Software Architecture in Practice

Chapter 3: A-7E Avionics System - A Case Study in Architectural Structures

Software Engineering Institute
Carnegie Mellon University
Pittsburgh, PA 15213-3890

Sponsored by the U.S. Department of Defense

Lecture Objectives

This lecture will enable students to

- **see examples of architectural structures used in a real system**
- **understand how these structures were engineered to achieve architectural quality attributes**
- **understand how information hiding came to be accepted as an important architectural principle**

A-7E Corsair II Aircraft

U. S. carrier-based, light attack aircraft

Used from the 1960s through the 1980s

Small computer on board for navigation, weapons delivery

Background of Old System

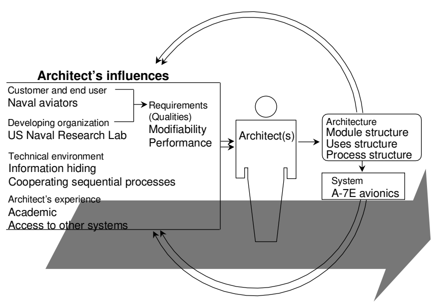
Fit into 32K of memory

Written in Assembler

Had to be optimized for *efficiency*

Brittle, hard to modify

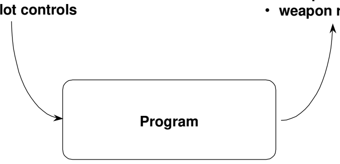
ABC for the A-7E II



Behavioral Requirements - 1

Data in from
- **sensors**
- **pilot controls**

Data out to
- **cockpit display**
- **weapon release hardware**



Behavioral Requirements -2

Read data from sensors such as
- air probe
- aimable forward-looking radar
- Doppler radar
- inertial measurement set
- type of weapon loaded on each wing station
- dozens of switches in the cockpit

Behavioral Requirements -3

Release wing-mounted weapons.

Manage cockpit displays such as
- heads-up display (HUD)
- moving map display
- keypad and alpha-numeric display
- warning lights
- cockpit dials

Behavioral Requirements -4

The pilot could communicate the location of a ground target to the software by
- moving a cursor on the HUD over it, and pressing a “designate” button
- moving a cursor on the map over it, and pressing a “designate” button
- manually aiming the forward-looking radar to the point and pressing the “designate” button
- entering its latitude/longitude via the keypad

The software then computed the time to target, heading, and other values.

Behavioral Requirements -5

Software was responsible for

- computing real-world values (such as position or altitude) by choosing the best currently-available sensor(s) and performing appropriate integration/smoothing
- navigating by providing pilot with current location in any of 18 different navigation modes
- computing ballistic weapon solutions
  - 100 different weapon types
  - 21 different delivery modes
- releasing the chosen weapon at the right time

Quality Requirements

The behavioral requirements were easy to satisfy compared to these quality requirements.

- The weapons and navigation calculations had to be performed 25 times per second on a very slow computer.
- The entire program still had to fit in 32K.
- The program had to be extremely modifiable because this was a demonstration of information hiding as a design discipline.

Architectural Approach

Concentrated on three architectural structures

- *module structure*
  - to achieve modifiability
  - to achieve flexibility of producing subsets
  - to allocate expertise
- *uses structure*: to ease production of subsets
- *process structure*: to achieve portability, performance tuning

Carnegie Mellon University
Software Engineering Institute

A-7E Architectural Structures

→ ***Module structure***

Uses structure

Process structure

Carnegie Mellon University
Software Engineering Institute

Principles for Creating Modules

Units of this structure are modules (work assignments).

Information hiding was the design principle.

- **identify areas of likely changes and assign a module to each**
- **encapsulate the changeable aspects in the module's implementation**
- **build the constant aspects into the module's interface**
- **decree that all uses of the module occur via the facilities on its interface**
- **hide data structures, algorithms, and other changeable aspects**

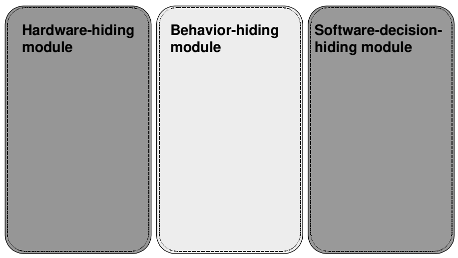
Carnegie Mellon University
Software Engineering Institute

Classifying Changes

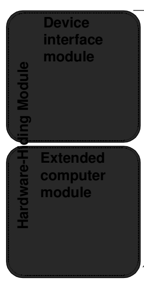
Three classes of change

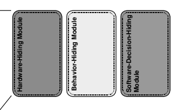
- **hardware**
  - **new devices**
  - **new computer**
- **required behavior**
  - **new functions**
  - **new rules of computing cockpit displays**
  - **new modes**
- **software decisions**
  - **new ways to schedule processes**
  - **new ways to represent data types**
  - **new ways to keep data current**

Three First-Level Modules (Work Assignments)



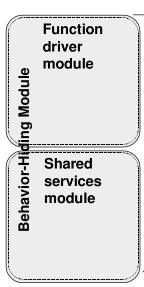
Hardware-Hiding Modules

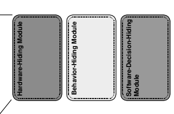




Two classes of hardware change
- peripheral devices: device interface module provides virtual, abstract devices
- on-board computer: extended computer module provides virtual machine

Behavior-Hiding Module

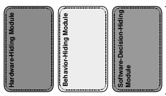


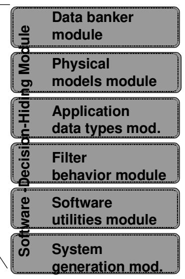


Function driver module encapsulates requirements-based rules for computing outputs; e.g.,
- when to release a weapon
- where to position a HUD symbol

Shared services module encapsulates rules shared by multiple outputs; e.g.,
- choosing from multiple sensor values
- current system modes

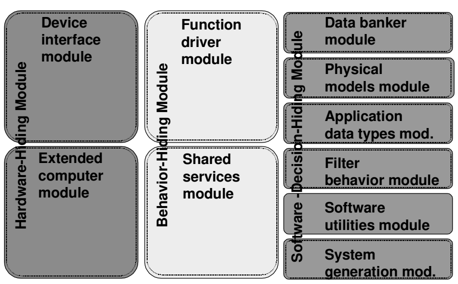
Software Decision-Hiding Module



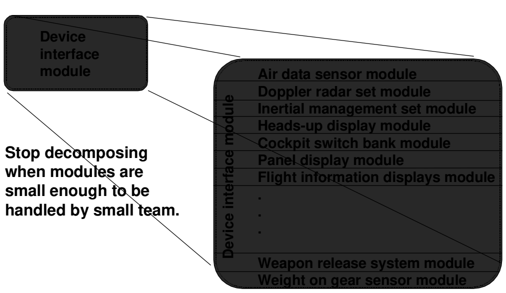


Six kinds of software decisions:
- producers/consumers of data
- algorithms for calculating real-world values based on sensor values and aircraft state
- representation of data types
- algorithms for filtering and smoothing value sequences
- algorithms for common utilities
- software for building system

A-7E Module Structure (2 Levels)



Example of Third-Level Modules



Stop decomposing when modules are small enough to be handled by small team.

Module Structure As Team Structure

Basis for team assignment: One team was formed for each second-level module.

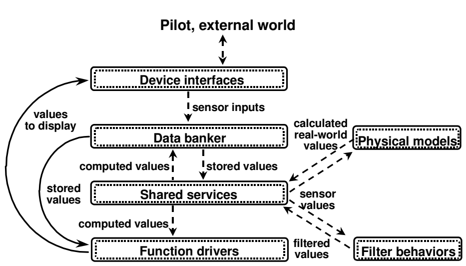
Basis for document organization: The bulk of the document corresponded to modules, although other structures were documented separately.

How Modules Work Together

Function driver module produces output values at appropriate times by
- **asking data banker module for current data**
- **asking physical models module to calculate real-world values**
- **computing output values**
- **telling device interface module to send values to output devices**

Data banker is updated by
- **device interface module, with sensor values**
- **shared services module, with current mode, best sensor choice, other data**

Data Flow View



A-7E Architectural Structures

Module structure

→ ***Uses structure***

Process structure

Definition of Uses Relation

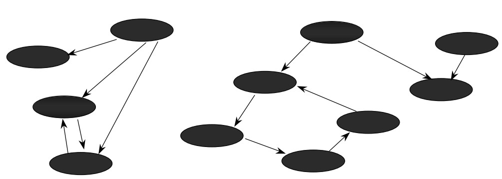
Units of this structure are programs.

Program A *uses* program B if a correctly functioning B must be present for A to meet its requirements.

Similar to calls, but not quite the same
- **A might call B, but not use it (e.g., if B is an exception handler, A’s correctness does not depend on anything that B computes).**
- **A might use B even if it doesn’t call it (e.g., assumption that B has left some computed value in an accessible place).**

How Does Uses Structure Help Define Subsets?

If program *A* is to be included in subset *S*, then so must the transitive closure of *A*’s uses relation.



A-7E Uses Rules (Simplified)

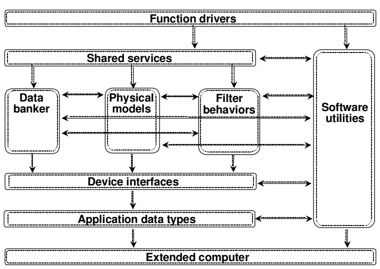
Extended computer module use no other programs.

Application data types programs use only extended computer programs.

Device interface programs can use extended computer programs, data types, filter behavior, and physical models programs.

Function driver and shared services programs can use data banker, physical models, filter behavior, device interface, extended computer, and application data types programs.

Layers Emerge from Uses Rules



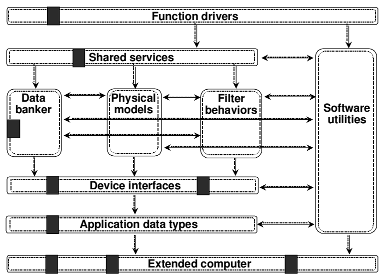
Layering

Layering is a well-known style that can provide portability across computing platforms and quick reimplementation of applications.

Layering is not clean. There are often “short-cuts” for performance or other reasons.

The uses structure suggests a layering, but they are not interchangeable. The layered structure allows only a very restrictive definition of subsets.

A-7E Subset: Display HUD Altitude



A-7E Architectural Structures

Module structure

Uses structure

→ ***Process structure***

Process Structure - 1

Units of this structure are processes.

In A-7E, processes resided in

- **function driver modules**
  - **periodic processes to continuously compute values (usually displays)**
  - **sporadic processes that take an action in response to events (e.g., release weapon)**
- **value-computing modules, when timing required a value to be pre-computed and waiting**

Process Structure -2

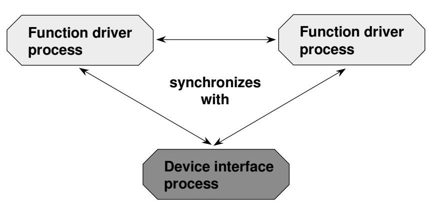
The computer had only one processor.

Off-line scheduling was used to build a schedule without the expense of a runtime executive.

The primary relation was "synchronizes with" or "excludes" (in the case of using shared resources). The scheduler used these relations to generate a schedule.

Processes could be merged by the scheduler for performance gains.

A-7E Process Structure



Case Study Summary -1

Three distinct structures (uses, module, and process) were used to design this system. Those structures (and others) *are* its architecture.

Each structure was *engineered* to achieve particular quality attributes. Structures were not allowed simply to happen on their own.

Information hiding was new and untested at the time of the A-7. It was shown to be a viable design strategy for building hard-real-time embedded computer software.

Case Study Summary -2

Information hiding has come to be accepted as a standard structuring technique for software architectures.

The requirement of fitting the program into 32K was not met.

Discussion Questions -1

1. **Suppose a version of the A-7E software were to be developed for installation on a flight trainer version of the aircraft. This aircraft would carry no weapons, but it would teach pilots how to navigate using the on-board avionics. What structures of the architecture would have to change, and why?**

Discussion Questions -2

2. **Later in the course, we will discuss using architecture as a basis for incremental development: starting small and growing the systems, but having a working subset at all times. Propose the smallest subset of the A-7E software that you can think of that still does something (correctly, in accordance with requirements) that is observable by the pilot. (A good candidate is displaying a value such as current heading on some cockpit display.) Which modules would you need and which could you do without? Now propose three incremental additions to that subset and specify the development plan (i.e., which modules you need) for those.**

Discussion Questions -3

3. Suppose that monitors were added to ensure that correct values were being stored in the data banker and computed by the function drivers. If the monitors detected a disparity between the stored or computed values, and what they computed as the correct values, they would signal an error. Show how each of the A-7E's architectural structures would change to accommodate this design. If you add modules, state the information-hiding criteria for placing it in the module hierarchy.