Prof. Tim Bell:

Kia ora koutou. My name is Tim Bell, and I'm from the University of Canterbury in Christchurch, Aotearoa New Zealand. I'm a computer scientist.

Prof. Tim Bell:

The thing about computer science is that, although it is the basis of how we've constructed our digital world, it's not really visible. Especially these days. I'm going to use a few examples to show ways that we can engage students with understanding how our digital world works. All of the demonstrations in this talk are freely available online, and I'll provide links to them at the end. If you've already seen some of these, I'll give you some ideas on how to extend them further.

Prof. Tim Bell:

When I first learned computer programming, we'd store information using paper tape like this, where the holes in the tape represent the data being stored. All the text, numbers, and programs that I worked with were encoded as these holes. The data is very visible. It's very simple. A hole counts as a one digit, and a lack of a hole counts as a zero digit. That's it. Just two digits, zero and one.

Prof. Tim Bell:

Yet they can represent anything stored on a computer. And this approach is still used on modern devices. It's just harder to see the digits. Each zero and one is a single binary digit. And because these are so common, we abbreviate binary digit to bit. This is where the term digital comes from. Digital devices simply store and process binary digits. Digital photographs are stored using bits, and digital security uses mathematics on bits instead of physical logs to protect information. On this tape, the binary digits might be storing some text, or some numbers, or even a computer program. The reason that we use binary representation is that it's just cheaper and easier to build systems with two digits instead of the usual ten in the decimal system. Binary isn't a secret code. It's just a really simple one to work with.

Prof. Tim Bell:

Young students will be able to work out the binary times table. Zero times zero is zero. Zero times one, zero. One times zero, zero. One times one, one. That's the entire times table. And when they discover how simple it is, students are often keen to switch to binary instead of decimal arithmetic. The other useful thing with digits is that they're really easy to store and transmit accurately.

Prof. Tim Bell:

Although I've just told you that computers store bits, which are zeros and ones, they don't really store actual zeros and ones. In this case, it's just holes and not holes. The bits, the binary digits, have a physical representation, and we need to get used to the abstract idea that anything with two states, binary states, can represent binary digits.

Prof. Tim Bell:

On a magnetic disc like this one, which I carefully opened earlier, this surface has billions of magnetised particles, that are either north or south, which can be interpreted as zeros and ones. The trouble is you're not meant to take it apart like this. I don't think this one will work again. And even if you do, it's not obvious that this is storing thousands of digital photos, digital videos, digital email messages, digital computer programs, digital student grades, digital shopping lists, digital reports, digital music, and much more. Storing just one photo on paper tape would need about five kilometers of tape, so storing things on disc is pretty handy, but what is happening has become almost invisible as it continues to get even smaller.

Prof. Tim Bell:

I'm not here to talk about how much better technology is compared with the past, even though us old timers like to do that. But we want to look at how to make this digital world visible to your students so that they can gain insight into what's going on, and hopefully even work with these invisible digital elements to create useful software and devices in the future. Given that this disc is equivalent to a couple of million kilometers of this paper tape, you think the paper is pretty outmoded for data storage, but in fact, paper is pretty versatile, and chances are you still use paper-based data storage.

Prof. Tim Bell:

One ubiquitous use of it is so-called quick response codes, usually called QR codes. A QR code like this one stores about the same amount of data as this much tape, about half a meter, or the equivalent of a couple of hundred characters of text, which is more than enough to identify which building I'm going into. The information on these paper-based codes can also represent websites, ticket credentials, details on courier packages, or just plain text. The thing with QR codes is that the binary digits, the bits, are completely visible. Each black or white square is a zero or a one.

Prof. Tim Bell:

My main point is that these binary digits are in plain sight, and they're incredibly useful to society, but because it is so abstract to represent information as digits, students can easily see them as magic created by this mysterious group of technocrats called them. They have created a COVID tracing app. They are developing self-driving cars. They have created a drone that delivers pizza. They think digital technologies, to them, is connected to an idea called screen essentialism, where the user sees the interface as the entire computer system, and doesn't think about what's happening behind the screen. You can get away with this in everyday life, but if you want to reinvent the future, then treating everything behind the screen as mysterious, and leaving it hidden disempowers our students.

Prof. Tim Bell:

By teaching digital technologies in an engaging way, we can break the stereotype of who they are. By helping students to see digital technologies that are hidden in plain sight, we can empower them to realize that they were once kids sitting in a primary school class, and to see themselves as being able to understand and influence that digital world.

Prof. Tim Bell:

In fact, a well-known psychologist called Albert Bandura once observed that everyday life is increasingly regulated by complex technologies that most people neither understand nor believe they can do much to influence. We want to turn that around, to help them to understand and influence our digital world. So how can students understand how bits can represent everything on a computer? Here's a simple exercise with cards that can be done with a class, or in this case, individuals. This clip is about five minutes long. So if you're already familiar with the activity, you're welcome to fast forward five minutes.

Joanne Roberts:

We're going to look at how to send information just using yes or no. That sounds pretty cool, eh?

Children:

Mm-hmm (affirmative).

Joanne Roberts:

That's pretty cool, eh?

Children:

Yeah.

Joanne Roberts:

First, I'd like you to turn over this card please. How many dots does that show?

Children:

One.

Joanne Roberts:

One. You're right. Turn over this card.

Children:

Two.

Joanne Roberts:

Great. How many dots do you think will be under this card?

Children:

Three?

Children:

Three?

Children:

Three?

Children:

Three.

Joanne Roberts:

Let's have a look. Fantastic. You might see a little bit of a pattern. Can you work out how many dots will be shown on this card?

Children:

Six.

Children:

Eight.

Children:

Ah, I get it now. [inaudible 00:07:38].

Children:

Ah, I get it.

Joanne Roberts:

You get it? So what do you think this one's going to show?

Children:

16.

Joanne Roberts:

Oh. Flip it over. Fantastic. Well done. You're pretty smart.

Children:

I figured out the trick.

Joanne Roberts:

Now we want to show nine dots. When we're using these cards, there's just one rule, okay? We either have them showing up with all the dots showing, or down with no dots showing. Okay?

Children:

I already know the answer.

Joanne Roberts:

So do we want this card?

Children:

No.

Joanne Roberts:

No.

Children:

Yes. No.

Joanne Roberts:

Do we need this one? No. Do we need this one? Yes. Let's if you can do the number 11.

Children:

No. Yes.

Joanne Roberts:

This one?

Children:

No.

Joanne Roberts:

This one?

Children:

Yes. Yes.

Joanne Roberts:

So we've shown 11 dots just by saying no, yes.

Children:

No. Yes. Yes.

Joanne Roberts:

That's pretty cool, isn't it? I'm going to tell you what month I was born in just by saying yes or no.

Joanne Roberts:

Okay. No. No. Yes. Yes. No. What month was I born in?

Children:

Six.

Joanne Roberts:

What month do you think that might be?

Children:

June.

Joanne Roberts:

You're absolutely right. Well done. How did you get June?

Children:

Because my brother's birthday is on June as well.

Children:

July.

Joanne Roberts:

Nearly. How did you work that out?

Children:

I just guessed.

Children:

January, February, March, April, May, June.

Joanne Roberts:

How did you work that out?

Children:

Because since there's 12 months in the year, I know that four plus two is six. And it's either June or July.

Children:

June?

Joanne Roberts:

I see no, no, yes, yes, no. And you worked out that I was sending you the information of the six month, which is June.

Children:

Okay.

Joanne Roberts:

All right.

Joanne Roberts:

If you were wanting to use these dots, do you think you'd be able to tell me some letters using just dots?

Children:

Because with the alphabet, A is one, and then B, two.

Children:

The alphabet has numbers, and you have to use the numbers to create a certain letter, and then use the letters to create words.

Joanne Roberts:

How many dots do you think we should show for the letter A?

Children:

One.

Joanne Roberts:

One. That's a good idea. And how many dots would we show for letter B?

Children:

Two.

Joanne Roberts:

Yep. And for C?

Children:

Three.

Joanne Roberts:

Yep. And four? Four is not a letter of the alphabet. Right. Do you think we could say that A was one dot?

Children:

No.

Joanne Roberts:

No? Could we say A was one dot, and then B's two dots? And then C would be three dots. Do you think we could do that?

Children:

No.

Joanne Roberts:

Should we have a go at it anyway?

Children:

Okay.

Joanne Roberts:

So I'm going to say no. Turn the card over. Yes, no, no, no. What's the first letter of my message?

Children:

H.

Children:

A B C D E F G.

Children:

H.

Joanne Roberts:

You're right. How did you work that out?

Children:

I counted on my fingers.

Children:

The first four letters of the alphabet is D. And then if you just carry on, you get to H.

Children:

I just went to A B C D E F G H.

Joanne Roberts:

Can you count to the second letter of my message? No, yes, no, no, yes.

Children:

I.

Joanne Roberts:

How did you know it was I?

Children:

I just counted these dots in letters in my head.

Joanne Roberts:

What's my message?

Children:

Hi.

Children:

Hi.

Joanne Roberts:

Hi. Good job. Do a high five? Yeah.

Prof. Tim Bell:

Students don't need to know how to perform a binary conversion. And very few people do this for their day-to-day job, but because they've constructed the concepts around binary representation for themselves, they develop self-efficacy about how data works, and can see what limits are created by this representation. For example, what the highest possible number can be in a representation, how much more power we gained by adding just one bit to a cryptographic key. Why the number 256 keeps coming up as a limit. Why the size of the internet protocol numbers is changing. Why some computers could run out of dates in 2038. Yep. Again. And so on. Since these bits are what gives us the digital in digital technologies, understanding them as the equivalent of understanding atoms in science. They are the thing that everything is made of. From the exercise with cards, we could see how to use bits to represent numbers, but also months of the year, and letters of the alphabet.

Prof. Tim Bell:

In fact, everything on digital devices is just a collection of bits. Photos, sound, everything. We can think of the internet as a network that's dedicated to transmitting bits, binary digits, between devices. That means that the same infrastructure can be used to share pictures, recordings, websites, and more. So it's not just about students being good at converting binary numbers, but feeling that they can understand how two different values, in this case, showing which way the card is, can be used to represent all kinds of information now, and possibly in the future.

Prof. Tim Bell:

Incidentally, this example is from the CS Unplugged website. Unplugging computer science is about helping students engage with ideas of computer science using games and activities away from computers. It's not a substitute for using computers, but it does help them to get engaged, and it helps them to think about what's happening on computers beyond a screen essentialist view of devices. This activity, and lots of other free resources, are available at csunplugged.org, or just use this QR code to get there.

Prof. Tim Bell:

Another point is that although technology is constantly changing, the key ideas of how it works last a long time. This set of scales is from three generations ago, yet the algorithm used for weighing is the same as the one used for the binary cards. The weights that I can combine here are one ounce, 2 ounces, 4 ounces, 8, 16 ounces, 1 pound, and 32 ounces, which is 2 pounds. To weigh this disk, then I can start with the 32 ounces. And it's too much, so I won't use it. I can try the 16 ounces. It's not enough, so we'll leave it there. The 8 ounces, too much, so we won't use that one. The 4 ounces, not enough, so it can stay there. 2 ounces. Woop, too much. So we get rid of that one. And 1 ounce, and ooh, it's almost about right.

Prof. Tim Bell:

So this disk is the sum of 14, 4, and 1 ounces. In other words, 21 ounces. It's the same reasoning that we were doing with the binary cards before. So if I have a 32 card, and I'm trying to make the number 21, then I don't want that one. But the 16, well, that's not enough, so keep it. The 8 would give us more than 21 dots, so we'll get rid of that. The 4 is less than 21, so that can stay. The 2 would be too much. And 1 will get us to 21. So here I have six bits representing a value. We could ask questions like, "what's the largest six bit number?" Well, that would be if all of them are turned over. And if we add all of that up, then we end up with the number 63. Likewise, with the weights, what's the highest weight that I can measure? It's going to be 63 ounces because that's the combination of all of those.

Prof. Tim Bell:

Anyone using these scales in my grandparents' day would also have known that 63 ounces is the largest value we can represent. Or to use this pattern for a different purpose, suppose I want to measure the length of this disc. I've got some links here that are 32, 16 and 8 centimetres, and so on. Start with the largest. That doesn't fit, so we won't use that. We'll try the 16. Oh yeah. That's not too big, so that can stay. We'll try the 8. No, that's too big. The 4 is too big. 2, looks a bit too big. And we'll put the 1. And so I've now found the length of it, 17 centimetres, by combining the 16 and the 1. Exactly the same reasoning as we were using with binary digits, and the cards, and with the weights. So that's one of the properties of binary numbers at work, in a variety of situations.

Prof. Tim Bell:

Let's get back to those QR codes. Here's one that simply contains some text. In fact, let's scan it. And it says, "Welcome to STEM 2021." let's alter one of the binary digits on here. Let's pick this one here, and I'll change it from white to black, which you would think would change the message. But if I scan it, it still says "Welcome to STEM 2021." That's nice. So what if I change a few more bits? In fact, let's change quite a few, and see if that still scans. Still says "Welcome to STEM 2021." How could it be that I'm changing some of these binary digits to different values, and it's still scanning as "Welcome to STEM 2021"? Let's really alter it. Come on now. Right. Scan that. So with this many changes, it won't scan. That's better than it coming up with the wrong message, but how does the scanner know that things aren't right?

Prof. Tim Bell:

Here's an unplugged activity that introduces this idea using a magic trick. This trick is also about five minutes long. So if you've seen it before, you can fast forward five minutes.

Joanne Roberts:

I need two people to set up a grid for me please. It'll be five by five. Okay? You two? That would be great. Cool. All right. So it's going to be totally random, some black, and some white. That's it. Good. I think we're done. I'll have those cards back. Fantastic. We've got five rows of five, haven't we? Good job. Right. Good job. I've been doing this for a while, so I'm going to add some more to make it a little bit harder just for me, because otherwise I get a bit bored sometimes. There we go. Right. Now, I'm going to turn away, and I'd like you, please, while I've got my eyes covered and I'm turned away. I'd like you to turn over one card please. Okay? So the rest of you can see which card it is, but I'm not going to see which card it is. Okay.

Joanne Roberts:

Is it flipped?

Children:

Not yet.

Joanne Roberts:

Okay.

Children:

Okay, now it has.

Joanne Roberts:

Now? Okay I'm turning around. Right. Now, if a computer got this information, it wouldn't be able to use it. It would be wrong. And so the computer would know it had to turn that bit over.

Children:

How did you know?

Children:

You picked.

Joanne Roberts:

I picked? I didn't pick. I was sitting with my back around. You guys picked.

Speaker 13:

You might've saw us staring at it.

Joanne Roberts:

I was looking there. I had my eyes covered.

Children:

Can the glasses be used as a mirror?

Joanne Roberts:

Mine are just very boring glasses. Hang on. Let's do it again. Just to make sure I wasn't cheaters, I will cover up the eyes in the back of my head as well. Okay? Here we go. All right. This time I want you to turn the card over. Okay? Here we go.

Joanne Roberts:

Is it flipped?

Children:

Yep.

Joanne Roberts:

Okay. All right. Which one of you is it? I will use my mighty powers. I think it was this one.

Speaker 13:

Oh, I know how you did that.

Joanne Roberts:

How did I do it?

Speaker 13:

You memorize all of the way they looked, and then you found which one looked different from the way before.

Joanne Roberts:

I would love to have a memory that good, but no. I'm going to tell you a secret. ere we go. How many white cards are in this row?

Speaker 13:

Two.

Joanne Roberts:

How many in this row?

Speaker 13:

Four.

Joanne Roberts:

This row?

Speaker 13:

Two.

Joanne Roberts:

This one?

Speaker 13:

Four.

Joanne Roberts:

This one?

Speaker 13:

Four. Four.

Joanne Roberts:

Fantastic. Now we'll go this way. How many white cards in this row?

Speaker 13:

Four.

Joanne Roberts:

This one?

Speaker 13:

Four. Two. Four. Four. Two.

Joanne Roberts:

Fantastic. What then do the numbers four and two have in common?

Speaker 13:

I'm pretty sure because they're patterned.

Joanne Roberts:

They are patterned. What is the pattern?

Speaker 13:

There's just fours and twos.

Joanne Roberts:

Just fours and twos. And what's the same about fours and twos?

Speaker 13:

They're both equal numbers.

Joanne Roberts:

Is equal to word? Not quite. Starts with E.

Speaker 13:

Even!

Joanne Roberts:

Even. They're all even numbers, aren't they? So what happens if we turn one over?

Speaker 13:

They'll be odd.

Joanne Roberts:

You're exactly right. Did you guys set that up so they were all even?

Speaker 13:

No.

Joanne Roberts:

No. Because I added these ones, didn't I?

Speaker 13:

Yeah.

Joanne Roberts:

You guys set up the five by five, didn't you? And then I said it was to make it harder, but I was cheating. I was making it easier. You guys are going to help me to put them back now. So to make this one right, do we want black or white?

Speaker 13:

[crosstalk 00:21:56]

Joanne Roberts:

Black. Why do we want black? You're right.

Speaker 13:

Because then there'll be two.

Joanne Roberts:

Two white ones. We want to make it even numbers, don't we? What color do you want one here?

Speaker 13:

White.

Joanne Roberts:

White. And here?

Speaker 13:

Black.

Joanne Roberts:

Black, because we're making it so we've got even number of whites, aren't we?

Speaker 13:

White.

Joanne Roberts:

Hang on. White.

Speaker 13:

Black.

Joanne Roberts:

To make it even. There we go. Now we'll do this row here.

Speaker 13:

Wait, are we going down?

Joanne Roberts:

We'll go across here. And this row needs what to make it even?

Speaker 13:

White.

Joanne Roberts:

White. You've got the pattern. This one?

Speaker 13:

White.

Joanne Roberts:

Yep. This one?

Speaker 13:

Black.

Joanne Roberts:

This one?

Speaker 13:

White.

Joanne Roberts:

Now, this one. Are we going to look at this one, or this one? We'll look at this one? What would we need? We need black or white to make this one even?

Speaker 13:

White.

Joanne Roberts:

We'd need white. And this one here, would we need black or white to make it even more?

Speaker 13:

White.

Joanne Roberts:

White. So that's how I know that I've set it up right. If this one works for both that row and that row, then I've got it right. If I get here, I need a black one for that one, and a white one for this one. I've done it wrong. Now, who of you can say you'd be able to do it, or happy to do it? [inaudible 00:23:05]

Joanne Roberts:

Yeah?

Speaker 13:

Yes.

Joanne Roberts:

Yeah. Okay. Here we go. So you need to turn around. All right. Cover up your eyes, and your eyes in the back of your head. Awesome. Can you please choose one. Flip one card over. Good job. All right. Okay. Turn around. All right. Is this row okay?

Speaker 13:

Yes.

Joanne Roberts:

Is this row okay?

Speaker 13:

Yes.

Joanne Roberts:

This one?

Speaker 13:

Yes.

Joanne Roberts:

This one?

Speaker 13:

Yes. Yes. No.

Joanne Roberts:

Oh. Mark that one off then. Is this row okay?

Speaker 13:

Yes. Yes. Yes. No. Yes, yes. No.

Joanne Roberts:

Oh, [inaudible 00:23:49]. Okay. So we know that something's wrong in this row, and something's wrong in this row. Which card do you think she flipped?

Speaker 13:

This one.

Joanne Roberts:

Is he right?

Speaker 13:

Yes.

Joanne Roberts:

Good job.

Prof. Tim Bell:

That method of correcting errors is based on parity. Parity just means whether a number is odd or even. It's another big word for a simple idea. Although, you've probably come across other variants of the word parity relating to things being even, such as a pair of socks, or a golf score being on par.

Prof. Tim Bell:

At this stage, I should introduce you to our mascot, Arnold the wonder parrot. Arnold joined our team after someone made a bad joke about parity errors. Parrot ears, get it? Yeah. Well, moving on. QR codes is a similar idea to parity, but instead of adding just one bit to each row, they add several bits, which makes sure that the data is unlikely to be corrupted. And if it is really messed up, the extra error control bits ensure that the digital device knows that the QR code shouldn't be relied on. We can use this idea to play a game that I like to call, Will It Scan?

Prof. Tim Bell:

Okay. So you don't need to deface QR codes because often they're already damaged. Let's try a few.

Prof. Tim Bell:

Upside down. Ripped paper. Through two layers of glass. Can two people scan at once? Can you scan a camera that's already scanning a code? Backwards through glass?

Prof. Tim Bell:

Incidentally, another very visible digital code is the product code on items in a shop. Not only are the bars a binary representation, but the digits follow a rule where, like the parity bit that was added to the row in the magic trick, the last digit is calculated from the other ones. This is used at checkouts, to make sure that the code has been scanned correctly. And here's a link to another mind reading trick that you can do based on this calculation.

Prof. Tim Bell:

Speaking of representing data on paper, one person who found out the hard way that QR codes contain readable data was a former Australian prime minister called Tony Abbott, who tweeted a photo of his airline tickets. The hacker known as Alex, that's his online name, the hacker known as "Alex", matched the code to the QR codes, and from them, not only got the flight details, but used it to track some extra online information to get Abbott's frequent flyer number, his passport details, and his phone number. This lead to an awkward phone conversation with the prime minister about how QR codes work. This QR code will get you to the whole story as told by Alex.

Prof. Tim Bell:

So that's a lot of information about data. But to use digital data, we need to write programs. These are what bring digital devices to life. The power of programming is to automate ideas by manipulating data. Of course, it takes a bit of time to learn how to wield this tool effectively, but like all skills, there are plenty of ways a beginner can have rewarding experiences creating things out of their imagination.

Prof. Tim Bell:

Once a computer program is ready to use, you might want to share it, or even sell it. A computer program is just a file stored on a computer, so in other words, a program itself is stored using binary digits, bits. This means that we can share programs using the same systems that we use to share photos and music. They're just bits being stored on disks, or transmitted over the internet. And like all data sent over the internet, they're packaged with error-correcting codes, like we did in the parity trick. So this means if you write a program, you can share it with as many people as you want, and be sure they'll get an accurate copy. Or if something goes wrong, they'll get an error message telling them to try again. And because it's all digital, if you sell a million copies, it's not much extra effort at all to deliver a million identical programs. They're a waitless and a weightless export.

Prof. Tim Bell:

When someone buys a program, they might give you money for it. But actually, the money itself is just binary digits, which get transferred to your bank. Ultimately, you convert those bits into something useful, like coffee, by transferring the bits on your card to the bank, which authorizes the bank to transfer bits, representing money, to the cafe's bank, who then give you something tangible. Mm, coffee.

Prof. Tim Bell:

To understand the digital world, and be able to influence what that world might be like, students need to get beyond the screen, and understand the hidden world of data and algorithms, which are brought to life by writing computer programs. These aren't just random facts to know about, but they describe the fabric of our digital world. It's something that students can engage with. It's not magic. Well, it kind of is, but at least it's possible to learn the tricks that make cool stuff happen.

Prof. Tim Bell:

All of the activities and demonstrations I've used today are available freely online. Most of them are explained on the two main websites that we maintain, CS Unplugged, which has activities away from computers, and the CS Field Guide, which explains key concepts from computer science, and gives online activities that students can interact with. I've got a bunch of links to these sites that I want to share with you. So here they are, a bunch of binary digits that will provide you with some practical information.

Prof. Tim Bell:

Thanks for your time. Ka kite ano.