



CSC313 High Integrity Systems/ CSCM13 Critical Systems

Course Notes

Chapter 6: The Development Cycle for Safety-Critical Systems

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[http://www.cs.swan.ac.uk/~csetzer/lectures/
critsys/current/index.html](http://www.cs.swan.ac.uk/~csetzer/lectures/critsys/current/index.html)

December 8, 2016

- 6 (a) Life Cycle Models
- 6 (b) The Safety Life Cycle
- 6 (c) Development Methods
- 6 (d) Designing for Safety
- 6 (e) Human Factors in Safety
- 6 (f) Safety Analysis
- 6 (g) Safety Management
- 6 (h) The Safety Case

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(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

Life Cycle Models

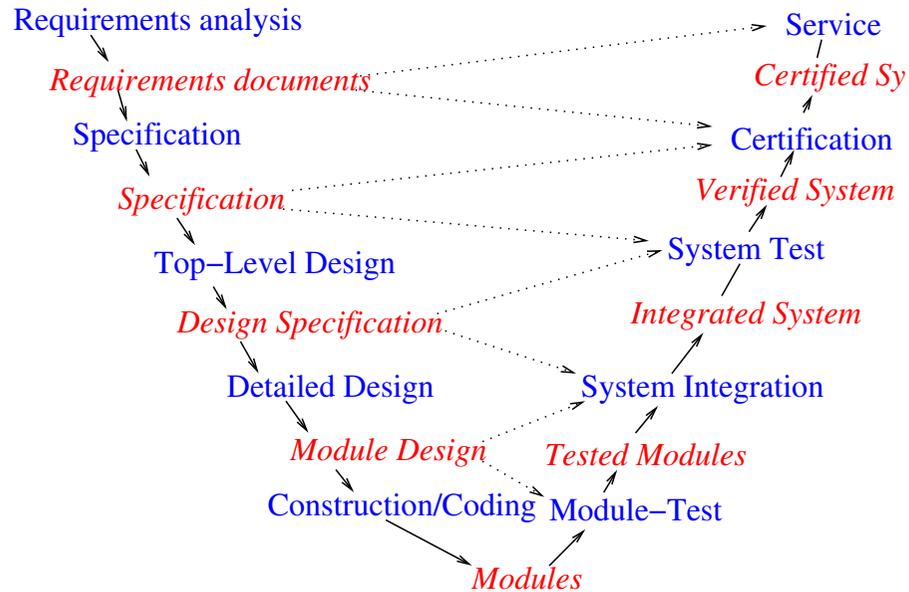
- ▶ Specification and verification are much more important than for ordinary software.
- ▶ The standard life cycle model used for critical systems is the **V-model**, which is very close to the waterfall model.
 - ▶ The V-model was developed independently simultaneously in Germany by a company in cooperation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

Explanation Next Slide

- ▶ The origins of the V-model explain its suitability 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.

- ▶ Items in **blue Roman** are development phases.
- ▶ Items in *red italics* are output from the development phases.
- ▶ → is the primary flow of information.
- ▶ --> 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.

Material Moved to Additional Material

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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.

Problems of Natural Specifications

- ▶ Most specifications 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?

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

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

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.

▶ 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.

(d) Designing for Safety

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Software Partitioning

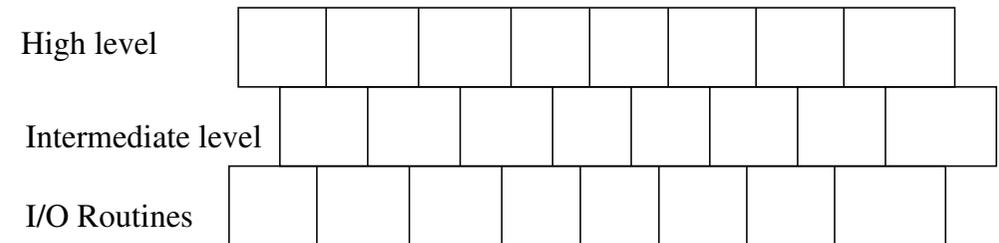
- ▶ Reason for partitioning of software:
 - ▶ Small units are **easier to understand** than a large monolithic program.
 - ▶ Partitioning provides **isolation** between software functions.
 - ▶ Allows to design the program so that **faults are contained** in one modules.
 - ▶ Makes **fault tolerance** 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:



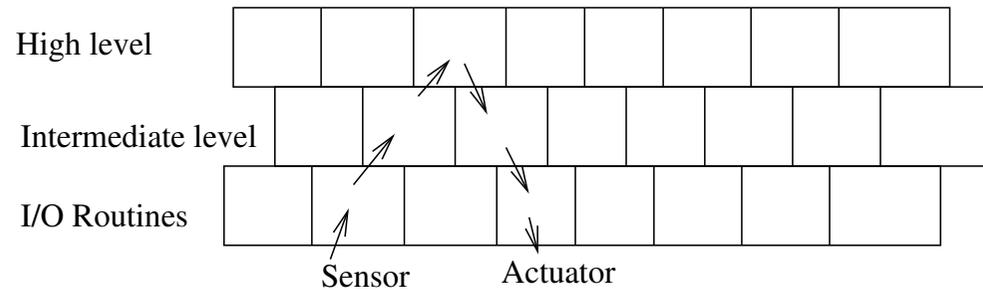
Layered Structures

- ▶ 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.

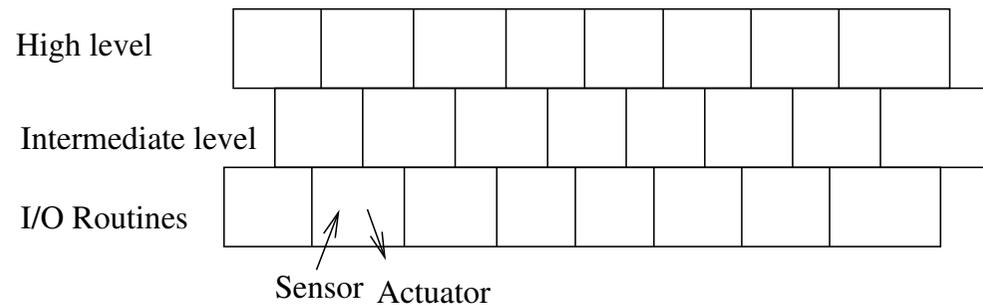
Long Chain of Responsibility



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



Better Architecture

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 - ▶ And it is much easier to verify a smaller module, rather than a big chain of modules.

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.

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.

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.

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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**.

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.

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**.

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.

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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 **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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