The arms of the Carnegie Mellon University Highly Intelligent Mobile Platform have treads for traveling on all fours.
A PENTAGON-SPONSORED COMPETITION COULD SPUR THE NEXT STAGE IN ROBOT EVOLUTION: THE ABILITY TO OPERATE IN THE HUMAN WORLD.

ESCAPE FROM THE LAB

NAME: ROBOSIMIAN

This robot, built by NASA's Jet Propulsion Lab, walks like a spider but can climb and manipulate tools like an ape.

NASA'S JET PROPULSION LABORATORY (JPL)
The robot looks relaxed behind the wheel of the all-terrain vehicle—one three-fingered hand gripping the wheel, the other clamped to the roll bar overhead. One mechanical foot hovers over the accelerator. The bipedal robot has the aspect of a laid-back teenage driver, flouting the rules of every driver’s-ed teacher in the world.

The casual pose is meant to keep the 209-pound machine from sliding in the seat as five young Japanese engineers from Tokyo-based Schaf, wearing blue vests and white hard hats, check power connections and run diagnostics on a laptop. It’s almost time for S-One—which looks like a minifrige with unnaturally long arms and strong legs that bend backward at the knee—to go for a ride.

There are hundreds of spectators at Homestead-Miami Speedway in Florida this December weekend, but instead of Nascar or IndyCar races, the crowd, pressed to a chain-link fence, is waiting to watch the teleoperated bot drive a Polaris Ranger XP 900 down a winding course. The 250-foot route is hemmed in with lane dividers, and empty plastic barrels are stacked two high at each of the six turns. Officials from the Defense Advanced Research Projects Agency (DARPA), including director Arati Prabhakar, join the media on the other side of the fence to get a closer look before S-One powers up. Prabhakar is a diminutive woman in a red baseball cap, her trademark white hair poking out the bottom, and a matching red vest that says DARPA Director on the back. She eyes S-One with interest and some suspicion. “People here are pretty comfortable with a robot behind the wheel,” she says of the swarm of technicians and media surrounding the all-terrain vehicle.

The machines have center stage, but the drama is human. The robot is only a tool, controlled by human masters. Housed in a garage several hundred yards away, the operators have only S-One’s cameras and laser sensors with which to perceive the outside world.

Finally the humans on the route clear a space and the robot is ready to roll. Its right foot pushes down on the accelerator and the Ranger lurches forward. At the first turn the foot lifts and the ATV halts—there’s no need for S-One to tap the brake, since the vehicle uses engine braking to automatically slow down. This isn’t Nascar: Six stop-and-go turns take 20 minutes. Applause and cheers fill the morning air when the vehicle crosses the finish line.

The Schaft team has become the first to complete the drive, one of eight tasks at the DARPA Robotics Challenge (DRC) trials, held late last year. Sixteen teams from universities, companies, and NASA have gathered at the speedway to compete in the most demanding robotic competition ever staged. Each event is designed to prove that robots can help people in the aftermath of disasters. DARPA intends to award $1 million for each of the top eight finishers, who will appear in the finals, to be held in 2014 or early 2015.

The DRC winner will take home $2 million, but those competing believe the stakes are larger. If the robots here perform well, they could jump-start a lucrative industry and re imagine the relationship between man and machine. “Mobile robotics is where the dot-com boom was during the 1990s,” Eric Meyhofer, lead technician of Team Tartan Rescue from Carnegie Mellon University, says. “We’re starting to see real general interest in this market. We’re lucky to be smack-dab in the middle of it.”

Modern robots are very good at a few very particular things. In an auto factory, for example, they are fast, precise, and powerful. But factory robots work in predictable environments and structured surroundings—on a stable base, in the same conditions, using identical tools to perform repetitious tasks. To make robots more useful in daily life, engineers need to get them ready for unpredictable places—like disaster zones.

DARPA modeled events at the DRC on conditions at the Fukushima Daiichi nuclear plant in Japan during its 2011 meltdown. Throughout that disaster, wheeled robots entered radioactively contaminated areas but could only transmit video images. If a robot had been able to open valves to vent hydrogen gas from the reactor, it might have prevented subsequent explosions. A robot capable of commandeering fire trucks abandoned in Fukushima’s contaminated zone could
The DARPA Robotics Challenge aims to prove robots can assist in the aftermath of disasters. Above: Members of Team MIT, inside a garage at the Homestead-Miami Speedway in Florida, prepare to teleoperate an Atlas robot during one of eight events. Right: An Atlas robot navigates uneven terrain. Below: S-One, from the Japan-based firm Schaft, climbs a ladder using legs that bend backward at the knee.
have refilled water in the ultrahot spent-fuel pools. "The world is built for human beings," Gill Pratt, the DARPA program manager who spearheaded the robotics challenge, says. "Robots need to operate in that environment."

To take robots out of the labs and factories, Pratt based the challenge around basic skills. Each team’s robot must walk across uneven terrain, climb a ladder, pick up a human tool and use it to cut through drywall, connect a fire hose, and turn valves. These are all tasks that a human being can easily do, and faster than a robot, but not in a radioactive or chemically toxic environment. "You won’t see robots racing to the rescue," Pratt says. "You’ll see robots being deliberate to the rescue."

DARPA added another wrinkle by limiting communications between the robot and its operators. Every other minute a black box in each team’s garage disrupts the signal to the robot, cutting the bandwidth to a narrow sliver. Such disrupted communications were a hallmark of Fukushima, and will likely be the case at future disaster sites.

The crucial engineering challenge at the DRC is to field a single robot that can perform all eight tasks. A door-opening robot is easy to envision and program, but making one that can also drive an ATV and climb a ladder adds a lot of complexity to the challenge. Most of the teams here are using man-size and shapped robots that can navigate environments built for humans—think of the height of stairs, the size of doors, and the location of cabinets. This also benefits the operators, who can more easily imagine what a robot is doing if it is built like a human. But a few DRC robots have alien aspects: NASA’s Jet Propulsion Lab, creator of the Mars rovers, operates a 238-pound, four-limbed creation called RoboSimian that uses seven actuators (joints) in each limb to brace itself when a limb applies force. Each of the six legs of the spindly, 150-pound Chiron, made by Utah-based Kairos Autonomi, can also perform manipulation tasks.

The most common robot at the DRC is the Atlas, a 6-foot 2-inch, 330-pound humanoid built by Boston Dynamics. DARPA purchased six for teams that earned their way to the DRC by writing code and defeating rivals in a virtual contest. Atlas has cameras and a scanning laser radar (lidar) where a human’s face would be. Given the DRC’s restricted bandwidth, the cameras provide only grainy views of the surroundings. The flickering lidar forms a rainbow of points on the operators’ screen, giving them the long-distance perception lacking in the cameras. The operator uses a mouse and joystick to tell the bot where to move its limbs. The robot processes the request, calculating the movement of each joint. These plan-into-motion equations are called inverse kinematics.

The DRC focuses on disaster response, but the teams envision much broader uses for their robots. The tasks here showcase attributes—dexterity, sensory awareness, and reliability—that robots will need to operate as our proxies in various environments. For example, a robotic attendant in a nursing home would have to open cabinets and doors that have different handles, latches, and heights, the same way it would when searching for survivors in a chemical-plant fire.
To have a future working for and with humans, limb control is crucial. “Robots are ridiculously strong, and things are fragile in the world,” Daniel Lofaro, a graduate student at Drexel University and leader of the school’s team, Hubo, says. “We need good feedback, and really quickly. The robot will turn the doorknob but tear the door off its hinges.”

One of the believers in the future of mobile robotics is Google. It bought eight robotics businesses in 2013, a dramatic move that is reshaping the industry. Two of these newly acquired companies are represented at the DRC trials—Schaft, founded by researchers from the University of Tokyo, and Massachusetts-based Boston Dynamics. Google announced its purchase of Boston Dynamics just a week before the DRC, and the news brought fresh excitement and relevancy to the event.

Boston Dynamics employees at the DRC seem happy about their new bosses. “I’ve been a part of more than seven acquisitions during my career,” one says. “This definitely doesn’t feel like a bad one.” Boston Dynamics made its money by fulfilling DARPA contracts for advanced prototypes, but employees say it’s a good time to trade Pentagon funding for Google investment. In 2015 several high-profile DARPA programs are ending—as is Gill Pratt’s tenure. “We weren’t sure where the next millions were going to come from,” the Boston Dynamics employee notes. “Now we do.”

DARPA, despite its military trappings, is fairly open about sharing its marvelous new robots. Google is tight-lipped about its advances. This proprietary mindset can already be seen at the speedway. The behavior of Team Schaft at the DRC stands in stark contrast to that of the other groups. Most teams bring along public relations staff to tout their universities and institutions, but Schaft is represented by one overworked Google employee from the California headquarters who didn’t even know the DRC existed before she was ordered to Florida to support it. Schaft offers no access and no comment, and even chases off journalists standing in permitted areas outside the garage, where signs establish a cordon and forbid any contact. Like a celebrity baby kept out of the limelight, the Schaft S-One robot draws a crowd whenever it appears. Other teams make sure to check out the cutting-edge machine—and indulge in some robot envy.

Christopher Rasmussen, a computer-science professor at the University of Delaware and member of Team Hubo, aims his camera as S-One begins the terrain task. It must walk 40 feet over a jumble of increasingly uneven and steep concrete blocks.
Like all robots here, S-One is secured by a safety tether to protect it in case of a fall. The robot takes its first step and the clock starts. S-One is stronger than most other competitors. Instead of using hydraulics, like Atlas, S-One is all electrical. Rather than relying on just a battery, it uses capacitors that can quickly supply lots of current to a limb. These millisecond bursts of power to its motors enable the robot to, for example, quickly generate torque in its knee to stabilize itself if it loses its balance.

Between each step, a cover in S-One’s boxy body tilts open to reveal a laser radar. Rasmussen crouches to peer inside, trying to glean details. “The inside surface of the door could help reflect the laser to the ground,” he guesses. He notes that the knees are constantly, minutely bending. “That makes it easier to balance,” he says, “but it sort of looks like it’s breathing.”

S-One takes a step down from a block and scrapes a knuckle on concrete. “That would have knocked over a lesser robot,” Rasmussen says. Unfazed, S-One continues down the pile and reaches level ground in less than 15 minutes. The cheers from observers in the stands cause teams at other events to turn their heads. Schaff scores three more points. The team hangs the unpowered robot on its wheeled carrier and spirits it off to the garage without a word to admirers.

By the middle of the second day, after S-One performs its final event, it has racked up 27 out of a possible 32 points, a first-place victory for the robot—and a clear win for Google.

The scoreboard tells dramatic tales as the trials come to an end. CHIMP, made by Carnegie Mellon’s Team Tartan Rescue, is staging an epic comeback. One of the few robots that was designed just for the competition, it has 10,600 mostly homemade parts. CHIMP—a beefy machine encased in a red metal shell and with tracks on its arms for traveling on all fours—scores a perfect four points in two events by turning three valves and cutting a neat
triangle in drywall. At day’s end it has scored 18 points, enough to place third.

Team Hubo is not so fortunate. Hampered by breakdowns, it finishes with just three points. “Disappointing,” Lofaro says.

NASA has mixed results. JPL’s RoboSimian places fifth with 14 points, but Valkyrie, made by the Johnson Space Center, tips over frequently and doesn’t earn a single point.

Team WRECS and its Atlas robot, Warner, are on the edge. Warner had a strong second day at the DRC, driving the entire ATV course in just 6 minutes. No other team finished the drive as quickly, and no other Atlas drove across the finish line. Now it has to perform well in its last event—the walk through uneven terrain—to secure a coveted spot in the top eight.

The robot picks its way through the rubble, earning two points, then pauses at the top of the third brick pile, teetering as it tries to regain stability. Team WRECS calls this the Atlas dance.

Warner steadies itself, to cheers, but two steps into its descent, the robot topples and swings like a marionette in its safety harness. The crowd moans, then applauds. Two points is enough to propel WRECS into a tie for sixth place. As one of the top eight teams, they’ll be back for the finals.

The DRC ends at sunset on Saturday. Hundreds of competitors file to the closing ceremonies, held at the speedway under a large white tent. They are exhausted, thrilled, disappointed, giddy, and happy to be here, surrounded by peers who understand what they are up to, and how hard it is to accomplish.

The emcee of the event introduces DARPA bigwigs, who give speeches. They proclaim what these believers already hold as canon—robots are coming. There’s a sense among the crowd that this is the place and time that the mobile-robot revolution found its footing.

It won’t happen again, not like this. Things can begin only once. PopMech