PETER J. BENTLEY

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the science of computers and how it shapes our world

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Peter J. Bentley

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In 2010 the Department of Computer Science, University College London, celebrated its 30th anniversary. May it celebrate many more!

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Introduction

They obey our instructions with unlimited patience. They store the world's knowledge and make it accessible in a split second. They are the backbone of modern society. Yet they are largely ignored.

Computers. They comprise our crowning achievements to date, the pinnacle of all tools. Computer processors and software represent the most complex designs humans have ever created. The science of computers has enabled one of the most extraordinary transformations of our societies in human history.

You switch on your computer and launch the Internet browser. A one-word search for 'pizza' finds a list of pizza restaurants in your area. One click with the mouse and you are typing in your address to see if this restaurant delivers. They do! And they also allow you to order online. You choose the type of pizza you feel like, adding your favourite toppings. The restaurant even allows you to pay online, so you type in your credit card number, your address, and the time you'd like the delivery. You choose 'as soon as possible' and click 'pay'.

Just thirty-five minutes later there is a knock on your door. The pizza is here, smelling delicious. You tip the delivery guy and take the pizza to your table to eat.

Ordering pizza is nothing unusual for many of us around the world. Although it may seem surprising, this increasingly common scenario with cheap prices, fast delivery, and access to such variety of food for millions of customers is only possible because of computers. In the situation above you might have spotted just one computer. If we take a look behind the scenes, the number of computers involved in bringing your pizza is astonishing.

When you switched on your computer, you actually powered up many computers that all work together to make the display, mouse, keyboard, broadband, and main computer operate. Your computer linked itself to the Internet—which is a worldwide network of computers—with the help of computers of the phone company and Internet service provider. When you searched for 'pizza' the request was routed between several computers before reaching the search engine computers. These special machines keep an up-to-date index of the Internet and search this summary to provide near-instant results for you—a list of links to pizza restaurants. When you clicked on a link, your computer was directed (through another chain of computers) to the restaurant computers, which provided details of their products back to your own computer. The pizza toppings you selected on your computer were sent to their computer so it could calculate the price. When you clicked 'pay', your computer talked via a secure encrypted link to another computer, which talked using more secure links to the bank and transferred the payment from your account into the account of the restaurant.

With the payment completed, the main computer of the restaurant chain then sent your order to the computer of your local restaurant. The kitchen received the order just thirty seconds after you paid online and they began making your pizza. It's a good restaurant so they made

it from scratch using ingredients such as cornmeal, wheatflour, tomato sauce, mozzarella cheese, pepperoni, olive oil.

But there is a contradiction—the restaurant has very cheap prices and yet it uses good quality ingredients. It can only have this fine selection of Italian ingredients because of highly accurate stock-keeping which minimizes waste, and high-volume ordering which reduces the price. To achieve this, the restaurant's computer keeps track of the sales and stock levels each day (combined with data gathered over the last two years), automatically preparing a proposed order for the manager to approve or amend.[1] The approved order is then sent to the main computer of the restaurant chain, which in turn places the combined orders from all its restaurants to the various food suppliers. The orders cause a ripple of computers to talk to each other in distribution companies, food-processing factories, shipping companies, and food production companies, all over the world.[2] The mozzarella may have come from Italy, your pepperoni from Ireland, your cornmeal from USA. Every company relies on its computers to maintain and enable their accounts, salaries, schedules, stock, communications, and many use computer-controlled machines in their factories.

Just ten minutes after you clicked 'pay' on your computer, your pizza had been made using those fresh ingredients. The chef then placed it on a computer-controlled conveyer oven designed to be energy efficient and fast. It rolled in raw and less than ten minutes later it rolled out perfectly cooked. The delivery man then packed the pizza in a box (which had been manufactured by a computer-controlled cardboard-cutting machine a few days earlier). He collected several deliveries together into a bag designed to keep the food hot, and went to his vehicle.

In your case, since the restaurant services a large area, the delivery man used a car. Like most modern cars, his was packed full of computers to make the engine run efficiently, provide traction control, anti-lock braking, climate control, and even make his radio work. The radio signal he listened to had originated in a studio a split second earlier, and yet another chain of computer-controlled communication had brought the radio signal to his car. He was new to the job so he used a GPS gadget to find his way—a computer which listened to signals beamed from orbiting satellites produced by their computers (and calibrated by yet more computers).

Unknown to you, he still managed to become lost. Thirty minutes after you clicked 'pay' he was using his mobile phone to call the restaurant to check your address. The device used its tiny internal computers to send a special wireless signal, which was received by several computers in nearby cellular receivers. They negotiated with each other and his phone, calculating the best way to route his signal to the restaurant, and dynamically changing the route based on signal strength and capacity of each receiver. His conversation was successful thanks to this constantly changing network of computers, and he realized he'd typed in your address incorrectly.

Five minutes later he arrived at your home. He took out your pizza from his bag and knocked on your door.

Computers uncovered

Look at any common activity in the modern world and you'll find more computers lurking behind the scenes than you ever imagined. Our computers are hidden to such an extent that most of us are completely oblivious to their existence. If they could feel emotions,[a]

they'd be feeling quite unappreciated right now. Computers are camouflaged but we don't need to wear Safari clothes and use binoculars to find them—we can just look a little more deeply at any common activity. Switch on a light and your room is brightened because computers in the power station enable the right flow of electricity at the right times. Call a friend on your phone and you initiate an extraordinary network of computers talking to each other so that your voice can reach the ear of your pal. Watch television and you're seeing images decoded in real-time by a computer, which were transmitted using computers and recorded digitally with computers. Computers are our invisible helpers, discreetly enabling almost every aspect of our lives.

I can't help being astonished at the impact of computer science on people. Just a few short years ago it was only computer scientists like myself who spoke the obscure language of emails, Web pages, directories, and operating systems. Today I can sit on a train and hear people, from toddlers to Grandmothers, using these words—and using them correctly. Gossip and fashion magazines now feature articles about computers, and the same magazines can be read online or on tablet computers. The technology that was once confined to our computing labs has spread across the world like wildfire. Imagine if a similar revolution had happened in biology. We'd all be using complicated words like plasma membranes, ribosomes, and cytoskeletons.

Twenty years ago I remember seeing prototype videophones and 3D television in the depths of computer labs—technologies that are now becoming mainstream consumer products. I remember the first optical character recognition (OCR) programs, which struggled to read anything correctly. Now fifteen (and rising) per cent of all books ever written have been digitized using OCR technology, allowing us to

perform instant searches for occurrences of phrases or words through their 500 billion words.[3]

I recall the beginnings of the World Wide Web very clearly.[b] When I saw my first Web page, I couldn't see the point of it. Why would anyone want to wait ten minutes for some text and an image? Twenty years later and my television can browse the Internet and play movies provided online by television companies. My phone can browse the Internet and show me a satellite picture of my exact location anywhere on Earth. I can buy almost any product online from almost any country in the world and have it delivered direct to my home. In the next twenty years it is hard to predict what we will be able to achieve. I suspect the technology will be cheaper, faster, and more impressive than anything we might imagine today.

Whatever you do, no matter which job or recreational pursuit, you will be using a computer of some kind, whether you are aware of it or not. They are so useful, and so cheap to make, that we use them for every conceivable activity. Industries centred on computers are predicted to be the fastest growing of all for the foreseeable future, with only medical services matching this growth.[c,4] The industries that are growing the most did not even exist a few decades ago: information technology consulting, Internet hosting and publishing, cable and satellite programming, computer systems design, software publishing. It's no co-incidence that many of the world's richest people are in the computer business.[5] Who would have guessed that computers could outsell oil, steel, food, or fashion? Whatever your ambitions, you need to understand computers (or at least how to use them effectively) in order to succeed in the modern world.

Today to say that you are working with computers is meaningless. We all do. The question is what do you use the computer for? Are you

an artist or musician? A writer or blogger? Are you a financial trader or salesperson? A product designer or engineer? A surgeon or nurse? A supermarket assistant or fast food cook? A college or school student? Computers are such a fundamental part of our lives that it's hard to understate the importance of computer literacy. Your whole working life (or your children's lives) is likely to involve using these electronic machines.

In this book I'll reveal the secrets of computer science that are not taught in schools or colleges, but which enable our computer-filled world to function. We will go on a journey through the hidden labs of computer scientists. I'll introduce you to many of the researchers (and one or two self-made millionaires) who have developed and are still developing the technological miracles that surround us. With their help we will see how computers are used in myriad different applications.

I'll show you that computers are fundamentally very simple to understand, and how you can use that knowledge to excel in your work and play. Together we will explore how this young discipline grew from its theoretical conception by pioneers such as Alan Turing, through its growth spurts in the Internet, its difficult adolescent stage where the promises of artificial intelligence were never achieved, and the dot-com bubble which grew until it burst, to its current stage as a (semi)mature field, now capable of remarkable achievements. We will see the successes and failures of computer science through the years with the help of leading researchers and pioneers, and discover what innovations may change our world in the next twenty years.

I am an enthusiastic guide, for I am a computer scientist myself. You can't grow up building robots and programming computers without having a fascination for the subject. They may be our silent slaves,

performing every instruction blindly, but I believe that computers have much to teach us about our world and ourselves.

The science of computers

The pizza story may have helped you to spot computers living in the wild. Yet the physical devices and the software that they run are just the tip of the iceberg. There is so much more to computers than a bunch of silicon chips and programs. There has to be—for otherwise computers could never have become so widespread.

Computer science is the music of mathematics and engineering. Just as it is impossible to understand the diversity and complexity of music from a few instruments or popular songs, it is not possible to learn about computers from a few specific examples of computers or software packages. Music has a rich history and tradition, controversy and emotion. It is filled with ideas and theories, methods and instruments, virtuoso performers. Computer science is the same. Its history may be much shorter, but there is plenty of it. Computer science has its traditions, its controversies, and emotions. At its core are theories and ideas, which are built into methods and performed using computing instruments. There are virtuosos in computer science, although they may never wear tuxedos or perform in front of audiences, and they rarely receive rapturous applause from the general public, despite transforming the lives of millions. More likely they are ordinary-looking people who work in jeans and drink too many soft drinks or too much coffee.

Ask members of the public what they think about computer science, and you hear some interesting replies. Here are a few I've heard when I asked this question:

Computer science has to do with hardware and software.
Computer science is messing about with computers.
Computer science is mainly programming, engineering, and maths.
Computer science is as wide as the food industry.

These answers are not wrong, and perhaps you agree with them. But I hope that by the time you reach the end of this book your answer might be a little different.

Computer science is the mysterious field from which all computer technology originates. Its practitioners often work in university laboratories or technology companies. But some may be found in unlikely places such as cancer research laboratories, banks, computer games companies, art studios, car manufacturers, or publishers. If you are a computer scientist you could be working on almost anything, anywhere—it's one of the joys of working in the field.

The discipline of computer science is so new and diverse that some prefer to call it a branch of engineering or mathematics. Perhaps surprisingly for a professional discipline, computer science has something of an identity problem. Biologists have a pretty clear idea of what their area includes and what it does not. Physicists are even more precise. But ask some leading computer scientists for their personal definition of computer science and the result is a little different. Their diverse answers provide a fascinating snapshot of the mixture of research and development that takes place in this field. To show you what I mean, I sent out the question, 'What is your personal definition of computer science?' to mailing lists, social networking sites, and chat groups used by computer scientists. (If you want to talk to computer scientists, it's best to use the computer.) Here are just a few of the responses I received, kindly sent to me from computer scientists all

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