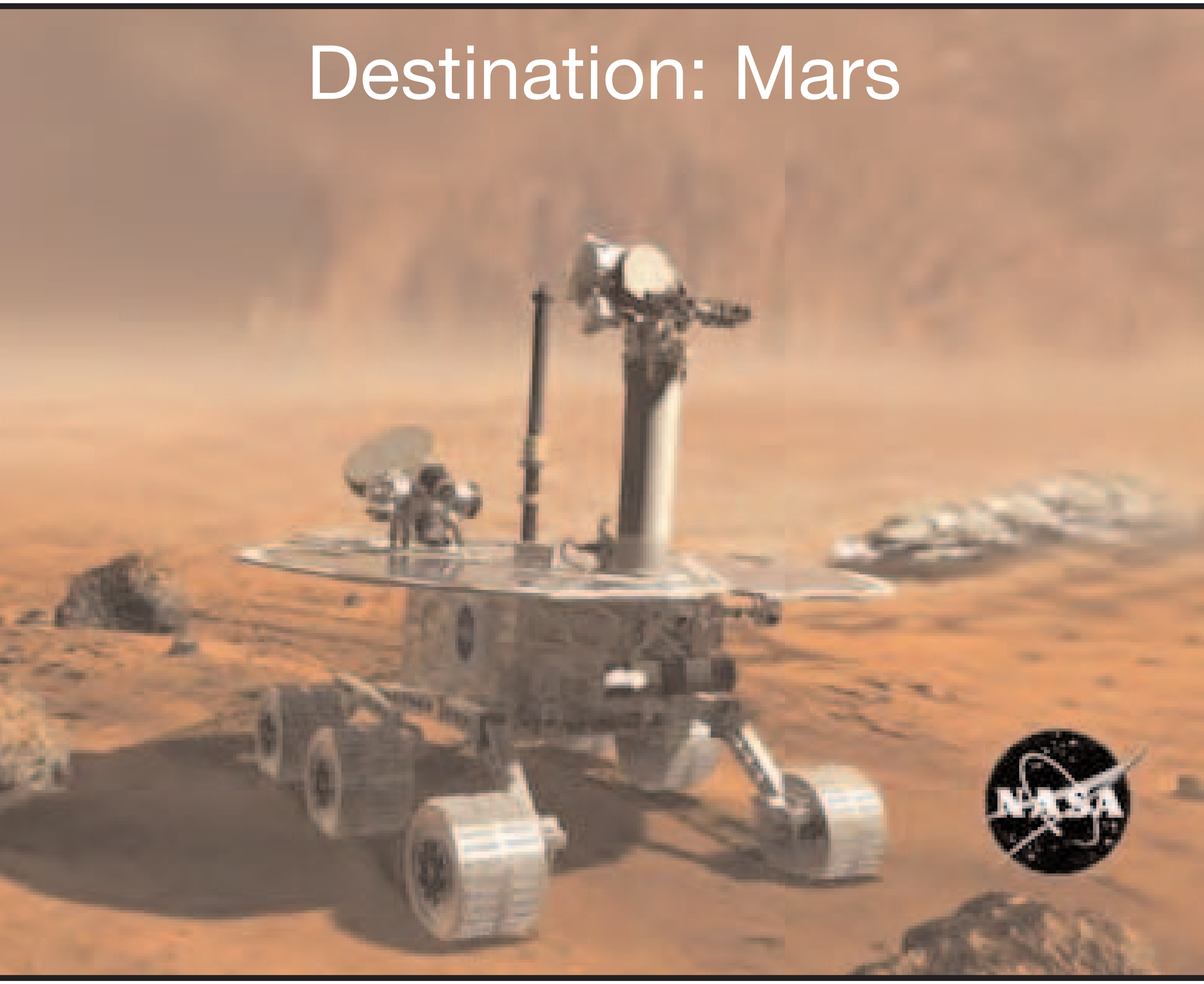
automated software engineering autonomy and robotics collaborative assistant systems neuro engineering

intelligence report

A publication of NASA Ames Research Center's Computational Sciences Division

Destination: Mars



From the division chief

Welcome to the *Intelligence Report.* At NASA Ames Research Center, the Computational Sciences Division (Code IC) is the premier organization for advanced NASA mission-driven, user focused, software research and development. We cover the spectrum from autonomy and robotic technologies, through neural-adaptive controls, to collaborative information architectures and automated software engineering.

Code IC R&D supports all of NASA's Enterprises, however this first issue we have decided to focus on some of the advanced software projects and research impacting the current Mars Mission managed by NASA's Jet Propulsion Laboratory in Pasadena, Calif. The technologies described here showcase some of the breadth and depth of our work.

We are justly proud of our role as a NASA, world-class research organization in computer science and information technology. We hope that this short report helps you to understand our work and the role that our Division plays in moving NASA toward its goals:

To understand and protect our home planet,
To explore the universe, and search for life,
To inspire the next generation of explorers
... as only NASA can

Dr. David Korsmeyer

Intelligence Report

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contact
Intelligence Report
Beth Minneci
mail stop 269-1
Moffett Field, CA 94035
outreach@email.arc.nasa.gov

Computational Sciences Division

on the cover

Each of the twin 2003 Mars Exploration Rovers is equipped with cameras and an instrument-packed robotic arm.

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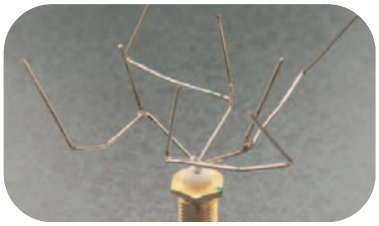

The Evolvable Systems group's evolvable antenna could become the first piece of evolvable hardware in space. The group's work is grabbing attention from the technology and engineering communities.

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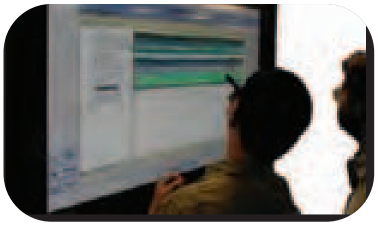


An around-the-clock Mars Exploration Rover Mission includes daily collaboration among hundreds of scientists and engineers. This calls for innovative information management and communication tools.

also in this issue

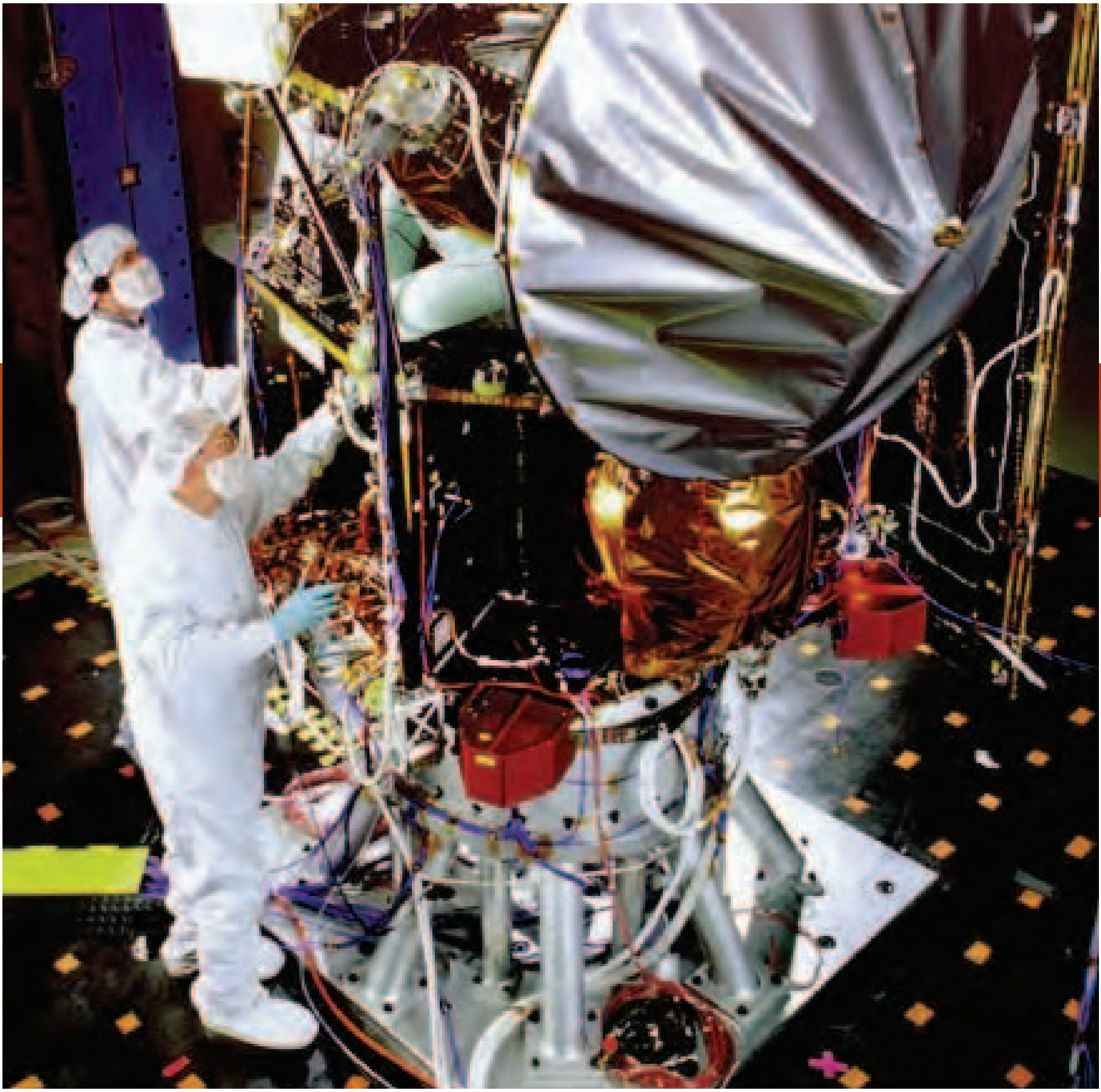
The Computational Sciences Division provides leadership in information sciences for NASA by conducting world-class computational sciences research, developing and demonstrating innovative technologies and transferring these new capabilities for utilization in support of NASA missions and national needs. Located at Ames Research Center in Silicon Valley, the division comprises four concentrated areas of computer science and information technology research and development:

Automated Software Engineering As software increases in size and complexity, future applications such as autonomous spacecraft control systems and advanced avionics will become enormous responsibilities in terms of human safety and mission costs. Automated reasoning tools that can generate new software code, verify that existing code is free of errors and prove that software has been designed correctly will be crucial to the development of these next-generation applications.

Collaborative and Assistant Systems The goal of this research is to design new information technologies to facilitate the process by which NASA engineers, scientists and mission personnel collaborate in their unique work settings. The research activities in this area focus on applying information management, artificial intelligence and computer-supported cooperative systems that are more usable, that augment human cognition and that facilitate the specialized work of distributed teams in NASA mission settings.

Autonomy and Robotics provides research and engineering applicable to various computer science applications and to new technology developments that enable a new era of autonomous spacecraft and autonomous robotic exploration with intelligent, self-monitoring and recoverable systems.

Neuro Engineering is focused on intelligent, self-monitoring systems that require adaptive behaviors to enhance mission effectiveness while providing substantial improvements in operational safety and efficiency. An enduring vision is to develop systems capable of control and recovery with minimal human intervention and to enhance analysis techniques that maximize science return and computational efficiency.



The Mars Climate Orbiter

C Global Surveyor

will enable NASA missions with greater reliability and reduced risk

During past missions to Mars, the results of software errors, or even design or process errors that lead to software problems, have ranged from the loss of scientific data to the loss of entire missions.

The Mars Climate Orbiter burned in the Martian atmosphere in 1999 after missing its orbit insertion because unit computations were inconsistent.

The same year Mars Polar Lander is suspected of having crashed on Mars when a software flag was not reset properly.

In contrast to those failures, the 1997 Mars Pathfinder (MPF) technology demonstration mission was considered a huge success when its Sojourner rover navigated about 100 yards across the planet in 87 days – far exceeding its life expectancy of seven days. However, a day's exploration time was lost when ground support teams were forced to reboot the system while downloading science data.

CGS is finding software errors automatically, and faster and more precisely than traditional, manual testing methods

Bugs are inevitable but must be uncovered early to ensure the most reliable software at the lowest cost. It is estimated that about half of software development costs are attributed to making sure the coding is correct. Considering the price of a space mission, the cost of an error could range from thousands during development to millions once a mission is under way.

About half of software development costs are attributed to making sure the coding is correct.

NASA's 2003 Mars Exploration Rover (MER) Mission is to land two rovers on the Martian surface in January 2004 to sample rocks, soils and the atmosphere for at least 90 days.

At $400 million a rover, a coding error that shuts down a rover overnight would in effect be a $4.4 million mistake, not to mention a loss of valuable exploration time on the planet.

To catch such problems in the software code that flies during missions, a software verification and validation technique being developed at Ames is finding flaws automatically, faster and more precisely than before.

“We detect what can interrupt the program, what can cause the program to crash,” says researcher Guillaume Brat.

Software systems driving missions such as MER contain hundreds of thousands of lines of code that NASA developers currently test manually by writing test drivers and running tests as they write the code. The task is time-consuming and cumbersome. Furthermore, NASA's large systems with real-time decision capability are difficult to develop and validate because the possibilities for outcomes are so vast.

In the future, software tools like CGS may prevent failures like the 1999 Mars Polar Lander mission

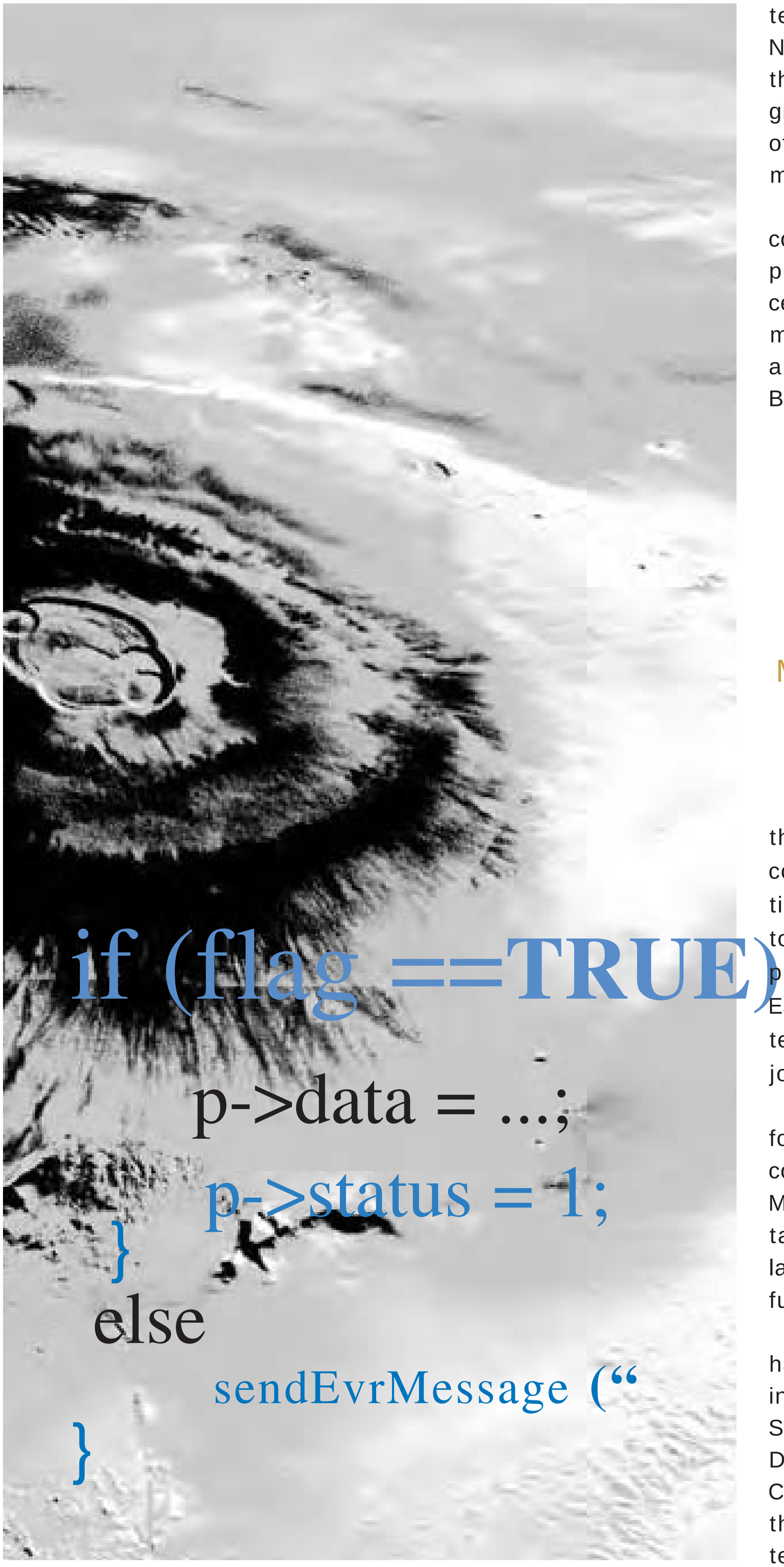
Brat is part of a team of two developing C Global Surveyor (CGS), a software program based on a technique pioneered in the 1970s that hides all the data except what is necessary for finding errors. The software detects errors automatically, covering all possible execution paths without ever executing the program. Using a tool like CGS can save developers countless hours debugging code, says researcher Arnaud Venet. “You make the computer work for you instead of spending hours doing it.”

With CGS, Brat says, “we can reason about all the behaviors with the program at once without having to go through each one of them.”

Since its inception, just a few researchers have worked with abstract interpretation, trying to prove that the technique is practical. At present, just 20 or so people in the world might be working to develop efficient algorithms for the technique.

The CGS team started its research with tests using a commercial software tool that uses algorithms for abstract interpretation, to evaluate its effectiveness and to generate interest in a validation and verification tool.

Between the summers of 2002 and 2003 the



```
if (flag ==TRUE)
        p->data = ...;
        p->status = 1;
   }
  else
        sendEvrMessage (“
}
```

team processed modules from NASA's Deep Space 1, a spacecraft that in 1999 flight-tested technologies for future missions, and parts of the 1997 Mars Pathfinder (MPF) mission and MER.

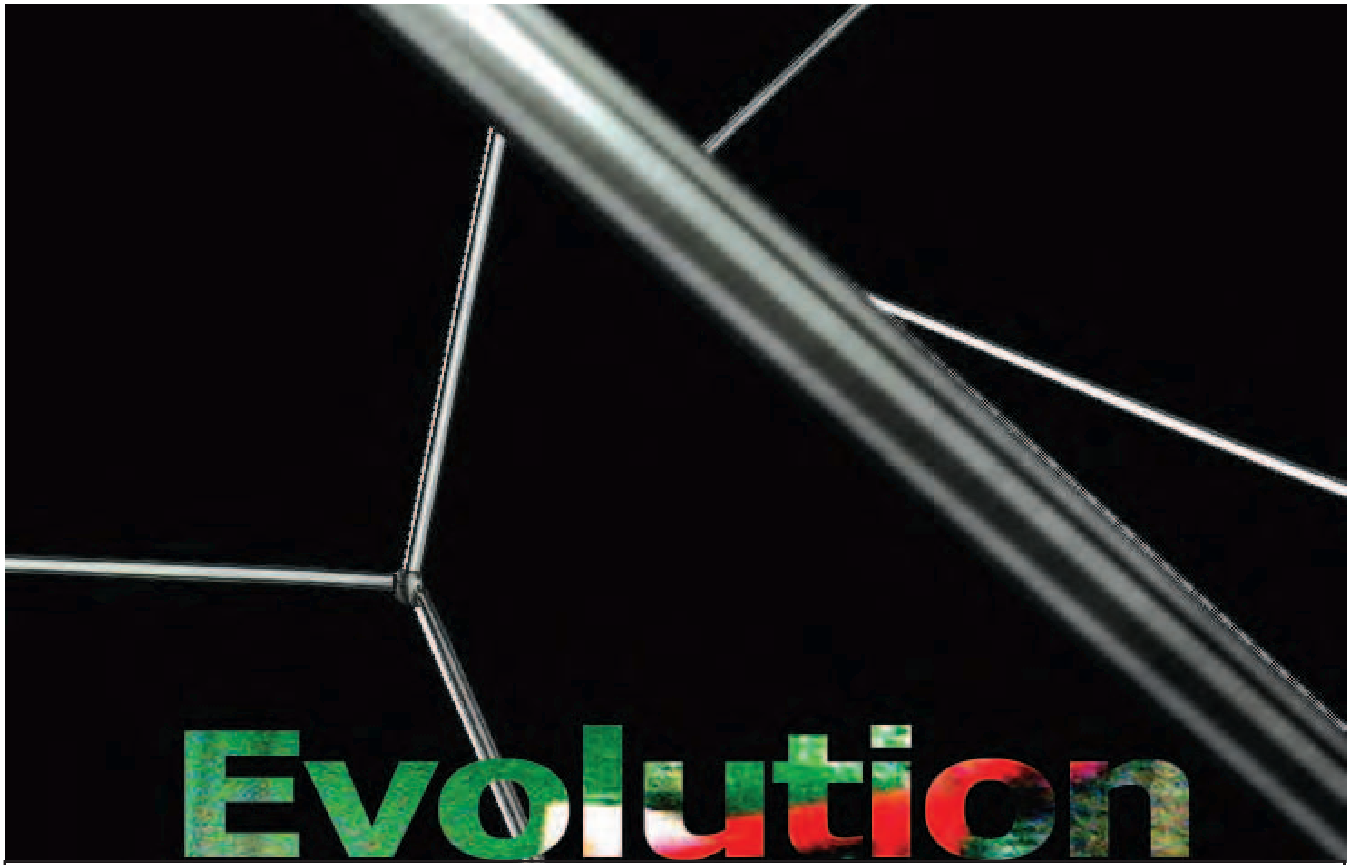
During a test with MPF code the commercial tool returned 80 to 85 precision, leaving 15 to 20 percent of the code to be checked manually. “In a mission, that's still a lot of things you have to verify,” Brat says.

> The Mars Technology Program has invested in CGS, and is studying its use for the 2009 Mars Science Laboratory mission.

Six months later, in June 2003, the team applied CGS to the same code, dropping the processing time dramatically, from 40 hours to 35 minutes -- and boosting precision to 90 to 95 percent. Early in July the team ran another test. The program completed the job in about 25 minutes.

Currently, CGS is built to look for runtime errors in C code, the coding language for the current Mars mission. Next the group will target C++, the programming language that will be adopted for future missions.

The Mars Technology Program has invested in CGS, and is studying its use for the 2009 Mars Science Laboratory mission. During the next few years the CGS team will customize and test the tool in the MSL software system environment. ■



Evolution in a computer

Computer scientists at NASA are building software programs that design hardware the way 19th century naturalist Charles Darwin might have suggested, by natural selection.

Darwin's theory says that evolution produces better species from organisms best adapted to their environment. The Evolvable Systems group at Ames Research Center's Computational Sciences Division builds software that mimics Darwin's theory to make new inventions. It's survival of the fittest hardware.

“We're taking our cue and inspiration from nature,” says Jason Lohn, who leads the group that captures evolution inside a computer.

➤

An antenna designed by a computer might become the first piece of evolvable hardware in space in 2004.

“This was designed by a computer, and it actually works.”

- Jason Lohn, project lead

With his fingertips Lohn holds what looks like a ball of unwound paper clips. The half dollar-sized piece of metal is a high-tech communications antenna capable of sending and receiving signals while orbiting Earth.

“It's actually a functioning antenna,” he says, pointing to its four symmetrical prongs. “This was designed by a computer -- that's the cool thing about it, and it actually works. No human would build an antenna as crazy as this.”

Evolutionary algorithms were invented about 40 years ago but only became practical in the 1990s when computers became fast enough to use them. The programs typically run on a supercomputer. This project runs on 35 PCs networked together using Linux. These days artificial evolution is gaining popularity as an application for building many types of hardware, from engines to circuits as well as antennas.

“It's an area that NASA is very interested in, and it's a growing field,” Lohn says. “We wanted to see if computers can do things without telling them how to design them. You tell a computer to do x,y,z -- out spits the design you want.”

The group's most recent design is the antenna Lohn holds, which is undergoing tests that will tell if it's fit to be launched with three miniature satellites scheduled for orbit in 2004. This New Millennium Mission, Space Technology 5, will test multiple technologies and mission concepts for future use. Each technology represents a breakthrough in performance, capability or application in a unique manner.

If launched the evolved antenna will be the first piece of evolved equipment in space.

Evolutionary algorithms start with a set of human-made specifications. From these the program will generate populations of hundreds of designs, each encoded in an artificial chromosome. For an antenna, genes might specify its branching structure and the lengths and widths of each wire.

The program's first populations will likely be quite rough, varying among themselves in their makeup, but will produce superior designs by repeatedly taking the best antennas and using them as "parents" to make new ones, says researcher Greg Hornby.

"Just like in the real world you'd breed horses or dogs or plants, the computer program breeds the antennas. After a while the population converges and doesn't get any better. In the natural world, crocodiles and dragonflies are the same they were a hundred million years ago."

Add to Darwin's evolution Mendel's genetics, which says individuals inherit characteristics through the combination of genes from parent cells. Genetic mutation and crossover create new designs called "children."

In a broad sense, genetic mutation makes a random change to a chromosome. In the computational world of artificial evolution a program performs genetic mutations by making small changes to the values of the genes in the artificial chromosome. With crossover, the program combines parts from two good designs to make children.

Says Lohn, "The idea is that you want to be able to come up with chromosomes that have a higher performance than their parents so that the kids are better designs than the parent designs."

In a few months the programs will have created hundreds of thousands or even millions of individuals with a few considered best, or genetically fittest.

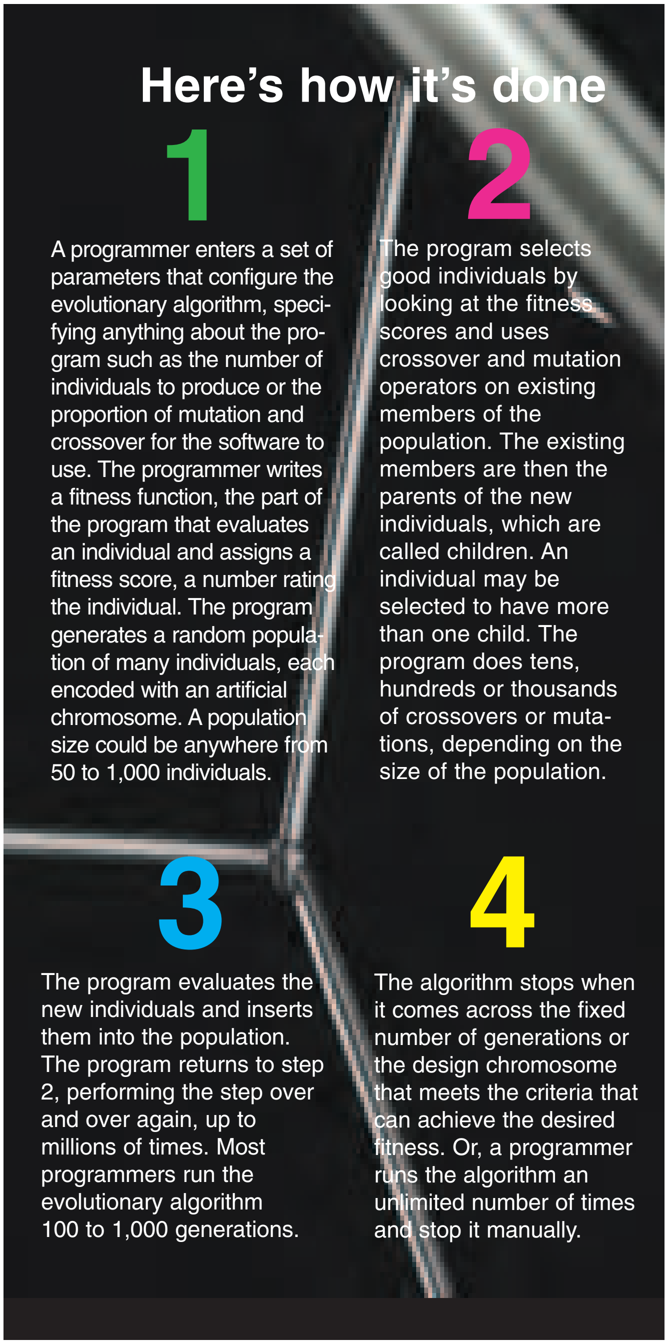
New Mexico State University researcher Bruce Blevins says an experienced antenna designer would need 12 years working full time to process 100,000 design evolutions, compared to five days for one processor. Blevins works for the university's Physical Science Laboratory, which built the actual mission antenna for ST5. "And there is no guarantee that the person would come up with a design that is as good," he adds. "I'm very interested in learning the techniques."

Starting an evolutionary algorithm is like an art form. The computer programmer must set up many parameters and build models that will slow or quicken an evolving system depending on the amount of detail the programmer wants the system to examine.

Conducting objects that are nearby affect an antenna's performance. "If you've ever played with a TV antenna you realize that every material within the vicinity of the antenna effects its performance," says Hornby. The Ames group mathematically models the environment in which the antenna will operate, a necessary feature for the evolutionary algorithms to work. The software designs the antenna as if it is bolted onto the spacecraft, "and that's not something that's easy for antenna designers to do," Lohn says.

The Evolvable Systems group began studying evolvable algorithms in 2001 building what's known as a Yagi-Uda antenna, the TV antennas that commonly topped houses before cable television. Next they did a proof of concept study, optimizing an antenna used by NASA's Mars Odyssey orbiter that was launched in 2001 and is still returning Mars images to Earth.

In addition to automated antenna design, the Evolvable Systems group builds algorithms that design chips that fix themselves, circuits, coevolutionary algorithms and schedules for satellite fleets. But antennas are a big focus because of their importance in NASA missions and because antennas are difficult to design. In the future, evolutionary designs may become a common tool for designers. ■



Here's how it's done

1

A programmer enters a set of parameters that configure the evolutionary algorithm, specifying anything about the program such as the number of individuals to produce or the proportion of mutation and crossover for the software to use. The programmer writes a fitness function, the part of the program that evaluates an individual and assigns a fitness score, a number rating the individual. The program generates a random population of many individuals, each encoded with an artificial chromosome. A population size could be anywhere from 50 to 1,000 individuals.

2

The program selects good individuals by looking at the fitness scores and uses crossover and mutation operators on existing members of the population. The existing members are then the parents of the new individuals, which are called children. An individual may be selected to have more than one child. The program does tens, hundreds or thousands of crossovers or mutations, depending on the size of the population.

3

The program evaluates the new individuals and inserts them into the population. The program returns to step 2, performing the step over and over again, up to millions of times. Most programmers run the evolutionary algorithm 100 to 1,000 generations.

4

The algorithm stops when it comes across the fixed number of generations or the design chromosome that meets the criteria that can achieve the desired fitness. Or, a programmer runs the algorithm an unlimited number of times and stop it manually.

Autonomy

“It’s not just a buzzword ...

NASA is exploring Mars, Earth’s neighbor in the solar system, to understand how life evolved here and to determine whether life exists or existed there. Mars is a cold, dry desert environment, but is thought to have once been warmer and wetter, more habitable.

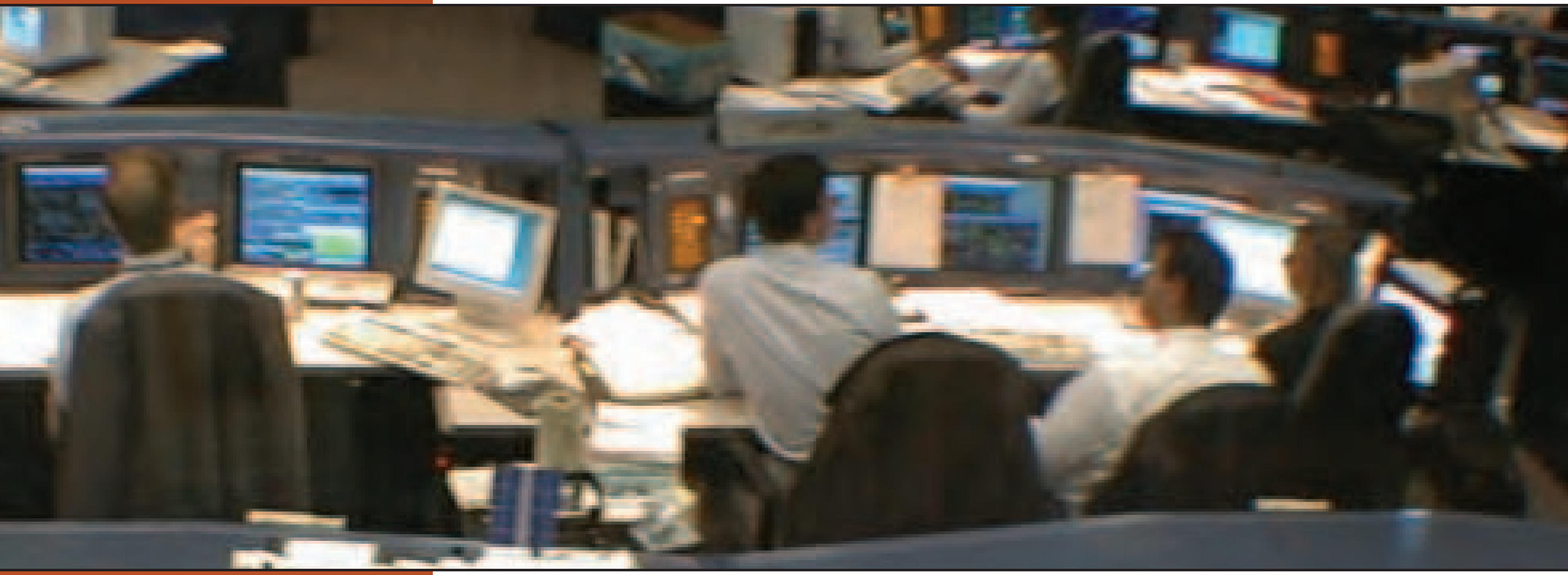
NASA is interested in expanding its search for life on Mars and in space – Carl Sagan said that one million other technological civilizations may exist in our galaxy, yet not a single extraterrestrial spore has been found. Advances in our planetary exploration depend on developing more sophisticated mission software.

Meanwhile, on Earth, scientists are finding life in some of the harshest, most forsaken places. Two miles under the frozen Antarctic, in an ancient lake near the Russian station Vostok, microbes live. Organisms thrive deep in the dark parts of the ocean, among plumes of sulfur and carbon dioxide, gases that until recently no one believed could sustain life.

Could life exist on Mars? Perhaps, says Ames Research Center robotics scientist Liam Pedersen, under Martian rocks, where moisture might be trapped. “Life is very tenacious. It does manage to hang on in the most extreme environments.”

While NASA explores Mars and develops technology for future Mars missions, researchers are discussing the possibility of one day finding microscopic life on Jupiter's moon Europa, where some suspect that an ocean exists between a mantle and a three-mile crust of ice. If so, are microbes living near undersea volcanic vents? Researchers are developing software that will enable vehicles to autonomously explore the moons and planets too far away for people to reach, to collect data without control from Earth.

Almost 30 years have passed since the Viking missions of the mid-1970s, the last successful science-driven NASA mission to land on Mars. Indeed, NASA has high hopes for a large scientific return with the 2003 Mars Exploration Rover (MER) Mission that is under way. • • MER involves twin six-wheeled rovers exploring opposite sides of the Red Planet for evidence the cold desert environment was or is a habitable place. To search for signs of past or present liquid water – a medium for life as we know it on Earth – the rovers are carrying nine cameras and an instrument-packed robotic arm, similar in size to a human arm, that will measure the makeup of Martian rocks and the atmosphere. • • While the rovers traverse Mars, acting as robotic field geologists, hundreds of Earth-based scientists and engineers super-



MER Mission –
NASA's most complex planetary exploration mission to date

- A 20-minute communication delay excludes the possibility of real-time control, and data capacity is limited, making the daily science discovery and planning process highly time-pressured.

- The Martian sun can only provide enough power for driving during a four-hour window around noon on Mars.

- Each day during surface operations engineers build and uplink detailed instructions for the rovers based on goals created for them by science teams.

- If a rover is unable to carry out an uplinked sequence it shuts down until the next command cycle, typically the next Martian day.

> ... It's something NASA really needs to do."
>
> *- Kanna Rajan,*
> *project lead, MAPGEN*

vise the rovers, which are dependent almost entirely on human intelligence for goal-setting and navigation. The mission staff works around the clock to analyze images and numerical data the rovers return, to choose science goals and to build plans that tell the rovers what to do and how to do it the next Martian day. • • In short, the current operations system is expensive, with high labor and communication costs. • • NASA is working to give rovers more autonomy so that missions can conduct more science with fewer people. Meanwhile, opinions vary about the degree of autonomy that is needed for future missions, or if any is even appropriate onboard planetary rovers and spacecraft. Most agree, though, that higher intelligence is imperative, for deeper space exploration and for more productive planetary missions. • • At Ames, researchers are developing and integrating software that will enable a robot to work more independently while accomplishing human-generated goals, to automatically form and adapt its behavior when uncertainty arises and to diagnose and repair problems. • • "Autonomy is not just a buzzword. It's something NASA really needs to do," says Kanna Rajan, project lead for MAPGEN, the automated planning and scheduling software for MER.

Advanced planning and

MAPGEN

The essence is in human interaction

MAPGEN (Mixed Initiative Activity Planning Generator) is a ground-based decision support system for MER mission staff that begins to give content to the notion of autonomous planetary exploration, providing mission staff with automatic planning and scheduling.

Each day during MER scientists decide science goals for a rover. Then mission engineers build a plan, or a set of software commands that tells the rover precisely how to accomplish the scientists' goals. Working with the mission operators, MAPGEN gives computers the intelligence to take care of many of the details involved with building the plan.

While making plans, scientists and engineers work together to enter constraints on particular science goals. For example, "these pictures should be taken between 30 and 60 seconds apart to make a 'cloud movie'," or "this picture should be taken at sunrise."

Mission engineers use the MAPGEN to squeeze in as many of the science goals as possible. The system makes sure the plan stays within safe boundaries for resources like battery power and enforces the science constraints like scheduling the picture at sunrise.

The planner can take into account hundreds of constraints when it lays out the schedule, says MER tactical activity planner Brian Chafin. "MAPGEN enables the mission staff

scheduling

to schedule potentially conflicting observations much more quickly than if a person made the plan without the software. MAPGEN is certainly critical in getting back a reasonable amount of science data from the mission"

MAPGEN enables the engineer to critique a plan that the system automatically produces, and ensures that resulting plans are viable within specified mission and flight rules, says MAPGEN project lead Kanna Rajan.

"In this way, while the routine plan generation process is handled by the machine, the human operator brings his unique knowledge and experience to bear to produce qualitatively good plans by relying on his judgment," Rajan says. Using the final MAPGEN plan, the surface operations team will use another piece of software, RSVP, to build the actual sequences for uplinking to the rover.

MAPGEN uses the planner from a software system that in 1999 demonstrated for the first time that a spacecraft could in effect fly itself. Rajan was a principal member of the team that developed the software, the Remote Agent, which enabled Deep Space 1 to generate a mission plan and execute it onboard with no human supervision. Remote Agent was risky but successful. It opened up the notion that autonomy is useful and it can be done onboard.

Says Bob Morris, NASA's project manager for Intelligent Systems, "MAPGEN is a step in the right direction." ■

NEXT 2009 MSL

Mars Science Laboratory

The next generation Mars rover – the 2009 Mars Science Laboratory (MSL) mission – involves an ambitious plan for increased robotic capability that is expected to significantly increase the quality and quantity of science conducted on the Martian surface.

Compared to the 2003 MER rovers equipped to travel up to 100 yards a day for three-months, the MSL rover will explore miles of the Red Planet during a multiyear mission, conducting science investigation in less time and with less human oversight than previous Mars rovers.

In preparation for the mission, Ames Research Center's Computational Sciences Division is working with MSL management at the Jet Propulsion Laboratory. Together the centers will design and develop technologies for MSL that will:

- Enhance the rover's data collection and analysis capabilities

A role Ames is playing with JPL addresses the fact that during planetary exploration, mission plans often go awry. Using the current NASA approach, when a mission plan breaks during execution the rover waits until operators build and uplink a new plan, usually the next Martian Day. Researchers are working to develop and test software that will automatically handle minor execution problems that would otherwise force the plan execution system to stop and wait for help from Earth. In the case of a plan execution error, the system will recover the day's science plan or adjust the plan to allow science investigation to continue.

- Reduce costs associated with debugging mission software

MSL calls for teams to conduct science and rover operations during regular business hours, for up to two years, from computers at their home offices, universities or other research centers. To enable this, new software tools and procedures for interpreting and sharing mission data and for building goals and instructions for the rovers must be developed.

- Enable close collaboration among scientists and engineers working anywhere in the world

Researchers are developing and testing software that checks mission code for errors automatically. The Mars Technology Program has invested in the C Global Surveyor tool, and is studying its use for MSL. (See page 4) ■

HUMAN CENTERED
computing

While advances in computer science and information technology are enabling more sophisticated Mars exploration, social scientists are working with computer scientists to improve communication and work processes for the scientists and engineers who are doing this exploration.

Human centered computing is a developmental process that starts with evaluating users and their needs instead of simply exploiting the capabilities of some available technology, say the researchers who are studying researchers at work to identify strengths and weaknesses in combinations of human and machine interaction.

"The person is at the center of the equation," says Roxana Wales, an Ames anthropologist who is part of the interdisciplinary Work Systems Design and Evaluation group within the MER Human Centered Computing project. "You don't build a technology and figure out where the person's going to fit."

> **The person is at the center of the equation.**
>
> *- Roxana Wales, anthropologist*

MER HCC has been working closely with the 2003 Mars Exploration Rover (MER) Mission, providing recommendations that enhance the role of technology in knowledge management, the scientific reasoning process and collaborative and group decision making. The MERBoard (page 14) was a product of MER HCC project research. The project's observations during MER rover field tests turned up pressing needs for the mission: information sharing tools, methods for scientists to document scientific intent during goal development and planning stages, and methods for naming objects the rover encounters on Mars. Ames Research Center's Human Factors Research and Technology Division provided fatigue countermeasures, decision support for running the mission on Mars time, shift handover procedures and system interface design.

By the time surface operations start in January, the MER HCC project will have had three years of experience with NASA managers, scientists and engineers. Once the rovers land on the Martian surface, the teams will continue evaluating operations. ■

MERBoard

The collaborative computer

MERBoard resulted from a unique proposal to JPL that pitched a process for making observations and a promise to deliver recommendations for a useful technology, tool or process.

When science and engineering teams navigate two rovers across the rocky Martian terrain, the daily science planning process is intense, with more than 100 people collaborating to work each rover.

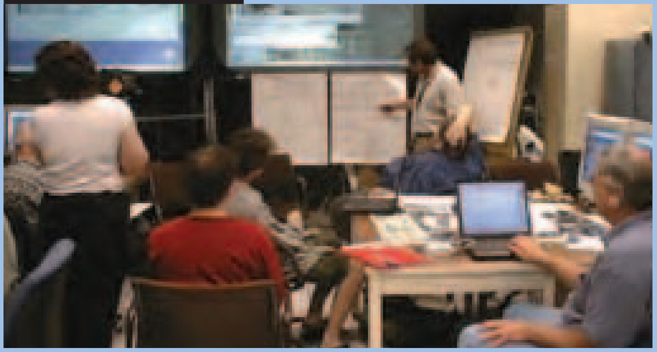
Good communication is essential. The efficiency with which the teams are able to access and share information will directly impact the amount of science data returned, and the success of the science-driven Mars Exploration Rover (MER) Mission.

A tool developed specifically to assist science and operations teams during MER surface operations planning is MERBoard, a product of Ames' MER Human Centered Computing (HCC) project and a new class of computing platform -- the collaborative computer.

A combination of software and five-foot touchscreen, MERBoard's large interactive work surface facilitates collaboration among planning teams that can gather around the board to retrieve, view, share and annotate mission data and rover images. The board provides an immersive work environment while its touchscreen literally puts information at the team members' fingertips, enabling a user to drag and drop data to a personal or group icon. Any data on the screen can be captured and annotated on the

see MERBoard page **22** ➤

Flipcharts

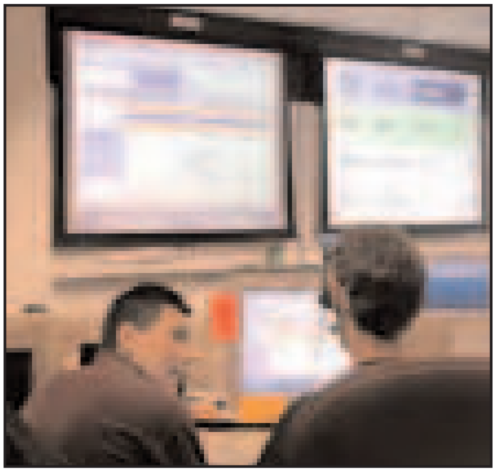


INFORMATION HUB

MERCIP

The one-stop spot for mission planning needs

Time. It's a precious resource. Just ask the hundreds of scientists and engineers who collaborate to choose a rover's next best move.



With CIP displayed in the surface mission support area, mission staff can follow the daily schedule as it changes. On their desktops, the staff can access essential information quickly.

This is more difficult than it sounds. During a Mars rover mission there are no joysticks. The rovers are too far from Earth to be remotely controlled in real time.

Instead, each day, ground support teams crunch piles of data into meaningful information. They debate exploration strategies that will get them more information and build software code that tells the rovers what to do and how to do it.

"They have a very tightly scheduled day," said Ames Research Center's Information Design Group lead Joan Walton.

Meanwhile, in a sense, time is changing. The teams work around the clock, in Mars time – a 24-hour, 37-minute day – in a 24-hour world, while operating rovers on opposite sides of Mars.

To keep the teams up to speed and coordinated during the mission, the Mars Exploration Rover Collaborative Information Portal (CIP) is a hub and distribution center for essential information. Using CIP, mission staff can determine the time of day in any time zone on Mars or on Earth at a glance. On almost any computer, through an interface custom built for the mission, a team member can quickly find relevant reports, images, daily schedules and plans stored in numerous databases.

"CIP is a one-stop location where science and operations teams go to find out what's going on," CIP project manager John Schreiner said. "CIP maps all the mission information and presents it to users in a very intuitive interface without the user needing to know data formats or where the data is stored."

Science team member Morten Bo Madsen called CIP "indispensable." Mission planner Elaina McCartney relies on CIP to track time. "I would be helpless without CIP."

The Information Design Group started developing CIP after talking with team members from the 1997 Pathfinder Mars exploration mission and current mission staff. The staff expressed concern about managing the vast collection of information and incoming data while coordinating 240 scientists and engineers.

The CIP team came up with a system

see MERCIP page **22**

MER Mission –

- The surface operation is a collaboration among hundreds of scientists and engineers working around the clock for at least 90 days.

- Across multiple floors at JPL, teams operate two rovers exploring opposite sides of the planet, in Mars time, a 24-hour, 37-minute day. That means that each shift starts 37 minutes later than on the previous day. If a scientist or engineer starts 8 a.m. Jan. 4, for example, that person begins work about midnight on Jan. 30.

- Teams of scientists begin each day analyzing images and data the rovers returned overnight, to come up with a prioritized list of science goals.

- The engineers who build the software code that enables the rover to carry out a science plan must understand the scientific intent and operational constraints that drive the daily plan.

- The 2009 Mars Science Laboratory (MSL) mission is proposed to last up to two years, a duration that mission staff will not sustain using the 2003 operations system. Instead, MSL calls for onboard autonomy and for remote collaboration among scientists and engineers.

The Work Systems Design and Evaluation group involves experts in computer science, anthropology, linguistics and psychology who use ethnographic methods to understand cooperation between people and systems.

Participatory observation

Its teams participate in workplace activities to discover how work really gets done. Computer scientists use the observations to develop technology that will enhance human performance. Observing how people actually work is the center of the group's methodology, which recognizes that knowledge is part of a community, existing within an environment in which people interact with each other and use various tools to get their work done.

How this happens is captured by observing this social environment. Knowledge obtained in this way is used to design more usable work tools and environments.

Modeling and simulation software Brahms is a tool to model how people behave (“activities”). Brahms is being applied to a range of space exploration areas, including Mars habitats in the Arctic and Utah (above), and operations for a lunar robot. Studying people while they simulate living and working on Mars, researchers from the Work Systems Design and Evaluation Group are gaining knowledge to prepare for human Mars exploration.

Brahms

modeling and simulation tool brings into view the roles people and technology play at work

Maybe it sounds like the making for an unpopular reality television show -- a program that simulates all the workplace business processes and interactions, from the fussy fax machine to the time spent responding to emails.

What the program called Brahms does, though, is help transform the workplace into a more productive and efficient environment.

Brahms is a multi-agent modeling and simulation environment that improves our understanding of interaction between people and systems. The software is a work system design and modeling tool that brings into view the roles people and technology play in how a job actually gets done. It puts together the overt and tacit interactions to produce information people can use to develop technology that will enhance work performance.

For example, how do people gather data that must be input to a computer tool? How do these people share its output? Bill Clancey, the project lead, says, “Instead of focusing on the screen design or keystrokes we consider how personal knowledge is called into play: Who is participating? How is that choice made? How does it affect what is input to the program? And how are the results are interpreted and acted upon?”

The Brahms environment consists of a number of software tools: a multi-agent programming language for modeling people's behaviors, geographical environment, movements, communications, systems and tools, as well as system behaviors and how technology might be inserted.

“It's understanding the differences between people and their environment and bringing them together,” says project manager Maarten Sierhuis. “It's based on the scientific study of communications, to help rather than replace people.”

The tool is being researched in context with the Mars Exploration Rover (MER) Mission operations, as well as other areas of space exploration, including the International Space Station, a Mars habitat and surface exploration vehicles.

Imagine starting a company for just three months that employs 240 highly skilled scientists and engineers who will work around the clock to manage a new space mission. That's MER. Never has NASA managed a planetary rover exploration mission involving so many collaborators. The days will be tightly scheduled, requiring order among the hundreds of team members.

Current research considers how the Brahms model can develop an actual workflow system for mission operations, based on the Brahms agent technology and models of mission operations. The Brahms team plans to observe mission operations at JPL, and is hoping to assist in designing and implementing a surface mission operation scheduled for 2009.

The tool could save the space agency money, says computer scientist Chin Seah. “You don't want to build a facility that you won't use or build technology that you won't use.”

Brahms is the result of 10 years of research by co-principal investigators Clancey and Sierhuis, both of the Work Systems Design and Evaluation group, in how understanding the interactions of people and their environment can improve the design of work processes. ■

Software puts science teams virtually on Mars

One of the toughest challenges for the Mars mission teams remotely conducting the experiments from Earth is to visualize a rover's position on the planet relative to objects in the Martian environment. A tool developed at Ames Research Center called Viz uses two-dimensional images a rover returns to display a three-dimensional picture, putting the teams virtually in the Martian environment.

“The idea is to put the scientist, as much as possible, on Mars,” says Viz project lead Larry Edwards.

Using a keyboard and mouse, teams can drive the rover around a reconstructed Martian surface to interactively explore and plan experiments. With Viz the teams can virtually travel across the surface to pick science targets, and select the safest, most efficient path.

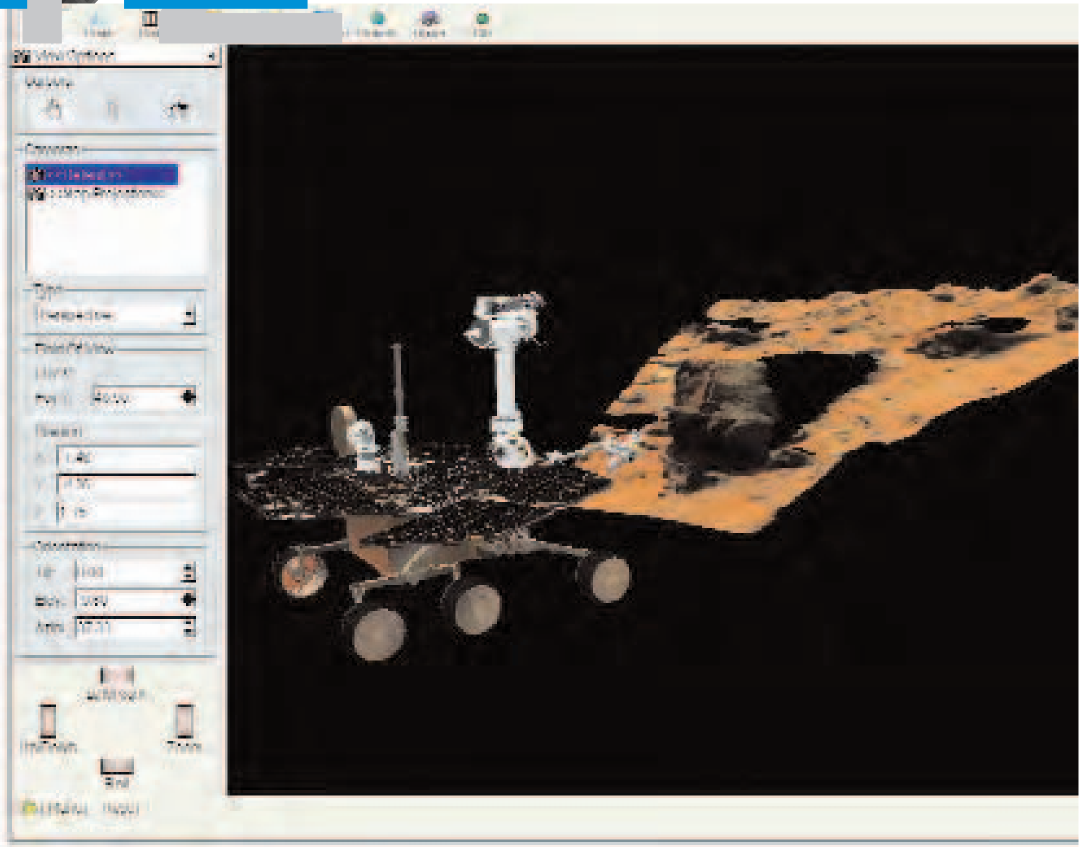
Viz and similar virtual reality tools are essential to controlling planetary rovers and for conducting science on Mars, says MER and Mars Pathfinder mission scientist Michael Sims. “In order to drive a rover one must know the context within which the rover sits and in order to understand a scientific measurement you must know the context of where that measurement was made.”

Viz is primarily used by science planning teams. With Viz teams can measure the rock surface areas and the distances between the rocks with clicks of a mouse. With the topographical information that Viz provides and the software's ability to pour virtual water into depressions, scientists can hypothesize what natural forces, such as ancient water or lava flow, might have shaped the planet.

Within the virtual Marscape, the software predicts when and where on Mars the sun will cast shadows on the rover and land surfaces so that mission planners can capture good images and other data. With Viz scientists can pan and tilt the camera to preview an image before the scientists send the real rover over to take a shot.

At a software laboratory at Ames' Computational Sciences Division, Edwards faces a computer monitor while wearing what resemble safety goggles. The goggles are stereo glasses that produce a 3-D image from the rover’s 2-D stereo pictures. The effect is a lot like that of

Viz



Placing a scaled model of the 2003 Mars Exploration Rover on Mars and using Mars data returned by the 1997 Mars Pathfinder mission, Viz shows science teams the rover's location relative to a large rock Pathfinder teams named Yogi.

the old blue and red 3-D movie glasses, but better. “They really reveal the subtle and sometimes not-so-subtle variations in the terrain that you don't always pick up in a two-dimensional image,” he says.

For example, during a mission field test in an Earth desert a couple of years ago scientists using two-dimensional photos spotted what looked like a ground depression between the rover and a rock the scientists wanted the rover to examine. Viz clearly showed the potential for danger. “In 3-D it was quite a sharp drop off,” says Edwards. “It showed them they probably wanted to take another path.”

Years before that, in 1997, the Viz predecessor called MarsMap provided the Mars Pathfinder teams with virtual exploration. Sims recalls that MarsMap proved critical as teams navigated Pathfinder's Sojourner rover up against a large rock. “The overhang was obvious in the Ames 3-D virtual reality models but almost unnoticeable in the direct 2-D images traditionally used for navigation.”

With the latest MER version of the Viz, its developers made the software adaptable to other NASA missions. Viz now supports network communications so that two or more people in different locations can communicate through Viz. The Viz software team will continue its research once MER surface operations begin in January 2004. The team plans to play a role in the next Mars rover mission, Edwards says, the 2009 Mars Science Laboratory (MSL), which calls for onboard autonomy and remote operations.

“With network capability, one thing for the future might be to have some real remote collaborative capability for scientists at different institutions to work in the Viz environment,” he says. In 2009, Viz might also help the MSL rover's autonomy software figure out on its own the best, safest route for reaching science targets the teams select. “One way might be to visualize the route.” ■

MERBoard from page 16

MERBoard's whiteboard, and content can be created on the whiteboard. One MERBoard can view what's happening on another, enabling collaboration from one board to another. A personal computer can be displayed or controlled from a MERBoard at the touch of a button, and data is easily transferable to and from the MERBoard and personal computers.

"It allows us to do planning for the mission in a very efficient way," says Andy Knoll, a Harvard professor and MER mission science team lead. "First, we can create things that are visually clear. Second, we can save these and email to people or have them called up later or bring them up in another room."

MERBoard is a mission enhancement that works with the mission's critical path tools provided by NASA's Jet Propulsion Laboratory (JPL), which is managing the MER mission. MERBoard was a product of a unique proposal by Ames to JPL in 2000 that didn't pitch technologies or tools but a process for making observations and a promise to deliver recommendations for technology and procedures that would enhance mission productivity.

During the next two years the MER HCC project's researchers interviewed and observed JPL current and previous mission staff and conducted observations during two rover exploration field tests performed in an Earth desert.

The field tests gave scientists and operations staff at JPL and at remote locations all over the world opportunities to operate a rover in a setting similar to the harsh Martian environment. The teams worked as if part of a real Mars mission, collaborating to come up with sequence plans based on rover images, sensor data and instrument data.

Meanwhile, the field training gave the MER HCC program a chance to observe the teams in action, critical to coming up with useful recommendations, said MER HCC program lead Jay Trimble. "People cannot consciously describe their total work experience. We saw where existing work tools and practice could be augmented to help productivity among scientists and engineers."

During the 2001 field test, surface operations teams at JPL gathered around flip charts and laptops to create, share and view information. The groups collaborated around the information display even though the information was difficult to see from just a few feet away. The charts would sometimes get lost. Information on the pages could not be archived for multiple users' reference.

"They were using flip charts for things like brainstorming, laying out scientific hypotheses, developing long-term strategic plans for the rover... With the MERBoard, we preserved that informal mode of expression you get on a flip chart or a whiteboard but added the ability to use multiple pages and share them, remote control and view them, and we added the ability to save and recall them at any time during the mission."

The informal mode of MERBoard enables the user to focus on the complexity of the task, not the tool. Fifteen MERBoards will be distributed throughout JPL during surface operations.

The MERBoard is being extended to the Xboard architecture, a development platform for NASA. It has a plug-in architecture that allows NASA developers to add capabilities to fit any NASA environment. The technology is Java based and runs on all industry standard operating systems, including Windows, Linux and Mac OS-X. ■

MERCIP from page 17

that can meet the needs of workers with different requirements, distributing information while the rovers collect and transmit data from Mars.

"They have a lot of specialized tools they need to do their science," Walton said. "This system has pulled together information from different places that might be difficult for them to get on their own."

For example, say that after a weekend a geologist punches in just as a meeting has ended. That person can find out what happened. That person can also find out what each team is working on, the condition and location of the rovers and the status of the planning and scheduling process.

CIP lets a user subscribe to information. Say the geologist is hoping a rover will return an image of what might have once been a Martian riverbed, and so are other people. The tool realizes when a document is in demand and makes it available. CIP can notify those people when new images and reports come in.

CIP is being used with another Computational Sciences Division technology, the MERBoard (page 16). ■