NASA/GSFC's Flight Software Architecture: Core Flight Executive and Core Flight System

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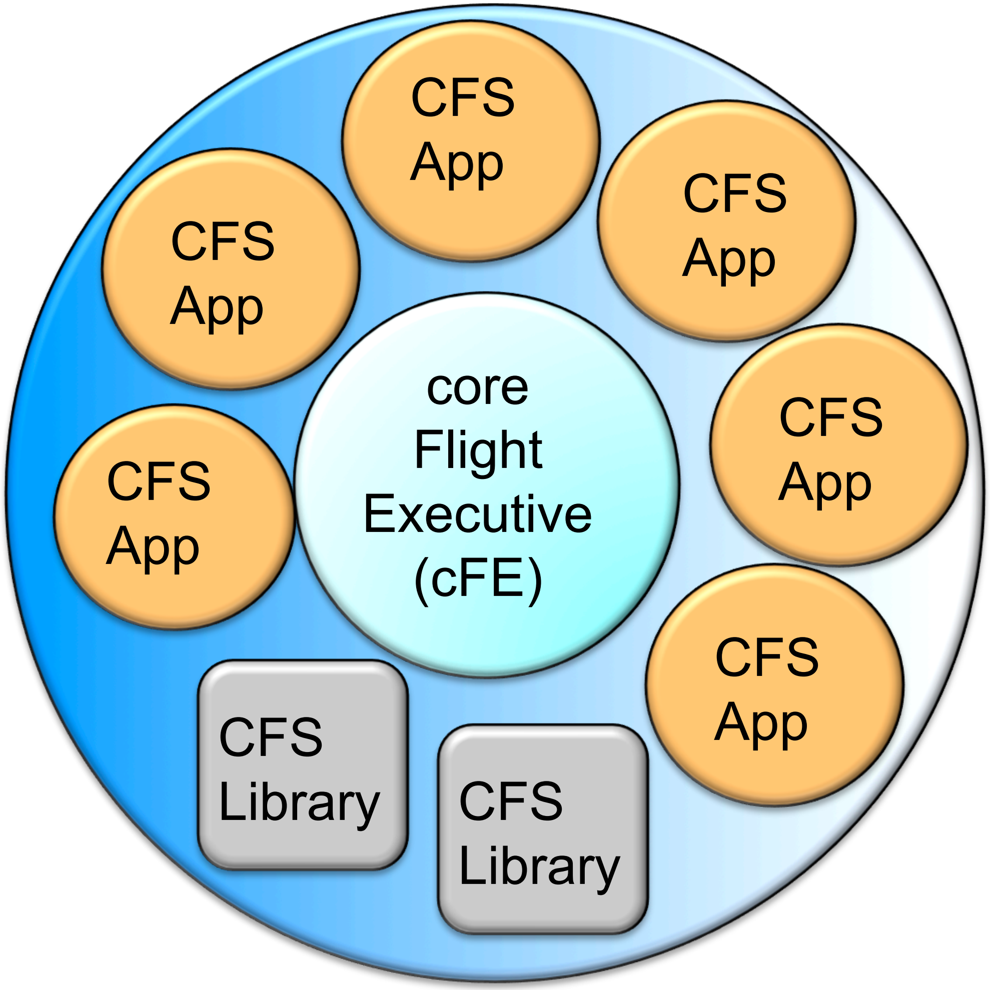
Introduction

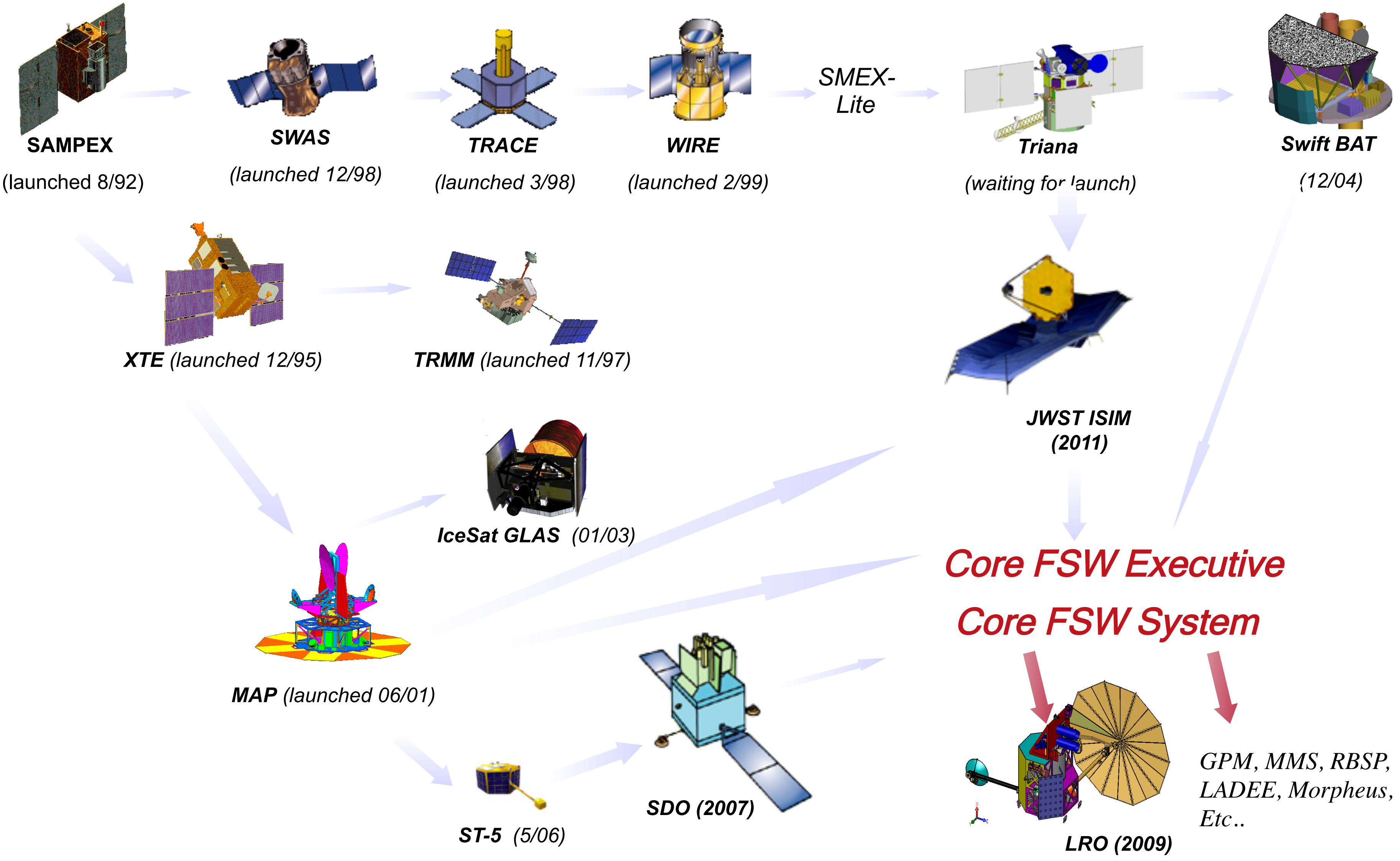
- **Core Flight System (CFS)**
  - A Flight Software Architecture consisting of the cFE Core, CFS Libraries, and CFS Applications

- **core Flight Executive (cFE)**
  - A set of *mission independent, re-usable, core* flight software services and operating environment

Core Flight System (CFS)



cFE/CFS Heritage



SAMPEX (launched 8/92)

SWAS (launched 12/98)

TRACE (launched 3/98)

WIRE (launched 2/99)

SMEX-Lite

Triana (waiting for launch)

Swift BAT (12/04)

XTE (launched 12/95)

TRMM (launched 11/97)

JWST ISIM (2011)

IceSat GLAS (01/03)

MAP (launched 06/01)

ST-5 (5/06)

SDO (2007)

Core FSW Executive

Core FSW System

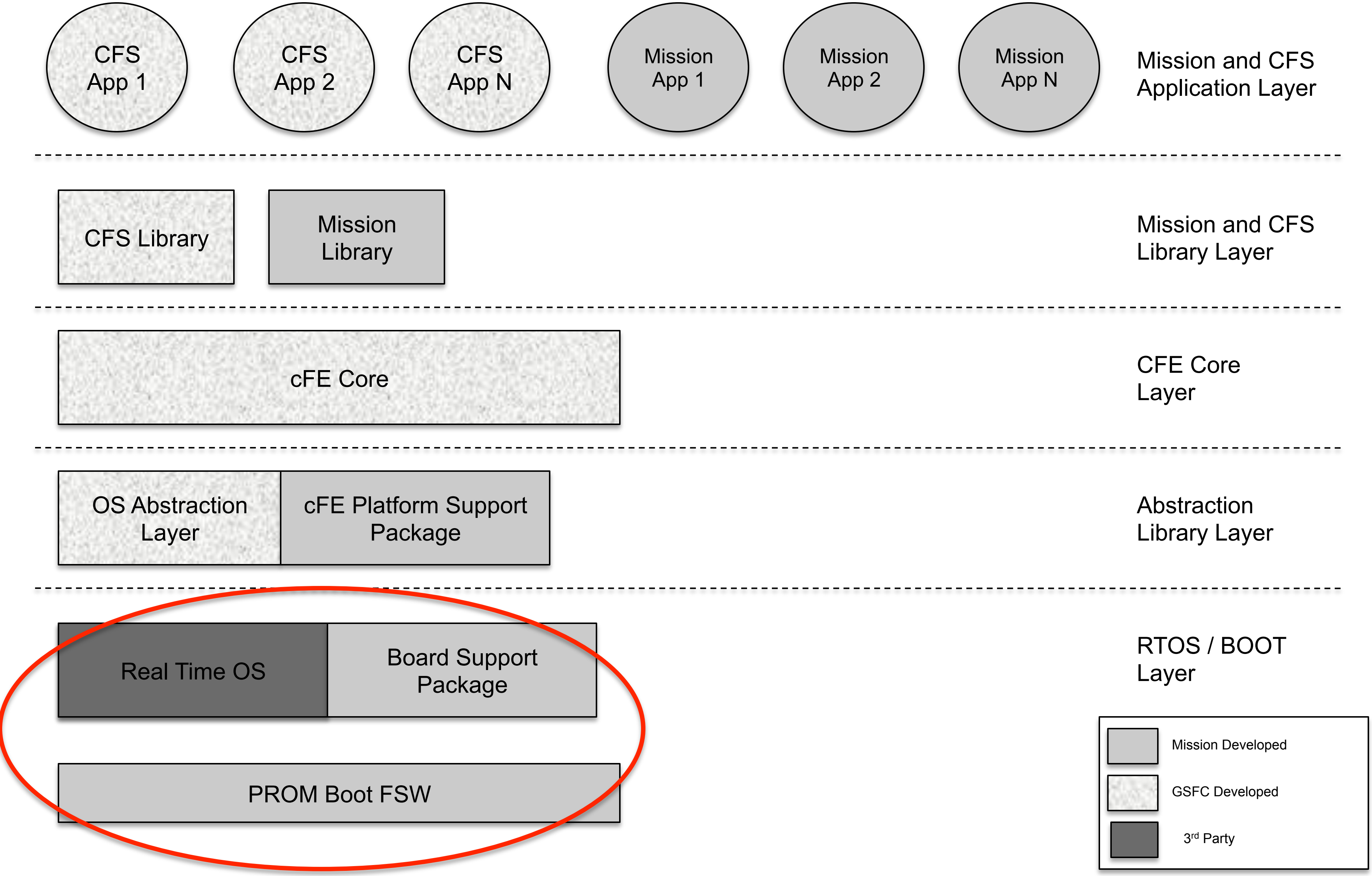
LRO (2009)

GPM, MMS, RBSP, LADEE, Morpheus, Etc..

cFE/CFS Customers

Organization	Purpose
NASA / GSFC	**LRO Spacecraft**
NASA / GSFC	**DSILCAS Project**
NASA / GSFC	**MMS Spacecraft**
NASA / GSFC	**GPM Spacecraft**
JHU / APL	**RBSP Spacecraft**
JHU / APL	**Solar Probe Plus Spacecraft**
NASA / ARC	**LADEE Spacecraft**
NASA / JSC	**Project Morpheus**
NASA / GSFC	**ATLAS Instrument Simulator**
NASA/GSFC and JHU/APL	**Memory Protection IRAD**
NASA/GSFC and JHU/APL	**Multi-Core IRAD**
NASA/GSFC	**Virtualization IRAD**
NASA/GSFC	**Various test beds and experiments**

CFS Flight Software Layers



CFS App 1

CFS App 2

CFS App N

Mission App 1

Mission App 2

Mission App N

Mission and CFS Application Layer

CFS Library

Mission Library

Mission and CFS Library Layer

cFE Core

CFE Core Layer

OS Abstraction Layer

cFE Platform Support Package

Abstraction Library Layer

Real Time OS

Board Support Package

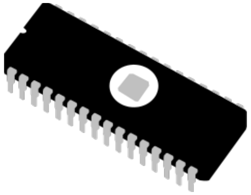
PROM Boot FSW

RTOS / BOOT Layer

▒	Mission Developed
░	GSFC Developed
▓	3rd Party

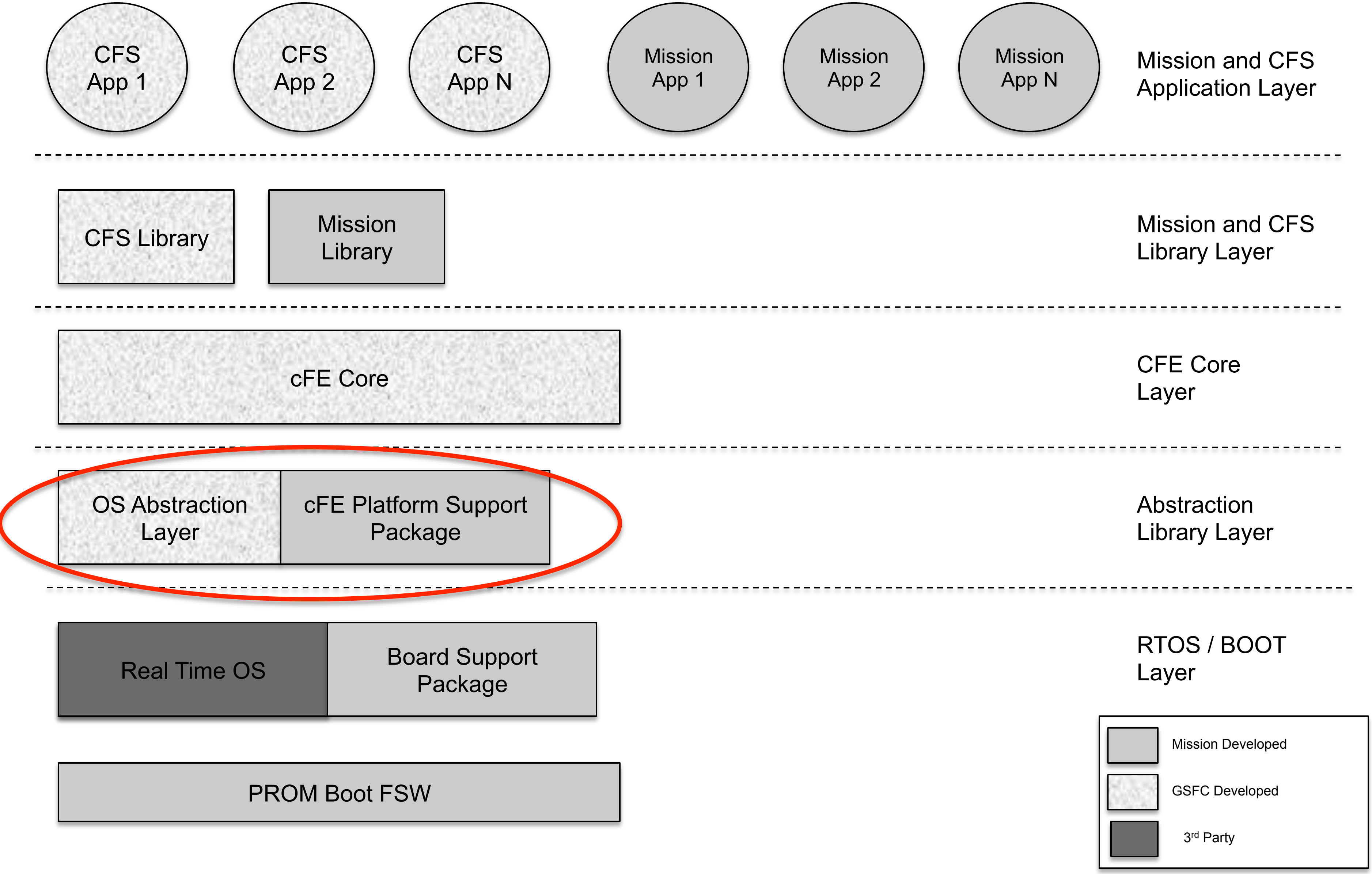
RTOS / Boot Layer

- **PROM Boot Software**
  - PROM resident software that does early initialization and bootstraps the Operating System
  - Provides ground based EEPROM/Flash loader
  - Keep it as simple as possible to minimize PROM changes
  - Commonly used Boot Software
    - RAD750 – BAE SUROM
    - Coldfire – Custom GSFC developed
    - LEON3 – uBoot – or Gaisler MKPROM



- **Real Time Operating System**
  - Pre-emptive priority based multi-tasking
  - Message Queues, Semaphores
  - Interrupt handling, Exception Handling
  - File systems, and shell
  - Supported Real Time Operating Systems
    - vxWorks
    - RTEMS
    - Linux (Not real time, but used for desktop development)

CFS Flight Software Layers



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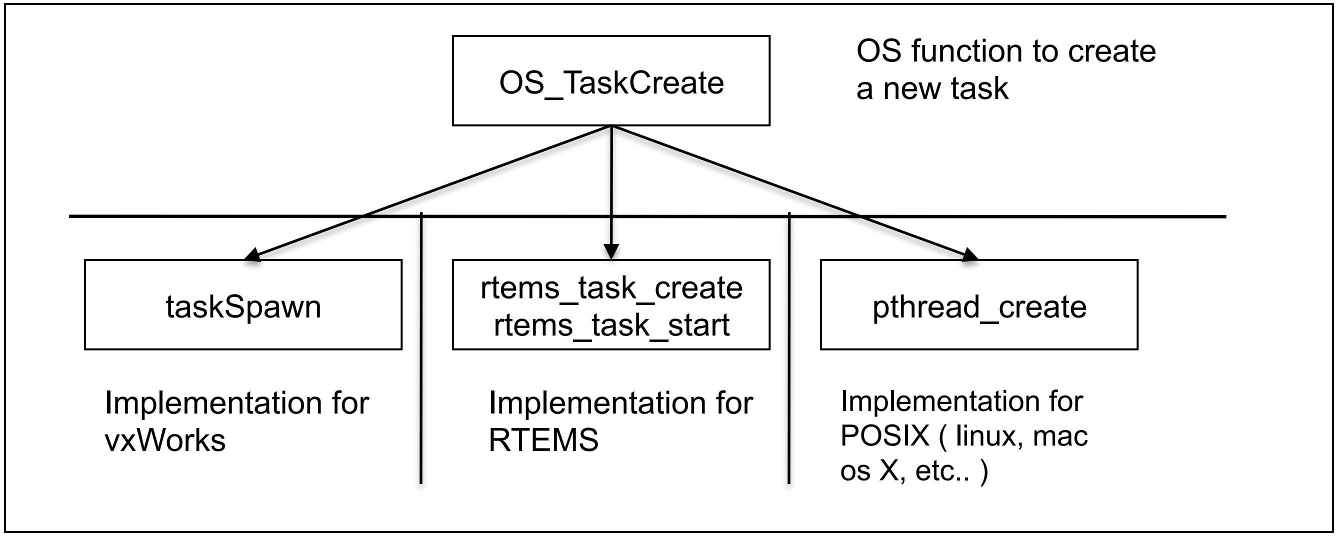
Abstraction Library Layer - OSAL

- The Operating System Abstraction layer (OSAL) is a small software library that isolates our Flight Software from the Real Time Operating System
- With the OS Abstraction Layer, flight software such as the Core Flight Executive can run on several operating systems without modification
- Current Implementations of the OSAL include:
  - RTEMS - Used on the RHCF 5208 Coldfire CPU
  - vxWorks - Used on RAD750
  - Linux / x86 - Used to run software on Desktop PC with Linux

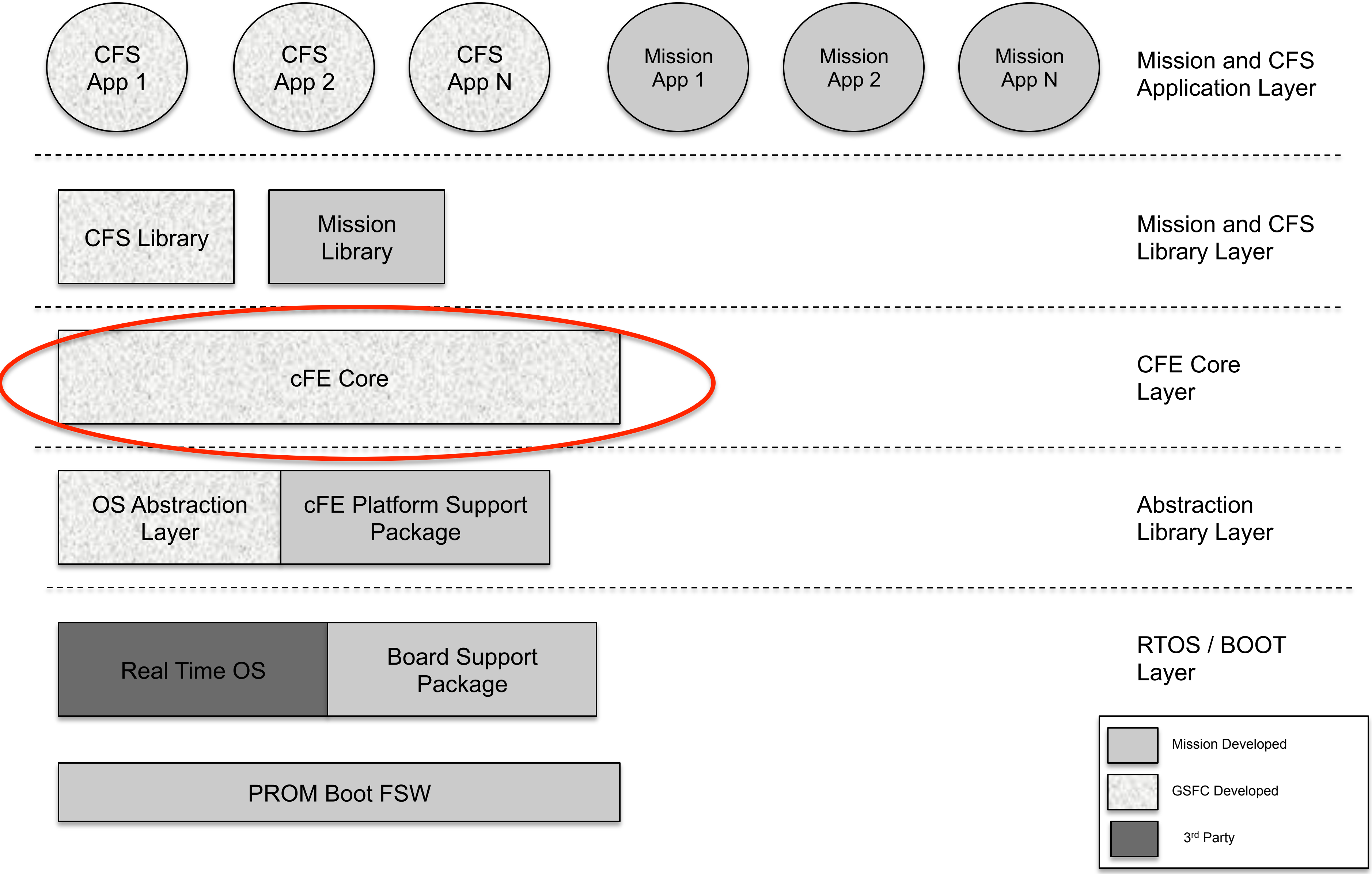

OS_TaskCreate
OS function to create a new task
taskSpawn
rtems_task_create
rtems_task_start
pthread_create
Implementation for vxWorks
Implementation for RTEMS
Implementation for POSIX (linux, mac os X, etc..)

Open Source release at: http://osal.sf.net

Abstraction Library Layer – Platform Support Package

- **Platform Support Package (PSP)**
  - A Platform Support Package is all of the software that is needed to adapt the cFE Core to a particular OS and Processor Card.
  - A Platform Support Package also includes all of the toolchain specific make rules and options
  - Each mission is expected to customize a Platform Support Package
- **Functions included**
  - Startup code
  - EEPROM rand Memory read, write, copy, and protection functions
  - Processor card reset functions
  - Exception handler functions
  - Timer functions
- **Common PSPs**
  - Desktop Linux for prototyping
  - Power PC MCP750 / RAD750 – vxWorks 6.x
  - Coldfire - RTEMS

Flight Software Layer Chart



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CFS Library

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Mission and CFS Library Layer

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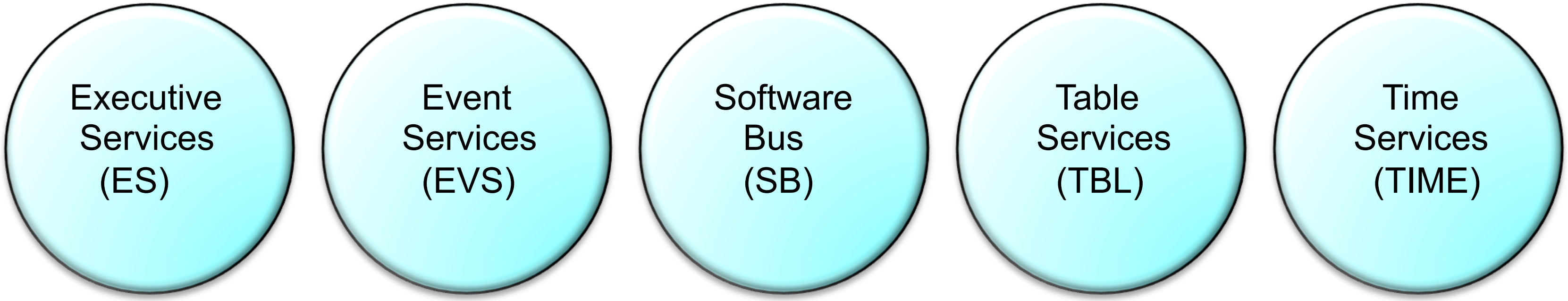
cFE Core - Overview

- **A set of** *mission independent, re-usable, core* **flight software services and operating environment**
  - Provides standardized Application Programmer Interfaces (API)
  - Supports and hosts flight software applications
  - Applications can be added and removed at run-time (eases system integration and FSW maintenance)
  - Supports software development for on-board FSW, desktop FSW development and simulators
  - Supports a variety of hardware platforms
  - Contains platform and mission configuration parameters that are used to tailor the cFE for a specific platform and mission.



Executive Services (ES)

Event Services (EVS)

Software Bus (SB)

Table Services (TBL)

Time Services (TIME)

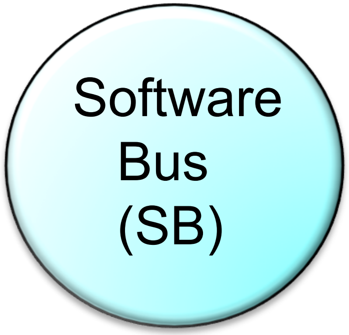
cFE Core - Executive Services (ES)

- Manages the cFE Startup
- Provides ability to start, restart and delete cFE Applications
- Manages a Critical Data Store which can be used to preserve data (except in the case of a power-on reset)
- Provides ability to load shared libraries
- Logs information related to resets and exceptions
- Manages a system log for capturing information and errors
- Provides Performance Analysis support

Executive Services (ES)

cFE Core - Software Bus (SB)

- Provides a portable inter-application message service
- Routes messages to all applications that have subscribed to the message.
  - Subscriptions are done at application startup
  - Message routing can be added/removed at runtime
- Reports errors detected during the transferring of messages
- Outputs Statistics Packet and the Routing Information when commanded



cFE Core - Event Services (EVS)

- Provides an interface for sending asynchronous informational/error messages telemetry to ground
  - Provides a processor unique software bus event message containing the processor ID, Application ID, Event ID, timestamp, and the request-specified event data (text string including parameters)
- Provides an interface for filtering event messages
- Provides an interface for registering an application’s event filter masks, types, and type enable status
- Provides an interface for un-registering an application from using event services
- Provides an interface for enabling/disabling an application’s event filtering
- <optional> Provide an interface for logging event into a local event log

Event Services (EVS)

cFE Core - TIME Services

- Provides a user interface for correlation of spacecraft time to the ground reference time (epoch)
- Provides calculation of spacecraft time, derived from mission elapsed time (MET), a spacecraft time correlation factor (STCF), and optionally, leap seconds
- Provides a functional API for cFE applications to query the time
- Distributes of a “time at the tone” command packet, containing the correct time at the moment of the 1Hz tone signal
- Distributes of a “1Hz wakeup” command packet
- Forwards tone and time-at-the-tone packets

Time
Services
(TIME)

cFE Core - Table Services

- Manages all CFS table images
- Provides an API to simplify Table Management
- Table Registry is populated at run-time eliminating cross coupling of Applications with flight executive at compile time
- Performs table updates synchronously with the Application that owns the table to ensure table data integrity
- Shares tables between Applications
- Allows Non-Blocking Table updates in Interrupt Service Routines
- Provides a common ground/user interface to all tables

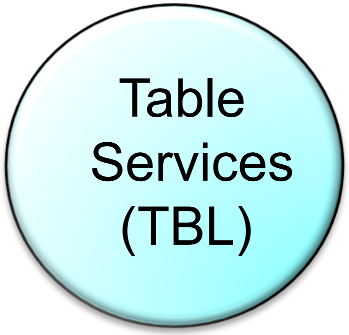
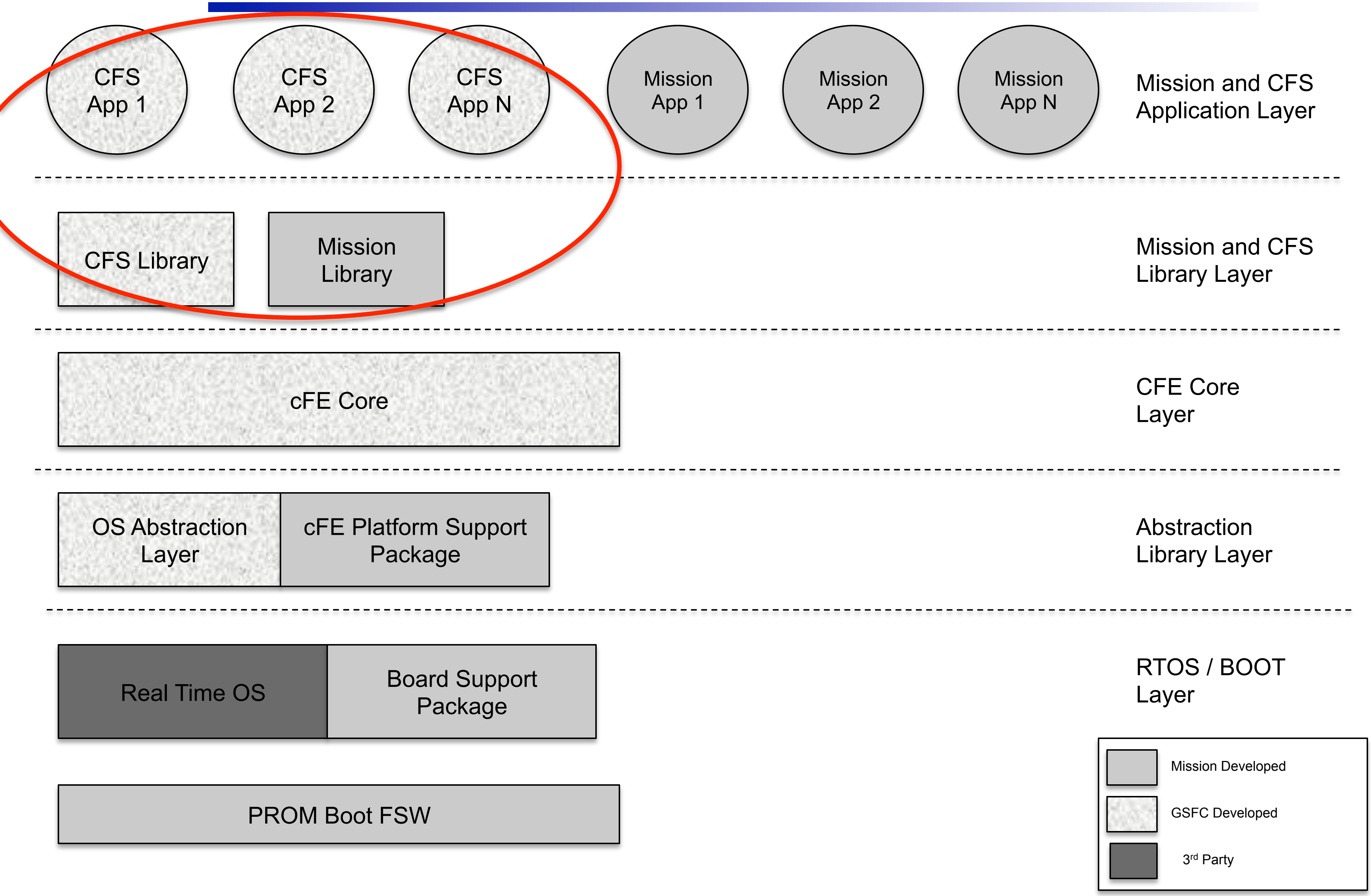


Table Services (TBL)

CFS Flight Software Layers



Health and Safety App / Housekeeping App

- **Health and Safety App**
  - Monitor Applications
    - Detect when defined applications are not running and take a defined action
  - Monitor Events
    - Detect table defined events and take a table defined action
  - Manage Watchdog
    - Initialize and periodically service the watchdog
    - Withhold periodic servicing of the watchdog if certain conditions are not met
  - Manage App Execution Counters
    - Report execution counters for a table defined list of Application Tasks

- **Housekeeping App**
  - Build combined telemetry messages containing data from applications
  - Notify the ground when expected data is not received

Data Storage App / File Manager App

- **Data Storage App**
  - Stores Software Bus messages (packets) to data storage files.
  - Filters packets according to packet filter table definition
  - Stores packets in files according to destination table definition

- **File Manager App**
  - Manages onboard files
    - Copy, Move, Rename, Delete, Close, Decompress, and Concatenate files providing file information and open file listings
  - Manages onboard directories
    - Create, delete, and providing directory listings
  - Device free space reporting

Limit Checker App / Memory Dwell App

- **Limit Checker App**
  - Monitors Table Driven Telemetry Watchpoints
    - Each watchpoint compares a telemetry data value with a constant threshold value
  - Evaluates Table Driven Actionpoints
    - Each action point analyzes the results of one (or more) watchpoints

- **Memory Dwell App**
  - Samples data at any processor address
  - Augments telemetry stream provided during development and debugging
  - Dwell Packet Streams are Specified by Dwell Tables
  - Up to 16 active Dwell Tables
  - Dwell Tables can be populated either by Table Loads or via Jam Commands

Scheduler App / Stored Command App

- **Scheduler App**
  - Operates a Time Division Multiplexed (TDM) schedule of Applications via Software Bus Messages
    - Synchronized to external Major Frame (typically 1 Hz) signal
    - Each Major Frame split into a platform configuration number of smaller slots (typically 100 slots of 10 milliseconds each)
    - Each slot can contain a platform defined number of software bus messages (typically 5 messages) that can be issued within that slot

- **Stored Command App**
  - Executes preloaded command sequences at predetermined absolute or relative time intervals.
  - Supports Absolute Time Tagged Sequences
  - Supports Relative Time Tagged Sequences

Checksum App / Memory Manager App

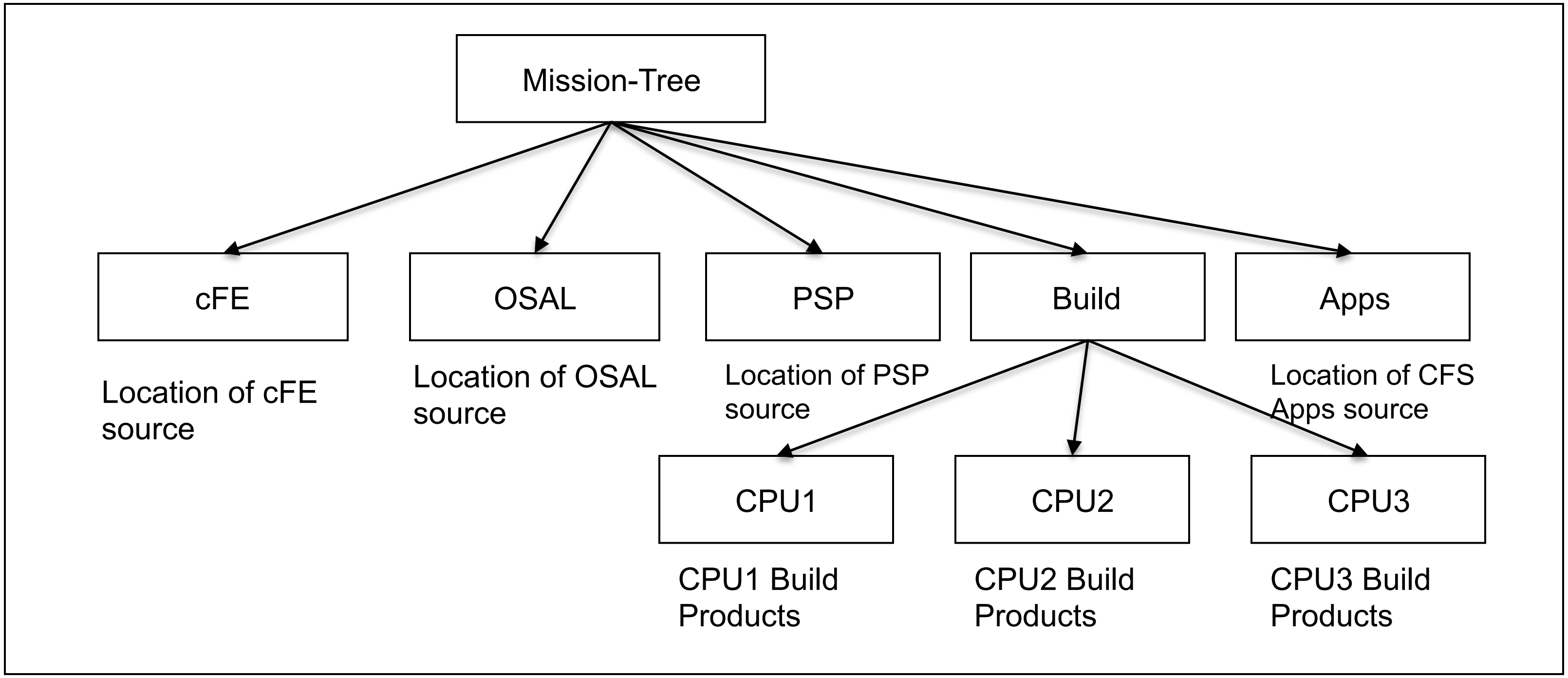
- **Checksum App**
  - Monitors the static code/data specified by the users and reports all checksum miscompares as errors.
  - CS will be scheduled to wakeup on a 1Hz schedule
  - CS will be byte-limited per cycle to prevent CPU hogging
- **Memory Manager App**
  - Performs Memory Read and Write (Peek and Poke) Operations
  - Performs Memory Load and Dump Operations
  - Performs Diagnostic Operations
  - Provides Optional Support for Symbolic Addressing

Other CFS Apps

- **CFDP App**
  - Implements flight portion of CCSDS CFDP Protocol
- **Command Uplink App**
  - Implements flight portion of CCSDS Command uplink
  - Usually mission specific
- **Telemetry Output App**
  - CCSDS Telemetry downlink
  - Usually mission specific
- **Memory Scrub App**
  - Memory Scrub – Scrubs SDRAM check bits
  - Usually mission specific
- **CI Lab & TO Lab**
  - UDP sockets based uplink and downlink apps for lab testing

Development Environment

- The CFS has a complete development environment that is designed to manage:
  - Builds of images for multiple processors
  - Multiple processor architectures
  - Multiple operating systems
  - Different application loads on each processor
  - As little duplication of code as possible



Mission-Tree

cFE

Location of cFE source

OSAL

Location of OSAL source

PSP

Location of PSP source

Build

Apps

Location of CFS Apps source

CPU1

CPU1 Build Products

CPU2

CPU2 Build Products

CPU3

CPU3 Build Products

What’s next for the cFE/CFS?

- **cFE Core 6.1 Open Source Release**
- **cFE 6.2 Release**
- **Ongoing CFS Application Update Releases**
- **Updated Platform Support Packages**
- **Research and Development**
  - cFE and Memory Protection
    - FY 2010, 2011 IRAD
    - Can run multiple cFE/CFS systems on a single vxWorks OS using RTPs
  - cFE on Multi-Core systems
    - Would like to research running cFE on Multi-Core flight processors
  - Virtualization platform
    - Would like to research running cFE on a hypervisor / VM system