, planning, learning, perception and robotics) require the agent to operate with incomplete or uncertain information. Starting in the late 80s and early 90s, Judea Pearl and others championed the use of methods drawn from probability theory and economics to devise a number of powerful tools to solve these problems.\[113\] [114]

Bayesian networks\[115\] are a very general tool that can be used for a large number of problems: reasoning (using the Bayesian inference algorithm),\[116\] learning (using the expectation-maximization algorithm),\[117\] planning (using decision networks)\[118\] and perception (using dynamic Bayesian networks).\[119\] Probabilistic algorithms can also be used for filtering, prediction, smoothing and finding explanations for streams of data, helping perception systems to analyze processes that occur over time\[120\] (e.g., hidden Markov models\[121\] or Kalman filters\[122\]).

A key concept from the science of economics is "utility": a measure of how valuable something is to an intelligent agent. Precise mathematical tools have been developed that analyze how an agent can make choices and plan, using decision theory, decision analysis,\[123\] information value theory.\[124\] These tools include models such as Markov decision processes,\[125\] dynamic decision networks,\[126\] game theory and mechanism design.\[127\]

### Classifiers and statistical learning methods

Main articles: Classifier (mathematics), Statistical classification, and Machine learning

The simplest AI applications can be divided into two types: classifiers ("if shiny then diamond") and controllers ("if shiny then pick up"). Controllers do however also classify conditions before inferring actions, and therefore classification forms a central part of many AI systems. Classifiers are functions that use pattern matching to determine a closest match. They can be tuned according to examples, making them very attractive for use in AI. These examples are known as observations or patterns. In supervised learning, each pattern belongs to a certain predefined class. A class can be seen as a decision that has to be made. All the observations combined with their class labels are known as a data set. When a new observation is received, that observation is classified based on previous experience.\[128\]

A classifier can be trained in various ways; there are many statistical and machine learning approaches. The most widely used classifiers are the neural network\[129\] kernel methods such as the support vector machine\[130\] k-nearest neighbor algorithm,\[131\] Gaussian mixture model,\[132\] naive Bayes classifier,\[133\] and decision tree.\[134\] The performance of these classifiers have been compared over a wide range of tasks. Classifier performance depends greatly on the characteristics of the data to be classified. There is no single classifier that works best on all given problems; this is also referred to as the "no free lunch" theorem. Determining a suitable classifier for a given problem is still more an art than science.\[135\]
[|] Neural networks

Main articles: Neural networks and Connectionism

A neural network is an interconnected group of nodes, akin to the vast network of neurons in the human brain.

The study of artificial neural networks began in the decade before the field AI research was founded, in the work of Walter Pitts and Warren McCullough. Other important early researchers were Frank Rosenblatt, who invented the perceptron and Paul Werbos who developed the backpropagation algorithm. [134]

The main categories of networks are acyclic or feedforward neural networks (where the signal passes in only one direction) and recurrent neural networks (which allow feedback). Among the most popular feedforward networks are perceptrons, multi-layer perceptrons and radial basis networks. [133] Among recurrent networks, the most famous is the Hopfield net, a form of attractor network, which was first described by John Hopfield in 1982. [136] Neural networks can be applied to the problem of intelligent control (for robotics) or learning, using such techniques as Hebbian learning and competitive learning. [137]

Jeff Hawkins argues that research in neural networks has stalled because it has failed to model the essential properties of the neocortex, and has suggested a model (Hierarchical Temporal Memory) that is based on neurological research. [138]

[|] Control theory

Main article: Intelligent control

Control theory, the grandchild of cybernetics, has many important applications, especially in robotics. [139]

Languages

Main article: List of programming languages for artificial intelligence

AI researchers have developed several specialized languages for AI research, including Lisp and Prolog. [140]
Evaluating progress

How can one determine if an agent is intelligent? In 1950, Alan Turing proposed a general procedure to test the intelligence of an agent now known as the Turing test. This procedure allows almost all the major problems of artificial intelligence to be tested. However, it is a very difficult challenge and at present all agents fail.

Artificial intelligence can also be evaluated on specific problems such as small problems in chemistry, hand-writing recognition and game-playing. Such tests have been termed subject matter expert Turing tests. Smaller problems provide more achievable goals and there are an ever-increasing number of positive results.

The broad classes of outcome for an AI test are:

- Optimal: it is not possible to perform better
- Strong super-human: performs better than all humans
- Super-human: performs better than most humans
- Sub-human: performs worse than most humans

For example, performance at draughts is optimal,[142] performance at chess is super-human and nearing strong super-human,[143] and performance at many everyday tasks performed by humans is sub-human.

A quite different approach measures machine intelligence through tests which are developed from mathematical definitions of intelligence. Examples of these kinds of tests start in the late nineties devising intelligence tests using notions from Kolmogorov Complexity and data compression [144][145]. Similar definitions of machine intelligence have been put forward by Marcus Hutter in his book Universal Artificial Intelligence (Springer 2005), an idea further developed by Legg and Hutter[146]. Two major advantages of mathematical definitions are their applicability to nonhuman intelligences and their absence of a requirement for human testers.

Applications

This section requires expansion.

Artificial intelligence has successfully been used in a wide range of fields including medical diagnosis, stock trading, robot control, law, scientific discovery, video games, toys, and Web search engines. Frequently, when a technique reaches mainstream use, it is no longer considered artificial intelligence, sometimes described as the AI effect[147]. It may also become integrated into artificial life.
Competitions and prizes

Main article: Competitions and prizes in artificial intelligence

There are a number of competitions and prizes to promote research in artificial intelligence. The main areas promoted are: general machine intelligence, conversational behavior, data-mining, driverless cars, robot soccer and games.

Platforms

A platform (or "computing platform") is defined by Wikipedia as "some sort of hardware architecture or software framework (including application frameworks), that allows software to run." As Rodney Brooks[148] pointed out many years ago, it is not just the artificial intelligence software that defines the AI features of the platform, but rather the actual platform itself that affects the AI that results, ie, we need to be working out AI problems on real world platforms rather than in isolation.

A wide variety of platforms has allowed different aspects of AI to develop, ranging from expert systems, albeit PC-based but still an entire real-world system to various robot platforms such as the widely available Roomba with open interface[149].

Philosophy

Main article: Philosophy of artificial intelligence

Artificial intelligence, by claiming to be able to recreate the capabilities of the human mind, is both a challenge and an inspiration for philosophy. Are there limits to how intelligent machines can be? Is there an essential difference between human intelligence and artificial intelligence? Can a machine have a mind and consciousness? A few of the most influential answers to these questions are given below.[150]

Turing's "polite convention"

If a machine acts as intelligently as a human being, then it is as intelligent as a human being. Alan Turing theorized that, ultimately, we can only judge the intelligence of a machine based on its behavior. This theory forms the basis of the Turing test.[151]

The Dartmouth proposal

"Every aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it." This assertion was printed in the proposal for the Dartmouth Conference of 1956, and represents the position of most working AI researchers.[152]

Newell and Simon's physical symbol system hypothesis

"A physical symbol system has the necessary and sufficient means of general intelligent action." Newell and Simon argue that intelligences consists of formal
operations on symbols. Hubert Dreyfus argued that, on the contrary, human expertise depends on unconscious instinct rather than conscious symbol manipulation and on having a "feel" for the situation rather than explicit symbolic knowledge. (See Dreyfus' critique of AI.)

Gödel's incompleteness theorem

A formal system (such as a computer program) can not prove all true statements. Roger Penrose is among those who claim that Gödel's theorem limits what machines can do. (See The Emperor's New Mind.)

Searle's strong AI hypothesis

"The appropriately programmed computer with the right inputs and outputs would thereby have a mind in exactly the same sense human beings have minds." Searle counters this assertion with his Chinese room argument, which asks us to look inside the computer and try to find where the "mind" might be.

The artificial brain argument

The brain can be simulated. Hans Moravec, Ray Kurzweil and others have argued that it is technologically feasible to copy the brain directly into hardware and software, and that such a simulation will be essentially identical to the original.

Prediction

Main articles: Artificial intelligence in fiction, Ethics of artificial intelligence, Transhumanism, and Technological singularity

AI is a common topic in both science fiction and in projections about the future of technology and society. The existence of an artificial intelligence that rivals human intelligence raises difficult ethical issues and the potential power of the technology inspires both hopes and fears.

In fiction, AI has appeared fulfilling many roles including; a servant (R2D2 in Star Wars), a law enforcer (K.I.T.T. "Knight Rider"), a comrade (Lt. Commander Data in Star Trek), a conqueror/overlord (The Matrix), a dictator (With Folded Hands), an assassin (Terminator), a sentient race (Battlestar Galactica/Transformers), an extension to human abilities (Ghost in the Shell) and the savior of the human race (R. Daneel Olivaw in the Foundation Series).

Mary Shelley's Frankenstein considers a key issue in the ethics of artificial intelligence: if a machine can be created that has intelligence, could it also feel? If it can feel, does it have the same rights as a human? The idea also appears in modern science fiction: the film Artificial Intelligence: A.I. considers a machine in the form of a small boy which has been given the ability to feel human emotions, including, tragically, the capacity to suffer. This issue, now known as "robot rights", is currently being considered by, for example, California's Institute for the Future, although many critics believe that the discussion is premature.

The impact of AI on society is a serious area of study for futurists. Academic sources have considered such consequences as: a decreased demand for human labor,
enhancement of human ability or experience,[165] and a need for redefinition of human identity and basic values.[166] Andrew Kennedy in his musing on the evolution of the human personality[167] considered that artificial intelligences or 'new minds' are likely to have severe personality disorders, and identifies four particular types that are likely to arise: the autistic, the collector, the ecstatic, the victim and suggests that they will need humans because of our superior understanding of personality and the role of the unconscious.

Several futurists argue that artificial intelligence will transcend the limits of progress. Ray Kurzweil has used Moore's law (which describes the relentless exponential improvement in digital technology with uncanny accuracy) to calculate that desktop computers will have the same processing power as human brains by the year 2029, and that by 2045 artificial intelligence will reach a point where it is able to improve itself at a rate that far exceeds anything conceivable in the past, a scenario that science fiction writer Vernor Vinge named the "technological singularity".[165]

Robot designer Hans Moravec, cyberneticist Kevin Warwick and inventor Ray Kurzweil have predicted that humans and machines will merge in the future into cyborgs that are more capable and powerful than either.[165] This idea, called transhumanism, which has roots in Aldous Huxley and Robert Ettinger, has been illustrated in fiction as well, for example in the manga Ghost in the Shell and the science fiction series Dune.

Edward Fredkin argues that "artificial intelligence is the next stage in evolution,"[168] an idea first proposed by Samuel Butler's "Darwin among the Machines" (1863), and expanded upon by George Dyson in his book of the same name in 1998.

Pamela McCorduck writes that all these scenarios are expressions of the ancient human desire to, as she calls it, "forge the gods."[165]