Welcome to MIT's Computer Science and Artificial Intelligence Labs Alliance's podcast. I'm Kara Miller.

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On today's show, one of the world's leading roboticists argues, not only are millions of robots hard at work in factories, on docks, and in warehouses right now, you ain't seen nothing yet.

The trajectory of robotics is like the trajectory of smartphones. And I believe that it is poised to transition from luxury to accessibility.

So how is that going to play out?

We are looking into, how can we begin to embed actuators and sensors in the clothes that we wear so that effectively your vest, or your jacket, or your pants could double up as a robot?

All of a sudden, you might be moving much more quickly or lifting heavier things than you ever could have before. And then there's the medical field, where robots already have a foothold. But the most stunning advances may still be to come.

I like to imagine a future where we could have surgical procedures without incisions, without pain, without the risk for infection by using essentially mini robotic pills.

A peek into the future of robots, it's coming up on today's show.

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When Daniela Rus was growing up, she only ever saw two American television programs.

Now, this was the 1970s Romania and it was a period marked by the communist regime under Nicolae Ceausescu, and so access to western television shows was extremely limited and tightly controlled by state because the regime promoted content that aligned with socialist ideas and often restricted western media because it was perceived as capitalist propaganda.

Now, the programs that the regime did allow were kind of a strange mix.

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One of them was *Dallas,* which told the story of an oil-rich clan in Texas that featured a lot of family disagreements.

I believe that at the time the officials believed that this show would expose the perceived decadence and moral bankruptcy of the west, but instead it fueled aspirations for freedom and a better standard of living among Romanians.

But it was the other American program, a show called *Lost in Space,* that really caught Rus's attention.

Identify yourself.

Robot model B9. Designed and computerized as a mechanized electronic aid for Earth voyagers engaged in astral expeditions.

It was about the adventures of the Robinson family. And this show I believe served a form of imaginative escape from the hardship of everyday life. The show presented a universe of possibilities and discoveries that were so far removed from the constraints of the daily lives under a repressive government.

Why shouldn't I be in love? I am no different than anyone else. Do you think I am just an insensitive collection of computer-oriented nuts and bolts? I have a central turbo mechanism that feels just like any other robots. You have your family, everyone has someone, except me.

The show introduced me to robots as companions and protectors. And it also showed the potential of technology.

Though Rus didn't know it when she was growing up, real robots had begun to penetrate the public's consciousness. In the 1960s, Joseph Engelberger, a robotics pioneer, demonstrated the Unimate, a new industrial robot, basically a robotic arm, on *The Tonight Show* with Johnny Carson. The Unimate played golf on air, it poured a drink, it even conducted Carson's band.

Now what he's doing now is to program what he's going to have in the machine do. I think he's putting this information into the machine. Take it on the downbeat.

Rus says, angle burgers demonstration bridged science fiction and reality.

I think that his decision to showcase the Unimate on national television was both visionary and strategic. It demystified robots, it showcased practical applications, it widened the public's interest, and no doubt, it garnered support and established some form of leadership in the field.

It's a field that Rus would soon fall in love with, a field she's helping to shape today. She's now the director of MIT'S Computer Science and Artificial Intelligence Lab, CSAIL, and she's a co-author of the new book *The Heart and the Chip,* which looks at how robots are poised to change the world even more than they already have.

She argues that robots may follow the trajectory of smartphones, expensive playthings for the wealthy at first, but then as the technology comes down the cost curve, suddenly, they're everywhere. And to be sure, that is a movie we've seen before.

For instance, the first color printer was introduced in the 1980s and it costs about $500,000 at the time. And now, if you think about the fact that we basically have throwaway color printers, it's really extraordinary. But this is akin to the early days of smartphones, which were very interesting. The smartphones were big, they were very expensive, they were really considered luxury items.

And I believe that as robotics technology advances, this high cost will become lower, and lower, and lower and it will benefit from both advancements in hardware and advancements in software. Because over time, as our manufacturing processes improve and the economies of scale kick in, the cost of producing robots will decrease.

I see, OK.

And then we will couple this trend with competitive pressures and I believe that this will make robotics much more affordable and accessible to a broader audience. If you think about it, we already have robots that have gone through this cycle. Everyone who has a robotic vacuum cleaner in their home is already benefiting of this cycle.

And what I would like to see is a future where just as smartphones have become an integral part of life, robotic technology will blend seamlessly into various aspects of our lives, helping people with physical work.

Now, in our projects, we have imagined the idea of a 24-hour robot manufacturing, a special kind of store where anybody could walk in with a general idea of a physical task that they might want to do.

Maybe a robot to play chess with them, or a robot to play with their cat while they are at work. And equipped with this conceptual description of the task, the customer could explore the design space using an intuitive interface.

Once the general design is finalized by the customer, the store could then map that concept into physical designs, and then into a physical prototype, and then augmented with a simple programming interface. And so we're imagining this kind of process to take place very quickly. Hence, we call it the 24-hour robot manufacturing store.

One of the things that strikes me, another kind of similarity with smartphones, is that, so you talk about robots making us a super version of ourselves. And in some ways, smartphones have that ability-- I'm talking to you and I say, well, I don't remember who that actress was in that movie.

But I can immediately know, it can extend my brain to things I can't remember or never knew in the first place. In what way do you think robots may make us that kind of quote unquote "super" version of ourselves?

I like to think about intelligent machines that assist people with both physical and complex cognitive tasks. And this actually could center on this idea of a personalized robot that could adapt to individual needs and preferences.

So what could these systems do for us? Well, they could do personalized assistants, they could support us with daily tasks, maybe household chores, like folding laundry, or cleaning, or cooking.

But then they could also help with more personal tasks, like helping the elderly with mobility and providing cognitive stimulation. Also for individuals with disabilities, these kinds of robots could offer customized support. For example, in our research we have worked with Andrea Bocelli.

The opera singer, right?

Exactly, the opera singer. And he is visually impaired. So we worked with him to build a wearable version of a self-driving vehicle that he could carry in the form of a belt and a necklace.

And the system could help him understand the space he's moving in at a much higher level of detail and at a higher level of cognition than what he could get today with a white walking stick. And so that's one example of personal assistance.

But we could also get cognitive support. So machines can help us with scheduling, they can help us with our medication plans, they can offer companionship, they can provide support through interactive and empathetic communication, which we already are beginning to see through the use of ChatGPT.

We also imagine-- I also like to imagine robots helping us learn new things. And this can be done in multiple ways. You can imagine a cute robot that meets you at the dentist and asks, have you been flossing recently? Or you could imagine a cute robot that helps you with a French drills, or the multiplication tables. All of these are now possible given the state of our machines.

Do you think that there is a barrier we have to surmount? Because I think about the Roomba, the robotic vacuum cleaner, certainly we talked about robots being pervasive in factories, but a lot of those things don't feel-- maybe they are, but they don't feel particularly smart. They feel very repetitive and very focused.

And I remember talking to Rodney Brooks, a MIT, of course, roboticist a few years ago about. He was saying, I just think self-driving is so complex even though robotic cars are pretty darn good, but it's so complex when it comes to fitting into human legal systems and the way humans do things.

There's all sorts of weird stuff that happens on the roads. So it feels like that's a tricky-- when you talk about a robot helping you with cooking. That's complicated, that's tricky, right?

Well, it's tricky if you have the aspiration to get an Iron Chef that will do everything in the kitchen for you.

OK, OK.

But it's less tricky if you are OK with a robot doing some simpler tasks for you. About 10 years ago, we built a robot we called BakeBot. And this robot was able to make cookies. In fact, it really read a recipe written in natural language, it mapped that recipe into robot commands, it looked for ingredients, it mixed them in the right order, and then it found the oven and it baked the cookie. The cookies were not very elegant, but they were tasty.

OK, OK.

But that's a simpler task than a task that might involve chopping onions for instance. And so it's all a question of, how complex is the task you want the robot to do for you? In the case of autonomous driving, we can have autonomy in simple environments at low speeds any time.

And in fact, there are so many products already deployed. We have robots in hospitals that deliver medication, we have robots in ports that move huge containers in ports. And that actually is improving the efficiency of our supply chain systems.

We have robotic forklifts. There are so many mobile robots that can deliver successful operation, but the challenge or the secret is that these robots move fairly slowly in fairly simple environments.

OK.

Now, let's consider what happens on I-90 at rush time.

That's the Mass Pike if you're listening outside Massachusetts, like a big old-- yeah, a big old highway.

Or let's consider what happens in Cambridge or in downtown Boston. There is chaos. There are vehicles that follow the traffic rules, there are pedestrians and vehicles that do not follow traffic rules.

Exactly.

There is a lot of-- there are a lot of things moving fast on the road. And so in these cases, autonomous driving is challenging because it's not possible for the perception system of a robot car to comprehend the scene fast enough and issue a correct instruction to the car fast enough.

And today, even some of the best object recognition systems, which are used for perception, have an accuracy of about 90%. This means that 10% of the time, they're going to make errors.

Well, if you're in a safety-critical system, like a self-driving car, it is just impossible to rely on an autonomous system that is likely to make a mistake 10% of the time. On top of that, our sensors are not so good in rain, and in snow, general in inclement weather.

And so dealing with all the practicalities of complex human traffic in a crowded city is difficult. But if you're going to drive on an empty desert road and there won't be many cars around, the robot cars will do just fine.

I think it's tricky too because-- we started off by talking about*Lost In Space.* I think that a lot of people think or dream of these kind of humanoid robots. And dexterity is a really hard thing.

Like when you think about the job of a waiter at a restaurant, taking orders, clearing plates, putting plates down, figuring out when you're done, when you're not done, that is super complex. They're taking in all these signals all the time. It seems like dexterity would be a real challenge for a roboticist.

That's right. We just talked about mobility. And it's really extraordinary to see how far along we have come with mobility. But it's important to remember that the first autonomous vehicle was on highways in the 1980s.

Yeah.

That is a long time ago. The robotics community has been working to improve these solutions, the hardware evolved, we got the LiDAR system that was a game changer for a perception for mobile robots.

With manipulation, we're much further behind. In fact, today, it's easier to send a robot to Mars than it is to get that robot to clear your dining table after your meal. And this is because manipulation or thinking about autonomy in the presence of physical interactions remains challenging.

We do not have the right robotic manipulators, we do not have the right mechanisms. The mechanisms do not exert the range of forces and torques that is needed to have robust manipulation systems. We do not have good perception systems for these robots.

We also do not have the right body of learning, planning, and reasoning algorithms. We're making a lot of progress. And with the advent of soft robotics, we're seeing increasingly more robust and compliant systems, we're seeing systems where part of the solution comes from mechanical intelligence, part of the solution comes from perception-based reasoning.

We're beginning to see systems where language is becoming an important part of solving the intelligent manipulation problem. But we still have a long way to go in order to get that robust mechanism, that robust robot that can clear your dining table for you.

Yeah. So let's talk a little bit about what you see in terms of robotic advances, let's say, over the next 10 or 15 years that could really change our lives. One example you give is the power of exoskeletons.

And I think about this particularly in the context of, for many wealthy countries around the world, one of the biggest challenges they face is an aging population, where there aren't going to be as many young people and there are going to be many older people. So do you want to talk about the potential of exoskeletons? And you actually talk about this in the context of your dad building a deer-proof fence I think in his backyard.

That story is really heartwarming for me. My father loves to garden, but the deer and the rabbits love to go after the bounty in the garden. And for years, he took care of gardening by himself together with my mother and we benefited from the bounty.

But recently, my father has begun to have trouble with lifting heavy things and digging holes. And so we sometimes go and help out, and we help him install these fences to keep the deer and the rabbits away.

Now, I think my father would be very happy to have an exoskeleton. So this means a wearable-robot system that would give him superpowers in strength. In other words, that would allow him to lift heavier things than his muscles are able to do and move with greater precision than he can.

And interestingly, the field of robotics is making huge advancements in building these kinds of wearable-exoskeletons. In some cases, we have big exoskeletons that construction workers can use in order to move large construction pieces at the construction site.

So this is already out in the market somewhere?

so there are some products already in the market.

OK.

We also see exoskeletons that are built for people with disabilities. Conor Walsh at Harvard has been pioneering this technology. And his exoskeletons are much more flexible, much more easily wearable in the home or in a more human-centric environment than a construction site.

And in our group, we are looking into how can we begin to embed actuators and sensors in our clothes, in the clothes that we wear so that effectively your vest, or your jacket, or your pants could double up as a robot to help you run faster, or lift heavier things, or move with greater precision.

That seems very science fiction. Is that far off do you think, or?

Well, we don't have products yet, but we have a lot of interesting ideas and research-grade prototypes. And we're very excited about how this line of work will evolve.

So give me a sense of, when you do think about the next 5, 10, 15 years, what are the areas that you think will be most changed by how-- by the advent of new kinds of robotics that if we were to have this discussion again in a decade, we'd be like, yeah, that really moved the needle there?

Well, it is now possible to work with intelligent machines that integrate language, perception, and action to reason in more cognitive and conceptual ways about the world. And this represents a significant leap forward in the fields of artificial intelligence and robotics. I imagine that there will be a lot of different ways in which robots will be seen as assistive tools for people.

So doing physical tasks maybe right next to you, also potentially organizing things right next to you, right?

Exactly. Doing physical tasks. But these robots will also be valuable outside the home. The robots will also be super valuable in advancing various industry sectors. And so for instance, in health, I think that robots will have a significant impact. We already have surgical robots that perform operations with great precision.

I like to imagine a future where we could have surgical procedures without incisions, without pain, without the risk for infection by using essentially mini robotic pills that could be ingested by the patient and then guided inside the body of the patient using an fMRI-style approach.

And with this new technology, just imagine the kinds of things that we could do without pain, without incisions, without risk for infection. I'm very, very excited about health care applications.

You tell a great story, that when I read it, it made total sense so I hadn't thought about it, that these button batteries that are these little tiny batteries that are in lots of electronic equipment now.

Increasingly little kids, not surprisingly, see these batteries around, they kind of look like candy or something, and they eat them. And they have to be gotten out immediately. And you talk about the possibility of robotics being used because you're talking about a very small patient, as you say, you don't really want to make incisions, but they have this thing in them that has to come out.

Exactly. So that is a real problem. I was not so sure how dangerous button batteries were.

Yeah.

And then one day my students brought a piece of meat in the lab, a steak, and they put a button battery on the steak. And within an hour, the button battery was completely immersed in the steak, and then I realized how dangerous these button batteries are.

Because when you ingest a button battery, within an hour that battery gets, in some sense, locked inside the tissue of the stomach, the only way to get it out is through surgical procedure. And that's what happens now.

But with our idea of the mini origami surgeon, we imagine the child swallowing a pill-sized robot that could be guided with precision using a magnetic field. And so you could drive this robotic pill to the location of the battery, and then using a magnet embedded in the robotic pill, you could extract-- you could extract the battery and then you could guide it out of the system through the digestive system.

And so now you can imagine that a procedure that requires hospitalization could be an assured procedure, where within a matter of minutes, the battery is dislodged and the child can go home without the need to recover from incisions and without pain, and without the risk of infection.

So as you mentioned, there obviously are surgical robots that exist, nothing like this. When you talk about that vision of a kid swallows the battery, you got to get it out, and maybe you could have, as you say, a pill-sized robot, does that feel like it's super far away? Do you think that's feasible soon? What's your sense of the timeline?

Well, Kara, we already built some of these robots in the lab and we demonstrated that they can be controlled in the way we imagine using a stomach model. So we created a silicone stomach and we showed that, in fact, our vision, our idea is feasible.

At this point, in order to go to the next step and build something that has the potential to be deployable and used in real clinical procedures we actually have to do a lot of work in vivo tests.

And we are talking about trying some in vivo tests using pigs because the size of the stomachs of pigs is comparable to the size of the stomachs of people. And if we were to be successful in that scenario, then we would have to do clinical trials with people. And so there is a way to go to develop human-safe technology.

But I will tell you that the mini origami surgeon, or the mini surgeon, as we call it, is actually made out of food. The robot itself is made out of sausage casing. So when you swallow it, it's actually safe, it's not toxic to the body.

Let me jump over for a second to the question of AI. And I just wonder. In the last year or two, we've seen such a ramp up in compute power. What has that meant for roboticists?

Kara, you should think of a robot as a physical mechanism that has a body and a brain.

OK.

How you design the body, what that body is capable of doing essentially defines the set of tasks that the robot can do. For instance, if you create a robot with wheels, that robot will not be able to go up stairs. If you want a robot to go up stairs, you need a different design.

So there is an important connection between the morphology of the robot and the tasks that it can do. But that robot will not do anything unless there is a brain that can guide the robot to do what it's meant to do.

So artificial intelligence is really about creating the brain of the machine and about guiding the machine to reason and to move autonomously in the world. In the last year, we have seen tremendous advances on transformer-based applications using foundational models. And this is absolutely extraordinary.

But these new methods for reasoning about data are not readily deployable on robots for a number of reasons. First of all, foundational models require a lot of compute and a lot of space. And that simply does not exist, or it's not possible to configure, in the body of a small robot. So imagine a drone.

Yeah.

Now, that drone has a small computer on it. You cannot run large language models, or diffusion models, or even predictive machine learning on the kind of computers we carry on drones.

And so in our lab, we are very interested in thinking about new machine learning models that actually work with edge devices, like robots. And we're making great advances. But the existing architectures are not ready for these platforms. So that's one reason.

Another reason is that, right now, it's quite difficult to explain how machine learning solutions reach their decisions. We also know that, in many cases, foundational models hallucinate.

And for a safety-critical system, we actually need some guarantees that if there is a machine learning model guiding that system, the guidance will be within a safe region of operation. So we need to do something extra, we need something beyond what today's machine learning systems are capable of. And we're working on these things.

The third thing is that robots move in the physical world and the physical world has constraints and it's governed by common sense reasoning. If I ask you to bring me a glass of water, you know very well how to pour water in the glass and you know that you have to carry that container in a certain way because otherwise the water would spill.

But the current AI models do not have this level of common sense reasoning. They also do not have encapsulated in them the physics of the world. And so in order to use these solutions with robots, we need to do additional computation that actually carries through it the laws of physics and the rules of behavior in the physical world.

Two final question for you. One is, I think you said to most people like, to what degree are robots a part of your daily life? They would say, not very much, maybe they have a Roomba. But I just wonder if you can take us behind the scenes.

So obviously lots of people get Amazon packages. And I know Amazon has been pretty aggressive in the last several years about buying up robotics companies. To what degree are robots actually in our lives, even if we don't see that?

We have a lot of robots in our lives. So we have tens of millions of robots in factories, we also have delivery robots in hospitals, we have vacuum cleaners in homes, but we also have many other types of robots.

And so for instance, robots, and especially drones, are now used in conservation efforts to monitor wildlife population, to track endangered species, and even to map habitats. We also have agricultural robots that plant seeds, that help with weeding, and harvesting.

We also have robots used in scientific research and exploration. We have robots that are exploring the depths of the oceans. We have robots that are exploring shipwrecks, and that are monitoring the coral reef life. We also have robots in the laboratory that automate tasks, like analyzing samples or pipetting.

Yeah.

We have robots used in clothing manufacturing. Name an industry sector and I assure you that there are some simple routine tasks in that sector that are, today, supported by robots. And if they're not supported by robots yet, they should be.

A final question for you. I was wondering what the biggest obstacle is in the field of robotics? And one of the things-- you can answer-- this can-- what I'm going to offer it you may not be it. But I kind of wonder.

I know in the last few years we've put so much emphasis on computer science, not wrongly, and learning to code that I wonder if you feel like, has robotics got the spotlight and the people that it deserves and that it needs to keep pushing these advances forward?

Well, Kara, we have a lot of talented people. And we hope that even more young people will join us to solve some of these extraordinary, and exciting, and imaginative problems.

I guess one concern may be that the field of robotics is actually a very multidisciplinary field. You need to know computer science, but you also need to know something about materials, something about mechanical engineering, something about electrical engineering, something about mathematics.

And so this interdisciplinary nature of the field is challenging and it really requires a broader set of skills. We also see that there is a booming demand for robotics skills across many industries.

And this demand is driving educational institutions and companies to invest in robotics, but this is also attracting a lot of the young graduates to companies rather than to PhD programs.

There are a lot of initiatives aimed at bringing visibility to the field. In my mind, those of us who know how to code and who know how to make things have superpowers because we can make real anything we imagine. And who wouldn't want to do this?

Daniela Rus is a professor of electrical engineering and computer science. She's the director of the Computer Science and Artificial Intelligence Lab, CSAIL, at MIT. She is also the author of the new book *The Heart and the Chip* with Gregory Mone. Daniela, thank you so much. This is really fun.

Thank you, Kara.

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