Big Software for SmallSats: Adapting cFS to CubeSat Missions

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Outline

• Motivation
• What is cFS?
• Experience: CSP / CeREs
• Experience: Dellingr
• Performance
• Future Work
• References

• NOTE: All images courtesy of NASA
Motivation

• Expanding requirements
  – Science
  – Risk tolerance
  – This stresses software (and teams!)

• Budgets are not expanding

• “Small” Satellite does not mean “small” software

• Solution: a trusted framework with reusable components
cFS: core Flight Software

- NASA recognized a need to move away from “Clone and Own”
- Developed to tackle the very issues that SmallSats now face
- Framework and core services (cFE)
- Common set of applications and libraries
- (McComas, 2012) (Fesq, Dvorak, 2012)

“The cFS follows a product line approach with the goal to support systematic reuse.”

(Ganesan, Lindvall, Ackermann, McComas, Bartholomew, 2009)

“At Goddard the main driver for changing the development process is cost, [...] An obvious way to reduce cost and schedule is to increase the amount of software reuse.”

(Wilmot, 2006)
Framework and Core Services (cFE)

- Layered architecture
- Supports Publish / Subscribe Applications
- Events
- Tables
- Time

![Diagram of cFE components]

- cFS Applications / Libraries:
  - CF
  - CS
  - DS
  - FM
  - HS
  - HK
  - LC
  - MD
  - MM
  - SBN
  - SC
  - SCH

- User Applications / Libraries:
  - ?

- cFE Services:
  - Exec
  - Event
  - Bus
  - Table
  - Time

- Operating System Abstraction Layer (OSAL)

- Operating System (Linux, RTEMS, VxWorks, FreeRTOS)

National Aeronautics and Space Administration
Libraries and Applications

• Currently 12 Applications are available (http://cfs.gsfc.nasa.gov/)

• Optional, depends on mission needs.

• Easy to create
  – Sample application demonstrates messaging, events, and application loop
Heritage

• cFE:
  - Lunar Reconnaissance Orbiter
  - Living With a Star / Radiation Belt Storm Probes

• cFS
  - Global Precipitation Measurement
  - Magnetospheric MultiScale
  - Lunar Atmosphere and Dust Environment Explorer
CHREC Space Processor

- Space Test Program, Houston 5 / ISS SpaceCube Experiment Mini
- CHREC Space Processor Experiment
- NSF Center for High-Performance Reconfigurable Computing
- Presented here last year (Rudolph et al, 2014)
- Two CSPv1 in tandem
  - Xilinx Zynq 7020
  - Arm Dual Core Cortex A9 and Artix-7 FPGA
- Runs cFS!
- Launch 2016
cFS on the CHREC Space Processor

- Work spread over 3 employees
- Created 11 custom applications / libraries
- Code is in well defined applications
- Vary in level of reusability
- This is in addition to existing cFS functionality
CeREs

- Compact Radiation Belt Explorer
- MERiT: Miniaturized Electron and pRoton Telescope
- Flight computer is a CSP
- cFS used for flight software
- (Kanekal, 2014)
Dellingr

- **Hardware:**
  - ARM7 processor (40 Mhz 2Mb RAM)
  - Reaction Wheels
  - Magnetorquers
  - Sensors (FSS)

- **Science**
  - INMS
  - Magnetometer
  - Thermal Louvre
Dellingr and cFS

- Work spread over three employees
- Ported OSAL to FreeRTOS
- Integrate with GomSpace software
- Custom
  - Hardware Library
  - Hardware telemetry
  - Radio
  - ACS
  - Science instruments
- Generated using David A. Wheeler's 'SLOCCount'

Custom Code for Dellingr Approx. 10k SLOC

- ACS
- HW Lib
- Radio
- INMS
- GPS
- SHK
- RW
- MAG
- Camera
Performance

- cFS imposes some performance costs
- Compared build with just FreeRTOS vs cFS
- Code available: https://github.com/jcmarsh/cpek

<table>
<thead>
<tr>
<th></th>
<th>FreeRTOS</th>
<th>CFS</th>
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<tr>
<td>Dhrystone (per second)</td>
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<td>10576.4</td>
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<tr>
<td>WhetstoneDhrystone (KWIPs)</td>
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<tr>
<td>Hardware ping (per second)</td>
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<td>621</td>
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</table>
Application Communication Costs

- cFS supports publish / subscribe message passing through the software bus.
- Adds functionality to FreeRTOS queues, increases overhead.
- Chart shows round trip messages passed between two applications.

FreeRTOS vs cFS Message Passing

![Graph showing comparison between FreeRTOS and cFS message passing performance. The graph plots application round trips (per second) against message size (bytes). The x-axis represents message size in bytes (4, 32, 64, 128, 256, 512, 1024), and the y-axis represents application round trips (per second). The graph includes a blue line for FreeRTOS and an orange line for cFS, showing the performance differences at various message sizes.](image-url)
Future Work

• 42 Simulator integration: http://fortytwospacecraftsimulation.sourceforge.net/

• cFS SDK

• Man Rated
Summary

• cFS is a mature framework
  – Strong heritage
  – Reduces personnel requirements
  – Available on a variety of platforms
  – Well suited to CubeSat missions

• Open Source (http://cfs.gsfc.nasa.gov/)

• Already being used on NASA CubeSats
References


