CS_313 High Integrity Systems/ CS_M13 Critical Systems

Course Notes

Chapter 5: The Development Cycle for Safety-Critical Systems

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5 (a) Life Cycle Models

5 (b) The Safety Life Cycle

5 (c) Development Methods

5 (d) Designing for Safety

5 (e) Human Factors in Safety

5 (f) Safety Analysis

5 (g) Safety Management

5 (h) The Safety Case

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5 (h) The Safety Case

(a) Life Cycle Models

- Critical systems have to be developed up to highest standards.
  - This means that one has to use methods which guarantee such standards.
  - The development of critical systems has to be well-documented and therefore the development process is much more formalistic the usual.
  - This is especially important since critical systems have often do be certified.
  - During certification, the documents used will be carefully checked.

Life Cycle Models

- Specification and verification are much more important than for ordinary software.
- The standard life cycle model used for critical systems is the **V-model**, which is very close to the waterfall model.
  - The V-model was developed independently simultanteously in Germany by a company in cooperation with the German Ministry of Defence, and by the National Council on Systems Engineering for satellite systems involving hardware, software and human interaction.

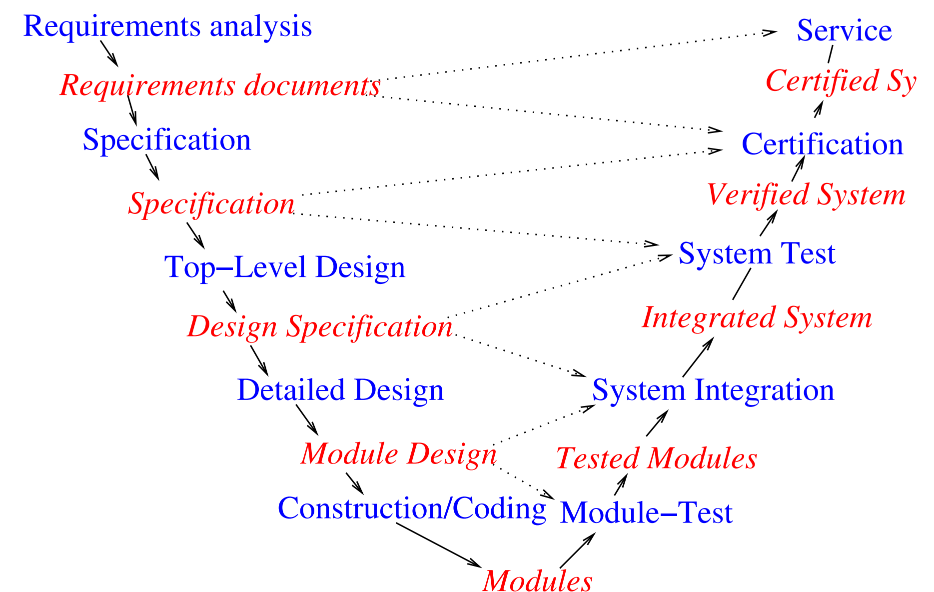
Life Cycle Models

- The origins of the V-model explain its tbfsuitability for critical systems, since **military software** are often **safety critical** and **satellite systems** are **mission critical**.
- Therefore that model was probably developed taking this into account.

Explanation Next Slide

- Items in blue Roman are development phases.
- Items in *red italics* are output from the development phases.
- $\longrightarrow$ is the primary flow of information.
- $\dashrightarrow$ is the secondary flow of information.

V-Development Life Cycle



Model from IEC 1508

The IEC 1508 model can be found in the Additional Material which is available from the website.

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Material Moved to Additional Material

Here we present only the material on Specifications. The rest has been moved to Additional material, which is available from the website.

Specification

- The goal of a **specification** is to define in an unambiguous manner, the precise operation of a system.
- Includes:
  - the functionality and performance of the system,
  - its interaction with other systems,
  - safety invariants of the system,
  - constraints of safety invariants on the design.
- In case of subcontracting of software, the specification forms a contract between the supplier and the customer.

Specification

- An ideal specification should be
  - correct,
  - complete,
  - consistent,
  - unambiguous.
- Especially completeness is often underestimated.

Example of an Incomplete Specification

- A carriage moves vertically along a guideway between two end stops.
- On each end-stop is a limit switch that should prevent further travel.
- If **neither limit-switch is closed** the system should allow the carriage to move in either direction under the control of other routines.
- If **the upper limit switch is closed** the system controlling the carriage should ensure that it can only move downwards and hence away from that end-stop.
- If **the lower limit switch is closed** the system controlling the carriage should ensure that it can only move upwards.

Example of an Incomplete Specification

- Missing: what happens if both switches are closed?
  - Could not happen if switches operate correctly.
  - However one switch might be broken, and then the system should deal with this error.
- As it stands, in this case the system might reach an unsafe state.

Problems of Natural Specifications

- Most specification are written in a natural language (e.g. English).
- There are 3 problems with natural language specifications.

1. Natural language is often **ambiguous**.
   - **Example:** "This toilet is available to disabled students and staff only".
     - Is it available to disabled staff only or to all staff?

Problems of Natural Specifications

2. Natural language specifications are much **longer** than mathematical formulations, and therefore it is more easy to **overlook** something.
   - That's the reason why in mathematics one writes formulae
     - e.g.
       $$\forall x, y.x = y \rightarrow y = x$$
   - instead of natural language texts
     - e.g.

       "for all x and y, if x is equal to y then y is equal to x"

Problems of Natural Specifications

2. (Cont.)
   - Without it would be much more difficult to keep an overview of what is currently available in a mathematical proof.
   - Similarly in natural language specifications one might insert **inconsistencies** or **inaccuracies**, which one would see immediately when using formal languages.
3. One cannot apply **automatic checks** (e.g. whether there are inconsistencies) to specifications written in natural languages.

Specification Languages

- Therefore **formal specification languages** have been developed.
  - Are used in industry.
  - Usually some **tool support** exists (syntax checks, some consistency checks).

Formal Specification Languages

- Two approaches:
  - **Model-based specification languages**:
    - Based on a general model for representing programs (usually a set theoretic model)
    - The system to be specified is constructed in this model using mathematical constructs such as sets and sequences.
    - The system operations are defined by how they modify the system state.

Formal Specification Languages

- **Algebraic specification languages**:
  - Systems are described in terms of operations and their relationship.
  - Relationships are described axiomatically.
  - With a consistent specification usually a large variety of models is associated.
  - The consequences of a specification are what holds in all models associated with a specification.

Formal Specification Languages

- Examples of formal specification languages:
  - **Algebraic languages:**
    - Sequential: Larch, OBJ, Maude, CASL
    - Concurrent: Lotos.
  - **Model-based languages:**
    - Sequential: VDM, Z, B-method, Event-B.
    - Concurrent: CSP, CCS, Petri Nets.
- Prof. Mosses was the leader of the initiative creating CASL.
- Dr. Roggenbach is a specialist on CASL, and has integrated CSP into it.
- Prof. Moller is a specialist on CCS.
- Prof. Tucker is a specialist on algebraic specification.
- Dr. Seisenberger, Dr. Harman are using and teaching Maude.
- Dr. Setzer is a user of CASL.

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(d) Designing for Safety

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Software Partitioning

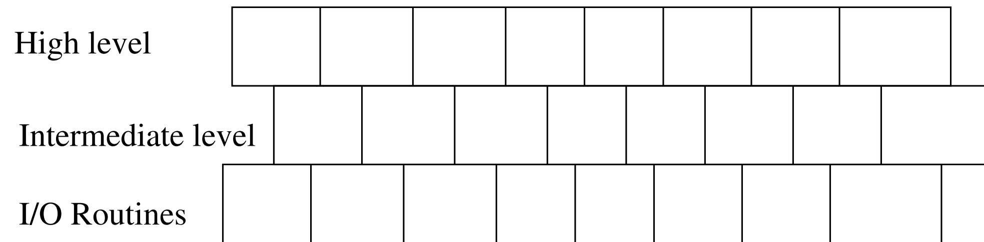
- Reason for partitioning of software:
  - Small units are **easier to understand** than a large monolithic program.
  - Partitioning provides **isolation** between software functions.
  - Allows to design the program so that **faults are contained** in one modules.
    - Makes **fault tolerance** possible.
  - Allows to assign to modules **different levels of integrity**.
    - If modules depend on each other, their criticality is that of the most critical one.
    - If modules are independent on each other, different (and often lower) levels of criticality can be assigned to them.

Hierarchical Design

- One approach towards designing systems is **hierarchical design**.
  - In a hierarchical design, a system is divided into a series of layers.
  - Modules within the higher layers depend for their correct operation on the correct functioning of lower-level components.
  - Lower levels might represent processors, control devices, sensors.
  - Higher levels might represent application-level software.
  - Intermediate levels are components like communication software and device drivers.

Layered Structures

- The result of a hierarchical design is a structure as follows:



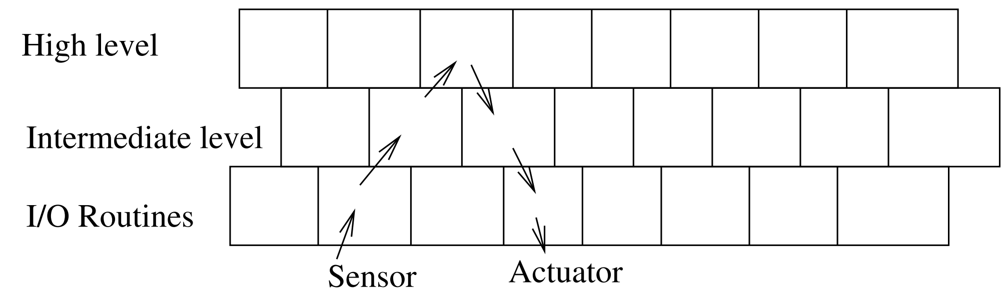
Layered Structures

- In a layered structure as before, upper modules depend on lower ones.
  - Therefore information about faults detected at lower levels have to be passed on to higher levels.
  - This is necessary in order to have good **fault management**, with the goal of having fault avoidance and fault removal.

Isolating Critical Functions

- It's important that critical functions are contained within modules, preferably within lower level modules.
- For instance, if a high level modules decides depending on information from one lower level module, whether a critical actuator controlled by another lower level module is activated, then this high level module and all intermediate modules involved have a high degree of criticality.

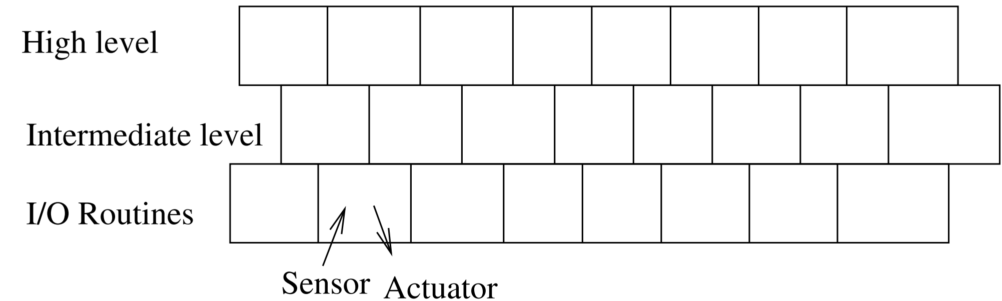
Long Chain of Responsibility



Better Architecture

- If instead this decision is done directly by one low level module, then only this small module is critical.
  - And it is much easier to verify a smaller module, rather than a big chain of modules.

Short Chain of Responsibility



Firewalls

- In critical systems, a **firewall** is a system which protects the critical elements of the system.
- A firewall might be
  - a **physical barrier**,
  - or a **logical barrier** to the system software, which prevents failure of the software outside the firewall from affecting the critical software within.
- Part of this is the **prevention of unauthorised access** or modification of data and code within the protected region.
  - That aspect of firewalls is what is associated with firewalls in the area of Internet security.

Safety Kernel

- A **safety kernel** is
  - a relatively small simple arrangement,
  - usually a combination of hardware and software,
  - that performs a set of safety-critical functions or provide operating system components that perform critical tasks.
  - Therefore the criticality of the system is concentrated in this kernel.
  - It is crucial that the kernel is well protected from outside influences.
    - Might be achieved physically, by use of separate hardware.
    - Might be achieved by software, by providing software isolation.

Example: Railway Control System

- For instance in a railway control system, one might have
  - A **small safety kernel**, which
    - receives high level commands about routes of trains to be chosen,
    - checks whether there are any conflicts,
    - and, if there are no conflicts, sets signals and activates switches accordingly.
  - A very **complex software**, which in an intelligent way controls the railway system
    - but all the commands of which are passed on to the small critical module.
  - Then one can assign a low level of integrity to the complex software, and only needs to assign a high level to the small safety kernel.

Software Isolation

- A unit in a program is **isolated**, if other modules can only influence it by using the public interface of the unit (which includes global variables).
- This means that
  - neither any local variable can be changed by any other unit,
    - access to the unit is only possible through the "front door",
  - nor the execution of the unit can be blocked by other modules consuming all the time or memory available.

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(e) Human Factors in Safety

- As operators or users, human beings can be considered as **components of critical systems**.
- Humans bring both complications and potential benefits to a system.
  - **Complications:**
    - Humans are often **unreliable** and **unpredictable**.
    - Therefore many accidents are attributed to human error.
    - **Computers** are **superior** in terms of **speed** and the ability to **follow a predefined set of instructions**.

Benefits of Humans in Critical Systems

- **Benefits:**
  - Humans are **flexible** and **adaptable**.
  - They are extremely good at **dealing with unexpected events**.
  - They are invaluable if a system **strays from its normal operating regime**.

Liveware

- Humans considered as a further component in a critical system, implement safety features.
  - E.g. a pilot, which in an emergency takes over control over the plane provides some kind of **fault tolerance**.
- Therefore, one can apply the terminology **liveware** to humans as components.
  - Besides hardware and software, safety features can be implemented by liveware.
- Appropriate partitioning of safety features between hardware, software and liveware is important.

Role of Liveware in Critical Systems

- Because of their adaptability, humans form some kind of **backup system** in critical systems.
  - In order to make this possible, it is necessary that the human operators can **take over responsibility** from the computer system.
    - For instance, in an aircraft the pilot is allowed to override the automatic landing system, by switching to manual control.
    - Therefore the pilot can make mistakes the computer system would avoid.
    - But this allows the pilot to overcome faults within the system.
- In general this means that humans can be used very well in order to provide additional **fault tolerance**.

Problems of Liveware

- Problem is that humans add **complexity** to a system.
- Humans are **not as reliable** as a computer system, when it is about performing routine tasks.
  - Therefore one usually attempts to remove humans from tasks that can be implemented by following a **well-defined set of rules**.
- From the above considerations it follows that one preferably should
  - remove humans from routine tasks,
  - but use them in the form of controllers, which take over responsibility in case of an emergency.

Human Error

- When an accident occurs, the reasons will in most cases be attributed to either **system failure** or **human error**.
- Very often the conclusion is **human error**.
- However, many human errors are due to to **deficits in the Human-Computer Interface (HCI)**.
  - **Example:** If an air plane crashes because the pilot does not notice that it is short of fuel this is human error.
  - If that happens several times, then one can question the display and warning system of the aircraft, and therefore the **HCI**.

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