NASA/JPL Future Computing Needs

Frontiers of Extreme Computing 2007
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Dr. Tom Cwik
Associate Chief Technologist
Jet Propulsion Laboratory
California Institute of Technology
Introduction

- Challenges of Space (Systems & Environment)
- Spaceborne Computing
- Ground-based Computing *(specific to NASA/JPL needs)*
- Spaceborne Computing Path
1958
First U.S. satellite
Explorer 1
Where are we now?

NASA has more than 50 missions exploring our solar system (some examples)

- Spitzers studying stars and galaxies in the infrared
- Ulysses studying the sun
- Spitzer studying stars and galaxies in the infrared
- Two Voyagers on an interstellar mission
- Cassini studying Saturn
- GALEX surveying galaxies in the ultraviolet
- Aqua studying Earth’s oceans
- Mars Odyssey, rovers “Spirit” and “Opportunity” studying Mars
- Aura studying Earth’s atmosphere
- Calipso studying Earth’s climate
- Hubble studying the universe
- Chandra studying the x-ray universe
- MESSENGER on its way to Mercury
- QuikScat, Jason 1, CloudSat, and GRACE (plus ASTER, MISR, AIRS, MLS and TES instruments) monitoring Earth
- New Horizons on its way to Pluto
Space Challenges
Environment

• High Radiation
  – Total dose (>mega rads for some missions)
  – SEU

• Temperature
  – Wide range (-270 deg F on Europa to >900 deg F on Venus)
  – Rapid cycling (>1000 cycles of 100 deg on MER)

• Vibration
  – Launch
  – Planetary Entry, Descent, Landing

…. These present severe constraints to the compute hardware
Space Challenges
Communications and Guidance

• **Bandwidth**
  – 6 Mbit/s max (modulator limit)
  – Typically much less based on SNR (100 bits/sec)
  – Spacecraft transmitter power typically less than light bulb in your refrigerator

• **Latency (one-way)**
  – 20 min to Mars
  – 13 hr to Voyager 1

• **Navigation**
  – Positional accuracy for critical events
  – Velocity determination (continuous)

... These present severe constraints to mission operations
• Only flight qualified parts are typically used
  – Systems are >5 yrs out of date when launched (two generations behind commercial art)

• Several Power and Mass Restrictions
  – 20-30 W for a flight computer

• Often can’t test final system until its flown
  – Importance of modeling and simulation

• Long mission duration challenges maintainability of ground assets in operations phase
  – Voyager is based on customer flight computer designed with MSI parts and ferrite core memory of the late 1960’s (programmed in assembler)
    • Ground computers based on Univac 1100 series

… Silver lining: software is about the only thing that can be changed after launch
Agenda

• Challenges of Space (Systems & Environment)
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• Future Spacecraft Computing Directions
Rad-hard components are always at least 2 generations behind commercial State Of The Art.
Future Mission Applications

New Types of Science
- Event detection
- Opportunistic science (e.g., dust devils detectors)
- Model based autonomous mission planning
- Multiple platform cooperative missions (fleets, swarms...)
- Smart high resolution sensors (e.g., gigapixel, SAR, ..)

Entry Descent & Landing
- Flight control thru disparate flight regimes
- Landing zone identification
- Hazard avoidance
- Soft touchdown

Surface Mobility
- Terrain traversal
- Obstacle avoidance
- Science Target identification
- Image/video Compression
**Data Mining of Image and Time-series Data**

**Capability**

**Recognize events & trends**
- machine-assisted discovery
- automatically generate catalogs, summaries
- Watch data streams and send alerts

**Technologies**

- Scale and orientation invariant template matching
- Time-series analysis
- Texture recognition
- Data fusion – correlate data from several sources to improve accuracy.

**Features**

- Craters
- Volcanoes
- Clouds
- Floods
- Ice

**Multi-Source Triggers**

Cloud-cover (GOES) + Infrared = Eruption

Ground sensors

**Time Series**

Match

Query

**Novelty & Changes**

Time
Planning and Scheduling

- Automatically generate plan of action that achieves goals while obeying resource & operations constraints.
- Continuously revises plan in response to events (~10s)

State Updates

commands

goals

execute

Error: have to retry close, takes longer
Duck Bay: Site of Opportunity’s descent into Victoria Crater
Fault Tolerant Space-Borne Scalable Computer (FTSSC)

- Spacecraft Control Computer
  - Rad-hard unbreakable
- Communication Subsystem
- Instrument Interface
- FTSSC
  - FPGA Based PIM Interface fabric
  - COTS Multi-core Compute engine Cluster
  - Intelligent Processor In Memory Data Server
- Instruments
- System Controller

Fault-tolerant recycle-able
Multi-Core Challenges for Space

General
- Programming and execution model
- Porting of legacy code
- Heterogeneous/homogeneous architectures
- Design tools, environments, libraries

Space critical
- Real-time
- Fault tolerance issues
- Testability / validation
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End-to-End Capabilities Needed to Implement Missions

- Project Formulation - Team X
- Mission Design
- Real Time Operations
- Environmental Test
- Integration and Test
- Spacecraft Development
- Mars Rovers
- Large Structures - SRTM
- Ion Engines
• NASA’s 2007 Phoenix Mars Lander mission is sending a spacecraft to land in the northern polar region of Mars (launch: August 2007; land at Mars: late May 2008)
  – Will sample water ice and chemical content of the soil, and also measure local weather phenomena
• A key phase of Phoenix is the approximately six-minute traversal of the Martian atmosphere, descent on parachute, and rocket-powered landing on Mars.
  – This phase is commonly termed “Entry, Descent and Landing” (EDL).
• The Phoenix EDL team has made extensive use of the JPL advanced computing, beginning in January 2007.

Continued supercomputer usage planned through Phase E - until actual EDL
Phoenix Mission Landing Simulation (cont’d)

- Primary *advanced computing* usage performed sets of 2000-case Monte Carlo simulations of the Phoenix EDL event, for a range of atmospheric entry conditions
  - Varying location, speed and attitude at the top of the Martian atmosphere
  - Varying random noise effects, and injecting various error modes, in the accelerometers, gyroscopes, and radar
  - Varying atmospheric density, winds, terrain features of the landing site, landing thruster performance characteristics …
- Each individual trajectory simulation “case” takes ~ 3.5 node-hours to run (due to the high-fidelity radar model)
- Each 2000-case Monte Carlo batch produces ~ 25 Gbytes of raw output data (compressed) that are post-processed by the Phoenix EDL engineers
- This simulation campaign has logged > 1 *Node-Decade* of run-time, and ~ 1 *TB* of useful raw data for sensitivity analyses, statistical characterizations, and outlier analyses.
Objective

• Perform design trade and sensitivity studies to assess the impact of a remote sensing instrument on specific science goals.

Challenges

• Building/establishing model interfaces
• Large-scale data assimilation
• High-productivity computing systems (distributed?)
• Validation of OSSE components
OSSE Framework
- Models
  Instrument
  Forecast, retrieval, radiative transfer
  Mission design
- Data Assimilation
- Integrated computational environment

Integration of
- Science goals
- Instrument development
- Mission design

Assessment and sensitivity
- Science goals to instrument and mission design

Constraints
1. Physics-based: conservation of energy, diffraction limit, photon noise
2. Experience-based: Team I/P historical database
3. Engineering-based: Phase B Preliminary Design and PDR

Proposed instrument requirements
Instrument specifications (measurements) proposed to answer science questions (spatial, spectral resolution, SNR, etc.)
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Spaceborne Computing Path

- **Current Generation (Phoenix and Mars Science Lab -‘09 Launch)**
  - Single BAE Rad 750 Processor
  - 256MB of DRAM and 2 GB Flash Memory (MSL)
  - 266 MFLOPS peak, 14 Watts available power
  - 19 MFLOPS/Watt Performance

- **NASA ST8 Honeywell Dependable Multiprocessor (‘09 task end)**
  - COTS Multi-board system with Rad Hard 603e controller
  - Fault-tolerant architecture
  - 6.4 GFLOPS peak/board & 31 Watts available power; overhead needed for FT
  - 220 MFLOPS/Watt Performance - but can scale total MFLOPS with power
  - Scalable to 20 COTS processing nodes

- **Target**
  - Radar Application, Large focal-plane array processing, autonomy …
  - > 1000 MFLOPS/Watt sustained performance
  - Can multi-core architectures improve power utilization?