Our intellectual directions:

- Mission Information Systems
  Complete, seamless, flexible and reusable mission software and data systems for JPL's deep space exploration missions

- Software Engineering
  State-of-the-art tools, techniques, processes and practices for cost-effective, predictable, repeatable development of the highest quality mission software systems

- Revolutionary Operations
  Customized, distributed mission operations systems and concepts for scientists and engineers to accomplish JPL's deep space exploration missions

- Revolutionary Engineering
  Information technologies, infrastructure and computing environments to enable continuous improvements in the quality and productivity of engineering for space systems

- IT Communications
  The premiere computer networking for engineering and operations of deep space missions, from the Deep Space Network to Mars Network and beyond

- Autonomy for In-Situ Science
  Onboard intelligence to plan and control space platforms interacting with remote planetary environments, for on-site exploration and discovery, especially the search for life

- Breakthrough Computer Science
  Research and development in information and computing technologies to enable revolutions in the application of computer science principles to deep space exploration

We have four Sections:

- Engineering and Communications Infrastructure (366)
  Collaborative engineering, virtual environments, supercomputing, modeling and simulation, high-speed networking
  Dr. Larry A. Bergman, Mgr.
  Larry.A.Bergman@jpl.nasa.gov

- Exploration Systems Autonomy (367)
  Artificial intelligence, automated planning and scheduling, control executives, data mining, quantum computing, biocomputing
  Dr. Anna M. Tavormina, Mgr.
  Anna.M.Tavormina@jpl.nasa.gov

- Mission Execution and Automation (368)
  Mission operations systems, operations automation, ground data systems, intelligent data management, data visualization tools
  Mr. David M. Nichols, Mgr.
  David.M.Nichols@jpl.nasa.gov

- Mission Software Systems (369)
  Software architectures, software systems engineering, mission data systems, middleware, distributed computing
  Dr. Roger A. Lee, Mgr.
  Roger.A.Lee@jpl.nasa.gov
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<td>2-4 PM</td>
<td>SETUP</td>
<td>A. Tavormina, E. Mjoslness, J. Roden</td>
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<td>A. Martin</td>
<td>A. Donnellan, A. Tavormina</td>
<td>M. O'Dell or D. Nichols</td>
<td>C. Miyazono, Levesque</td>
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<td>M. Meidinger</td>
<td>A. Tavormina &amp; GSs</td>
<td>J. Patterson</td>
<td>Lee, Larson</td>
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<td>L. Bergman</td>
<td>A. Tavormina &amp; GSs</td>
<td>C. Garcia</td>
<td>Lee, Larson</td>
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Support

C. Corrigan

Section
Managers & Deputies:
Group supervisors:

A. Tavormina, L. Bergman, R. Lee, A. Larson, D. Nichols
L. DeForest, C. Kirby, E. Mjoslness, A. Donnellan
Dr. Richard J. Doyle, Technical Division Manager
Dr. David J. Atkinson, Deputy Division Manager

Overview of Technology Work

June 28, 2000

http://it.jpl.nasa.gov
Mars Outposts

- **Remote Science Laboratories**
  - Tele-operated or autonomous laboratories in the planetary environment for handling and conducting in situ scientific investigations on collected samples

- **Three scales / resolutions**
  - remote sensing
  - distributed sensing
  - point sensing

- **Heterogeneous, cooperating networks**
  - distributed networks of sensors, rovers, orbiters, permanent science stations, probes: all of which respond to sensing events, discoveries, changing PI directions, etc., to provide rich presence in Mars environment for science community and public

- **Infrastructure**
  - Planetary permanent infrastructure to support series of science and/or commercial missions leading to human presence
Titan Aerobot

The aerobot conducts in-situ science operations when landed, and wide-area imaging when aloft. Archived and learned models of wind patterns assist path planning, enabling near-returns to areas of high scientific interest.
Perhaps more than any other, a mission of discovery in a truly alien environment: How to know what to look for? How to recognize it?
Thrust Leadership:
- Revolutionary Engineering
- IT Communications

Objective:
- Provide the premier computing, networking, and IT engineering infrastructure for JPL missions

Growth Areas:
- Intelligent synthesis environment
- Mars & interplanetary networks
- Virtual environments
- Virtual testbeds

Major Customers:
- NASA, DSN, DARPA, Army
Exploration Systems Autonomy Section

Dr. Anna M. Tavormina, Mgr

- Thrust Leadership:
  - Autonomy & IT for In-Situ Science
  - Breakthrough Computer Science

- Objective:
  - Provide the autonomy and computing technologies which enable the next generation of highly autonomous and scientifically-productive deep space missions

- Growth Areas:
  - Surface systems, next-generation computing
  - Smart science instruments
  - Onboard science algorithms
  - Mission planning & scheduling

- Major Customers:
  - NASA, DARPA, Army CoE, ONR

RJD/DJA 3/17/00
Mission Execution and Automation Section

Mr. David A. Nichols, Mgr; Ms. Bolinda Kahr, Dep Mgr

Mission Execution and Automation (368)

- Mission Control Systems
- Beacon Ops
- Intelligent Data Management
- Collaborative Ops Tools
- Distributed Science Data
- Remote Ops Systems

Thrust Leadership:
- Revolutionary Operations
- Mission Information Systems (supporting)

Objective:
- Provide robust and cost-effective mission accomplishment systems and concepts to a broad range of science, mission, and defense customers

Growth Areas:
- MDS Adaptation
- Mission software
- Mission design, ops concepts
- Science support

Major Customers:
- NASA
Mission Software Systems Section

Dr. Roger A. Lee, Mgr, Ms. Annette Larson, Dep Mgr

Mission Software Systems (369)

- MDS Development
- Software Architectures
- MDS Architecture
- Software Best Practices
- Software System Engineering
- Middleware
- GDS Architecture
- REE
- GDS Development
- Objective:
  - Provide leadership for the Laboratory in the design and development of quality mission software and use of state-of-the-art software practices

• Thrust Leadership:
  - Mission Information Systems
  - Software Engineering

• Growth Areas:
  - Mission Data System development
  - Mission software
  - Software engineering technology
  - Software fault tolerance

• Major Customers:
  - NASA, DSN, DISA

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Meta-Computing Environment

New Capabilities for Very Large Systems

- Knowledge Discovery
- Data Mining
- Simulation
- Interactive Data Analysis
- 3-D Visualization
- Image Processing Tools

- ~1 Teraflops per node
- 40 Gb/s per link
- High-Performance Network and Computing Resources

Satellite Sensor Data

Micronetwork Sensors
Remote Astronomy at Keck

OBJECTIVES: Validate use of high latency gigabit satellites and network protocol for remote astronomy.

MOTIVATION: High altitude (14,000 ft), long travel time points the need for remote astronomy. High bandwidth satellite communications can reach remote locations where optical fiber is unavailable.

EXPERIMENT & RESULTS:
• In Oct 96, LRIS (4Kx4Kx16bit) instrument operated via X-windows control application at Caltech Sun Workstation.
• 15 Mb/s throughout obtained with extended TCP/IP windows, but suffered slow rampup in speed.

SIGNIFICANCE: Remote astronomy via satellite is practical, but more efficient long latency, high bandwidth network protocols are needed.

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HTMT Petaflops Computer

GOALS AND OBJECTIVES

- Enable practical and effective Petaflops scale computing within a decade.
- Dramatically improve efficiency, generality, and programmability over today's supercomputers

INNOVATIVE TECHNOLOGIES

- Low power high speed (200GHz) RSFQ superconductor logic
- Smart processor-in-memories (PIM)
- Holographic intermediate (3/2) storage between disk and DRAM
- Advanced optical communications

ARCHITECTURE APPROACH

- Very high speed processors for reduced concurrency
- Merges diverse technologies to leverage complementing strengths
- PIM memory architecture for reduced communications bandwidth
- Multithreaded execution model for latency management & high efficiency
Virtual Science Operations

- NO HEAD GEAR FOR 3-D VISUALIZATION
- PHOTOGRAPHIC PROJECTION QUALITY

HOLODECK 3-D IMAGE PROJECTION OPERATIONS
\[ = n \log n \times 100L \times 10V \times 60 \text{ frames/sec} \]
\[ \approx 10^{18} \text{ operations/sec} \]
Mission Dome

End-to-end Virtual Environment for Mission Lifecycle
Remote Agent Architecture

- Smart Executive
- Planner & Scheduler
- Mode ID & Reconfiguration
  - ETS/IRS
  - MIR/Livingstone
- Monitors
  - Real-time Execution
  - Adaptive Control
  - Spacecraft Hardware

Mission Goals
Component Models

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Closing Loops Onboard

- Beacon Operations: Ground assistance invoked with focused report on spacecraft context and history
- Planner / Scheduler: Replanning of mission activities around altered resources or functions
- Mode Identification & Reconfiguration: Diagnosis of faults and informed selection of recovery actions
- Smart Executive: Local retries or alternate, pre-defined activities to achieve same goal
- Real-time System: Several layers of onboard recovery provides for unprecedented robustness in achieving mission goals in the face of uncertainty

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Remote Agent Experiment

- DS-1 has encountered an asteroid and will encounter a comet.
- Remote Agent Experiment (RAX) achieved 100% of its technology demonstration goals in May '99.
- RAX joined 11 other DS-1 technology experiments such as onboard optical navigation and solar electric propulsion.
- Remote Agent co-winner of 1999 NASA Software of the Year Award
Key idea: (borrowed from model-based fault diagnosis)
- Do not attempt to enumerate all possible s/w failures
- Rather, define and identify departures from acceptable bounds on software behavior
- Apply at design, test and run time
Formal methods-based approaches corrected errors in RA code
QuakeFinder

- Color wheel shows direction of ground motion.
- 2050x2050 10m pixels
- Displacement map computation increases effective resolution for motion detection to 1-2m
- Hue discontinuity shows movement due to fault (black line).
- Can be extended to process several images, and for general change detection.
- Applications being pursued for Europa and comet lander missions.

Landers Earthquake, June 1992
Nested Quantum Search

- NP-hard problems (constraint satisfaction, scheduling, planning, VLSI layout etc)
- Previous best quantum algorithm (Grover) had complexity $O\sqrt{N}$
- Ours is $O^{3\sqrt{N}}$ for the hardest instances
- Innovation: the use of problem structure to focus quantum search

How it Works

$N$ possible solutions in fringe
Extend search from just the "goods" at level $i$
Quantum Optical Gyroscope

Innovation
- Entangled Photons Replace Classical Light
- Quantum Effects Give Eight Order Improvement
- Proven Fiber Optic Technology
- Paradigm shift in Inertial Sensing
- Quantum Mechanics over Classical Mechanics

Ultra-Precision Optoelectronic Chip

Inertial Navigation
- Space Exploration
- Under Sea Navigation
- Commercial Applications

Missions
- General Relativity
- Deep Space
- Asteroid Surveying

Photon number scaling law for "classical" two-port gyro.

Photon number scaling law for quantum two-port gyro.

Change in the Phase Sensitivity

$$\Delta \phi_{\text{min}} \propto \frac{1}{\sqrt{N}}$$
Automated Quantum Circuit Design

Technical challenge
Compile desired unitary matrix into a quantum circuit that implements it

Technical approach
Genetic programming plus partial gradient descent
Target algorithm = unitary matrix
Create population of random circuits
Define fitness based on closeness of operator that the circuit implements to the desired target operator
Select parents, mate & mutate

Innovations
"Over-complete" basis gates
Partial gradient descent
Mission Data System

State Knowledge

State Determination

State Control

Models

Hardware Proxies

Hardware

Telecommand

Goals

Coordinate
Elaborate

Measurements

Actions

Sense
Act

Report

Telemetry

RJD/DJA 3/17/00
MDS Architectural Themes

- Unifying state-based paradigm behind all elements
- Extensive and explicit use of models
- Goal-directed operations specifies intent, simplifies workload
- Closed-loop control enables opportunistic science gathering
- Fault protection is natural part of robust control, not an add-on
- Explicit resource management (power, propellant, memory, etc)
- Navigation and attitude control build from common base
- Clean separation of state determination from control
- State uncertainty is acknowledged & used in decision-making
- Clean separation of data management from data transport
- Upward compatibility through careful design of interfaces
- Object-oriented components, frameworks, design patterns
Definition

- **State** is a representation of the momentary condition of an evolving system
- **Models** describe how a system’s state evolves
- These are what one needs to know
  - To operate a system,
  - To determine or control its future, and
  - To assess its performance
Theme: Goal-Directed Operation

A goal specifies *intent*, in the form of *desired state*.

A *goal* is a **constraint** on the **value** of a **state variable** during a **time interval**.

- Goal-directed operation is simpler because a goal is easier to specify than the actions to accomplish it.

- Goal-achieving modules (GAMs) attempt to accomplish submitted goals.

- A GAM may issue primitive commands and/or sub-goals to other GAMs.

- A GAM must either accomplish a goal or responsibly report that it cannot.