Lecture 1: Why Does Software Fail?

Some background

- What is Software Engineering?
- What causes system failures?
- The role of good engineering practice

Are software failures like hardware failures?

- Shuttle flight STS51-L (Challenger)
- Ariane-5 flight 501

Some conclusions

- e.g. Reliable software has very little to do with writing good programs
- e.g. Humans make mistakes, but good engineering practice catches them!

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Defining Software Engineering

"Engineering…

- …creates cost-effective solutions to practical problems by applying scientific knowledge to building things in the service of humankind"

Software Engineering:

- the "things" contain software (??)

BUT:

- pure software is useless!
  - …software exists only as part of a system
- software is invisible, intangible, abstract
- there are no physical laws underlying software behaviour
- there are no physical constraints on software complexity
- software never wears out
  - …traditional reliability measures don't apply
- software can be replicated perfectly
  - …no manufacturing variability

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Failures and Catastrophes

System Components often fail

- Parts wear out
- Wires and joints come loose
- Cosmic rays scramble your circuits!
- Components get used for things they weren't designed for
- Designs don't work the way they should

Point failures typically don't lead to catastrophe

- backup systems
- fault tolerant designs
- redundancy
- certification using safety factors (eg 2x)

Good Engineering Practice prevents accidents

- failure analysis
- reliability estimation
- checks and balances

But how does this work in *Software* Engineering???

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Shuttle Flight 51-L (Challenger)

Contracts for shuttle awarded 1972:

- Rockwell - Orbiter
- Martin Marietta - external tank
- Morton Thiokol - Solid Rocket Boosters (SRBs)
- Rocketdyne - Orbiter Main engines

3 NASA centers provide management:

- JSC - Manage the orbiter
- Marshall - Manage engines, tank and SRBs
- KSC - Assembly, checkout and launch

4 orbiters were built:

- flights began in '81;
- declared operational July '82 after STS-4
- 24 flights over 57 months up to Dec 1995

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Challenger Disaster

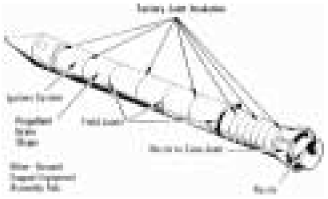
Technical cause:

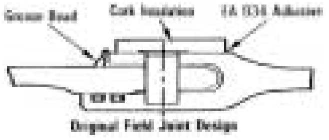
- failure of a pressure seal ("O-ring") in the aft field joint of the right solid rocket motor
- Solid rocket motor assembled from four cylindrical sections, 25 feet long, 12 feet diameter, containing 100 tons of fuel
- 2 O-rings seal gaps in the joints caused by pressure at ignition

Factors:

- temperature: cold reduces resiliency of the O-ring
- chance of O-ring failure increased by test procedures causing blow holes in the putty used to pack the joint

But this was just the point failure…





What really happened?

1977: Tests show rotation of joints causes loss of secondary O-ring as a backup seal

1980: SRB joint classified as criticality 1R

1981-82 Anomalies in O-rings found in initial flights

- but not entered into Marshall's problem assessment system

Dec 82: Tests show secondary O-ring no longer functional under 40% of max operating pressure.

- Criticality changed to 1
- Paperwork after this time still shows SRB joints as 1R

<u>1985</u>

Jan 24: STS 51-C launched in lowest ever temperature: 53°F (≈11°C)

- O-ring erosion worst yet.

Feb 8: Analysis by Thiokol noted risk of O-ring failure

- concluded risk should be accepted because of secondary O-ring.

Leading up to the launch

<u>1985 (cont.)</u>

April 29: STS 51-B:

- primary O-ring never sealed, secondary eroded beyond predicted limits
- as a result, Marshall placed a launch constraint on 51-F and all subsequent flights
- Thiokol were unaware of this constraint (which was waived for each flight thereafter)

July:

- Thiokol engineers set up task force to solve the O-ring problem
- Oct: task force complains of lack of cooperation from management.
- Dec: Thiokol management recommends closure of O-ring problem

Oct/Nov: 61-A & 61-B both experience O-ring problems

<u>1986</u>

51-L Launch originally scheduled for Jan 23rd

- Jan 23: Flight 51-L re-scheduled for 25th
- Jan 25: Unacceptable weather forecast
- Jan 27: countdown halted - jammed exit hatch

Launch re-scheduled for Jan 28th, at 9:38am

- temperature of 27°F (≈-3°C) predicted for launch time
- previous coldest launch: 53°F (≈11°C)

The Launch decision

<u>Jan 27, 1986</u>

2:30pm

- Thiokol engineers express concern at predicted low temp.

5:45pm

- Thiokol presents its concerns to Marshal
- recommends launch should be delayed

8:45pm

- Thiokol re-presents its conclusions to larger meeting
- Marshall criticizes it for changing the launch criteria

10:30pm

- meeting recessed for Thiokol discussion
- engineers express strong objections to launch

11:00pm meeting reconvened

- Thiokol management withdrew objections to launch

<u>Jan 28, 1986</u>

11:39am: flight 51-L launched

- 73 seconds later, Challenger explodes

Report of the Presidential Commission on the Space Shuttle Challenger Accident

William P. Rogers, Chairman (Former Secretary of State under President Nixon 1969-1973, and Attorney General under President Eisenhower 1957-1961)

Lack of trend analysis

Management Structure:

- safety, reliability and QA placed under the organizations they were to check
- organizational responsibility for safety was not adequately integrated with decision-making
- No safety representative at the meetings on 27 Jan.

Problem reporting and tracking

Complacency:

- Escalating risk accepted
- Perception that less safety reliability and QA activity needed once Shuttle missions became routine

Program Pressures were a factor

- Pressure on NASA to build up to 24 missions per year
  - Shortened training schedules, lack of spare parts, and dilution of human resources.
  - Customer commitments may have obscured engineering concerns
- Reduction of skilled personnel

Ariane-5 flight 501

Background

- European Space Agency's reusable launch vehicle
- Ariane-4 a major success
- Ariane-5 developed for larger payloads

Launched

- 4 June 1996

Mission

- $500 million payload to be delivered to orbit

Fate:

- Veered off course during launch
- Self-destructed 40 seconds after launch

Cause:

- Unhandled floating point exception in Ada code

Ariane-5 Events

Locus of error:

- Platform alignment software (part of the Inertial Reference System, SRI)
- This software only produces meaningful results prior to launch
- Still operational for 40 seconds after launch

Cause of error:

- Ada exception raised and not handled:
  - Converting 64-bit floating point to 16-bit signed integer for Horizontal Bias (BH)
- Requirements state that computer should shut down if unhandled exception occurs

Launch+30s: Inertial Reference Systems fail

- Backup SRI shuts down first
- Active SRI shuts down 50ms later for same reason

Launch+31s: On-board Computer receives data from active SRI

- Diagnostic bit pattern interpreted as flight data
- OBC commands full nozzle deflections
- Rocket veers off course

Launch+33s: Launcher starts to disintegrate

- Self-destruct triggered

Why did this failure occur?

Why was Platform Alignment still active after launch?

- SRI Software reused from Ariane-4
- 40 sec delay introduced in case of a hold between -9s and -5s
  - Saves having to reset everything
  - Feature used once in 1989

Why was there no exception handler?

- An attempt to reduce processor workload to below 80%
  - Analysis for Ariane-4 indicated overflow was not physically possible
  - Ariane-5 had a different trajectory

Why wasn't the design modified for Ariane-5?

- Not considered wise to change software that worked well on Ariane-4

Why did the SRIs shut down?

- Assumed faults are random hardware failures, hence should switch to backup

Why was the error not caught in unit testing?

- No trajectory data for Ariane-5 was provided in the requirements for SRIs

Why was the error not caught in integration testing?

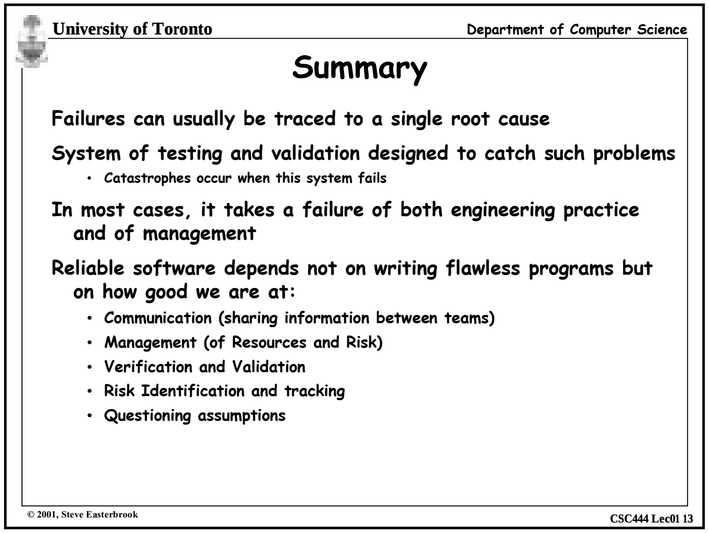
- Full integration testing considered too difficult/expensive
- SRIs were considered to be fully certified
- Integration testing used simulations of the SRIs

Why was the error not caught by inspection?

- The implementation assumptions weren't documented

Why did the OBC use diagnostic data as flight data?

- They assumed this couldn't happen???



Summary

Failures can usually be traced to a single root cause

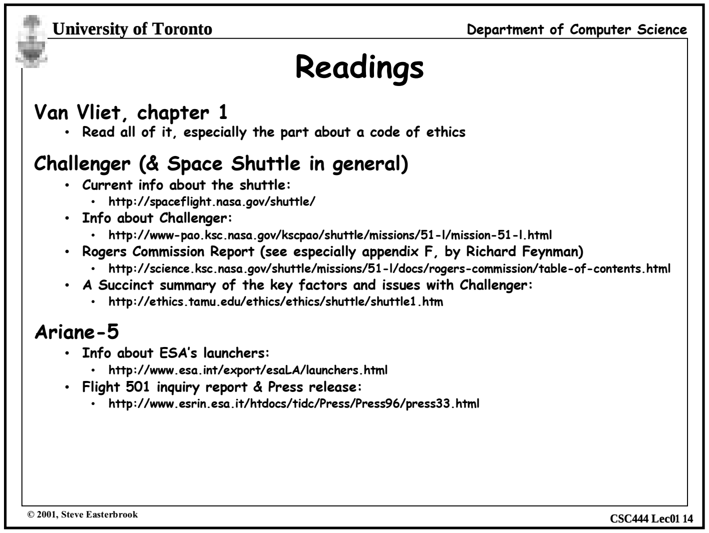
System of testing and validation designed to catch such problems

- Catastrophes occur when this system fails

In most cases, it takes a failure of both engineering practice and of management

Reliable software depends not on writing flawless programs but on how good we are at:

- Communication (sharing information between teams)
- Management (of Resources and Risk)
- Verification and Validation
- Risk Identification and tracking
- Questioning assumptions



Readings

Van Vliet, chapter 1

- Read all of it, especially the part about a code of ethics

Challenger (& Space Shuttle in general)

- Current info about the shuttle:
  - http://spaceflight.nasa.gov/shuttle/
- Info about Challenger:
  - http://www-pao.ksc.nasa.gov/kscpao/shuttle/missions/51-l/mission-51-l.html
- Rogers Commission Report (see especially appendix F, by Richard Feynman)
  - http://science.ksc.nasa.gov/shuttle/missions/51-l/docs/rogers-commission/table-of-contents.html
- A Succinct summary of the key factors and issues with Challenger:
  - http://ethics.tamu.edu/ethics/ethics/shuttle/shuttle1.htm

Ariane-5

- Info about ESA's launchers:
  - http://www.esa.int/export/esaLA/launchers.html
- Flight 501 inquiry report & Press release:
  - http://www.esrin.esa.it/htdocs/tidc/Press/Press96/press33.html