Lecture on

Dependable Computer Systems

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Overview on lectures

- Dependable systems and incidents
- Basic concepts and terminology
- Fault-tolerance and modelling
- Failure modes and models
- Processes, Certification, Standards with an Aerospace focus
- System aspects
- Conclusion

Part 1:

Dependable systems and incidents

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The “Dependability Problem”

Our society depends on a broad variety of computer controlled systems where failures are critical and may have severe consequences on property, environment, or even human life.

Aims of this lectures

- to understand the attributes and concepts of dependability,
- to understand reasons for low dependability and
- gain knowledge on how to build dependable computer systems

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“Fly-by-wire”

- pilot commands are transmitted as electrical commands
- a flight control system (FCS computer) is used
- the pilot flies the FCS and the FCS flies the plane
- military planes require FCS to get artificial stability
- for civilian use the advantages are:
  - weight savings
  - enhanced control qualities
  - enhanced safety

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The SAAB JAS Gripen:

- 1989: Crash after sixth test flight due to exceeded stability margins at critical frequency, software was updated
- 1993: Crash on a display flight over the Water Festival in Stockholm, again due to pilot commands the plane became instable
- the cycle time of the Gripen FCS is 200 *ms*
- the probability of instability was estimated by the engineers as “sufficiently low”

The Airbus A320:

- 4 hull losses (plane crashes)
- all crashes are attributed to a mixture of pilot and computer or interface failures

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Patriot vs. Scud

During gulf war a Scud missile broke through the Patriot anti-missile defense barrier and hit American forces killing 28 people and injuring 98

A software problem

- time is represented as an 32 *bit* integer and converted to 24 *bit* real number
- with the advent of time this conversion loses accuracy
- tracking of enemy missiles becomes therefore faulty
- the software problem was already known, and the update was delivered the next day

Bank of America financial system:

- development during 4 years costs $20 millions
- $60 millions in overtime expenses
- $1.5 billion in lost business
- system was abandoned after nearly one year in service

Airport of Denver, Colorado

- one of the largest airports worldwide
- intelligent luggage transportation system with 4000 “Telecars”, 35 *km* rails, controlled by a network of 100 computers with 5000 sensors, 400 radio antennas, and 56 barcode readers
- due to software problems about one year delay which costs 1.1 million $ per day

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Dependable systems and incidents

Harsh environment:

- The “bug”: On a Mark II in 1945 a moth came between relay contacts
- train cars were changed form external to disc brakes, trains vanished from display
- near a broadcast transmission tower it was possible to "hear rock and roll on the toaster"
- an overripe tomato hung over an answering machine, dripping tomato juice into the machine which caused repeated call to the emergency line
- pigeons may deposit a "white dielectric substance" in an antenna horn

Examples may seem funny but:

- system are designed to endure within a given operational conditions
- it is **very hard** to anticipate the operational conditions correctly
- illustrates difficulties of *good* system design

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The Therac-25 accidents

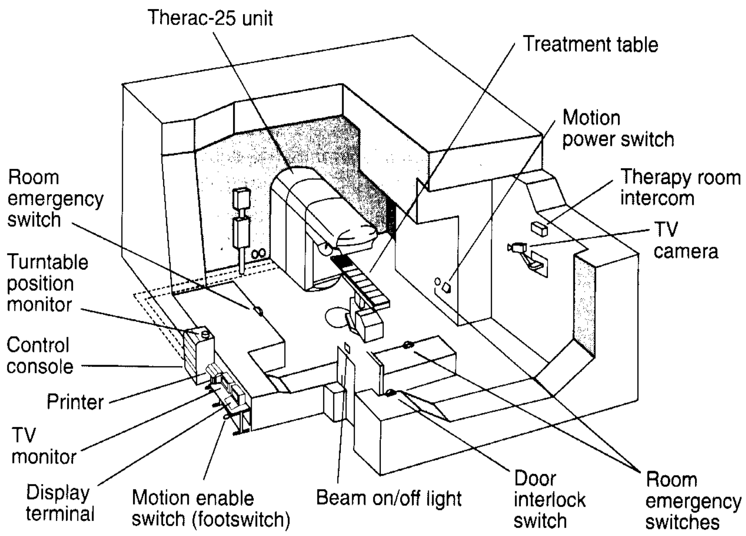
- Therac-25 is a machine for radiation therapy (to treat cancer)
- Between June 1985 and January 1987 (at least) six patients received severe overdoses:
  - two died shortly afterwards
  - two might have died but died because of cancer
  - the remaining two suffered of permanent disabilities

Functional principle

- “scanning magnets” are used to spread the beam and vary the beam energy
- Therac is a “dual-mode” machine
- electron beams are used for surface tumors
- X-ray for deep tumors

X-ray and electron mode

- a tungsten target and a “beam flattener” is moved in the path to the rotating turntable
- the target generates the X-rays but absorbs most of the beam energy
- the required energy has to be increased by a factor of 100, compared to electron mode



Typical Therac-25 facility

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Major event time line

	1985
Jun	**3rd:** Marietta, Georgia, overdose. Later in the month, Tim Still calls AECL and asks if overdose by Therac-25 is possible.
	26th: Hamilton, Ontario, Canada, overdose; AECL notified and determines microswitch failure was the cause.
Jul	
	AECL makes changes to microswitch and notifies users of increased safety.
Sep	Independent consultant (for Hamilton Clinic) recommends potentiometer on turntable.
	Georgia patient files suit against AECL and hospital.
Oct	**8th:** Letter from Canadian Radiation Protection Bureau to AECL asking for additional hardware interlocks and software changes.
Nov	
	Yakima, Washington, clinic overdose.
Dec	**1986**
	Attorney for Hamilton clinic requests that potentiometer be installed on turntable.
Jan	**31st:** Letter to AECL from Yakima reporting overdose possibility.
Feb	**24th:** Letter from AECL to Yakima saying overdose was impossible and no other incidents had occurred.

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Major event time line (cont. 1986)

Mar
- **21st:** Tyler, Texas, overdose. AECL notified; claims overdose impossible and no other accidents had occurred previously. AECL suggests hospital might have an electrical problem.

Apr
- **7th:** Tyler machine put back in service after no electrical problem could be found.
- **11th:** Second Tyler overdose. AECL again notified. Software problem found.
- **15th:** AECL files accident report with FDA.

May
- **2nd:** FDA declares Therac-25 defective. Asks for CAP and proper renotification of Therac-25 users.
- **13th:** First version of CAP sent to FDA.

Jun
- **23rd:** FDA responds and asks for more information.

Jul
- First user group meeting.
- **26th:** AECL sends FDA additional information.

Aug
- **30th:** FDA requests more information.

Sep
- **12th:** AECL submits revision of CAP.

Nov
- Therac-20 users notified of a software bug.

Dec
- **11th:** FDA requests further changes to CAP.
- **22nd:** AECL submits second revision of CAP.

FDA = US Food and Drug Administration
CAP = Corrective Action Plan

Major event time line (1987)

Jan
- **17th:** Second overdose at Yakima.
- **26th:** AECL sends FDA its revised test plan.

Feb
- Hamilton clinic investigates first accident and concludes there was an overdose.
- **3rd:** AECL announces changes to Therac-25.
- **10th:** FDA sends notice of adverse findings to AECL declaring Therac-25 defective under US law and asking AECL to notify customers that it should not be used for routine therapy. Health Protection Branch of Canada does the same thing. This lasts until August 1987.

Mar
- Second user group meeting.
- **5th:** AECL sends third revision of CAP to FDA.

Apr
- **9th:** FDA responds to CAP and asks for additional information.

May
- **1st:** AECL sends fourth revision of CAP to FDA.
- **26th:** FDA approves CAP subject to final testing and safety analysis.

Jun
- **5th:** AECL sends final test plan and draft safety analysis to FDA.

Jul
- Third user group meeting.
- **21st:** Fifth (and final) revision of CAP sent to FDA.

1988

Jan
- **29th:** Interim safety analysis report issued.

Nov
- **3rd:** Final safety analysis report issued.

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Lessons learned from Therac-25 accident:

- Accidents are seldom simple
- Accidents are often blamed to single source
- Management inadequacies, lack of following incident reports
- Overconfidence in software
- Involvement of management, technicians, users, and government
- Unrealistic risk assessment
- Less-than-acceptable software-engineering practices

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Reasons for low dependability:

- **Chips with everything:**
  Computers are increasingly used for all types of devices and services.
- **Interface design:**
  Complex systems must have a “friendly” interface that is easy to understand and must not confuse or mislead the user.
- **The “system” includes the operator:**
  The total system requires some functions to be carried out by the operator.
- **The “system” includes the documentation:**
  Operator failures may occur due to hard to understand or misleading documentation.
- **The “system” includes its operating procedures:**
  Just as the operator and the documentation are regarded as part of the system, so must the procedures for using it.

Reasons for low dependability (cont.):

- **"System" failures are human failure:**
  Not only the operator, but other humans and ultimately the designer are causing system failures.
- **Complexity:**
  Problem inherent complexity—not solution induced complexity—is hard to handle.
- **System Structure:**
  Unsuitable system structures can lead to low dependability
- **Wrong assessment of peak load scenario:**
  Systems can only be designed to handle a priori known peak load scenarios.
- **Wrong assessment of fault hypothesis:**
  Systems can only be designed to handle a priori known fault hypothesis.

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Reasons for low dependability (cont.):

- **Low dependability of components:**
  "A system is as strong as its weakest link"
- **Misunderstanding of application:**
  Customer and system manufacturer have different understandings of the services
- **Incomplete problem description:**
  Unintended system function due to incomplete problem description
- **Coupling and interactive complexity:**
  cf. next slide
- **Discontinuous behavior of computers:**
  cf. foil after slide
- **No system is fool-proof**

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Concept of coupling and interactive complexity

The concept of coupling and interactive complexity is a model to explain what type of systems are potentially hazardous [Perrow 1984].

- **Tightly coupled systems:**
  In a tightly coupled system components affect one another automatically with great rapidity, so that errors propagate too quickly for a human operator to detect, contain and correct them.
- **Interactive complex systems:**
  In an interactive complex system components interact in many ways simultaneously, so that the behavior of the system (as a whole) is inherently difficult to understand.

Problem of discontinuous behavior

or the Problem of Software

- discrete computers are symbol manipulating machines
- symbols are represented in binary form of 0´s and 1´s
- computers are finite state machines
- large state space (combinatorial explosion)
- mapping of actual state and input to new state
- in contrast to analogue systems there is no continuos trajectory
- discontinuous trajectories are intractable by simple mathematics
- is worse than chaotic behavior (of analog systems)
- continuous or analog systems have an infinite number of stable states while discrete systems have only a small (finite) number of stable states

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