OO Frameworks for On-Board Satellite Software

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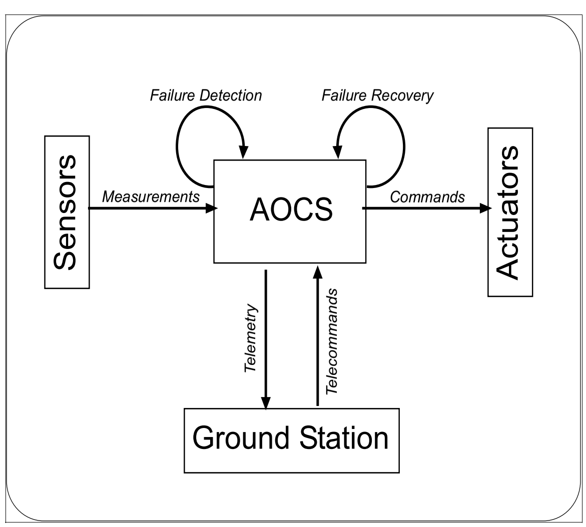
Contents

- Overview
- Design of selected subsystems
  - Telemetry Manager
  - Closed-Loop Controller Manager
- Reuse model, resource requirements
- Framework development methodology
  - Framelets
  - Implementation cases
- Project status & future activities

Overview

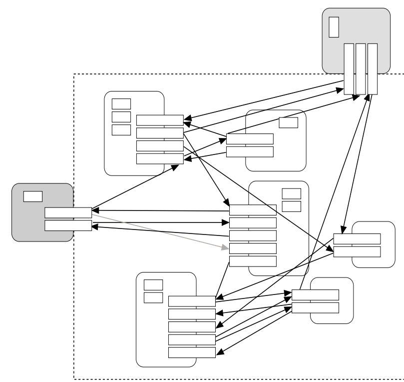
Background

R&D contract with the European Space Agency (ESA) to study SW reuse in Attitude and Orbit Control System (AOCS)



Selected Software Technology

Software Frameworks:collection of components with pre-defined interactions defining a reusable architecture optimized for a certain domain



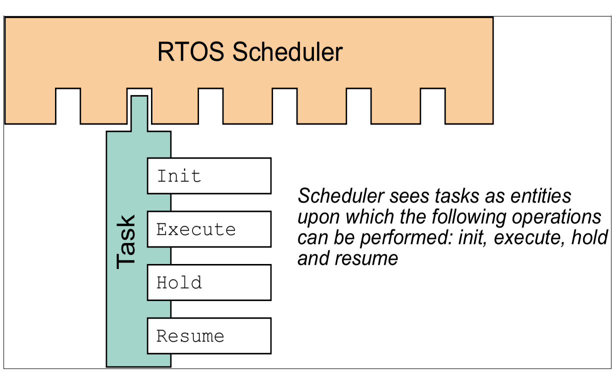
FWs define a reusable architectural skeleton (unshaded in figure) that is customized for a specific application by plug-in components (gray components in the figure)

Our Aim: design and prototype a sw framework for the AOCS

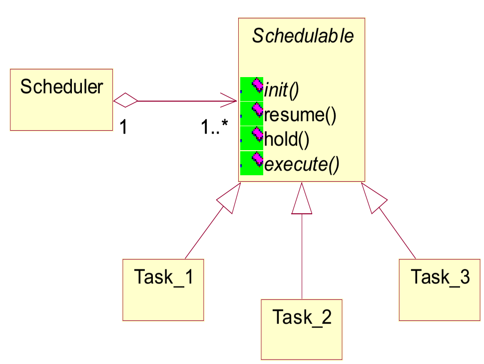
Reuse Approach : The RTOS Model

RTOS‘s are examples of reuse in real-time field → inspiration for AOCS f/w

Plug-In View



Class View



Task *management* separated from task *implementation* through an abstract i/f

The RTOS Example and the AOCS

- The RTOS example shows that the management of some functionalities – like task scheduling – can be packaged in reusable components

- For typical AOCS functionalities such as:

  telecommand management, telemetry management, closed-loop controller management, failure detection management, failure recovery management, sensor\actuator management, etc

  Can application-independent (and hence reusable) functionality managers be constructed?

Reuse Approach for the AOCS

- Divide the AOCS into functionalities: TM management, TC management, unit management, FD management, FR management, etc.

- For each functionality:
  - **Define an abstract interface** separating the functionality management from its implementation
  - Build a reusable **functionality manager component** (core component)
  - Build reusable component providing default implementations of recurring functionality implementations (**default components**)

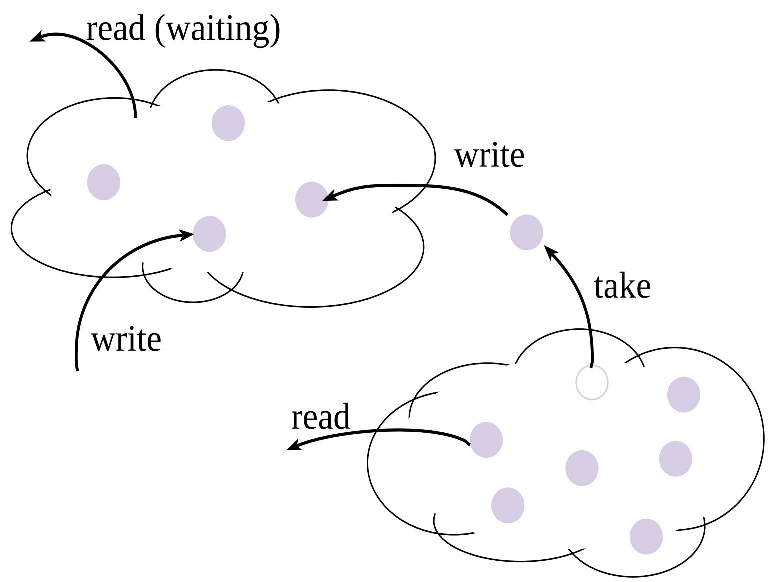
What the AOCS FW Offers

- AOCS-Specific Design Patterns
  - Solutions to commonly occurring architectural problems in AOCS systems
- Core Components
  - Binary modules encapsulating application-independent functionalities (eg a closed-loop controller manager)
- Default Components
  - Binary modules encapsulating common AOCS functionalities (eg. PID controller)
- Abstract Classes/Interfaces
  - Definition of external interfaces to be implemented by default components

Some AOCS Design Patterns - 1

- The AOCS is made up of **independent framelet components that cooperate** by exchanging data …
  - → Shared memory design pattern modelled on **JavaSpaces**

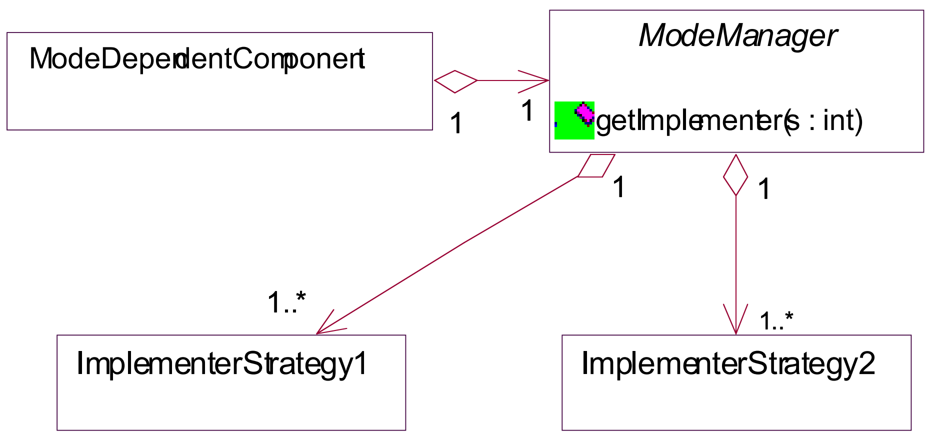
JavaSpaces architecture overview



Some AOCS Design Patterns - 2

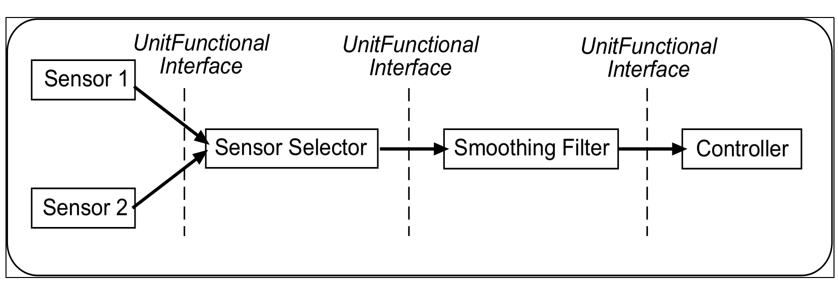
- AOCS components need to monitor each other to detect failures and to synchronize their behavior …
  - monitoring mechanisms modelled on **JavaBeans property monitoring**: direct monitoring, conditional monitoring, monitoring with notification
- AOCS components exhibit mode-dependent behavior …
  - Modified version of the “Strategy Pattern” from Gamma *et al*

AOCS Strategy Pattern



Some AOCS Design Patterns - 3

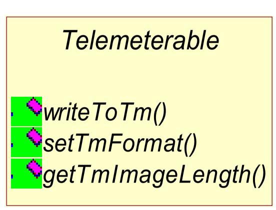
- AOCS need to implement data processing chains …
  - Block/Superblock mechanism mimicking the similarly named concepts in MatrixX/Xmath
- Data from sensors and to actuators need to go several processing stages …
  - Definition of `UnitFunctional` abstract interface to be implemented by each unit processing component



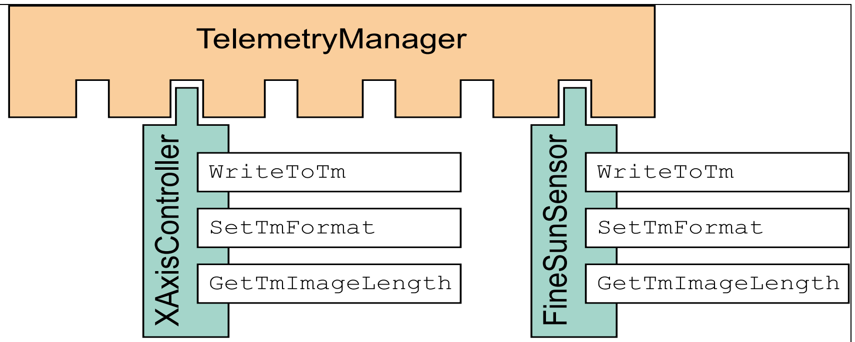
Some AOCS framelets

Telemetry Management Example

- Identify abstract operations required to handle telemetry:
  - `writeToTm()` : object writes its own state to the TM stream
  - `setTmFormat(newFmt)` : set the TM format to newFmt
  - `getTmImageLength()` : return the length (In bytes) of the object's TM image
- Define an abstract interface for telemetry operations:



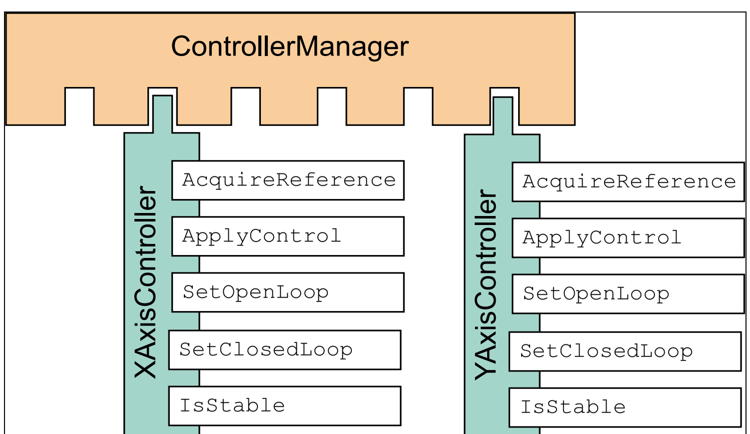
Telemetry Manager



TM Manager maintains a list of pointers to objects of type Telemeterable and periodically processes them using the Telemeterable operations:

```
Telemeterable* list[N];
. . .
for ( i=0; i<N; i++ )
{    list[i]->setTmFormat(fmt);
     size = list[i]->getTmImageLength();
     if (image fits into TM buffer)
          list[i]->writeToTelemetry();
     else
          . . . // error!
}
```

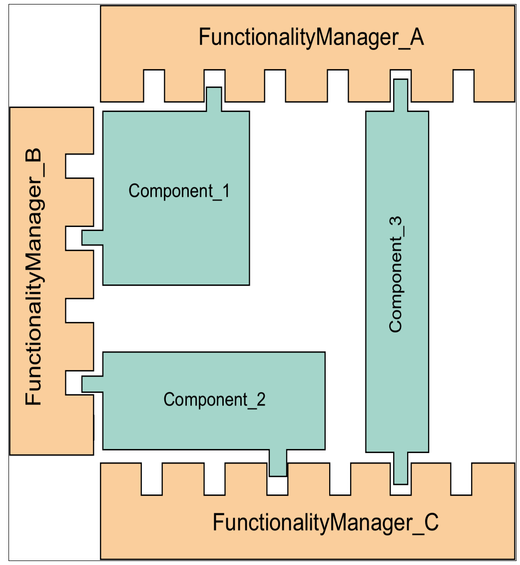

Closed-Loop Controller Manager



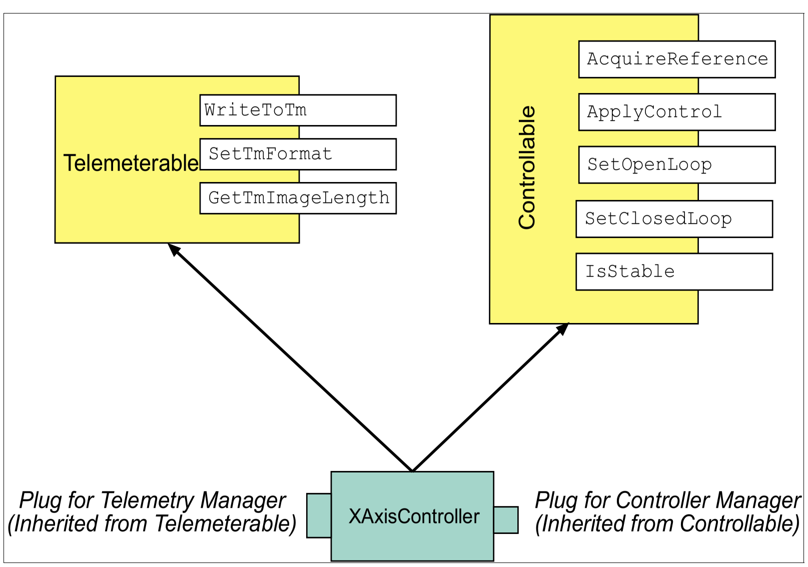

```
Controllable* list[N];
. . .
for ( i=0; i<N; i++ ) do
   if ( list[i]->isStable() )
   {   list[i]->acquireReference();
       list[i]->applyControl();
   }
   else
    . . . // error situation!
```

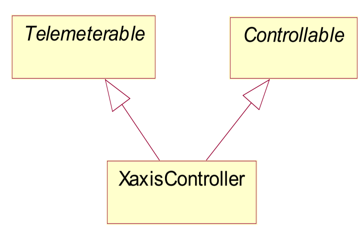
Conceptual AOCS Architecture

- Red blocks are application-independent and reusable
- Blue blocks tailor generic architecture to needs of a specific application
- Each FM defines an abstract interface
- A component may contribute to tailoring several FM's



Multiple Interface Implementation





Java-model of multiple inheritance is used (safe!)

Summary of Reuse Model

- *Abstract interfaces* decouple functionality management from functionality implementation
- *Core components* encapsulate reusable functionality managers

  Functionality managers do not perform actions *upon* objects, rather they ask objects to perform actions *upon themselves*

- OO language is required, in particular to support multiple abstract interfaces
- AOCS framework captures many aspects of any embedded control systems

Prototype Implementation

- Prototype implementation language: C++ (GNU compiler)
  - Any OO language can be used
  - Ada95 was considered but discarded due to poor support for MI
- No dynamic memory allocation
  - Non-trivial objects are created at initialization and never destroyed (no dangling pointers)
- No exceptions, no run-time type identification, …
  - Error situations are handled through creation of event objects in shared memory areas
- Target processor: ERC32 + RTEMS operating system
  - SPARC processor qualified for use in space by ESA (megabytes memory, ~ 10 MIPS)

Resource Requirements

- Timing requirements for “empty” functionality managers: 0.2 ms @ 14 MHz per AOCS cycle
  - This is the overhead introduced by the framework infrastructure
  - Typical AOCS cycle durations are 50-500 ms
- Memory requirements for functionality managers: 43 kB (code) + 19 kB (data)

- AOCS Prototype requirements (inclusive of RTEMS and C++ run time systems but with some modules missing):
  - 1 AOCS cycle in 3.9 ms
  - 245 kB (code) + 92 kB (data)
  - AOCS prototype not really representative of “real” AOCS

Framelets & implementation cases

Product Line Complexity

- Two forms of complexity
  - *Quantitative complexity*: large number of design constructs
  - *Qualitative complexity*: high level of abstraction
- Two forms of complexity → Two conceptual tools
  - *Framelets* address quantitative complexity
  - *Implementation Cases* address qualitative complexity

The framelet concept

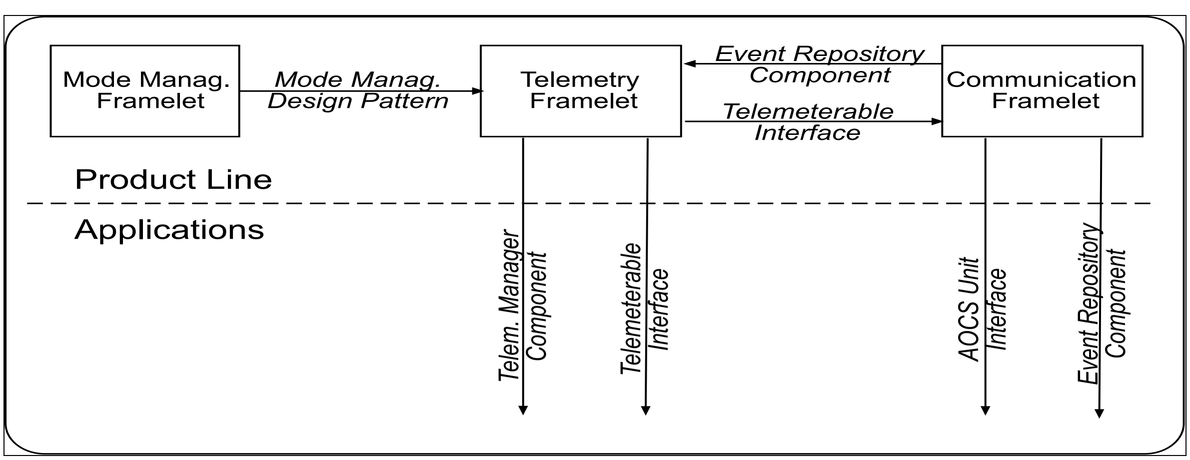
Framelet Features

- Framelets are units of design that address, as self-standing units, specific problems within the framework, in particular the **modularization of large frameworks**
- The overall framework is obtained by combining the framelets
- Framelet features
  - Small size
  - **No execution control assumptions**
  - Self-standing

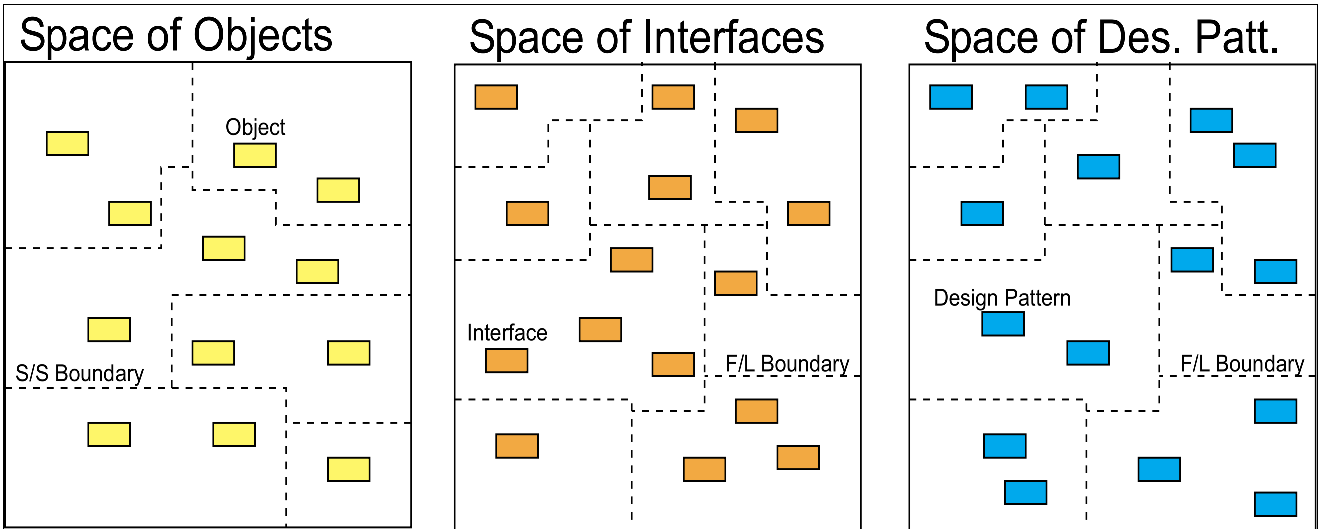
Framelet constructs

F/Ls export either horizontally (towards other F/Ls) or vertically (towards applications) three types of constructs

- Abstract interfaces
- Design patterns
- Interface implementations (as components)



Framelets and subsystems



Subsystems partition the space of objects in an application

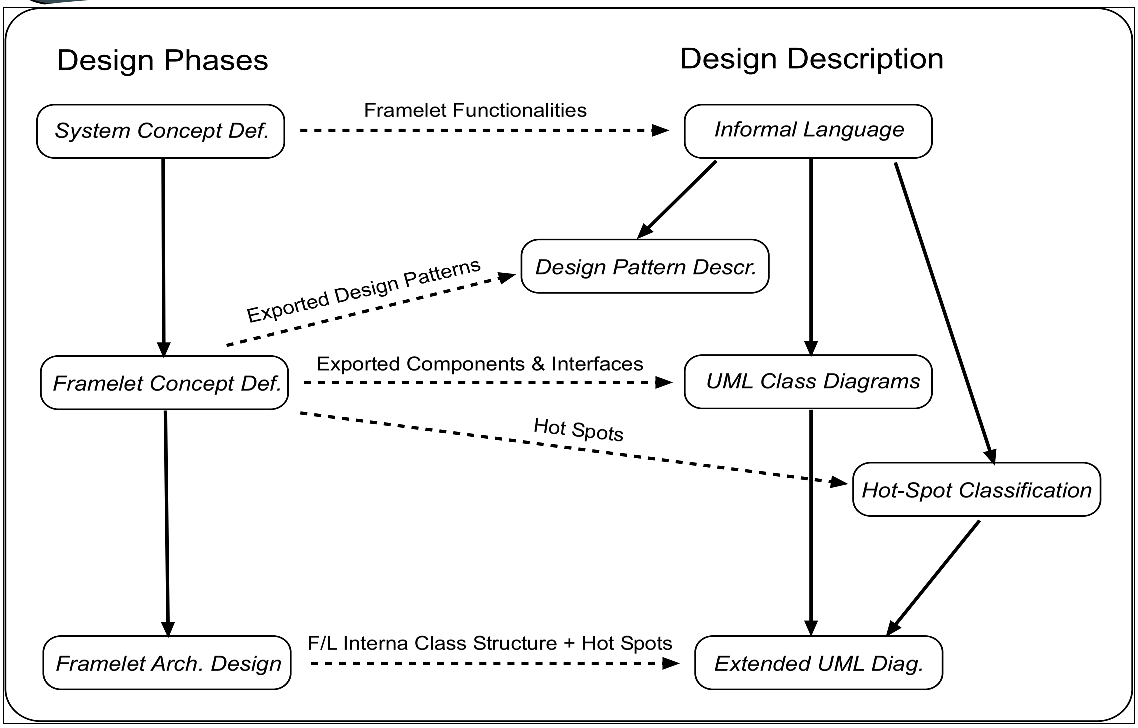
Framelets partition the space of interfaces and design patterns in a product line

Heuristics for F/L identification

The following heuristics were found useful in the AOCS project

- Map clusters of related application requirements to a F/L
- Build a F/L around one (or a related set of) hot-spot(s)
- Map a task to a F/L (for embedded applications)
- Map an abstract use case to a F/L

Framelet design description



Implementation cases

Use of Implementation Cases

- Continuous check of FL design adequacy

  ICs are **initially defined when FL design commences** and are worked out in parallel to the FL design. They are thus used to verify the adequacy of the abstractions proposed by the FL.

- Product line specification

  ICs describe how the FL is used (in the same sense in which use cases describe how an application is used)

- Product line user manual = cook book

  At the end of FL development, ICs are available as commented pseudo-code illustrating how the FL is used (cookbook-type recipes).

IC example

Objective
Build a telecommand to perform an attitude slew manoeuvre

Description
Attitude slews are normally started by a ground command (telecommand). This implementation case shows how to build a telecommand to perform an attitude slew manoeuvre.

Framelets
Telecommand Framelet
Manoeuvre Management Framelet

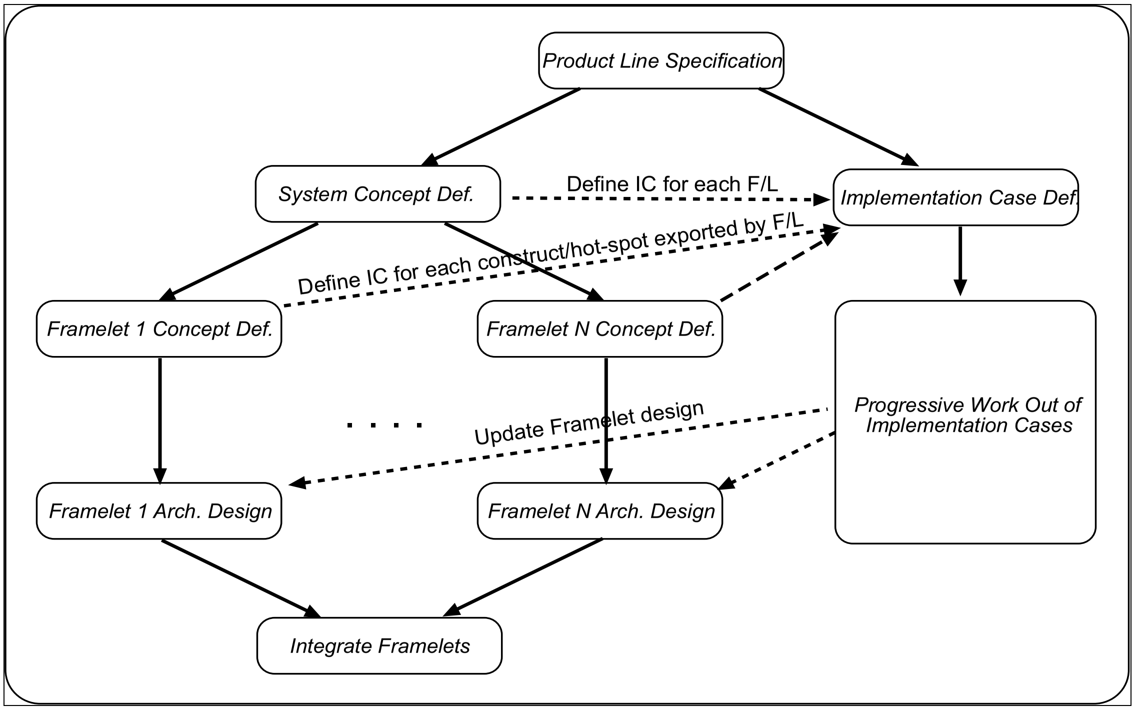
Framelet Constructs
`Telecommand` Interface
(exported from Telecommand Framelet)
`AocsManoeuvre` Interface
`ManoeuvreManager` Component
(exported from Manoeuvre Management Framelet)

Framelet Hot Spots
Telecommand Definition
(exposed by Telecommand Framelet)

Related Implementation Cases
Attitude Slew Manoeuvre Implementation Case
(this implementation case uses the component built in the attitude slew manoeuvre implementation case)

As design progresses, pseudo-code is added to the IC

IC & design process



Concluding remarks

- F/Ls and ICs were successfully tested in the AOCS project
  - Use of F/Ls made design more manageable and will make it easier to extend the FL to other application domains (some F/Ls can be carried over unchanged to other domains)
  - ICs were the main source of design changes in the AOCS project
- F/Ls and ICs are being used as the core of a complete methodology for FL development

Project status & future activities

Future Activities

- Contract with ESA set up to use the AOCS framework to develop and test AOCS for the Proba satellite
  - Proba is mini-satellite to be launched by ESA in 2001 as a technology demonstration mission
- Evolution of the AOCS F/W to form a generic embedded control system framework
- Contract with ESA under negotiation to port the AOCS framework to a real-time version of Java
  - Java is a “natural” implementation medium for sw frameworks

AOCS Framework Status

- AOCS Framework project to be completed in December 2000
- Framework code and design documentation to be made publicly available on our web site