"ROBOTS ALIVE!"
SHOW 705

EPISODE OPEN

ALAN ALDA Sixty miles an hour and the car's driving itself. On this edition of Scientific American Frontiers we'll explore a world where machines don't need people.

NARRATION We'll see robots that get around, that look, that grab -- all on their own. We'll meet Toddler as he takes his first steps. We'll watch helicopters trying to fly without pilots. And we'll get to know Cog, who's teaching himself about life.

ALAN ALDA I'm Alan Alda. Join me now for Robots Alive!

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MAZES AND SQUIGGLES

IGOR I am looking for tennis balls.

ALAN ALDA (NARRATION) We're on the track of robots with a mind of their own.

ALAN ALDA Why did he stay in with it?

SPECTATOR In case it goes wild.

ALAN ALDA Well, is it liable to attack us? What do you mean wild?

ALAN ALDA (NARRATION) At the fifth annual artificial intelligence convention in Portland, Oregon robots are competing to show how they can recognize and manipulate... And how they can find their way in a maze of corridor and rooms. It's a forum for some of the world's top robot scientists to see what they can do. Here we are at the preliminaries of the maze contest.

AMELIA I have arrived at Conference Room One.

ALAN ALDA (NARRATION) Things are already getting tense.

REID SIMMONS It's doing better than I am. I feel like I'm about to pass out.
AMELIA If there is someone here they are probably pacing up and down - giving a talk. This room is occupied. Excuse me for interrupting your meeting.

ALAN ALDA (NARRATION) In the maze contest, robots have to: start in the director's office; find which one of two conference rooms is empty; set a meeting time; invite two professors to it; and then return to summon the director exactly one minute before the meeting. The robots are given the rough layout but not exact sizes -- they've got to finds rooms and doorways for themselves, and watch out for the foyer, a notorious trap. In the preliminaries, the foyer was Amelia's downfall. She thought it was a room, and got stuck. The team will work on it tonight.

REID SIMMONS One more chance!

ALAN ALDA (NARRATION) Most entries are single robots, but in this innovative approach two small robots find the rooms, under the direction of a central planning computer. They use a system like the Internet to talk to each other -- at least that's the theory.

KURT KONOLIGE Didier, it doesn't look like he's got the right plan here at all. It's just more than twice as hard to do two robots because you have to coordinate them and communicate between them... ah...but it's pushing us.

ALAN ALDA (NARRATION) Now the finals. Early on the pace is set by Kansas State. KSU 1 I am going to search for people in the room.

ALAN ALDA (NARRATION) Throughout the contest the judges will demonstrate that Conference Room One is busy.

ALAN ALDA How did he know that there were people in here?

PETE BONASSO So this is one of the teams that is using the camera to follow motion. Basically, in successive frames of the camera they'll see a change to detect that there must be someone in the room, because they're moving.

ALAN ALDA (NARRATION) Rows of sonar range-finders are used by all the robots to sense their surroundings. Not hitting obstacles is a contest requirement.

ALAN ALDA What if it hadn't stopped?

JUDGE It was interesting.

ALAN ALDA He came very close.

ALAN ALDA (NARRATION) Kansas State breezes through the foyer, finds Conference Room Two, sets up the meeting time, and alerts the professors.

KSU 1 The meeting will be in Conference Room 2. The meeting will be held in two minutes thirty-one seconds. Two minutes thirty-one seconds...

ALAN ALDA (NARRATION) The final arrival is perfectly timed.

KSU 1 Excuse me director. The meeting will be in Conference Room Two. The meeting is scheduled to take place in one minute.

JUDGE They have the fastest time of any one robot entrant - nine minutes twenty-five seconds, and they have maximum possible, 295 points. So give them a big round of applause.

ALAN ALDA (NARRATION) The only way to beat this score is speed -- there's a fifty point bonus for the fastest round. On Yoda, the cameras are not working.

YODA I'm going to conference room one. The next landmark after I start moving. Find the landmark.

ALAN ALDA This robot has multiple-personality disorder. Every time it talks it's got a different voice.

YODA Is there anybody in the room? Please come and get an M and M's.

ALAN ALDA (NARRATION) To detect motion Yoda has to entice people within range of his sonar.

YODA Thank you.

ALAN ALDA Oh, thank you. So far, this is my personal favorite.

ALAN ALDA (NARRATION) Yoda also makes a flawless round.

YODA The meeting starts in one minute.

ALAN ALDA (NARRATION) Perfect timing, too. But Yoda took twice as long as Kansas State. SRI's multi-robot strategy has the greatest speed potential, simply because two traveling robots can get done in half the time. Blue moves out to check Conference Room One... While Red heads immediately to Conference Room Two.

ALAN ALDA He's passing right by... oh no there he goes.

ALAN ALDA (NARRATION) SRI's prepared to take a ten-point penalty for demanding red shorts on the judge -- it's easier for the camera to detect.

ALAN ALDA Was he told beforehand to first go to the conference room and then the professor's room?

KURT KONOLIGE He was told to go to the conference room and check it and then check back to see what to do next.

ALAN ALDA (NARRATION) At the same time, Red was discovering that Conference Room Two was free. Both robots now talk to the central computer which sets the meeting time and sends each robot to a different professor's office. Nobody gets lost, and the total time is less than half Kansas State's.

ALAN ALDA The thing is over now, they did it huh?

PETE BONASSO And the time is incredible!

ALAN ALDA That's amazing!

ALAN ALDA (NARRATION) Poor old Amelia is off to a bad start.

REID SIMMONS Just go back and restart.

ALAN ALDA What happened here?

REID SIMMONS One of the software programs crashed - something that's never happened to us before.

ALAN ALDA Is that it now, are you...

REID SIMMONS Well, we're gonna restart.

ALAN ALDA Restart. How many times does the competition allow you to restart?

REID SIMMONS I think you... I think you can do it as many times as you want but you get points deducted each time you restart...

ALAN ALDA I see...

REID SIMMONS This is a fairly major hit.

ALAN ALDA (NARRATION) Once restarted, Amelia is fine at the first conference room and heads across the dreaded foyer. It looks like the same problem as the preliminaries. But with overnight software changes, Amelia can now recover if she gets lost.

ALAN ALDA Amelia come back. Amelia is headstrong here. Come back, you've gone to far.

ALAN ALDA (NARRATION) She gets out of the foyer and slowly figures out where she is.

ALAN ALDA That process was really fascinating. I mean that was like thinking practically!

ALAN ALDA (NARRATION) But it's all too much for Amelia. She crashes for the second and last time. With their time bonus, SRI's multiple robots came first. But that's not really the point -- pushing the state of the art is what counts, and by that measure everybody won. It's hard to say where research like this will lead, but this can give you an idea. Many machines can be hard for people to handle, especially if you're new at it.

ALAN ALDA I'm not trying to do this. I'm... I swear I really am not... I'm not trying to crash. Ow!

ALAN ALDA (NARRATION) Now look at this. Same wheelchair but with a robot navigator added.

ALAN ALDA It won't let me race as fast as I went before...

RICH SIMPSON Right, but part of that is that this is a crowded environment and it... it reduces the speed in proportion to how crowded its surroundings are.

ALAN ALDA Yeah, I'm driving as wildly as I did before but it's not letting me.

ALAN ALDA (NARRATION) Based directly on the systems in the contest, it's a first glimpse into a world with robots, where humans and smart machines cooperate. For the second contest it's another deceptively simple task: find ten tennis balls spread around the court; pick them up; put them in the corner. Precise but slow-moving machines like this will have a hard time, because there's a ten minute time limit... Plus a couple of moving squiggle balls for an extra bonus.

PETE BONASSO Hand-eye coordination is an intelligent thing and if you can get the robots to do that, we're... we're advancing the... the state of the art.

CONTESTANT You can pick up trash on a cluttered desk or something like that, you know, maneuver around various objects on your desk...

ALAN ALDA So if you said, while you're at it catch my two-year old, forget it!

ALAN ALDA (NARRATION) Small agile robots are the favorites in this contest. Here the Walleye team has opted to paint the balls black so their black and white camera can see them. There's a twenty point penalty though.

CONTESTANT There's a very wide gripper and we have a tendency to catch the gripper on the wall. OK, there, it got it.

ALAN ALDA (NARRATION) In a couple of minutes, the first load's delivered. But then...

CONTESTANT Ah... it looks like it just went down.

ALAN ALDA (NARRATION) You just know it's going to crash at the worst possible minute. Restart, and then try again.

CONTESTANT Alright, we're ready to start up again.

ALAN ALDA (NARRATION) Right off the bat, the Walleye traps and captures a moving squiggle ball, worth fifty points. Then another crash.

CONTESTANT Ah... this never happened in practice, so I don't know what's going on here.

ALAN ALDA (NARRATION) At the second restart, the team leaves the balls in the grippers. But after restarting the robot thinks it has to start looking again It's not smart enough to know it's already loaded up.

ALAN ALDA This machine is a glutton.

ALAN ALDA (NARRATION) As it grabs its sixth ball, it finally reaches overload and stops for good. This robot is based on a powerful carrying platform used in hospitals.

IGOR I am looking for tennis balls.

ALAN ALDA (NARRATION) It efficiently gathers tennis balls, but it's too slow to get squiggle balls. In a piece of luck, it runs into one by accident. Then against all odds, the second squiggle ball runs into the collector as well. Accident or not, it's worth points. Next up, a robot using a powerful combination of a systematic search pattern, with a TV camera ball-spotter. Amazingly, first thing there's another lucky squiggle encounter. And then... yet another. It's annoying for the team because their efficient machine can track and catch squiggle balls on its own. And it also has a special strategy for those hard-to-get balls placed along the edge by the judges. It's an almost perfect score.

ALAN ALDA So now it's going to try to find any more... with the same pattern?

CONTESTANT Yeah, because the tennis game could go on and there could be new balls.

ALAN ALDA You mean you picture somebody playing tennis in the middle of this, with this thing roaming around under your feet?

ALAN ALDA (NARRATION) They saved the best for last...

ALAN ALDA All right! There it goes, there it goes! Woah!

ALAN ALDA (NARRATION) At least the most entertaining.

CONTESTANT So the robot, in fact, with it's camera, can see about halfway um.. through the rink.

ALAN ALDA (NARRATION) This little guy really seems alive. Helped by a super-fast color vision system, chasing down a squiggle ball, it's like a cat chasing a mouse. What seems like a victory dance is actually a quick search for the dumping corner, now too far for the robot to see. So, it decides to follow the wall all the way around. After delivering the first squiggle ball, it quickly spots another. It's single-minded, ignoring a low-value tennis ball for the bigger prize.

CONTESTANT ... there are two little stops under the gripper with white ends on them...

ALAN ALDA (NARRATION) The robot makes quick work of nine of the ten tennis balls on the court. And then, it's faced with a serious problem. There's just one ball left, but it's dead center of the court, just out of range of the robot's camera -- a camera that the team had to angle downward to avoid the glare of the convention hall's lights.

ALAN ALDA Oh no... oh no, it's gonna miss it now, huh?

PETE BONASSO The ball is exactly where it has to be so it can't be seen by that field of view from around the walls. And that's a singularity. It just happens to be just exactly the right circumstances to beat this machine.

ALAN ALDA (NARRATION) Until, that is, the robot turns in a slightly different place... It was artificial intelligence -- or AI as the scientists say -- but it sure seemed alive.

PETE BONASSO There's something about these robots!

ALAN ALDA It's true, you know, when that machine caught that tennis ball today at the last second, when I didn't think it was going to get it and it did it, it was like Rocky, and I was cheering for it. And the combination of AI and a machine that almost seemed to have a human will was exciting, and that alone can make people want to do more in both these fields.

ALAN ALDA (NARRATION) Robotics and artificial intelligence are the two frontiers of computer science. And it's got to be the robot people who have the most fun.

ALAN ALDA Hello Cybot! CYBOT Would you like a drink?

ALAN ALDA Yes, please... so, you here for the whole convention?

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LOOK NO HANDS!

ALAN ALDA (NARRATION) I guess this has to be one of the strangest things I've ever taken a ride in. Nobody seems to be in charge.

ALAN ALDA Is this driving itself now?

MARTIAL HEBERT It's driving itself now, you can see the steering wheel turning.

ALAN ALDA How does it know where to go?

MARTIAL HEBERT I designated the goal point about a hundred meters away.

ALAN ALDA (NARRATION) The goal point that Martial has chosen cannot be reached directly -- there are obstacles in the way. Using pictures from a set of TV cameras, the onboard system generates height and position information for the terrain ahead, decides which features are too big to be ignored, and then plots a course around them. This is one of a long series of experiments to develop autonomous vehicles -- vehicles which can get around on their own. The work has been continuing for more than a decade, at Carnegie-Mellon University in Pittsburgh, directed by Chuck Thorpe.

ALAN ALDA How did everything change when you went to this next model?
CHUCK THORPE OK... when we were working on this one we were thinking a lot about driving in hazardous environments and our picture of hazardous environments was really military environments. But we started to realize that the highways are pretty hazardous environments too. We still kill 40,000 people per year in the US on the highways.

ALAN ALDA (NARRATION) This is now their fifth generation of autonomous vehicles. It uses a simple personal computer, hooked in to a radar range-finder for detecting obstacles, and a single miniature TV camera. Dean Pomerleau, who wrote most of the software that ties it all together, took me out for a spin.

ALAN ALDA What's this big, blue square here?

DEAN POMERLEAU That's actually a representation of the back of the vehicle... um, you can see the vehicle and the two tires below it - the little gray squares - and then below that the two yellow markings that are dancing back and forth - those represent the uh... where it believes the edges of the lane to be. Because we're out in a parking lot right now, you don't actually... it's not finding any road, so those are sort of dancing around as it's hunting for the road ahead.

ALAN ALDA Now how about this red...

DEAN POMERLEAU Trapezoid?

ALAN ALDA Trapezoid, yes. I knew there was a word for it.

DEAN POMERLEAU That's the portion of the scene ahead that the system is actually processing. So it isn't processing the whole image.

ALAN ALDA (NARRATION) For computer vision systems the real world is a mess -- it's cluttered and complicated. So this system tries to make it simpler. It takes just the central part of the picture -- showing the road -- and looks for some kind of structure. Right now it's finding this series of intersections just as confusing as the parking lot. But then it settles down.

DEAN POMERLEAU So right now we're in a fairly well structured setting. There are lane boundaries on the sides and dash marking down the middle. So the system is... quite confident and as you can see from the display, has locked on quite well to the lane center and the two ah... lane boundaries.

ALAN ALDA So you would feel confident here letting the car go by itself?

DEAN POMERLEAU For that stretch yes, but here we come up to ah... an intersection, there's a stop light, in fact this stop light appears not to be working. That guy giving me hand signals that it's safe to go through the intersection, is... is far beyond the kind of stuff that any machine vision system is capable of now.

ALAN ALDA (NARRATION) Even so, the system is not entirely dumb.

DEAN POMERLEAU The most interesting thing about the system is it in fact is not explicitly tracking those lane markings. There isn't a hand-programmed, lane-marker detector in here. The system basically adapts to utilize whatever features are visible on the road ahead.

ALAN ALDA What other features would it... would it track?

DEAN POMERLEAU Things like what we see here, like the uh... the uh cracks in the road where they've been filled - the dark discoloration - even the uh... slight discoloration down the lane's center.

ALAN ALDA (NARRATION) The system works best in the simpler setting of the highway. That's where I'm going to try it out in what they call warning mode. This is probably the way smart cars like this will first come into widespread use.

ALAN ALDA Now I'm going to deliberately drift here, I'm gonna drift that way.

DEAN POMERLEAU Yeah, see what happens. Right as your tire crossed the lane boundary, it basically gave you the audible warning that ah... there's, there's something wrong here - you want to steer back toward the lane's center.

ALAN ALDA All right, here I go again. Drifting.

DEAN POMERLEAU The goal of this initially is to uh... basically deploy it on trucks. They're the... where a large problem is with drowsy drivers in particular.

ALAN ALDA So we're getting down to one lane, and there's no stripe on the left so it must just be reading the oil spots on the center.

DEAN POMERLEAU Uh huh... the oil spots and there is a slight seam, a crack in the road that the system is also seeing.

ALAN ALDA Right, yeah.

DEAN POMERLEAU So it will adapt what features it utilizes to the circumstances.

ALAN ALDA (NARRATION) Now we're going to go to full, autonomous steering. Better to have Dean in the hot seat.

DEAN POMERLEAU Nervous?

ALAN ALDA A little bit, yes - just a little bit.

DEAN POMERLEAU So what I'm going to do now is change the mode now into the mode where we can automatically drive the vehicle.

ALAN ALDA How many times have you done this? Have you done this a lot?

DEAN POMERLEAU Hundreds...

ALAN ALDA Hundreds? A hundred times?

DEAN POMERLEAU Oh, minimum.

ALAN ALDA (NARRATION) We rejoin the high-speed traffic on the highway.

DEAN POMERLEAU So we can see the system has locked on to the road ahead.

ALAN ALDA Yeah.

DEAN POMERLEAU And so I will now hit the red button - and now it is steering on its own.

ALAN ALDA How fast are we going?

DEAN POMERLEAU Fifty-five, fifty-seven miles per hour.

ALAN ALDA Well this is not nearly as frightening as I thought it would be. I'll tell you what's even more amazing is we've been chatting about this and I've completely forgotten that you have your hands off the wheel. I can't get over that! There, it's going around a curve now, it's great to see that wheel actually take the curve.

DEAN POMERLEAU Yeah.

ALAN ALDA (NARRATION) It's still up to the driver to apply the brakes, but the system will be able to handle that, too.

ALAN ALDA OK, now look, this car just pulled into our lane. Did we respond in any way to that?

DEAN POMERLEAU The radar located it - you can see the uh.. pink line with the white dot right in the middle of it - that's indicating it's tracking it and it knows its in our lane.

ALAN ALDA (NARRATION) At the same time, the system excludes the overtaking car from the red trapezoid, so the view of the lane ahead is not disrupted. Ten years ago our cameras recorded some of Chuck Thorpe's early experiments. The first NavLab, as they called it, detected obstacles with a laser scanner. It worked as well as the radar on the latest version, but it was slow -- like everything on NavLab 1. Just like today's system, it combined obstacle-detection with processed TV-camera pictures. But its computers took ten seconds to process each new frame of picture. So it found the road and stayed on it, but at less than walking pace. Today the limit's no longer the computers -- it's the law. There's not much doubt that we'll be riding in robotic cars before long. But is that really such a strange idea?

ALAN ALDA How much are we controlled by computers now - that we just accept without giving it too much thought?

DEAN POMERLEAU The interesting thing is that... that probably fifteen, even ten years ago, the view of robotics was you'd have a... human-appearing servant in your house, for example, that would uh... clean your dishes, make your bed in the morning... uh... what's really happened in robotics is that the technology has become embedded and really invisible. So there are a lot of things... uh, your microwave oven has a pretty sophisticated ah... computer in it. So robotics is actually becoming less and less visible, but more and more prevalent through society. And that's what we see for this technology... um, just a few years ago, was a camera about this big and needed a big platform to sit on, but it's shrinking down and eventually we hope to put everything in a box smaller than that. And... and just stick it on the back of the rear-view mirror and the person won't even realize it's there - until they begin to drift off the road and it warns them and hopefully saves their life.

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TODDLER'S FIRST STEPS

ALAN ALDA (NARRATION) It's almost 20 years since the Imperial Walkers first lumbered into action in the movie "The Empire Strikes Back." And if they look a bit tentative, it's not surprising. Even movie magic can't disguise how hard it is to make a robot walk. Looking remarkably like a model Imperial Walker, this machine was actually built over 30 years ago by an engineer named Ralph Mosher. Without the benefit of computers, Mosher's walker translated his hand and foot motions into footsteps powered by hydraulic motors. Mosher's machine was eventually abandoned as impractical. But as well as inspiring the Imperial Walker it also inspired this creation... A six-legged robot built in the mid-1980s at Ohio State University. Sixteen onboard computers made sure its center of gravity was kept safely over its legs. Today, this four-ton monster is also in mothballs. Needing always to be in balance made it simply too slow and cumbersome. But also in the mid-1980s, an entirely different type of walking machine was being pioneered at Carnegie Mellon University. In these machines, balancing was an active rather than passive process.

RAIBERT These machines balance the same as me balancing this broom on my finger. If I keep my finger under the body, it will stay stationary; if I move my finger away it will tip towards me and if I move my finger towards me it - the broom - will tip away. If I want to make it fall towards me, I can put my finger away.

ALAN ALDA (NARRATION) Marc Raibert's hopper had to keep moving to keep balanced -- but could perform some spectacular tricks. Today, his two-legged hopper can bounce along without a boom to steady it, and its gymnastic skills are even more impressive. Unlike people, on the other hand, this biped can't simply stand still, and it needs a lot of computing power to constantly figure out what it needs to do to stay on its feet. This little robot, being built at the University of New Hampshire, is an attempt to much more closely mimic the way humans walk. Its creator, Tom Miller, has not only modeled it's legs and feet on our own, but also the way it acquires its skills.

MILLER Our approach is to try and learn from past experiences and just remember what you've done in the past and how that worked and then to try and make controlled decisions for future actions.

ALAN ALDA (NARRATION) In other words, his robot learns. And the first thing it learns, every time it has to stand on its own two feet, is how not to topple over. Easing its top heavy body into a crouch, the robot -- nicknamed Toddler -- not only stands alone, but can even cope with some gentle nudging. Toddler's brain is kept safely on a nearby desk, while its knowledge about what's happening comes from force sensors in its feet, as well as balance and movement sensors in its torso.

MILLER The body of the biped has accelerometers on the front and side of the robot and gyroscopes which measure the rotation of the body of the robot. And that essentially gives it a sense of what its orientation is relative to the world.

ALAN ALDA (NARRATION) Each time it's switched on, Toddler has to start from scratch.

MILLER It's experimenting with how far to lean right before it lifts its left leg, and you see the knee flexes, it's trying to lift the left and if it doesn't get off the ground it gets stable again and then leans a little farther. Um, and now that time when it finally got off, you see, it leaned a little too far.

ALAN ALDA (NARRATION) Miller hovers protectively as his robot experiments first with swinging from side to side, while standing in place. With every sway it's learning what works and what doesn't. Then, cautiously, it takes its first, tiny steps.

MILLER It has very simple intuitions about how to walk. It knows to move side to side and that when it leans to one side it should try and pick up the opposite foot. And then with the learning it kinda... that's the problem, I kinda have to look at the robot when its learning. This process is somewhat like a toddler learning to walk. Just like a toddler, it needs an adult standing right here to catch it when it makes mistakes. Let's try two centimeter steps.

ALAN ALDA (NARRATION) Tom Miller's basic interest is in making machines that can learn from experience, and a robot that can walk on its own two feet is a perfect challenge for machine learning.

MILLER We've programmed in procedures by which it can evaluate its stability based on its sensors and so as it does these motions it evaluates how stable it is and then makes modifications to its primitive actions and if those modifications improve the stability when it tries them and it remembers that and um... tries it again and each time it tries to just continually improves on its sense of stability.

ALAN ALDA (NARRATION) Like all toddlers, this one still has a lot of learning to do before it can make its own way in the world. As for what a walking robot might be useful for... well, what did someone once say? What use is a baby?

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ALMOST HUMAN

ALAN ALDA IT -- wake up! Hello. Good morning.

ALAN ALDA (NARRATION) Meet IT -- a robot that makes human-looking faces.

ALAN ALDA I'm sorry. Would you just say that again?

ALAN ALDA (NARRATION) IT is the creation of Rodney Brooks, a world-famous robot-builder, and a professor at the Massachusetts Institute of Technology

RODNEY BROOKS There's a detector at the front, here...

ALAN ALDA (NARRATION) Get too close to one of ITs infra-red detectors, and you trigger an annoyed-looking response.

ALAN ALDA It opens its mouth in utter surprise.

RODNEY BROOKS Yes, and it raised its eyebrows. It's sort of got this reaction of, Oh, what's happening here! Get away from me! Thanks to microphones in the head and motion detectors in the eye, IT seems to follow the back and forth of your conversation. And IT smiles whenever there's a lot of activity going on. IT tries to appear to be a human, so that we can interact with it in a way that is like a human. And it's meant to be a robot that you might interact with in an entertainment sort of thing, in an amusement park or something like that.

ALAN ALDA (NARRATION) Of course, IT is far from human. But it does exhibit a certain lifelike behavior, thanks to a programming technique Rod invented. Instead of giving his robots complex instructions, he uses layers of simple fast programs, which all run at the same time and work like reflexes. In Rod's famous insect robots, each leg independently senses, and lifts over, obstacles. So these robots move quickly without doing a lot of thinking. Rod used this same idea in developing small, autonomous rovers for NASA to send to Mars. And now, he's attempting to build the most ambitious robot ever -- a humanoid called Cog. The goal is for Cog to one day have the dexterity, intelligence and understanding of a real human being. When I first met Cog two years ago, much of it was still in pieces on the laboratory bench, waiting to be assembled. Cog is supposed to learn about the world the way a child does. Early in life children don't know much of anything -- not even how to coordinate their own limbs. Yet out of the desire to explore and experience the world, comes knowledge.

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 a human. And it will have the same sorts of experiences that a human has when a human develops in a human society with other humans interacting with it.

ALAN ALDA It's got two parts to each eye. Why's that?

RODNEY BROOKS Well that's much like humans have a wide angle view of the world and a very foveal view. And if we come over here to the monitors...

ALAN ALDA (NARRATION) The fovea is the high resolution, central part of our eyes. In Cog's monitor bank I could see both a close-up foveal view, and a wide-angle one -- corresponding to the two cameras in each eye. Cog needs both views to follow what's going on in the world.

RODNEY BROOKS Just like in your eyes, you're able to see things without much detail off in the distance. You know if you see a ball coming in, you'll rapidly move your eyes over to see what's coming. And then with your fovea track where it is and go out and catch it.

ALAN ALDA (NARRATION) Like humans, Cog must constantly shift its eyes to see the details of interesting objects. Rod built in the ability to analyze the wide angle view and pick out motion -- which shows up on this display as white areas. But Cog had to learn by trial and error how to actually move its eyes. To make Cog's vision system fast, the components are split up among separate computers.

ALAN ALDA Do you think that that imitates more accurately how people are made?

RODNEY BROOKS That is how the brain is organized. There is this very distributed system.

ALAN ALDA Distributed meaning?

RODNEY BROOKS There's lots of little pieces. They all will have evolved over time separately. And they're all running separately. And they don't even know about the other pieces that are going on there. There're doing their stuff, sending messages off to muscles or the cerebellum demanding things to happen and maybe those things happen and maybe they don't. Maybe some other part of the brain gets control at that particular time.

ALAN ALDA (NARRATION) Cog's neck is another piece of the robot that's controlled separately.

ALAN ALDA If the eyes look over there, and in your heart of hearts you want the head to look where the eyes go, how do you get the head to get that information from the eyes and use it?

RODNEY BROOKS Then we have another program that's sitting running and it tries to always make the eyes be centered looking straight ahead. But the only control it has is control of the neck. So when the eyes are pointing over there, the only way it can make the eyes be centered in the head is to turn the neck. Because that's the only thing that particular program has control of.

ALAN ALDA (NARRATION) Cog's neck will also be controlled by a second program -- one that reproduces the human reflex to turn towards the source of sound. Just like with babies, being able to focus on where a sound comes from should help Cog to find the interesting sounds around it, and eventually to understand them.

RODNEY BROOKS Let's come and look at the hand here.

ALAN ALDA (NARRATION) Cog will also be able to experience the world through touch.

RODNEY BROOKS This is a three-fingered and one thumb hand. Here are the three fingers on the left hand. And we've got just a little piece of skin attached to it so it's touch sensitive and moves when we touch it. We just programmed it to do that. Why don't you see if you can make it move? Okay, it felt you and now it's going to grab the object it's feeling.

ALAN ALDA So, it's sort of programmed now to grab what it feel pressure on.

RODNEY BROOKS Just with that one little finger. Eventually, as we finish building this hand, we'll have the fingers completely wrapped with this touch-sensitive material.

ALAN ALDA (NARRATION) Yet another independent computer will control Cog's sense of touch. It will sit inside Cog's hand, so that touch information can be processed right on the spot.

RODNEY BROOKS In the human, of course, our spine makes a lot of decisions for us. It doesn't go all the way up our neck to our brain. Because there's just not enough time to get your hand out of a burning fire, or your foot out of a burning fire.

ALAN ALDA You haven't got time to decide to?

RODNEY BROOKS There's not enough time for the message to travel up your leg, then all the way up to your brain, then all the way back down. So as soon as it gets to the base of the spine, makes the decision to lift your leg up real quick. Here's the arm and you can see it sort of matches the left arm of a human here...

ALAN ALDA (NARRATION) The more I learned about Cog, the more I appreciated how closely it had been modeled after humans.

RODNEY BROOKS And it's got an elbow, and a shoulder, and a wrist

ALAN ALDA (NARRATION) Of course, robot arms used in factories bend and twist with apparently the same freedom as their human counterparts, but using them on Cog would lead to a disaster the minute people got involved.

RODNEY BROOKS A conventional robot arm in a factory, if you tell the robot arm to straighten out to be 85 degrees, it starts moving and it hits an obstacle here and there's a feedback loop and it realizes it's not getting to 85 degrees so it starts sending force to its motors and it pushes harder and harder. It's made of metal and you're made of flesh and it will just plow right through the middle of you.

ALAN ALDA (NARRATION) By installing a metal strip between each motor and the joint it moves, Rod has in effect put springs all over the arm.

ALAN ALDA So it will give. As soon as it gets to my chest, it will start giving...

RODNEY BROOKS It will start giving. But then we do something clever. Grab hold of the arm.

ALAN ALDA (NARRATION) As I twist the arm, I notice its resistance varies.

ALAN ALDA OK, now there's more resistance.

ALAN ALDA (NARRATION) The arm's computer can adjust the resistance. So it can be rigid like a factory robot for hammering a nail, or springy for interacting with people. Two years after first visiting Cog, we returned for a progress report. The arm was now mounted -- with a temporary hand -- and Rodney set the robot's memory back to zero to show us how Cog had been learning. For this demonstration, he'll have Cog reach for a hockey puck. First, Rodney checks to be sure Cog can see the puck. With its wide-angle camera, Cog has the puck in view far to the right. The motion detection system picks up the movement, and commands the eyes to shift, putting the puck on the close up screen. Cog is focusing on his target well, so now it's time to try reaching for it. At first Cog doesn't even come close. Because nobody programmed into Cog any information about how its arm works or what the various motors do, it has to learn by trial and error.

RODNEY BROOKS Right now it doesn't know how to move its arm. It moves its arm out towards what it saw, then sees where its arm ended up and sees that it's wrong, and learns that it should move slightly differently. And slowly over time, it's going to get better and better at reaching towards the thing that it's seeing. Babies take a few months to do this well. Cog takes a few hours to do not quite as well as babies.

ALAN ALDA (NARRATION) Sure enough, Cog reaches for the puck perfectly after practicing just a few hours. If Cog can keep learning like this, as more parts are added, who knows how far it can go?

ALAN ALDA What's the picture in your head now? What do you think of when you think of a mature Cog, a Cog that has reached some point where you can say, that's our Cog?

RODNEY BROOKS What I really think of is a starfleet officer out there being a lieutenant commander on a starfleet vessel.

ALAN ALDA First you've got to get these robots to build the vessel, because that's already pretty advanced. So you see, does that mean that you actually have a fantasy of a bunch of your robots getting into a spaceship and traveling for a thousand years out into the galaxies?

RODNEY BROOKS I have a fantasy of being able to build a human-level equivalent robot which is able to operate in the world in the way we operate. And maybe even better than we operate , eventually.

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ROBOFLYERS

ALAN ALDA (NARRATION) Dawn in Atlanta. And competitors-- many exhausted from working all night-- are gathering at Georgia Tech for a contest that has never been won. It's a contest between flying robots. Here's the task. With no one at the controls, each robot must take off from one corner of a 60 by 120 ft. field, then find and fly to a ring containing 6 metal disks. Still without human control it must pick up the discs one at a time and carry them over a 3 ft. barrier to a second ring, where the discs are deposited. In five years of competition, no robot has even come close to completing the mission. First on the field this year is a blimp from the Technical University of Berlin, Germany.

ALAN ALDA Have you tried this out on a field back home?

MARION FINKE Yes, but inside.

ALAN ALDA Inside?

MARION FINKE Yeah, it's working very well inside. We still have some problems with the...

ALAN ALDA (NARRATION) Like all the robots here, once it starts, it's on its own.

GERMAN STUDENT OK, and we are autonomous.

ALAN ALDA (NARRATION) And at once the Berlin blimp demonstrates why the contest is so difficult-- especially for blimps. Its six battery-powered propellers try hard to steer it toward the ring - but the gentle dawn breeze wafts it away.

ALAN ALDA Has it lost control, do you think it's --

ROB MICHELSON No, not completely.

ALAN ALDA (NARRATION) As Marion dashed off to help rescue her balloon, I sought out the contest organizer, Rob Michelson.

ALAN ALDA What do you think happened there?

ROB MICHELSON They had the props going as hard as they could down, and they were able to catch it before it went into the power lines. But that's the problem with a blimp.

ALAN ALDA (NARRATION) Taking a radically different tack is the next robot. This is the fifth consecutive year the University of Texas at Arlington has entered what amounts to a flying propeller.

ALAN ALDA Just from your previous years' experience, what's it like once you throw the switch and the thing starts to go on its own, you can't do anything? All the work you put into it matters, but you can't do anything at that point.

TEXAS STUDENT 1 This, this year different from the previous years, I'm really, really nervous because this is the closest we've ever been.

ALAN ALDA (NARRATION) The first year of the contest, the Texas tailsitter was one of the few machines even to get off the ground-- briefly. Last year-- after 3 years improving its control systems-- the tailsitter flew beautifully. The problem was still the landing.

JUDGE First thing I need you to (inaudible) show me is how your emergency set up --

ALAN ALDA (NARRATION) This year, the contests' judges are taking no chances.

JUDGE I want to see the emergency set up first thing --

ALAN ALDA He said he wants to see the emergency procedures. I want to see your emergency procedures too. I'll be over here.

ALAN ALDA (NARRATION) What had caught my attention was what looked like a giant inflatable pig. It turned out to be another blimp, this one from the University of British Columbia.

ALAN ALDA Are you about to take off for the first time now? CANADIAN STUDENT We were flying earlier. What we're going to try is a manual flight just to see that the system is working, which isn't.

ALAN ALDA Do you know what the problem is?

CANADIAN STUDENT No, I don't, engine trouble.

ALAN ALDA (NARRATION) The engine got fixed. But the navigation system-- involving a video camera watching the size and shape of the black spots-- got confused by a glint of sunlight, and the Canadian robot waltzed off the field. Meanwhile, last year's best performer-- a helicopter from the University of Southern California-- was also having a bad morning.

JIM MONTGOMERY We crashed last night about 4 in the morning. It was flying great, things were looking good. We were, we crashed and something mechanically is wrong with it. The craft is not functioning right.

ALAN ALDA (NARRATION) Despite improvised repairs...

JIM MONTGOMERY -- let's reset, start again.

ALAN ALDA (NARRATION) ...and last minute adjustments, the USC 'copter simply couldn't get off the ground.

JIM MONTGOMERY Aagh! Man! You look at this, you know, you think "Gees". You go pick up a disk, you carry it across the barrier and drop it off. That's so simple, what's the problem? But they don't realize that, you know, what's very easy for humans is much more difficult for robots. You have sensing problems, you have to deal with variables such as wind and such and it's not a very trivial problem at all. It just shows you just how flexible and adaptive humans are.

ALAN ALDA (NARRATION) I really liked this little device, designed to pick up the discs when dangling from its helicopter.

TEAM MEMBER Pick it up, and we have --

ALAN ALDA That works really smoothly.

ALAN ALDA (NARRATION) The problem was it wasn't quite so smooth once its helicopter was carrying it. But now the Texas tailsitter was taking off, guided by scanning laser beams. It seemed to be flying very nicely, but made no attempt to go pick up any discs. Everyone seemed very pleased when it landed without toppling over. I was a bit puzzled by all the excitement.

ALAN ALDA What happened?

TEXAS STUDENT 2 That was a completely autonomous flight and we took off, hovered, and landed completely autonomously.

TEXAS STUDENT 3 That's world history for this competition; that's the first time that's ever been done in this competition and I've been here for five years.

TEXAS STUDENT 2 We're pumped now. The next step is a disk.

ALAN ALDA (NARRATION) But now Stanford University was taking the field. These guys looked like pros. And they had a navigation system to prove it, employing the Defense Department's Global Positioning Satellite System.

ALAN ALDA What is that thing over there?

STEVE ROCK That is a GPS antenna. That is our ground station. That GPS antenna sees satellites in the sky and we basically fly to that reference station. We have four of those little antenna on board the helicopter. And the thing that's neat about this is that with this new GPS technology we're able to tell you where each one of these little antenna is to within a centimeter.

ALAN ALDA A centimeter?

STEVE ROCK A centimeter.

ALAN ALDA (NARRATION) Once the helicopter locked on to the satellite...

ANDREW CONWAY The flashing red lights on the back of the helicopter means that everything is working.

ALAN ALDA (NARRATION) The Stanford robot took off without a hitch. STEVE ROCK This is flying under complete computer control right now.

ALAN ALDA (NARRATION) And unlike the other teams, didn't bother with preliminaries.

ALAN ALDA Are you just going for autonomous flight now? Or are you going to try to go over and get a disk?

STEVE ROCK We're going to try to pick up a disk right now. We're flying the whole trajectory.

ALAN ALDA (NARRATION) To pick up a disc, the machine simply trawls with a magnet.

STEVE ROCK Whoa! We're close. We're going to, he goes into a search pattern so there'd be a little random motion here where we'll try to drag it around, hoping that we'll bump onto a disk.

ALAN ALDA (NARRATION) It looked to me as if the helicopter was flying too low to drag the magnet around the whole circle. I found myself making an acute observation..

ALAN ALDA So the problem here is that you need to make the string shorter.

STEVE ROCK Maybe we need, yeah, high tech solution. (laughter) Make the string a little bit shorter. Whoa, it got one.

ALAN ALDA (NARRATION) The robot had finally got a disk-- but then it picked up another one-- and that's against the rules. But the Stanford team still had plenty of time. For the Texas team, though, time was running out-- and their tail-sitter was heading the wrong way.

JUDGE Four minutes guys.

TEXAS STUDENT 1 Think quickly.

ALAN ALDA What are you trying to come up with?

TEXAS STUDENT 1 We're just trying to adjust the gyros as the instruments warm up.

ALAN ALDA (NARRATION) But the drift problem affecting the tailsitter proved unfixable. At least this year, the Texas robot didn't scatter itself across the field. The German team was also coming down to the wire.

ALAN ALDA So you made it up.

MARION FINKE Yes.

ALAN ALDA You got up just barely. You have to be up off the ground before you leave that square, huh?

MARION FINKE Yes.

ALAN ALDA (NARRATION) Sailing serenely-- and autonomously-- the blimp headed in the right direction... Only to overshoot.

ALAN ALDA If it just gets a little calm air it might be able to settle into that - oh no. Outside.

GERMAN STUDENT OK. So we can put it again --

ALAN ALDA 45 seconds left. Watch out! Watch out!

ALAN ALDA (NARRATION) The blimp had begun its day battling the breezes.

ALAN ALDA 20 seconds. JUDGE You want to get it restarted. STUDENT Yes.

ALAN ALDA (NARRATION) And it was the breeze that finally defeated it.

MARION FINKE I think one could see that we could manage with a little luck and with less wind.

ALAN ALDA Yeah. Congratulations.

MARION FINKE Thank you.

ALAN ALDA (NARRATION) Another blimp was having similar problems. But this one-- with a distinctly home-made look-- turned out to be the work not of a college team but of students from the Thomas Wooten High School in Rockville, Maryland.

ALAN ALDA When you have school to worry about, how much of your day can you spend on this?

WOOTEN STUDENT Oh, we would spend until midnight a lot. We would spend 5, 6 hours a night on it. And, I mean that bag, everything here is home made. We didn't buy anything, you know, bought.

STUDENT 2 Go that way.

WOOTEN STUDENT I'm going, I'm going.

ALAN ALDA The wind is too strong for you, huh?

WOOTEN STUDENT Yeah, too strong, too strong. Just a slight wind throws everything off for the blimp at least. That's why a lot of these college teams have helicopters.

ALAN ALDA Yeah.

WOOTEN STUDENT And you can see the other two blimps have the same problems we do.

ALAN ALDA Yeah.

ALAN ALDA (NARRATION) Under direct radio control, the high school blimp wasn't even trying to fly autonomously.

ALAN ALDA You're in, you're in.

WOOTEN STUDENT No, OK. Concentration people. It's not working Mr. Best.

ALAN ALDA (NARRATION) But just by being here and flying, the Thomas Wooten Students have led the contest organizers to consider a high school version of the contest in the future.

ALAN ALDA What do you think you've learned here?

WOOTEN STUDENT The biggest thing I've learned is that, you know, even though we're a high school team we can overcome whatever challenge we need to overcome. It's amazing. I came here thinking, "Wow, we're out of our league." And coming and see that they have the same problems we do, it, it's, it's kind of a relief, you know?

ALAN ALDA Yeah, yeah. It gives you confidence.

WOOTEN STUDENT Right.

ALAN ALDA (NARRATION) The high schoolers had devised from a cylinder and magnet a clever device for picking up and dropping the discs -- a system that made Stanford's method for snagging discs look primitive.

STANFORD STUDENT How much do we want to shorten the string?

ANDREW CONWAY Oh, about that much.

STANFORD STUDENT About half, about half a meter?

ANDREW CONWAY Yes.

ALAN ALDA (NARRATION) But now that they'd taken my advice and shortened their string, Stanford took off again.

STEVE ROCK Hands off.

ALAN ALDA Oh you've got it, you've got it, you've got it. (applause)

STEVE ROCK OK, let's not get another one. If we can just move it to the center fence we can get points.

ALAN ALDA (NARRATION) The helicopter, all on its own, did everything it could to complete its mission.

STEVE ROCK All right, that's it whew!

ALAN ALDA (NARRATION) But the one thing its designers didn't have time to include was a way to drop the disk once it had reached its target. Ironically, what they'd planned to use was a device using a magnet and a cylinder.

ALAN ALDA Using that cylinder seems to be the way that the high school team solved that problem too.

STEVE ROCK It's almost an identical solution to the high school team; I was looking at that earlier. And they've got a real neat little system and it's the same kind of an idea that we had.

ALAN ALDA Is that as well as that's ever been done?

ROB MICHELSON That's the best it's ever been done in the history of the competition. And if they just had an intelligent device to let go of the dog gone thing, they would have totally completed the mission.

ALAN ALDA (NARRATION) In the final scores, the Texas tailsitter took third place, the Berlin blimp was second, and the Stanford helicopter-- so close to completing the mission-- came in first.

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