

Cyberbotics' Robot Curriculum

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Chapter 1

About this book

Learning about Intelligent Robots

This book is intended to students, teachers, hobbyists and researchers interested in intelligent robots. It will help you understanding what robots are, what they can do for you, and most interestingly how to program them. It includes two parts: a short theoretical part and a longer practical part. Practical part is decomposed in one chapter about the computer configuration and five chapters of exercises corresponding to five level of difficulty (see the next section). After reading this book, you should be able to design your own intelligent robots.

From Beginners to Robotics Experts

Even if you never wrote a computer program before, you will learn easily how to graphically program the behavior of a simple robot. From this first experience, you will be smoothly introduced to higher level computer programming and discover more possibilities of intelligent robots. This practical investigation is organized in projects for which a difficulty level is associated. You are free to stop at any level if the projects suddenly become too difficult to handle, but if you reach the latest levels successfully, you should consider yourself as a genuine robotics researcher! Here are the levels of difficulty:

- beginner: no prior knowledge needed, suitable for children from 8 years old and people without a scientific background (see [Beginner programming Exercises](#))
- novice: scientific or technological interest needed, suitable for children from 8 years old (see [Novice programming Exercises](#))
- intermediate: general computer science background needed, intended to student from 12 years old with some interest in computer science (see [Intermediate programming Exercises](#))
- advanced: programming skills needed, intended to post-graduate students and researchers (see [Advanced Programming Exercises](#))
- expert: research spirit needed, intended to post-graduate student and researchers (see [Cognitive Benchmarks](#))

Important: The code to which we refer in the exercises is freely available at sourceforge.net. You can download it directly from the SVN at this address:

`http://robotcurriculum.svn.sourceforge.net/svnroot/robotcurriculum`

Easy-to-use robotics Tools

The practical part of this book relies on a couple of software and hardware tools that will allow you to practice intelligent robot programming for real. These tools are the e-puck robot and the Webots software. They are both widely used for education and research in Universities worldwide and are commercially available and well supported. These tools will be described in chapter [E-puck and Webots](#).

Enjoy Robot Competitions

Several exercises are provided along this book. Starting from very simple introductory exercises in chapter [Beginner programming Exercises](#), the reader will learn progressively how to create more and more advanced robotics controllers throughout the following chapters. Finally, the chapter [Cognitive Benchmarks](#) will introduce the reader into the realm of robot competitions through a cognitive benchmark: Rat's Life ¹.

Further reading

- [Cyberbotics Official Webpage](#)
- [E-puck website](#)

¹See their website, [Rat's Life Programming Contest](#)

Chapter 2

What is Artificial Intelligence?

Artificial Intelligence (AI) is an interdisciplinary field of study that includes computer science, engineering, philosophy and psychology. There is no widely accepted precise definition of Artificial Intelligence, because Intelligence is very difficult to define. John McCarthy defined Artificial Intelligence as “the science and engineering of making intelligent machine”¹ which does not explain what intelligent machines are. Hence, it does not help either to answer the question “Is a chess playing program an intelligent machine?”.

GOFAI versus New AI

AI divides roughly into two schools of thought: GOFAI (Good Old Fashioned Artificial Intelligence) and New AI. GOFAI mostly involves methods now classified as machine learning, characterized by formalism and statistical analysis. This is also known as conventional AI, symbolic AI, logical AI or neat AI. Methods include:

- *Expert Systems* apply reasoning capabilities to reach a conclusion. An Expert System can process large amounts of known information and provide conclusions based on them.
- *Case Based Reasoning* stores a set of problems and answers in an organized data structure called cases. A Case Based Reasoning system upon being presented with a problem finds a case in its knowledge base that is most closely related to the new problem and presents its solutions as an output with suitable modifications.
- *Bayesian Networks* are probabilistic graphical models that represent a set of variables and their probabilistic dependencies.
- *Behavior Based AI* is a modular method building AI systems by hand.

New AI involves iterative development or learning. It is often bio-inspired and provides models of biological intelligence, like the Artificial Neural Networks. Learning is based on empirical data and is associated with non-symbolic AI. Methods mainly include:

¹ See [John McCarthy, What is Artificial Intelligence?](#)

- *Artificial Neural Networks* are bio-inspired systems with very strong pattern recognition capabilities.
- *Fuzzy Systems* are techniques for reasoning under uncertainty; they have been widely used in modern industrial and consumer product control systems.
- *Evolutionary computation* applies biologically inspired concepts such as populations, mutation and survival of the fittest to generate increasingly better solutions to a problem. These methods most notably divide into *Evolutionary Algorithms* (including *Genetic Algorithms*) and *Swarm Intelligence* (including *Ant Algorithms*).

Hybrid Intelligent Systems attempt to combine these two groups. Expert Inference Rules can be generated through Artificial Neural Network or Production Rules from Statistical Learning.

History

Early in the 17th century, René Descartes envisioned the bodies of animals as complex but reducible machines, thus formulating the mechanistic theory, also known as the “clockwork paradigm”. Wilhelm Schickard created the first mechanical digital calculating machine in 1623, followed by machines of Blaise Pascal (1643) and Gottfried Wilhelm von Leibniz (1671), who also invented the binary system. In the 19th century, Charles Babbage and Ada Lovelace worked on programmable mechanical calculating machines.

Bertrand Russell and Alfred North Whitehead published Principia Mathematica in 1910-1913, which revolutionized formal logic. In 1931 Kurt Gödel showed that sufficiently powerful consistent formal systems contain true theorems unprovable by any theorem-proving AI that is systematically deriving all possible theorems from the axioms. In 1941 Konrad Zuse built the first working mechanical program-controlled computers. Warren McCulloch and Walter Pitts published A Logical Calculus of the Ideas Immanent in Nervous Activity (1943), laying the foundations for neural networks. Norbert Wiener’s Cybernetics or Control and Communication in the Animal and the Machine (MIT Press, 1948) popularized the term “cybernetics”.

Game theory which would prove invaluable in the progress of AI was introduced with the paper, Theory of Games and Economic Behavior by mathematician John von Neumann and economist Oskar Morgenstern ².

1950’s

The 1950s were a period of active efforts in AI. In 1950, Alan Turing introduced the “Turing test” as a way of creating a test of intelligent behavior. The first working AI programs were written in 1951 to run on the Ferranti Mark I machine of the University of Manchester: a checkers-playing program written by Christopher Strachey and a chess-playing program written by Dietrich Prinz. John McCarthy coined the term “artificial intelligence” at the first conference devoted to the subject, in 1956. He also invented the Lisp programming language. Joseph Weizenbaum built ELIZA, a chatter-bot implementing Rogerian psychotherapy. The birth date of AI is generally considered to be July 1956 at the Dartmouth Conference, where many of these people met and exchanged ideas.

²Von Neumann, J.; Morgenstern, O. (1953), “Theory of Games and Economic Behavior”, New York

1960s-1970s

During the 1960s and 1970s, Joel Moses demonstrated the power of symbolic reasoning for integration problems in the Maccsma program, the first successful knowledge-based program in mathematics. Leonard Uhr and Charles Vossler published “A Pattern Recognition Program That Generates, Evaluates, and Adjusts Its Own Operators” in 1963, which described one of the first machine learning programs that could adaptively acquire and modify features and thereby overcome the limitations of simple perceptrons of Rosenblatt. Marvin Minsky and Seymour Papert published *Perceptrons*, which demonstrated the limits of simple Artificial Neural Networks. Alain Colmerauer developed the Prolog computer language. Ted Shortliffe demonstrated the power of rule-based systems for knowledge representation and inference in medical diagnosis and therapy in what is sometimes called the first expert system. Hans Moravec developed the first computer-controlled vehicle to autonomously negotiate cluttered obstacle courses.

1980s

In the 1980s, Artificial Neural Networks became widely used due to the back-propagation algorithm, first described by Paul Werbos in 1974. The team of Ernst Dickmanns built the first robot cars, driving up to 55 mph on empty streets.

1990s & Turn of the Millennium

The 1990s marked major achievements in many areas of AI and demonstrations of various applications. In 1995, one of Ernst Dickmanns’ robot cars drove more than 1000 miles in traffic at up to 110 mph, tracking and passing other cars (simultaneously Dean Pomerleau of Carnegie Mellon tested a semi-autonomous car with human-controlled throttle and brakes). Deep Blue, a chess-playing computer, beat Garry Kasparov in a famous six-game match in 1997. Honda built the first prototypes of humanoid robots (see picture of the Asimo Robot).

During the 1990s and 2000s AI has become very influenced by probability theory and statistics. Bayesian networks are the focus of this movement, providing links to more rigorous topics in statistics and engineering such as Markov models and Kalman filters, and bridging the divide between GOFAI and New AI. This new school of AI is sometimes called ‘machine learning’. The last few years have also seen a big interest in game theory applied to AI decision making.

The Turing test

Artificial Intelligence is implemented in machines (i.e., computers or robots), that are observed by “Natural Intelligence” beings (i.e., humans). These human beings are questioning whether or not these machines are intelligent. To give an answer to this question, they evidently compare the behavior of the machine to the behavior of another intelligent being they know. If both are similar, then, they can conclude that the machine appears to be intelligent.

Alan Turing developed a very interesting test that allows the observer to formally say whether or not a machine is intelligent. To understand this test, it is first necessary to understand that intelligence, just like beauty, is a concept relative to an observer. There is no absolute intelligence, like there is no absolute beauty. Hence it is not correct to say that a machine is more or less intelligent. Rather, we should say that a machine is more or less intelligent for a given observer.



Figure 2.1: Asimo: Honda's humanoid robot

Starting from this point of view, the Turing test makes it possible to evaluate whether or not a machine qualifies for artificial intelligence relatively to an observer.

The test consists in a simple setup where the observer is facing a machine. The machine could be a computer or a robot, it does not matter. The machine however, should have the possibility to be remote controlled by a human being (the remote controller) which is not visible by the observer. The remote controller may be in another room than the observer. He should be able to communicate with the observer through the machine, using the available inputs and outputs of the machine. In the case of a computer, the inputs and outputs may be a keyboard, a mouse and computer screen. In the case of a robot, it may be a camera, a speaker (with synthetic voice), a microphone, motors, etc. The observer doesn't know if the machine is remote controlled by someone else or if it behaves on its own. He has to guess it. Hence, he will interact with the machine, for example by chatting using the keyboard and the screen to try to understand whether or not there is a human intelligence behind this machine writing the answers to his questions. Hence he will want to ask very complicated questions and see what the machine answers and try to determine if the answers are generated by an AI program or if they come from a real human being. If the observer believes

he is interacting with a human being while he is actually interacting with a computer program, then this means the machine is intelligent for him. He was bluffed by the machine. The table below summarizes all the possible results coming out of a Turing test.

The Turing test helps a lot to answer the question “can we build intelligent machines?”. It demonstrates that some machines are indeed already intelligent for some people. Although these people are currently a minority, including mostly children but also adults, this minority is growing as AI programs improve.

Although the original Turing test is often described as a computer chat session (see picture), the interaction between the observer and the machine may take very various forms, including a chess game, playing a virtual reality video game, interacting with a mobile robot, etc.

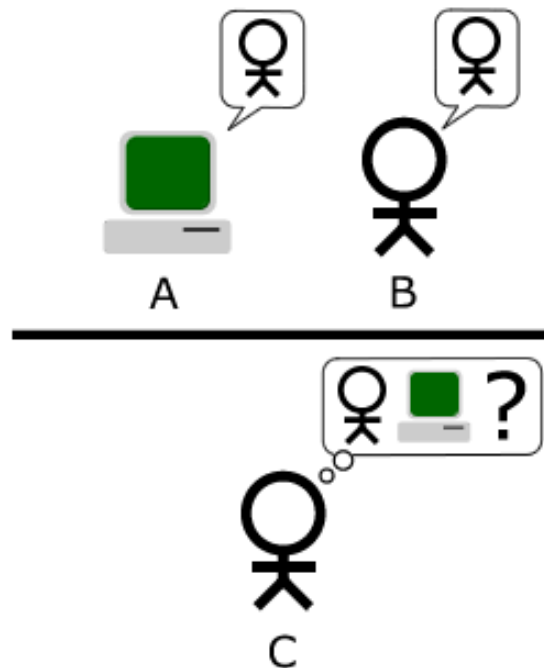


Figure 2.2: The Turing test

Similar experiments involve children observing two mobile robots performing a prey predator game and describing what is happening. Unlike adults who will generally say that the robots were programmed in some way to perform this behavior, possibly mentioning the sensors, actuators and micro-processor of the robot, the children will describe the behavior of the robots using the same words they would use to describe the behavior of a cat running after a mouse. They will grant feelings to the robots like “he is afraid of”, “he is angry”, “he is excited”, “he is quiet”, “he wants to...”, etc. This leads us to think that for a child, there is little difference between the intelligence of such robots and animal intelligence.

	The machine is remote controlled by a human	The machine runs an Artificial Intelligence program
The observer believes he faces a human intelligence	undetermined: the observer is good at recognizing human intelligence	successful: the machine is intelligent for this observer
The observer believes he faces a computer program	undetermined: the observer has troubles recognizing human intelligence	failed: the machine is not intelligent for this observer

Table 2.1: All possible outcomes for a Turing test

Cognitive Benchmarks

Another way to measure whether or not a machine is intelligent is to establish cognitive (or intelligence) benchmarks. A benchmark is a problem definition associated with a performance metrics allowing evaluating the performance of a system. For example in the car industry, some benchmarks measure the time necessary for a car to accelerate from 0 km/h to 100 km/h. Cognitive benchmarks address problems where intelligence is necessary to achieve a good performance.

Again, since intelligence is relative to an observer, the cognitive aspect of a benchmark is also relative to an observer. For example if a benchmark consists in playing chess against the Deep Blue program, some observers may think that this requires some intelligence and hence it is a cognitive benchmark, whereas some other observers may object that it doesn't require intelligence and hence it is not a cognitive benchmark.

Some cognitive benchmarks have been established by people outside computer science and robotics. They include IQ tests developed by psychologists as well as animal intelligence tests developed by biologists to evaluate for example how well rats remember the path to a food source in a maze, or how do monkeys learn to press a lever to get food.

AI and robotics benchmarks have also been established mostly throughout programming or robotics competitions. The most famous examples are the AAI Robot Competition, the FIRST Robot Competition, the DARPA Grand Challenge, the Eurobot Competition, the RoboCup competition (see picture), the Roboka Programming Contest. All these competitions define a precise scenario and a performance metrics based either on an absolute individual performance evaluation or a ranking between the different competitors. They are very well referenced on the Internet so that it should be easy to reach their official web site for more information.

The last chapter of this book will introduce you to a series of robotics cognitive benchmarks (especially the Rat's Life benchmark) for which you will be able to design your own intelligent systems and compare them to others.

Further reading

- [Artificial Intelligence](#)
- [Embedded Control Systems Design/RoboCup](#)

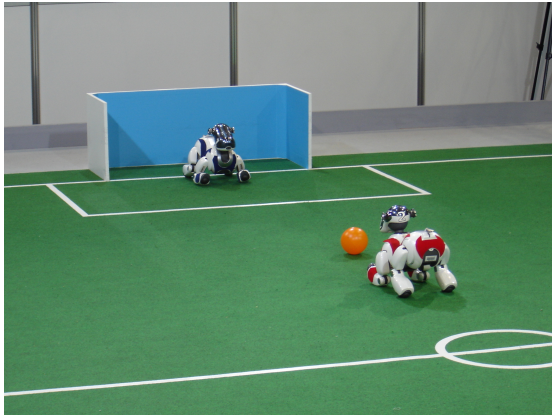


Figure 2.3: Aibo Robocup competition

Appendix A

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