Introduction to Software Testing

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- Why do we test software?
    - 1.1 What is software?
    - 1.2 What is bug?
    - 1.3 Fault, Error and Failure
    - 1.4 Adverse Effects of Faulty Software

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1.1 What is Software ?

➢ A software system usually consists of a number of :

- Instructions within separate programs that when executed give some desired function
- Data structures that enable the programs to adequately manipulate information
- Configuration files which are used to set up these programs
- System documentation which describes the structure of the system
- User documentation which explains how to use the system and web sites for users to download recent product information

Early Days of Software

- Computer-based systems were developed using hardware-oriented management
  - Project managers focused on hardware
  - Project managers applied the controls, methods, and tools that we recognize as hardware engineering

- Programming was viewed as an art form
  - The programmer often learned his craft by trial and error
  - The software world was undisciplined

The Crisis in Software Engineering

- In the 1970's there were a number of problems with software:
  - Projects were running over-budget
  - Projects were running over-time
  - The Software products were of low quality
  - The Software products often did not meet their requirements
  - Projects were chaotic
  - Software maintenance was very difficult

Software Engineering

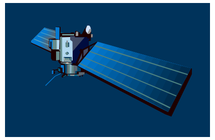
- The actual term Software Engineering was first proposed as far back as 1968 at a conference held to discuss “software crisis”
  - Individual approaches to program development did not scale up to large and complex software systems.
  - These were unreliable, cost more than expected, and were delivered late.

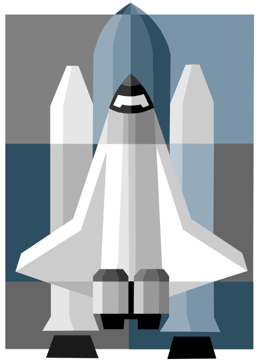
- A variety of new software engineering techniques and methods were developed
  - Structured programming, Information Hiding , Object-Oriented Development
  - Software Modeling, Software Development Process , Project Management
  - Tools and standard notations that were developed at that time are now extensively used

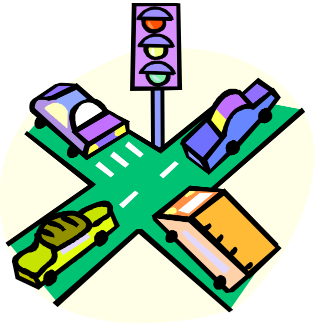
Software in the 21st Century

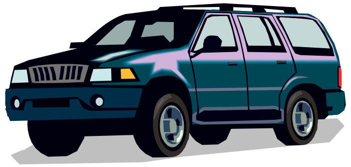
- Software defines behavior
  - Servers, Storage, Network routers, Switching networks, other Infrastructure
- Today’s software market :
  - much bigger
  - more competitive
  - more users
- Embedded Control Applications
  - Airplanes, air traffic control
  - Spaceships
  - Watches
  - Ovens
  - Remote Controllers
- Agile processes put increased pressure on testers to assure the software quality

Software is a Skin that Surrounds Our Civilization









Quote due to Dr. Mark Harman

Software in the 21st Century

- More safety critical, real-time software
  - Embedded software is ubiquitous … check your pockets
  - Enterprise applications means bigger programs, more users
  - Paradoxically, free software increases our expectations

- The web offers a new deployment platform
  - Very competitive and very available to more users
  - Web apps are distributed
  - Web apps must be highly reliable

- Security is now all about software faults
  - Secure software is reliable software

Industry desperately needs our inventions !

Industry is going through a revolution in what testing means to the success of software products

Quality and Software

- There are risks associated with Software Development
  - Modern programs are complex and have ten thousands of lines of code
  - The customer's requirements can be vague, lacking in exactness
  - Deadlines and budgets put pressure on the development team

- The combination of these factors can lead to a lack emphasis being placed on the final quality of the software product
  - Poor quality can result in software failure resulting in high maintenance costs and long delays before the final deployment
  - The impact on the business can be loss of reputation, legal claims, decrease in market share

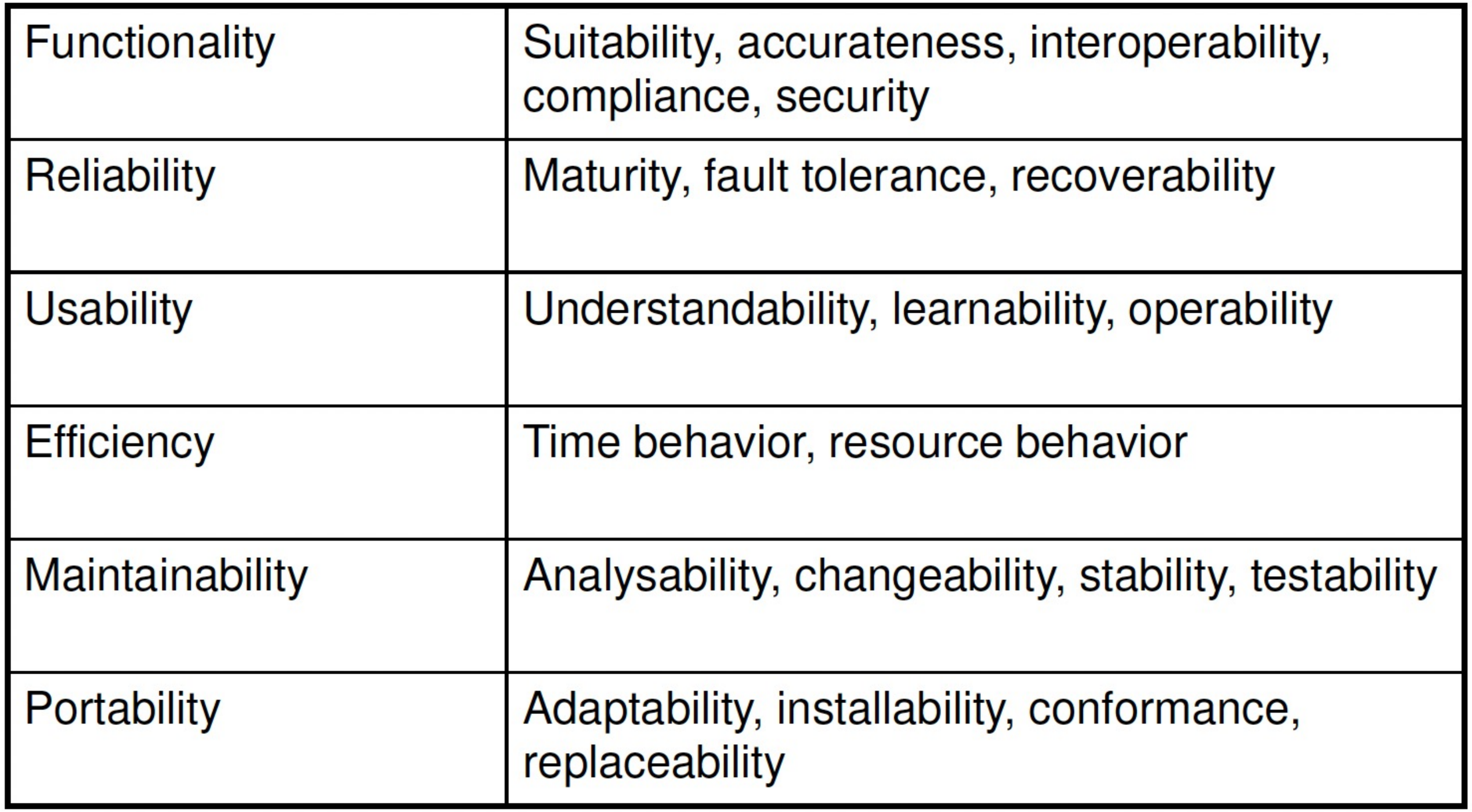
ISO 9126-1 Software Engineering – Product Quality

- The quality model was structured around six main attributes and its subcharacteristics

- Quality can be measured using a mix of objective and subjective metrics
  - provide consistent terminology for software product quality
  - provide a framework for specifying quality requirements for software and making trade-offs between software product capabilities

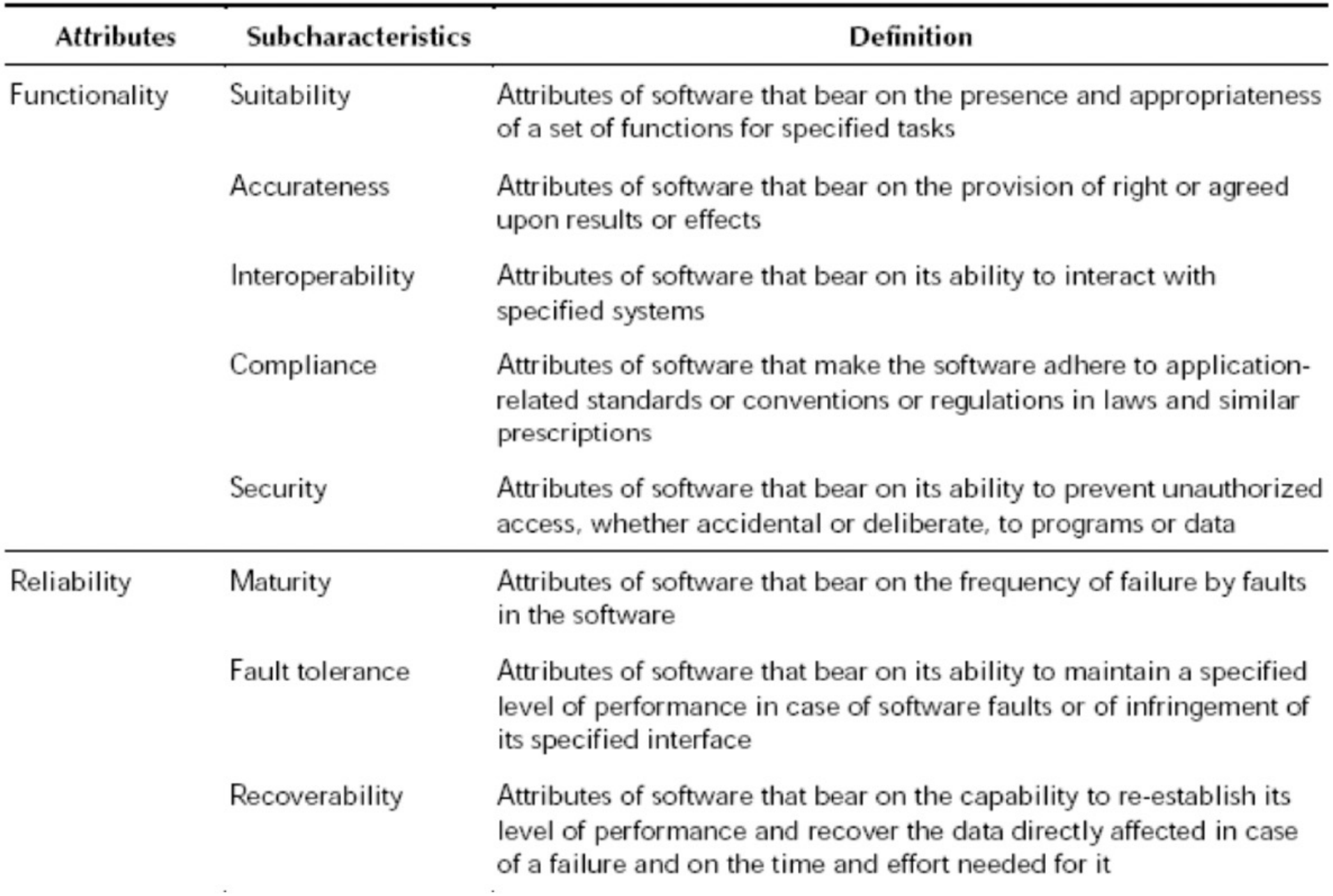
- Be applicable to every kind of software
  - including computer programs and data contained in firmware

ISO 9126-1 Product Quality – Six Attributes



Functionality	Suitability, accurateness, interoperability, compliance, security
Reliability	Maturity, fault tolerance, recoverability
Usability	Understandability, learnability, operability
Efficiency	Time behavior, resource behavior
Maintainability	Analysability, changeability, stability, testability
Portability	Adaptability, installability, conformance, replaceability

ISO 9126-1 Product Quality – Detailed description



Attributes	Subcharacteristics	Definition
Functionality	Suitability	Attributes of software that bear on the presence and appropriateness of a set of functions for specified tasks
	Accurateness	Attributes of software that bear on the provision of right or agreed upon results or effects
	Interoperability	Attributes of software that bear on its ability to interact with specified systems
	Compliance	Attributes of software that make the software adhere to application-related standards or conventions or regulations in laws and similar prescriptions
	Security	Attributes of software that bear on its ability to prevent unauthorized access, whether accidental or deliberate, to programs or data
Reliability	Maturity	Attributes of software that bear on the frequency of failure by faults in the software
	Fault tolerance	Attributes of software that bear on its ability to maintain a specified level of performance in case of software faults or of infringement of its specified interface
	Recoverability	Attributes of software that bear on the capability to re-establish its level of performance and recover the data directly affected in case of a failure and on the time and effort needed for it

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1.2 What is Bug ?

- What is your understanding for Bug?
  - They think...(0.33min)
- Bugs a.k.a. …

- Defect
- Fault
- Problem
- Error
- Incident
- Anomaly
- Variance

- Failure
- Inconsistency
- Product Anomaly
- Product Incidence
- Feature :-)

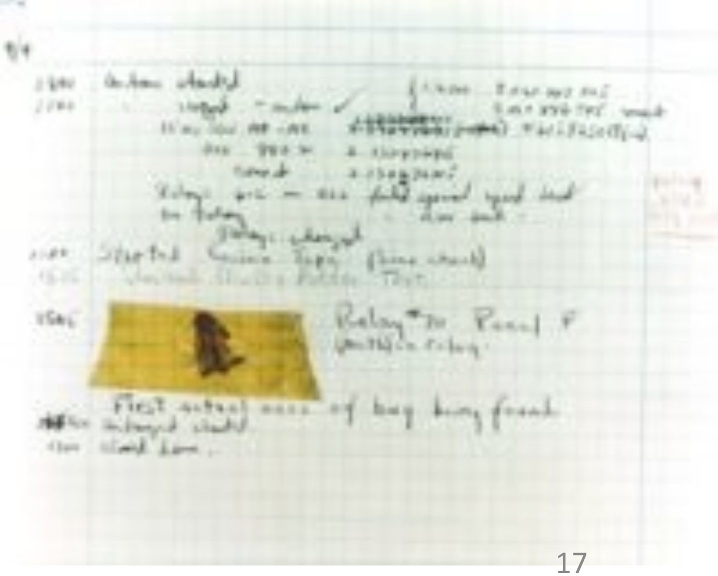
The term *Bug* is used *informally*

Where is *Bug* from ?

- Bug story (03:35 min)

- In 1947 Grace Hopper was operating a room-sized computer called the Mark II in Harvard University .
  - mechanical relays
  - glowing vacuum tubes
  - technicians program the computer by reconfiguring it
  - Technicians had to change the occasional vacuum tube.
- A moth flew into the computer and was zapped by the high voltage when it landed on a relay.

Hence, the first computer bug!



9/9

[illegible]

1100 Started Cosine Tape (Sine check)

[illegible] Test.

1545 Relay #70 Panel F (moth) in relay.

First actual case of bug being found.

[illegible]

Where is *Bug* from ?

- Grace Hopper (01:15min)
  - Distinguished Mathematician and computer scientist
  - Rear Admiral in the U.S. Navy
  - ” *The first Lady of Software* ”

- Programing Accomplishments
  - Discovered the first Bug
  - Created the biggest Bug - Y2K
  - Created the first Compiler A-0 for computer languages
  - Developed the first commercial programming language

    COBOL(Common Business-Oriented Language)
  - Defined the model for high-level programming languages

Dec.9,1906 ~ Jan.1,1992

Grace Hopper and the Invention of the Information Age

Where is *Bug* from ?

- Grace Hopper
  - Encouraging young people to learn how to program
- The Grace Hopper Celebration (GHC)
  - The world’s largest conference of women in technology
- Quotes

“People have an enormous tendency to resist change. They love to say, 'We've always done it this way.' I try to fight that.” —Grace Hopper

“Compiling in '51, nobody believed that. I had a running compiler and nobody would touch it, because, they carefully told me, computers could only do arithmetic, they could not write programs. It was a selling job to get people to try it.” —Grace Hopper

“I tell everybody, 'Go ahead and do it. You can always apologize later.’” —Grace Hopper

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1.3 Fault, Error and Failure

- Use Terms that have precise, defined, and unambiguous meanings

Software Fault : A static **defect** in the software

Software Failure : **External, incorrect behavior** with respect to the requirements or other description of the expected behavior

Software Error : An **incorrect internal state** that is the manifestation of some fault

Sometimes *bug* mean fault, sometimes error, sometimes failure
… often the speaker doesn’t know what it means !

Faults, Errors and Failures Example

A patient gives a doctor a list of symptom	Failure
The doctor tries to diagnose the root cause, the ailment	Fault
The doctor may look for anomalous internal conditions (high blood pressure, irregular heartbeat, bacteria in the blood stream)	Errors

Difference :

Most medical problems result from external attacks (bacteria, viruses) or physical degradation as we age.

Software faults were there at the beginning and do not “appear” when a part wears out.

Faults in software are equivalent to design mistakes in hardware.

A Concrete Example

Fault: Should start searching at 0, not 1

```
public static int numZero (int [ ] arr)
{  // Effects: If arr is null throw NullPointerException
   // else return the number of occurrences of 0 in arr
   int count = 0;
   for (int i = 1; i < arr.length; i++)
   {
     if (arr [ i ] == 0)
     {
       count++;
     }
   }
   return count;
}
```

Test 1

[2, 7, 0]

Expected: 1

Actual: 1

Error: i is 1, not 0, on the first iteration

Failure: none

Test 2

[0, 2, 7]

Expected: 1

Actual: 0

Error: i is 1, not 0

Error propagates to the variable count

Failure: count is 0 at the return statement

PIE Model

A test may not execute the location of the fault !

Execution/Reachability:
The location or locations in the program that contain the faults must be reached

A test executing the fault may not produce an error!

Infection:
The state of the program must be incorrect

An error may not be propagate to the output !

Propagation :
The infected state must propagate to cause some output of the program to be incorrect .

PIE Model

- Execution
- Infection
- Propagation

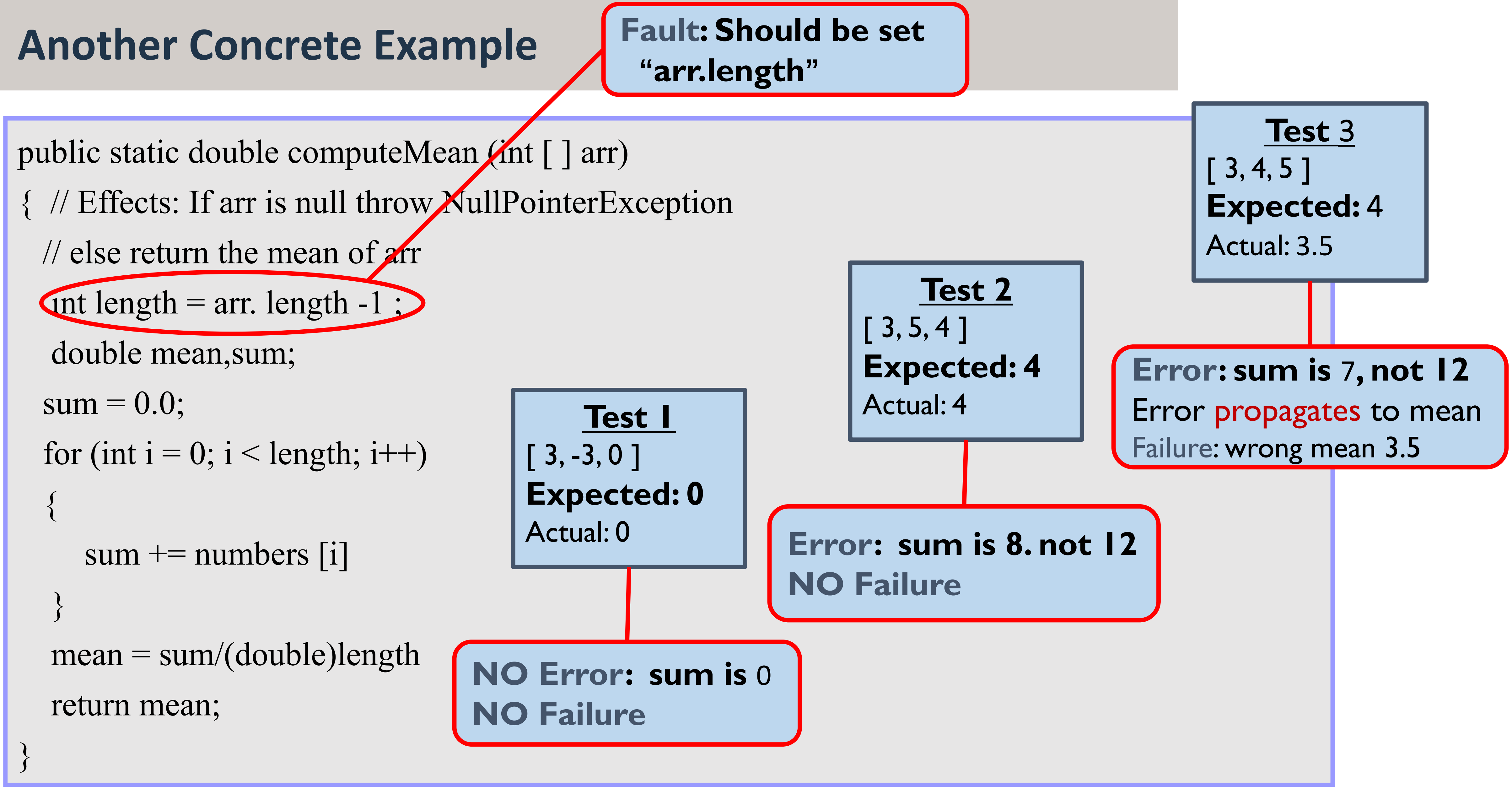
- Fault
- Error
- Failure

Discussion:

Could you construct a simple program *P* (with a fault) and 3 tests , s.t.

1) T1 executes the fault , but no error;
2) T2 executes the fault and produces an error, but no failure;
3) T3 produces a failure.

Another Concrete Example



```
public static double computeMean (int [ ] arr)
{  // Effects: If arr is null throw NullPointerException
   // else return the mean of arr
    int length = arr. length -1 ;
    double mean,sum;
   sum = 0.0;
   for (int i = 0; i < length; i++)
   {
       sum += numbers [i]
    }
    mean = sum/(double)length
    return mean;
}
```

Fault: Should be set "arr.length"

Test 1
[3, -3, 0]
Expected: 0
Actual: 0

NO Error: sum is 0
NO Failure

Test 2
[3, 5, 4]
Expected: 4
Actual: 4

Error: sum is 8. not 12
NO Failure

Test 3
[3, 4, 5]
Expected: 4
Actual: 3.5

Error: sum is 7**, not 12**
Error propagates to mean
Failure: wrong mean 3.5

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1.4 Software Faults -Categories

Algorithmic faults

Algorithmic faults are the ones that occurs when a unit of the software does not produce a correct output corresponding to the given input under the designated algorithm

Syntax Faults

These occur when code is not in conformance to the programming language specification, (i.e. source code compiled a few years back with older versions of compilers may have syntax that does not conform to present syntax checking by compilers (because of standards conformity).

Software Faults -Categories

Documentation faults

Incomplete or incorrect documentation will lead to Documentation faults

Stress or overload faults

Stress or Overload faults happens when data structures are filled past their specific capacity where as the system characteristics are designed to handle no more than a maximum load planned under the requirements

Capacity and boundary faults

Capacity or Boundary faults occur when the system produces an unacceptable performance because the system activity may reach its specified limit due to overload

Computation and precision faults

Computation and Precision faults occur when the calculated result using the chosen formula does not confirm to the expected accuracy or precision

Software Faults -Categories

Throughput or performance faults

This is when the developed system does not perform at the speed specified under the stipulated requirements

Recovery faults

This happens when the system does not recover to the expected performance even after a fault is detected and corrected

Timing or coordination faults

These are typical of real time systems when the programming and coding are not commensurate to meet the co-ordination of several concurrent processes or when the processes have to be executed in a carefully defined sequence

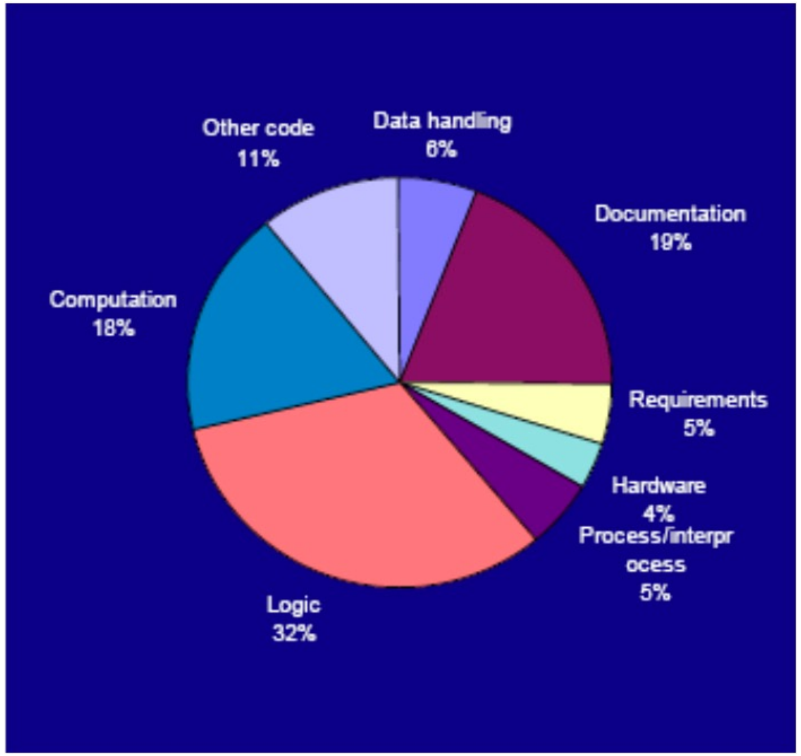
Software Faults -Categories

Standards and Procedure Faults

Standards and Procedure faults occur when a team member does not follow the standards deployed by the organization which will lead to the problem of other members having to understand the logic employed or to find the data description needed for solving a problem.

Software Faults

- A study by Hewlett Packard on the frequency of occurrence of various fault types, found that 50% of the faults were either Algorithmic or Computation and Precision



Software Failures

- Failures can be classified by their severity

Level 1. Failure causes a system *crash* and the recovery time is extensive; or failure causes a loss of function and data and there is no workaround

Level 2. Failure causes *a loss of function or data* but there is manual workaround to temporarily accomplish the tasks

Level 3. Failure causes *a partial loss of function or data* where user can accomplish most of the tasks with a small amount of workaround

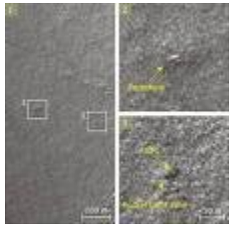
Level 4. Failure causes cosmetic and *minor inconveniences* where all the user tasks can still be accomplished

Adverse Effects of Faulty Software

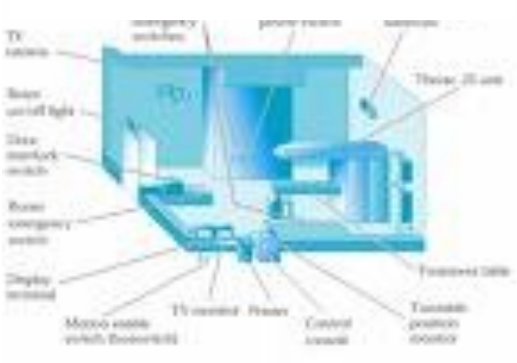
- Communications: Loss or corruption of communication media, non delivery of data.
- Space Applications: Lost lives, launch delays.
- Defense and Warfare: Misidentification of friend or foe.
- Transportation: Deaths, delays, sudden acceleration, inability to brake.
- Safety-critical Applications: Death, injuries.
- Electric Power: Death, injuries, power outages, long-term health hazards (radiation).
- Money Management: Fraud, violation of privacy, shutdown of stock exchanges and banks, negative interest rates.
- Control of Jails: Technology-aided escape attempts and successes, accidental release of inmates, failures in software controlled locks.
- …….

Spectacular Software Failures

- NASA's Mars lander: September 1999, crashed due to a units integration fault



Mars Polar Lander crash site?



THERAC-25 design

- THERAC-25 radiation machine : Poor testing of safety-critical software can cost *lives* : 3 patients were killed
- Ariane 5 explosion : Millions of $$
- Intel's Pentium FDIV fault : Public relations nightmare

Ariane 5: exception-handling bug : forced self destruct on maiden flight (64-bit to 16-bit conversion: about 370 million $ lost)

We need our software to be dependable

Testing is *one* way to assess dependability

Spectacular software Failures

- Boeing A220 : Engines failed after software update allowed excessive vibrations
- Boeing 737 Max : Crashed due to overly aggressive software flight overrides (MCAS)

- Toyota brakes : Dozens dead, thousands of crashes

- Healthcare website : Crashed repeatedly on launch—never load tested

- Northeast blackout : 50 million people, $6 billion USD lost … alarm system failed

Software testers try to find faults before the faults find users

Northeast Blackout of 2003

508 generating units and 256 power plants shut down

Affected 10 million people in Ontario, Canada

Affected 40 million people in 8 US states

Financial losses of $6 Billion USD

The alarm system in the energy management system failed due to a software error and operators were not informed of the power overload in the system

Costly Software Failures

- NIST report, “The Economic Impacts of Inadequate Infrastructure for Software Testing” (2002)
  - Inadequate software testing costs the US alone between $22 and $59 billion annually
  - Better approaches could cut this amount in half
- Huge losses due to web application failures
  - Financial services : $6.5 million per hour (just in USA!)
  - Credit card sales applications : $2.4 million per hour (in USA)
- In Dec 2006, *amazon.com’s* BOGO offer turned into a double discount
- 2007 : Symantec says that most security vulnerabilities are due to faulty software

World-wide monetary loss due to poor software is staggering

What Does This Mean?

Software testing is getting more important

What are we trying to do when we test ?

What are our goals ?

Discussion

- Have you heard of other faulty software ?
  - In the media?
  - From personal experience?
- Does this embarrass you as a future software engineer?