"NATURAL BORN ROBOTS" -
SHOW 1002

EPISODE OPEN

ALAN ALDA: Kismet here is very happy to be joining a whole lot of other robots whose design is inspired by living things.

ALAN ALDA (Narration): Cockroaches inspire mostly loathing and fear -- unless you're trying to build a walking machine. And if you want a robot swimmer...

ALAN ALDA: I've taken its brain out.

ALAN ALDA (Narration): What better model than a tuna? But for robots to be like us...

ALAN ALDA: Excuse me, I'm talking to him.

ALAN ALDA (Narration): They have to pass the slinky test...

ALAN ALDA: I'm getting it now.

ALAN ALDA (Narration): As well as play a world class game of soccer.

ALAN ALDA: I'm Alan Alda. Join Kismet and me as Scientific American Frontiers ventures out to meet a whole new generation of Natural Born Robots.

back to top

ROBOROACH

ALAN ALDA (Narration): There was a time when people thought that if you wanted to fly, you should do what birds do -- get yourself a pair of wings, and flap...

ALAN ALDA: A lot of people got hurt that way. So engineers have mostly gone their own way in making machines, using materials and motors that substitute brute strength and raw power for the delicate finesse that nature uses. But if engineers have so far done just fine ignoring nature, suddenly imitating nature has become a very desirable thing to do, certainly among those trying to build the next generation of robots. The reason is that when it comes to solving the really tricky design problems, nature has a head start of three and a half billion years...

ALAN ALDA (Narration): I'm in Cleveland, at Case Western Reserve University, about to meet some creatures that may not have been around since life began -- but have been here way too long for me: 300 million years, in fact, give or take a million or two.

ALAN ALDA: Oh my God!

ROY RITZMANN: You gotta get in close.

ALAN ALDA: Wait a minute. Oh, jeez, put it back, put the lid on. Oh, I backed into something. They're all over the place.

ROY RITZMANN: This is Blaberus gigantius.

ALAN ALDA: Ah!!

ALAN ALDA (Narration): Confirming my opinion of cockroaches in general, this one immediately sets about clawing the hand that feeds him.

ALAN ALDA: I tell you what, he and I would both feel better if you put him back...

ROY RITZMANN: You want to pet him?

ALAN ALDA: Do I want to pet him? No. Put him back and you'll make us both happier. Look, you can't get rid of him.

ROY RITZMANN: Well, they have very efficient claws, that they engage, just like cat's claws.

ALAN ALDA: While we discuss this, could you put the lid back on? Well, you look really happy to be in your element here. Why are you studying cockroaches like this?

ROY RITZMANN: Cockroaches are incredibly good locomotory animals. They run, they jump, they turn…

ALAN ALDA: I've noticed that!

ROY RITZMANN: And if we can get a robot to walk half as well as a cockroach, we'll have the best robot in the world.

ALAN ALDA (Narration): Roy Ritzmann once studied cockroaches simply out of his misplaced admiration...

ROY RITZMANN: Roger Quinn.

ALAN ALDA: Hi Roger.

ROGER QUINN: Hello Mr. Alda.

ALAN ALDA (Narration): But for the last three years he's been working with engineer Roger Quinn to make a giant roach robot.

ROGER QUINN: You see that it's very much like a cockroach.

ALAN ALDA: So what, do you put out a giant crumb of coffee cake it and moves, or what?

ROGER QUINN: I wish it was that simple.

ALAN ALDA: Oh look, what's happening? If you wanted to make something that was just like a cockroach, you succeeded. You scared me just as much as the real cockroach did.

ROGER QUINN: Well at least it doesn't bite yet.

ALAN ALDA (Narration): Powered by compressed air, the robot is as perfect a scaled-up imitation as Roy and Roger can devise of a cockroach called Blaberus. Back in Roy's lab, I keep my distance as a Blaberus is anesthetized with carbon dioxide.

ALAN ALDA: Boy, that's fast. So I take it to the extent that he's capable of feeling anything, he's not feeling anything right now.

RESEARCHER: Right, he's completely out.

ALAN ALDA (Narration): When it wakes up, this Blaberus, like hundreds before it, will be going for a run on a cockroach treadmill. Silver dots on the roach equivalent of hips, knees, and feet will help keep track of exactly how its legs move. And wires finer than a human hair will record from muscles in its legs just when and how strongly they contract. With a little encouragement, the cockroach puts on a fine display of speed. Scaled up 25 times to the size of the robot, this would be like running at 30 miles an hour! A video camera records the run. By tracking the white dots from frame to frame, Roy has plotted the exact position of each leg and the exact angle of each of its joints as it walks, runs and climbs.

ROY RITZMANN: And so every one of the joint angles that the robot uses to do this kind of walking and climbing has been matched to what we got out of the cockroach. So we measured them, they scaled it up and made the cockroach so that the joint angles are the same.

ALAN ALDA (Narration): The robot's front legs, for example, can move through the same range of motions as the roach's front legs. But just knowing how the legs move isn't nearly enough. The trickier question is how they're controlled. That's where the wire electrodes come in, picking up the electrical signals the cockroach gives to tell the muscles when and how much to contract.

ALAN ALDA: It changes from motion to motion, depending on where he's going, what he's doing, it changes when he gives that signal?

ROY RITZMANN: That's right. He's going to give a little bit more juice here, a little bit less there, so that he'll be able to get over things or else turn and stuff like that.

ALAN ALDA: So you really need to know that to get a robot to be as efficient and as agile as one of these insects.

ROY RITZMANN: Exactly, exactly.

ALAN ALDA (Narration): The team especially wants the robot to be as agile as the roach in climbing over things. So they copied the way the cockroach uses each of its three pairs of legs differently to get itself up and over an obstacle.

ROGER QUINN: For climbing, the front legs can come way up here and grab on to something. But they're not so strong, so it would be better to actually pitch the body up with the middle legs...

ALAN ALDA: And that lifts the body up?

ROGER QUINN: And then push and the whole body can pitch up like this. Now it's in the right place for the big old rear legs to give a mighty shove that way and drive the robot right over the obstacle.

ALAN ALDA (Narration): The Case Western Reserve robot is far from the first to borrow from insects the idea of having six legs. Over the last 20 years, robots small -- and large -- have exploited the fact that six legs enable you always to keep three on the ground and so avoid falling over. But none of these robots has come even close to being as agile as an insect, because their legs don't move like an insect's. The legs of the roach robot, its makers hope, one day will.

ALAN ALDA: What do you see this doing when it can crawl and climb and maneuver really well?

ROGER QUINN: This is still a research vehicle. But we can see vehicles later taking what we learn about how to do this locomotion and for example going to Mars. An unmanned Mars mission would be fantastic, you could climb up mountains and go places that wheeled vehicles just can't really hope to accomplish.

ALAN ALDA: It could climb into craters here on earth too, couldn't it, like some volcanic...

ROY RITZMANN: Or going into jungle terrain to find land mines. The people that put them out there are, they don't want you to find them so they don't put them on flat surfaces and things like that, they put them in rough terrain where wheeled vehicles have a hard time going. Cockroaches would have no problem and presumably this thing would not have much of a problem if it walked like a cockroach.

ALAN ALDA: It's great, nature works all these years to make a cockroach that we don't like, and we work to make a cockroach that we can really use. That's wonderful.

ALAN ALDA (Narration): But while I was there, the roach robot barely managed to lurch to its feet and look belligerent -- as if taunting Roy and Roger with the difficulty of the task they've set for themselves. For now at least, real roaches are preserving their 300-million-year lead.

back to top

SWIM LIKE A FISH

ALAN ALDA (Narration): Another creature robot builders admire and envy is the tuna. Like the cockroach, it's been honed by hundreds of millions of years of evolution to complete mastery over its environment. And again like the cockroach, it too now has a mechanical rival.

ALAN ALDA: Now why did you pick a tuna to study here?

MICHAEL TRIANTAFYLLOU: The tuna is the champion of swimmers.

ALAN ALDA: In what way? MICHAEL TRIANTAFYLLOU: In the sense that they are very poor at capturing prey so they have to go big distances...

ALAN ALDA: So they have to go very far. And they have to be fast? MICHAEL TRIANTAFYLLOU: And they have to be fast so they can cover big distances and encounter things. And they have to swim all the time.

ALAN ALDA (Narration): This robot tuna swimming languidly down the tow tank at MIT is helping Michael Triantafyllou and his students understand just why tuna are such champion swimmers. A fluorescent dye reveals its secret -- circles of water -- vortices -- flipped by its tail into its wake.

ALAN ALDA: OK, so I see these great circles come off of it. These are the vortices?

MICHAEL TRIANTAFYLLOU: These are the vortices, the circles that you see spinning, one on one side, one on the other side.

ALAN ALDA (Narration): These vortices, the MIT group discovered, act together to propel a swimming fish through the water. The vortices are created as water drags along the side of the moving fish. What makes them so potent is the flapping tail, which flips each vortex off to the opposite side. Their spinning now combines to push a stream of water away from the fish -- making it, in effect, jet-propelled. This insight -- gained from studying live fish as well as the robot tuna -- is helping design of a new generation of swimming machines.

ALAN ALDA: This is a pike you've got here?

JOHN KUMPH: Yeah, it's a robopike. Which is based on a small pike, which is a freshwater predator, and they turn and swim and like start really well 'cos they hide in the mud and they come out and grab the little fish.

ALAN ALDA: This fish is more agile than other fish?

JOHN KUMPH: Yeah, it's incredibly agile. They've put accelerometers on these things and they've measured acceleration rates that are just absurd, like 24 Gs.

ALAN ALDA (Narration): John Kumph's robopike has an external skeleton of plastic ribs, housing three motors that bend and flex its body. It's controlled by a computer in its head.

JOHN KUMPH: Let's give it a try.

ALAN ALDA (Narration): The head is also the only part of the robot that needs to be waterproof. John has experimented with several different skins for the body -- and this one is brand new.

ALAN ALDA: Have you ever made this swim with this skin? This is going to be the first time?

JOHN KUMPH: The very first.

ALAN ALDA: Good luck.

ALAN ALDA (Narration): After an uneasy moment...

ALAN ALDA: OK, you're getting rid of the air now?

JOHN KUMPH: Yeah, 'cos the back half is flooded.

ALAN ALDA: And this wire on here...

JOHN KUMPH: There we go.

ALAN ALDA: Oh look, it's right side up. This wire just supplies power, you're not controlling the fish's movement with this, right?

JOHN KUMPH: Exactly. I think that's working. Let's give this a try and see if it's still swimming.

ALAN ALDA (Narration): One thing I'm learning about robot researchers is that their creations are never actually finished.

ALAN ALDA: Ah, here, it's wiggling.

JOHN KUMPH: Ah, it's wiggling, uh?

ALAN ALDA (Narration): Their robots are always being taken apart, tweaked here and there, then they're put back together to see if they're improved. What all this means is that visitors like me often turn up at just the wrong moment...

JOHN KUMPH: I'm a bit worried there's a leak in the nose cone. See those big air bubbles coming from there? I'm going to take it out in a second. See how heavy it is?

ALAN ALDA (Narration): So a sinking robot pike joins the stubborn robot roach in demonstrating just how hard it is to copy Mother Nature. Though in this case the problem's straightforward -- a leaky head gasket.

JOHN KUMPH: There's the water coming out of the computer.

ALAN ALDA (Narration): A brain drain and a slow bake in a low temperature oven are all it takes for the robopike to swim again. But it's clear that it will need many more upgrades before it can compete with its role model. Meanwhile, another mechanical fish has already made it out of its hatchery. This robot tuna was built by a team headed by Jamie Anderson.

ALAN ALDA: Ah, you got the tail off, huh? That's what it looks like underneath?

JAMIE ANDERSON: That's what's powering the fish. Four hydraulic cylinders, one activating each link.

ALAN ALDA: So what, it bends right there?

JAMIE ANDERSON: Yeah, you can see the four pivots. There's one here, we call it the hip, the most powerful joint. And there's one right here. It's kind of stiff right now 'cos it's full of hydraulic fluid. There's one here. And then this one on the end...

ALAN ALDA: Right on the very end.

JAMIE ANDERSON: ...where the caudal fin hooks on.

ALAN ALDA: These flippers down here don't look biological to me.

JAMIE ANDERSON: No, those are conventional engineering style control surfaces. This is the same type of surface you'd have on an underwater vehicle like a submarine or torpedo. We designed these to break away so if the fish actually hit a wall or a rock or something it would not damage the pressure hull.

ALAN ALDA: What are they doing here?

JAMIE ANDERSON: Right now we're pulling on the neoprene skin. You see this joint ring here will engage the back of the pressure hull. That is screwed on in a number of places. And then we secure this flap of skin down so it has a very smooth hydrodynamic watertight surface.

ALAN ALDA (Narration): The robotuna is about to go swimming in the test tank of the University of New Hampshire. But it was built by Jamie and her colleagues at the Draper Lab in Cambridge Massachusetts.

ALAN ALDA: What's this cable here?

DIVER: That's an umbilical that enables us to update the program that runs inside the fish, tell sit what to do and where to go.

ALAN ALDA: So you're sending data from the computer through this now?

DIVER: Correct. We're downloading a mission script that tells the fish where to swim and how fast to swim.

ALAN ALDA: Is it okay if I unplug this now?

DIVER: Sure.

ALAN ALDA: What do I do?

DIVER: Pull straight up.

ALAN ALDA: Straight up.

DIVER: There you go.

ALAN ALDA: Taken its brain out.

ALAN ALDA (Narration): Apart from its brain, the robotuna is self-sufficient. The pressure hull that's the front two-thirds of its body houses batteries and motors to activate the hydraulic links that flap its tail. Its speed right now is limited to one body length per second -- about half that of a cruising tuna, and only a fraction of the speed of a tuna going flat out. But swimming with it, it's hard to believe it isn't alive.

ALAN ALDA: You know, when I swam with seals in the Galapagos, it was a little different because they played with me. But this guy swam as if he had a mind of his own and he was just in the water, swimming. I mean it was like that's what he does...

DIVER: That's what he does.

ALAN ALDA: And if you change what's in his brain, he does something else.

DIVER: Exactly.

ALAN ALDA: What are you going to put in his brain now?

DIVER: We'll have him swim straight down to the length of the pool and then take a hard right at the end.

ALAN ALDA: OK, you want to put the cable in?

DIVER: Yeah.

ALAN ALDA: I think I knocked off his flipper again.

DIVER: We'll fix that.

ALAN ALDA (Narration): What makes a robot fish attractive as an unmanned underwater vehicle is that in principle it is much more efficient than a conventional submarine. The invisible vortices streaming of its tail push it along without all the wasteful churning of a propeller. And it can turn on a dime.

JAMIE ANDERSON: What the tuna will do for you is it will give you increased maneuverability, you'll be able to go into places you wouldn't normally fit -- say you want to swim up a pipe, to check the sewage out-fall, or go into waves, into a harbor. This enables you to go potentially further, faster and be more maneuverable when you get there.

ALAN ALDA: If you want I suppose one day you could make a tuna that would hook up with a school of tuna and find out how they operate all around the world.

JAMIE ANDERSON: That is a wonderful mission. As a matter of fact, there is very little known about tunas. Because they swim for a living, it's hard to keep up with them, so scientists would love to have an imposter in the school to keep track of their movements.

ALAN ALDA: We've got to come back and do a story about that...

JAMIE ANDERSON: I hope we get to that point.

ALAN ALDA: It would be really fun to see how they accept it. Maybe they'd kind of like it, you know, a special tuna -- "Look, he's already in the can!"

back to top

BODY BUILDERS

ALAN ALDA (Narration): Robots, to most people, mean machines based not on insects or fish, but us. The robot recently unveiled by Honda certainly qualifies. Modeled on how people move, it wowed the world of robotics with its superb engineering. But right now it's an elaborate puppet, its every motion controlled by an operator behind the scenes, or programmed in advance. Change the width of these stairs, for instance, and the robot would be in trouble. To really walk as a human walks means you have to really understand how people do it -- and that's the reason for this machine, strutting its stuff around a basement laboratory at MIT.

ALAN ALDA: Is it helped to stand erect in any way by this bar?

JERRY PRATT: The boom keeps it so it can't go side to side. It only -- oops.

ALAN ALDA: Uh, it seems to have taken a dive.

JERRY PRATT: Yeah.

ALAN ALDA: What happened?

JERRY PRATT: One of the motors gave out. I'm having a problem with one motor, I have to fix it...

ALAN ALDA (Narration): I'm beginning to wonder if I'm some sort of robot jinx, but happily Jerry Pratt is unfazed.

JERRY PRATT: It's usually pretty reliable. Probably walked about ten miles since I built it.

ALAN ALDA: You're imitating a human gait, but you don't have human materials here, you don't have any muscle or...

JERRY PRATT: The materials we have to work with are a lot different than biological materials, but we still can get a lot of the flavors of controlling the motion.

ALAN ALDA (Narration): The robot gets a natural spring to its step not from muscles and tendons but from actual springs built in to its motors.

ALAN ALDA: Do you keep having to go back to studying legs and feet and stuff every time you run into a problem to see how nature solves it?

JERRY PRATT: Yeah, we watch a lot of video, watch a lot of people walking on treadmills and animals. And it's just, almost frustrating how good they are at walking.

ALAN ALDA: But you've been watching people walking for all the years of your life.

JERRY PRATT: Well, I've been walking for all but two years of my life, and I don't know how I do it.

ALAN ALDA (Narration): For instance, there's the little matter of kneecaps.

JERRY PRATT: One nice thing that we found by looking at nature is kneecaps. What are they good for? One way to look at it is, if you don't have a kneecap, your leg is in a kind of buckling configuration. It wants to buckle in one direction or the other, and to control that is rather difficult, because if it's a little bit that way, you've got to push it that way. If it's a little bit that way, you push it that way, and it will start chattering, what we call chattering. If you have a kneecap, you can simply push it until you hit the kneecap, and that's it.

ALAN ALDA (Narration): But Jerry Pratt has a bigger goal than simply making a robot walk like a person.

JERRY PRATT: Say you have a person who has a spinal cord injury, and they can't control their legs anymore. If you have to control their legs for them, you have to know what...

ALAN ALDA: You have to do it in a way that would work best...

JERRY PRATT: So the more you understand what walking is all about, the more you can build these devices.

ALAN ALDA: That's very interesting. I hear that over and over again, that as we look at nature and make machines that copy nature, we understand nature better. It's funny, because you'd think you'd have to understand it an awful lot to be able to make the machine, and yet making the machine actually gives you a deeper look at nature, doesn't it?

JERRY PRATT: Yup, it's a two-way street.

ALAN ALDA (Narration): Banging its own drum is a robot that's being built specifically to explore that two-way street between nature and machines.

RODNEY BROOKS: Alan, if you get hold of this, you'll be able to feel...

ALAN ALDA (Narration): We first visited Rodney Brooks and his creation COG at MIT six years ago. Back then Rod was unusual in taking a biological approach to robot design -- and widely regarded as arrogantly ambitious in choosing to model not an insect or a fish, but a human being.

RODNEY BROOKS: By being a human shape and having the same arrangement of eyes, etc., it will encourage people to interact with it as though it was human, and it will have the same sort of experiences that a human has when a human develops.

ALAN ALDA: Last time I was here... ha, excuse me, I'm talking to him... last time I was here, he could do some basic things. I was wondering, what can he do now that's different?

BRIAN SCASSELLATI: We do a lot of different things right now. Partly we've built on the skills that we acquired earlier, but what we've also moved into is some more manipulative tasks, doing things with the two arms that we have now, and also some more social tasks, of more interaction with people.

ALAN ALDA: What's it interested in doing? I mean, here it's looking at my hands. What is it planning to do about that?

BRIAN SCASSELLATI: Well, right now it doesn't plan to do much other that pay attention to what's happening. So the robot attends to certain things like movement, faces, quickly moving objects, brightly colored objects.

ALAN ALDA: That tilt of the head and the eyes really focusing in does give you the impression that it's paying attention to you.

ALAN ALDA (Narration): In 1994, COG had only one arm -- and that was still attached to the laboratory bench. Two years later, arm in place, COG was learning to reach. This time, COG has both his arms -- and has, apparently, become a very bad drummer. Now I confess to being baffled as to what Matt Williamson is trying to prove here. I think the idea is for COG to pick up Matt's rhythm, but the opposite seems to be happening.

ALAN ALDA: Yeah, it sounds to me like you're starting one rhythm and then you're synchronizing with its rhythm, and it's not changing its rhythm. It's a lot smarter than we are, I see what you mean!

ALAN ALDA (Narration): So I have a try. What's supposed to be happening is that COG should be synchronizing the drumbeats by listening to both my beats and its own. But I don't hear it. What's more, I don't quite get the point.

ALAN ALDA: Can you tell me what you're doing here that's different from other robots?

MATT WILLIAMSON: The difference is having the feedback loop that appears on the surface to be completely irrelevant!

ALAN ALDA: What is it at a much deeper level?

ALAN ALDA (Narration): Matt, a very patient young man, sets up COG so that its left hand doesn't know what its right hand's doing, except by listening to it.

ALAN ALDA: Make it not listen, OK? OK, sometimes it's in phase and sometimes it's not.

ALAN ALDA (Narration): Matt now switches on COG's ears.

MATT WILLIAMSON: It's listening now.

ALAN ALDA: Yeah, it took about three or four beats to find itself.

MATT WILLIAMSON: Yeah, that's 'cos it's listening to both sounds.

ALAN ALDA (Narration): I think I'm getting it. The trick is to stop thinking of COG as a conventional robot. If it were, you'd simply program the two arms to hit together. But then you'd miss the fact that the right drumstick is free to bounce, and so it isn't completely predictable.

MATT WILLIAMSON: Exactly. That is exactly the point.

ALAN ALDA: OK, now I get it. OK, this is good. You see, you couldn't get a machine to understand this way.

ALAN ALDA (Narration): Matt promises that COG's next party trick will demonstrate the point more obviously.

MATT WILLIAMSON: We've got the two arms and they're moving completely independently. Each joint is moving up and down independently.

ALAN ALDA: Yeah, I don't see any particular pattern in the way they're moving.

MATT WILLIAMSON: What we can do is we can, if we connect the two arms through the slinky, they are now coupled through this mechanical coupling of the slinky itself, right?

ALAN ALDA: Now, they're really doing it the way a little kid would to make them go back and forth. And it found that rhythm pretty quickly, in just a couple of gestures, a couple of cycles.

MATT WILLIAMSON: So what's happening is that as the weight of the slinky goes from arm to arm, the control of the joint is sensing that weight and adjusting how it moves to produce this motion.

ALAN ALDA: So the signal that it's looking for is the full weight of the slinky. It knows it's going to work with a slinky, right?

MATT WILLIAMSON: Um....

ALAN ALDA: Or does it?

MATT WILLIAMSON: I don't like saying it knows it's working with a slinky....

ALAN ALDA: Right, fine, it's not a person to that extent yet, but its looking for a signal that is the weight of the slinky. When it gets that signal, it's programmed to toss it back the other way.

MATT WILLIAMSON: Exactly, exactly. The only motion the two arms are kind of happy in is ones where they're moving in this sort of out of phase motion.

ALAN ALDA: Kind of happy, huh? You're talking as if it's alive.

MATT WILLIAMSON: Well... I know.

ALAN ALDA: It's hard not to.

ALAN ALDA (Narration): Now, just when COG is kind of happy with its pink plastic slinky, Matt switches it for a heavier metal one.

MATT WILLIAMSON: There we go.

ALAN ALDA: It found it. It found it in, like, two tries. And look, the rhythm is completely different now. It's vroom, vroom... vroom, vroom. It's a very different rhythm. And it's not programmed -- I'm getting it now -- it's not programmed to have a certain rhythm depending on what weight you put on, it finds the weight of the slinky because it just responds to whatever you do to it.

MATT WILLIAMSON: Exactly.

ALAN ALDA: It's responding to the world outside and adjusting itself to that world. That's really interesting. That really is more like the way people work than the way a lot of robots work.

MATT WILLIAMSON: I think so. I hope so.

ALAN ALDA (Narration): But for COG's creator, there's at least one major skill people have that COG still doesn't.

RODNEY BROOKS: I wish we had the system being able to understand objects better than it can. It doesn't understand objects.

ALAN ALDA: Meaning what?

RODNEY BROOKS: It's sitting in a sea of movement, and faces it understands but it doesn't understand that this is a slinky and that this is a slinky, and they look different but they're really the same sort of thing. It can tell that when you attach them but it can't look at them and figure that out for itself.

ALAN ALDA: What would that enable you to do when you get that hurdle cleared?

RODNEY BROOKS: That will enable COG to generalize from previous acts and future acts. And that generalization is a key to the further development of a child.

ALAN ALDA (Narration): Since COG was born, its major inspiration has been the way a child explores its world. But children have to master social as well as physical skills. Can robots learn to be social? Stay tuned.

back to top

ROBOTS HAVE FEELINGS, TOO

ALAN ALDA (Narration): Roving among fossil dinosaurs in Pittsburgh is a robot that may not look very human, but is programmed to act like one.

ALAN ALDA: OK, here you go.

SAGE: Hello, and welcome to Dinosaur Hall at the Carnegie Museum of Natural History. I'm SAGE, the world's first Self Aware Guided Electro-educator -- sort of like Socrates, Aristotle, Galileo and Einstein all rolled into one. With wheels! But you didn't come here to learn about me, did you? You came here to find out about dinosaurs.

ALAN ALDA: I actually came here to learn about you.

ALAN ALDA (Narration):

SAGE is a robot with attitude. Stand in its way too many times, and it can get a little testy.

SAGE: Excuse me. I'm giving a tour right now.

ILLAH NOURBAKHSH: It has a lot of different emotions. So it has frustration, loneliness, confusion, happiness; and you can think of each of these as a little bar, a little meter, that goes up and down. And gradually over the course of the day, depending on how people interact with it, each of these will go up and down slowly.

ALAN ALDA: You mean if it gets too many bad interactions earlier in the day, it's crankier at the end of the day than it was at the beginning of the day?

ILLAH NOURBAKHSH: Yeah. Now, it wears off...

ALAN ALDA: Why? What's the advantage of having a robot? I can hire people to do that…

ILLAH NOURBAKHSH: Just like a human being...

ALAN ALDA: That's what I get most of the time when I go into a store on a bad day!

ILLAH NOURBAKHSH: Exactly. And the reason we want the robot to act that way is because people respect it more. So if a robot acts like a machine, you keep playing with it, you get in front of it and you don't care if it doesn't go right, you just stand there and say, "I'm smarter than you, ha, ha, ha." But when it actually responds and emotes, then people actually pay attention. And they go, "Oh, excuse me, you're giving a tour, I'm sorry." So the reason we take inspiration from the way humans behave emotionally is because it makes it do a better job of interacting with humans.

ALAN ALDA (Narration): Just the fact thatSAGE moves and talks already makes it a magnet for children.

ALAN ALDA: The kids love following it, don't they?

ILLAH NOURBAKHSH: Yeah, they attribute life to it because it moves.

SAGE: I'm going to wait till you move. I'm a robot. I'm more patient than you.

ALAN ALDA: He's so happy to be able to stop the robot.

ALAN ALDA (Narration): At the end of each day's work as a tour guide, SAGE e-mails Illah with an account of how things went.

ILLAH NOURBAKHSH: It says, "I gave 15 tours today, Illah, and my happiness level is at 95%, my frustration's at 5%, and I'm a little lonely."

ALAN ALDA: A little lonely! How do you use that information?

ILLAH NOURBAKHSH: We play with the way it behaves with people. So we actually play with its affection, the way it interacts with people. We'll change how frustrated it makes itself sound. We'll change how noisy it is when it's lonely.

ALAN ALDA: Then you check to see if further interaction with people makes a happier machine.

ILLAH NOURBAKHSH: Exactly.

ALAN ALDA: And do you want a happier machine?

ILLAH NOURBAKHSH: We love happy machines. Because the way it gets happy is with good interactions with humans.

ALAN ALDA: (Narration) Illah foresees robots you can relate to not just in museums, but throughout society. And he's not alone.

ALAN ALDA: You know, when you first walked in, I thought you were holding a real baby. There was something about the way you were holding it.

ALAN ALDA (Narration): Helen Greiner's baby is actually a robot called Bit.

HELEN GREINER: Like a baby, if you don't treat it well, it will start to get cranky. But if you play with it, and if you nurture it, it will remain happy and responsive and gurgle and coo and act like a real kid.

ALAN ALDA: Oh, it's unhappy.

ALAN ALDA (Narration): Bit's slightly spooky realism is another attempt to make robots less like machines and more like us.

HELEN GREINER: The idea is that as robots become more ubiquitous, they need to act more and more like things we think of as alive, so we know how to interact with them automatically basically. If you give this to someone, they'll start treating it like a real baby.

ALAN ALDA (Narration): Well, we'll see.... Bit Burp.

HELEN GREINER: You got it to do one thing!

ALAN ALDA: It's really into belching.

HELEN GREINER: How about giving it its bottle?

ALAN ALDA: Alright, here.

ALAN ALDA (Narration): It's a strange feeling. Bit's very obviously not real, but it's hard not to empathize with it.

ALAN ALDA: Heh, heh, heh, there's a definite smile there. That's great, I mean it's... quiet… it's amazing how you get such a range of expressions.

HELEN GREINER: They key is to have a behavioral control system that has a lot of really small simple rules all running in parallel that builds complexity from the ground up.

ALAN ALDA: Oh, look at that distress. Maybe it just has gas. What's inside there?

HELEN GREINER: Well, although it looks like a baby on the outside...

ALAN ALDA: Oh. I saw this movie.

HELEN GREINER: What it really is, is a mechanism and a computer and sensors over its body...

ALAN ALDA (Narration): Bit was created by a company called IS Robotics, and is the direct descendent of a robot I met six years ago.

ALAN ALDA: It, wake up. Oh, very good. Hello, good morning.

ALAN ALDA (Narration): "It" was also created at IS Robotics...

ALAN ALDA: I'm sorry. Could you just say that again.

ALAN ALDA (Narration): The company had been recently founded by Rodney Brooks. "It" was able to react to things like getting too close to its infrared detectors with a caricatured human response.

ALAN ALDA: Heh, heh, it opens its mouth in utter surprise.

RODNEY BROOKS: Yeah, and it raises its eyebrows. It's got this reaction of, "Oh, what's happening here, get away from me."

ALAN ALDA (Narration): "It" was one of the first attempts to give robots an appealing if somewhat exaggerated appearance of being human.

RODNEY BROOKS: It tries to appear to be human, so that we can interact with it in a way that's human.

ALAN ALDA (Narration): This idea has now found its fullest expression in a robot called Kismet, being brought to synthetic life in the same MIT lab that COG inhabits.

ALAN ALDA: These robots, like babies, are going to seem especially appealing to us. We spend a lot of time with babies, and we can't resist them.

ALAN ALDA (Narration): Kismet's expressions -- ranging from boredom... to happiness... to sadness... to interested... -- are deliberately over-the-top.

CYNTHIA BREZEAL: It's very much a caricature to make it that much easier for you to read the robot. So that when it looks happy, it's obviously happy; when it looks sad, it's obviously sad. You kind of go, "Oh, I did something to upset it. I should do something to make it happy." So it's really trying to get you involved at this kind of unconscious emotional level.

ALAN ALDA (Narration): Cynthia spends long hours in front of Kismet, as she works on giving it giving the ability to recognize objects and react with its cartoon-like response. And her willingness to invest the effort is itself a demonstration of the goal of the research -- to make people want to help their robots, so that robots can more easily learn the ways of humans. The idea is that one day, COG himself will have a Kismet-inspired head, so that its human companions will treat him like an endearing -- if somewhat clunky --child. Right now, Kismet can make facial expressions but can't recognize them. That's Cynthia's next task -- but it's one she believes Kismet itself will help with.

ALAN ALDA: Facial expressions are so subtle. How can you tell whether I'm smiling or making an angry look?

CYNTHIA BREZEAL: This is the nice thing. When parents interact with young children -- that's another reason this is a robot infant -- we have very exaggerated behavior. We're leveraging off of that. If you're dealing with an adult, you know... I might smile a little, I might shift my gaze and so on... but it's very subtle cues. When you're playing with an infant, you're very exaggerated. Your face is exaggerated, your intonation... "Oh, you're such a good robot"... you know, everything is so exaggerated...

ALAN ALDA: You're such a good robot!

CYNTHIA BREZEAL: Exactly... that it's making the perceptual problems for the technology much easier than it would be if you were trying to interact at a human level.

ALAN ALDA: So you're counting on that behavior?

CYNTHIA BREZEAL: I'm very much counting... I'm trying to pull it from you.

ALAN ALDA: Yeah, yeah, I see.

ALAN ALDA (Narration): But one thing's been nagging at me all during our encounters with robots that their makers describe as happy, or frustrated or surprised. What's really going on in these machines is that little computer programs are running that enable each robot to appear as if it's feeling.

ALAN ALDA: I mean, if it makes faces and changes expressions, we'll read stuff into that. But how can it possibly have a base from which to be surprised, for instance?

RODNEY BROOKS: Right, this is the really big question, I think. Whether we can make machines really, really, really be surprised, really, really understand, or just appear to be surprised. That's I think the...

ALAN ALDA: How can they possibly feel? I mean what would represent feeling?

RODNEY BROOKS: Well, in principle, I think we're machines. You know, we're made up of lots of mindless little atoms and molecules which work together, and they produce this behavior. Now, some vitalist might say that there's an elixir of life inside us, or some people might say there's a soul, but as a scientist, fundamentally, I think we are just... I think we are just machines. Now, I don't treat you like a machine...

ALAN ALDA: Not so far, anyway.

RODNEY BROOKS: I'm willing to treat COG as... COG doesn't have it, but you have it.

ALAN ALDA: That gets right to the point of it. You can take COG apart and put him back together again. You can't do that to me -- take me all apart...

RODNEY BROOKS: Surgeons can do a lot...

ALAN ALDA: Yeah, but take me all apart; you take all the little parts you talked about and try to put them back together, there's going to be something missing.

RODNEY BROOKS: Well, that's how we think right now. But suppose we get these robots to the point where they really make me feel as comfortable with them as you make me feel comfortable -- have all these social cues, have all these social interactions -- and then at the same time, I'm able to take them apart and put them back together. What does that say about us?

ALAN ALDA: Let's say you can do that. Let's say you can get a machine to give every indication that it's feeling stuff. So what? What will that do? Will that just make me more comfortable with my computer, or what will that do? How will that change the world?

RODNEY BROOKS: I'm interested in understanding what it is about us that makes us human, what aspects. I'm trying to do the reduction, which science always tries to do, the reduction. Science looks at chemical processes and tries to break it down to the simplest things. This is my attempt at trying to break down what it is that makes us human into simpler components to therefore understand them.

back to top

GO, TEAM!

MAJA MATARIC: Think of yourself as the mother duck. Now you're the mother duck.

ALAN ALDA: Haven't played that part before.

ALAN ALDA (Narration): What's more, I suspect the robot ducklings know it.

ALAN ALDA: It's crawling up my leg! I hope you can explain it...

BARRY WERGER: There's a very large gap between these two sonars, and when an object is at precisely this angle, the robot has a lot of trouble sensing it.

ALAN ALDA: Look at this. They keep standing on my foot. What is he doing? What does he want from me?

BARRY WERGER: They want you to move.

ALAN ALDA (Narration): At the University of Southern California in Los Angeles, Maja Mataric and Barry Werger are trying to get robots to behave like animals that live in social groups -- ducklings, for example... My status as mother duck is conferred by the orange tube taped around my leg.

ALAN ALDA: He's still sensing me, isn't he? What is it, the little camera on top?

MAJA MATARIC: Yeah. The camera sees your leg, it sees the orange, and it says, "Mommy, I'm lost in the grass!"

ALAN ALDA (Narration): While the camera is looking for me, the sonar on each robot is checking for obstacles. What's amazing is that while the programs Barry has written for the robots' computers are very, very simple, the robots' behavior is anything but.

ALAN ALDA: Oh look, he went around that tree and found me again. This is really good. Is he tuned in primarily to the camera so he's trying to find...

BARRY WERGER: The trick is the part of the robot, the consciousness that's trying to find your leg is completely independent from the part that's trying to avoid the obstacles. And they actually kind of battle it out inside the robot's brain to decide who's going to take control of the robot. So the priority always goes to the obstacle, because that's the danger. When something's in its way it always does what it takes to not hit something. And then, if it's not actively avoiding something then it goes towards the object of desire.

MAJA MATARIC: You might ask, why do we do it this way? Why don't we just put one big program the way people traditionally do or traditionally used to do in robotics. And the whole point is that we're being biologically motivated. So in biology, we know that the brain is distributed and there are collections of drives, some very, very old drives like run away from anything that's attacking you, or go follow the mother. And that's exactly the drives we're modeling here.

ALAN ALDA (Narration): Many living things act collectively, cooperating to achieve tasks like getting food. In this experiment, Maja and her students study different ways a group of robots can collaborate to gather up hockey pucks as efficiently as possible.

MAJA MATARIC: That's the queen bee. She takes care of the home region and they take care of the rest of the world. And see, they're doing a good job. There's almost nothing left.

ALAN ALDA (Narration): Again, like the robot ducklings, these mechanical bees are following very simple rules. Among humans, soccer is a game in which simple rules -- and brilliant technical skills -- can combine to produce dazzling complexity -- as if the team shares one big mind. A few years ago, a small group of robot researchers began arguing that getting robots to play soccer would be what Maja likes to call "the grand challenge."

MAJA MATARIC: And it was not at all widely accepted. People said, "Oh this is just fun and games, what's soccer? Big deal, you just move around and kick the ball." Turns out, it's really, really hard. And it's hard for two reasons. Because at the low level you have to find the ball, kick the ball -- you know, survive. At a very, very fast clip. That's very hard. So robotics cannot do that yet. And then at another level, you have to have strategy. You have to interact with your team, figure out who should do what so that you win.

ALAN ALDA (Narration): Speed and strategy -- those are the keys to success in robot soccer. And few groups have done more to achieve them than the research team at Carnegie Mellon University in Pittsburgh, headed by another of the originators of robot soccer, Manuela Veloso.

MANUELA VELOSO: Shoot again, shoot!

ALAN ALDA (Narration): One of the stars of CMUnited is their goalie. Trying to beat it gives me the chance to learn some of the secrets of the team's success.

ALAN ALDA: How is this working? Does that little guy have eyes in its head somehow?

MANUELA VELOSO: No, actually the robot does not have any eyes. There is a camera that is overhead and sees the whole field.

ALAN ALDA (Narration): From the video image, a computer extracts the position of the ball and any robots on the field. Then it predicts from the movement of the ball its current direction and speed -- indicated by the length of the line. The computer does this 30 times a second -- fast enough to cope with all but the speediest shots.

MANUELA VELOSO: There you go.

ALAN ALDA: I went too fast.

PETER STONE: Vision's fine.

ALAN ALDA (Narration): Behind the scenes, Peter Stone's running the vision system, while Mike Bowling's laptop is sending wireless instructions to the robots on the field. But during competition, it's hands off.

ALAN ALDA: You're not allowed, by the terms of the competition, to give it any directions from a human during the game?

MANUELA VELOSO: Yes, we cannot give it any directions.

ALAN ALDA: It all has to be done beforehand, as you design the software.

MANUELA VELOSO: Right. And the challenge is that the domain, the task, is very uncertain. So we have to up front program or make the robots think about a very large number of situations.

ALAN ALDA (Narration): One of the things the robots think about is when and where to pass.

MANUELA VELOSO: Now, here is a pass.

ALAN ALDA: Oh yeah, yeah. That was a real pass.

MANUELA VELOSO: It's actually trying to predict where the ball is going to be. So it needs to think about where is the best point where it should intercept the ball.

ALAN ALDA: Does that help you to actually think of them as thinking and being confused? Is that a real description of what's happening, do you think?

MANUELA VELOSO: We want to build robots, but we are humans, right? So we can only build them similar to how we think ourselves. So that's why formations came about, roles came about, your strategy comes about by thinking, how would you do?

ALAN ALDA (Narration): For instance, if you're a defender faced with two attackers, when and how would you clear the ball? The CMU defender is programmed to check the gap between the attackers to make sure it's wide enough before kicking the ball between them. If the attackers are too close, the defender clears the ball to the side. With four months to go before the robot soccer contest, the CMUnited team is in good spirits.

MANUELA VELOSO: Shoot, shoot!

ALAN ALDA (Narration): Even during practice scrimmages, Manuela finds it hard to contain her competitive instincts.

ALAN ALDA: Now look, you designed this. How can you be talking to it as if it can understand you? Shoot, shoot, go, go!?

MANUELA VELOSO: I know!

ALAN ALDA (Narration): CMUnited's speed and strategy have already won past robot soccer championships. But in this year's contest, to be held in Stockholm, they'll be up against some formidable opponents.

ALAN ALDA: What do you think? Do you think you'll win in Stockholm this year?

MANUELA VELOSO: Let me tell you. Probably we will. I'm not sure. But if I ask Mike and Sorin and Huan and Peter...

SORIN ACHIM: We win.

MANUELA VELOSO: Sorin says, "We win."

SORIN ACHIM: I always think we are going to win. We did it two times...

ALAN ALDA: You always do, right?

ALAN ALDA (Narration): Stockholm in August. Outside, the temperature is in the 80s.

REFEREE: Three, two, one...

ALAN ALDA (Narration): Inside, it's even hotter, as teams from around the world compete before an audience of computer scientists in RoboCup 99. It's the quarter-finals, a match between a team from Singapore and one from Cornell University -- and Cornell strikes first.

RAFFAELLO D'ANDREA: Oh, yeah!

REFEREE: Three, two, one...

ALAN ALDA (Narration): Along with CMUnited, Cornell's team, Big Red, is a favorite to win. Fast and strong, its robots can play different roles at different times.

RAFFAELLO D'ANDREA: This is a very good role for us. It's called "corner shoot". If we have the ball in the corner and we notice that the goalie is slightly out in the field, we just do a quick spin with the hope of putting it across the crease hoping that either one of our players rushes in or that it accidentally goes off their player, which is exactly what happened.

REFEREE: Three, two, one...

RAFFAELLO D'ANDREA: It's all based on the position of the players and the position of the ball. We have another role called "jam and shoot". If it sees the ball and there is no opponent nearby and there's a clear line to the net, it just rushes it and goes for the net.

ALAN ALDA (Narration): Sorin Achim from CMU watches anxiously as Singapore's only goal comes from a penalty, and Cornell sweeps on to a convincing win. Also witnessing the victory, both as competitor and mentor, is CMU's Manuela Veloso.

RAFFAELLO D'ANDREA: We in fact invited Professor Veloso to give a talk at Cornell, because they are right at the forefront of AI research, and we wanted

Professor Veloso to tell us what strategies they took, and we based a lot of our artificial intelligence on what they've done. So we definitely borrowed from our competitors.

SORIN ACHIM: I lost my confidence. I guess if we get to the final and play against Cornell we need a lot of luck to win.

ALAN ALDA (Narration): In fact, CMUnited's luck is to run out well before the final. After easy wins in the qualifying rounds, CMU's robots in their quarter-final match seem hesitant and confused. Manuela Veloso: Clear. Clear. Clear now!

ALAN ALDA (Narration): Against the fast and aggressive robots of another team from Singapore, Lucky Star, the CMU team is getting literally pushed around.

REFEREE: Charging. Yellow card for robot number three. And it's a free kick for CMU.

ALAN ALDA (Narration): This play sums up the match. A penalty attempt by CMU turns into a beautiful goal for Lucky Star... who go on to crush CMUnited 8-0.

MANUELA VELOSO: We are sad. But it's somehow... we did not change any of our hardware, so it's the same robots as '98. Technology improves every year. They came with much faster robots than ours, and definitely we were still always worried about strategy and not making the robots faster. So... they just won!

ALAN ALDA (Narration): Now it's Big Red's turn to face Lucky Star in the first semi-final.

RAFFAELLO D'ANDREA: This is the fastest team that we've played against, so we have to be sure we can cope with their speed.

ALAN ALDA (Narration): And it's immediately obvious that this is going to be a match between two superbly skilled teams. Cornell strikes first -- and more often. Big Red's robots more than hold their own in both speed and strategy to win the first semi-final 6-2.

RAFFAELLO D'ANDREA: Excellent game, guys.

ALAN ALDA (Narration): In the other semi-final, a team of just three amazingly speedy and maneuverable robots from Korea faces the stolid but powerful machines of the FooFighters, from the Free University of Berlin. The FooFighters' weapon is a devastating kick... delivered by rotating paddles at the front of each robot. Their shooting skills win the game... and cause the Cornell team to make some last-minute adjustments before the final.

RAFFAELLO D'ANDREA: What we've done is we've always made sure that we position our midfielder always between the ball and the goal at a slight offset and the goalie will take up the rest.

ALAN ALDA (Narration): The plan succeeds brilliantly.

REFEREE: Three, two, one...

ALAN ALDA (Narration): Big Red's defense is more than enough to stop the powerful shots of the FooFighters -- and Cornell's attacking game is relentless. Final score: 15-0.

MANUELA VELOSO: And the first prize is for Big Red from Cornell University, who only suffered two goals during the whole tournament.

ALAN ALDA (Narration): Cornell's win was in one of no less than four different robot categories at RoboCup 99. In a sign of things to come, one of the other categories was for teams of four-legged robots. The robot dogs are very obviously beginners. But like all the other robots in the contests, they're on their own once play begins. All their programmers can do is cheer them on.

MANUELA VELOSO: Go blue!

ALAN ALDA (Narration): But for Manuela Veloso and her colleagues in robotics research, the challenge of creating robot teams goes far beyond the soccer field. Their goal is teams of autonomous robots cooperating on complex tasks like search and rescue missions, or building space stations -- even cleaning house. Meanwhile, the RoboCup organizers have their own dream: a team of humanoid robots taking the field against the winners of the Soccer World Cup in the year 2050.

back to top