Robotics Topic 1 – Introduction

Prepared for the module team by Jeffrey Johnson and Tony Hirst, updated by Jon Rosewell and Daniel Gooch

1 Introduction to *Robotics and AI*

Hello and welcome to this block on *Robotics and AI*. This block focuses on some of the fundamental issues involved in robotics and AI including what robots are, how their 'intelligence' is created and the ethics of robotic and AI systems, particularly in how they are used in everyday life.

This topic, in common with the other topics, is split into a number of sections that are listed to the left of this page.

We start this topic with an overview of the whole block, explaining how it is organised and how to approach your studies.

We then turn to a fundamental question: just what is a robot? We'll look at both some current examples of robotics and some historical examples of artificial beings.

One of the features that might distinguish a robot from other machines is intelligence, so we will need to explore what we mean by *intelligence* and *artificial intelligence (AI)*.

After this, we will introduce you to the practical aspects of the block.

2 About the block

Figure 2.1 A Starship Technologies robot delivering food

Show description

Robotics and the AI algorithms that control them are now visible throughout our daily lives. This block is designed to show that robots are not only used in factories, but increasingly in shops and offices, in hospitals and in our homes. Here are just a few of the many kinds of robots that already exist or are being developed:

- robot vacuum cleaners, lawnmowers and window cleaners
- robot surgeons, therapists and helpers for disabled people
- robotic aeroplanes and cars
- robots that unblock pipes and weld undersea structures
- robot food delivery, bartenders, waiters and butlers
- robot football players, dancers and performing artists
- robots that rescue people from collapsed buildings
- robot pets, insects and animals.

In this block we'll explore the fundamentals of how robots work, and the huge technical progress that has been made over the last few years. But we'll go far beyond this by examining the relationship between humans and robots and the enormous impact they are having on our lives and on society. In doing this we will often have to reflect on what it means to be a human being interacting with other human beings, before considering the range of possible relationships between humans and robots.

2.1 Aims and learning outcomes

This block is intended to be studied by students with a variety of backgrounds. Students will range from people who know nothing about robots to those who know a great deal, and from people who are new to studying to those with a lot more experience. Whichever group you fall in, we hope that you will find the Robotics and AI block interesting and rewarding. The School of Computing and Communications offers further modules that relate to the use of AI and data technologies at stages 2 and 3; if you are interested then take a look at all of the modules on offer.

The aims of this block are:

- **To enable you to understand robots**: learning about the various technologies involved in robotics and how to program or train robots.
- **To enable you to understand how robots are affecting our lives**: how robots will help us and our families at home; their role in health and social care; and their contribution to industry, transportation, science and philosophy.
- **To alert you to the many ethical issues concerning robots**: to help you reflect on and find your own answers to questions such as the following: Should we use a robot babysitter? Is it murder to switch off a robot? Are robot soldiers acceptable? Should there be a charter of robot rights? Will robots take over the world? Should a human be allowed to marry a robot?
- **To share with you a sense of excitement and fun**: robots can make you laugh; making robots do things can be very satisfying; robots can be fascinating and can motivate us to learn.

Learning outcomes for the block

Knowledge and understanding

By the end of the block you should be able to:

- demonstrate your knowledge of the theory and principles underlying robot design, assembly and programming
- organise information for effective communication
- apply basic programming metaphors to robots
- apply simple control strategies for robot control
- demonstrate your appreciation of the ways in which robots are impacting on human beings and human society.

Cognitive skills

By the end of the block you should be able to:

- identify the key features necessary for a robot to undertake a task in a given environment
- create a sequence of instructions to control a robot
- explain the interactions between humans and robots

- reflect on your learning and evaluate your achievements.

Key skills

By the end of the block you should be able to:

- develop your abilities to communicate information to an intended audience
- make use of different sources of information
- search for relevant information on the web.

Practical skills

By the end of the block you should be able to:

- write simple programs to control a robot
- train a robot to perform a given task
- find relevant information on the web
- organise and document information from different sources.

2.2 Structure of the block

The Robotics and AI block of the module lasts nine weeks. It is organised into weeks of study, each representing about 10 hours of study time. This is split approximately equally between reading and practical activities. There are eight main study weeks and a final week devoted to assessment – more on this later.

The study planner on the module home page suggests a study plan for the block. We recommend that you follow the suggested pacing if you can because that will allow you to participate in the forums with other students at the appropriate time. However, if you can't follow the study plan, then you can get ahead a little or drop behind a little in your study, but you need to submit the assignment on time.

The first part of each study week will involve reading web pages like this, and answering some self-assessment questions (SAQs) to test your understanding. The duration will vary, but typically this will take you about five hours a week. In the second part of each study week you will be doing some related practical work. This will involve working through some activities with a simulated robot. Each study week concludes with a summary of what you have learned during that week.

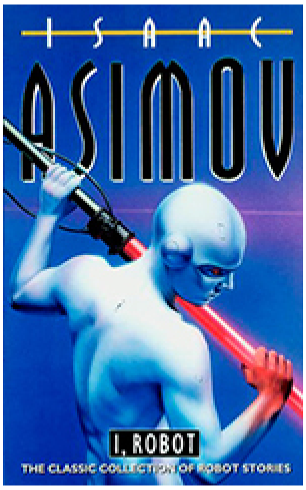
In later weeks of the block, you will read extracts from the set book: Isaac Asimov's *I, Robot*. You won't be expected to remember all the details; these web pages will summarise and develop what you have seen and read.

You will also explore the block wiki, which is kept up to date with examples of interesting robots, and there is a forum where you can exchange information with other students.

So in any one week you might expect to do most of the following:

- read that week's material on the module website
- watch some video clips
- explore some of the links to other sites on the web
- do the activities
- answer the SAQs
- perform experiments and record results
- look ahead to questions in the assignment.

I, Robot



Show description

In weeks 23 to 26 you will read some of the short fictional stories in Isaac Asimov's book *I, Robot*. (You can also find these stories and more in Asimov's collected edition *The Complete Robot*, 1982.) Asimov wrote these stories in the 1940s and 1950s, but the issues they raise about the way human beings and robots coexist are increasingly relevant today. Having seen examples of real robot technology in the first four weeks, you will be well placed to understand the significance of Asimov's ideas later in the block.

The Robopedia wiki

Robotics is a fast-moving field. To keep the block up to date, we will be using a wiki to build a collection of examples of current robotics. At several points in the block, you will be asked to explore this wiki. If at any time you come across interesting examples of robots in the news or in your reading, we encourage you to add information about them to the wiki. You can find the Robopedia wiki through the Robotics section of the Resources page on the module website.

You may not know much about wikis, but you will probably have come across Wikipedia, a huge online encyclopedia built by volunteer contributors. Our wiki will be only a fraction of the size but, like Wikipedia, it is a shared endeavour – your contributions are welcome and will be most valuable to your fellow students. Contributing to the wiki is very easy – simply click on 'Edit' and start typing!

By the way, if you are curious to know why a wiki is called a wiki, why not use Wikipedia to find out?

The forums

The forums provide a meeting place where you can ask questions, give answers and exchange information with other students. Besides your Cluster group forum, the Technical help forum can be used to ask for help on technical issues from experienced moderators and other students.

We encourage you to use the forums. If you have questions or need help, you will probably get an answer from other students very quickly. The forums can save you a lot of time and make studying more enjoyable. They are also a place for interesting discussions around issues raised by the block.

Practical activity software

The practical activities for this block use a variety of different software packages. We will provide you with full instructions on how to get started in the practical activities themselves.

Hands-on experimentation is an important part of this block. We hope you will find the activities interesting and fun. Lab work can be very time-consuming, so we have tried not to overload this part of the block. We have included some additional optional activities in case you want to go further; these are intended to enrich the module, but are not compulsory and will not be directly assessed.

Although the amount of practical work may vary from week to week, you should find that it takes you on average about five hours to complete.

Assessment

The assessment for this block consists of a single tutor-marked assignment (TMA). Week 27 contains no new module teaching or practical work; instead you can devote all your study time to completing the assessment for the block. We suggest you take a brief look at the assignment soon so that you know what to expect.

The TMA contains a number of different questions. These include:

- short-answer questions that test your knowledge and understanding of the key principles of robotics, including some key historical developments
- an extended question to test your understanding of robot control programming
- a short piece of research and writing that allows you to demonstrate your knowledge of recent developments in robotics and your understanding of the wider social and cultural issues raised by them
- a reflection on your learning as evidenced by your ePortfolio of learning activities.

You will find the burden of your assignment considerably lessened if you do not leave it until the last minute! Remember to carry out the ePortfolio activities as you study the block. This will ensure that you have time to reflect on the learning and skills that you have developed and can demonstrate them in your ePortfolio.

2.3 Topic 1 learning outcomes

By the end of Topic 1 you should:

- know what the block is about
- understand how to use the teaching materials provided
- be able to define what an intelligent, autonomous, mobile robot is
- know some robot history
- know something about the uses of robots – current and future
- understand some of the ethical issues in human–robot interaction
- have practised some basic study skills, including making summary notes, conducting experiments and recording the results.

3 What is a robot?

The term ‘robot’ is attributed to the Czech Karel Čapek, who wrote a play in 1920 called *RUR*. The initials stand for Rossum’s Universal Robots, and the word ‘robot’ comes from the Czech word *robota*, which means forced labour. So, right from the start, robots were seen as artificial beings acting as slaves to humans.

Čapek’s robots were actually made from biological parts, although now we tend to think of robots as being made from mechanical parts. With advances in biotechnologies (e.g. growing spare parts), we may yet turn full circle and return to the idea of a biological race of manufactured *robota*.

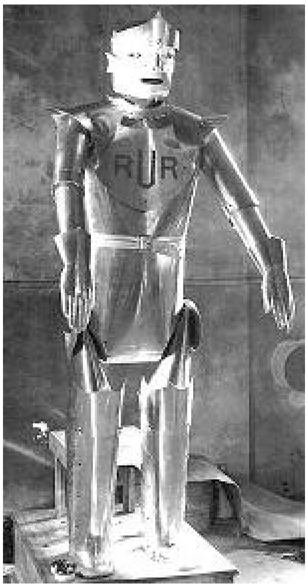


Figure 3.1 The RUR robot that appeared in an adaptation of Karel Čapek’s *Rossum’s Universal Robots*, circa 1930s

Show description

The term ‘robot’ soon gained widespread use through the work of science fiction authors, including Isaac Asimov.

Science fiction has been surprisingly important in developing the field of robotics. According to the *Oxford English Dictionary*, even the word ‘robotics’ first appeared in one of Isaac Asimov’s short stories rather than in a scholarly journal.

3.1 Definitions of robots

There is no single definition of what a ‘robot’ is, with different experts offering different opinions. We are focusing on robots in the physical world, rather than ‘bots’ on the Internet. The following definition is broad enough to make it possible to classify most types of physical-world robot:

1. A machine that can sense its environment, process information from its sensors and other internal information, decide what to do next and execute that decision will be called a *robot*.
2. A robot that can move using wheels, legs or other means with an on-board power supply will be called a *mobile robot*.
3. A robot that can operate without the assistance of a human is said to be *autonomous*. Like many technical terms, the word ‘autonomy’ is rooted in two Greek words – *auto*, meaning ‘self’, and *nomos*, meaning ‘law’. Consequently, autonomy literally means ‘self law’ and so the degree of autonomy refers to the extent to which the robot’s behaviour is subject to its own law or, one might even say, its own free will.
4. A robot that can perform its functions in the presence of uncertainty is *intelligent*.

For example, a lawnmower that cuts grass without any intervention is autonomous. It needs sensors to know where the lawn is and where the grass has already been cut. It needs to use that sensor information to stay on the grass and not cut down the flower beds. There’s a lot of uncertainty in a garden, especially when there are cats, dogs and children around, and I’d say some intelligence is necessary. So this grass-cutting machine is an example of an intelligent, autonomous, mobile robot.

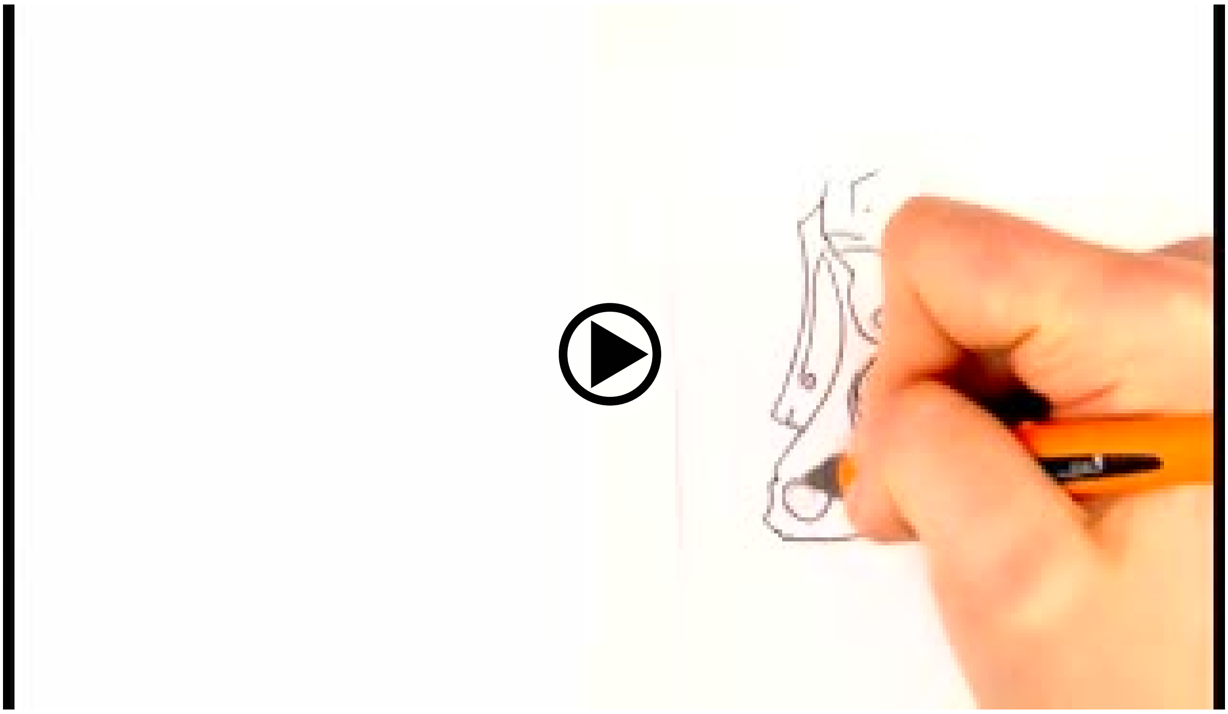
It is also worth considering how this definition encompasses a variety of ‘smart’ devices. Let us consider a smart thermostat, such as the Nest Learning Thermostat in Figure 3.2. Such thermostats use a variety of sensors to learn about your daily routine so that they can automatically optimise the heating and lighting in your home. Interestingly, many of the sensors such devices use are not actually present in the device. For example, through connecting your smart thermostat to your smartphone, it has access to your location (via GPS and Wi-Fi location) and your calendar. When considered as part of a house heating system, the smart thermostat alongside the boiler and radiators, is an intelligent autonomous robot, installed in thousands of homes worldwide.

Figure 3.2 The Google Nest Learning Thermostat

Show description

Activity 3.1 Watch

Watch this video from the Tech Policy Lab at the University of Washington, which explores different definitions of robots. Note how each of the different definitions includes and excludes different robot systems.



Throughout this block you will be asked to reflect on various issues and questions. Usually the questions relate to material that you have recently studied, but sometimes you are expected to form your own opinion on things.

One of the objectives of the Robotics and AI block is to encourage you to think about issues and construct reasoned arguments. So spend a few minutes answering the following self-assessment questions (SAQs).

3.2 Some questions

SAQ 3.1

A cruise missile, illustrated below, is a pilotless rocket designed to carry an explosive warhead. It can have a long range and determines its own path using on-board cameras and position data supplied by satellites. Once it has been given a target, it guides itself towards that target at high speed and explodes on reaching it. Over the past 30 years cruise missiles have been used in many conflicts, killing and injuring many soldiers and civilians.

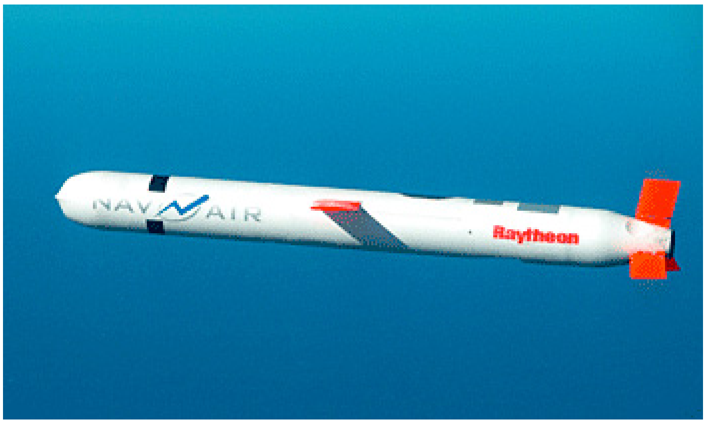


Figure 3.3 Cruise missile

Show description

a. To what extent can a cruise missile be described as a robot? (Hint: see my definitions of robot characteristics.)
b. To what extent can a vacuum cleaner that cleans rooms by itself be described as a robot?

Make a note of your answers, before looking at mine.

Reveal answer

Study note

My answer to SAQ 3.1 demonstrates an important method of analysing and classifying things. Even if you don't like my four definitions, you can probably apply them without too much trouble. So you can say, 'According to the block definitions, a cruise missile is an intelligent, autonomous, mobile robot. However, I don't like the block's definition of intelligence. For me, for a machine to be intelligent it must be able to speak. So, as far as I am concerned, a cruise missile is just an autonomous, mobile robot.'

The point here is that the classification is based on the definitions used. If you use a different definition, you may get a different classification. Often the most important thing is not which particular definitions are used, but that the definitions are explicit, they are agreed by everyone and they are applied consistently to produce a classification.

SAQ 3.2

a. To what extent is a remote-controlled car a robot?
b. To what extent is a supermarket self-checkout kiosk a robot?

Reveal answer

4 Artificial beings

4.1 Automatons

There are stories of artificial beings in legend and literature. By the eighteenth century, artificial life must have seemed close to reality as skilled engineers produced remarkably lifelike mechanisms. For example, Pierre and Henri-Louis Jaquet-Droz created a young woman who played the piano and a boy who could write.

Figure 4.1 Automatons created by Pierre and Henri-Louis Jaquet-Droz

Show description

Although the elaborate clockwork mechanisms of Pierre and Henri-Louis Jaquet-Droz are not robots in our terms, they are human-like machines doing human-like things. They are examples of automatons, defined in *The Shorter Oxford English Dictionary* as mechanisms with ‘concealed’ motive power. In this module we will use the term ‘automaton’ to mean a machine that operates automatically, but does not make its own decisions in a changing environment. Some automated factories fall into this category as they have limited ability to make decisions in unexpected situations.

Automatons play an important part in understanding the history of robotics because they demonstrate the high level of engineering necessary to build robots. They also demonstrate the extent to which mechanisms can be used to recreate human-like behaviour.

Historically, the means of achieving artificial life reflected the technology of the day. In the mid-eighteenth century it was the technology of metalworking and clockwork, like the automatons shown above. Later, Luigi Galvani’s discovery that electricity could make a dissected frog’s legs twitch led to the idea that electricity could supply the life force.

Although the automatons do interesting things, they lack intelligence to do new things in the face of changing circumstances. The sort of control that an automaton is subject to is sometimes referred to as *automatism*. An automaton is ruled by automatic behaviours that deny any sort of free will at all, unlike the behaviour of an autonomous robot. Automatic behaviours are fixed, built-in behaviours that are constructed so that they cannot help but work in that way, such as a particular wash program in a standard automatic washing machine.

As the automaton builders discovered, there was a limit to which they could make their creations perform new tasks. The automatons also lacked sensory inputs that would allow them to respond to things happening in the world around them. However, there were a few notable hoaxes. One such hoax was the Turk, a chess-playing automaton constructed by Wolfgang von Kempelen in the eighteenth century. Inside the 'automaton' box was a small human chess player! If you have time you can read more about the Turk in an article in *Wired* magazine (Standage, 2002).

The limits of mechanical ingenuity had been reached in the construction of automatons, and it was not until the coming of computers that further advances could be made towards artificial beings.

Activity 4.1 Watch and read (optional)

One of the Jaquet-Droz automatons featured in the BBC documentary *Mechanical marvels: clockwork dreams* by Simon Schaffer; you can watch a clip here. You will also find more information and videos about the Jaquet-Droz and other automatons by searching the web.

4.2 From automatism to autonomy

The nineteenth century saw the first computing machines. This led to a more modern view of robotics, in which information processing and intelligence became important.

In 1834 Charles Babbage designed his Analytical Engine, which, if built, would have been the first programmable computing machine. It could be 'programmed' by the user to execute its repertoire of instructions in any required order. The earlier Jacquard loom developed the idea of punched cards to store the information necessary for weaving different types of cloth. Babbage took up this idea, using punched cards to store programs and data that could be fed into the machine.

The Analytical Engine had a store and a mill, corresponding to the memory and processor of a modern computer. Like modern computers, the Analytical Engine could repeat the same sequence of operations many times, or loop. Also, it could perform conditional branching using 'if-then' statements, allowing its flow of calculations to be determined by the results of its earlier calculations.

Babbage collaborated extensively with Ada Lovelace, held by some as the first computer programmer for her published development of an algorithm for calculating Bernoulli numbers tailored for implementation on a computer. Some historians argue that she was the first person to foresee that computers would one day go beyond processing purely mathematical functions, and be used in music and other processes that follow a clear process. In addition to having the Ada programming language named after her, she is also celebrated on Ada Lovelace Day as an inspiration for women working in STEM.

Babbage and Lovelace never succeeded in building the Analytical Engine, due to the accurate machining required and funding difficulties. Nonetheless, it is now seen as a major step in the history of computing machines. If you have time and want to know more, you can read about it on the Science Museum website.

As highlighted in the book and film *Hidden Figures*, the term ‘computers’ used to refer to people – often women – manually running calculations. Such computers were essential in many areas of life, but are exemplified in the space race. Katherine Goble has become emblematic of these human computers. Raised to public awareness through *Hidden Figures*, the under-acknowledged accomplishments of these computers in getting humans into space are now becoming well known. The use of the term ‘computers’ to refer to machines became more widespread during the second half of the twentieth century as electronic computers became increasingly mainstream.

One of the first electronic computers, Colossus, was developed by Tommy Flowers and others at Bletchley Park (code name: Station X) in Buckinghamshire to decipher German signals intelligence during the Second World War.

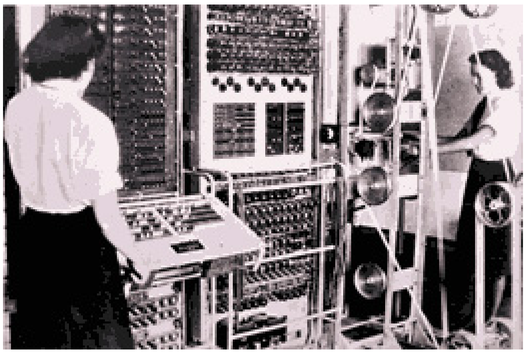


Figure 4.2 The Colossus computer developed at Bletchley Park in the 1940s

Show description

Even though computers were developed for ‘number crunching’ applications, many scientists saw them as logical devices and were interested in programming them to perform intelligent tasks such as playing chess. The amazing progress in the development of digital computers since the 1960s has led to them being used as the major platform for investigating machine intelligence up to the present day.

5 Robot brains and computers

Many explanations have been offered of how the brain works. A large proportion use metaphors that reflect the latest technologies of the time. These include clockwork mechanisms (e.g. automatons), mechanical calculating machines, telephone switchboards routing messages, and, most recently, computers and supercomputers.

Many modern robots use digital computers and programs, applying this computer power to solve problems. In principle, the more powerful the computer, the more computations it can perform and the more difficult the problems it can solve.

Underlying the power of a computer is the amount of computation that can be performed on a computer chip. This, in turn, is related to the number of individual transistors or switches that can be manufactured on each chip. According to Moore's law, computer power doubles about every 18 months, or by a factor of four every three years. This gives the breath-taking prediction that in 20 years' time, computers will be thousands of times more powerful than they are now!

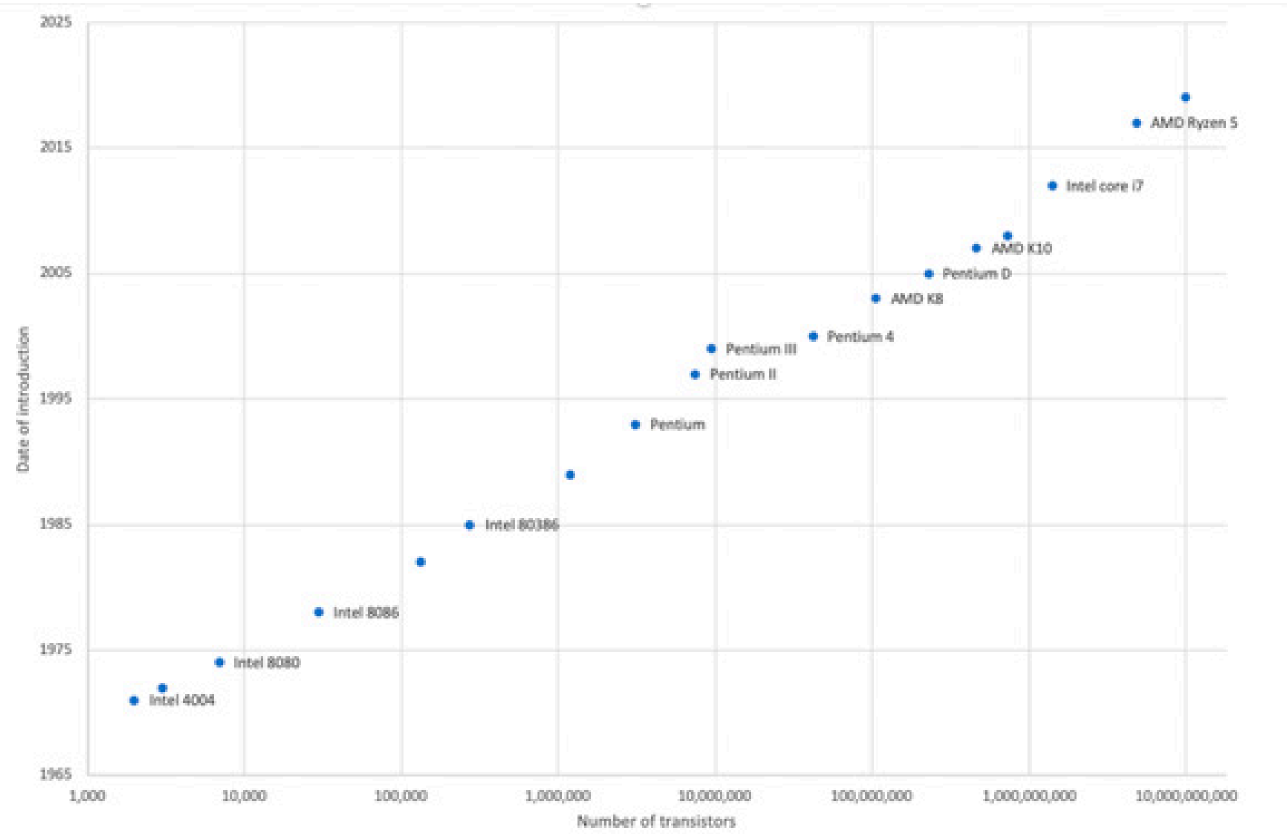


Figure 5.1 Increasing computer power from 1970, illustrating Moore's law

Maximise

Data from Wikipedia: Transistor count (accessed January 2020)

Show description

Common sense suggests that there are limits to this increase. Moore's law is actually related to the number of microscopic components that can be laid down in a given area of silicon. It is recognised that ultimately the laws of physics will limit this, possibly in the next 10 to 20 years. In the meantime, the increase in computer power – and the 'bang for your buck' – marches relentlessly on.

Are brains computers?

If intelligence depended on raw computer power and the ability to process more and more computer instructions faster and faster, then we could expect to see the intelligence of machines increase rapidly. We don't see this rapid increase, so 'intelligence' appears to involve more than the ability simply to compute. Clearly, the digital computer is completely different from the benchmark of intelligence, the human brain.

Our brains are made up of nerve cells called neurons, billions of them all connected together. As shown in Figure 5.2, a neuron has many inputs (called dendrites), a cell body, and a long thread-like output called an axon. The dendrites of each individual neuron receive electrochemical signals from many other neurons. When these inputs collectively exceed a threshold, the nerve cell ‘fires’ and a signal passes to the axon. This is, in turn, conveyed to other nerve cells.

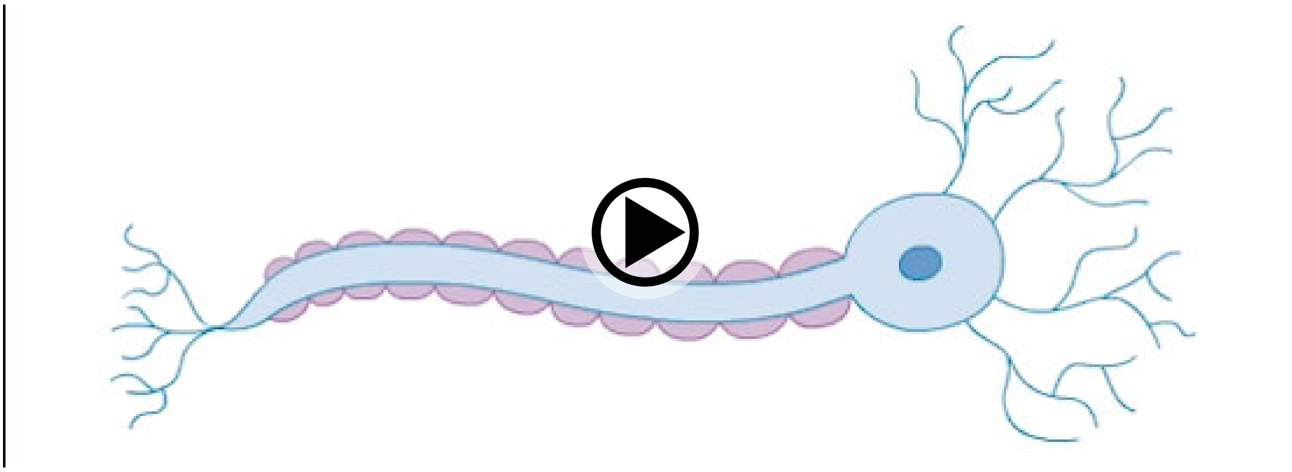


Figure 5.2 A neuron

Neurons are much slower than digital computers. They work on a timescale of milliseconds (1/1000 second) while computers work on a timescale of nanoseconds (1/1,000,000,000 second). That is, computers work about a million times faster than the neurons in our brains.

You can get a feel for the rate at which the brain processes information at a conscious level from the following example. Early films were displayed at 12 frames per second, about one every 85 milliseconds. Our brains can detect the flicker at this rate. A television displays 50 images per second, or one every 20 milliseconds. This suggests that our eyes and brain process visual information in a time frame of somewhere between 20 and 85 milliseconds.

Even though computers work millions of times faster than our eyes and brains, computers currently have limited vision abilities. This suggests that the way computers are programmed to understand visual scenes differs from the way in which our eyes and brains process similar information. One difference is that current computers execute only one or maybe a few instructions at a time, whereas in the brain myriads of neurons may be firing at the same time, perhaps processing different features of an image in parallel.

Artificial neural networks

Whereas digital computers have been the dominant technology in robotics research, artificial neural networks have been the subject of intense research only over the past 40 years.

In 1943 Warren S. McCulloch, a neuroscientist, and Walter Pitts, a logician, developed a simplified model of a neuron. These model neurons could perform simple logical calculations, and it was thought that with millions of such neurons the brain could be modelled by a computer. However, McCulloch and Pitts’s mathematically defined neurons lacked the ability to learn. Modifications were made to the model but, even so, there followed a period of about 20 years in which research in neural networks virtually stopped. In the 1980s new methods for training these networks were discovered, allowing the networks to learn to perform various tasks. These techniques in ‘parallel distributed processing’ brought about an explosion of research interest in artificial neural networks that continues to this day.

5.1 Artificial intelligence

It is difficult to give a good definition of intelligence for both humans and robots. One definition of artificial intelligence (AI) is that it is behaviour that if carried out by humans would be considered intelligent – but that leaves us needing to define human intelligence.

A measure of human intelligence widely used in the past was IQ (intelligence quotient) tests, which were based on a mixture of general knowledge and puzzles. The AI community of the 1950s and 1960s made good progress in writing computer programs that could solve similar logical puzzles. But the appealing idea that IQ tests are an objective measure of human intelligence – let alone artificial intelligence – is highly problematic in practice, because of the inevitable cultural context of some of the questions in IQ tests, and because some people can improve their performance by practising the tests.

Human intelligence is now frequently seen as having many dimensions, including the ability to carry out spatial reasoning, write and speak fluently, use imagination, and deploy emotional intelligence in social relationships. Intelligence is too complex to be represented by a number.

Artificial intelligence has reached the point where for some tasks, such as image recognition, it is as good as – or better than – humans. However, while AI algorithms can carry out restricted tasks like recognising people from videos and translating from one language to another, they can’t then tell you *why* the person is doing what they are doing or what the translated words *mean*. In terms of there being an AI system that has general intelligence, progress is much slower. This is an issue we will continue to return to throughout this block.

5.2 Animal analogies in robotics

Roboticists are increasingly finding biological systems a rich vein of inspiration: animals move, sense their environment and behave in so many different ways. And, while we may not consider a cockroach very intelligent, its combination of sensing, moving and behaviour patterns is sufficient for it to function autonomously in the world. Creating a robotic cockroach may be a more achievable goal than building a humanoid robot.

Biomimetics is the name given to this approach to robotics which is inspired by biological systems.

For example, thinking about insects could influence the design of robots. Having six legs makes walking easier because it enables an insect to keep three legs on the ground at all times. Legs are also well adapted to coping with rugged terrain. The study of such creatures suggests that multi-legged robots could be better than wheeled robots for many purposes.

One of the great problems in robotics is making them self-sustaining and autonomous. *Homeostasis*, the process by which living things keep themselves in a functional state in a changing environment, is a challenge in robotics. For example, just as keeping body temperature constant is a very important homeostatic process in humans, it may also be a requirement of robots that contain sensitive electronic equipment.

Respiration, excretion and reproduction are other essential features of natural life, which may be useful to a greater or lesser extent in robots.

Biomimetics may also give us a different slant on 'intelligence'. In contrast to early attempts at building robots, which tried to build artificial brains with human-like intelligence, it is now known that animals such as insects, with much simpler brains, can achieve feats of great complexity by working together. The success of insects suggests that they may have something to teach us about robotics.

Figure 5.3 Magnetic Termite Mound, Litchfield National Park, Northern Territory, Australia

Show description

Termite mounds are complex, resulting from many termites acting together without the aid of a 'termite in charge'. Thus complex behaviour can emerge from the interaction of many relatively simple animals. It is possible that complex robotic behaviour will emerge from the interaction of a swarm of many relatively simple robots.

5.3 Will robots take over the world?

The desire to create artificial beings often has the associated fear that our creations might behave undesirably or that they might take over. The first robots – Rossum's Universal Robots – were used to serve the human race in factories and the military. Badly treated by their human masters, they revolted and killed nearly everyone.

Another concern is that we could reach 'the singularity' as popularised by science fiction author Verner Vinge and futurist Ray Kurzweil. This is the point at which machine intelligence surpasses human intelligence, and the subsequent pace and impact of technological change would outstrip human understanding and control.

Study note – The technological singularity

The technological singularity is controversial. If you're interested in exploring this concept, we recommend the following resources as starting points.

> Ray Kurzweil's 2005 TED talk is an excellent introduction to his theories. These are presented in more depth in his book *The Singularity Is Near*.
>
> Vernor Vinge's 1993 essay, alongside annotations from 2003, can be read online. In addition to exploring AI algorithms as the cause of the singularity, Vinge also explores other potential causes of the singularity.
>
> Critics have noted the lack of scientific rigour in many of the claims made, particularly the need to distinguish between true exponential curves and those which are logistic (i.e. those which only appear to be exponential to start with, before flattening out).
>
> Rather than focusing on the myth of the singularity, many scientists believe we should be more concerned about the current uses and weaknesses of AI systems.

Whatever your judgement, the concept of the 'singularity' remains persistent.

There are many reasons to believe that robots will not take over the world in this way during our lifetimes.

However, it is worth considering to what extent we could exist without current levels of automation and the use of robots. Many manufacturing industries and aspects of agriculture and healthcare are already dependent on robots. If they were all to stop working, then our societies would stop functioning as they currently do. Additionally, as we shall see in later weeks, AI algorithms are increasingly influential in our daily lives, such as determining whether or not you are eligible for a loan. Some would argue that this means that robots and AI algorithms have already 'taken over' the world.

By the time you finish this block you will be able to make a considered judgement for yourself.

5.4 Asimov's three laws of robotics

One of the means of ensuring that robots remain under human control is to embed within them some fundamental rules. Isaac Asimov outlined three laws which, while from fiction, state with brilliant simplicity some of the most basic desirable characteristics of robots:

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.

(Asimov, 1996 [1950], p. 8)

Of course, machines should not wilfully hurt human beings, and should obey orders – unless someone orders a robot to hurt someone else. Clearly, it is also undesirable to have machines that damage themselves and then need to be repaired. Not all robots fulfil these criteria – such as military drones – and cannot be thought of as obeying Asimov's laws.

The laws also say something about how robots might be expected to work. For example, it is a fundamental requirement that robots do not harm people, as required by the First Law. In order for this law to work, the robot must be aware of what is going on in its surroundings. For example, the robot should be able to perceive threats to humans and act to minimise any threat. The Second Law suggests that a robot can be commanded to do things. Finally, the Third Law implies that a robot can modify its behaviour and the way it operates in order to perform a task safely.

The brains of Asimov's robots had the three laws of robotics deeply embedded in them. The idea is that the way the robot brain is constructed (that is, its *architecture*) constrains robots, making it impossible for them to break the three laws. In the second half of the block you will read some of the chapters from Asimov's book *I, Robot*, which explore the consequences when the three laws interact and give many practical insights into the problems we are likely to face in trying to ensure the safe behaviour of robots in the twenty-first century.

While the three laws and the 'positronic brains' in which they are embodied are purely fictional devices, you will see how they reveal several important ideas about how we should regulate real robotic systems, especially in situations where they come into contact with humans.

SAQ 5.1

a. Do cruise missiles violate any of the laws of robotics? (Hint: think about the three laws.)
b. Do robot vacuum cleaners violate any of the laws of robotics?

Reveal answer

6 Moving and sensing

Having briefly explored how robots are made intelligent, let us consider the technologies that allow robots to move about and sense the world around them.

Until relatively recently, this was the area which received the most engineering attention. Certain things that we take for granted – such as walking or seeing – are extremely difficult to replicate in robots.

While research efforts continue to explore these difficult systems, there has also been a trend of using commercially available components. This allows roboticists to focus more on the software aspect of robots, and has led to the development of robot systems that are capable enough to be used today.

Autonomous cars are a good example of this shift (Burns, 2019). Early attempts to develop autonomous cars invested a lot of time, money and effort in developing the mechanical systems to control the accelerator and brake pedals, and to turn the steering wheel. Newer cars are controlled as ‘drive-by-wire’ where the pedals and steering wheel produce electrical signals which are sent to a computer. This is much easier to adapt for autonomous control, allowing more time, money and effort to be spent on developing the software to make the car behave safely when operating autonomously.

Another good example is the use of automated pickers in factories and warehouses, something that the company Amazon has been focusing on. In this context, there is little need to innovate the physical aspects of the robots. However, for these robots that are collaborating with humans in a shared space – so-called *cobots* – there is a huge amount of research currently going on in terms of the development of AI algorithms and the design of the physical environment to ensure that cobots can operate safely.

6.1 Sensing

In the same way that humans and animals have a range of senses, so do some robots. Each of the external human senses (vision, hearing, touch, taste and smell) refers to a different *sensory modality*. Each sense responds to a particular physical property. Of course other sensors exist – weight, water movement, barometric pressure – that are customised to fulfil whatever tasks the robot is designed for.

Here we will concentrate on sensors relating to vision and hearing.

Electromagnetic spectrum

One of the most common carriers of sensory information is the electromagnetic spectrum. Only one small part of this spectrum is visible to humans (the ‘visible’ spectrum), but we can design machines to use other parts of the spectrum such as luggage scanners which detect X-rays and TV remote controls that detect infrared signals. Some animals can see outside the ‘visible’ spectrum. For example, some fish can see infrared and penguins can see ultraviolet light.

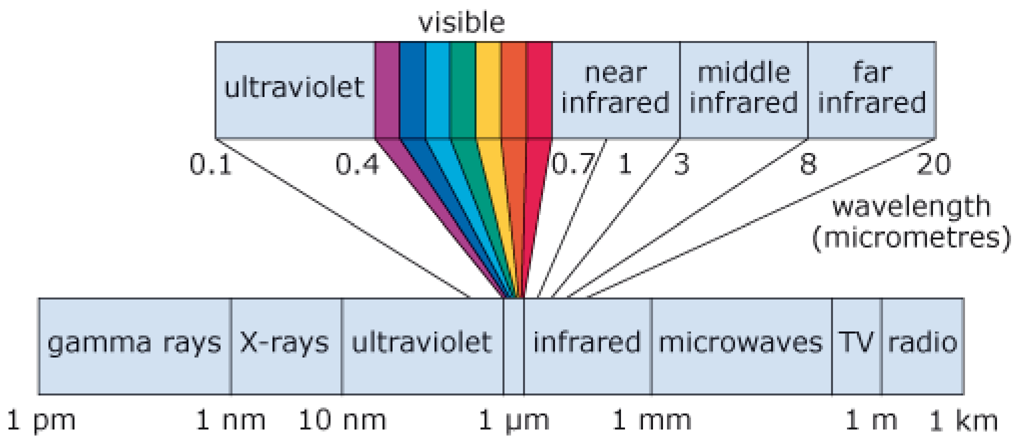


Figure 6.1 The electromagnetic spectrum

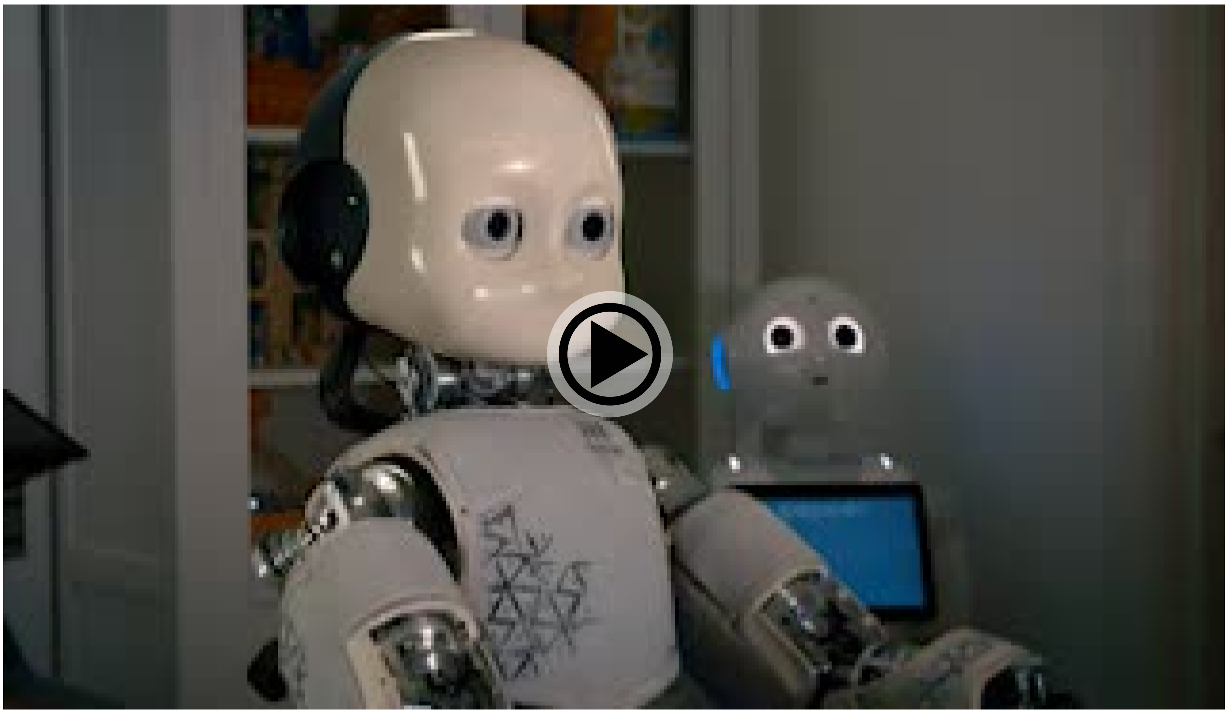
Show description

By looking for reflections of high-frequency electromagnetic radio pulses that are invisible to the human eye, we can use radar to build up a picture of what is around us up to several miles distant. For example, marine radar can be used to locate landmarks and other ships even through fog.

Increasingly we are also able to use machine vision approaches to process the imagery from video cameras and provide robots with the ability to recognise what certain objects are.

Activity 6.1 Watch

Watch this clip from the BBC series *Hyper Evolution: Rise of the Robots*.



Sound

Sound is another physical phenomenon that robots can utilise through their sensors. What we experience as sound is vibration through the air, as illustrated in Figure 6.2. A loudspeaker generates sound by moving a paper cone backwards and forwards at the required frequency. This causes a pressure wave to be transmitted through the air. The more rapidly the cone vibrates, the closer are the wavefronts, which we perceive as higher-pitch (higher-frequency) sounds. Larger movements of the cone produce greater changes in pressure which we perceive as louder (greater-amplitude) sounds. On the graph in Figure 6.2, higher frequencies would be shown by more cycles in a given time, and greater amplitude by higher waves.

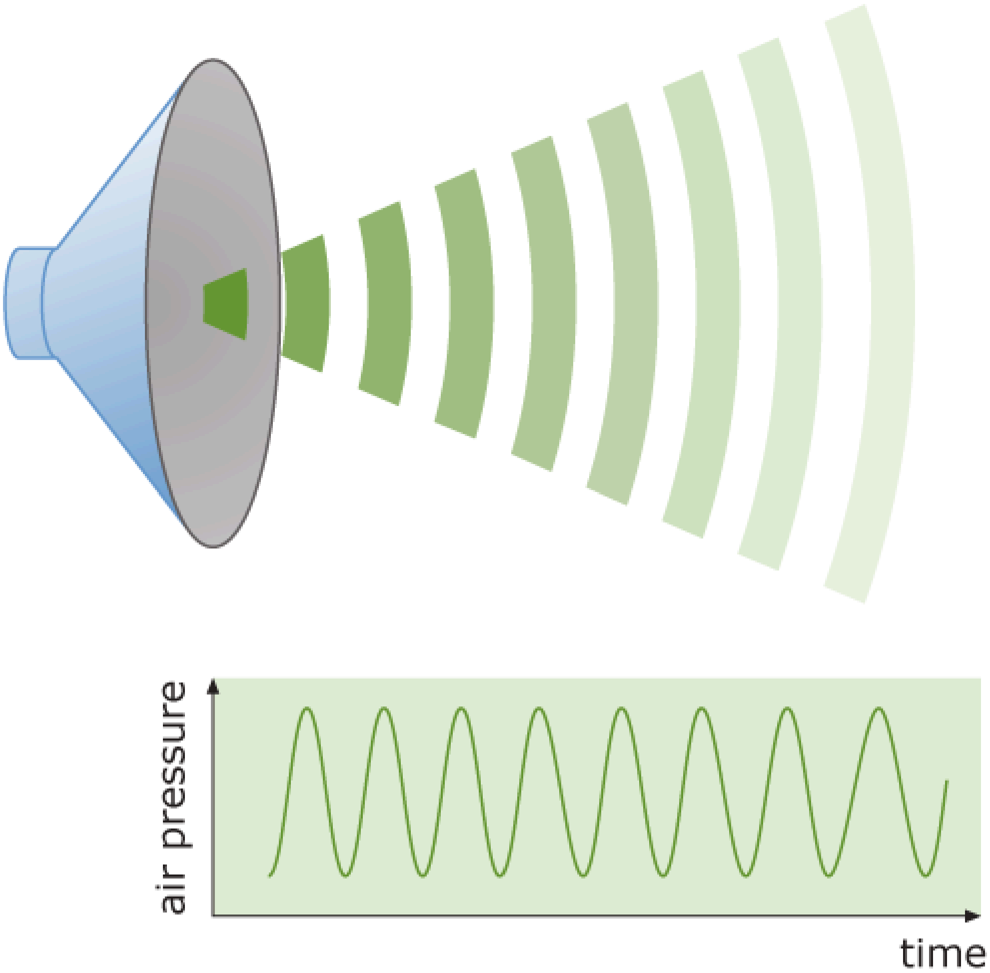


Figure 6.2 Sound waves

Show description

Sound has a spectrum of frequencies. The human ear can detect frequencies as low as 20 vibrations per second, and as high as 20,000 vibrations per second. Dogs can detect frequencies up to around 50,000 vibrations per second, which is beyond the human hearing range. Bats can detect even higher frequencies of about 100,000 vibrations per second. By emitting high-frequency sound at about 50,000 vibrations per second and listening for an echo, bats can locate objects around them.

These frequencies, beyond the higher end of the human hearing range, are called ultrasound. There are ultrasound devices which act as rangefinders. These devices emit a ping of ultrasound and measure the time taken to receive an echo; by using the velocity of sound, it is possible to calculate the distance to the object. This technology was used in early autofocus cameras, and devices are cheap enough to be used in hobby robots such as the Lego Mindstorms kit.

Sound travels through liquid and solids as well as air. Sonar is the sound equivalent of radar and is used for undersea navigation.

Laser rangefinders are also now available. These work on a similar principle to an ultrasound rangefinder, but with a tightly focused laser beam their directionality and accuracy is much higher. When the laser beam is scanned back and forth, it is possible to build an image. This is called lidar – by analogy with radar and sonar. The majority of autonomous cars use a lidar system to build a picture of where the vehicle is travelling and the obstacles surrounding it.

Sensor noise

Noise is an issue that roboticists must face when dealing with any sensor input: sensor input is rarely perfect and usually contains some spurious information that we call noise. Technically, noise is unwanted energy in an electronic or communication system. White noise is random noise across the spectrum of a signal, for example the noise that makes loudspeakers hiss. Impulse noise is caused by single momentary disturbances that make loudspeakers click. Noise on sensors means that the signal they give has some spurious information, which may have to be filtered out by some form of information processing. For example, an image from a photograph may have noise so that, for example, ‘white’ may not be 100% bright and ‘black’ may not be 0% bright.

SAQ 6.1

a. What are the human senses, and which is dominant?
b. Give examples of animals having better sensors than humans.
c. Give examples of common robot sensors.

Reveal answer

6.2 Moving

For this block we define an ‘actuator’ as a component of a machine that is responsible for moving and controlling a mechanism. We do not have the space within this block to unpack the mechanical complexities of how the vast range of actuators used in robotic and movement systems work. Instead, we introduce you to a range of robots to highlight how different their mobility systems can be.

Activity 6.2 Watch

Our first robot is from Starship Technologies, and is used to delivery groceries from supermarkets straight to a person’s home. Watch the clip.

Note the use of wheels and how this is workable because the robot only uses tarmacked roads and pavements. How well do you think the robot would cope in the snow?

Activity 6.3 Watch

Our second robot is SPOT from Boston Dynamics. Watch the clip.

https://www.youtube.com/watch?v=aFuA50H9uek

SPOT is a large quadruped designed to operate over difficult terrain. You can see how it is able to keep its balance even on unstable ground.

Activity 6.4 Watch

One of the major challenges for two-legged (bipedal) robots is balance. There are two aspects to this: *static stability* means that the robot is stable at rest or even mid-stride (as a tripod gait is stable in a hexapod walker); *dynamic stability* means that the robot maintains its stability by continually correcting movements.

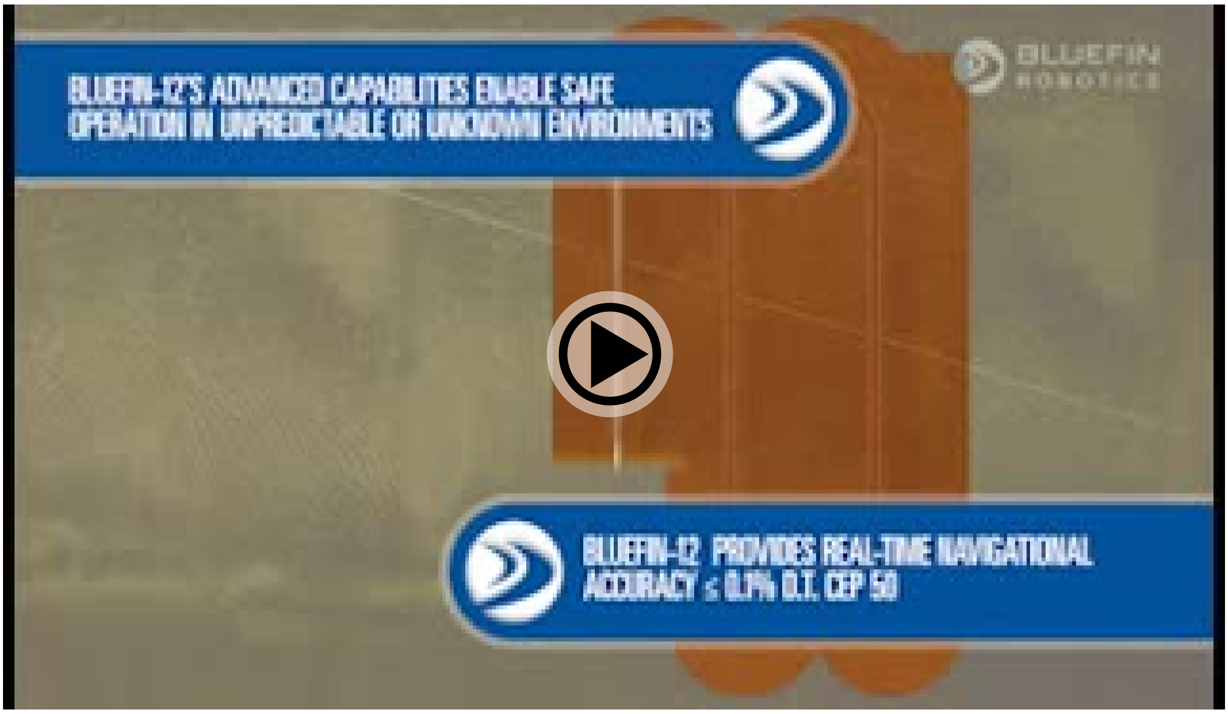
Our third clip is of the ATLAS robot from Boston Dynamics. Watch the clip.

https://www.youtube.com/watch?v=_sBBaNYex3E

ATLAS demonstrates the state-of-the-art in terms of robots balancing. Many people believed that achieving human-like levels of balance in bipeds would be impossible; the parkour demonstration from ATLAS proves that it is not.

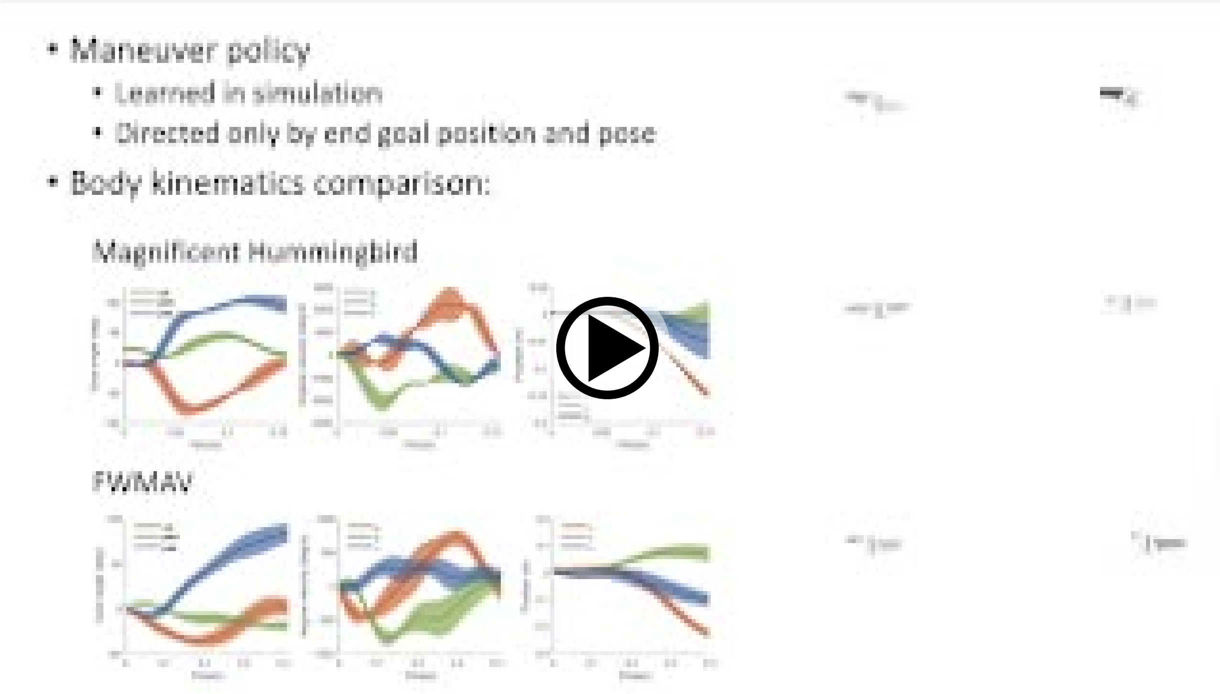
Activity 6.5 Watch

Of course, robots do not only move around on the ground. Our fourth robot, Bluefin SandShark from General Dynamics, is an unmanned underwater vehicle. Watch the clip and note how many different types of movement and actuators there are.



Activity 6.6 Watch

Moving from underwater to the sky, we wanted to highlight that drones, helicopters and planes are not the only robots that can fly. Watch the clip.



These hummingbird robots from Purdue University are an excellent example of a biomimetic-based robot. This novel system provides a great deal of manoeuvrability, which would be ideal for navigating through collapsed buildings and other cluttered spaces.

Activity 6.7 Research

The five robots we have highlighted provide only a small insight into the range of sensors and movement systems that are used in robots today.

Spend 30 minutes exploring the IEEE robotics website, looking for examples of different sensors and mobility systems.

If you find an interesting example that is not in the Robopedia wiki, please add a short page describing it.

6.3 Power

Providing power to mobile robots remains a significant challenge. For larger mobile robots it is feasible to use internal combustion engines that have good reserves of power. But many mobile robots rely on electric batteries to provide power both for the computers used in their control subsystem and for electric motors used in their actuation or mobility subsystem. And, as Ruth Aylett quips, ‘if robots are going to take over the world, they’ll have to do it pretty fast before their batteries run out’ (Aylett, 2002, p. 94).

To give a robot greater autonomy, it can be designed to sense the power level remaining in its batteries and to seek out a recharging station when the power level drops. This assumes that the robot can detect a charging station and has enough power to reach it, and that introduces some complex issues in designing the robot's control strategies – just when should the robot give up its current task and seek more power?

Alternatives to conventional batteries that are being explored include the following.

- Solar cells that can be used to recharge batteries. The amount of power that can be obtained by mounting solar cells on a mobile robot is very limited, but solar cells have been used to power robots such as the Mars exploration robots Spirit and Opportunity. Opportunity was able to power itself for 14 years (2004–2018).
- Some robotic spacecraft, such as the Voyager and Cassini missions to distant planets, and recently the Mars rover Curiosity, have generated electricity from the heat of decay of radioisotope fuel. These generators can provide steady amounts of power over several years, allowing the spacecraft to operate where solar radiation is weak. Voyager 1 has been operating for 43 years and is now in interstellar space at a distance of approximately 13 billion miles from the Sun.
- Fuel cells use a chemical reaction between hydrogen (stored on the robot as fuel) and oxygen (obtained from the air) to generate electrical power. Fuel cells potentially offer greater power for the same weight than do electrical batteries.
- Animals use chemical energy derived from their food, and some researchers have investigated the possibility of robots that can gather and 'eat' their own food. A microbial fuel cell developed at King's College London uses bacteria or yeast to metabolise simple foods such as sugar and generate small quantities of electrical power. The University of the West of England's (UWE) EcoBot I and II robots carried these microbial fuel cells and could be 'fed' with either sugar or dead flies. UWE's SlugBot robot was designed to hunt and catch slugs; the prey could have been returned to a central fermentation system that would create methane to generate electricity to recharge the robot's batteries. Combining these two approaches would give an autonomous robot that could feed itself.

7 Practical activities

The practical work in this block makes use of various robotics software. There is one practical activities session per study week. The session this week gives you an overview of the practical work you will be doing in this and coming weeks. As you work through the activities in Robot practical activities Session 1 you will begin to appreciate how the software works.

Follow the link below to Robot practical activities Session 1. This tells you how to get started and gives you full instructions. You will need to read and follow the instructions carefully. The practical work should take you about four to five hours. When you have completed Robot practical activities Session 1 read the Summary in the final section before moving on to Topic 2.

Activity 7.1 Robot practical activities

Follow the instructions on this week of the study planner and carry out the activities.

8 Summary

In Topic 1 you have been introduced to *Robotics and AI*. We have looked at the development of robotics since the early eighteenth century. Some of the most significant milestones you have met so far include:

- automata such as those of Pierre and Henri-Louis Jaquet-Droz
- Babbage's calculating machines
- Rossum's Universal Robots
- Asimov's three laws of robotics
- the invention of digital and neural computation
- developments in artificial intelligence
- Moore's law
- animal metaphors and intelligence emerging in robot swarms
- ATLAS, a bipedal robot that can perform parkour
- autonomous cars.

In this topic you have considered the questions:

- What is a robot, and how can robots be classified?
- Should all robots obey the three laws of robotics?
- What is intelligence in machines?
- Is there danger of robots taking over from humans?

We hope you enjoyed this first taste of robotics and found the many questions it has raised stimulating.

Where next

This is the end of Topic 1.

Topic 2 considers the implications of what it means to add intelligence to machines.

References

Asimov, I. (1996 [1950]) *I, Robot*. Gnome Press.

Asimov, I. (1995 [1982]) *The Complete Robot*. Granada Publishing.

Aylett, R. (2002) *Robots: Bringing Intelligent Machines to Life?*. Hauppauge, NY: Barron's Educational Series.

Burns, L. (2019) *Autonomy: The Quest to Build the Driverless Car and How It Will Reshape Our World*. William Collins.

Standage, T. (2002) ‘Monster in a Box’, *Wired*, 1 March. Available at: https://www.wired.com/2002/03/turk/ (Accessed: 1 May 2020).

Acknowledgments

Grateful acknowledgement is made to the following sources:

Figure 2.1: © Starship Technologies:

I, Robot cover: Taken from: https://www.bustle.com/articles/49003-11-fictional-female-scientists-wholl-stun-you-with-their-brilliance

Figure 3.1: © Topical Press Agency / Stringer / Getty Images

Figure 3.2: *Source Google*

Figure 3.3: © US Federal Government

Figure 4.1: © Rama / https://commons.wikimedia.org/wiki/File:Automates-Jaquet-Droz-p1030472.jpg This file is licensed under the Creative Commons Attribution-Noncommercial-ShareAlike Licence http://creativecommons.org/licenses/by-sa/2.0/

Figure 5.3: © Litchfield National Park Australia. This file is licensed under the Creative Commons Attribution-Noncommercial-ShareAlike Licence http://creativecommons.org/licenses/by-nc-sa/3.0/

Every effort has been made to contact copyright holders. If any have been inadvertently overlooked the publishers will be pleased to make the necessary arrangements at the first opportunity.