A Flight RTEMS OSAL With Runtime Loader Support and Other Enhancements

Kevin Gordon, Allen Brown
Odyssey Space Research, LLC

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This presentation does not contain US
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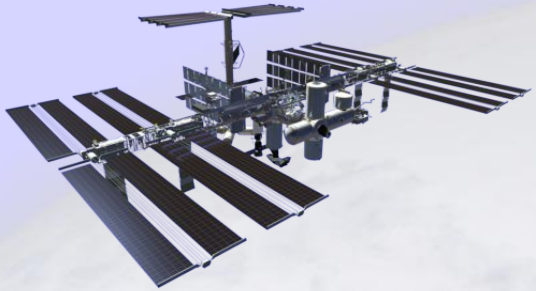
Company Background

- Odyssey Space Research LLC
  - Established 2003
  - Houston TX (Denver CO, Austin TX)
- Core Areas
  - GN&C algorithms, design, analysis, integration, evaluation, test
  - Flight software development, integration, test
  - Simulation development, integration
  - Trajectory / Mission design, analysis
- Current Principal Projects
  - Orion Multi-Purpose Crew Vehicle
  - Commercial Crew
  - Commercial Resupply Services 1 & 2
  - ISS Visiting Vehicle Integration
  - Exploration Mission analysis and design
  - Flight dynamics for mission operations
  - Commercial launch vehicle development
  - Satellites: LEO and beyond



Company cFS Areas

- NASA Support
  - Integrated FSW Simulations
    - Project Gateway
    - Moon Mission
    - ...and others
  - Class A Certification (Human Rating)
  - New cFS platforms (Xenomai, ARINC 653)
  - cFS Voting Architecture
  - Distributed cFS Integration
  - New cFS Apps/Libs for Commands/Telemetry

- Commercial Applications
  - Integrated FSW Simulations
  - DoD test satellite
  - Commercial Science Satellite
  - Orion BFS

- Internal Research & Development
  - Integrated FSW Simulations
  - Human-in-the-Loop Flight Mockup (displays, vehicle & environment sim, cFS FSW)
  - Integrated Development Environments
  - Command and telemetry UI architecture & development
  - Data management

Company cFS Areas (cont'd) and Current FSW Direction

- Company cFS Areas (cont'd)
  - Full-stack development
    - BSP, custom drivers up through custom cFS applications
    - C&DH, GNC, etc.
  - Ground dev/test and operations support
  - cFS Training & Consulting
    - Internal and for commercial customers upon request
    - Training classes and materials
    - Templates, guidelines, HOWTO's

- Right now:
  - FSW development opportunities growing
  - Both Government and Commercial applications
  - Both cFS and custom solutions

Commercial Project and an RTEMS OSAL

- Supporting LASP
  - Laboratory for Atmospheric and Space Physics, University of Colorado Boulder
  - Development of flight software
  - Spacecraft slated to perform a multi-year deep space mission
- Technical Background:
  - Cobham UT700 LEON3FT 32-bit SPARC v8 processor
  - cFS: current release (6.5.0a, released applications, etc.)
    - Strong objective: Minimal changes
  - Custom: BSP, PSP, new cFS mission apps

Commercial Project and an RTEMS OSAL

Technical Background (cont'd)

- RTOS: RTEMS
  - RTEMS 4.10 and prior: Statically built (cFS limitations)
  - RTEMS 4.11+: Contains Run-Time Linker/Loader (RTL)
- OSAL: Currently released version (4.2.0a): Supports RTEMS 4.10 (no RTL)

Objectives

- Space Mission
  - Runtime loading of cFS applications and libraries
  - Project needs a flight-quality OSAL that uses RTEMS RTL
  - Enhance RTEMS OSAL functionality and robustness
- Community
  - Release updated RTEMS OSAL back to the cFS community
  - Engage RTEMS developers with RTL testing and feedback

Flight RTEMS OSAL
Summary

- Functional Improvements
  - Runtime loading fully implemented using RTL
  - Compatibility with RTEMS versions
  - Task names
- Quality Improvements
  - Error detection, mutex timeouts, string operations, debugging info
- Testing Improvements
  - Test BSPs
  - Functional Tests, Unit Tests
- Lessons learned:
  - Module dependencies on static libs vs. exposed symbols
  - *libm* in RTEMS kernel with loadable modules
  - Options: select symbols in kernel or put lib in cFS library

Flight RTEMS OSAL
Functional Improvements

- Dynamic loading implemented using RTL for:
  - Loading and unloading/replacing cFS applications and libraries from ELF .o files at runtime
  - Full Symbol table dump including RTEMS symbols (not just module entry points); and unresolved symbols (bad loads)
  - Module information (code, data, and BSS addresses/sizes)
- OS API updated to support RTEMS 4.11.1 & 4.12 (5.0)
- RTEMS task name length support
  - RTEMS: Has a 4 char task name limit and allows duplicates
  - OSAL/cFS: OS_MAX_API_NAME (~20 chars) supports task-by-name access
  - cFE system would map to: “CFE_”, “CFE_”, “TIME”, “TIME”, …
  - Added mapping of cFE names into unique 4-char RTEMS task names

Flight RTEMS OSAL
Extra Runtime Protection

"But what about…?"

- If unresolved symbols exist after module load?
  - (RTEMS RTL allows this for possible future load resolution)
  - This OSAL: automatically unloads module and optionally shows missing symbols
  - cFE controls module load order
  - Conservative stance: *"no undefined symbols"*
- Changing a loaded module's file?
  - Confirmed with RTEMS RTL
    - No effect on in-memory image...
    - ...When a loaded module's file in filesystem is altered.

Other OSs have ***different behavior!***

Flight RTEMS OSAL
Quality Improvements

- Improved: error detection - all RTEMS return values checked
- Identified and added: missing logic (off-nominal cases)
- Added: missing arg checks
- Changed OSAL internal resource mutex use:
  - Modified take/give locations for better protection and avoiding race conditions
  - Added optional and configurable timeouts when appropriate
  - Return values in OSAL API will indicate “timeout” if it occurs (Checked all cFE and cFS apps return value logic)
  - Concern: deadlock when no timeout can be used
- Replaced: unsafe string ops
- Added: significant debug output with OS_DEBUG_PRINTF

Flight RTEMS OSAL
Test BSP Improvements

- Completed pc-rtems (i386) BSP Implementation
  - Added Makefiles and 2-step link for linking RTEMS symbol table
  - Updated BSP start file and volume table
    - tasking-example & OSAL functional tests
    - qemu-system-i386
- Added sparc-rtems-leon3 BSP
  - Added Makefiles and 2-step link for linking RTEMS symbol table
  - Created all other files needed
    - tasking-example & OSAL functional tests
    - qemu-system-sparc (and hardware)

Flight RTEMS OSAL
Test Improvements

- Enabled FP tasks in functional tests
  - To match flight & cFE
- Functional Test Upgrades
  - Added: Loader API Tests
    - Load, unload, function calls, shared resource access, etc.
    - Corner case tests for memory, resources, repeated load/unload
  - Added: File API Tests
    - OS_ShellOutputToFile() - Supported cFE shell command bugfix testing
    - Missing File API function tests for OS_cp(), OS_mv(), OS_rmfs(), etc.
- Unit tests: Added RTEMS support!
  - Only VxWorks, Linux, and ARINC 653 supported previously

Flight RTEMS OSAL
Tested Platforms

- Current: RTEMS 4.11.1 open-source toolchain
  - RTEMS' sparc-leon3 and i386 OSAL Test BSPs
    - sparc-leon3 on QEMU and hardware and i386 on QEMU
  - UT700 LEON3FT Flight BSP
    - Both on hardware and QEMU
- Functional tests confirmed on:
  - Cobham rcc1.3-rc1 (RTEMS Cross Compiler, RCC)
  - RTEMS 4.11.1 release and 4.11.99 HEAD (Oct 2017)
- In work:
  - RTEMS 4.11.99/4.12/5.x Cobham rcc1.3-rc2
- Final destination:
  - RTEMS release on Cobham release toolchain

Feedback to RTEMS Team

- We have tested the RTL through OSAL functional tests
- Reported three RTL-related issues to RTEMS
  - Memory leak after module unload with dlclose()
  - Infinite loop condition in dlopen() resulting from leftover external reference resolution attempt after dlcose()
  - Module can be unloaded with current dependencies
- We want to help improve the RTL and form a relationship with the RTEMS developer community

Flight RTEMS OSAL Current Status

- Functionally complete
  - No API changes
- Testing on various platforms/toolchains continues
- Public release to the cFS & RTEMS communities
  - Planned, cleared internal review
  - In-work: Release date, site, and logistics

Thank You:

LASP

The cFS Community

Special thanks: Alan Cudmore/NASA, for RTEMS 4.10 OSAL

The RTEMS Community

...Q & A?