

Automating CapCom

Computer agents assist geologists at the Mars Desert Research Station

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PHOTOGRAPHY **WILLIAM J. CLANCEY**

“GPS tracking is enabled,” said the computer.

“Begin our walk to head of canyon activity,” said the geologist, simulating an astronaut walking on Mars.

As commander of NASA’s two-week mission to deploy and test a futuristic Extra-Vehicular Activity (EVA) computer system, I was thrilled to hear geologist Brent Garry’s words—our network of computer “agents,” strung over 5 kilometers of desert hills was finally working. With programs watching and talking to astronauts to guide their work, we had taken another step towards supporting the human exploration of Mars.

Here in a red dusty abandoned corner of Utah, my team of over twenty geologists, computer scientists, robotics engineers, and communications experts, was using the Mars Society’s Desert Research Station as a kind of technology development retreat. Seventy five miles north of Lake Powell and more than an hour’s drive west of Moab, this nearly lifeless desert isolated us from the interruptions of daily life, while providing a ready-at-hand inspiring and challenging terrain for simulated Mars EVAs. A crew of six lived in the Hab itself; everyone else bunked in Hanksville, a four-restaurant town and hole-in-the-mountain gas station, about 20 minutes away on a winding, rocky BLM road. Each morning at 9 a.m. we walked downladder for the briefing, while our companions arrived by SUV and truck to begin another day of program debugging and patience-demanding trials.

We learned our lesson well at the previous year’s field test in Arizona: Setting up computers under tarps in the desert is not a good idea. In September near Meteor Crater, we were alternately chased away by sky-high abstersos dust storms and pelting rain. Then our shoes cake-walked in the clay for hours after.

The Mars Society called its two-floor 8-meter diameter cylinder a “research station,” so why not use it that way? Although other Mars aficionados, including myself, had run Mars mission simulations here—following strict daily protocols, wearing simulated suits outside, and using water sparingly—we chose to set up a camp for software engineers, and do our work comfortably. So we filled both floors with dozens of laptops, set up a voice-commanded robot (from Johnson Space Center) in a trailer outside, configured

wireless relays linking our “multi-agent” software (Ames Research Center), and dragged down the road a 6 foot satellite dish (Glenn Research Center). Now we just had to make it work.



People versus robots? It's no contest: On a simulated Mars Extra-Vehicular Activity (EVA), geology graduate students, Abby Semple and Brent Garry, freely explore Lith Canyon. Using the Mobile Agents software developed at NASA-Ames Research Center, they record descriptions, associate samples, photos and named locations, and send their data to a remote team by email—all via voice commands. Johnson Space Center's EVA Robotic Assistant is on the ledge to the right; this prototype robot, like the rovers we now send to Mars, is unable to go where the geologists work.

Under generally fair and warm spring skies, our team struggled for nearly two weeks to bring the complex system to life. Our goal was an ambitious stretch, even for early 21st century computing technology: To automate the role of CapCom, that third player in the Apollo lunar traverses, the person sitting in Mission Control, back in Houston, the astronaut's point of contact with the flight directors and the backroom scientists. When we walk on Mars, such conversations with Earth will not be possible because of the time delay in radio transmissions. The Mars crew itself will be responsible for observing and advising their away team. Could a computer system help by watching and talking to the astronauts?

Apollo's CapCom, an always-present voice in the astronauts' ears, provided essential advice for navigating, keeping on schedule, and logging basic observations about the

Clancey: Automating CapCom

lunar surface and samples. Here is an excerpt from Apollo 17, EVA 2 (CapCom is Bob Parker):

- 146:17:08** CapCom: And just press on the same heading you've been carrying there, Gene, and that will get you to Camelot.
- 146:17:17** Cernan: We want the southwestern edge, huh?
- 146:17:20** Schmitt: Do you want to go where Station 5 is, Bob [that is, to the planned spot on the southwest rim]?
- 146:17:23** Parker: That's my understanding, Jack. So press on towards there unless I tell you otherwise.

These interactions were sometimes tedious, relaying data that can be transmitted automatically today using computerized sensors and wireless telemetry:

- 146:53:16** CapCom: And how about a frame callout [from the cameras] before you get back on, guys.
- 146:53:19** Cernan: Got it.
- 146:53:23** Schmitt: Yeah, I need some new...[Responding to Bob] Do you want me to get it [a new film magazine] here?
- 146:53:33** Cernan: CDR's [Gene's] at fifty.
- 146:53:34** CapCom: Copy that.
- 146:53:35** Schmitt: A hundred and seventy.
- 146:53:36** CapCom: Copy one seven zero.
- 146:53:37** Schmitt: LMP's 170.

Besides analyzing Apollo's historical record for ideas, I also had direct experience from two other stints in the Mars Society's research stations. Two years before I had joined the inaugural crew of the Flashline Mars Arctic Research Station on Devon Island in the Canadian High Arctic as an anthropologist–systems analyst, in a kind of “Mars boot camp” (*Popular Science*, October 2001). Then again, at the second research station, the near twin in Utah, I was commander for a rotation in April 2002, where I promoted the idea of a “closed simulation,” with no visitors and only email contact with the outside world. In both occasions, I watched my teammates fumble their handheld GPS devices, and argue over arcane coordinate systems—UTM or degrees? WGS84 or NAD27?

In studying our practices and imagining what could make work easier and more reliable, I was applying the design method I've pioneered at NASA—using the scientific method to experimentally use, study, and improve complex interactions of human roles, facilities, procedures, and tools. It's a world away from my earlier academic research experience, a form of “if you build it, they will come” or simply, throwing stuff over the wall.

In our unhappy experiences with GPS devices, I realized I had stumbled on the perfect application for our emerging technology we called “agents”: Connect the GPS devices to computers in the astronauts' backpacks, and have the programs (the agents) chat to each other to create maps and log EVA events. People wouldn't have to learn how to use the devices or handle them in the field at all. Astronauts could simply tell the computer

Clancey: Automating CapCom

“Name this place ‘Camelot crater,’” and later ask the computer for navigation directions for returning to that location. And so was born NASA’s “Mobile Agents” project—software running on moving backpacks, on robots and ATVs, linked to other laptops in the Hab, GPS devices, and PDAs receiving heart rate, blood oxygen, and other biosigns from sensors worn by the astronauts.



Simulating an EVA, Abby Semple and Brent Garry, struggle with maps and GPS devices to find their way. As happens on almost every traverse at Haughton in the Canadian Arctic and here in Utah, they have missed their turn and are unsure where they are. Perhaps surprisingly, this happened all the time on the moon, too.

My journal from MDRS Rotation 5 a year earlier (<http://www.marssociety.org/mdrs/fs01/0415/log.asp>) shows how the Mars Society’s mission simulations feed technology development:

I want [my colleagues at Ames] to begin thinking about designing software that will make the GPS unit fully invisible to an explorer. I don't want to wait for a satellite fix; I don't want to transcribe readings. I don't want to ever know the coordinates at all, let alone have to manually enter or compare them or number waypoints. I want a program to answer questions while I'm on EVA: "Has anyone taken samples near here before?" I also want the program to tell me things like: "Warning, you are

within 10 minutes of the reserve fuel supply required for safe return to the hab." Being here at MDRS this past week has given me very clear ideas about the navigation assistance and other monitoring required during remote exploration on ATVs. Until now, back at Ames and JSC, we weren't sure what to build; we had the methods, but not the requirements. That's why I call what we are doing here "empirical requirements analysis"—finding out what you need to build by doing simulations in the field.

After a year of development, we were now ready to deploy and experiment with the Mobile Agents system. The description of what this combination of devices can do is slightly mind boggling, even for the inventors: A voice-operated computer system that monitors astronauts' health, tracks their locations, and helps them keep on schedule—while recording all conversations and automatically emailing photographs, voice annotations, and tracking data to offsite observers. Although we replicated but a small part of what CapCom could do (for example, the agents cannot interpret the meaning of observations), we were also automating tasks Apollo engineers could only dream about 25 years ago. Especially, by using names for places and computer representations of EVA plans, we were giving the Mobile Agents system a way to follow what people were doing and provide useful warnings and rudimentary advice. Agents are by design proactive programs: They create models of their environment (and other programs), communicate their beliefs and ask questions of other agents, and carry out activities that respect their physical and temporal context.

Of course, that's all the theory; getting it to work is another matter. We had two weeks at MDRS—including three weekends—but we struggled continuously to resolve an apparently endless chain of problems. We had tested the system at NASA-Ames in California a few weeks before, but Silicon Valley's world of buildings and high-density radio communications posed entirely differently challenges than we now faced in a real geology terrain.

The field test was structured into "scenarios," based on sites I had scouted out the year before with geologists and biologists. We'd start easy, just walking out to the front porch of the Hab, progress to a walk around the Hab, then go down a ravine nearby. If all that worked, we'd move on to explorations a kilometer or more distant, climbing up and down hills and canyons.

Although conventionally called a field test, our expedition was not simply a test or a demonstration, but a full-blown effort to fix, try, study, and improve both software and hardware. We were here at MDRS to get the system working, and oddly this was the cheapest and fastest way to do it—learning as we went along, in the field itself, living and working together as a team, discovering and implementing a capability we'd need for Mars.



The Mars Desert Research Station appears as a twin of the Mars Arctic Research Station. On the ridge to the left is the Elon Musk Observatory, with a Celestron telescope. The Michigan Mars Rover is a prototype vehicle for long-duration EVAs, including eating, sleeping, and working areas for a crew of three. To the right is Johnson Space Center's EVA Robotic Assistant, a voice-commanded device. In the foreground is Rocky-C, an ATV equipped with laptop and antenna, serving as a repeater node in the Mobile Agent's network.

Our lessons would fill a small book, because our mistakes were numerous. Most problems were small matters we might have anticipated, but lacked the time back home to worry about and resolve. For instance, on the first trial outside the minibooks overheated and shut down. Adding more airholes in the plastic enclosure did the trick.

But frustrations quickly mounted as simple tests revealed the real problems in walking on an EVA with all this gear. At least misrecognized voice commands brought a few smiles: Once the speech system heard Abby say, "Send it time in cucumber and halt." Quite appropriately, the program responded, "I do not understand that command." After this experience, we modified communication agents to explicitly acknowledge each command, and just ignore everything else. Later, the speech system confirmed a command by pronouncing "camera" as came-R-A. People will always enjoy laughing at such mistakes, and we can look forward to decades of making fun of our robots.



Fish-eye view of the upper deck of MDRS. Private quarters for a crew of six appears to the right; a laptop work area lines the wall. The team is reviewing their individual “models” and making changing for the next test.

At the Thursday morning briefing, after we were still not running the system reliably outside in a simulated EVA mode with the geologists, I urged everyone to consider carefully what extra parts they might need and express mail them to Hanksville. “I don’t want to hear on Monday that you need something and don’t have it,” I said. But that day was a breakthrough, as everything worked “on the bench,” and we progressed to a test outside with the geologists wearing the backpacks and helmets with ordinary clothes.

The Mars Society helmets, although sometimes maligned for being adapted from garbage can lids, wonderfully solved a wind noise problem that made the speech recognition difficult. Cheered by success, I began to script a hour-long walk around the Hab. Meanwhile, adjustments were made to speed up the system by eliminating automated email of alerts and science data. Changing the Mobile Agents “models” in this way in the field was easy using our comfortable MDRS laboratory.

At the evening briefing we discussed an ongoing dilemma: Should we make sure everything worked inside the Hab, with all the components wired together, before moving outside to a wireless, and often radio-unfriendly environment? Logic argued both ways: Why go out if it’s not working yet in a controlled setting where it’s easier to

work? Experience replied: Well, it won't work anyway when you go outside because everything's different out there!

Faced with the harsh facts of system interactions, making the system work felt like a kind of adventure game, with surprises behind every door. For instance, our script called for the astronauts to tell the Mobile Agents system that they are starting to don their suit. But that was impossible in practice, because the geologists did not have their headsets connected to their backpacks until after their suit was on. Also, they could not tell the system to start tracking their location until they left the hab, because their GPS units were unable to acquire a signal inside. Back in the lab at home, nobody thought of these now obvious problems. Although the day-to-day progress was often slow and frustrating, we were making important discoveries, and dramatically improving the Mobile Agent design as we went along.



Sekou Crawford, an engineering graduate student at Stanford University, checks that the biosensors are properly taped on Brent. Sensors include heart rate, ECG, EEG, and blood oxygen. A wireless “NEXI-clip” (with software designed by the Stanford-NASA National Biocomputation Lab) enables the sensors to communicate with a PDA worn in an outside pocket (using the Bluetooth protocol), which then communicates with the Mobile Agents network. Using the headphones and microphone, the astronaut can inquire about the state of his biosigns and receive alerts, enabling the explorer to monitor his own health and make adjustments. On the right is a Mars Society EVA backpack, with a Mobile Agents computer package mounted in a rudimentary enclosure. Wires are for connecting the astronaut’s headset and GPS device which is strapped on top.

Clancey: Automating CapCom

Our life in the desert station went quickly over the next week, as we introduced repeaters into the wireless network, and began new struggles with the echo effect of “multipath” bouncing around the hills, and all too familiar bugs in the agent “models” that processed the voice commands. Bit by bit (literally), the Mobile Agent system was toughened, and we became optimistic that our favorite scenario could be attempted: The walk in Lith Canyon, about 5 km north of MDRS.

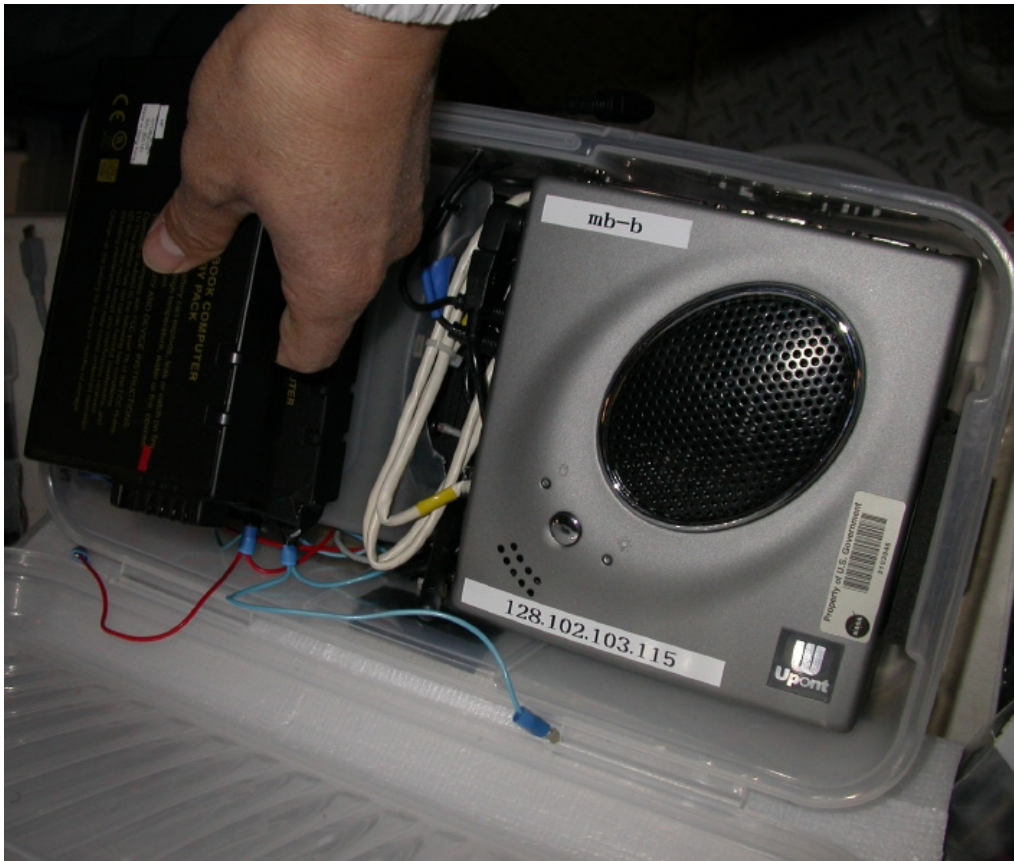
I awoke to a brisk, freezing Hab on Thursday morning of the second week. Wearing shorts and sandals as usual, I looked forward to the intense sun and warm breezes of late afternoon—not much like Mars, but it’s how Californian computer scientists like to work. Making people happy and productive was key to my scheme in bringing this complex operation to the desert. The weather was ideal for the plan: set up the repeaters from MDRS to Lith Canyon, and walk through the scenario to prove computer connectivity back to the Hab. We’d also use the IP (Internet Protocol) telephones provided by our network collaborators (from Glenn Research Center, sponsored by NASA's Research and Education Network (NREN)). The sorry static and thin voices of our walkie-talkie radios would be insufficient for this long-distance test.



Like a miner roaming the hills with a telescope searching for uranium, Rick Alena has the help of GPS and walkie-talkies to set up a wireless computer network. He is working above the head of Lith Canyon, the intended EVA site. The second repeater is located on the nearby brown hill to the left, framed by the Henry Mountains 30 miles distant in the south.

“Sekou will help me set up the first repeater on the hill about a mile north of here,” said Rick Alena, our computing network specialist, “then we’ll drive out of Lith and set up another near Lith.” It sounded like a good plan, but setting up and aligning the first antenna took most of the day. We didn’t drive out to Lith to set up the second repeater until nearly 6 p.m. To my disappointment, by the time we had established a solid internet link back to the hab, it was too late to run the walkthrough, allowing for safety in driving ATVs in the dark. So a tired group returned to the hab after 8 p.m. for a late meeting. I reminded everyone we still could make our objective of running a full-suit test with the geologists the next day. But this would be our last opportunity.

Meanwhile, the Mobile Agents software team made progress (we hoped), wringing out the identified bugs and tweaking the Brahms language to hasten agent responses. As commander and director of this movie-shoot-like operation, I prepared the final scenario script, using the online Terra Server map to interpolate a missing GPS coordinate in the computer's representation of the EVA plan. I reviewed the map and plan with Abby and Brent, with the idea that although they will see Lith for the first time during the EVA, on Mars they would have reviewed an aerial map and helped prepare an exploration plan.



Each geologist carries a Minibook computer, which runs the Mobile Agents software. On board is the “communication agent” that processes the astronaut’s commands and “astronaut personal agent” that relays alerts from the agents running on the HabCom computer back at MDRS.

As everyone else rushed to fine-tune the computer network and software, I also used the available time to round out Abby and Brent's geology exploration of the area. We investigated a plateau we call Oyster, because of its millions of preserved shells. Hiking up a long narrow passage on a spine of uneroded rock, about a mile south of MDRS, we climbed up from our Jurassic Period landscape, past a hard limestone cap, into the Cretaceous Period.

As an experiment, I asked our geology graduate students to find the oysters. In fact, shells covered many hills around us, but they resembled all the other sandy mounds visible over barren Old West horizon. Finally, after leading them directly to an oyster-

covered hill, they recognized the shells at their feet. Another lesson for me: Finding and identifying rocks, fossils, and other features is specialized know-how, and you often have to see something in the field to learn how to identify places and things like it.

Before I followed geologists around, I believed a folk view of geology, that scientists go around classifying rocks and layers according to textbook diagrams. I would have expected Abby and Brent to say, “This is Dakota limestone” and “We are passing from the Jurassic into the Cretaceous Period.” Instead, geologists who are truly exploring devote most of their effort to describing what they see. They may be reminded of home rocks and layer patterns. But if it is truly exploration—as on Mars or even an unfamiliar region of Earth—the activity involves following layers through hills, determining inclines, comparing grainsize and hardness, thinking about mineral types, and so on. Geologists combine a highly detailed local investigation of specific rocks (often opening them up to distinguish colorations from weathering effects) with attempts to make broad comparisons across the horizon. My baseline study of geologists was a key part of advising mission support back in Houston, too, about how we would plan a long stay on Mars.



Baseline Geology Study: Brent Garry investigates a strange pipelike structure at the top of a sandy hill. By studying how geologists prefer to work when unencumbered, we can learn what tools they will need on Mars, and be able to compare how suits, gloves, and rigid safety protocols affect the quality of their work.

Returning to the Hab for dinner, after a day of waiting for repeaters to be deployed, the crew chose to watch *The Dish*, a comedy about the Parke, Australia satellite dish used to relay Apollo 11 video from the moon to Earth. When the engineers declared that a 90 decibel signal was received, we nodded knowingly. Two weeks in the field and we were experts already.

The next morning, Friday, the crew awoke energized and focussed on the final test. As we walked outside with our coffees (no stuffy suits required on this technology retreat), the desert was already warm and promised a hot afternoon. Heat was a potential problem for the meager fans of the Mars Society's canvas suits. Already Brent had reported incipient heat exhaustion from a long EVA trial near the Hab, so I was concerned to monitor the situation closely.

We began the day with a thirty-minute meeting to sequence the day's activities, aiming to complete the Lith Canyon scenario. Rick Alena, working at the second repeater and Lith, would tune the repeater relay to achieve a stable computer network signal over the 5 km. Sekou Crawford would drive an ATV to the first repeater a mile north of MDRS to provide a radio relay to Rick. When we received a call back at the Hab on the IP phone, Maarten Sierhuis, the onsite Mobile Agents manager, would drive the backpacks with mini-books to Lith. John Dowding and Charles Lee, responsible for the voice commanding software, would then walk the backpacks through the scenario, while Maarten and Rick, monitoring from an ATV running a local area network (802.11b) searched for blind spots—network dropouts—from the minibooks back to the Hab. Ron van Hoof, playing the role we called HabCom, would provide this final information using a monitoring tool that instantly showed every agent on the network and what it was doing. (Including this in our toolkit was another hard-earned lesson from Arizona the previous year.) Putting all this together, we would know when and whether we could run Mobile Agents system in the Lith Canyon area.

Unfortunately, the restriction of two repeater hops required us to use a local area network in the canyon itself. Time would not allow reconfiguring the PDAs used by the biosensors to connect to the network, so this part of the test would need to be dropped. Such unexpected problems were typical and always left me puzzled: Who should have known this might occur? How might they have discovered the limitation and planned a work-around? What might I have done in coordinating the group to help them fit things together better?

But all those questions were for the next year of analysis. Today we were making the best of the system we had brought to the field. The IP phone call arrived at MDRS about 12:30 p.m.; Maarten departed for Lith with the backpacks and computers in an SUV.

Abby, Brent, and I then began preparing to drive Everest, the Michigan “pressurized” rover, to the canyon. This modified truck would provide a handy changing room for suiting up at Lith, plus add a note of drama to the test. I was always visualized these tests cinematically, planning my shots, the angles, and the scenes like a movie director.

Clancey: Automating CapCom

We arrived at Lith Canyon just before 1:30 p.m. at a quite warm (77 F), dry (6% humidity), and breezy site. Today was the first time Abby and Brent would see this dramatic place, and I felt butterflies of anticipation as we drove down the BLM road from the Hab.

Maarten's orchestrated walkthrough had established that the first third of the canyon was invisible to the ATV we called Rocky-C, which was distributing the LAN signal. However, the middle third, as well as the approach area above, was in good range. The return walk out of the canyon around the bend was visible to the ATV, but too far to detect the backpack computers. With this configuration, we could run the planned EVA scenario, but voice commands would queue in the geologist's personal computers, to be relayed when they stepped into range of Rocky-C.

Brent and Abby began suiting up in Everest about 2:45 p.m. The minibooks were turned on about 3 p.m. This established the end of the sim as 5:30 p.m., when batteries would be exhausted.



After donning their suits and backpacks inside Everest, Abby and Brent review their maps and the scenario activity plan, while they wait for Maarten to signal that the Mobile Agents system is initialized. The author, who scripted and documented this EVA scenario, is just visible reflected between them. Meanwhile, Nathan Howard moves Boudreaux into position. The uneven terrain prevents “autonomous” movement along the canyon ledge.

Meanwhile, JSC engineers, Nathan Howard and Rob Hirsh, drove the ERA (Boudreaux) along the canyon rim to a point near the bend, where it was parked right on the edge. Besides being the most picturesque setting, this location enabled the ERA to serve as a LAN bridge for the computer backpacks down in canyon. However, this configuration

proved to destabilize the network because of antenna placement on the ERA and had to be abandoned. I made another mental note: Who could have known this? When?

The geologists suited up inside Everest, and stepped down the precarious ladder. But the link to Abby's minibook remained unstable. The Mobile Agents initialization process required that all computer platforms—minibooks, ERA, Rocky-C, and HabCom—be in contact with each other. Standing in the shade outside Everest did not help, possibly because the huge metal reflector of the truck's side, or possibly because Everest, Rocky-C, and the nearby differential GPS transmitter on a hill used by the ERA were nearly aligned. Also, winds were now picking up, causing the distant repeaters to sway out of alignment.

Piqued a bit by this discoordination, I agreed that the first steps of the scenario had to be adjusted. So the geologists' initial commands would occur at the first stop, the hill of fossilized wood. On the way, Maarten detected, using software that linked to Abby's backpack, that a mess of icons were littering her desktop. So Charles Lee ran over, lifted the hood, and rebooted Abby's minibook.



Charles Lee opens up Abby's minibook to unplug the network cable and restart the system. Possibly the problem began while starting the computer inside Everest, where network connectivity was sporadic.

Rick became agitated, suddenly realizing that placing Abby's water pouch between the backpack's frame and the minibook might be hiding the LAN signal. "People don't realize," he said, "but water is a good insulator!" Sure enough, the walkthrough test just a few hours before had not included the water pouches. I covered my face with my hands. Another mental note. Why hadn't the walkthrough started back at the parking area? We

might have discovered the problem with the GPS antenna or Everest's shielding. These experiences only reinforced our wariness with "on the bench" testing—you might as well set up the full scenario and run it, for that is the system you must get working.

Finally, about 4 p.m., already an hour after starting the minibooks and pressure mounting to begin the EVA lest the test be scrubbed for the day, Maarten successfully "pinged" Abby's minibook. Ten minutes later Ron, speaking to Maarten at Rocky-C via IP phone, reported connection back at MDRS and began the Mobile Agents initialization process. Amazingly quickly, after so many months of anticipation and false starts, Abby and Brent were following the scenario, naming the location, creating a sample bag, taking photos, and providing voice annotations for these.

"Name this location cauliflower," said Abby.

"Do you want to name this location Cauliflower?" responded her personal agent.

"Yes," replied Abby. "Associate sample bag 3 with Cauliflower."

"Download all images from my camera," Brent commanded.

"Do you want to download all images from your camera?" his personal agent asked.

"Yes," Brent replied.



First EVA image to be transmitted automatically from the field to a remote science team, using the NASA-Ames Mobile Agents system. The image was downloaded by voice command, then automatically sent by FTP (file transfer protocol) by the astronaut's personal agent to HabCom's computer at MDRS (5 km distant). The image was then automatically emailed by HabCom's personal agent, using the internet service provided by the NREN/NASA-Glenn satellite dish.

After working independently for about 20 minutes, Brent and Abby talked briefly about their work. “I named this location Cauliflower,” Abby said. “Oh, I forgot to give it a name,” Brent replied. Another mental note for me: How would the astronauts know the names each had used if they worked independently? The Mobile Agent system could tell them that a name had already been assigned. Or they might wear a map on their wrist that would immediately light up with a new name on the map of their location.

I was excited that in the first few minutes we had already learned ways to improve the system, and that although rudimentary, our first attempt to automate the role of CapCom was useful.

The geologist-astronauts then proceeded into the canyon, into the shadow of the Rocky-C relay, and explored the area. Brent recorded a voice note while walking to the head of the canyon—another surprise, for we had visualized that voice notes would be about rocks and surfaces described while standing still.



Abby and Brent can independently address their personal agents, running on their backpacks. Abby takes a sample, and Brent takes a photo. When work here is completed, Brent says, "Start walk to the head of canyon activity." The activity plan is represented using Brahms activity modeling language, as named locations with GPS coordinates and scheduled work durations with alert thresholds. The plan allowed for the walk to take ten minutes; the crew was alerted automatically that they exceeded this time. A future version might also help them find their way.

While walking around the bend of the canyon, they encountered an obstacle that required climbing down, precariously close to a puddle of deep red water, well visited by martian cattle. They elected to take a different route, which brought them to the ledge where Boudreaux was parked—nicely illustrating how the activity tracking system must be extended to allow the astronauts to tell the computer they are making a detour. Posing and smiling, Brent and Abby asked Boudreaux to take a picture of them. Shortly

thereafter Brent reported that his minibook was no longer responding. With battery power exhausted, and the NREN folks waiting for me to arrive back at MDRS to participate in a video conference, we elected to not replace the batteries. The long anticipated Lith Canyon scenario, visualized nearly a year before when I was commander of MDRS Rotation 5, was now a wrap.



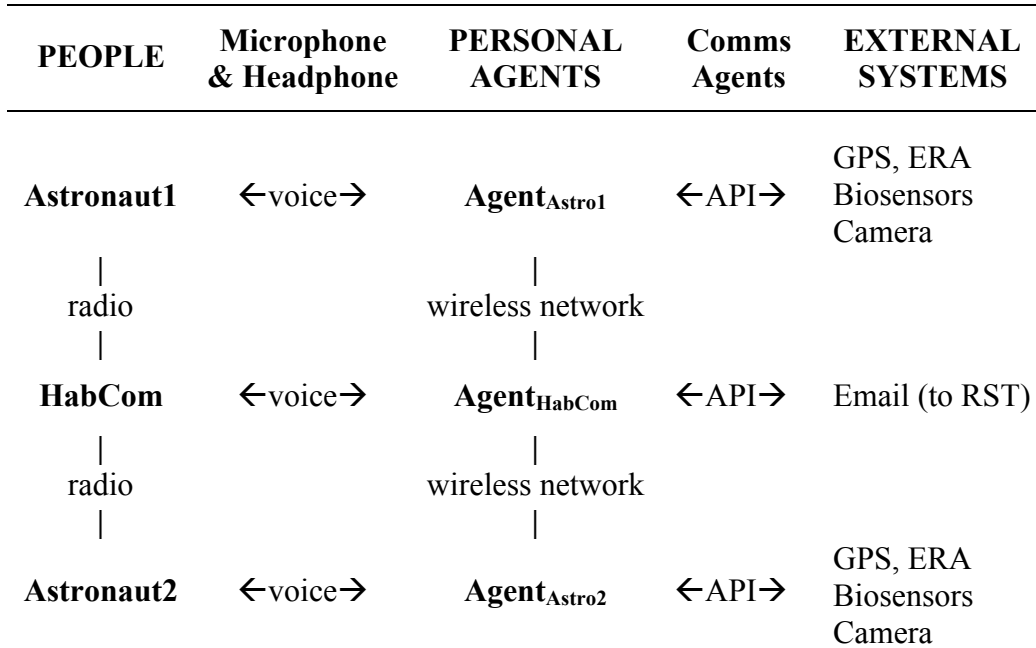
“Boudreaux, take a picture of me.” Having climbed up to where Boudreaux is parked, and standing strategically in front of the camera, the geologists use voice commanding to ask the robot to take a picture. The command is routed through Rocky-C, a Mobile Agents node running on laptop on the back of the ATV parked on the other side of the canyon to their far left. Another Mobile Agents laptop attached to Boudreaux translates the request into a command that controls Boudreaux’s camera and sends the photo to the MDRS hab, again using Rocky-C and two repeaters. Monitoring in the Hab, the crew member can track the entire process as it unfolds over just a few seconds.

The drive back to the Hab in Everest, and all the evening’s activities felt like a victory dance. Smiling wide and commenting on the group’s progress, Brent said, “Ten days ago, we couldn’t get off the front porch. Today I was walking through a canyon 5 km away talking to the hab computer!”

I nodded. We had done what we said we would do. For the first time, a field geologist, miles from any town or pavement, had told a computer to transmit photographs—of a place named, recording his location, time, and activity automatically—out over a satellite to a remote scientist. In the decades to come, there is little doubt that EVAs will be done this way, using a computer system that listens to the astronauts and supports their work,

lessening the monitoring tasks for the crew in the Hab. This is how EVAs will be done on Mars, and here in the red desert of Utah, we had made the next step to making it real.

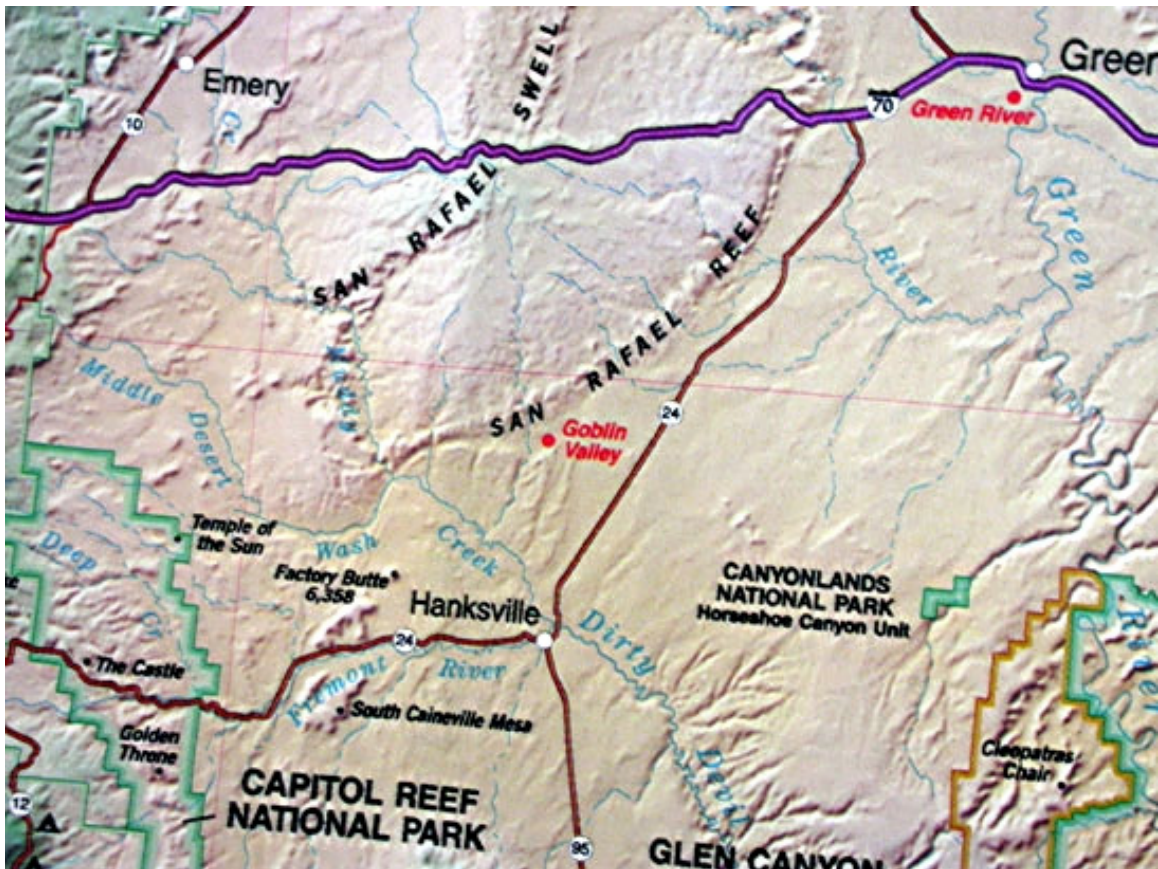
SIDEBAR: How the Mobile Agents System Works



Simplified schematic of automated CapCom implemented in the Mobile Agents architecture: People (astronauts and HabCom) communicate via radio; people speak to their Personal Agents on local computers using a microphone and receive feedback on their headphone. Personal agents are communicating locally with external systems (e.g., biosensors) via “communications agents,” providing an Application Programming Interface (API) to read data and control devices (e.g., camera). Finally, Personal Agents (implemented in the Brahms language on different computers) communicate with each other via a wireless network (with repeaters) using an “agent registration” system, similar to how computers communicate on the web via IP addresses.

FIGURE: Where's the Mars Desert Research Station?

The Mars Desert Research Station is in the Morrison Formation, popularly called a “painted desert,” near Hanksville, UT. The “Hab” is the large white cylinder just below the picture’s center. (Photo by Frank Schubert)



The Mars Desert Research Station is south of San Rafael Reef, northwest of Hanksville, UT. (Map is copyrighted.)

SIDEBAR: Voice Commands: How people talk to their computer agents

The vocabulary for the Mobile Agents voice commanding system tested at MDRS during Rotation 16 included both commands for doing geology and for controlling the software system. Many variants are possible. For example, one could say “photos” or “pictures” instead of “images.” Location names were selected from a predefined list of vegetables (e.g., okra) or referred to as numbered sites or waypoints.

The voice commanding system was implemented by John Dowding, member of the RIALIST group, which is part of the RIACS organization at NASA-Ames.

Science Data Gathering and Robot Control Commands

call this location <location name>

where is {<location name> | Boudreaux}?

where am I?

record/play a voice note {associated with <location name> | sample bag #}

associate (this) voice note with <location name>

create sample bag #

associate {this} sample bag {#} with <location name>

start <activity name> activity

how much time is left {until next activity}?

Boudreaux take a picture of {tracked astronaut | <location name> }

Boudreaux move to <location>

Boudreaux follow me/stop following me

Boudreaux come to me

Boudreaux wait at <location> {for <N> minutes}

Boudreaux go home

Boudreaux halt

Administrative Commands

{start | stop} tracking my location {every <N> seconds}

set distance threshold for <activity name> to # {meters | minutes}

{start | stop} logging my bio sensors {every <N> seconds}

download {all | one} images {from my camera}

{enable | disable} all alerting

disable last alert

{enable | disable} automatic email

SIDEBAR: Representing an EVA Plan in the Computer

EVAs are described in the computer as a list of activities with locations, durations, and thresholds. These descriptions are called *representations* and constitute part of the Mobile Agent *model* of agents, locations, and devices. Besides a list of several dozen predefined names (e.g., “climbing out of canyon”), activities may be described using the phrases “site <number>” or “waypoint <number>.” Astronauts may skip around or omit activities. By telling the agent system what they are doing, expectations are defined according to the plan of where the astronauts will go and how long they will be working at this location.

For example, here is the start of the Scenario #3, the EVA at Lith Canyon. Each activity specifies (duration in minutes, duration threshold in minutes, distance threshold in meters).

ACTIVITY PLAN	GEOLOGISTS' SCRIPT
<EVA PREP> (-,-,-)	<ol style="list-style-type: none"> 1. Drive in EVEREST with backpacks, helmets, suits, all equipment 2. Start Minibooks & GPS 3. Don suit with boots, gaiters, radios & headsets 4. Put on backpack & helmet & connect cables
Checking equipment (20, 5, 20)	<ol style="list-style-type: none"> 1. “Start CHECKING EQUIPMENT activity” 2. “Start tracking my location every 60 seconds” 3. “Start tracking my biosensors every 5 minutes” 4. “Start WALKING TO TOP OF CANYON activity”
Walking to top of canyon (10, 0, 10)	
Sample fossils (10, 5, 0)	<ol style="list-style-type: none"> 1. “Start SAMPLE FOSSILS activity” 2. Sample bag, voice annotation, association, photo 3. “Start WALK TO HEAD OF CANYON activity”
Walk to head of canyon (10, 0, 10)	< Walk carefully down the hill and proceed to the head of the canyon to the south (your left) >