# Warts, Bumps, and Blemishes

***Experimenting with Sensor Webs Using EO-1***
***2 March 2004***

Systems Engineering Seminar

Come Hear the Experts!

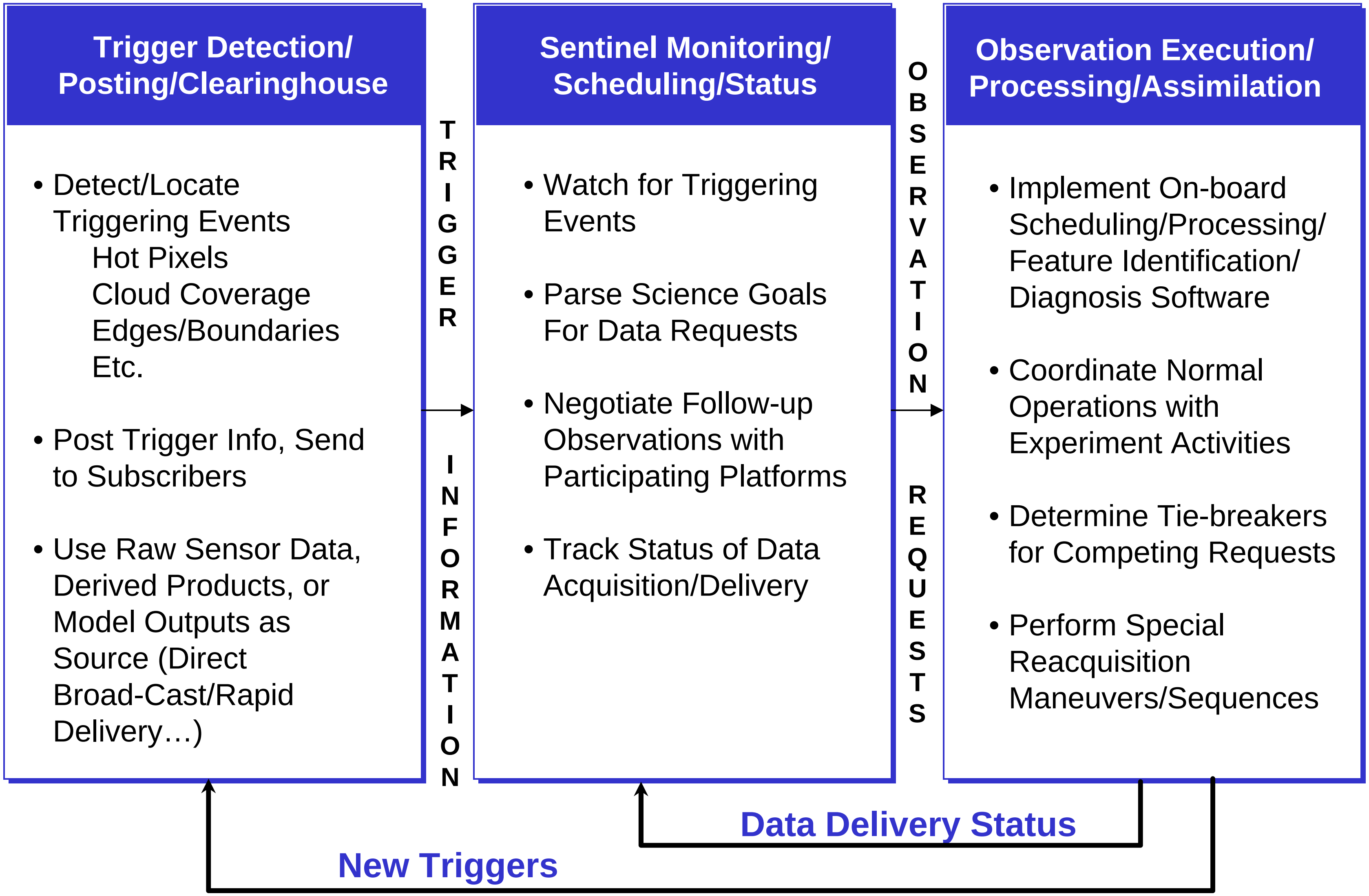
*Stuart Frye*
*Mitretek Systems*

*EO-1 Systems Engineer*

# Contents

- ***EO-1 Sensor Web Functionality***
- ***Mission Systems Configuration***
- ***System Modeling for Autonomy Migration***
- ***Interface Scripts and Glue Code***
- ***Mission Planning Activities***
- ***Ground System Accommodations/Upgrades***
- ***Flight Software Changes***
- ***Issues, Warts, Bumps, and Blemishes***
- ***Lessons Learned***

# EO-1 Sensor Web Functions



**Trigger Detection/ Posting/Clearinghouse**

- Detect/Locate Triggering Events
  - Hot Pixels
  - Cloud Coverage
  - Edges/Boundaries
  - Etc.
- Post Trigger Info, Send to Subscribers
- Use Raw Sensor Data, Derived Products, or Model Outputs as Source (Direct Broad-Cast/Rapid Delivery…)

TRIGGER INFORMATION

**Sentinel Monitoring/ Scheduling/Status**

- Watch for Triggering Events
- Parse Science Goals For Data Requests
- Negotiate Follow-up Observations with Participating Platforms
- Track Status of Data Acquisition/Delivery

OBSERVATION REQUESTS

**Observation Execution/ Processing/Assimilation**

- Implement On-board Scheduling/Processing/ Feature Identification/ Diagnosis Software
- Coordinate Normal Operations with Experiment Activities
- Determine Tie-breakers for Competing Requests
- Perform Special Reacquisition Maneuvers/Sequences

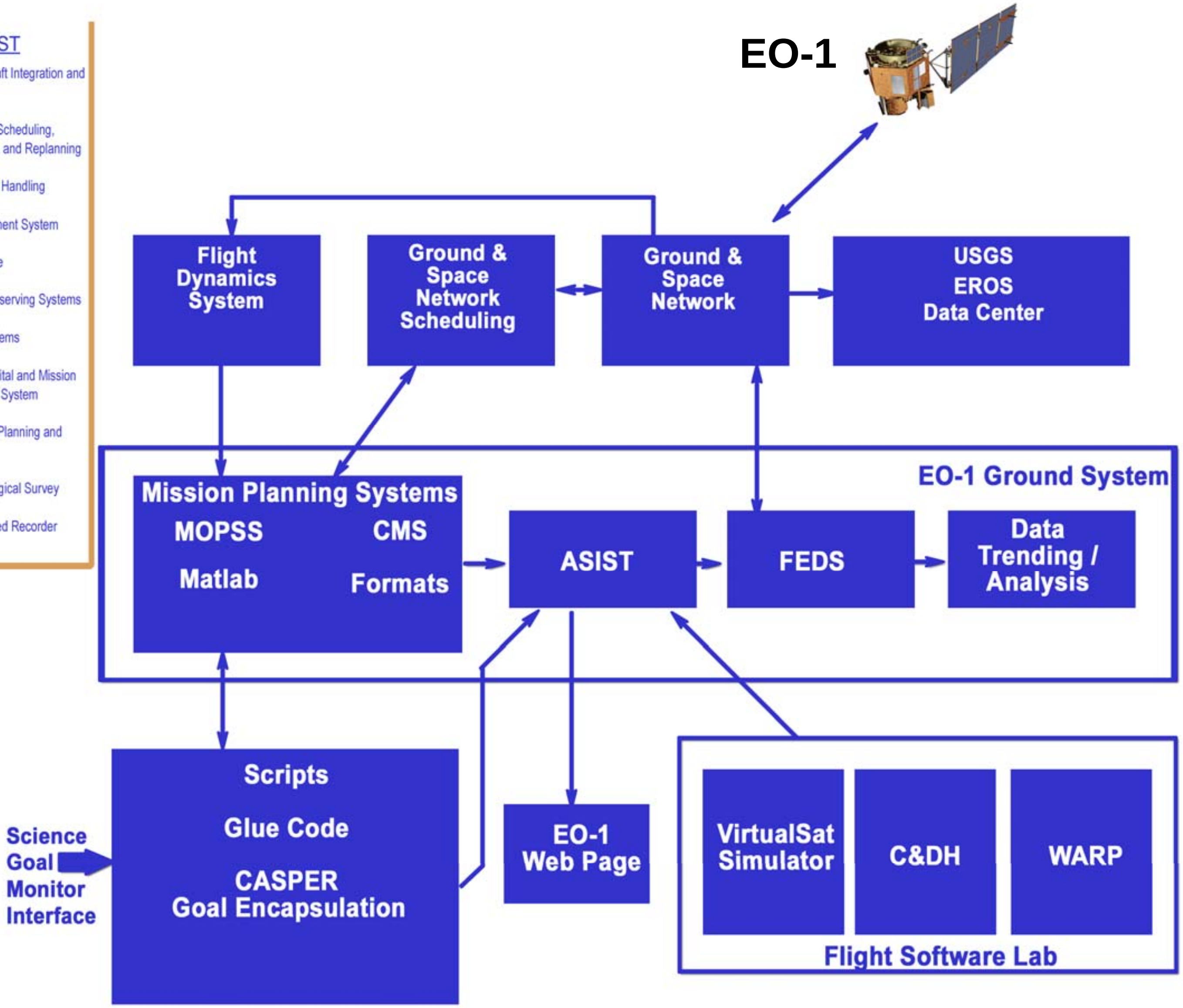
**Data Delivery Status**

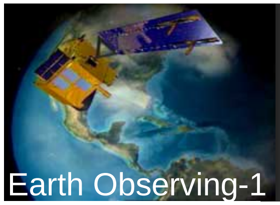
**New Triggers**

# EO-1 Mission Systems

## ACRONYM LIST

| | |
|---|---|
| ASIST - | Advanced Spacecraft Integration and System Test |
| CASPER - | Continuous Activity Scheduling, Planning, Execution, and Replanning |
| C&DH - | Command and Data Handling |
| CMS - | Command Management System |
| EO-1 - | Earth Observing One |
| EROS - | Earth Resources Observing Systems |
| FEDS - | Front End Data Systems |
| FORMATS - | Flight Dynamics Orbital and Mission Aids Transformation System |
| MOPSS - | Mission Operations Planning and Scheduling System |
| USGS - | United States Geological Survey |
| WARP - | Wide-band Advanced Recorder Processor |





# *Automated Sequence Generation*

- ***Mission goals***
  - ***E.g. – image Kilauea (Lat/Lon)***
- ***To Command Sequence***

```
2003:233:16:49:57 CMD ACSETWHLBIAS(INERTIAL,X=0.341589,Y=1.1749,Z=-0.118046);
2003:233:17:56:57 CMD ACGOTOMANEUVER(ORBITAL,TIME=900,XLIMDEG=0.02,YLIMDEG=0.062699,…);
2003:233:18:07:06 CMD I_SETFPEPOWER(POWER_MASK=5);
2003:233:18:07:06 CMD YHEASTBY;
2003:233:18:07:16 CMD YHEASETSWIR(GAINA=1,GAINB=1,GAINC=1,GAIND=1,…);
2003:233:18:07:26 CMD YHEASETVNIR(VNIRALV8,VNIRBLV8,VNIRCLV8,VNIRDLV8);
2003:233:18:11:06 CMD I_CONFIGFPE(CONFIG_COMMAND=16908); …
2003:233:18:17:06 CMD BCMMODESCRS422;
2003:233:18:17:16 CMD WRMSREC(IDWS=65535,IDWV=65535,…);
2003:233:18:17:54 CMD I_SET_FPE_DG(DURATION=-1);
                  …
```

# Uses Model of Activities

variable, dependent
on activity duration

***Resources***

Activity: Science Image Acquisition

***States*** Uses 14 files; uses XXX memory

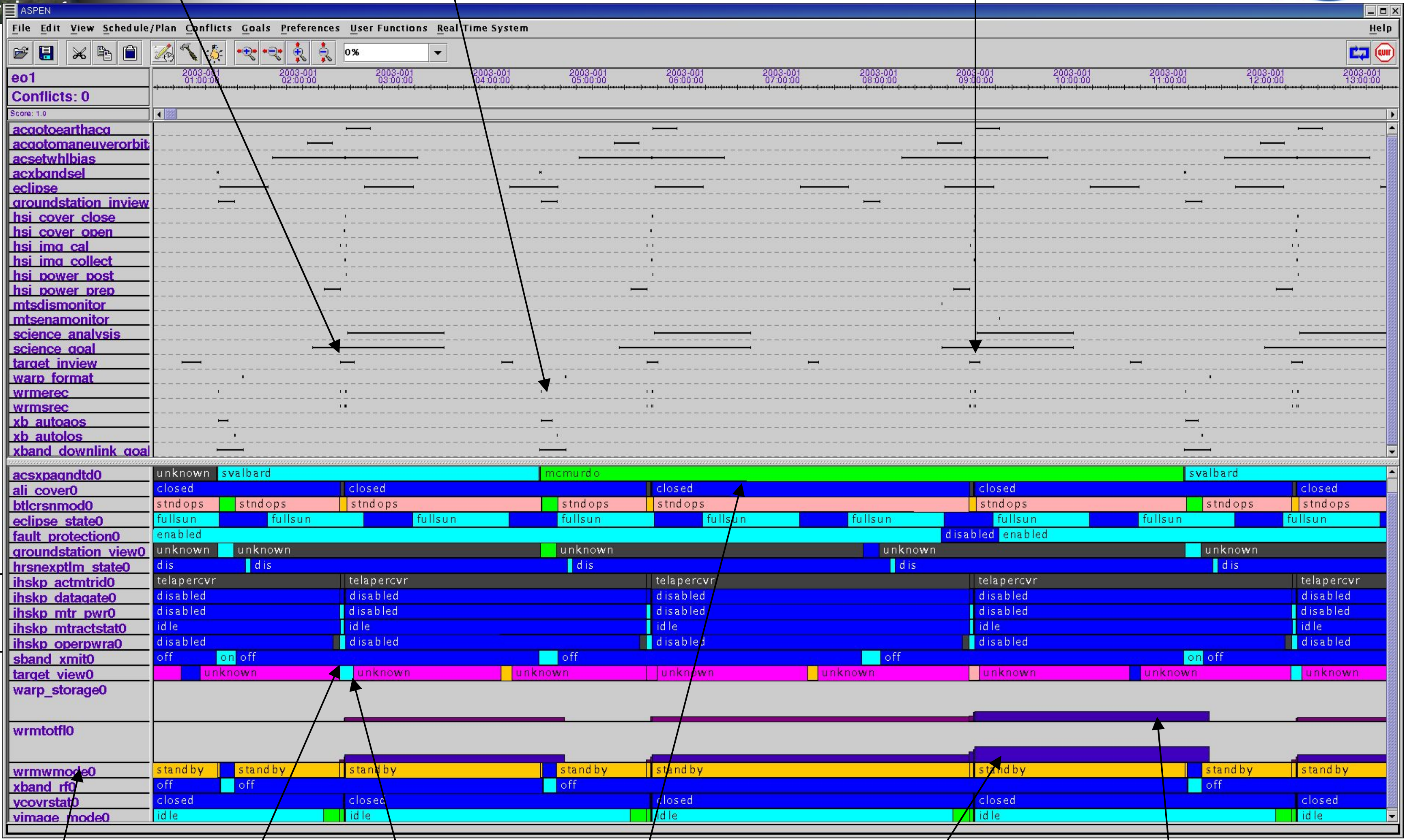
***Other Activities*** requires target pointing

***These models are then combined to model the world as it changes due to activities***

Day collect

Downlink

Night collect



Hyp State

Warp mode

Hyperion Preparation

Target in view

X-band Ground Station

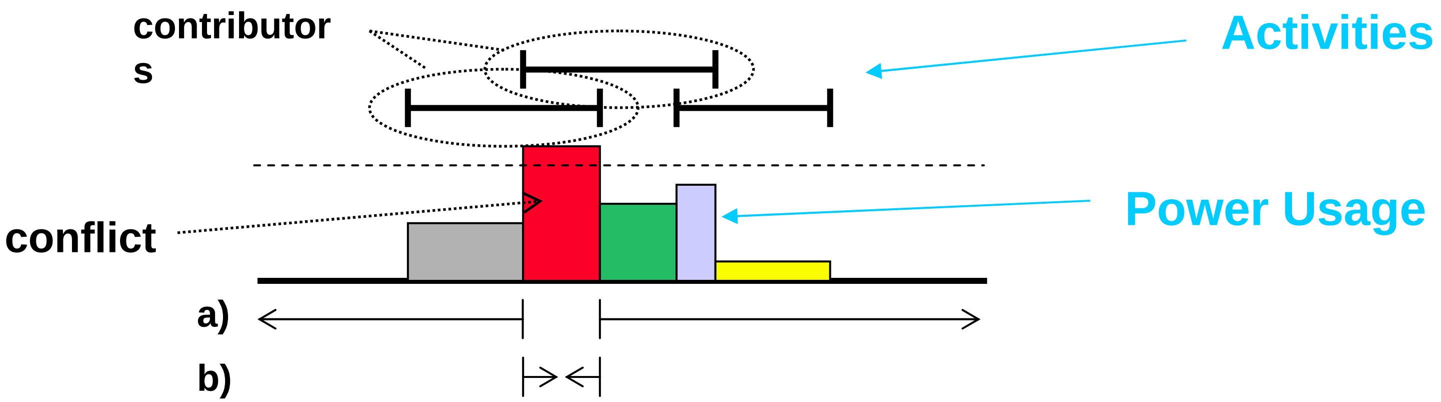
WARP file count

WARP data volume

# *CASPER Planning*

- ***CASPER can implement nominal procedures through decompositions (similar to scripts)***
  - *In order to image: do x, then y, then z…*
- ***CASPER can also perform planning "from scratch" via search***
  - *If want ACS-mode state variable = standby, consider adding an activity that changes ACS-mode (then the requirements of these activities may be new conflicts,…)*
  - *Most commonly used search framework "iterative repair"*

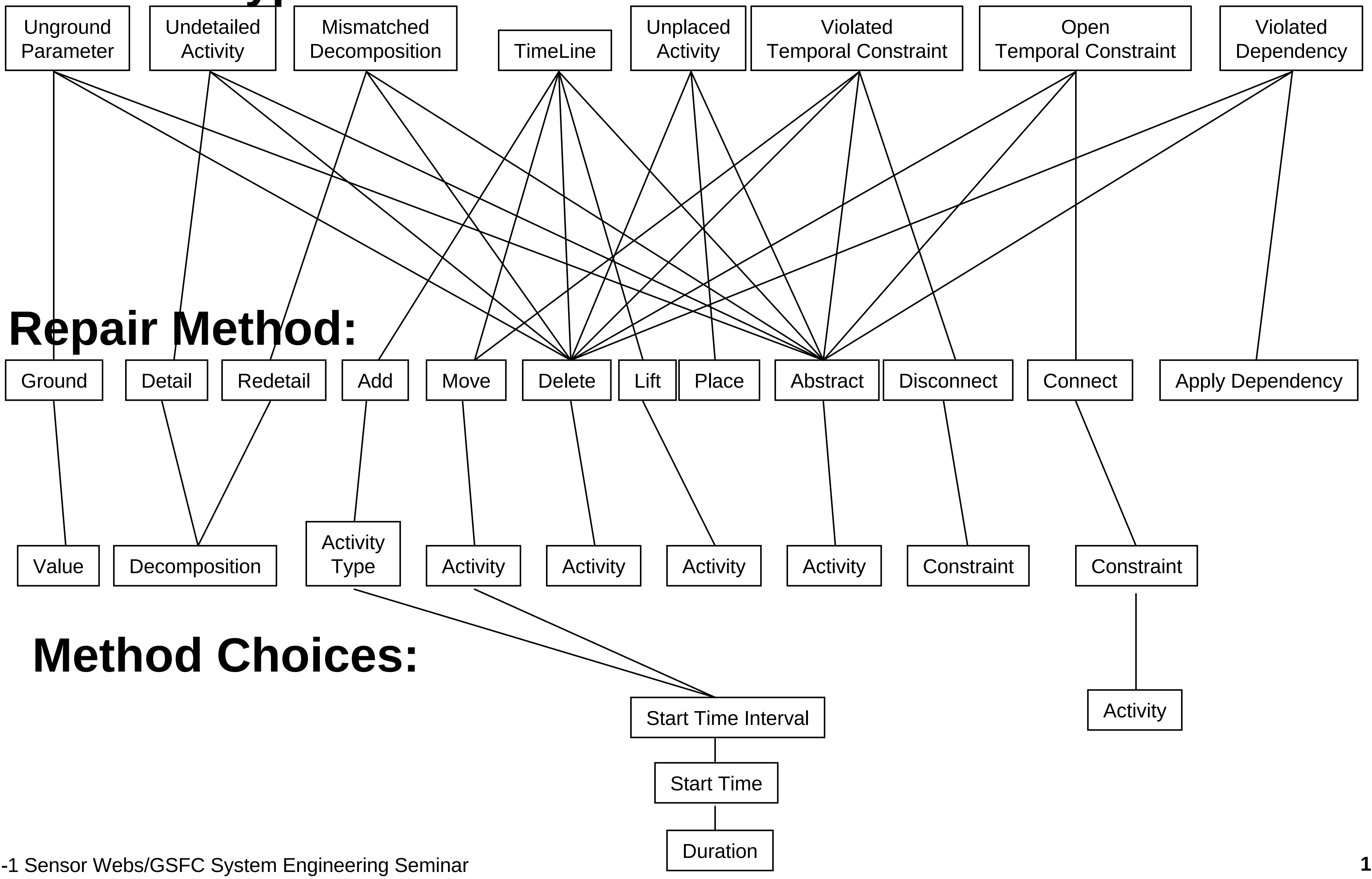
# *Activities, Constraints, Repairs*



| | | |
|---|---|---|
| ***Constraint*** | ***Property that must hold for plan to be valid*** | ***Must always use less power than available*** |
| ***Conflict*** | ***Violation of a constraint*** | ***Current plan uses more power than available from 18:00-18:30*** |
| ***Repair Method*** | ***Modification to plan that may remove conflict*** | ***Delete activity using power during conflict*** |
| ***Repair Choice*** | ***Which activity to delete*** | ***Delete largest user?*** |

# *Constraint Resolution Tree*

## Conflict Type:



Unground Parameter
Undetailed Activity
Mismatched Decomposition
TimeLine
Unplaced Activity
Violated Temporal Constraint
Open Temporal Constraint
Violated Dependency

## Repair Method:

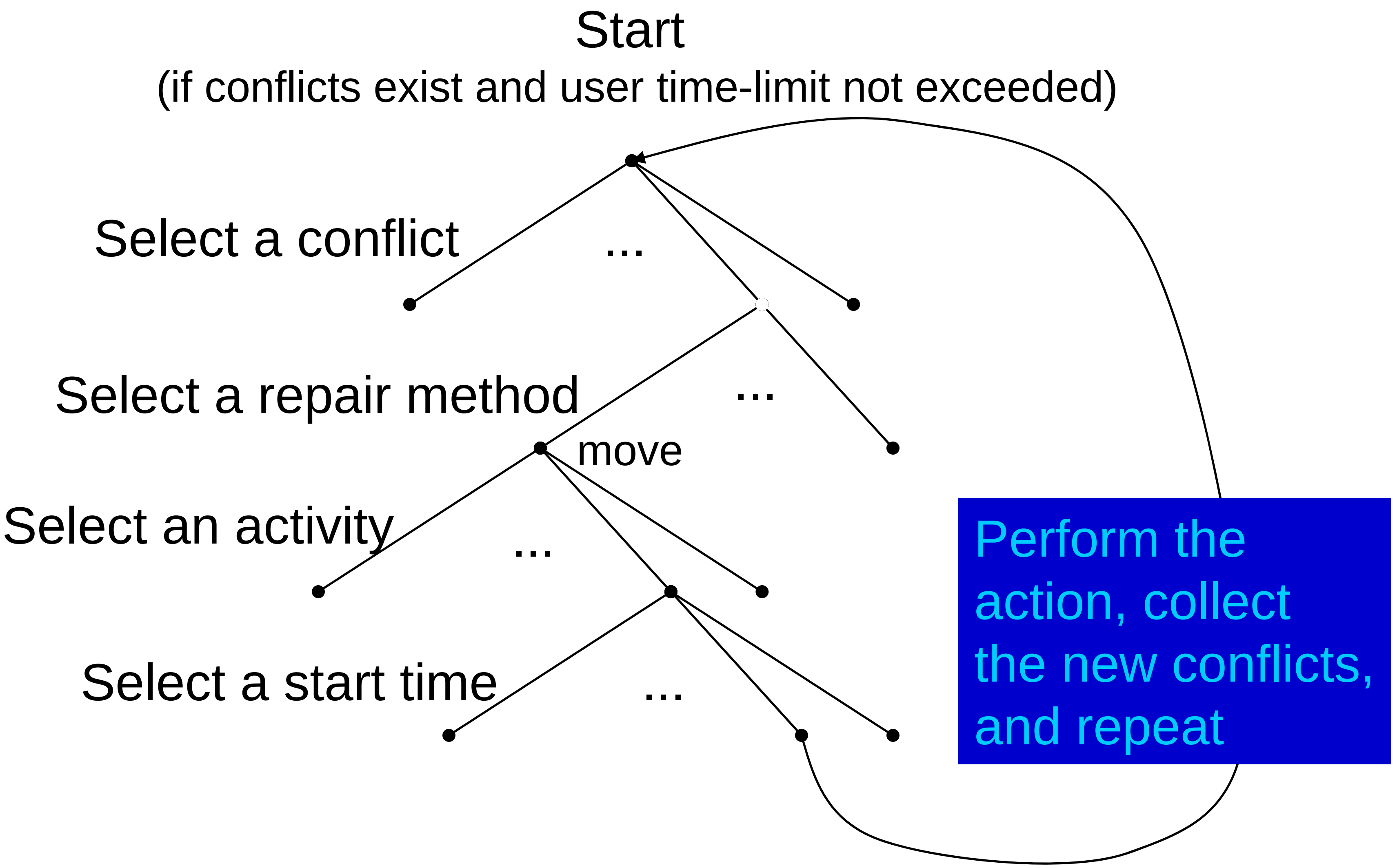
Ground
Detail
Redetail
Add
Move
Delete
Lift
Place
Abstract
Disconnect
Connect
Apply Dependency

Value
Decomposition
Activity Type
Activity
Activity
Activity
Activity
Constraint
Constraint

## Method Choices:

Start Time Interval
Start Time
Duration
Activity

# *Repair Algorithm*



Start

(if conflicts exist and user time-limit not exceeded)

Select a conflict ...

Select a repair method ...

move

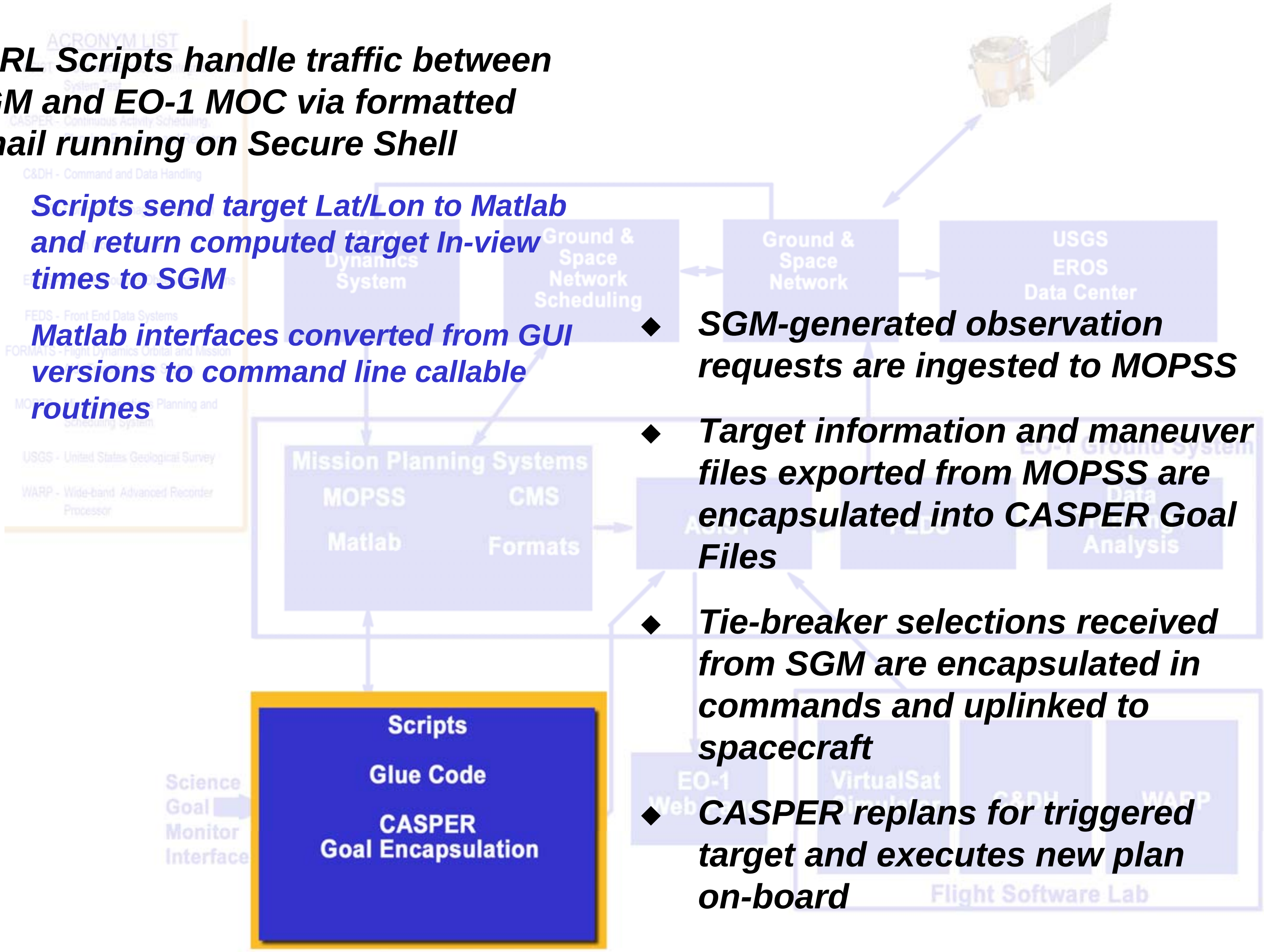
Select an activity ...

Select a start time ...

Perform the action, collect the new conflicts, and repeat

# Interface Scripts and Glue Code

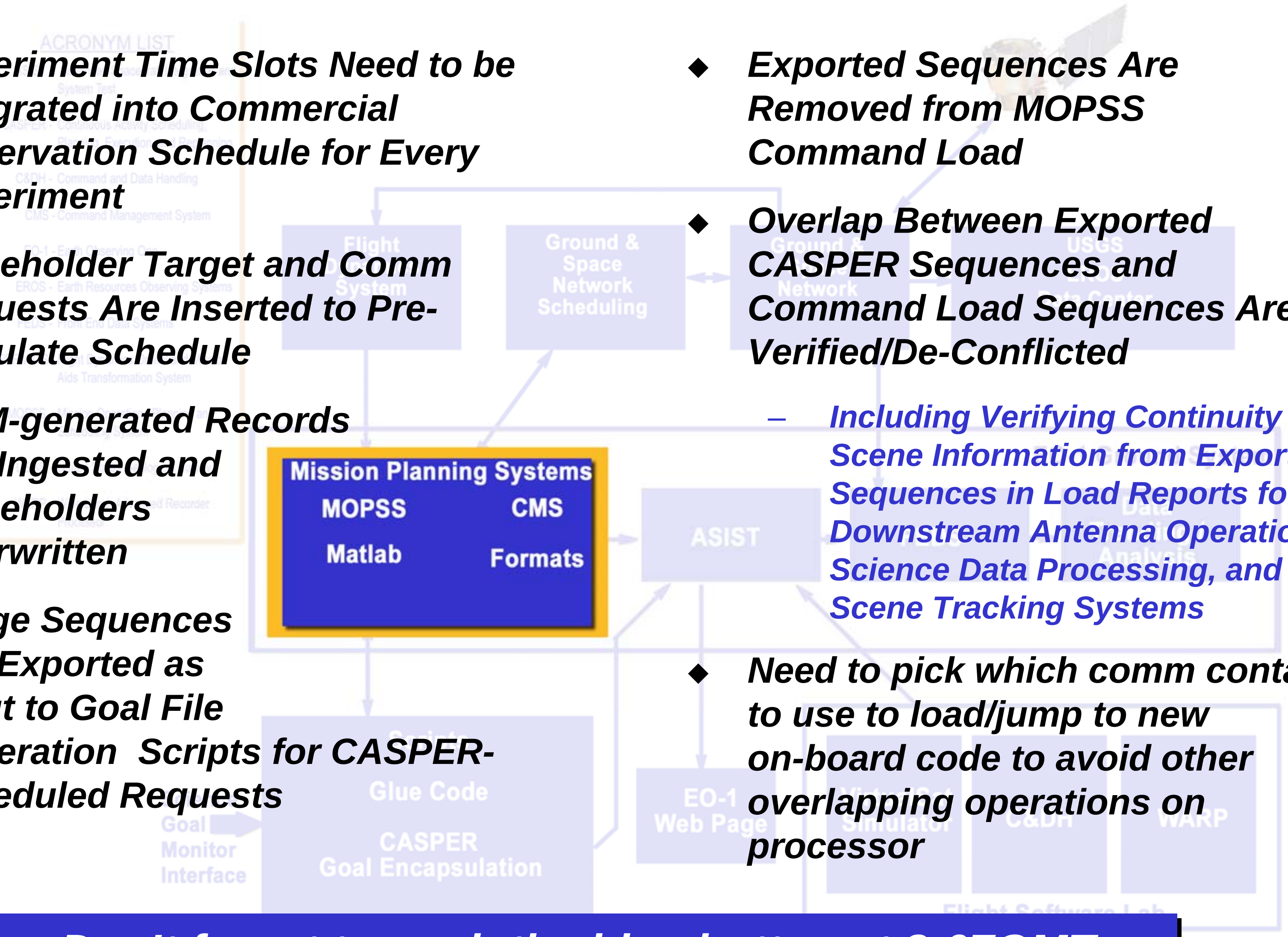
- ***PERL Scripts handle traffic between SGM and EO-1 MOC via formatted Email running on Secure Shell***
  - ***Scripts send target Lat/Lon to Matlab and return computed target In-view times to SGM***
  - ***Matlab interfaces converted from GUI versions to command line callable routines***


ACRONYM LIST
CASPER - Continuous Activity Scheduling,
C&DH - Command and Data Handling
FEDS - Front End Data Systems
FORMATS - Flight Dynamics Orbital and Mission
MOPSS - Mission Operations Planning and Scheduling System
USGS - United States Geological Survey
WARP - Wide-band Advanced Recorder Processor
Flight Dynamics System
Ground & Space Network Scheduling
Ground & Space Network
USGS EROS Data Center
EO-1 Ground System
Mission Planning Systems
MOPSS
CMS
Matlab
Formats
ASIST
FEDS
Data Analysis
Scripts
Glue Code
CASPER
Goal Encapsulation
Science Goal Monitor Interface
EO-1 Web
VirtualSat
C&DH
WARP
Flight Software Lab

- ***SGM-generated observation requests are ingested to MOPSS***
- ***Target information and maneuver files exported from MOPSS are encapsulated into CASPER Goal Files***
- ***Tie-breaker selections received from SGM are encapsulated in commands and uplinked to spacecraft***
- ***CASPER replans for triggered target and executes new plan on-board***

# New Mission Planning Activities

- ***Experiment Time Slots Need to be Integrated into Commercial Observation Schedule for Every Experiment***
- ***Placeholder Target and Comm Requests Are Inserted to Pre-Populate Schedule***
- ***SGM-generated Records Are Ingested and Placeholders Overwritten***
- ***Image Sequences Are Exported as Input to Goal File Generation  Scripts for CASPER-Scheduled Requests***
- ***Exported Sequences Are Removed from MOPSS Command Load***
- ***Overlap Between Exported CASPER Sequences and Command Load Sequences Are Verified/De-Conflicted***
  - *Including Verifying Continuity of Scene Information from Exported Sequences in Load Reports for Downstream Antenna Operations, Science Data Processing, and Scene Tracking Systems*
- ***Need to pick which comm contact to use to load/jump to new on-board code to avoid other overlapping operations on processor***



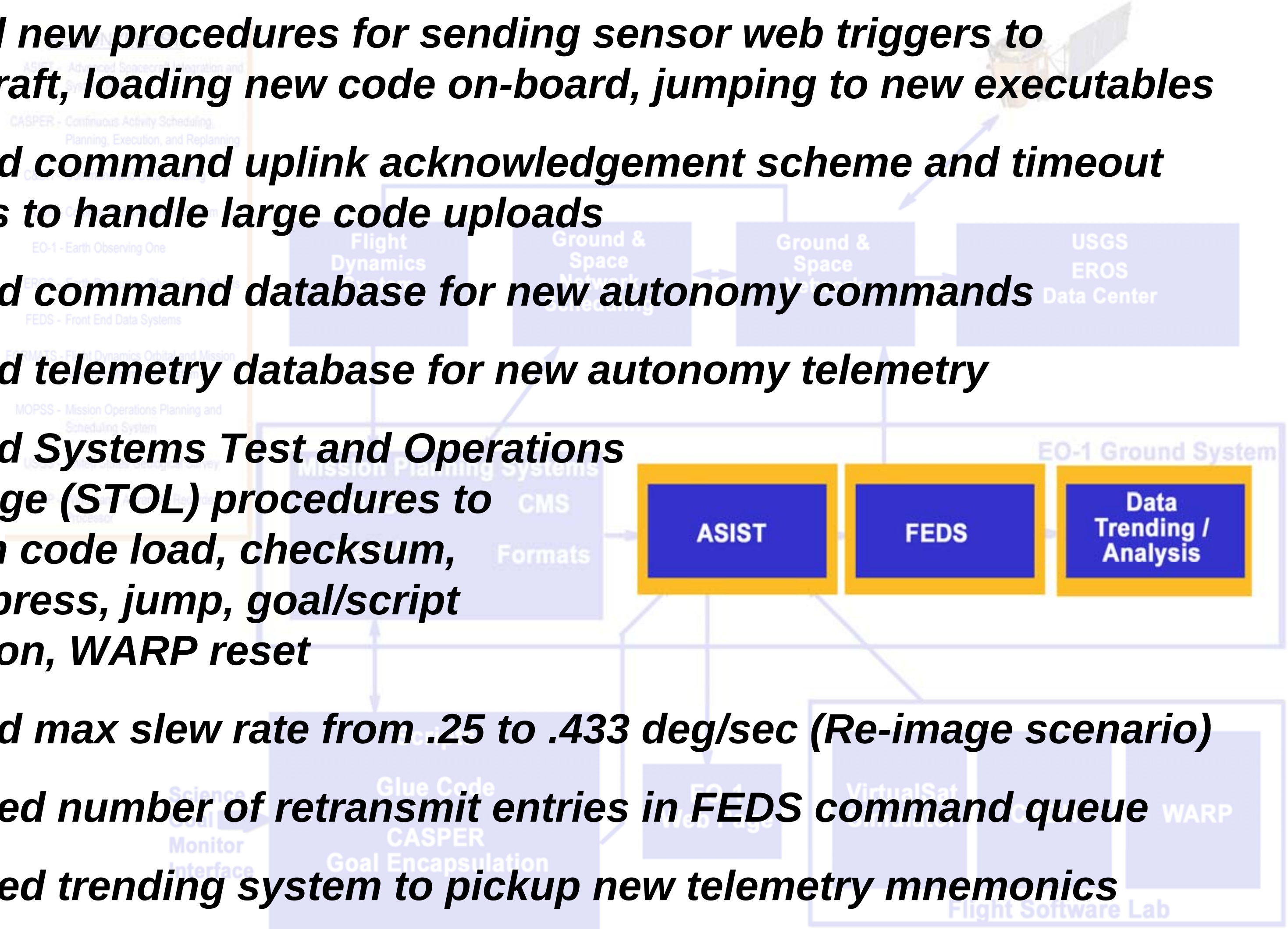
***Don't forget to push the blue button at 8:07GMT***

Earth Observing-1

# Ground System Accommodations/Upgrades

March 2, 2004

- *Created new procedures for sending sensor web triggers to spacecraft, loading new code on-board, jumping to new executables*
- *Modified command uplink acknowledgement scheme and timeout settings to handle large code uploads*
- *Modified command database for new autonomy commands*
- *Modified telemetry database for new autonomy telemetry*
- *Modified Systems Test and Operations Language (STOL) procedures to perform code load, checksum, uncompress, jump, goal/script activation, WARP reset*
- *Modified max slew rate from .25 to .433 deg/sec (Re-image scenario)*
- *Increased number of retransmit entries in FEDS command queue*
- *Upgraded trending system to pickup new telemetry mnemonics*

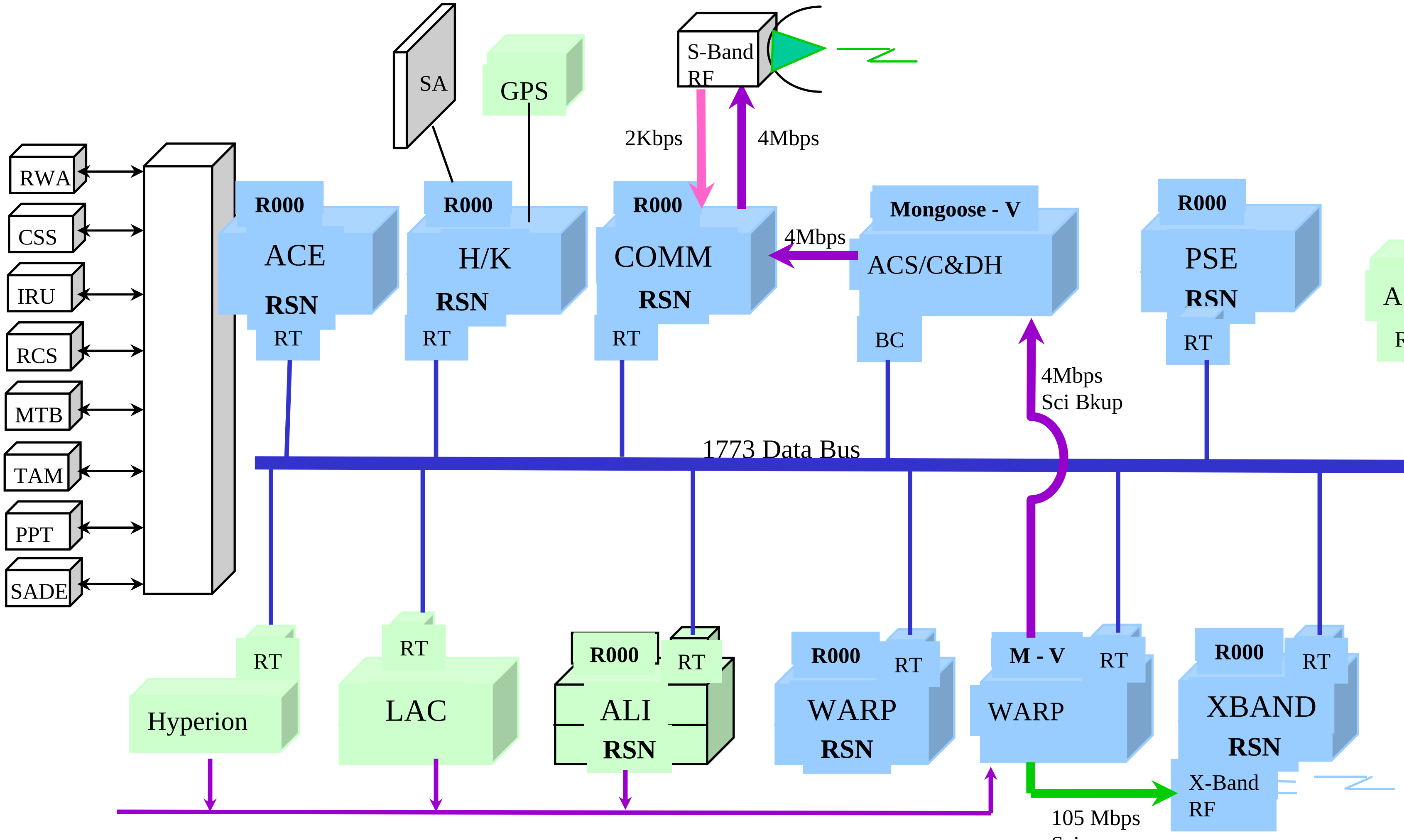


CASPER - Continuous Activity Scheduling, Planning, Execution, and Replanning
EO-1 - Earth Observing One
FEDS - Front End Data Systems
MOPSS - Mission Operations Planning and Scheduling System
Flight Dynamics
Ground & Space Network Scheduling
Ground & Space Networks
USGS EROS Data Center
EO-1 Ground System
Mission Planning Systems
CMS
Formats
ASIST
FEDS
Data Trending / Analysis
Science Goal Monitor Interface
Glue Code CASPER Goal Encapsulation
EO-1 Web Page
VirtualSat Simulator
WARP
Flight Software Lab

***No, not THAT blue button!***

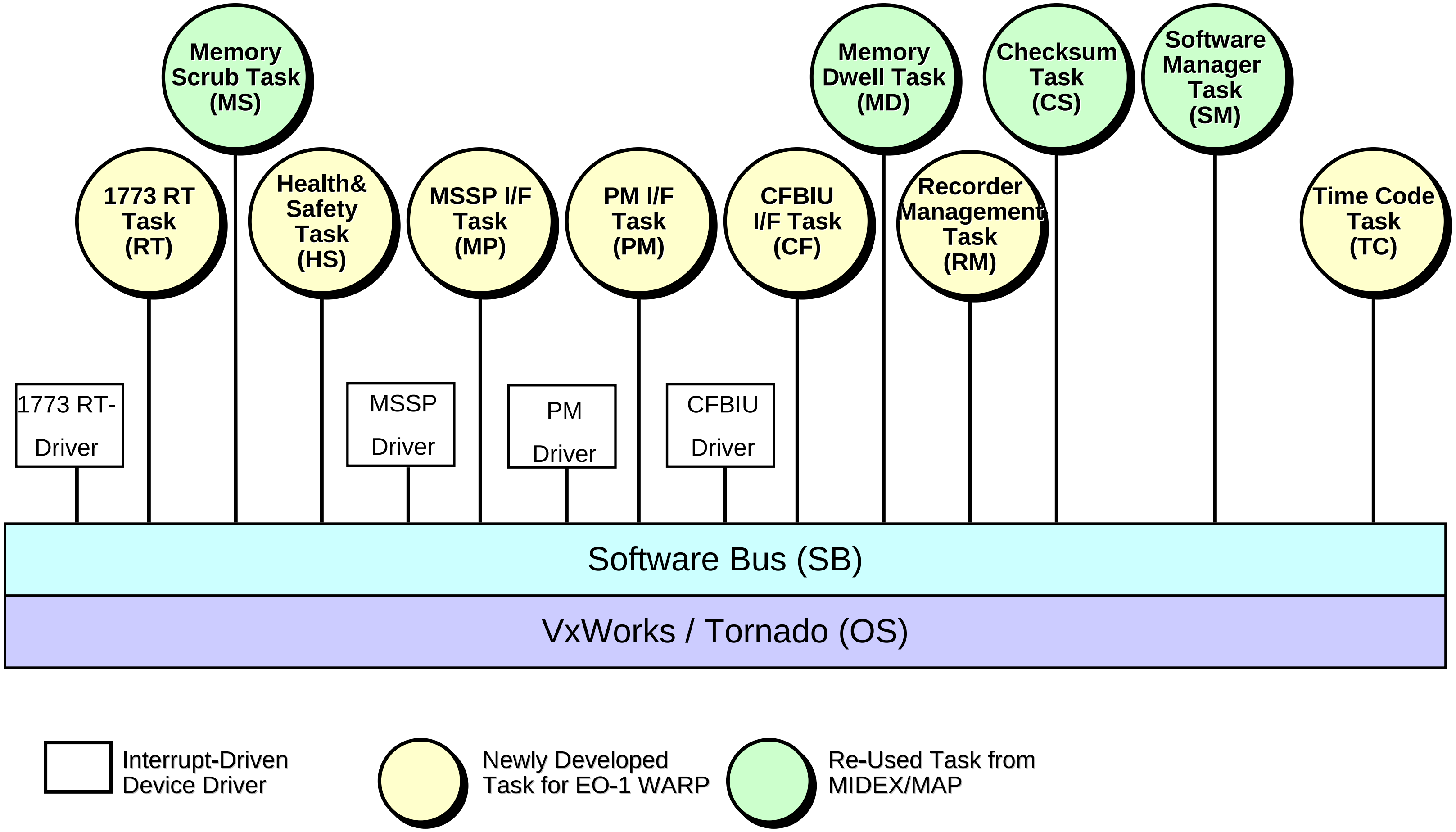
# *FSW Overview (Block Diagram)*

March 2, 2004



🟦 - GSFC managed 🟩 - instrument or procured

# *WARP Software Architecture*



Memory Scrub Task (MS)

1773 RT Task (RT)

Health& Safety Task (HS)

MSSP I/F Task (MP)

PM I/F Task (PM)

CFBIU I/F Task (CF)

Memory Dwell Task (MD)

Recorder Management Task (RM)

Checksum Task (CS)

Software Manager Task (SM)

Time Code Task (TC)

1773 RT- Driver

MSSP Driver

PM Driver

CFBIU Driver

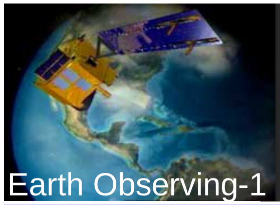
Software Bus (SB)

VxWorks / Tornado (OS)

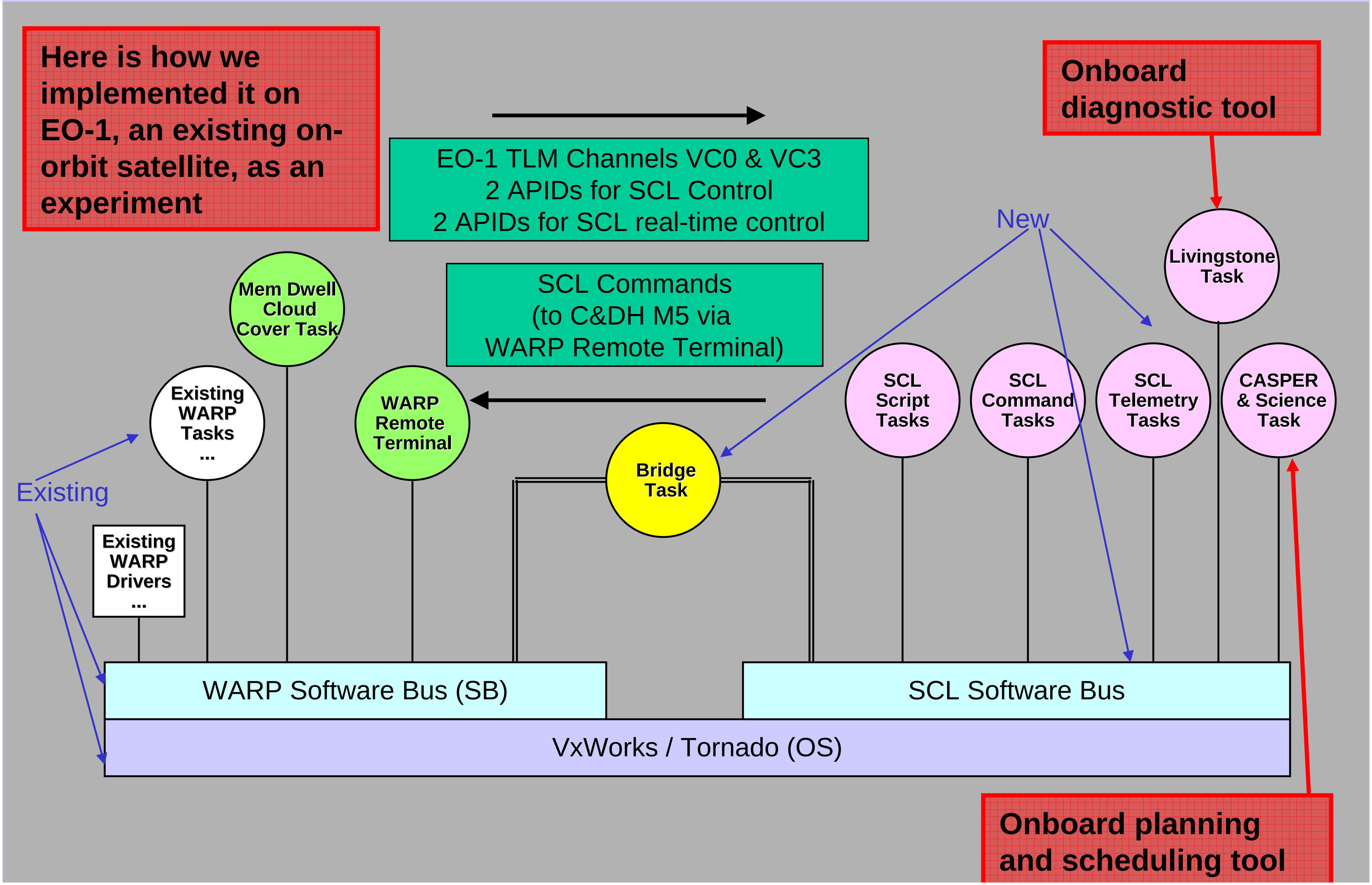
□ Interrupt-Driven Device Driver

○ Newly Developed Task for EO-1 WARP

○ Re-Used Task from MIDEX/MAP



# *Integrated "Plug and Play", using SCL as adapter*



**Here is how we implemented it on EO-1, an existing on-orbit satellite, as an experiment**

EO-1 TLM Channels VC0 & VC3
2 APIDs for SCL Control
2 APIDs for SCL real-time control

SCL Commands
(to C&DH M5 via
WARP Remote Terminal)

**Onboard diagnostic tool**

New

**Livingstone Task**

**Mem Dwell Cloud Cover Task**

**Existing WARP Tasks ...**

**WARP Remote Terminal**

**Bridge Task**

**SCL Script Tasks**

**SCL Command Tasks**

**SCL Telemetry Tasks**

**CASPER & Science Task**

Existing

**Existing WARP Drivers ...**

WARP Software Bus (SB)

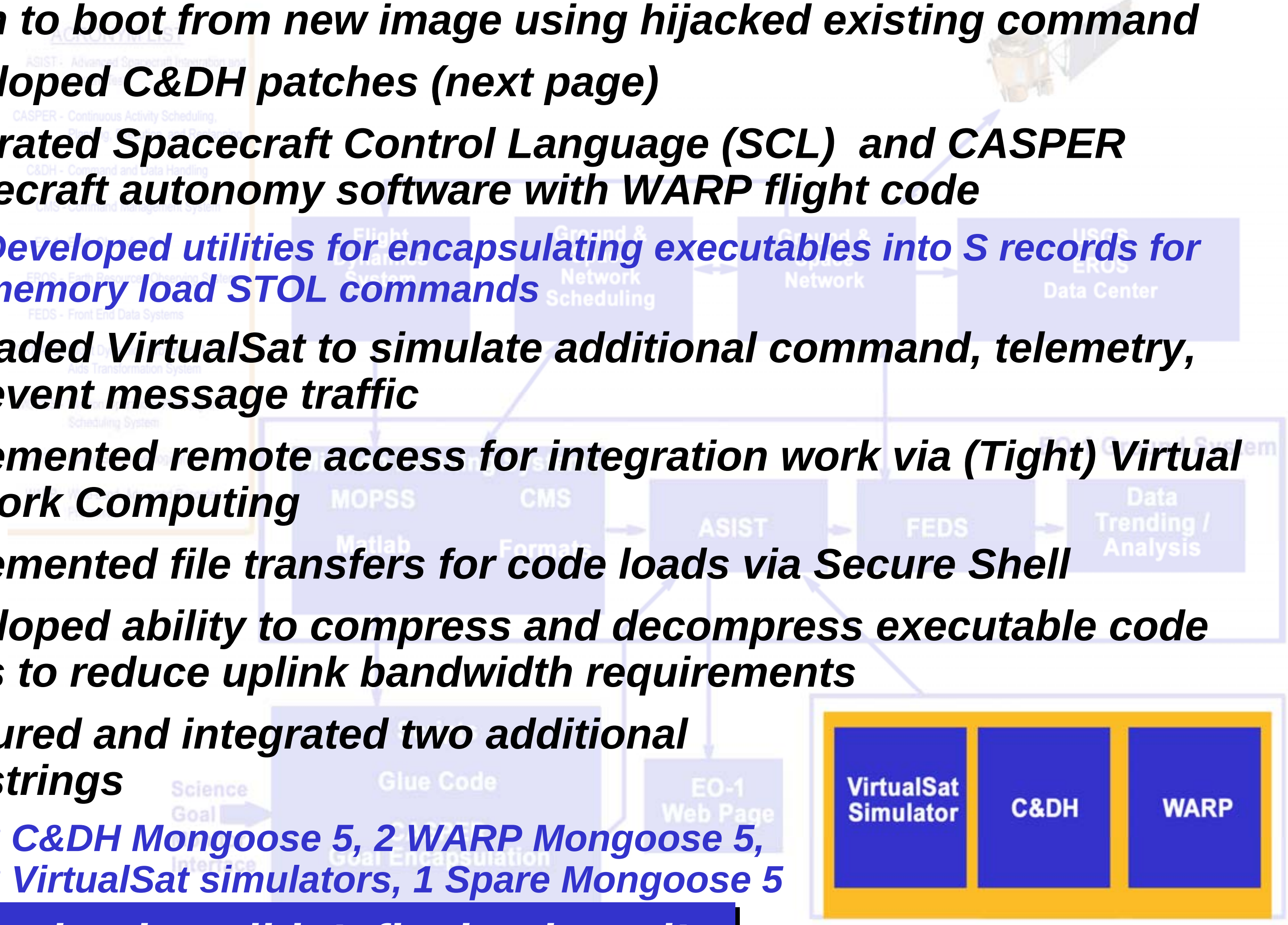
SCL Software Bus

VxWorks / Tornado (OS)

**Onboard planning and scheduling tool**

# Flight Software Lab

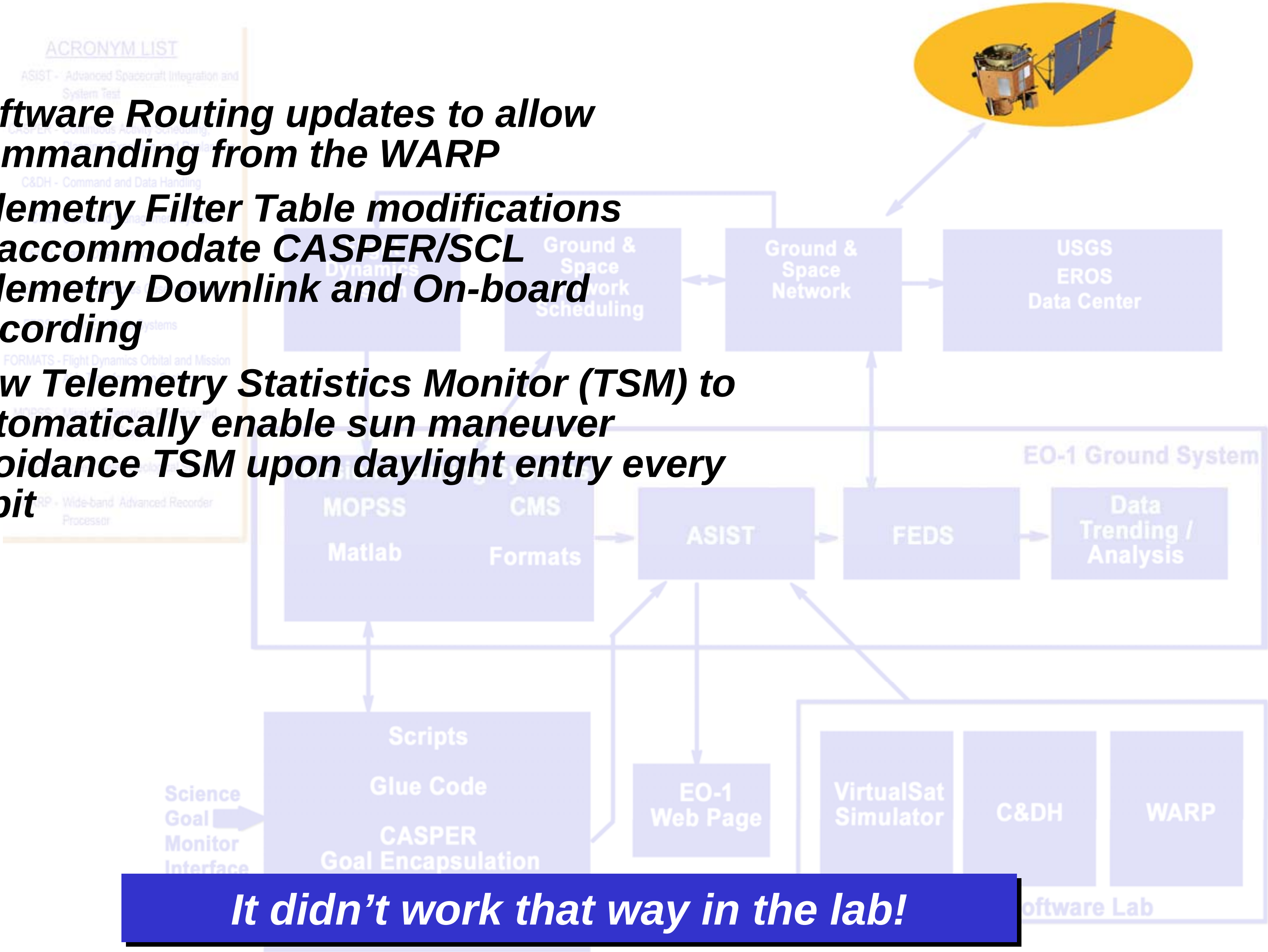
- Developed capability to reload WARP Flight Software kernel and patch to boot from new image using hijacked existing command
- Developed C&DH patches (next page)
- Integrated Spacecraft Control Language (SCL) and CASPER spacecraft autonomy software with WARP flight code
  - Developed utilities for encapsulating executables into S records for memory load STOL commands
- Upgraded VirtualSat to simulate additional command, telemetry, and event message traffic
- Implemented remote access for integration work via (Tight) Virtual Network Computing
- Implemented file transfers for code loads via Secure Shell
- Developed ability to compress and decompress executable code loads to reduce uplink bandwidth requirements
- Procured and integrated two additional test strings
  - 2 C&DH Mongoose 5, 2 WARP Mongoose 5, 2 VirtualSat simulators, 1 Spare Mongoose 5



**Now I see why they didn't fly that board!**

# On-Board Changes to C&DH

March 2, 2004


ACRONYM LIST
ASIST - Advanced Spacecraft Integration and System Test
CASPER - Continuous Activity Scheduling, Planning, Execution, and Replanning
C&DH - Command and Data Handling
FEDS - Front End Data Systems
FORMATS - Flight Dynamics Orbital and Mission Aids Transformation System
MOPSS - Mission Operations Planning and Scheduling System
USGS - United States Geological Survey
WARP - Wide-band Advanced Recorder Processor
Flight Dynamics
Ground & Space Network Scheduling
Ground & Space Network
USGS EROS Data Center
EO-1 Ground System
MOPSS
CMS
Matlab
Formats
ASIST
FEDS
Data Trending / Analysis
Scripts
Glue Code
CASPER Goal Encapsulation
Science Goal Monitor Interface
EO-1 Web Page
VirtualSat Simulator
C&DH
WARP
Software Lab

- ***Software Routing updates to allow Commanding from the WARP***
- ***Telemetry Filter Table modifications to accommodate CASPER/SCL Telemetry Downlink and On-board Recording***
- ***New Telemetry Statistics Monitor (TSM) to automatically enable sun maneuver avoidance TSM upon daylight entry every orbit***

***It didn’t work that way in the lab!***

# On-Board Changes to WARP

- ***Reloaded entire WARP code image and jumped to it via patch***
- ***Modified Memory Dwell task and S-band playback function in WARP Flight Code to read science data into RAM from near-line bulk storage***
- ***Created various SCL and CASPER-related tasks***
- ***Hijacked telemetry packets and commands for SCL and CASPER use***
- ***Loaded new CASPER, SCL and cloud assessment algorithm on-board***
- ***Added Event Messages for status reporting***
- ***Modified checksum configuration on WARP for upload verification***
- ***Increased WARP Watchdog timeout to prevent reset when booting to new larger code***
- ***Turned Off CPU hogging and changed Memory Dwell task check-in error to an event – had caused warm restart***
- ***Implemented a decompression utility on-board based on zlib library inflate function***

***Explain to me again why I can't playback science data over S-band or run memory diagnostics with CASPER running***

# System Engineering Issues

- ***CASPER knows spacecraft state and resources***
  - *Doesn’t do navigation, orbit propagation,…*
  - *Doesn’t do momentum management/maneuver planning*
  - *Has to coordinate file naming conventions with Command Load observations*
  - *Changeover from Command Load to CASPER control*
- ***Better coordination required because more complex activity sequences are being undertaken***
  - *Operational sequences are not independent*

# ***Warts*** *(1 of 3)*

- ***FSW lab hardware not identical to flight hardware***
  - ***WARP Flight Processor has 256Mbytes RAM, but breadboard in lab has 32M memory for integration work – limits use of full on-board memory***
  - ***Off-line WARP bulk memory cards not procured for EO-1 lab (>$1M) limits testing for image data file manipulation code***
  - ***Insufficient memory in Flight Software Lab Breadboard caused several month delay in integration effort***
  - ***Sensors and Mechanisms simulated using VirtualSat***
- ***Cannot duplicate on-board dynamics in lab (e.g., CPU starvation)***
- ***Unexpected spacecraft reactions encountered during experiments***
- ***On-orbit debugging required***
- ***Had to use outgassing periods every 16 days to run experiments***
  - ***Always a stretch to define scope, schedule support, deliver tested code and unzip/jump/verify procedures in time for uplink***

# **Bumps** *(2 of 3)*

- ***Code loads to testbeds in FSW Lab slow at first - sped up by implementation of ICEPROMS and/or Ethernet on Mongoose boards***
- ***Takes 3-4 days to uplink code loads to spacecraft***
  - ***15-20 ground station contacts***
  - ***TDRS not reliable for large uplinks – can only use ground stations***
  - ***6Mbyte code loads to spacecraft compress by about 6-1***
- ***Encountered problems verifying large uplinks***
  - ***Not enough time to do full dump and compare***
  - ***Using checksums was labor intensive and discrepancies hard to isolate***
  - ***Made for some exciting tests….***
- ***WARP reboots during dumps causes dump flag to hang on C&DH***
  - ***Had to stuff WARP dump bit to YES, then send abort to clear C&DH flag***
  - ***Still ran experiments on non-verified code – Oh Well!***

# And Blemishes *(3 of 3)*

- ***On-board Cloud Detection takes 15 minutes to run on-board***
  - *Not sufficient for look-ahead/assess/retarget scenarios*
  - *Next load of FSW will allow selectable readout of hyperspectral bands and selectable readouts of particular rows of the image data file to speed up*
- ***Special care has to be taken to avoid invoking on-board memory operations during command load event windows***
  - *No code loads, script updates, dumps, jumps, or other activation/deactivation memory operations during WARP Record or Playback events*
- ***Crashed WARP once – memory starvation issue***
  - *Spacecraft was under CASPER control*
  - *Crash occurred during image sequence – Watchdog check-in*
  - *Left spacecraft maneuvered with instruments on and covers open*
  - *Had to recover manually during next communications contacts*

# Lessons Learned

- ***Build excess CPU and memory capacity into Flight Segment***
  - *Enables sensor web/autonomy improvements post-launch*
- ***Include at least 2 flight processors on-board in future designs***
  - *Can do development work without disturbing C&DH operations*
  - *If 2nd processor is not executing new FSW properly, reboot to old code*
- ***Build ground FSW Lab with identical hardware to Flight Segment***
- ***Minimize time spent on development of support tools and utilities during early part of software effort***
  - *Concentrate on primary functionality until better tools would save time*
- ***Learn through failure if it's safe to do so – if you wait until you're 100% sure of success, you may never get anything done***
- ***Setup safeguards to auto-recover via command load after crashes are encountered during experiments***
- ***Need to setup process for delivery of science data from experiments - problematic in commercial data sales setting***