**Machines that can think: real benefits, the Apocalypse, or 'dog-spaghetti'?**

CBC Radio Ideas

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**Male reporter’s voice on the radio [recording]**

The seas are running as a convoy battles its way across the Atlantic.

**Nahlah Ayed**

It's 1941 and Britain is being torpedoed into submission by German submarines.

**Male reporter’s voice on the radio [recording]**

But what you'll see is a dramatic incident from the Battle of the Atlantic, your cargo ships and escort somewhere in 31 and a half million square miles of Atlantic Ocean.

**Nahlah Ayed**

The Nazis have an advanced encryption device called the Enigma machine.

**Unknown male voice [recording]**

Enigma used a combination of rotors, (inaudible), and wires to put the German messages into secret code.

**Nahlah Ayed**

If the Allies could break their encryption and listen in, it would change the course of the war.

**Male reporter’s voice on the radio [recording]**

The U-boat campaign, certain to be intensified, is Hitler's greatest hope of staving off defeat. He has hundreds of U-boats at sea now.

**Nahlah Ayed**

I'm Nala Ayat. Welcome to Ideas.

**Unknown male voice [recording]**

Details of every surprise attack, every secret convoy and every U-boat in the bloody Atlantic going to that thing.

**Nahlah Ayed**

Germany's Enigma machine was the non-human star of the 2014 Oscar winning movie, The Imitation Game, in which Benedict Cumberbatch plays Alan Turing.

**Benedict Cumberbatch [recording]**

If the allies break Enigma, well, it would turn into a very short war indeed.

**Nahlah Ayed**

Enigma was a marvel of technology. It looked like a typewriter with 26 keys, one for each letter of the alphabet. And whenever a message was typed, a seemingly random set of letters was generated.

The only way to break the code was to run it through another Enigma machine. But this other machine would have to have the exact settings of the first one sending the message. And those settings changed every day.

**Benedict Cumberbatch [recording]**

I like solving problems commander. And Enigma is the most difficult problem in the world.

**Nahlah Ayed**

Breaking Enigma's code was thought to be the impossible. It could generate 100 billion billion potential combinations every time it was used.

**Roger Melko**

Figure like this. It's basically the same as the number of grains of sand on Earth.

**Nahlah Ayed**

Roger Melko calls massive problems like cracking the Enigma code, the complexity frontier. He's a Canada Research Chair in computational many body physics and gave a talk at the Perimeter Institute for Theoretical Physics in Waterloo, Ontario. In his lecture, and in a later conversation I had with him, Roger Melko outlines how computing and artificial intelligence are now facing their own complexity frontier, just as the allies did in World War Two.

**Male voice over radio [recording]**

The Battle of the Atlantic continues, as our convoys pass to and fro, U-boats lurk in the vast waters preparing to cut our lifelines at every opportunity.

**Nahlah Ayed**

How algorithms and neural networks are changing our lives and what happens now that we're teaching machines how to learn.

**Roger Melko**

You know, the situation was really dire. I mean, this was, I guess I would call this at the time, you know, really the complexity frontier of World War Two, the idea that you needed somebody to do this kind of impossible task, which was encoded by this machine was really the bottleneck, the complexity was the bottleneck. And the situation was so dire that in June 1941, Winston Churchill knew that if they didn't break this Enigma machine, he was warned that, the supply lines to Britain would be cut off. So, there's many heroes, there's many people who contributed to the breaking of the Enigma code, as we know. But the one man that stands out, amongst all others is Alan Turing. And so, for those of you who watched this famous movie, The Imitation Game, you really get a good idea for what Alan Turing's contribution to the war was. And he and his group cracked that code. They cracked the Enigma problem, the Enigma settings. And they did it just in time. They did it in the same month that Winston Churchill got that warning in June 1941. Right before the war in the Atlantic is about to ramp up. And that's where my story begins today is with Alan Turing and the other thing that he was thinking about during the war, right? How did he crack this code? How did Alan Turing crack the Enigma machine? He basically built another machine that did the task of counting all the grains of sand on Earth, essentially, every day. And so, the allies could start listening into the U-boat communications, essentially, starting in 41.

**Nahlah Ayed**

The first questions kind of seem to imagine that you are a senior British military officer back in 1941 and you knew what the Enigma machine could do. And then someone tells you that it could actually be cracked. How do you think you'd have responded?

**Roger Melko**

I think I would have been surprised, although I also, I'm also not sure, at that time, humans really understood sort of the concept of complexity and how large these numbers were that that, you know, they were battling against. You know, these, massive amounts...like counting every grain of sand on Earth. That's sort of the number of Enigma settings that were required to be cycled through each day. I'm not sure a lot of the people in charge really had a grasp of how difficult that problem was. And maybe they just, you know, like, we often see how technology advances and take it for granted. It's possible that that was taken for granted too.

**Nahlah Ayed**

How revolutionary was it in the 1940s, to think that a mechanical device could solve these sorts of complex mathematical problems, the way that a human can?

**Roger Melko**

I think, sort of mechanical computational devices have been envisioned for a long time. There's famous cases where Babbage and others tried to make different machines, sort of machines that could mechanically say add, subtract, do more complicated mathematical functions. And there were inklings, even probably in the 1800s, that these mechanical machines could actually be more general than calculators, they could actually be universal, which means they can attack sort of general problems in general settings.

**Nahlah Ayed**

How did Alan Turing's work in cracking the Enigma code set the foundations for today's computers?

**Roger Melko**

Well, he laid in his writings after the war, and some from before the war, really the foundation for a lot of the foundational theory for the technology that we have today, which, in some sense, is related to the machines that cracked the enigma. But it's much more general obviously. You know, it's not just the straightforward evolution of what happened during the war. Alan Turing's ideas were quickly grasped on after the war by people like von Neumann, who was working at the IS and Princeton. And this group of people, were advancing both, you know, theoretically the concepts of generalized computing or universal computing and also, if you will, the hardware at the same time.

**Nahlah Ayed**

So, can you draw a line from his thoughts to what's going on today?

**Roger Melko**

I believe, yes, absolutely. I mean, people do study Turing's writings, in today's context, and one of the most fascinating things that Turing really was responsible for was sparking the notion of artificial intelligence, sort of in the more popular context with the public. So, people knew that artificial intelligence was something that could spring out of the machines that were invented, you know, during that time during and after the war, because of Turing's writings. I believe he wrote letters to the editor for the newspapers at the time in London, talking about artificial intelligence. So, these ideas that we have today, the direct lineage is back to Turing's writing the hardware that we have today is a direct result of what he largely, what von Neumann and others did in Princeton immediately after the war, and just directly related.

**Nahlah Ayed**

And just an aside to that, though, how recognizable were those ideas back then? Was it widely known or understood by anybody, what he was, how wide his ideas were, that they were beyond?

**Roger Melko**

There were certainly groups of mathematicians and I guess what we now call computer scientists, who did know what he was thinking. Of course, there's literature, scientific literature that brings these communities together across the world. And you know, Turing spent time in America, a short amount of time visiting von Neumann and (inaudible) after the war to exchange these ideas. So just like we have a scientific community now that communicates through journal articles and letters, like physical letters was what Turing and those used back then to communicate. So, the ideas were in the scientific literature.

**Nahlah Ayed**

Today's supercomputers like the one Roger Melko uses at the University of Waterloo, are 50 billion times more powerful than those used in the 1960s when NASA first sent a man to the moon. Still, even those aren't nearly powerful enough to answer all the questions that science is asking today to illustrate how even the tiniest things can bring us right to the edge of the complexity frontier, Melko uses the example of a speck of dust, a very small speck made up of only 268 atoms.

**Roger Melko**

So, in my field of physics, we are interested in the possible states. Let's call them states of matter, let's imagine that. I could imagine liquids solids, gases, insulators, conductors, superconductors. I've just listed half a dozen. But, you know, there's a fundamental question about how many of these types of states are possible in say, a chunk of material. And so the, example I give with 268 is that if I have a sort of nanometer speck of dust, something completely tiny, but I enumerate the possibilities, sort of the mathematical possibilities of all the different states, it's astronomical. So that's the complexity. That's complexity in the sense that once I get up to more and more atoms, molecules, start putting things together into materials, the number of states that are supported, it's not necessarily gas, liquid water, you know, blah, blah, blah. It could be things we haven't imagined, you know, continues to go up exponentially.

**Nahlah Ayed**

Roger Melko calls this exponential number of states of matter: The Quantum Many Body Problem.

**Roger Melko [lecture audio]**

If I want to encode or store or search through the state space, the different types of states possible in a 268 atomic system, which is very small, it's equivalent to the problem of counting all the particles in the universe. It's like the Enigma machine but way, way worse, you know. So, this is the complexity frontier right now. This is what stops us in some sense from fully understanding or appreciating the quantum many body problem, the problem many quantum particles. And so now you're asking, okay, well, what are they paying me for basically right? [laughs] This looks impossible. And even with the world's best computer, it seems to be impossible because I'm never going to make a computer hard drive that contains all the particles in the universe cause then what will we make you out of? What will be left? So clearly, there's problems that computers will never solve, will never, ever solve a problem of that complexity. Right? In that sense, and you already knew this, right? That's the point. I mean, I just gave you a mathematical argument for some sort of physics or mathematical understanding of the universe. But we already know that there's other problems that computers are terrible at, you know, writing poetry. You're never going to have a computer, recreate this poetic...being creative, all these human type things, right? There's a lot of creativity that goes in putting a urinal in an art gallery. I saw it. I mean, only a human could do that. [audience laughter] Painting, you know, Rembrandt painting all these weird old people, I mean, could a computer do that? Of course not right? Even something simple like a tree. So why not? Why can't a computer paint a tree? Or, you know, if I wanted to construct a computer program and algorithm to paint a tree, I guess at first, I would have to tell a computer what a tree is. So, let's ask the question, how would I get a computer to understand what a tree is? It's a simpler question. There's a simpler tree. It's black and white, black, white picture of a tree, a photo, if you will and I want to design an algorithm so that if I feed that image into a computer, I can identify that as a tree. Okay, so let's make it simpler. Let me pixelate it, it's a pixelated tree. There's maybe, I don't know, a couple hundred, maybe a couple thousand black and white pixels. Okay. And let me imagine I have a computer program where I feed in those pixels. And I ask the computer "is this a tree?". And the computer says, "well, okay, I'm looking for a trunk in the middle, maybe some branches on the side. I guess there should be nothing around the edges and maybe some ground in the front, but that doesn't matter if it's still basically a tree". And so, I can imagine, okay, I'm going to code in the XY coordinates and blah, blah and try to make up a deterministic program to, you know, and oh, somebody says, "oh, what about this? Is this a tree?". Well, yes, but now I got to think about, okay, I need to have the trunk kind of going horizontal in some cases. And then quickly, what you see is that the complexity of making a deterministic algorithm to take in these pixels and tell you that that's a tree is difficult. And how difficult? Maybe you can ask that question. Well, pixel space can be counted. Here's a pixel: black and white. It has two states, right? So, two states per pixel. If I have two pixels, it's two times two is four states of those pixels. So, an image, you know, there's four possible images that I can make of four pixels, and you see where I'm going. If I have three pixels, there's eight possible images that I can make out of those. And I can, you know, again, 260 pixels, it's not a very high-resolution photo. You're essentially never going to be able to search all of that pixel space or all of that picture space.

**Nahlah Ayed**

So as powerful as they are, there are limits to what computers can do, at least for now. But the machines are learning even things we thought it was impossible for them to learn, like creating art. You talk about a computer not being able to draw a tree, its inability to draw tree. What I'm wondering is, I mean, we've seen computers come up with images, they draw all sorts of things. What exactly is the principle that makes it impossible for a computer to paint a tree? In your view?

**Roger Melko**

I think that's exactly the point is that we know from experience now, in this day and age that it is not impossible for a computer to paint a tree. But if you asked people in the 1950s, 60s maybe, if that was possible...if it was possible for a sort of a computer to generate an image of a tree that looked acceptable to a human in the sense of human thought perhaps another human painted it, it would be very difficult to imagine, based on the counting of the number of images possible with pixelized, you know, with pixels or something like that. So, in my lecture I talked about, you know, if I feed a computer and pixelized the image of a tree, how difficult is it for that computer to recognize that it's a tree? First of all, because just like a human, it's probably easier to look at a picture and recognize what it is, before I learn how to draw it. And, you know, from these arguments of just counting the number of pixels available to the computer artist, it looks like the number of possible trees or interpretations of what those pixels could be, approaches this very large or infinite number. So how do you program a computer in what they call it the deterministic way? With hard coded programs, how would you ever code that into a computer so that it recognized a tree and then the harder problem is how do you tell the computer "okay, now show me what you think, in your mind what a tree looks like?". So, this is why I believe the abilities that we've seen in the last decade or so, of computers to recognize images, paint, pictures, drive cars, and so on are really astounding.

**Nahlah Ayed**

So just so I'm clear, you're saying now that you do believe that computers can draw a tree like a Rembrandt?

**Roger Melko**

Right? It was like a straw man argument [laughs]. In the lecture, I try to convince people that it's not true, right? And then I show them "Oh, yeah, by the way, here's a tree that looks just like a Rembrandt".

**Nahlah Ayed**

Gotcha, okay. So, in the 40s, they thought it was impossible for a computer to break the Enig ma code. So, let me ask you this, is your certainty that computers won't be one day able to do what they can do today, a little bit overconfident?

**Roger Melko**

Well, the ultimate question that many people ask is, will a computer be able to fully simulate a human mind? Computers are made of stuff, materials, physics, they're bound by physics, humans are bound by physics, right? We just have an organic computer in our head. That's a very different, I guess, architecture than what's in our pocket, regarding the phone. Will we be able to build computers that fully mimic a human mind in the sense that if I talk to that computer, perhaps, you know, over a computer screen or in person if it was a robot, if I talked to that computer, could I be fooled into thinking it's a human? We don't theoretically know if that's possible. But there's no theoretical reason why it's not.

**Nahlah Ayed**

But are those two things mutually exclusive? But can you not believe... if there's nothing holding it back, does that not mean that it is possible?

**Roger Melko**

In Rumsfeld speak it's unknown unknowns, right? So, we know some things are unknown in the complexity frontier, or at least we believe very strongly that certain things can't be calculated or simulated. There's of course, known knowns, which we've attacked. And then there's these unknown unknowns, right? So, we really don't know, in many cases, what the limits of computational technology are.

**Nahlah Ayed**

So, where does this all lead? You'll find out about some of the known knowns of where artificial intelligence is taking us as you keep listening to ideas on CBC Radio One in Canada, across North America, on Sirius XM, in Australia on RN and around the world at CBC.ca/ideas. You can also find us on the CBC listen app, or wherever you get your podcasts. I'm Nala Ayat [pause] Roger Melko is the Canada Research Chair in Computational Many Body Physics at the University of Waterloo. He gave a public talk on something he calls the complexity frontier, that place where its existing technology meets seemingly insurmountable obstacles. In the case of Alan Turing, it was finding a way to crack a code through billions of possible combinations. Today, it's unlocking the power of artificial intelligence.

**Roger Melko [lecture audio]**

This is something very new in the world of computer science. It's a new breed of algorithms. Artificial Intelligence, that's what we call it. Artificial Intelligence is kind of a catch all term for many different types of, you know, ideas related to smart machines, if you will. And a subset of these I'm going to talk about. These algorithms are called neural networks. So, this new breed of algorithm does tasks that seem impossible for computers, but are possible for human minds, like adult human minds, okay. It's very new. But it's actually not that new. The idea. If you go back to Turing's writings during the war, before the war, and even especially after the war, he could envision exactly what's happening today with artificial intelligence. Even, looking at the sort of rudimentary hardware that we had back in World War Two. So, you know, he was saying, if you want to have a computer that simulates an adult mind, essentially, you should build a computer that's like a child's mind. And you should take that child's mind and teach it, expose it to data, educated it. That was curing vision of artificial intelligence. And, it took years for us to realize that vision, but the revolution we're seeing now, in Amazon Web Services, and all over in Canada and other places, is because of this vision. So, what does this mean? You know, educate a computer and obtain the adult brain. Well, these algorithms, these deep neural networks are called that for a reason. They're essentially motivated or, a design based on principles that we see in human and animal brains. So, the idea that there's pathways and that pathways of sensory input, which strengthens them, and which leads to some sort of thought process and so on. This is really motivated by the way we process data ourselves, and hence the name, neural networks and so on. So, the workhorse of most of the machine learning breakthroughs that have happened recently is this object, artificial neural network. An artificial neural network is like a small piece of that human brain, encoded in the computer to learn based on experience. And how it works, as you can imagine, on the right-hand side, like the pixels of an image, maybe it's your retina, maybe it's your eye and as you go further back in the network, there's neurons and pathways. And the pathways take signals and the neurons, let them pass or maybe stops them or maybe amplifies them, such that you can train this thing, or you can educate this thing. So, the way it's done in Amazon, and most other places, you take a whole bunch of images, billions of images a day. And you might have somebody tell that network for each one of those images, whether or not the person in the image is happy or sad. So, you yourself don't have to program that computer. You know, what the neural networks doing is strengthening pathways that take you from that pixelated image space to the output that you want. The last neurons were fired happy or sad based on that pathway. So, then you can take an image that it hasn't seen before, like a happy Trump, and you could put it in the neural network. And if everything goes well, in the training or the education, the neural network will fire the neuron that tells you that that's a happy face. And that's what's going on at Amazon and with many of these neural networks trained on tons of images. If you take that same neural network and feed it in a sad picture of Trump [audience laughter], then they'll hopefully fire the pathway that tells you that there's a sad picture coming into it right. So, the idea of neural networks is sort of the same philosophy as learning. But what I just showed you is that image space. You know, these pixelated images are very similar in many ways to the state stage of quantum mechanics.

**Nahlah Ayed**

The field of image interpretation seems to be exploding right now.

**Roger Melko**

Absolutely, the field of computer vision has very much exploded, I believe, since sort of 2012, 2013 and Canada and Toronto play a very large role in that. Geoffrey Hinton and his group at the University of Toronto, now at the Vector Institute for Artificial Intelligence, pioneered this technology that really demonstrated to other mathematicians and computer scientists that computer vision or the classification of images say, in a standard data set was very possible. In the field of artificial intelligence, there's something called these standardized datasets, like, pictures of cats, pictures of dogs, pictures of people doing things, pictures of animals. And they these data sets have been static for years. And so when computer scientists and mathematicians and scientists come up with new algorithms for image classification, feeding all the pixels, "this is a tree, this is a cat", we can compare their algorithms, and in 2012, 2013, there was a huge breakthrough here in Canada, which the benchmarking associated with these data sets, and everyone in the field recognized that there was a breakthrough in computer vision.

**Nahlah Ayed**

[inaudible] can you explain that breakthrough, just briefly?

**Roger Melko**

It's fairly simple in the sense you have images, maybe thousands of images that a human has labeled, cat, dog, tree. You train a computer, you train a neural network algorithm on those images and the associate labels and then you feed in new images that the computer hasn't seen before, and ask what percentage is misclassified? And we saw a jump in the success of these algorithms, essentially, in this last decade.

**Nahlah Ayed**

How do you teach a computer to, to recognize complex images like the dog or whether a person is happy or sad?

**Roger Melko**

You do it with data. It's data driven. And that's where the learning comes in. So, when I try to motivate this strawman argument in my lecture that, you know, we cannot teach a computer to recognize a tree. I haven't talked about data, I want the audience to think, if I was programming a computer to just take black and white pixels and look at different arrangements of them, maybe spatially in the image, will I be able to write a program that says definitively this and every other image of a tree I give it, is what we want to be a tree. The data driven approach is feeding examples, you know, thousands, millions, billions of examples to a computer program that learns from that data. And that's the paradigm that most of the breakthroughs that we're witnessing in real time now are based on. It's data driven.

**Nahlah Ayed**

So, are you able to talk about how you teach a computer to actually learn? What is the process of learning? When you're presenting this data? What does that mean for the computer?

**Roger Melko**

So, the most successful strategy in the last decade has been to program what's called these neural networks fashioned after the human and maybe mammal brains. And the neural network is really kind of a signal processing program, where signals propagate through the machine in pathways similar to the way signals in the human brain propagate between neurons. So, when you are teaching a computer to recognize a photo, you strengthen the pathways that will lead to the output of that neural network successfully classifying that photo. So learning is strengthening these pathways. It's strengthening the signal propagation that go from pixelated image to ‘label cat’, ‘label dog’, ‘label tree’.

**Nahlah Ayed**

AI has been making headlines also for the last few years. What do you make of computer programs being able to teach themselves? Like how to play chess, for example?

**Roger Melko**

Right, so I think even the programs that do gameplay, like chess, or go as the famous one, do have some element of data being forced into them or data being propagated through them to strengthen pathways. We can't, I believe divorce the concept of neural networks and machine learning from the idea that they're data driven, although we can have other programs or sub programs produce the data. For example, a self-driving car is something that takes action based on sensor input from the environment. So, they call it reinforcement learning. It's being trained off data that's being streamed in real time, perhaps and then discarded. These types of agents, robotic agents, like self-driving cars, and so on, can learn without data. And it is a very powerful paradigm. I think it's fascinating. I think it's a fascinating way of changing our perspective on how we program computers. Again, we don't exactly know what's capable in this paradigm when computers teach themselves. When computers can collect data, teach themselves and change the behavior, I really think that's what we as a society are pursuing in a lot of these technological advances that come from machine learning, it's very hard to predict what's going to come out of that.

**Nahlah Ayed**

In fact, it may be impossible to predict. But research into computer learning is definitely expanding our idea of what is possible. Physicist Roger Melko, about how computers are taught to learn, in this case, how to recognize pictures with the help of something called neural networks. You do mention the concept of neural networks that gather large amounts of data and are able to interpret an image. If we took the same data, could we recreate an image with it? For example, in that scenario, could you teach a computer to draw a tree like Rembrandt?

**Roger Melko**

Yeah, absolutely. And the idea is that if you feed this neural network enough data, those pathways are strengthened in a way that you can essentially let's call it, run it backwards, and you can have the neural network spit out pixels that to a human mind look a lot like a tree. And this has been demonstrated in my lecture we look at these Rembrandt-like trees that are produced by deep neural network programmed by a Stanford student named Robbie Barrat, very, very, very much an artist.

**Nahlah Ayed**

And what did they look like?

**Roger Melko**

To me they look exactly like a Rembrandt, but I'm not much of an art aficionado.

**Nahlah Ayed**

[laughs] But enough so.

**Roger Melko**

Absolutely.

**Nahlah Ayed**

So elsewhere, in the lecture, you mentioned the concept of something called deep dreaming. What do you mean by deep dreaming?

**Roger Melko**

Yes, deep means in this context, the idea of deep learning. Deep Learning means that we've stacked neural networks into multiple layers. Each layer of that neural network typically encodes in a hierarchical way information. So, at the lowest level it's, say, individual words or individual pixels of an image. If you go deeper into the neural network, and you try to interpret what's going on, you'll see images being formed sort of maybe edge by edge, block by block and fully assembled deep within the machine into something that could almost be recognizable. So now what you can do is tweak the deep dark depths of that neural network and ask it to spit out what it's thinking inside those multiple layers. And that's deep dreaming. It'll spit out new images, it'll generate new text, it'll generate new data, that is essentially its dream coming from deep within.

**Nahlah Ayed**

And you said there are some that seem random that we don't understand, but others that we can recognize.

**Roger Melko**

Absolutely. I think most of the time when you do this procedure, what the machine dreams is something that's uninteresting to humans. But there's very striking examples where deep dreaming gives you something that is very interesting to humans.

**Nahlah Ayed**

So, what are some of the possibilities that these teachings create for you as a scientist?

**Roger Melko**

For me as a scientist, this is one of the most exciting strategies in the sense that we can dream up things by tweaking these deep neural networks that may not have been something that we ourselves invented. So, I like to train deep neural networks. For example, on data that comes from physics, physics experiments, let's use the example of a quantum computer. We do a lot of work on that. I feed neural networks and data from a quantum computer. The network gets trained, the pathways for signals sort of get strengthened and amplified. And then after I trained them on as much data as I can get from the laboratories of my friends, I fiddle with the inside of the neural network and ask it to dream me up a new quantum computer configuration. So many times, what it spits out might be useless. But every once in a while, you'll see something that you never imagined yourself was possible.

**Nahlah Ayed**

Can you give an example?

**Roger Melko**

My favorite example is dog spaghetti.

**Nahlah Ayed**

Dog spaghetti?

**Roger Melko**

Yes, it's an image, where a deep neural network was fed pictures of dogs and spaghetti, I guess, at the same time, and then asked, "what are you dreaming about?". And it's a hideous sort of mash up of dog faces and spaghetti, you know, together on the same plate. [Nala laughs] You got to see it to believe it.

**Nahlah Ayed**

Sorry, it sounds terrible [joint laughter]. But what's the applicability of that?

**Roger Melko**

Well, for science, it's really to augment human imagination in some sense, or the human scientific procedure, by which we come up with new theories and so on. So, what we use deep dreaming, generative models and other types of machine learning for, is to really augment our own scientific process. Famously, science progresses through inspiration. Often times, what we're asking the computers to do is give us an inspired guess on what they think something might look like, a quantum computer, dogs and spaghetti, whatever it is. It's just another perspective on the physical sciences.

**Nahlah Ayed**

That's inspiring in itself. But how often does that happen? That you draw inspiration from precisely that process?

**Roger Melko**

Personally, for me, it happens all the time because the machine learning algorithms that we devise, are designed on very difficult... they're designed to handle very difficult problems that humans aren't exactly adept for. We're very good at pattern matching things like images and language and so on. But other things like states of matter, the process underlying quantum computing, those things aren't made for the human mind. But the same artificial intelligence that's been developed for human like applications can be used for these sort of scientific, hard science physical endeavors.

**Nahlah Ayed**

I'm speaking with Professor Roger Melko, a physicist at the University of Waterloo, about something he calls the complexity frontier. And the dog spaghetti he mentioned, you can see what that looks like if you're so inclined on our website cbc.ca slash ideas. Roger is not in the business of predictions, but as you'll hear in his public talk, he is excited by future developments.

**Roger Melko [lecture audio]**

So, I don't know what the future will bring us. But some things will definitely be great, like a universal translator. You know, this is almost reality. In 2016, Google changed its translation services from the old system, which I will mention, to the neural machine translation system, which basically takes phrases and different languages and trains these massive deep neural networks. You know what's going to happen in the very near future is like an earbud in your ear and somebody speaks in French, and I no longer have to go to French class. My total translates done in real time, great, what I always wanted. So that's one thing you can look forward to. For every good thing in the future, there's also things like this, facial recognition technology that can now text you a fine as you're jaywalking across the street. This isn't the future; this is happening now. This is today's technology. Basically, you got to, I guess, wonder what kind of future you want to live in? Are we creating human like intelligence? Do we want to create human like intelligence? Are we capable of it? What would artificial intelligence look like? I get asked this question quite a bit. So, in terms of human like artificial intelligence, you know, creating a brain out of these artificial neural networks. I think we're a long way from this. The only kind of intelligence we know is our own. And our own brains are very complex, they have the same amount of neurons as there are stars in the Milky Way galaxy. That's a big number, that's 100 billion. That's the number that quantifies the complexity of your brain. We're nowhere near making artificial neural networks that have this type of capacity, this type of neurons and this type of connections and so on. The brain is a fabulously complex device. But what we are very close to, is augmenting our current reality and our intelligence with the very technology that we're basically creating now. You already live in augmented reality when you listen to headphones and music superimposed on your everyday experience. Virtual Reality is kind of the limit of how you would completely immerse yourself. But really the idea of augmenting your day to day life with you know, a watch that sends you your emails, I don't know why you'd want that. I hated my...my Apple Watch lasted three days on my wrist, but you know that that device is augmenting your reality. It's telling you the weather, it's telling you your emails, your texts, and in turn, you're feeding data up into, the big neural networks that live on a cloud, very symbiotic type relationship. The thing with a human level intelligence, like building a brain that's the size of our brain and as complex as our brain is, you really have to teach it things just like Turing told us. You have to expose it to experiences and you have to structure that data in a way that enables it to learn. And the best way to do that is with devices like this, these Amazon and Google Home speakers that are constantly on, constantly listening to you. Very convenient. You can ask things off them. But the trade-off is that your data is constantly being used, just like it's used in Amazon Web Services, to train these neural networks, you know, billions and billions of natural language texts, you know, sentences a day or something like that. So, we can augment our reality and our intelligence, and one question is, how far do we let that go? Are we willing for example to get rid of our iPhone screens? Shrink the size of the device down and just project the image directly into our eye? What I'm showing you now isn't the future. These are real companies. Okay, look up [inaudible] These are patents filed. These are startup companies that are in the process of essentially integrating your phone with your body. So smart lenses is a nice first step. Put contact lenses in, heads up display. You know, finally, when I'm meeting my grad students, their name comes on the bottom. I mean, I know who they are. I could really use that kind of augmented reality. You know this technical problem is only with this type of smart lens. Some people are putting their money more on retinal projection. [Inaudible] is a prototype retinal projection system where you might wear glasses, but instead of having a screen, you essentially project your iPhone screen or whatever directly on the back of your retinas. So now it's starting to be a little creepy, right. How much do I really want to be directly into my brain? Well, you can ask the other question, how do I change the way that I interact with the phone. I mean, this is the phone feeding me data. How do I want to interact with my phone? Isn't it annoying when you have to reach up here to turn your headphone up and down? Don't you wish that you could do that with your mind, just thinking about it? That's crazy right? Brains phone interfaces, the idea that we move ahead by letting our phones literally know what we think. Just think it, it's a nice logo. Actually, this is a real company, Orbital Labs. Orbital Labs who I met in Toronto recently, is a startup company building the world’s first ear buds that let you control things with your mind. And they're going to start with the volume on your phone. You're walking down the street, you want your phone, your headphone, your music at a higher volume, you basically think it. The EEG pattern, you know, produced by your brain can be interpreted by these earbuds to essentially give instructions to your phone, and the easiest instruction is the binary instruction, up or down. That's a real company. This is again not the future. And you know what else is not the future? Getting rid of that pesky skull on your mind that surrounds your mind that interferes with those EEG signals. Because wouldn’t it be much more energy efficient to get those EEG signals directly from your brain? So, no kidding I'm not kidding. There's syringe injectable electronics, being developed. This is a paper out of Harvard with plug and play input output interfaces. The idea is that you'll syringe inject, basically, a sort of electronic wiring into your brain, which enables these types of interfaces to happen. And big breakthroughs have been achieved in injectable electronics that don't provoke some sort of immune response. That was the big holy grail, not rejecting these brain implants. I don't know how you feel about that.

**Nahlah Ayed**

So, you ask your audience how they feel about injectable electronics being wired into their brains. How do you feel about it?

**Roger Melko**

I think if we asked somebody maybe 80 years ago, how they would feel about constantly being tethered to their iPhone, they might be repulsed by the idea that humans have evolved to a point where they can't put down their phones. When they lose their phone on the way the washroom. They feel anxiety. So…[laughter]

**Nahlah Ayed**

Like I just did, right just before the interview. That was just a random example, right? [laughter]

**Roger Melko**

Just a random example. But you see the effect that I mean we're living in an age where we are already tethered both to the internet, which itself is made up of a lot of big neural networks sucking in your data, but also to each other. So, maybe it's natural to just integrate ourselves more, both with, you know, the internet and what's out on the internet but with each other.

**Nahlah Ayed**

So, you sound more accepting of it than maybe the rest of us are willing to admit.

**Roger Melko**

Well I don't know if I would do it myself, but my wife always worries about if we give our son too much screen time. And I say to her, you know when he's 18 he's going to be asking “Dad, can I get implants?”. I mean, technology will just progress to the point where…we already do have things like retinal projection glasses. Actually, Focals by North, a startup that came partially out of Waterloo and Toronto produces sort of a heads-up display for your notifications being directly into your retina. That seems already invasive, but you know it exists, it's a product. Some people like it, some people don't. I personally don't want to see my text messages, constantly scrolling on my eyeball. But why not a contact lens? Why not a lens in your eye, then why not replace your lens like you do with cataract surgery, why not replace it with something that can project onto your retina directly? Why not, get signals out of your brain, not through your thumbs or through your mouth, but directly through injectable electronics that have a USBC adapter say for example or just have a Bluetooth connection on the outside of your skull. It's up for each individual human I suppose to decide what they're willing to do but what's fascinating is that industry is pushing us in this direction.

**Nahlah Ayed**

So, if your son came to you in a few years and said, “Dad, can I have an implant?”, what would you say?

**Roger Melko**

I hope my wife's not listening, but I got no problem with it.

[laughter]

**Nahlah Ayed**

It's one version of a question that we're all going to have to answer but there are people who are out there, who have raised alarms about this, and about AI technology, and technology in general. The most famous example is with Stephen Hawking, of course, who was a friend of the Perimeter Institute, who said that AI could spell the end of the human race. Do you believe that?

**Roger Melko**

Oh, it's certainly true that it could spell the end of the human race. I think what gives me a bit of pause is it's very difficult to predict how that could happen. I would make an analogy with maybe where we were in the 1980s when internet technology was first being developed. I believe that, you know, given an individual, whatever 286, you know, IBM running on Intel and maybe a modem. It would be very difficult for us to predict the Ice Bucket Challenge, or memes, or things like that. So, now we're at an analogous point where we have a lot of the building blocks of artificial intelligence. We're coupling them together, we're feeding them data, which they need to live. Yes, you know, there could be dangers that come out of that just like dangers came out of the fully connected internet that we now live in, and there's also opportunity. So, it's worth thinking about. But I would say it's very difficult to predict what will emerge.

**Nahlah Ayed**

Some people say that those threats should mean that research like what you're doing should stop altogether.

**Roger Melko**

Yeah, absolutely. It's like the same. It's a similar scenario when physicists were tinkering with the atom. The problem I believe is that science and technology progress, much faster than policy in many areas or much faster than humans’ ability to keep up with the ramifications of what's actually being invented. So clearly, there are dangers inherent with what we're building in terms of artificial intelligence. But who is the person who will understand the ramifications or be able to predict the ramifications?

**Nahlah Ayed**

You know Hawking is somebody we all respect and admire, but he's scared, shouldn't we be scared?

**Roger Melko**

I think people are right to take heed of these warnings, and I do, I do take heed of the warnings. Some of the things that we're doing, like what we do in our lab is we couple artificial intelligence, a couple of neural networks to present a quantum device. So, we build hybrid quantum computers, artificial intelligence. They're rudimentary, we're still understanding them, but we really don't know what they're capable of.

And that's scary isn't it. There's no prior to be technical there's, it's hard to predict again. People were concerned about creating black holes in the LHC.

**Nahlah Ayed**

LHC?

**Roger Melko**

Large Hadron Collider at CERN. You smash two particles that are massive enough. The argument was there's a possibility that you could create a black hole that swallows the earth. The research was never stopped. The prior doesn't exist. You don't have any sort of way of understanding the actual risk involved. The reward for us was larger. Discovering the Higgs boson. There's always risk inherent and things. I think with the problems that we're dealing with, sort of, as humans in society. Things like climate change, inequality, things like that. We tend to search for technological solutions and technological solutions may certainly lie in this sort of, you know, human AI hybrid augmented reality that we're creating. And so, I think it's worth pursuing those ideas and yes there's risks and we have to mitigate those as we develop the technology. These are where technologies are going, um, you know, again it's, it's, accessing massive amounts of data, it's taking all this big data that you're producing every day and training these massive neural networks. Okay, it's interfacing yourself with, with the phone in a much more sort of fluid way so that this data transfer back and forth really helps you augment reality with all these pesky things like typing on a keyboard, turning your headphones up and down. I don't know, I don't know what you guys think about it but I'm pretty excited about what this technology means for my type of research. All of these pesky quantum particles that I had, you know, a hell of a time, I guess characterizing and understanding. Now, what we're doing is we're essentially interfacing these neural networks directly into other the data produced in our computers or the real experimental big data that's being produced and measurements of these wave functions and these neural networks coupling with our sort of, you know, quantum data are really augmenting that data in such a way that I can understand it myself. When I look at my computer screen, when I look at the processing that comes out of our scripts, I've really seen that neural networks have augmented the reality that is quantum mechanics. As we move forward into the future and we build the next type of intelligent machines, which are quantum mechanical quantum computers. We will also control those machines will interface with those machines will do readouts you know will nurture them will train them will give into it. All of that will be done through artificial intelligence it all be done through these types of neural networks that we're developing today. So, we're really on the verge of actually doing this experimentally. And we're really taking our next generation quantum intelligence and augmenting it with our most advanced, you know, artificial intelligence that we have today. So, I can't predict the future, like I say I don't really know where this is going. I'm very excited. And what it means to me is that, you know, we've taken what I thought the frontier was the sort of complexity frontier of quantum mechanics and we've pushed it to some other level that we don't even fully understand yet. So that's my vision of complexity frontier. Everybody, thank you for your attention.

[applause]

**Nahlah Ayed**

At the end of your talk you say that you are excited about it, you know, of areas of research areas into intelligent machines like quantum computers. You say that you're excited about it. I'm just wondering what it is that you've experienced that sort of underwrites that excitement, why are you excited about it? What proof do you have that we should all be excited about it?

**Roger Melko**

I guess I'm excited about the fundamental limits of what we're capable of as humans. You know, we are building something here that is bigger than all of us. We're building a sort of massive interconnected network that is capable of emergent phenomenon that we've never imagined as humans. It's our greatest achievement. This technology and the science that underlies it. It could transform our species or it could be the end of our species. But I guess I lean on the optimistic side of, we will transform ourselves in a way that we don't know what it is. I just like being part of that transformation.

**Nahlah Ayed**

Thank you very much Roger.

**Roger Melko**

Thank you.

**Nahlah Ayed**

You were listening to Ideas, and to the complexity frontier with Roger Melko, Canada Research Chair in computational many body physics and associate faculty member at the Perimeter Institute for Theoretical Physics. This episode was produced by Terry Reith, technical production by Danielle Duvall our web producer is Lisa Luc, senior producer, Nicola Lipschitz, the executive producer of Ideas is Greg Kelly and I’m Nala Ayat.