Reaching into space TOGETHER

Spacecraft On Board Software

December 2017

- OBSW Characteristics
- OBSW Process
- OBSW Architecture
- OBSW Environments

- **OBSW Characteristics**
- OBSW Process
- OBSW Architecture
- OBSW Environments

- OBSW Characteristics
  - **OBSW Constraints**
  - OBSW Dependability
  - OBSW Criticality
  - OBSW Properties
- OBSW Processes
- OBSW Architectures
- OBSW Environments

OBSW: Constraints

On Board Software has to cope with constraints stemming from its execution environment in space:

- **Embedded** Software
  → Cross Development Environment, bounded Memory Footprint and Processor Consumption
- **On Board** Software
  → Single Event Effects (Upset, Latch Up), Memory Scrubbing
- **Real Time** Software
  → Processor load, scheduling issues, deadlines
- **Deterministic** Software
  → No dynamic thread creation or memory allocation, budget and schedulability
- **Remote** Software
  → Need for autonomy
- **Critical** Software (see further down)
  → Possible catastrophic consequences of failure
- **Dependable** Software (see further down)
  → Need for high Reliability, Availability, Maintainability and Safety

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OBSW: Dependability

Achieving mission objectives and ultimate mission success relies on dependability of the space systems and of the software.

As software plays more and more a prominent role in space systems, its contribution to the overall system dependability becomes a vital aspect of system development

RAMS

- **Reliability**:
  continuity of correct service.
- **Availability**:
  readiness for usage.
- **Maintainability**:
  easiness of repair/upgrade.
- **Safety**:
  non-occurrence of catastrophic failure

- **Integrity**
  Maintenance of data consistency
- **Security**
  Non disclosure of unauthorized info

- **Certifiability**
  Ability to get stamp from certification body

Analysis

- **SCA:**
  Software Criticality Analysis (see next slide)
- **HSIA:**
  Hardware Software Interaction Analysis
- **FMECA:**
  Failure Mode Effects and Criticality Analysis
- **FTA:**
  Fault Tree Analysis
- **FHA**
  Functional Hazard Analysis
- **SCCFA:**
  Software Common Causes Failure Analysis

Troubles

- **Error:**
  A wrong or missing human action or thought
- **Fault:**
  An incorrect step, process or data definition in a program
- **Failure:**
  The inability of the software to perform its required functions

Strategies

- **Fault Prevention**
  avoidance and reduction of fault causes
- **Fault Tolerance**
  avoidance and reduction of fault consequences
- **Fault Removal**
  removal of fault occurrences
- **Fault Forecasting**
  prediction of behaviour in presence of faults

FDIR

- **Fault**
  hardware or software
- **Detection**
  e.g. through monitoring
- **Isolation**
  determination of the cause
- **Recovery**
  e.g through redundancy

FDIR is imperative to guarantee a dependable and autonomous system with a minimal risk of ruinous failure

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OBSW: Criticality

Critical Software
is a Software that if not executed or if not correctly executed or whose anomalous behaviour could cause or contribute to a System Failure resulting in :

A:	**Catastrophic Consequences**	Loss of Life, life threatening, personnel injuries, permanently disabling injury or occupational illness, Loss of an element of an interfacing manned flight system. Damage to other equipment. Loss of launch site facility facilities or loss of system. Severe detrimental environmental effects.
B:	**Critical Consequences**	Permanent or non-recoverable loss of the satellite's capability to perform its planned mission Temporarily disabling but not life-threatening injury or occupational illness. Major damage to flight system or loss or major damage to ground facilities. Major damage to public or private property or major detrimental environmental effects.
C:	**Major Consequences**	Negligible or minor effect on the satellite's mission and operability A detailed definition is left on a project by project basis and reported in its risk policy. *Example is Mission Simulation Software*
D:	**Minor Consequences**	A detailed definition is left on a project by project basis and reported in its risk policy. *Example is Test Software*

In the DO-178-C (Software Considerations in Airborne Systems),
the Design Assurance Level (DAL) is determined from the safety assessment process and hazard analysis
by examining the effects of a failure condition in the system. The failure conditions are categorized by their effects on the aircraft, crew, and passengers (catastrophic, severe/hazardous, major, minor, no effect).

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OBSW: Properties

- System-software co-engineering:
  Software is part of the System.
  Software properties must be derived from System properties.

  - End-to-end system response time will result into a
    → software schedulabity property.

  - System availability property will result into
    → software FDIR mechanisms that must have a particular behaviour.

  - System performance property may result in a
    → software numerical accuracy property.

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- OBSW Characteristics
- OBSW Process
  - **OBSW Phases**
  - OBSW Lifecycle
  - OBSW Verification
  - OBSW Standards
  - OBSW Documentation
- OBSW Architectures
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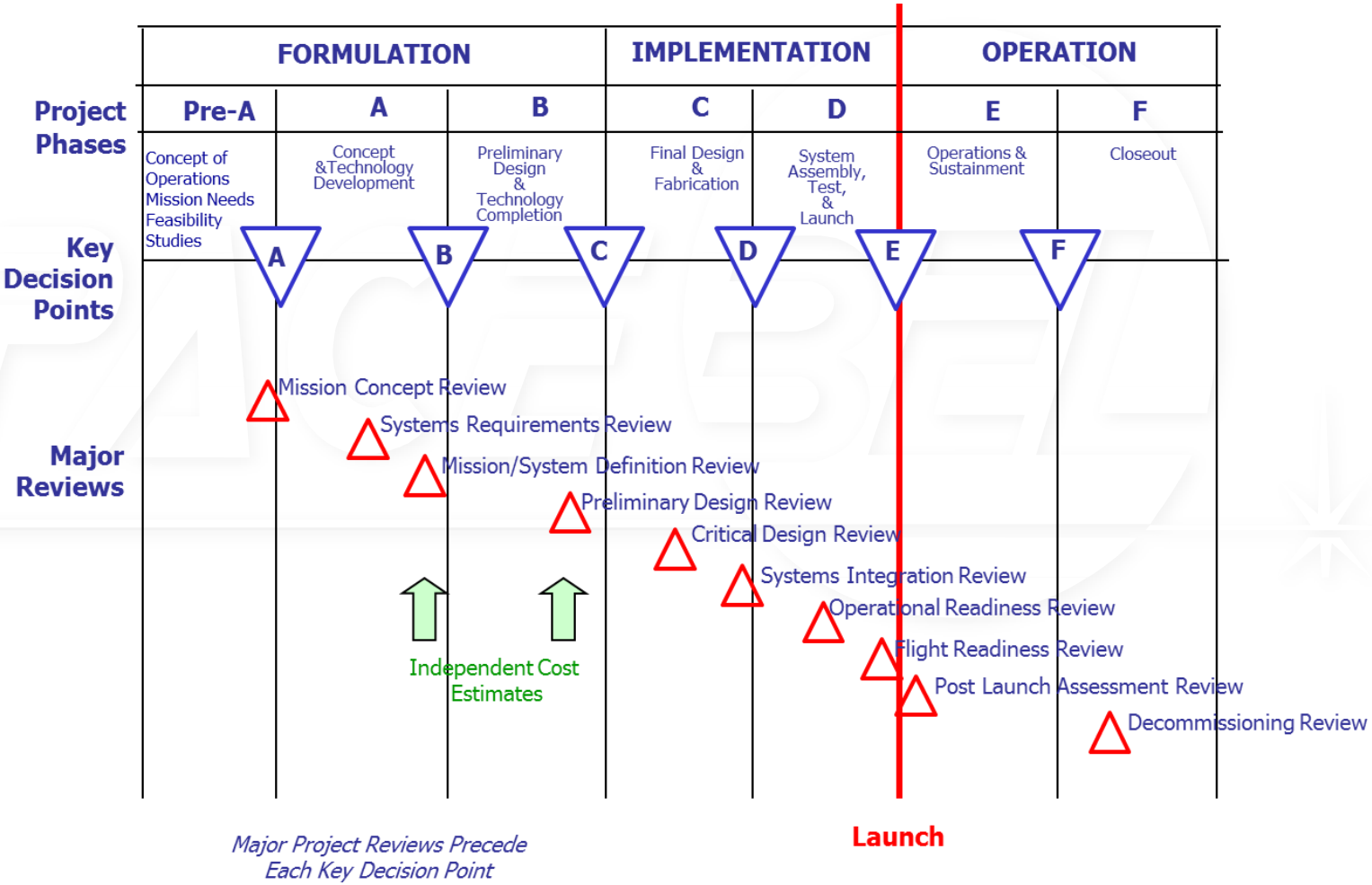
OBSW: Phases

On Board Software usually comes (too) late in the overall spacecraft development:



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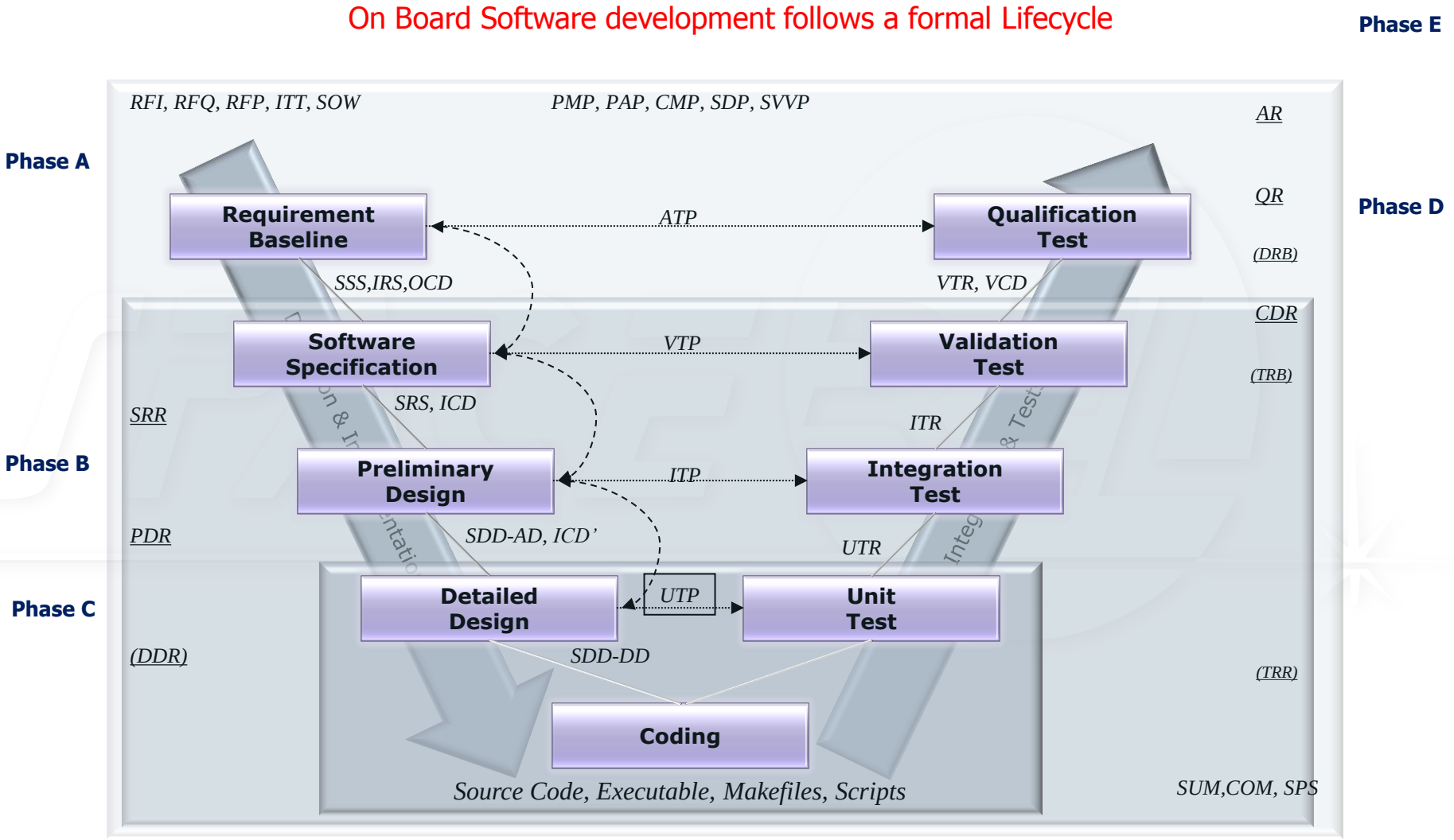
OBSW: Lifecycle

On Board Software development follows a formal Lifecycle



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OBSW: Verification & Validation

On Board Software Verification and Validation represent a very significant part of the total development effort

Verification

All Along the Development

Through Reviews and Analysis

Peer Review

Cross Reading

Static Code Analysis

Schedulability Analysis

Validation

At the end of the Development

Through Tests Campaign

(Unit Tests)
against Detailed Design

(Integration Tests)
against Architecture and Interface Definition

Validation Tests*
against Technical Specification

Qualification Tests
against Requirement Baseline

Supported by Software Engineering Tools
Model Verifiers
Static Code Analyzer
Traceability Matrices

Supported by Test Facilities
Software Test Benches
Hardware Models
Hybrid Facilities

*some requirement may alternatively be validated
by Analogy,
by Analysis of Design,
by Inspection of Code

Independent Sofware Verification and Validation is performed by an independent team or company in addition to normal Verification and Validation (required for Cat B)

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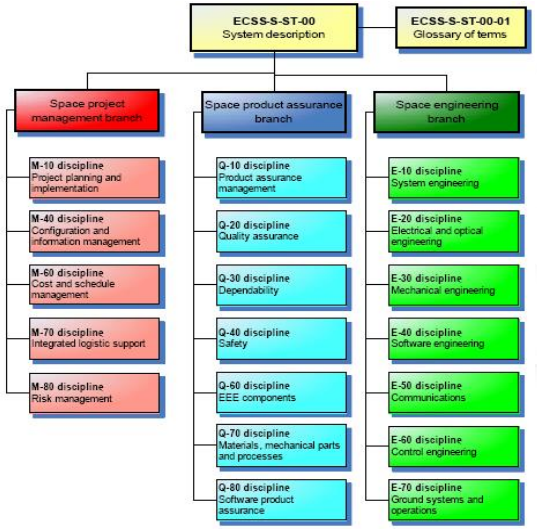
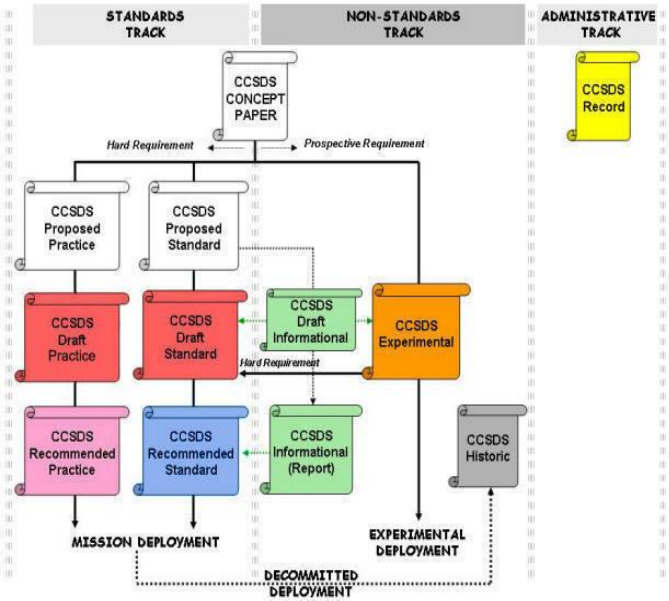
OBSW : Standards

European Cooperation for Space Standardization



Standards:
- Management Standards
  → ECSS-M-XXX
- Product Assurance Standards
  → ECSS-Q-XXX
- Engineering Standards
  → ECSS-E-XXX

Consultative Committee for Space Data Systems



Reports:
- **Blue**: Recommended Standards
- **Magenta**: Recommended Practices
- **Green**: Informational Reports
- **Orange**: Experimental or ongoing research
- **Yellow**: Record, but not Historical
- **Silver**: Historical

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OBSW : Documentation

Related file	DRL item (e.g. Plan, document, file, report, form, matrix)	DRL item having a DRD	SRR	PDR	CDR	QR	AR	ORR
RB	Software system specification (SSS)		✓					
	Interface requirements document (IRD)		✓					
	Safety and dependability analysis results for lower level suppliers		✓					
TS	Software requirements specification (SRS)			✓				
	Software interface control document (ICD)			✓	✓			
DDF	Software design document (SDD)			✓	✓			
	Software configuration file (SCF)			✓	✓	✓	✓	✓
	[illegible]					✓	✓	
	Software user manual (SUM)				✓	✓	✓	
	Software source code and media labels				✓			
	Software product and media labels					✓	✓	✓
	Training material					✓		
	[illegible]			✓				
	Software validation plan (SVaP)			✓				
	Independent software verification & validation plan		✓	✓				
	Software integration test plan (SUITP)			✓	✓			

MGT Management File
- Software development plan
- Software configuration management plan (DRD in ECSS-M-ST-40)
- Software review plan
- ...

RB Requirements Baseline
- Software system specification
- Software interface requirements document
- ...

DDF Design Definition File
- Software design document
- Software configuration file (DRD in ECSS-M-ST-40)
- Software release document
- Software user manual
- ...

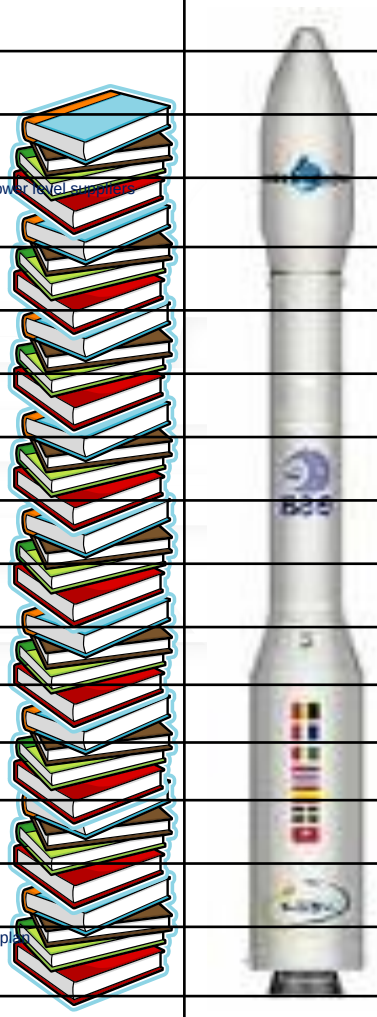
MF Maintenance File
- Maintenance plan (without DRD)
- Migration plan (without DRD)
- ...

PAF Product Assurance File
- Software product assurance plan
- Software product assurance milestone report
- Software product assurance requirements for suppliers
- ...

TS Technical Specification
- Software requirements specification
- Interface control document
- ...

DJF Design Justification File
- Software validation plan
- Software verification plan
- Software unit and integration plan
- Software validation specification
- Software reuse file
- Software verification report
- ...

OP Operational
- Operational plan
- Operational testing specification



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OBSW: Functional Architecture (1/3)

- Functional Architecture

definition of

- **functional break down** in
  - **functional modules** and
  - **functional interfaces** between these modules

Functional Architecture (2/3)

Note: interactions between functions are not depicted

TM/TC ***Telemetry & Telecommand***

space/ground communications or communications between spacecraft

HK ***Housekeeping***

Gathering, filtering and reporting of on board acquired data

MON ***Monitoring***

detection of on board events based on ranges or thresholds or trends

FDIR ***Fault Detection Isolation and Recovery***

for the on board software and system dependability

MMGT ***Mission Management***

for the execution of the mission timeline

SMGT ***Spacecraft Modes Management***

handles the on-board system through the different mission phases
defines the level of autonomy,

GNC/AOCS/ACNS ***Attitude and Orbit Control Software***

Computes the actuators commands from the sensors measurement in order to control the spacecraft attitude and position.
Control the propulsion system.

THERM ***Thermal Management***

for the temperature control of the spacecraft e.g. through thermal heater lines,

PWR ***Electrical Power Supply Management***

distributes the power coming from the battery and the solar arrays
and manages battery charge / discharge,

RDP/HRM ***Release, Deployment and Pyrotechnic Activation Management***

for solar arrays/antenna deployment,
for propulsion arming sequence before firing, or
for specific needs like shield jettison or spacecrafts composites dispatching,

OBT ***On-Board Time Management***

For the synchronization of the on-board clock with ground time,

ACQ ***Data Acquisition***

Acquisition of on board data
e.g. according to polling sequence table
and depending on mode

SADM ***Solar Array Drive Mechanisms Management***

for the optimal alignment of a satellite's solar panels towards the Sun.

SM ***Storage Management***

for the storage of TM in case of Earth link unavailability

EQPT ***Equipment Management***

for the maintain of the equipment table as the reflect of the actual equipment status, and the management of equipment interface,

RF ***Radio Frequency Management***

for the communications with ground or with other sapcecrafts
e.g. through S-Band or X-Band links.

PL ***Payload Management***

for scientific payload or additional units

(very mission specific)

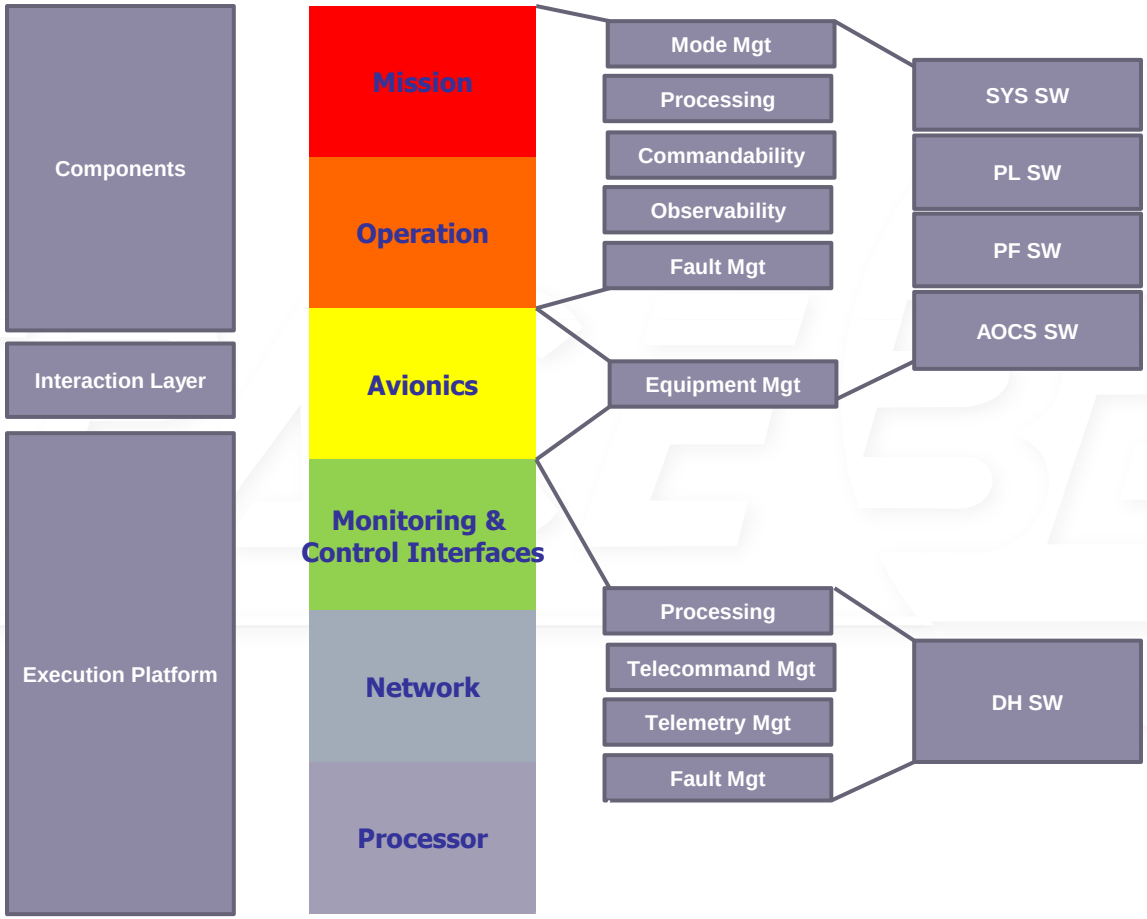
CM ***Context Management***

Saves the context (failure history buffer, GNC states, OBSW patches, equipment table, mission timeline) in case of processor failure.

ETC ***… And Many Others***

And many other functions depending on the platform bus and on the mission

Functional Architecture (3/3)



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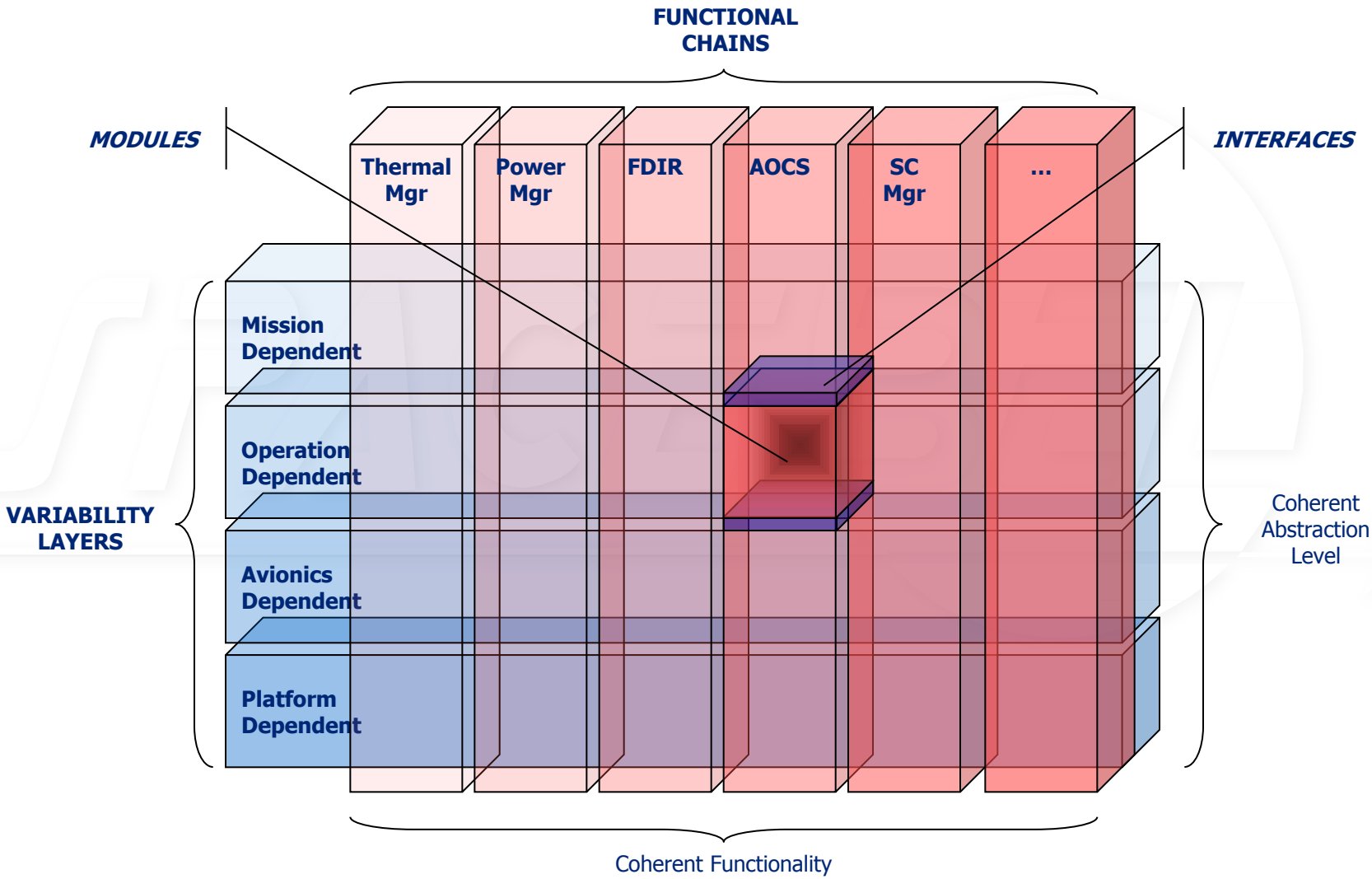
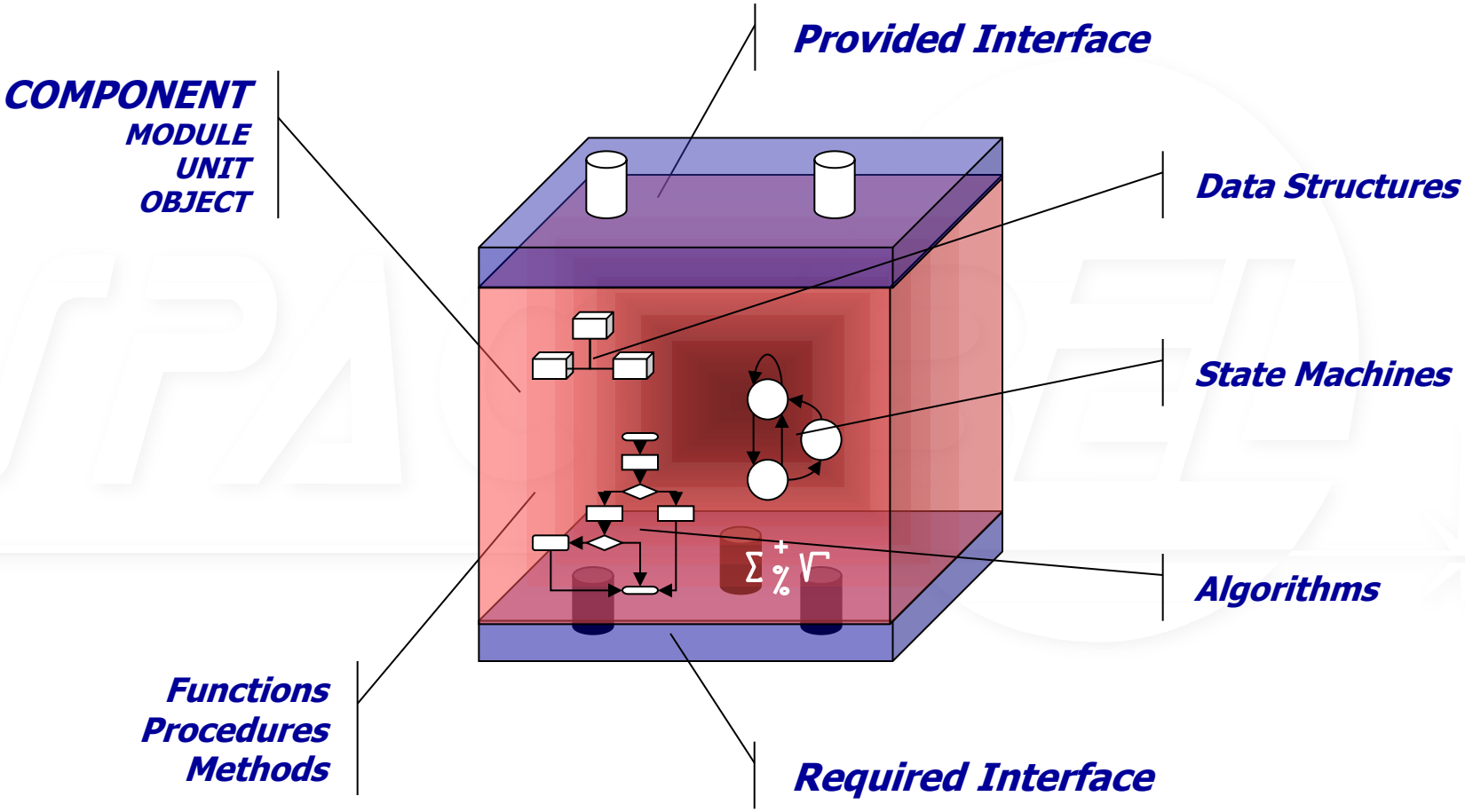
Static Architecture : Principles (1/4)

- Static architecture deals with
  - Functional Properties
  - Static Decomposition
  - Software Component Model
- Software is broken down
  - in software components (aka modules, units or objects)
  - with clear interfaces between them
- Components are organized (see slide 2/4)
  - horizontaly in variability layers with coherent abstraction level and
  - verticaly in functional chains with coherent functionality
- Component are functional units (see slides 2-3-4/4)
  - That encapsulate functional services,
  - that expose these services to other components through well defined interfaces, and
  - that can be assembled together to build a software product
- Components are made up of (see slide 3/4)
  - Algorithms, State Machines
  - Data Structures
- Major design decision is (see slide 4/4)
  - Central Data Pool vs
  - Distributed Data Flows
- Main programming paradigms are
  - Procedural programming vs
  - Object Oriented programming (not used so far in on board software)

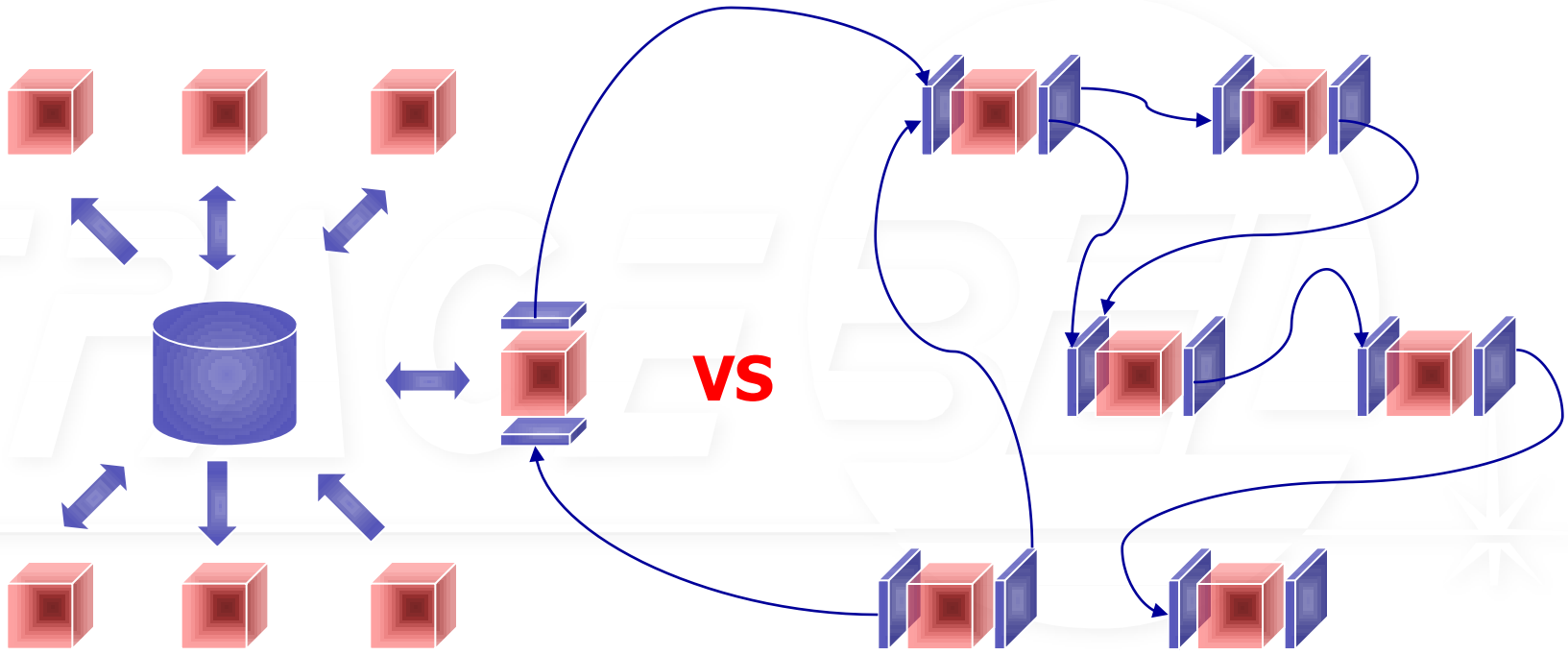
Static Architecture : Structure (2/4)



Static Architecture : Components (3/4)



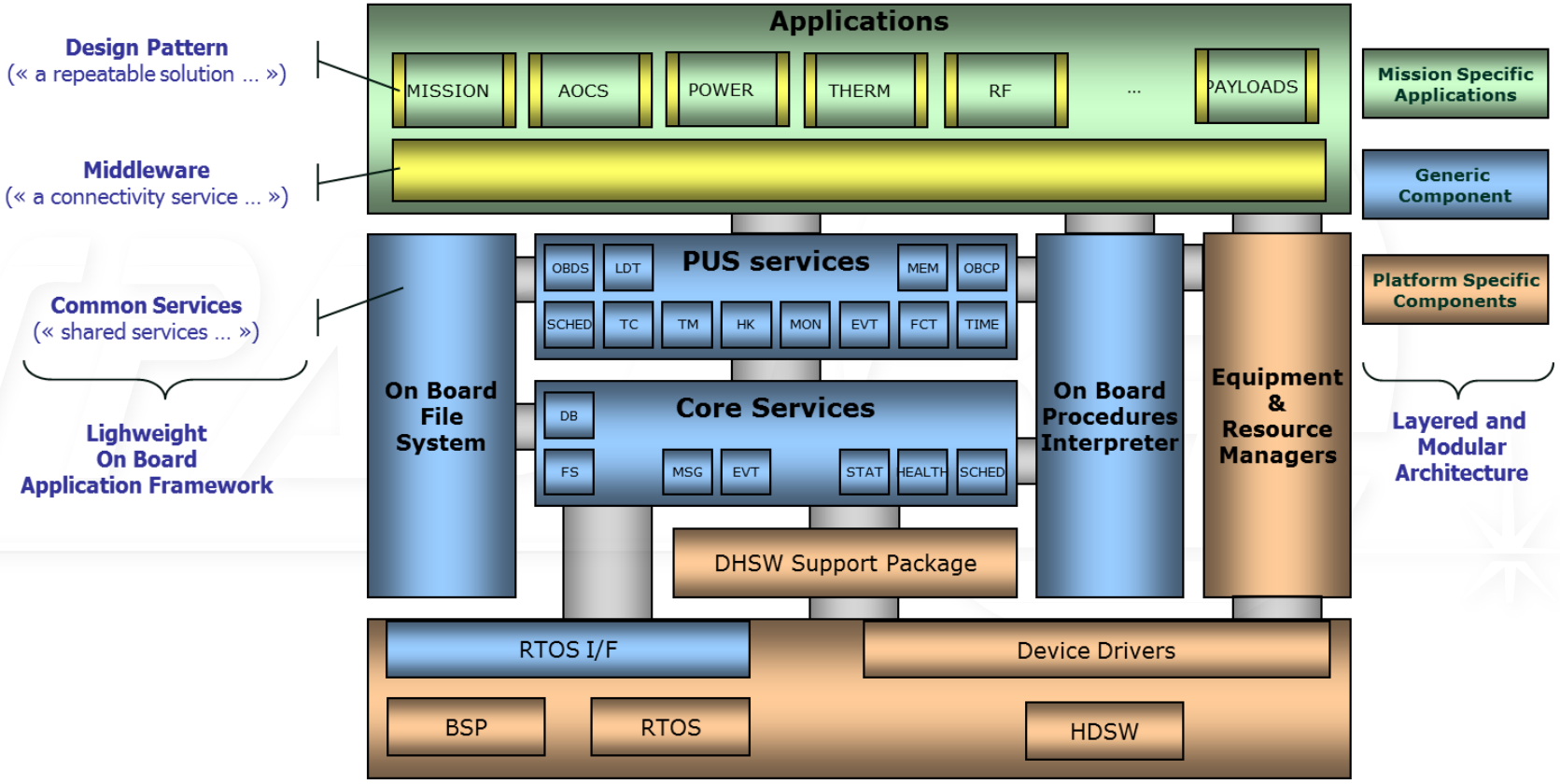
Static Architecture (4/4)



Central Data Pool

Distributed Data Flow

Static Architecture : Overview



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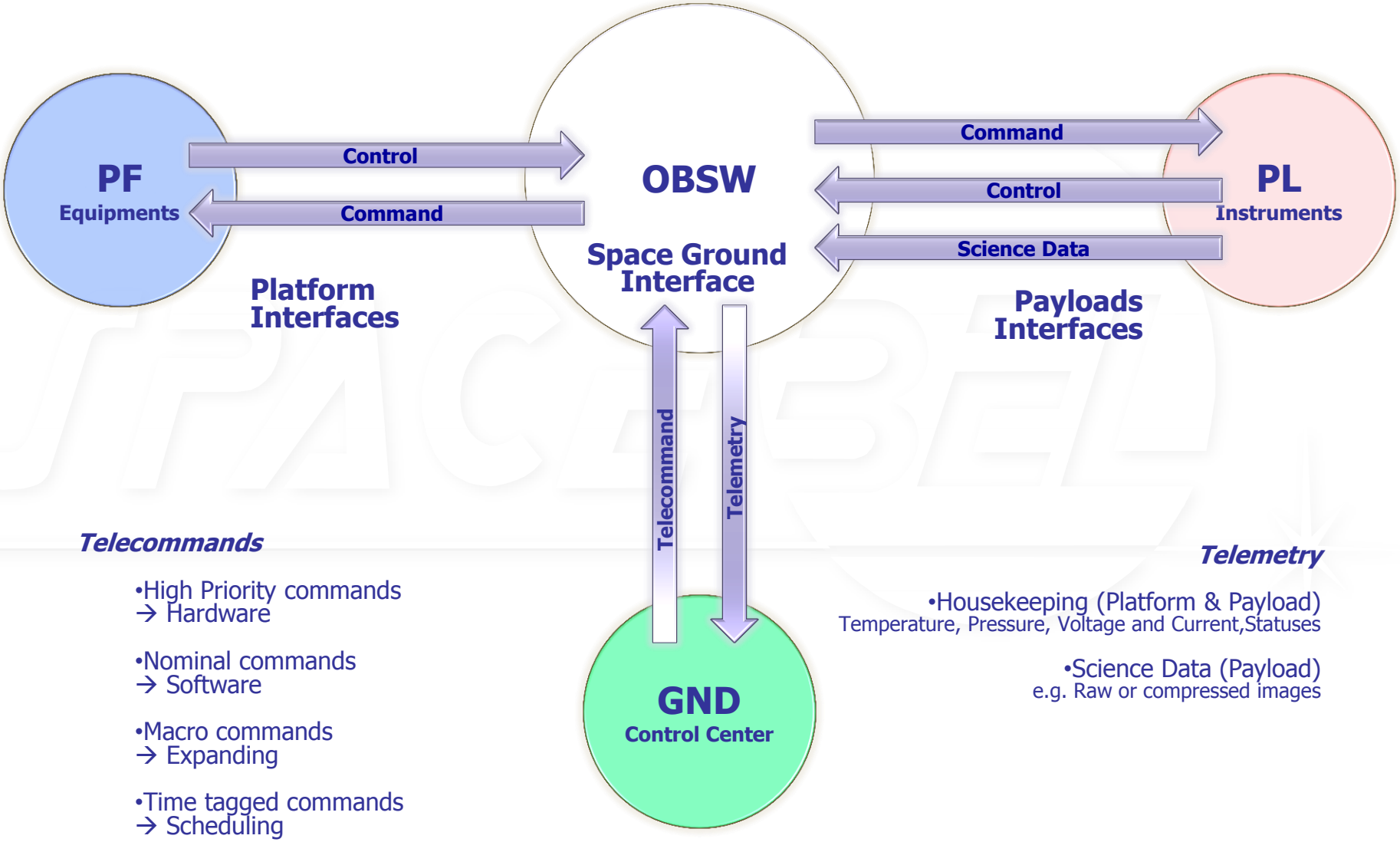
Interfaces & Data Flows



Telecommands

- High Priority commands
  → Hardware
- Nominal commands
  → Software
- Macro commands
  → Expanding
- Time tagged commands
  → Scheduling

Telemetry

- Housekeeping (Platform & Payload)
  Temperature, Pressure, Voltage and Current,Statuses
- Science Data (Payload)
  e.g. Raw or compressed images

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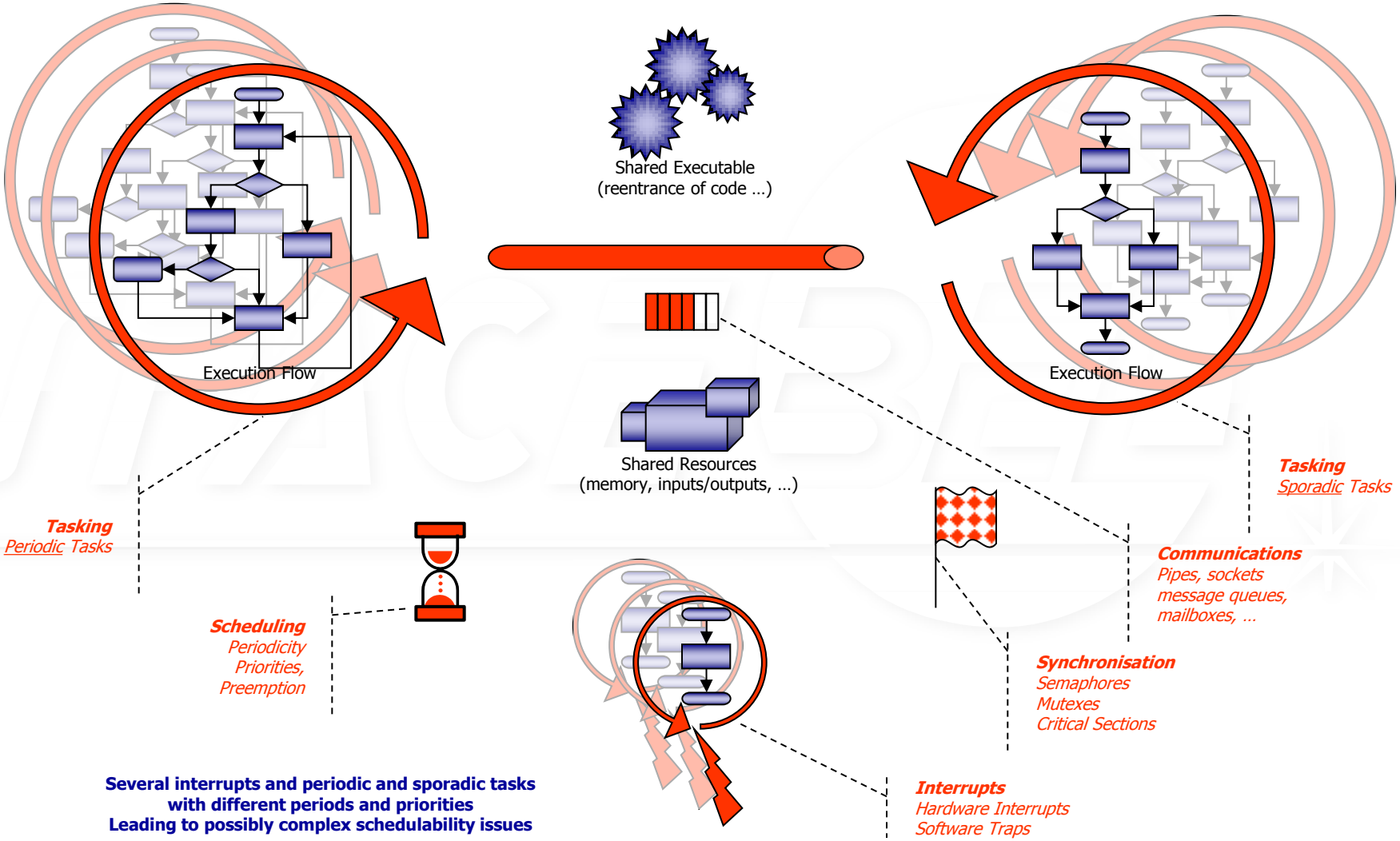
Dynamic Architecture : Principles (1/3)

- Dynamic Architecture deals with
  - Non Functional Properties
  - Dynamic Behaviour
  - Computational Model
- Main concepts are (see slide 2/3)
  - Tasks, Threads, Traps, Interrupts
  - Scheduling, Processing Time, Execution Time, Deadlines, Priorities
  - Communication, Synchronisation (Critical Sections, Mutual Exclusion)
- Major design decision is (see slide 3/3)
  - Periodic/Cyclic/Synchronous/Time Driven/Polling **vs**
    (Period, Offset)
  - Aperiodic/Sporadic/Asynchronous/Event Driven/Interrupts
    (Minimum Inter Arrival Time)
- Typical problems are
  - Race Conditions, Deadlock Starvations, Livelocks

Dynamic Architecture: Concepts



Several interrupts and periodic and sporadic tasks with different periods and priorities
Leading to possibly complex schedulability issues

Dynamic Architecture: Computational Model

- Computational Models
  - RMA: Rate Monotonic Algorithm
    Static priority preemptive scheduling. Applies to cyclic jobs. Shorter cycle get higher priority
  - DMA: Deadline Monotonic Algorithm
    Static priority preemptive scheduling. Applies also to sporadic jobs. Shorter deadline get higher priority
  - EDF: Earliest Deadline First Algorithm
    Dynamic priority preemptive scheduling. process closest to its deadline get highest priority
  - RCM: Ravenscar Computational Model
    Fixed-priority preemptive system with tight restrictions on tasking and synchronisation such as priority ceiling that optimally bound priority inversion, to achieve lock-free mutual exclusion and to avoid deadlocks. Warrants static analysability of the source code and predictability of execution

- *TSP: Time and Space Partitioning*
  hierarchical superposition of two computational models :
  round robin scheduling of partitions and
  fixed priority scheduling of tasks within partitions

See also Schedulability Analysis

Dynamic Architecture: Schedulability

- Proof of software schedulability
  - Dynamic Testing at Run Time (how to prove exhaustivity?)
  - Static Analysis (superior to testing)
    - Selected Computational Model (see dynamic architecture)
      - Implementation is assumed to comply to model
      - Mathematical schedulability criteria
    - Software Budget Report (estimated or measured)
      - Processor utilization
      - Worst Case Execution Times (WCET)
      - Memory Footprint
      - Stack Usage

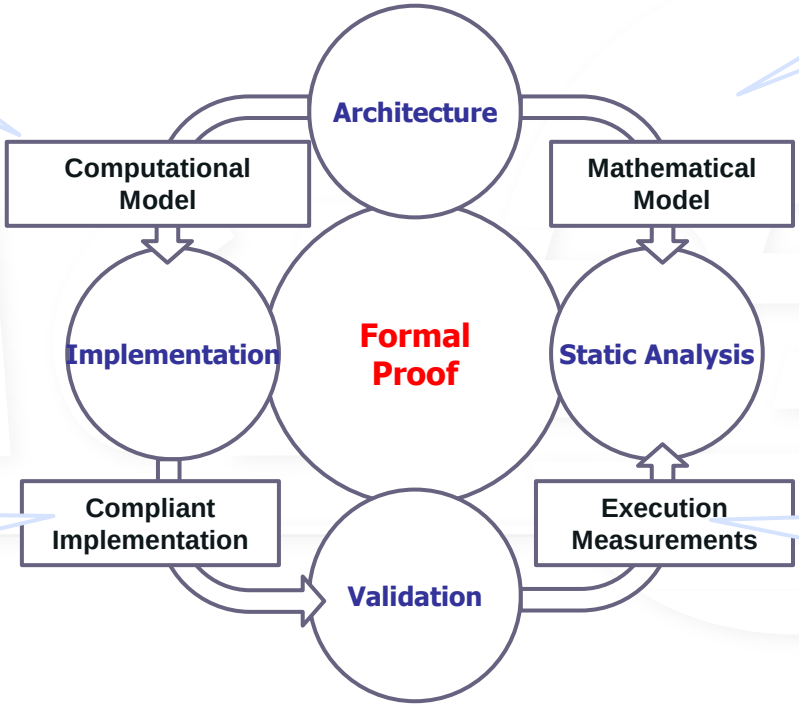
Dynamic Architecture: Schedulability

•Rate Monotonic Scheduling
•Deadline Monotonic Scheduling
•Earliest Deadlin First
•Ravenscar Profile
(See Dynamic Architectures)

Schedulability Condition

$$U = \sum_{i=1}^{n} C_i/T_i \leq n(\sqrt[n]{2} - 1)$$

$$\lim_{n \to \infty} n(\sqrt[n]{2} - 1) = \ln 2 \approx 0.693147\ldots$$



•Programming Model
•Design and Coding Rules
•Code Generation

Processor Utilization
Worst Case Execution Time
(Based on realistic scenarios)

Compliance to a selected Computational Model allows for Static Analysis and Formal Check of Schedulability Conditions, based on corresponding Mathematical Model fed by actual Measurement from execution of realistic scenarios.

To this respect, Static analysis is superior to testing, which faces exhaustivity issue in real-scale systems.

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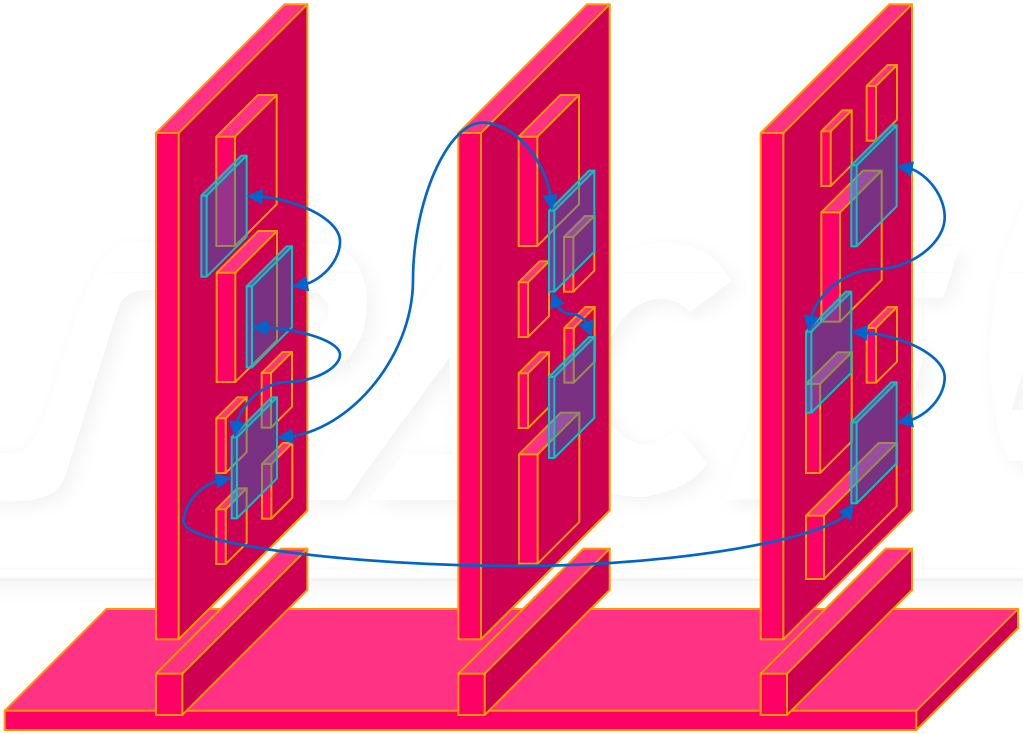
Deployment Architecture: Principles

- Deployment Architecture deals with the Mapping
  - of a logical architecture (software components)
  - to a physical environment (hardware resources).
- Main concepts are
  - Distribution
  - Communication
- Main design decision is
  - Centralised Architecture **vs**
  - Distributed Architecture
- Main Solutions are
  - Multi Processor
  - Multi Core
  - Time and Space Partitioning

Deployment Architecture: Mapping



A deployment architecture depicts the **mapping** of a **logical architecture** (software components) to a **physical environment** (hardware resources).

The physical environment includes the computing nodes, processors, memory, storage devices, and other hardware and communication devices

Deployment Architecture: SCM

Software Component Model

Platform Independent Model | **Platform Specific Model**

Design Level | **Implementation Level**

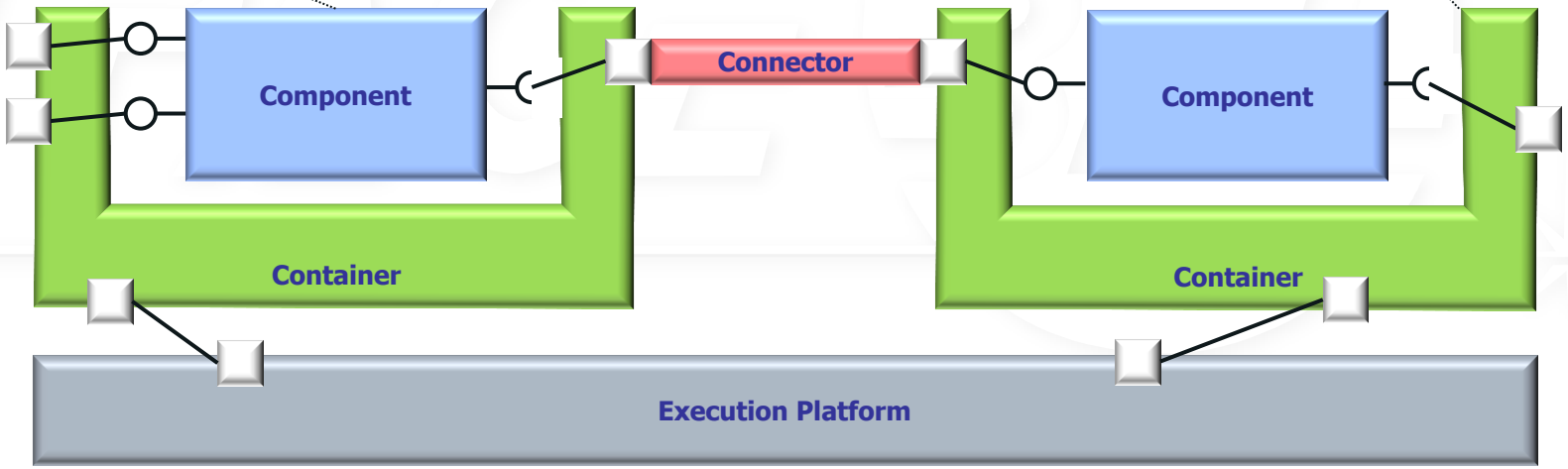
Separation of Concern

Pairing up

Functional Concerns (algorithms)

Non Functional Concerns (tasking, timing, config, init, security, …)

Required Interface | **Provided Interface**



Computational Model

Composition **Reusability** **Replaceability**

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- **OBSW Environments**
  - OBSW Execution Environment
  - OBSW Development Environment

OBSW Environment

Cross
Development
Environment

Development
Environment:

≠

Execution
Environment:

Powerfull Development Workstations
Confortable Operating System
Production Tools

On Board Computer with Limited Resources
Real Time Operating System with Constraints
Software Executable

- OBSW Characteristics
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  - **OBSW Execution Environment**
    - Processors
    - Operating Systems
  - OBSW Development Environment

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  - OBSW Execution Environment
    - **OB Processors**
    - OB Operating Systems
  - OBSW Development Environment

Exec Environment: Processors

- Hardened Space Qualified processors
  1990: 1750 – 16 Bits – 2 MIPS
  2000 : ERC32 – SPARC V7 - 32 Bits – 20 Mhz – 14 MIPS
  2010 : LEON2 – SPARC V8 - 32 Bits – Cache – Pipeline -100 Mhz – 84 MIPS
  2105 : LEON3/4– Quad Core LEON

- Commercial of the Shelf
  - ARM
  - Power PC 1600 MIPS but sensitive to SEEs

See Avionics Overview

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  - OBSW Execution Environment
    - OB Processors
    - **OB Operating Systems**
  - OBSW Development Environment

Exec Environment: Operating System

- RTOS: Real Time Operating Systems
  - VxWorks (Commercial)
  - RTEMS (Open Source)
  - Linux RT (Not widely used … in OBSW)

- TSP: Time and Space Partitionning
  - Hypervisor
  - µKernel

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  - OBSW Execution Environment
  - **OBSW Development Environment**
    - Modelling
    - Programming
    - Production
    - Validation

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  - OBSW Execution Environment
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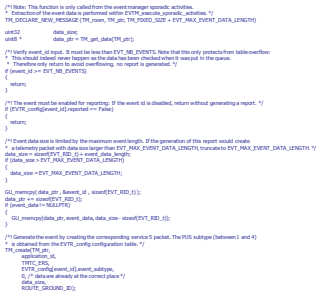
    - **OBSW Modelling**
    - OBSW Programming
    - OBSW Production
    - OBSW Validation

Development Environment: Modeling



```
/** Note: This function is only called from the event manager sporadic activities.
*  Extraction of the event data is performed within EVTR_execute_sporadic_activities. */
TM_DECLARE_NEW_MESSAGE (TM_room, TM_ptr, TM_FIXED_SIZE + EVT_MAX_EVENT_DATA_LENGTH)

uint32                  data_size;
uint8 *                 data_ptr = TM_get_data(TM_ptr);

/** Verify event_id input. It must be less than EVT_NB_EVENTS. Note that this only protects from table overflow:
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if (event_id >= EVT_NB_EVENTS)
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}

/** The event must be enabled for reporting: If the event id is disabled, return without generating a report. */
if (EVTR_config[event_id].reported == False)
{
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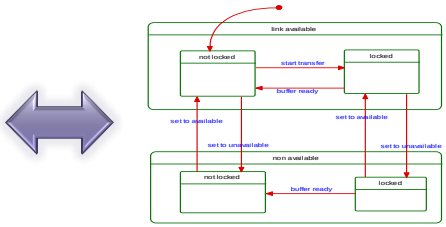
}

/** Event data size is limited by the maximum event length. If the generation of this report would create
*  a telemetry packet with data size larger than EVT_MAX_EVENT_DATA_LENGTH, truncate to EVT_MAX_EVENT_DATA_LENGTH. */
data_size = sizeof(EVT_RID_1) + event_data_length;
if (data_size > EVT_MAX_EVENT_DATA_LENGTH)
{
  data_size = EVT_MAX_EVENT_DATA_LENGTH;
}

GU_memcpy( data_ptr , &event_id , sizeof(EVT_RID_1));
data_ptr += sizeof(EVT_RID_1);
if (event_data != NULLPTR)
{
  GU_memcpy(data_ptr, event_data, data_size - sizeof(EVT_RID_1));
}

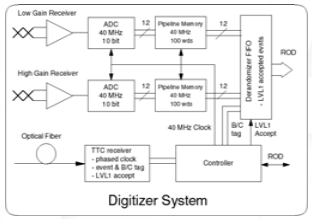
/** Generate the event by creating the corresponding service 5 packet. The PUS subtype (between 1 and 4)
*  is obtained from the EVTR_config configuration table. */
TM_create(TM_ptr,
        TM_PUS_id,
        TMTC_ERS,
        EVTR_config[event_id].event_subtype,
        0, /* data are already at the correct place */
        data_size,
        ROUTE_GROUND_ID);

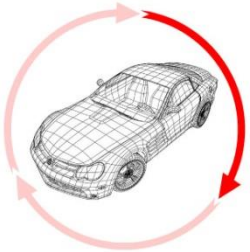

TM_send_telemetry(TM_ptr,
            data_size + TM_FIXED_SIZE,
            True,
            False);
```

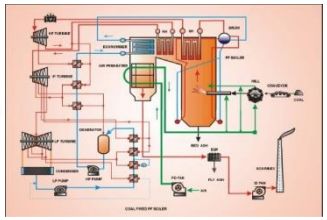


Software has the rare property that it allows us to directly evolve models into fully-fledged implementations without changing the engineering medium, tools, or methods

The software model may evolve into the system it was modeling in a seamless process.

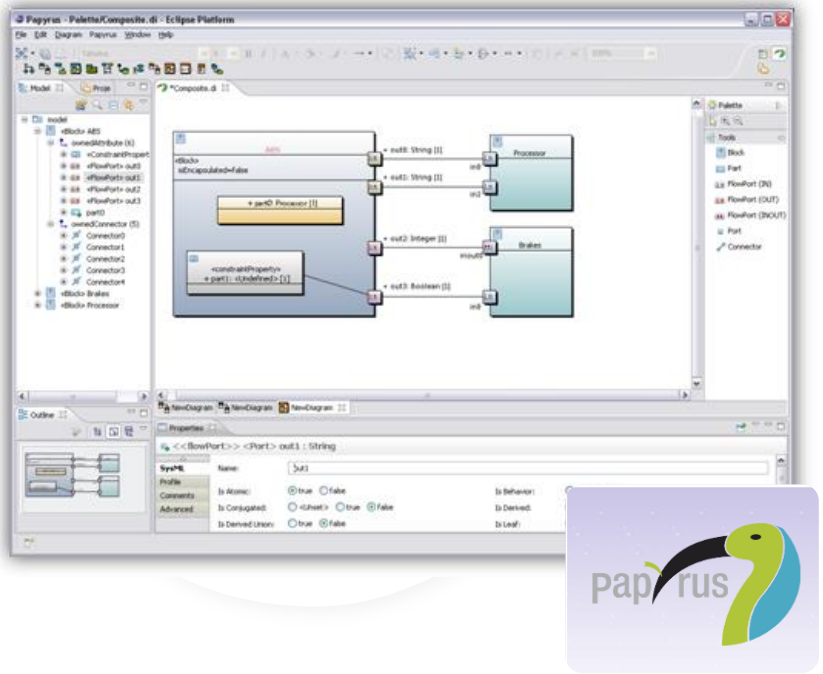






Development Environment: Modeling

- Paradigm Shift
  - From Programming to Modelling
  - Model Based Software Engineering
- Modeling Domains
  - Requirements
  - Architecture Modeling,
  - Data Modeling,
  - Behaviour Modeling
- Modelling Languages
  - UML, SYSML, AADL, AAML, SDL, …
- Model Verification
  - Strong Syntax, Formal Verification
- Automatic Generation
  - Code
  - Documents



ECLIPSE
Integrated Development Environment (IDE) and Eclipse Modelling Frameworl (EMF)

- OBSW Characteristics
- OBSW Process
- OBSW Architectures
- OBSW Environments
  - OBSW Execution Environment
  - OBSW Development Environment
    - OBSW Modelling
    - **OBSW Programming**
    - OBSW Production
    - OBSW Validation

Development Environment: Programming

- Languages
  - C:
    procedural language, widely used, poor expressivness but good control, well suited to system programming, efficient code but error prone
  - Ada:
    strong typing, well suited to embedded and real-time programming, mainly used in launchers
  - C++ :
    object oriented, based on C, less efficient due to object oriention, not used or poorly used on board so far
  - Java :
    object oriented, interpreted language, under investigation, possibly for OBCP
  - Assembler
    low level language, for specific usage

- OBSW Characteristics
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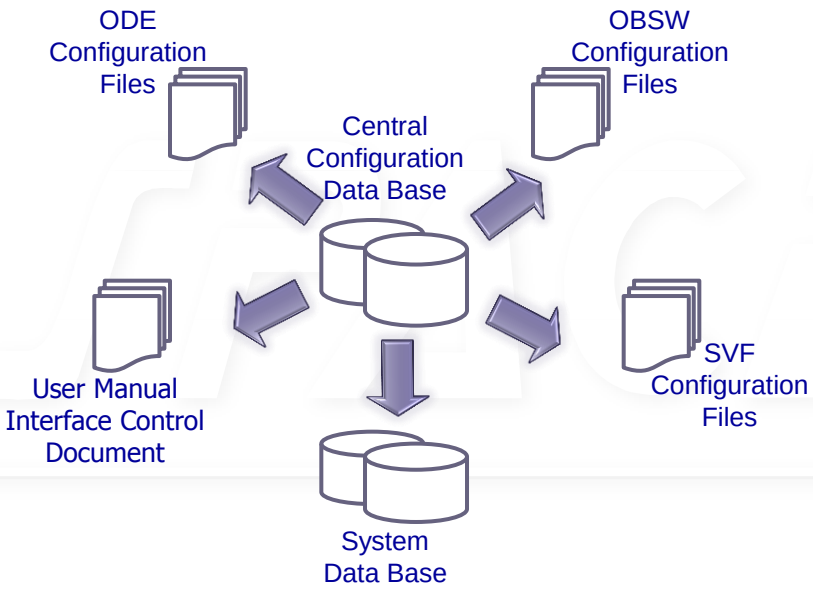
Development Environment: Production



Centralised Database

- Contains …
  On-board software configuration,
  Constant values, and
  Parameters useful for ground

  tasks, message queues, observable parameters, events, actions associated with events, default housekeeping, default monitoring, patch areas, Drivers commands, TC function ID's (PUS 8, 1), Memory partitions, File partitions, On-board stores, Default on-board storage allocation, PUS services and sub-services, Types of the parameters in the PUS TC/TM, Error codes, Application ID …

- Ensure coherency between …
  the different outputs

Production Tools

- Support Automatic generation of …
  Configuration Files and
  Documentation

- Allow for easy configuration

- OBSW Characteristics
- OBSW Process
- OBSW Architectures
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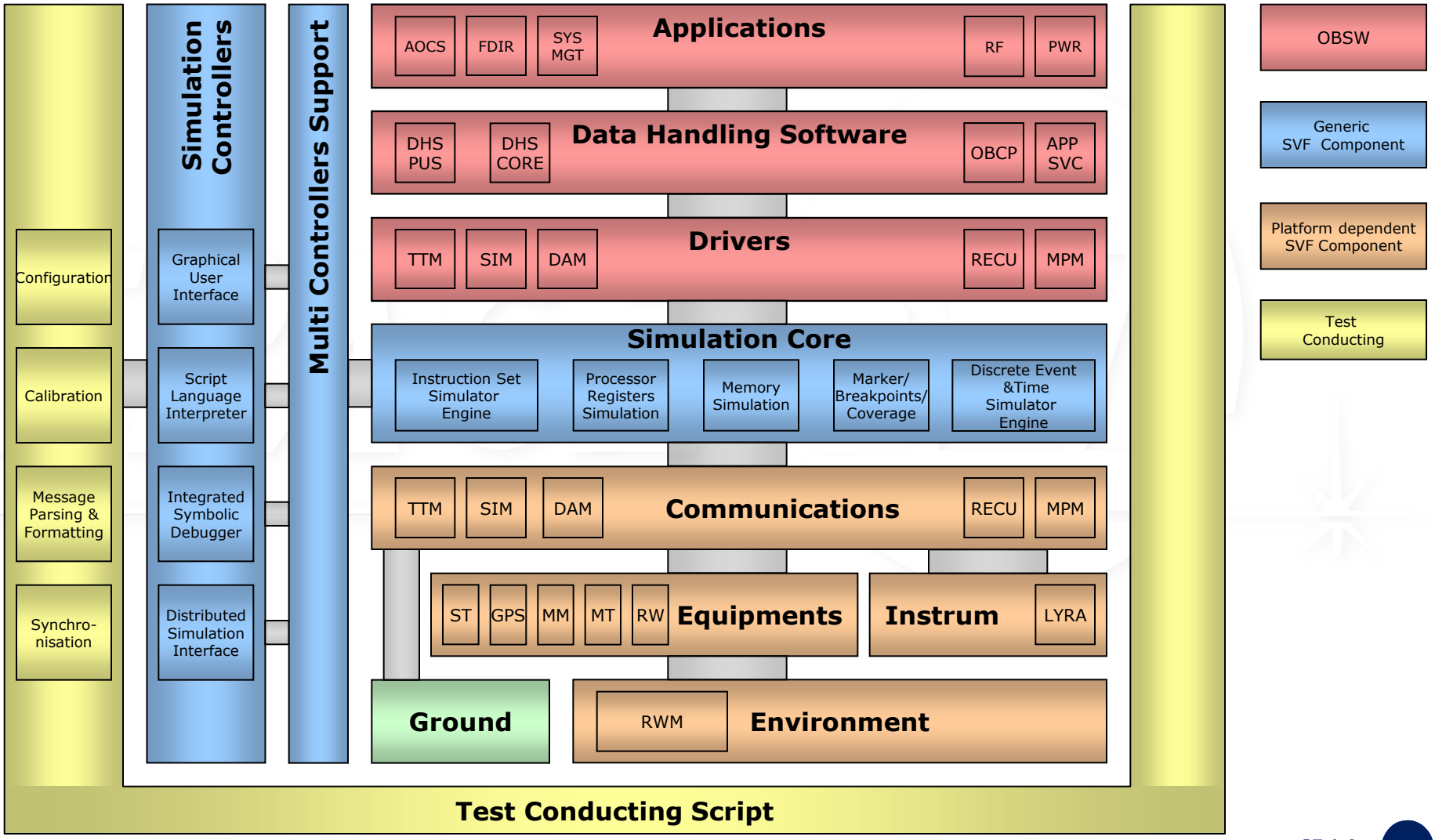
Development Environment: Validation



Reaching into space TOGETHER

OBSW

Modelling

OBSW Modeling

- Modeling Exemples
- Modeling Definition
- Modeling Objectives
- Modeling Characteristics
- Modeling Methods

Modeling : Examples


```
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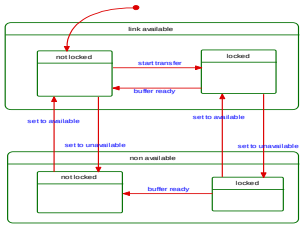

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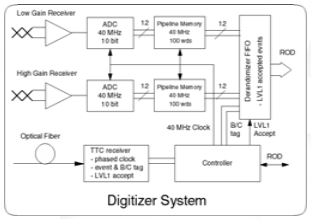
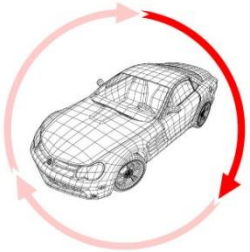
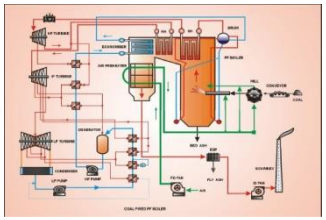






Modeling: Definition

- What is a Model?
  - A model is a **description** of (part of) a system written in a well defined language. A well defined langauge is a language with a well defined form (syntax), and meaning (semantic), which is suitablefor an automatic interpretatiojn by a computer. *(Anneke Kleppe et.al. « MDA Explained »)*
  - A formal **representation** of a function, behaviour and structure of the system we are considering. Expressed in an unambiguous language. (Chris. Raistrick et. Al. « Model Driven Architecture and Executable UML »)
  - Models are an **abstraction** of the reality captured in a specific representation format i.e. diagram or language.
  - A model is a **simplification** of something so we can view, manipulate, and reason about it, and so help us understand the complexity inherent in the subject under study. *(Steve Mellor et. All « UML Distilled »)*
  - A simplification of a system built with an intended goal in mind: the model should be able to answer questions in place of the actual system. (J. Bézivin & O. Gerbé. « Towards a precise définition of the OMG/MDA Framework »)
  - A model is a complex structure that represents a design artifact such as a relational schema, and interface definition (API), and XML schema, a semantic network, a UML model or an hypermedia document *(Phil. Bernstein. « A Vision of Management of Complex Systems »)*
  - A model captures a **view** of a physical system. It is an abstraction of a physical system with a certain purpose; This purpose determines what is included in the model and what is relevant. Thus the model completely describes those aspects of the physical system that are relavant to the purpose of the model, at the appropriate level of detail. *(OMG. « UML Superstructure »)*
  - A functional specification of the function, structure and/or behaviour of an application or system. *(OMG. « MDA Guide »)*

Modeling: Objectives

- Objectives of Software Modeling
  - To deal with complexity of systems development through
    - **Abstraction**:
      Abstract a problem to focus on some particular points of interest and to improve understandability of a problem
    - **Iteration**:
      Iterative modeling may be expressed at different level of fidelity
    - **Separation of Concerns**:
      Possible set of nearly independent views of a model (“Aspect Oriented Modeling”)
    - **Domain Specific Language**:
      To focus on specific domain expertise
  - To minimize development risks through
    - Through **analysis and experimentation** performed earlier in the design cycle
    - Enable to investigate and compare **alternative solutions**
  - To improve communication ...
    - to foster **information sharing** and reuse!
      A model is often best suited than a long speech !

Modeling: Characteristics

- Characteristics of Useful Models:
  - **Abstract**
    - Emphasize important aspects while removing irrelevant ones
  - **Understandable**
    - Expressed in a form that is readily understood by observers
  - **Accurate**
    - Faithfully represents the modeled system
  - **Predictive**
    - Can be used to answer questions about the modeled system
  - **Inexpensive**
    - Much cheaper to construct and study than the modeled system

To be useful, engineering models must satisfy all of these characteristics!

Modeling: Usage

- *In an attempt to formalize more and more the expression of the software documentation and production, the design, architecture and requirements have moved from simple text to drawings and from drawings to models.*

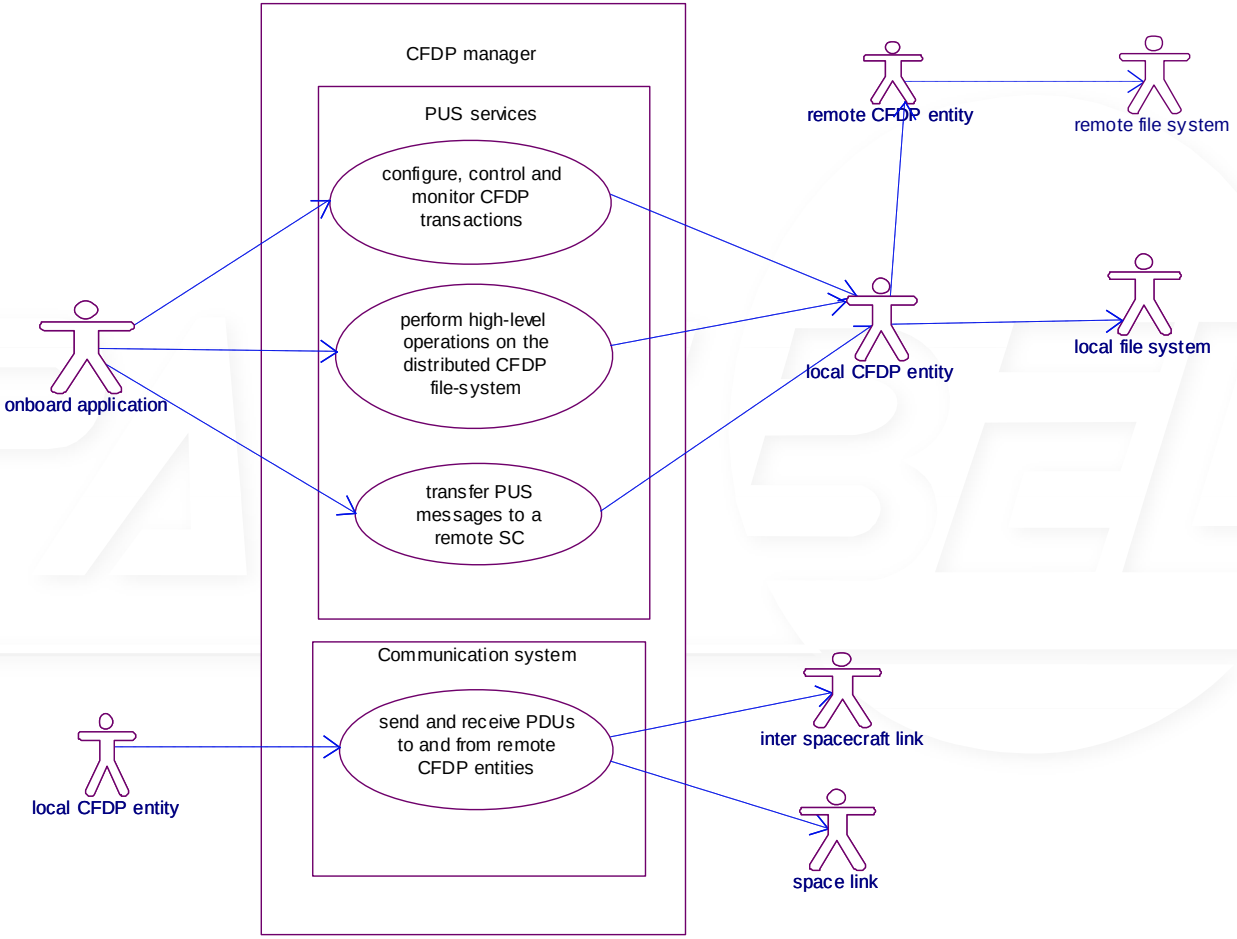
  With the emergence of new tools these model representations can be constructed, translated and exploited in different ways:

  - ***Analysis**: various types of model checking e.g. completeness and consistency analysis*
  - ***Simulation**: execution of model, behavior can be simulated*
  - ***Design**: decomposition of system in smaller components, establishing interfaces*
  - ***Coding**: automatic generation of source code e.g. C or Ada (auto-coding)*
  - ***Testing**: automatic generation of tests (auto-testing)*
  - ***Proving**: formal verification or proof*

Modeling: Methods

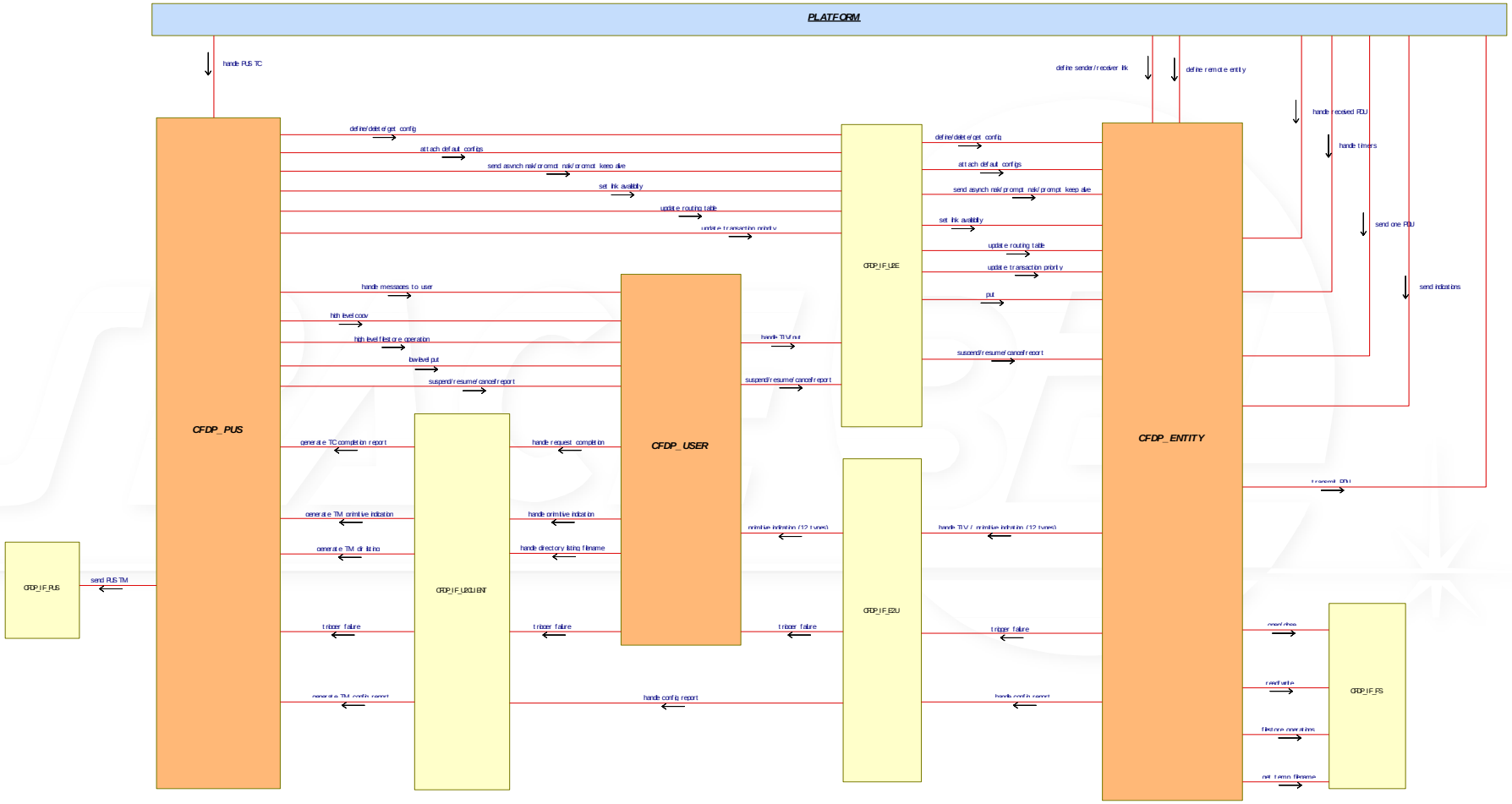
- Modeling Methods
  - **UML** (Unified Modelling Language)
    Not a method (weak semantic) but a notation (well defined syntax)
    Can be extended by profiles (e.g. SysML, MARTE, …)
    Can be complemented/supplemented (e.g. OCL)
  - **AADL** (Architecture Analysis and Design Language)
  - **SDL** (Specification and Description Language)
  - …. and many others (e.g. AAML …)
- See also Matlab/Simulink/Stateflow

Use Case Diagram



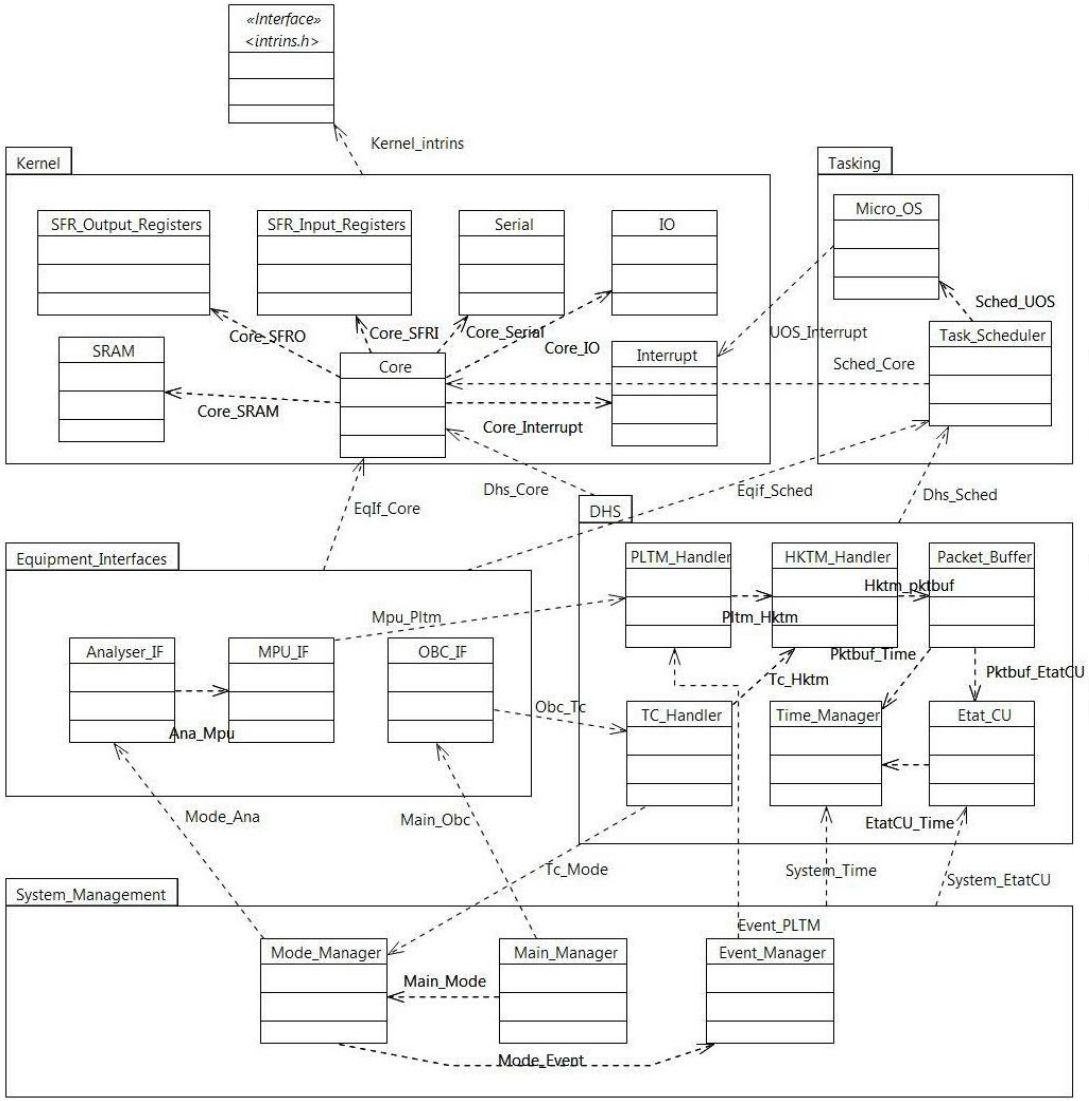
Collaboration Diagram

On Board Software > Modeling > UML > Collaboration Diagram



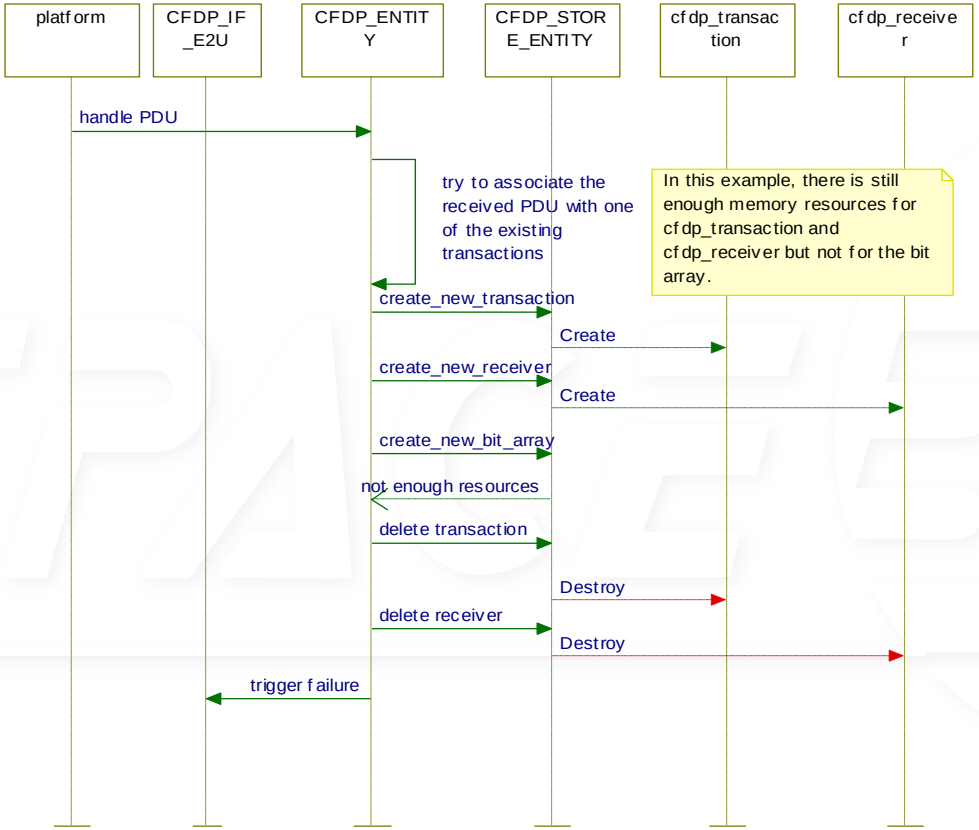
Class Diagram

On Board Software > Modeling > UML > Class Diagram



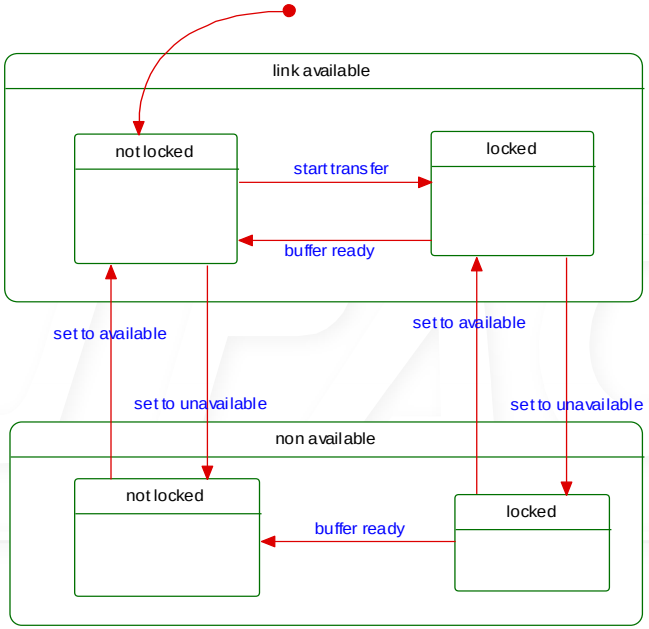
Sequence Diagram

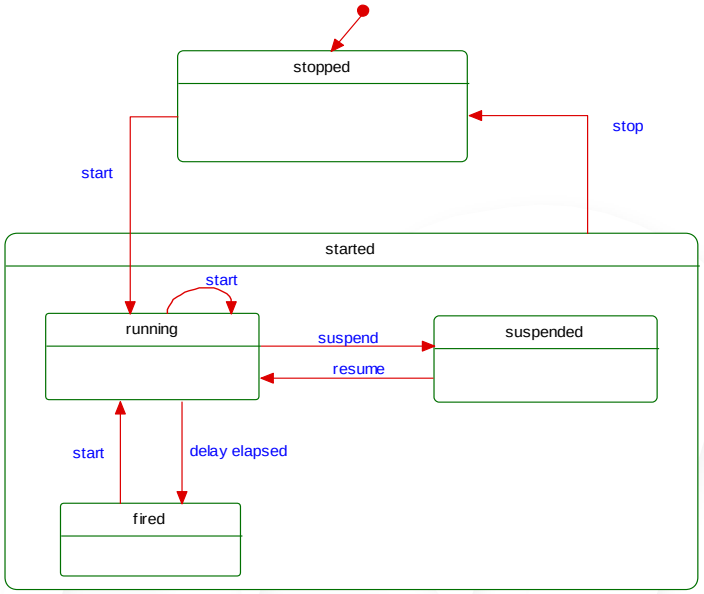
On Board Software > Modeling > UML > Sequence Diagram

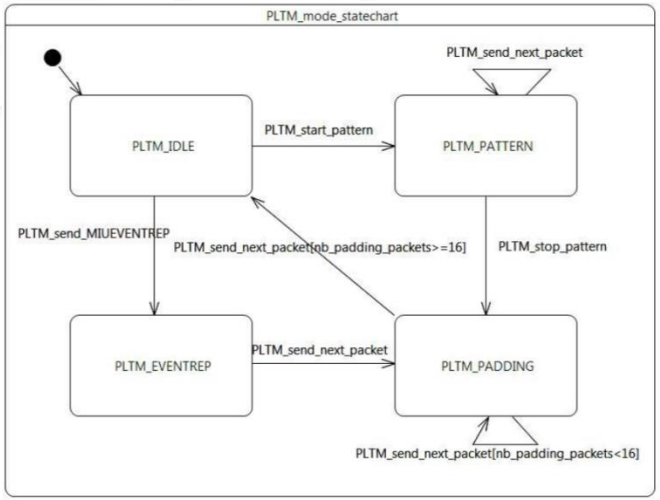


State Diagram

On Board Software > Modeling > UML > State Diagram







Reaching into space TOGETHER

OBSW

On Board Control Procedures

What are OBCPs?

- On Board Control Procedures (OBCPs) are flight procedures written in a high level language.
- These are pieces of software that can be resident on board or that can be uploaded to the spacecraft as required by ground,
- to be interpreted and executed on board, on demand, at any time and
- that may interact, to different extents, with the rest of the data handling system.
- They differ from native applicative components in that their invocation and execution may be controlled. This concerns in particular the ability to suspend or abort their execution.

Why OBCPs?

- OBCPs provide a flexible way to operate the spacecraft, to extend the on board software functionality or to modify the behaviour of on board applications, even in flight.

- OBCPs participate to on board autonomy when a rapid reaction is needed in spite of reduced spacecraft visibility or long propagation delay.

- Trend is to have generic functions implemented in the FSW and mission specific functions in OBCPs

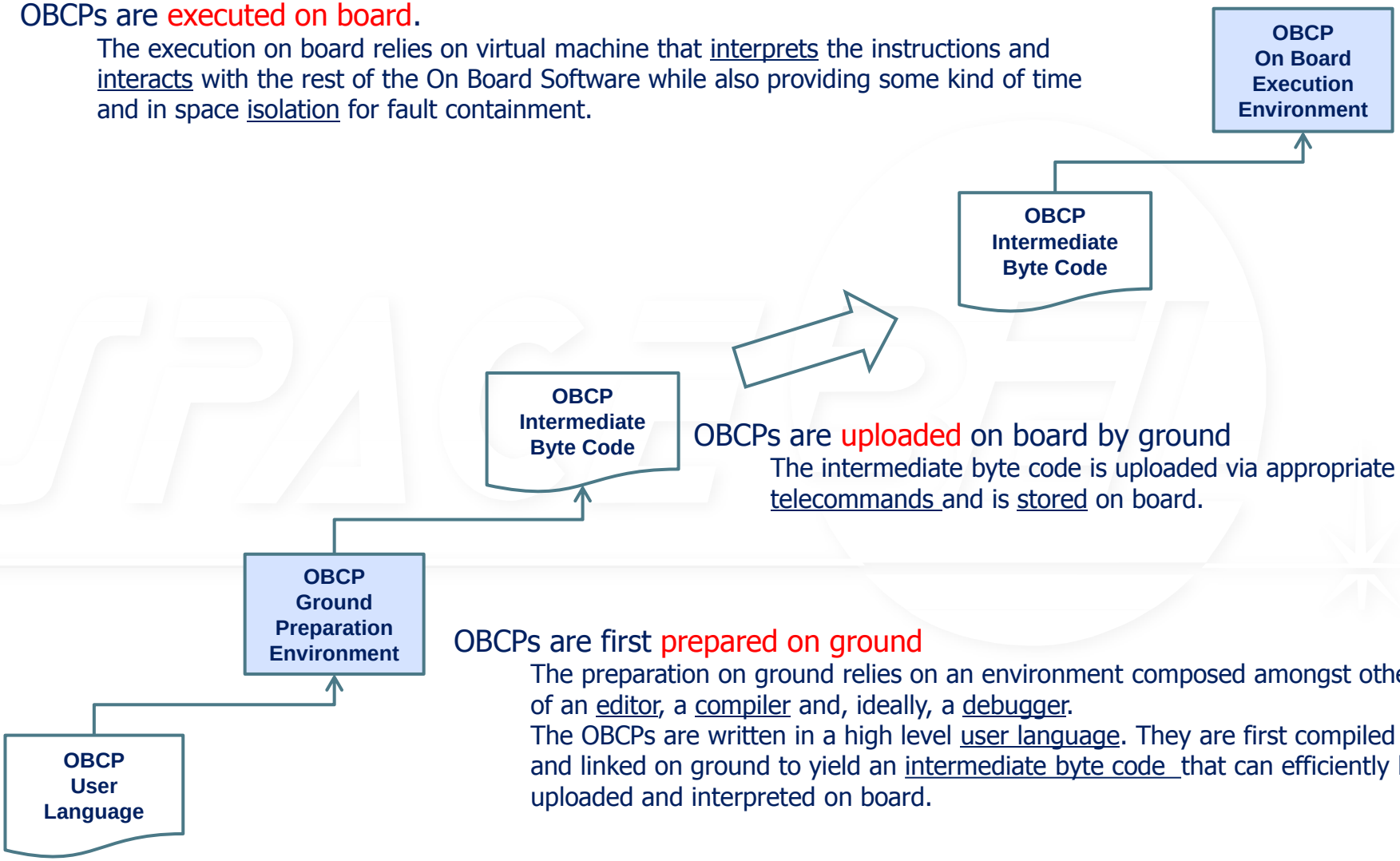
What are OBCP Used For?

Type		Applications	Interaction	User
OBOP On Board Operation Procedures	Command Sequences	- On Board Execution of Ground Procedures, - End-of-Life Operations	Limited to - Telecommand - Telemetry - Event	OP Engineer
		- Mode Management, - Configuration Sequences, - Recovery Procedures		PF or PL Engineer
		- Support to Assembly Integration and Testing - Long and complex configuration sequences - Fault injection and robustness testing - Temporary functions for testing purposes		AIT Engineer
OBAP On Board Application Procedures	High Level Script		Extended to - Data Pool - Equipments - Drivers	
		- Simple On Board Applications - Mission Specific Functions - Accomodation of Late Definition		PF or PL Engineer
		- Debugging - Short Term Work Around Solutions - On Board Patches - Adaptation to unpredictable environment		OBSW Engineer

How do OBCPs work?

OBCPs are executed on board.

The execution on board relies on virtual machine that interprets the instructions and interacts with the rest of the On Board Software while also providing some kind of time and in space isolation for fault containment.



OBCPs are uploaded on board by ground

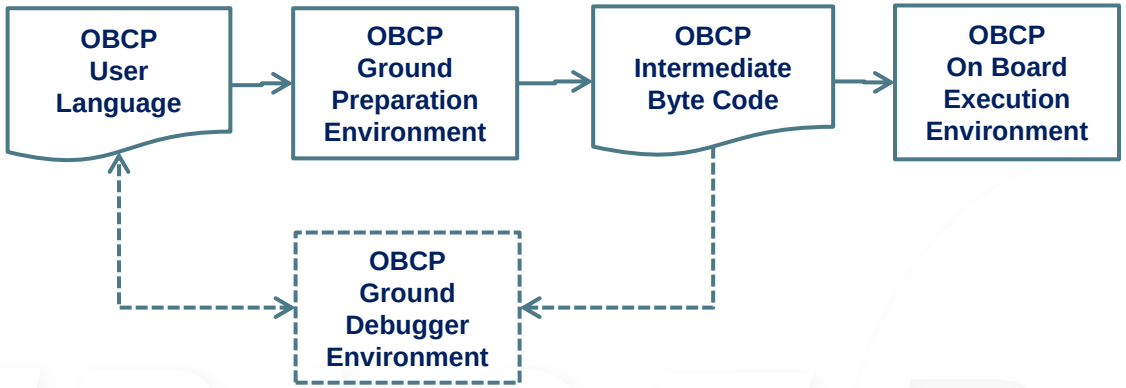
The intermediate byte code is uploaded via appropriate telecommands and is stored on board.

OBCPs are first prepared on ground

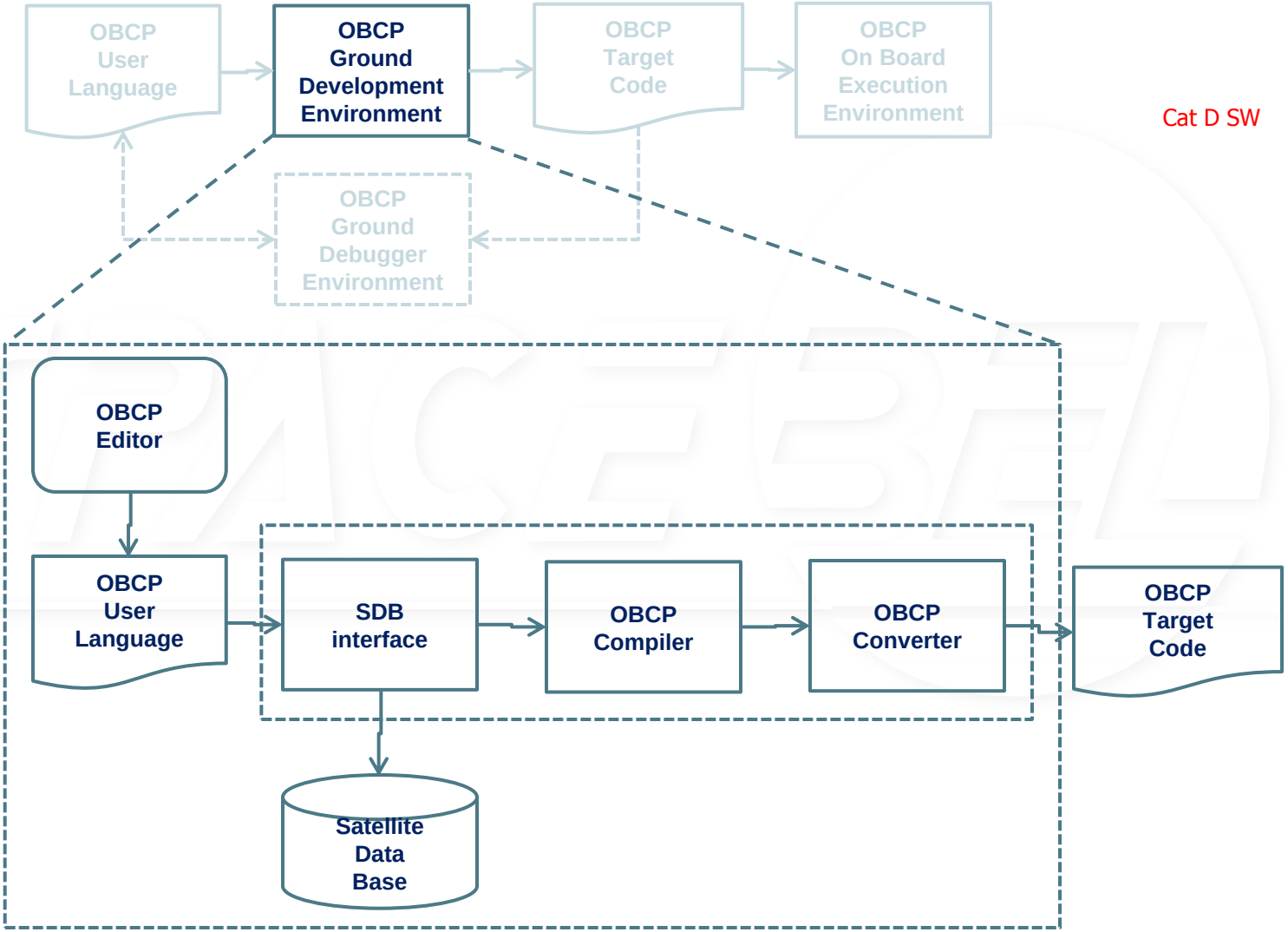
The preparation on ground relies on an environment composed amongst others of an editor, a compiler and, ideally, a debugger.

The OBCPs are written in a high level user language. They are first compiled and linked on ground to yield an intermediate byte code that can efficiently be uploaded and interpreted on board.

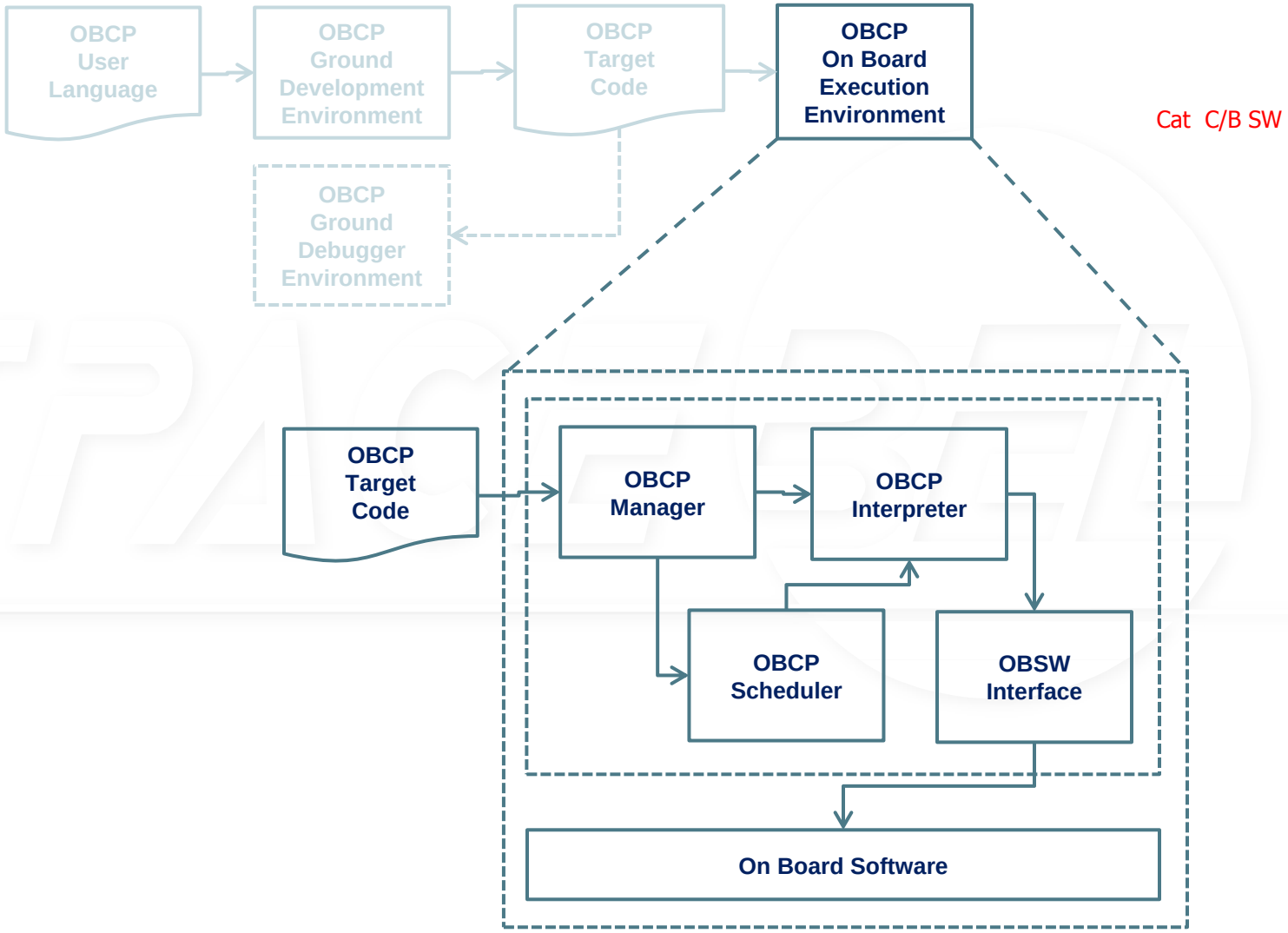
OBCP Overall Architecture



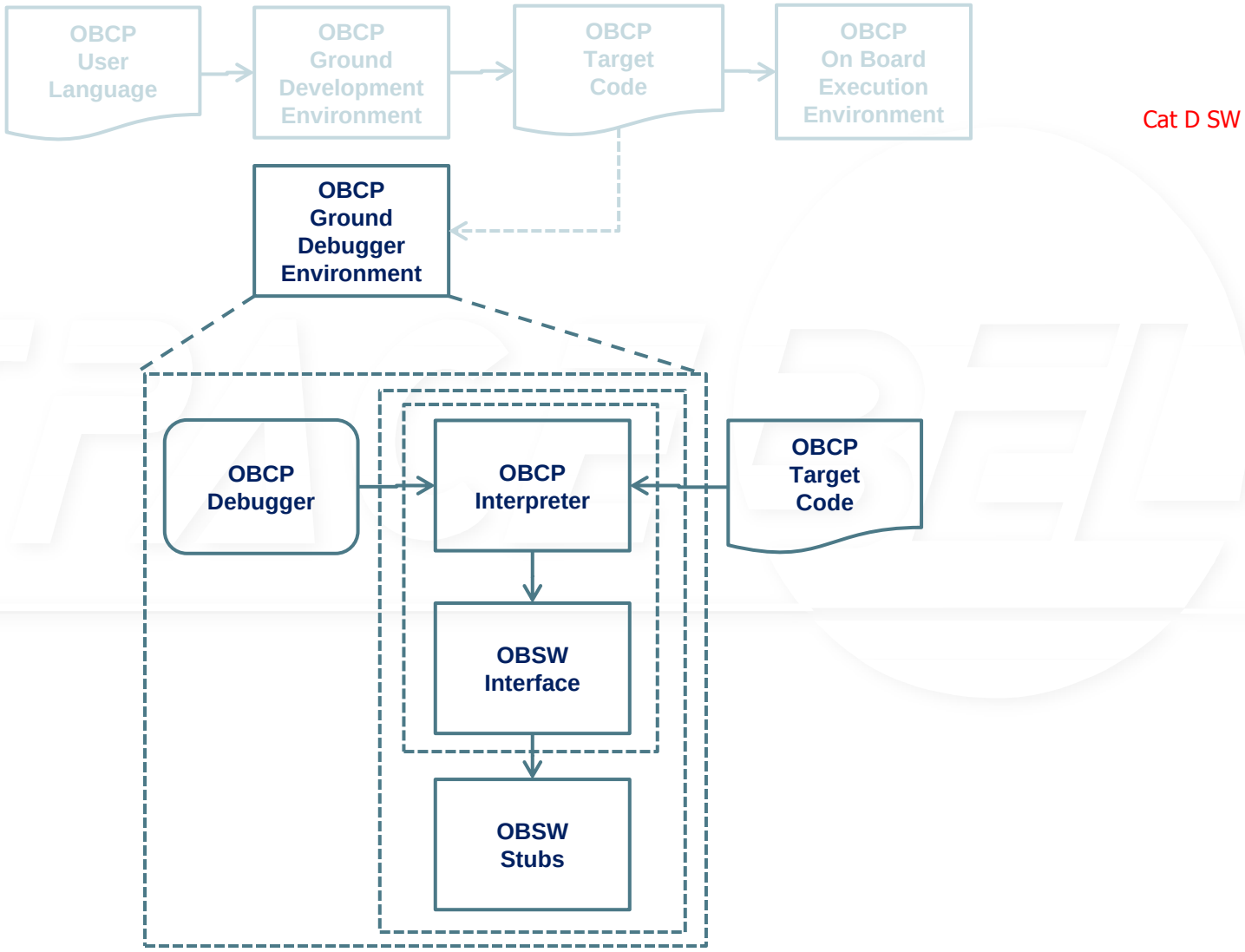
OBCP Ground Dev Env Architecture



OBCP OB Exec Env Architecture



OBCP Ground Debug Env Archi



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