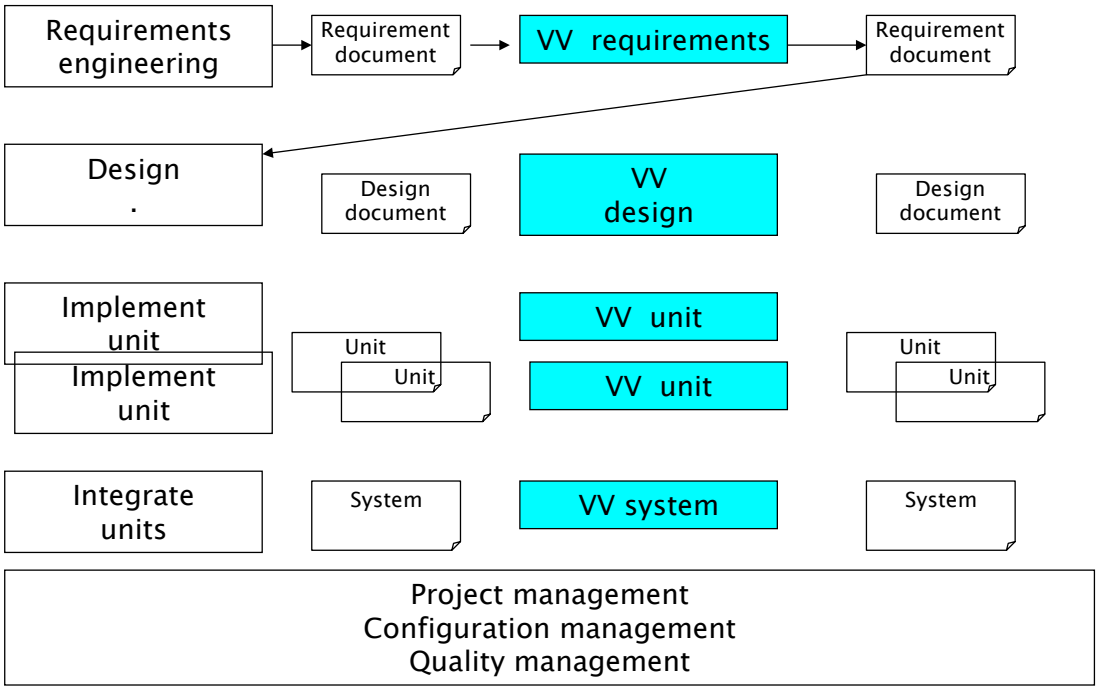
V&V

Version 1.9, May 2013

The whole picture



V&V

- Validation
  - is it the right software system?
  - effectiveness
  - external (vs user)
  - reliability
- Verification
  - is the software system right?
  - efficiency
  - internal (correctness of vertical transformations)
  - correctness

Scenario1 in a dev process

- Stakeholder
  - Real need: big car /6 seats
- Developers
  - R1: compact car (4 seats)
  - Result : compact car (4 seats)
    - Verification: passed
    - Validation : not passed

Scenario2 in a dev process

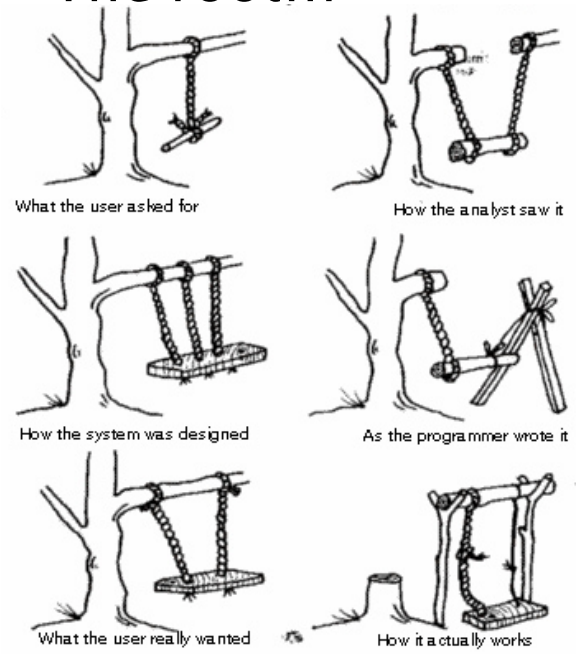
- Stakeholder
  - Real need: big car /6 seats
- Developers
  - R1: big car (6 seats)
  - Result : big car (6 seats)
    - Verification: passed
    - Validation : passed

Scenario3 in a dev process

- Stakeholder
  - Real need: big car /6 seats
- Developers
  - R1: big car (6 seats)
  - Result : compact car (4 seats)
    - Verification: not passed
    - Validation : passed

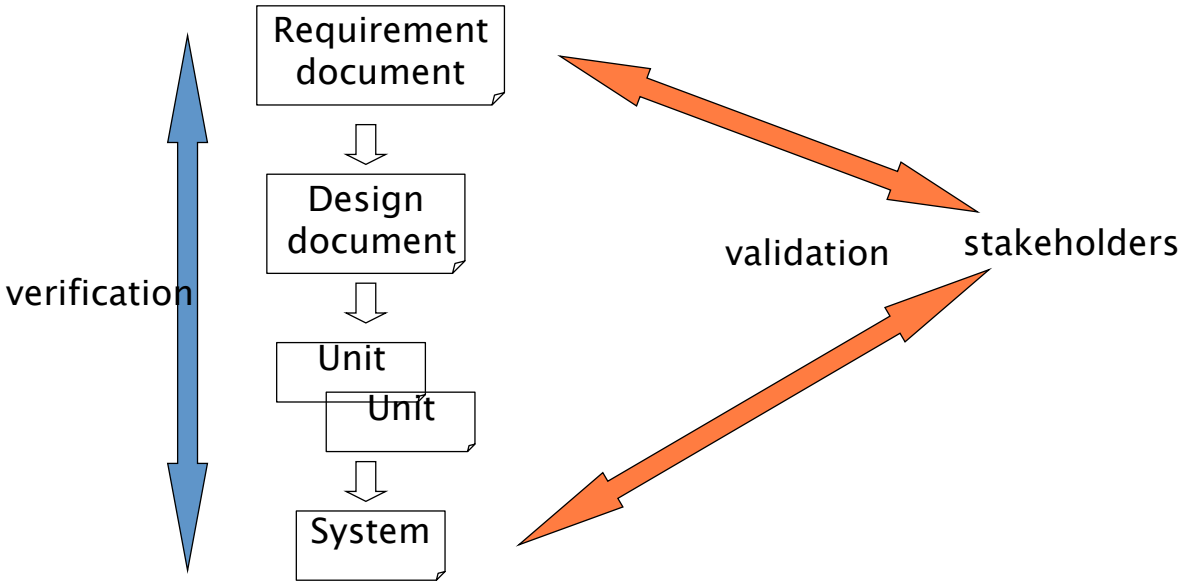
Requirements

- The root…



…of all evils

V & V



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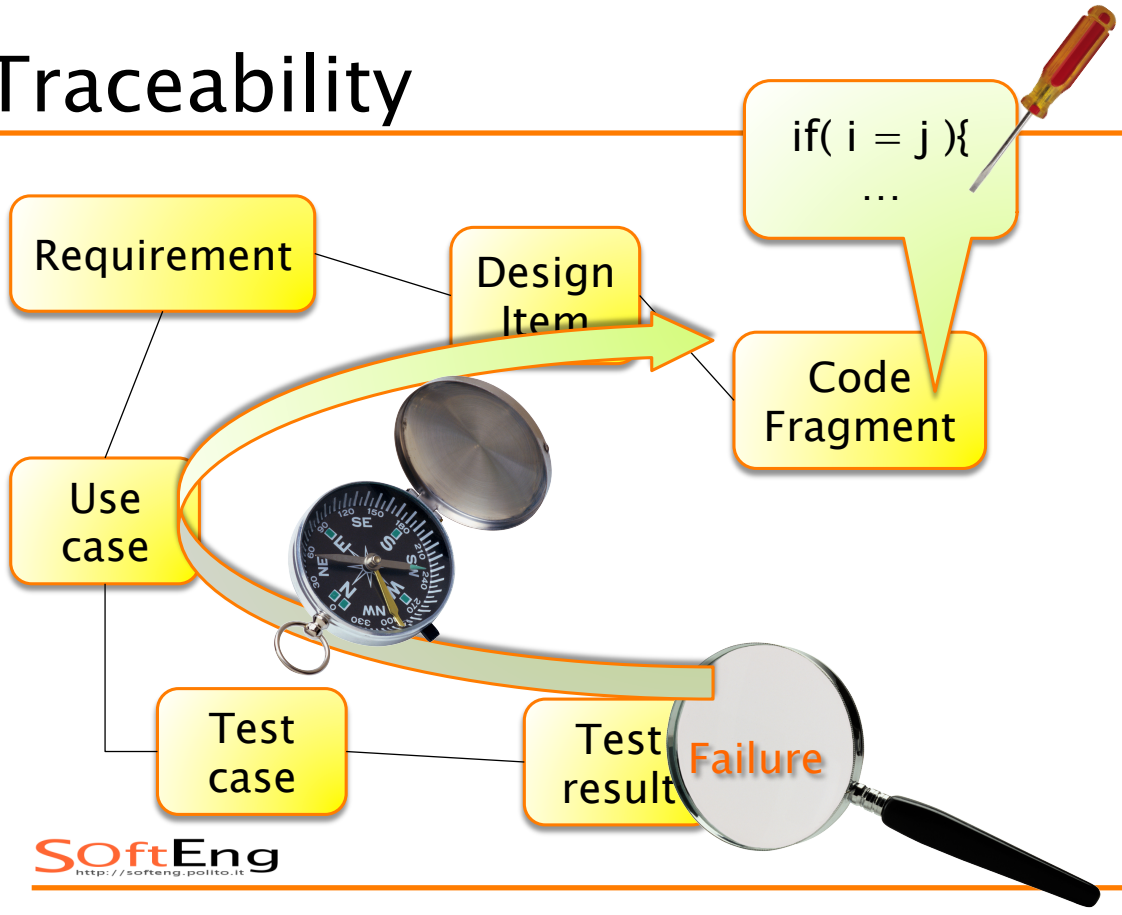
Traceability



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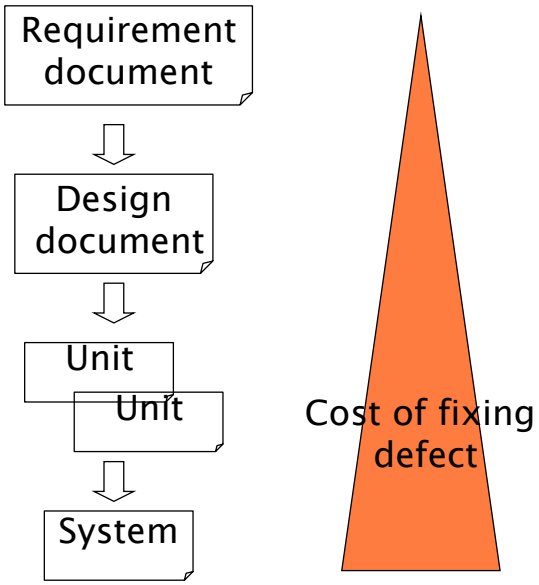
V & V vs. cost of fixing defect



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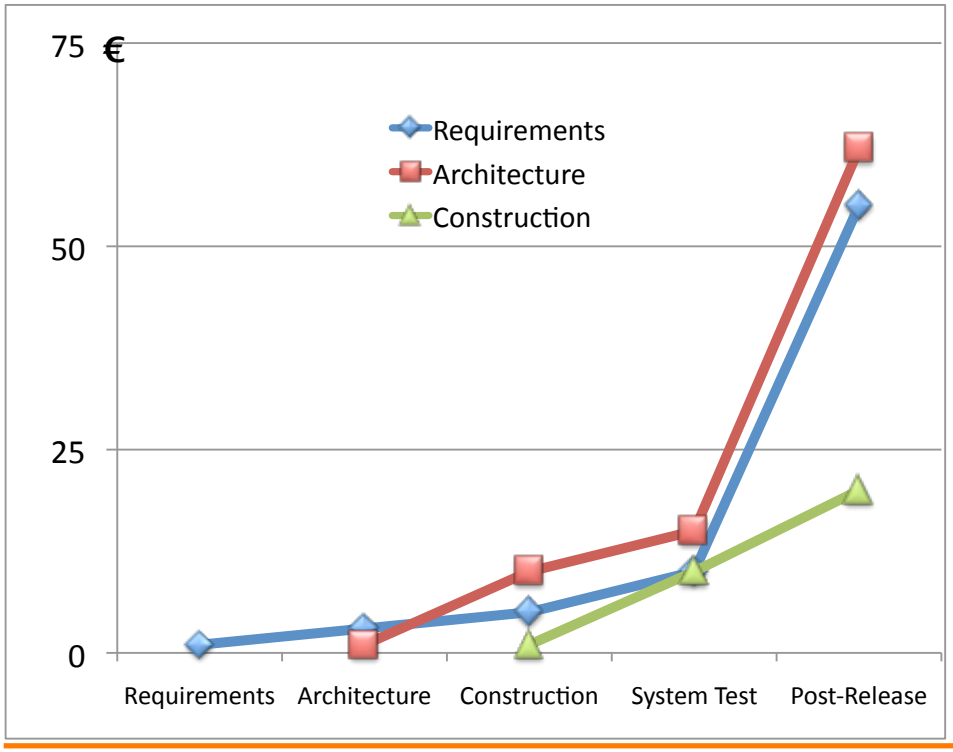
Cost of detection delay



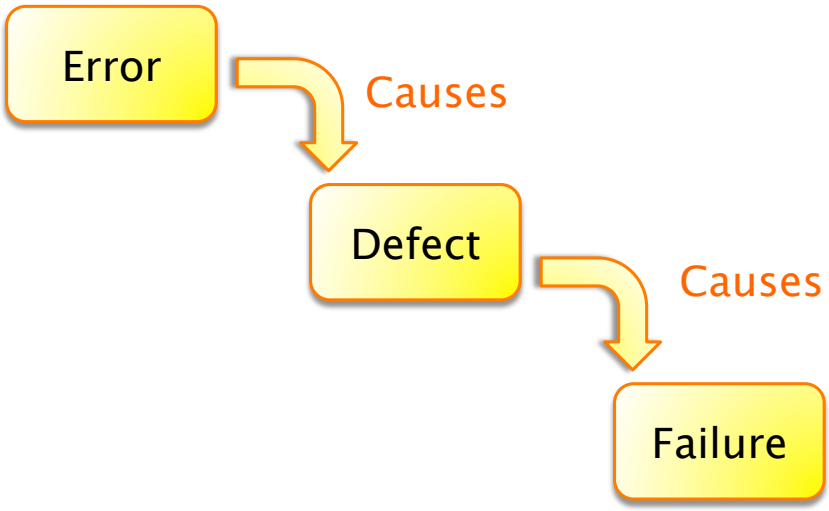
Failure, fault, defect

- Failure
  - An execution event where the software behaves in an unexpected way
- Fault
  - The feature of software that causes a failure
  - May be due to:
    - An error in software
    - Incomplete/incorrect requirements
- Defect
  - Failure or fault

Failure, fault, defect

- Error
  - A mistake e.g. committed by a programmer
- Fault or Defect or Bug
  - The feature of software that causes a failure
  - The result of an error
- Failure
  - An execution event where the software behaves in an unexpected way

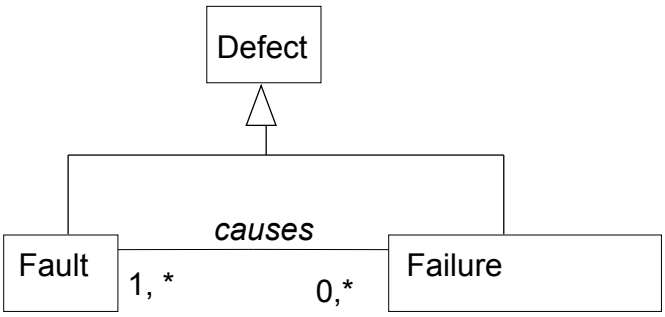
Error Defect Failure



Bicycle

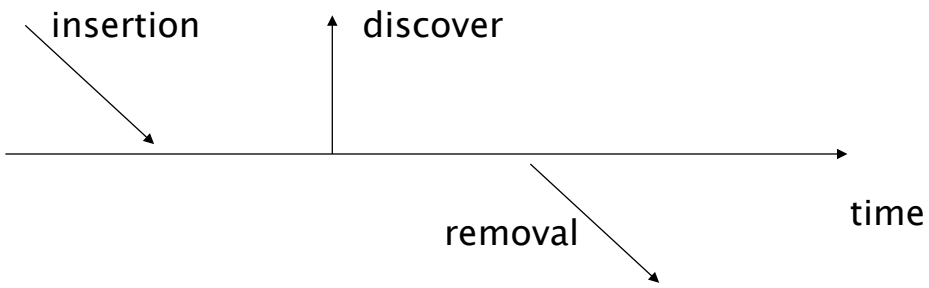
- Failure — Requirements
  - User falls down — R1 transport person
  - R1 not satisfied
- Why?
- Fault — Design
  - Hole in tyre — component fails

Failure fault defect



Insertion / removal

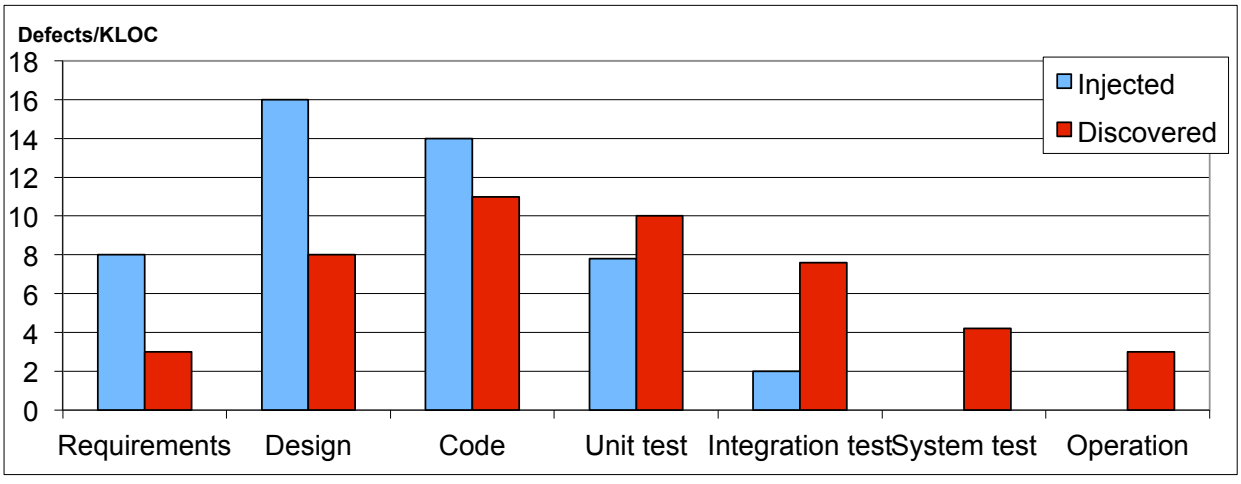
- Defect is characterized by
  - Insertion activity (phase)
  - Removal activity (phase)



Basic goal of VV

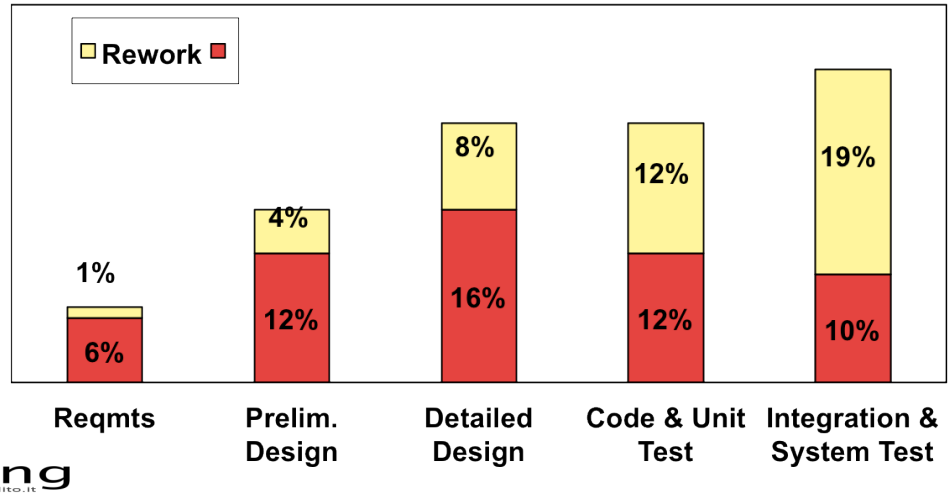
- Minimize number of defects inserted
  - Cannot be zero due to inherent complexity of software
- Maximize number of defects discovered and removed
- Minimize time span between insertion and discover and removal

Insertion/removal by phase – typical scenario



Rework Problem

- The longer the delay insert-remove, the higher the cost of removing defect
- Avoidable rework accounts for 40-50% of development [Boehm, 1987; Boehm&Basili, 2001]
  - More recent data available at www.cebase.org



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Basic goal of VV

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V&V techniques

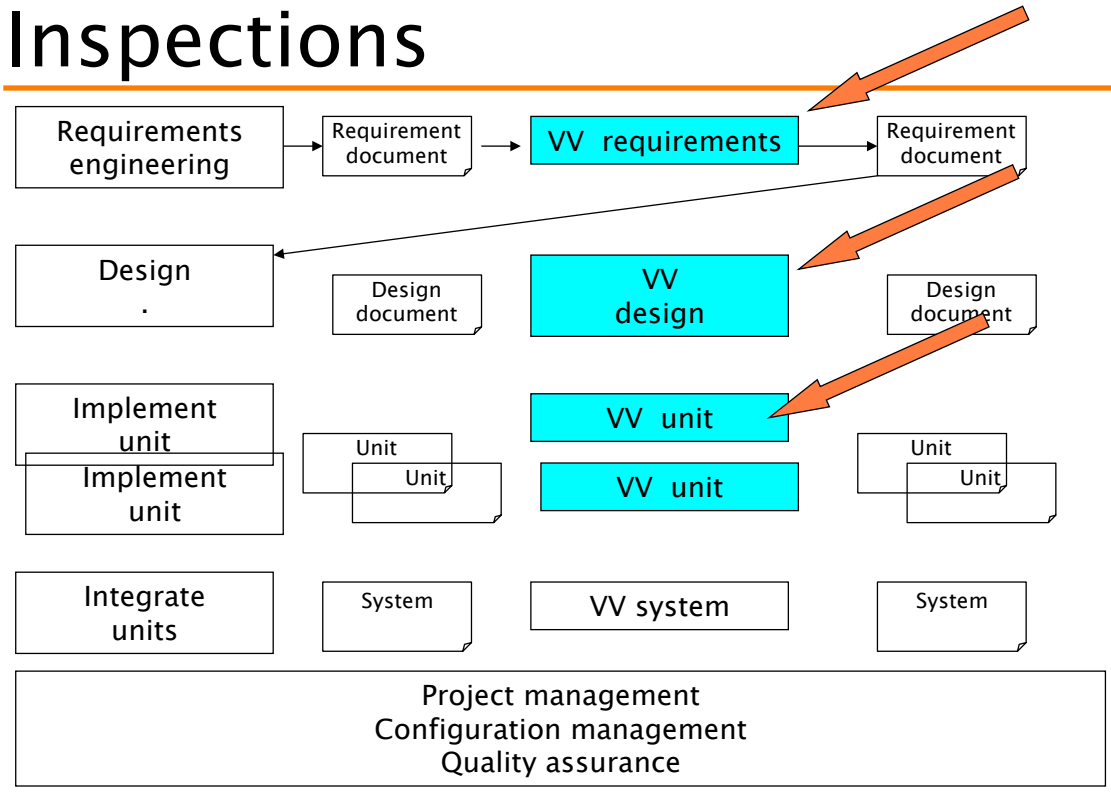
- Static
  - inspections
  - source code analysis
- Dynamic
  - testing

INSPECTIONS

Inspections

- Static
  - inspections
  - source code analysis
- Dynamic
  - testing

Inspections



Inspection

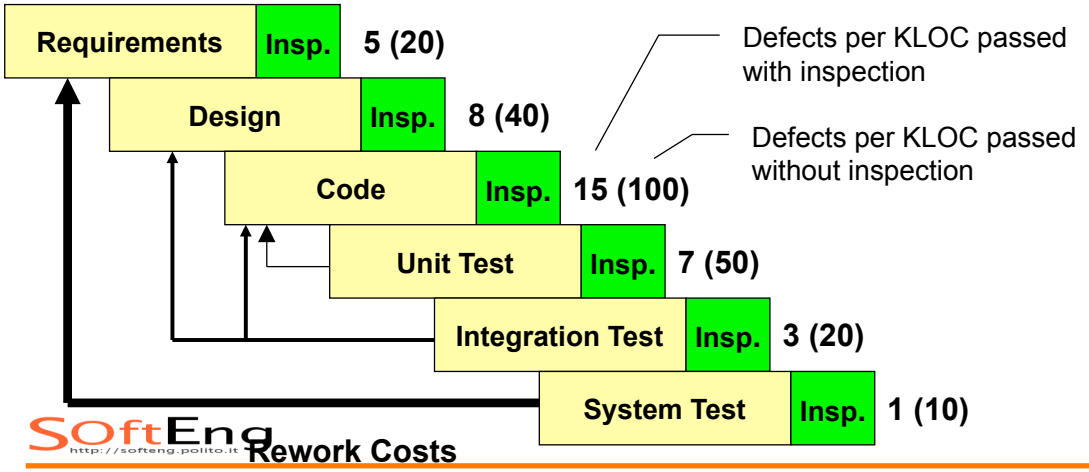
- Consists in
  - reading documents/code
  - By a group of people (3+, group dynamics)
  - With goal of finding defects (no correction)
- Variants of inspections
  - Reading techniques, walkthroughs, reviews
- Can find many defects
  - Test concentrates one defect at a time

Inspection

- Advantages
  - Can be applied to documents
    - Requirements, design, test cases, ..
  - Can be applied to code
    - Does not require execution environment
  - Is very effective
    - Reuses experience and know of people on domain and technologies
    - Has more global view (vs test: one defect at a time)
    - Uses group dynamics
- Limits
  - More suitable for functional aspects
  - Requires time (effort and calendar time)

Benefits

- Early defect detection improves product quality and reduces avoidable rework (down to 10-20%)
  - Data from industry averages [Capers Jones, 1991]
    - more data available at www.cebase.org



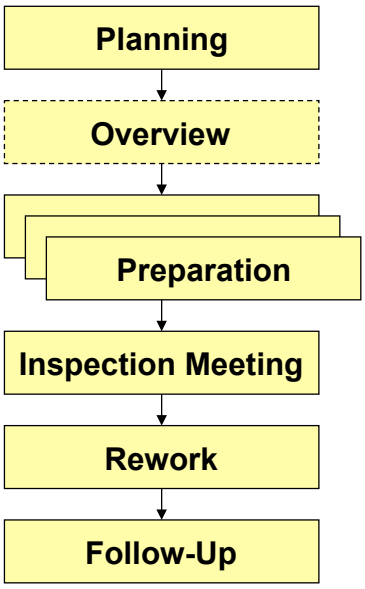
Inspection vs. testing

- Complementary techniques
  - Both should be used in V and V

Roles in group

- Moderator:
  - Leads inspection process and notably inspection meeting
    - Selects participants, prepares material
    - Usually not from project that produces document to be inspected
- Readers:
  - Read document to be inspected
- Author
  - Answers to questions that arise
- Scribe
  - Writes inspection log

Fagan Inspection Process



- Select team, arrange materials, schedule dates
- Present process, product
- *Become familiar with the product*
- **Team analysis to find defects**
- Correct defects
- Verify fixes, collect data

Inspectors are often unprepared. How to make visible the quality of preparation?

Process

- Overview
  - Quickly present inspection to group goals and document to be inspected
- Preparation
  - Read individually (applying inspection technique)
- Meeting
  - Group reads, discusses issues, agrees on problems. Scribe logs problems. Moderator keeps focus, keeps pace, stops (long) discussions
- Rework
  - Author fixes defects/problems
- Follow up
  - Repeat inspection or close and pass to next phase

Prerequisites for successful inspections

- Commitment from management
  - Effort invested upfront, that "does not produce anything"
- Find defects, not fix them
- Document under inspection meets quality standards
- Results not used to evaluate people (and notably author)
- Constructive approach
  - Group aims to produce best possible document
    - No "kill the author" game
    - No "relax and chat" meetings

Rates (code inspections)

- 500 LOC/hour (overview)
- 125 LOC/hour (preparation)
- 90-125 LOC/hour (meeting)
  - Ex. 500 LOCs, 4 people, 40 person hours
    - Overview 1hr X 4= 4person hours
    - Preparation 4hr X 4 = 16 person hours
    - Meeting 5hr X 4 = 20 person hours

Techniques

- Depend on document to be inspected
- Ad hoc (code, requirements, design)
  - Just read it
- Defect taxonomy (code, requirements, design)
  - Categories of common defects
- Checklist (code, requirements, design)
  - Questions/controls to be applied
- Code
  - Author or reader 'executes' code
  - Reader reconstructs goal of code from code
  - Reader defines and applies some test cases
- Requirements
  - Scenario based reading
    - Defect based
    - Perspective based

Defect Taxonomies for Requirements

One level
[Basili et al., 1996]

- Omission
- Incorrect Fact
- Inconsistency
- Ambiguity
- Extraneous Information

Two levels
[Porter et al., 1995]

- Omission
  - Missing Functionality
  - Missing Performance
  - Missing Environment
  - Missing Interface
- Commission
  - Ambiguous Information
  - Inconsistent Information
  - Incorrect or Extra Functionality
  - Wrong Section

Checklists for Requirements

- Based on past defect information
- Questions refine a defect taxonomy

[Ackerman et al., 1989]

- Completeness
  1. Are all sources of input identified?
  …
  12. For each type of run, is an output value specified for each input value?
  …
- Ambiguity
  18. Are all special terms clearly defined?
  …
- Consistency
  …

Checklists for code

- Depends on programming language
- Depends on previous results of inspections

Fault class	Inspection check
Data faults	Are all program variables initialised before their values are used? Have all constants been named? Should the lower bound of arrays be 0, 1, or something else? Should the upper bound of arrays be equal to the size of the array or Size - 1? If character strings are used, is a delimiter explicitly assigned?
Control faults	For each conditional statement, is the condition correct? Is each loop certain to terminate? Are compound statements correctly bracketed? In case statements, are all possible cases accounted for?
Input/output faults	Are all input variables used? Are all output variables assigned a value before they are output?
Interface faults	Do all function and procedure calls have the correct number of parameters? Do formal and actual parameter types match? Are the parameters in the right order? If components access shared memory, do they have the same model of the shared memory structure?
Storage management faults	If a linked structure is modified, have all links been correctly reassigned? If dynamic storage is used, has space been allocated correctly? Is space explicitly de-allocated after it is no longer required?
Exception management faults	Have all possible error conditions been taken into account?

Inspection checks

Scenario based reading

- Ask inspectors to create an appropriate abstraction
  - Help to understand the product
- Ask inspectors to answer a series of questions tailored to the abstraction Inspectors follow different scenarios each focusing on specific issues

Defect-Based Reading

[Porter et al., 1995]

- A scenario-based reading technique to detect defects in requirements expressed in a formal notation (SCR)
- Each scenario focuses on a specific class of defects
  - data type inconsistencies
  - incorrect functionality
  - ambiguity/missing functionality

Excerpt from incorrect functionality scenario

1. *For each functional requirement identify all input/output data objects: questions ...*
2. *For each functional requirement identify all specified system events: (a) Is the specification of these events consistent with their intended interpretation?*
3. *Develop an invariant for each system mode: questions ...*

Perspective-Based Reading

[Basili et al., 1996]

- A scenario-based reading technique to detect defects in requirements expressed in natural language
  - extended later for design and source code
- Each scenario focuses on reviewing the document from the point of view of a specific stakeholder
  - User (abstraction required: user tasks descriptions)
  - Designer (abstraction required: design)
  - Tester (abstraction required: test suite)

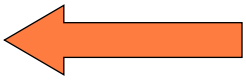
  For each requirement/functional specification, generate a test or set of tests that allow you to ensure that an implementation of the system satisfies the requirement/functional specification. Use your standard test approach and technique, and incorporate test criteria in the test suite. In doing so, ask yourself the following questions for each test:

  questions ...

TESTING

Testing

- Static
  - inspections
  - source code analysis
- Dynamic
  - testing



Testing

- Dynamic technique, requires execution of executable system or executable unit
  - system test
  - unit test

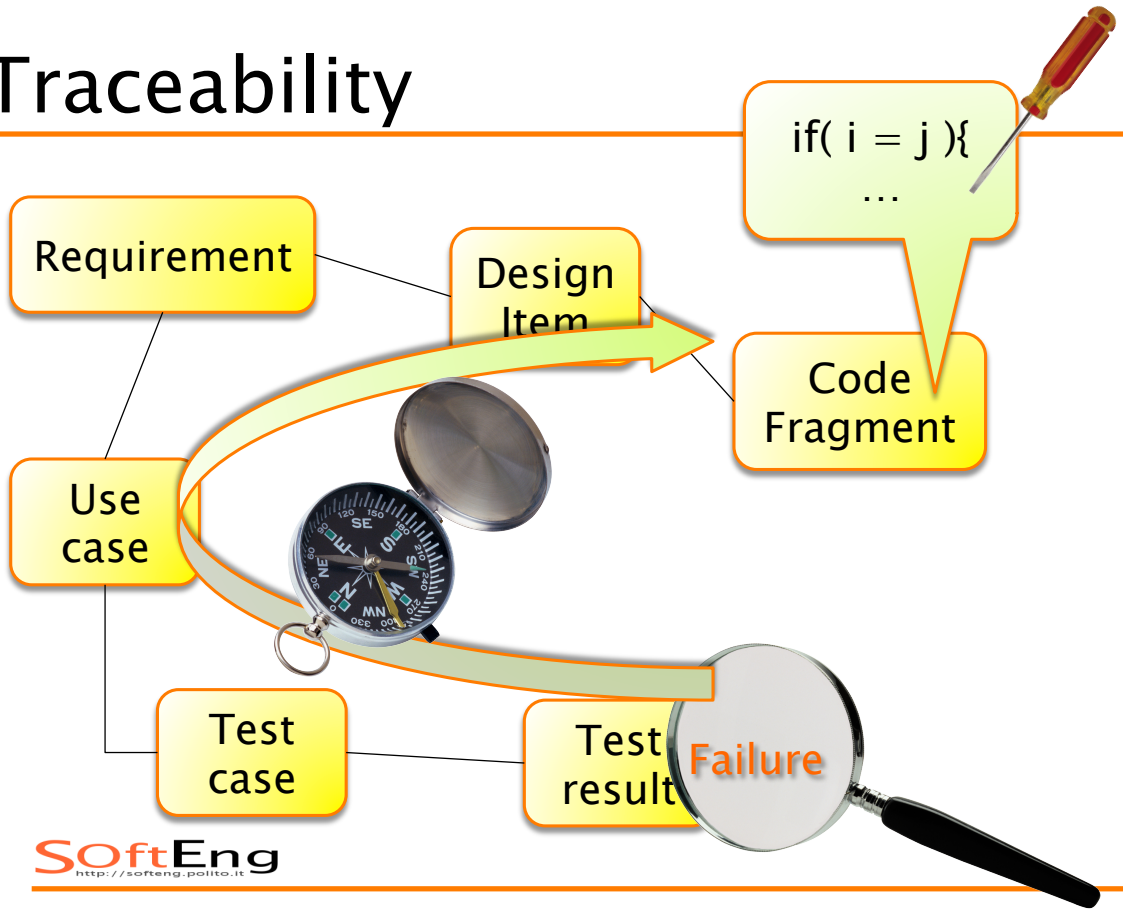
Purpose of test

- The purpose of testing process is to find defects in the software products
  - A test is successful if it reveals a defect
- The process of operating a system or component under specified conditions observing or recording the results to detect the differences between actual and required behavior (= failures)

Testing vs. debugging

- Defect testing and debugging are different activities
  - May be performed by different roles in different times
- Testing tries to find failures
- Debugging searches for and removes the fault

Traceability



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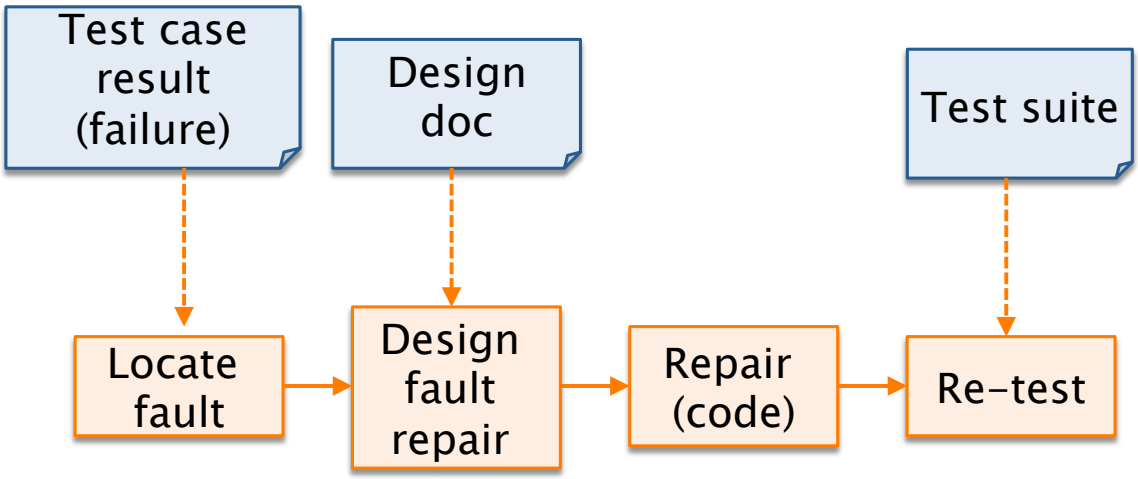
Debugging



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Test case

- Certain stimulus applied to executable (system or unit), composed of
  - name
  - input (or sequence of)
  - expected output
- With defined constraints/context
  - ex. version and type of OS, DBMS, GUI ..

Test suite

- Set of (related) test cases

Test case log

- Test case ref. +
  - Time and date of application
  - Actual output
  - Result (pass / no pass)

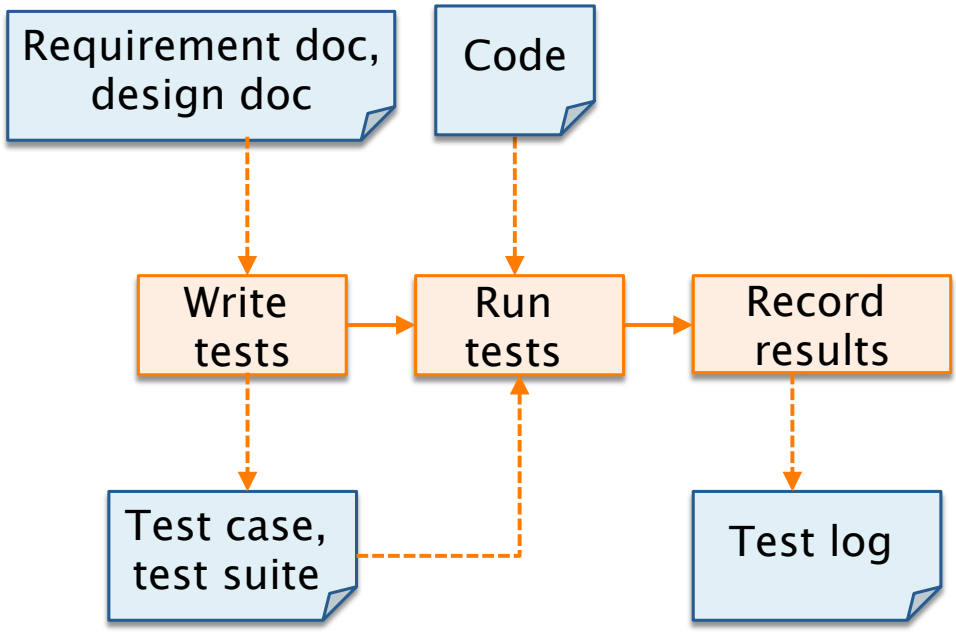
Ex.

- Function **`add(int x, int y)`**
- Test case:
  - T1(1,1; 2)
  - T2(3,5; 8)
- Test suite
  - TS1{T1, T2}
- Test log
  - T1, 16-3-2013 9:31, result 2, success
  - T2, 16-3-2013 9:32, result 9, fail

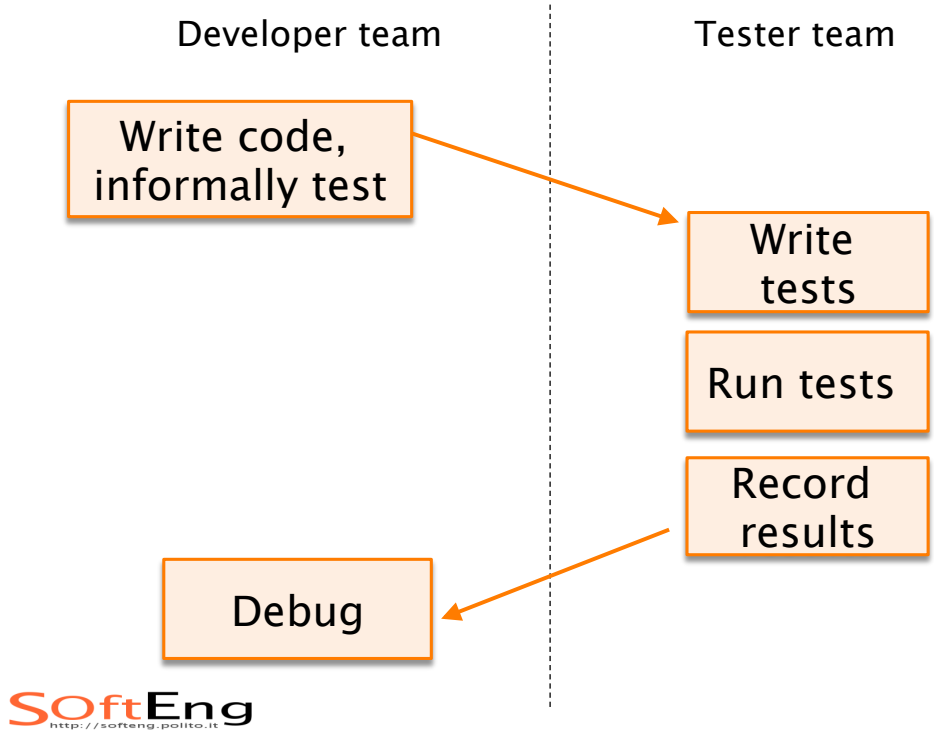
Test activities

- Write test cases
  - Test case, test suite
- Run test case (test suite)
- Record results
  - Test case log

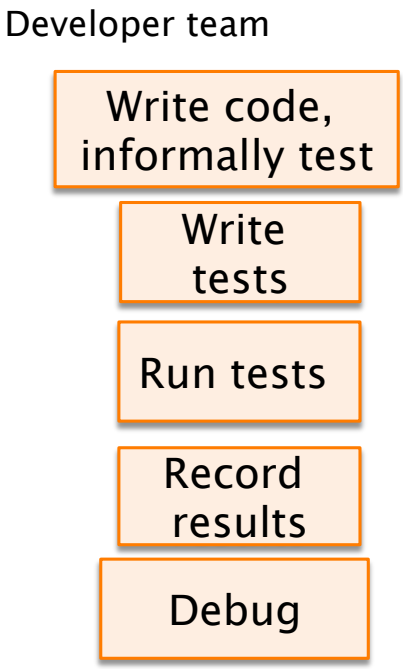
Test activities



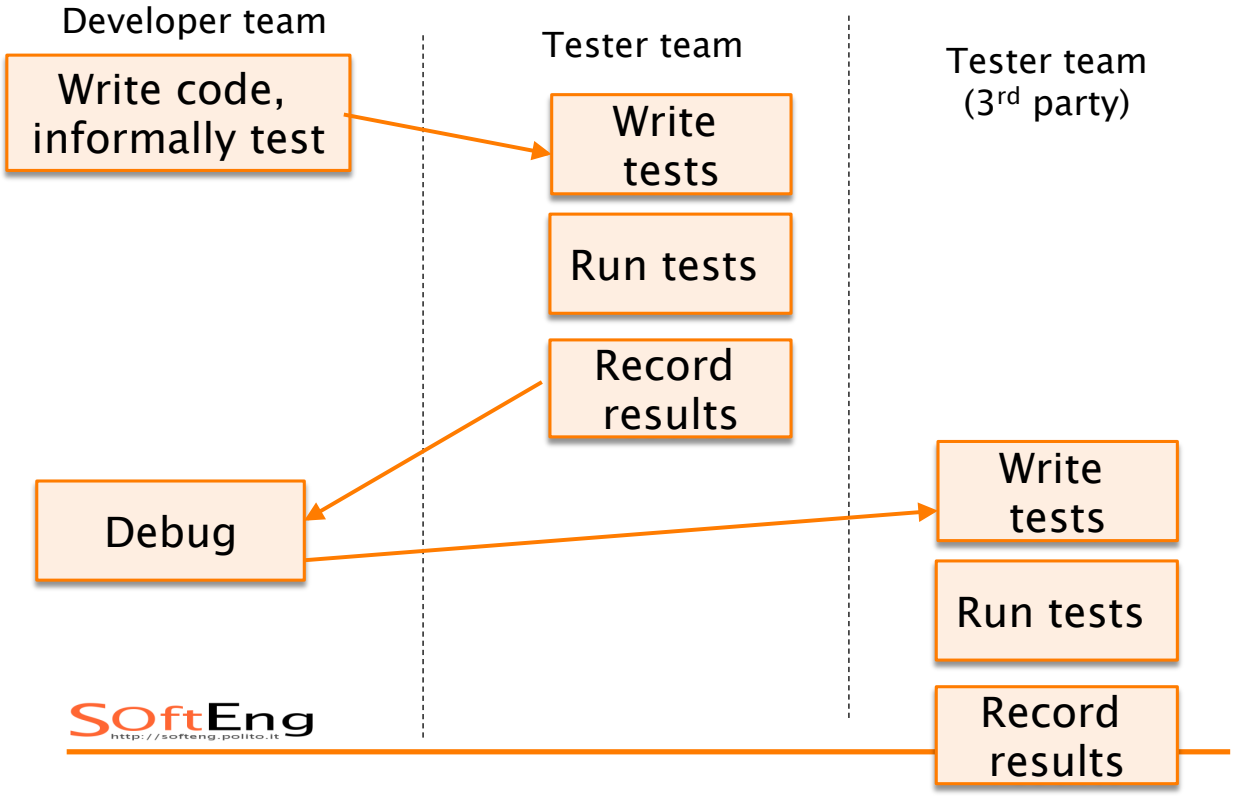
Possible scenario



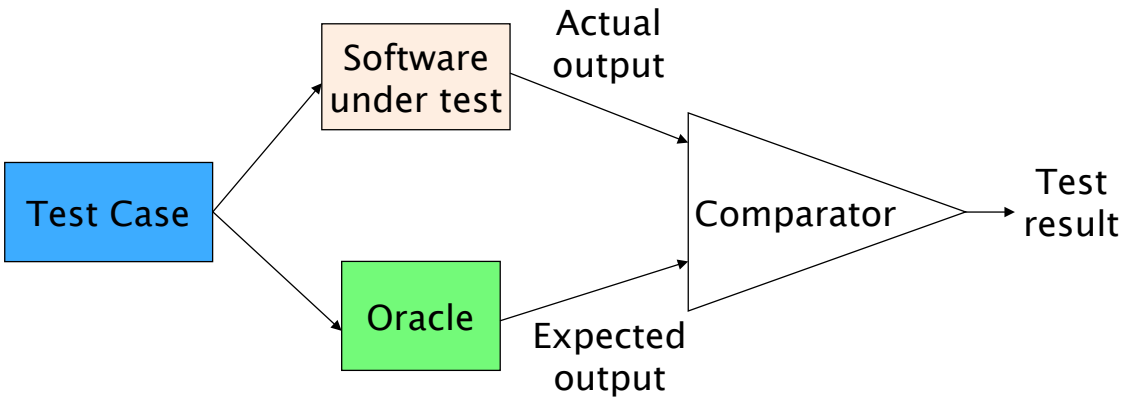
Scenario 2



Scenario 3



Oracle



Oracle

- The ideal condition would be to have an automatic oracle and an automatic comparator
  - The former is very difficult to have
  - The latter is available only in some cases
- A human oracle is subject to errors
- The oracle is based on the program specifications (which can be wrong)

Oracle

- Necessary condition to perform testing:
  - Know the expected behavior of a program for a given test case (oracle)
- Human oracle
  - Based on req. specification or judgment
- Automatic oracle
  - Generated from (formal) req. specification
  - Same software developed by other parties
  - Previous version of the program (regression)

Theory and constraints

Exhaustive test

Correctness

- Correct output for all possible inputs
- Requires exhaustive testing

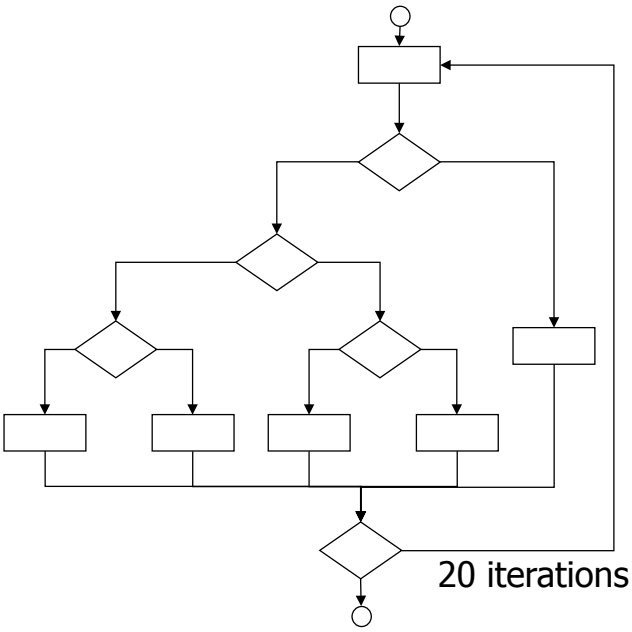
Exhaustive test

- function: Y = A + B
- A and B integers, 32 bit
- Total number of test cases : $2^{32} * 2^{32} = 2^{64} \approx 10^{20}$
- 1 ms/test ⇒ 3 billion years

Pentium case – 1994

- Error in division function
- 1 case in 9 billion

Exhaustive test



- 5 possible paths per iteration
- 20 iterations
- Overall: $5^{20} \approx 10^{14}$ possible paths
- 1 ms/test $\Rightarrow$ 3170 years

Exhaustive test

- Exhaustive test is not possible
- So, goal of test is finding defects, not demonstrating that systems is defect free
- Goal of test (and VV in general) is assuring a *good enough* level of confidence

Dijkstra thesis

- *Testing can only reveal the presence of errors, never their absence*

E. W. Dijkstra. Notes on Structured Programming.
In *Structured Programming,* O.-J. Dahl, E. W. Dijkstra, and C. A. R. Hoare, Eds. Academic, New York, 1972, pp. 1-81.

Basic concepts

- D: program domain (input)
- d ∈ D, P(d) is the program output
- OK(d) ⇔ P(d) corresponds to oracle
- Test: T ⊆ D
- SUCC(T) ⇔ ∀ t ∈ T, OK(t)

J. B. Goodenough and S. L. Gerhart. Toward a Theory of Test Data Selection. *IEEE Transactions on Software Engineering,* June 1975, pp. 26–37.

Criteria

- Tests can be selected by means of different criteria
- C : selection criterion for tests
- COMPLETE(T,C): T is selected by C

Validity

- $\exists d \in D, \neg OK(d) \Rightarrow (\exists T \subseteq D)$ COMPLETE(C,T) $\wedge$ $\neg$SUCC(P,T))

- *Valid Criterion:*
  - *C* is *valid* if and only if whenever *P* is incorrect *C* selects at least one test set *T* which is not successful for *P.*

Reliability

- $\forall T1, \forall T2 \subseteq D,$ COMPLETE(C,T1) $\wedge$ COMPLETE(C,T2)) $\Rightarrow$ SUCC(T1) $\Leftrightarrow$ SUCC(T2)

- *Reliable Criterion:*
  - *C* is *reliable* if and only if either every test selected by *C* is successful or no test selected is successful.

Fundamental theory

- Theorem

$(\exists T \subseteq D)(COMPLETE(T,C) \wedge RELIABLE(C) \wedge VALID(C) \wedge SUCC(T)) \Rightarrow (\forall d \in D)OK(d)$

- The success of a test T selected by a reliable and valid criterion implies the correctness of T

Uniformity

- Criterion uniformity focuses on program specification
  - Not only program
- A criterion *C* is uniformly valid and uniformly reliable if and only if *C* selects only the single test set $T = D$

E. J. Weyuker and T. J. Ostrand. Theories of Program Testing and the Application of Revealing Subdomains. *IEEE Transactions on Software Engineering,* May 1980, pp. 236–246.

Howden theorem

- For an arbitrary program P it is impossible to find an algorithm that is able to generate a finite ideal test (that is selected by a valid and reliable criterion)

W.Howden. Reliability of the Path Analysis Testing Strategy. IEEE Transactions of Software Engineering, 2(3), September 1976, pp. 208-215

Brainerd Landweber

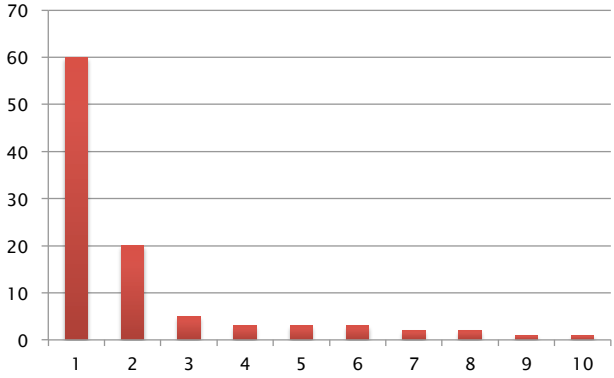
- Given two programs the problem of deciding whether they compute the same function is indecidible
- Therefore even if we have access to the archetype program we cannot demonstrate the equivalence of a new program

Weinberg's law

- A developer is unsuitable to test his/her own code
- Testing should be performed by
  - A separate QA team
  - Peers
- If a developer misunderstands a problem, he cannot find such error

Pareto-Zipf law

- Approximately 80% of defects come from 20% of modules
- It is better to concentrate on the faulty modules



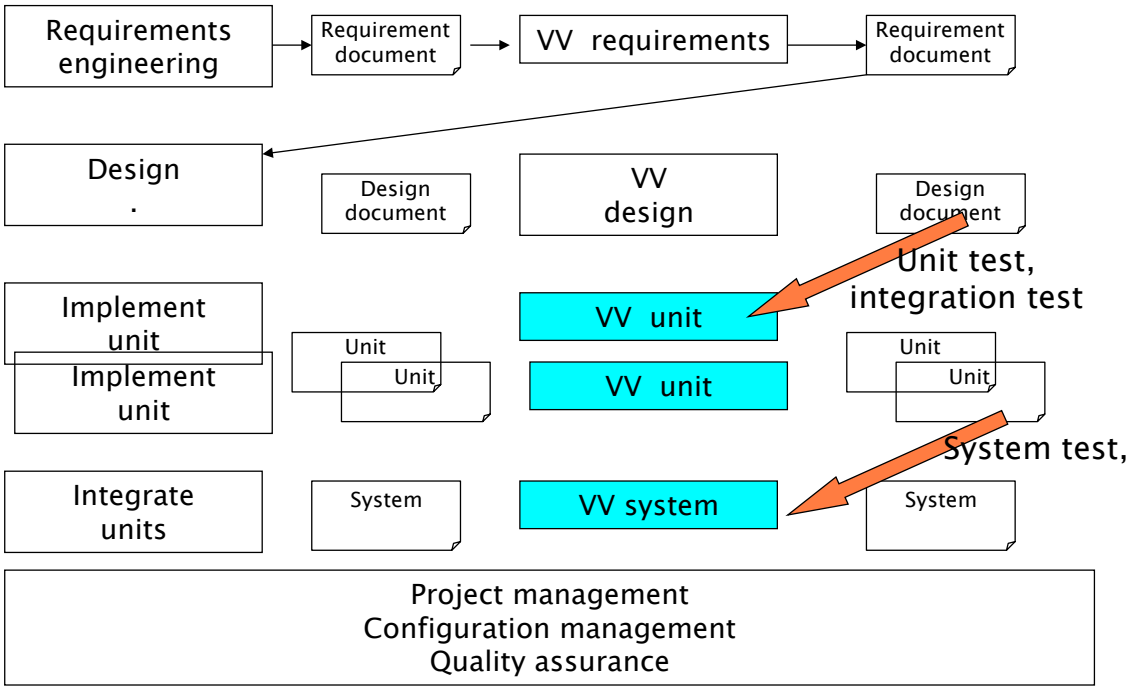
Test classification

- Per phase/granularity level
  - Unit, integration, system
  - Regression
- Per approach
  - Black box (functional)
  - White box (structural)
  - Reliability assessment/prediction
  - Risk based (safety security)

Test per granularity level/phase

- Unit tests
  - Individual modules
- Integration tests
  - Modules when working together
- System tests
  - The system as a whole (usable system)

Test per phase



Test per approach

- Given an object/artifact to test, approach can be
  - Requirements driven
    - Are the requirements of the object satisfied?
  - Structure
    - Is the object built as it should?
  - Reliability / statistic
    - Does it satisfy the customer need? (use most common operational scenarios)
  - Risk
    - Is it vulnerable to most likely risks?

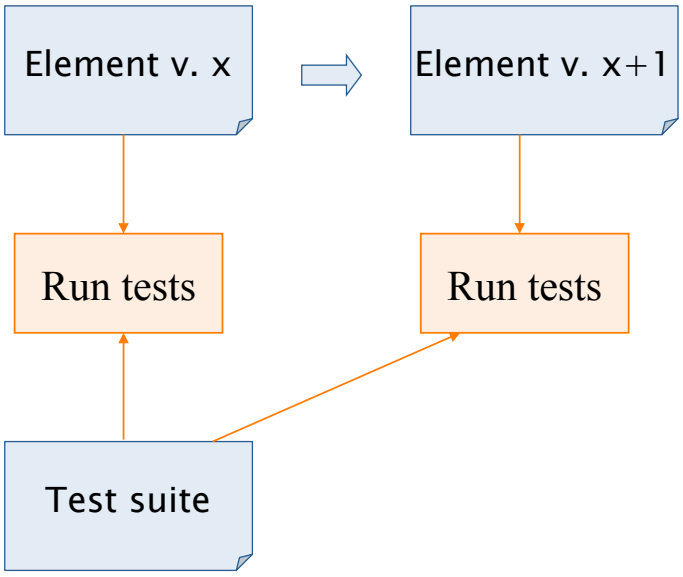
Testing classification (2)

	Phase		
	Unit	Integration	System
Functional / black box	X	X	X
Structural / white box	X		
Reliability			X
Risks			X

Test classification and coverage

Approach	Testing phase: Unit testing	Integration testing	System testing
Requirements-driven	100% unit reqs	100% product reqs	100% system reqs
Structure-driven	85% paths	100% modules	100% components
Statistics-driven			90-100% of usage profiles
Risk-driven	As required	As required	100% if required

Regression testing



UNIT TEST

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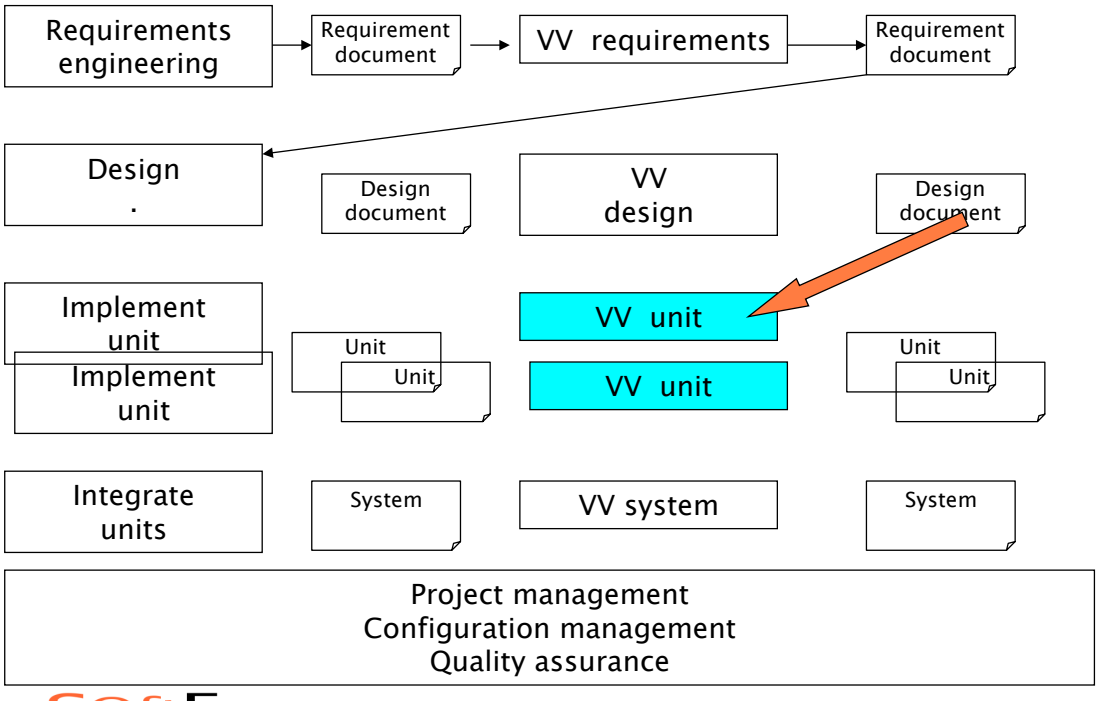
Unit Test



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Unit test

- Black box (functional)
  - Random
  - Equivalence classes partitioning
  - Boundary conditions
- White Box (structural)
  - Coverage of structural elements

UNIT TEST – BLACK BOX

Random

- Function **`double squareRoot(double x)`**
  - Extract randomly x
    - T1 (3.0 ; $\sqrt{3}$)
    - T2 (1000.8 ; $\sqrt{1000.8}$)
    - T3 (-1223.7; error)
- Function **`double invert(double x)`**
  - Extract randomly x
    - T1 (1.0 ; 1.0)
    - T2 (-2.0 ; -0.5)

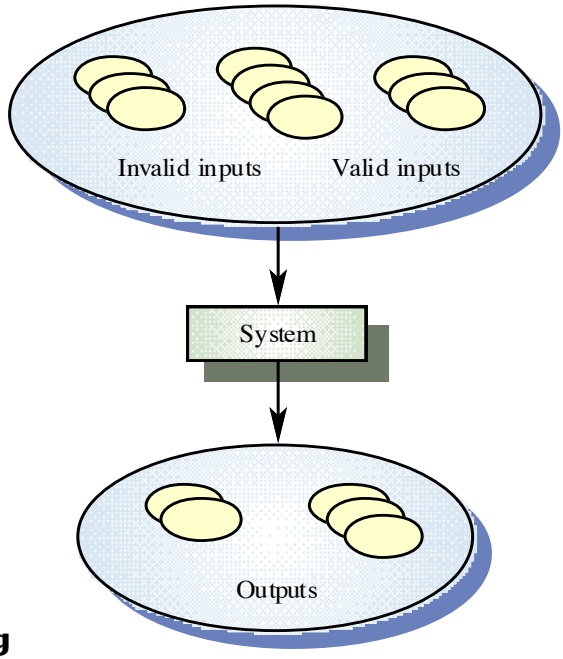
Random

- Pros
  - Indipendent of requirements
- Cons
  - Requires many test cases (easy to define the inputs, requires Oracle to compute the expected output)

Equivalence classes partitioning

- Divide input space in partitions
  - that have similar behavior from point of view of (requirements for) unit
  - Take one / two test cases per partition
- Boundary conditions
  - Boundary between partitions
  - Take test cases on the boundary

Equivalence classes



Equivalence classes

- A class corresponds to set of valid or invalid inputs for a *condition* on the input variables
  - If a test in a class has not success the other tests in the same class may have the same behavior

Conditions

- Common conditions:
  - Single value: age = 33
  - Interval: age between 0 and 200
  - Boolean: married = true or false
  - Discrete set: marital status = single, married, divorced

Conditions and classes

Conditions	Classes	Example
Single value	Valid value, invalid values < value Invalid values > value	Age = 33 Age < 33 Age > 33
Interval	Inside interval, Outside one side Outside, other side	Age > 0 and age <200 Age > 200 Age < 0
Boolean	True false	Married = true Married = false
Discrete set	Each value in set One value outside set	Status = single Status = married Status = divorced Status = jksfhj

Selection of test cases

- Every equivalence class must be covered by a test case at least
  - A test case for each invalid input class
  - Each test case for valid input classes must cover as many (remaining) valid classes as possible

Equivalence classes

- Function double **`squareRoot(double x);`**
  - Partitions
    - Positive numbers T1 (1 ; $\sqrt{1}$)
    - Negative numbers T2 (-1 ; error)
  - Boundary: zero, infinite
    - Zero and close
      T3 (0; $\sqrt{0}$) T4(0.01; $\sqrt{}$ 0.01) T5(-0.01; error)
    - 'Infinite' and close
      T6 (maxdouble; $\sqrt{}$ maxdouble) T7 (maxdouble+0.01; err)
      T8 (mindouble; $\sqrt{}$ mindouble) T7 (mindouble-0.01; err)

Equivalence classes

`int convert(String s)`
converts a sequence of chars (max 6) into an integer number. Negative numbers start with a '-'

Criterion to define the class	Equivalence classes and test cases	
String represents a well formed integer	Yes T1("123"; 123)	No T2("1d3" ; error)
Sign of number	Positive T1("123" ; 123)	Negative T3("-123" ; -123)
Number of characters	<=6 T1("123" ; 123)	>6 T4("1234567"; err)

Equiv. classes- combinatorial

WF integer	sign	N char	
yes	Pos	<=6	T1(“123”; 123)
		>6	T4(“1234567”; err)
	Neg	<=6	T3(“-123”; -123)
		>6	T5(“-123456”; err)
no	Pos	<=6	T2(“1d3”; err)
		>6	T6(“1sed345”; err)
	Neg	<=6	T7(“-1ed”; err)
		>6	T8(“-1ed234”; err)

Boundary - combinatorial

WF integer	sign	N char	
yes	Pos	<=6	“0” “999999”
		>6	“1000000” “9999999”
	Neg	<=6	“-0” “-99999”
		>6	“-999999”
no	Pos	<=6	“”
		>6	“ ” (7 blanks)
	Neg	<=6	“-”
		>6	“- ”

Equiv classes and state

- When a module has state
  - the state has to be considered to define the partitions
  - State may be difficult to read/create
  - Requires a sequence of calls

Equiv classes and state

- **`double Ave3(int i)`**
  - Computes average of last three numbers passed, excluding the negative ones
  - Criteria
    - state: n elements received
    - int i: positive, negative

Equiv classes and state

N elements	i	Test
0	NA	
1	Pos	T1(10; 10)
	Neg	T2(-10; ?)
2	Pos	T3(10,20 ; 15)
	Neg	T4(-10,-20; ?)
3	Pos	T5(10,2,6; 6)
	Neg	T6(-10,-2,-6; ?)
>3	Pos	T7(1,2,3,4; 2.5)
	Neg	T8(-1,-2,-3,-4; ?)

Test of OO classes

- Have state
- Many functions to be tested

- Identify criteria and classes
- Apply them to each function

Test of OO classes

```
// receives and stores events, with time tag
public class EventsQueue{
   public void reset();      // cancels all events
   public void push(int timeTag)
                                throws InvalidTag
     // discards events with negative or zero time tag
    // and with time tag already existing
     public int pop() throws EmptyQueue
     // returns and cancels event with lower time tag
     // raises exception if queue empty
}
```

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Test of OO classes

- Function push()

Empty	Repeated elements	Sign > 0	Test case
yes	yes	Yes	Reset(); Push(10); Push(10); Pop() → 10; Pop(); → EmptyQueue
		No	Reset();Push(-10); Push(-10); Pop(); → EmptyQueue
	no	Yes	
		No	
no	yes	Yes	
		No	
	no	Yes	
		No	

Test of OO classes

- Function reset()

Empty	Repeated elements	Sign > 0	Test cases
yes	yes	Yes	NA
		No	NA
	no	Yes	reset(); pop() → EmptyQueue
		No	NA
no	yes	Yes	NA
		No	NA
	no	Yes	NA
		No	NA

Unit test black box – summary

- Functional test of units (functions, classes) generates test cases starting from the specification of the unit
- Key techniques are
  - Random
  - Equivalence classes partitioning
  - Boundary conditions

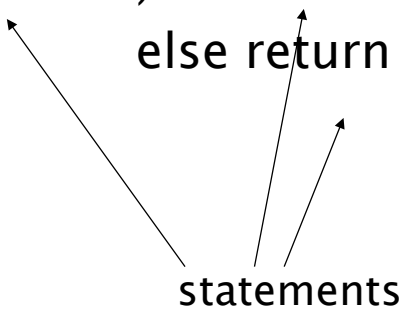
UNIT TEST – WHITE BOX

Unit test

- Black box (functional)
  - Random
  - Equivalence classes partitioning
- White Box (structural)
  - Coverage of structural elements
    - Statement
    - Decision, condition (simple, multiple)
    - Path
    - Loop

Statement coverage

```
double abs(double x){
  if (x>=0) then return x;
            else return -x;
}
```



Two test cases to cover all statements T1(1; 1)
T2(-1; 1)

Statement coverage

Try to execute all statements in the program

Measure:

statement coverage =

#statements covered/ #statements

Problem: statement?

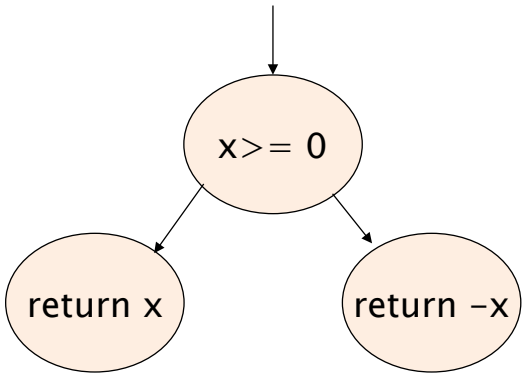
```
double abs(double x){
  if (x>=0) then return x;
                else return -x;
}
double abs(double x){
  if (x>=0) then return x;
                else return -x;
}
double abs(double x){
  if (x>=0) then return x; else return -
  x;
}
```


Transform program in control flow

- Node:
  - atomic instruction
  - decision
- Edge: transfer of control
  - and basic blocks
    - Nodes can be collapsed in basic blocks
    - A basic block has only one entry point at initial instruction and one exit point at final instruction

Node coverage

```
double abs(double x){
  if (x>=0) then return x;
            else return -x;
                }
```



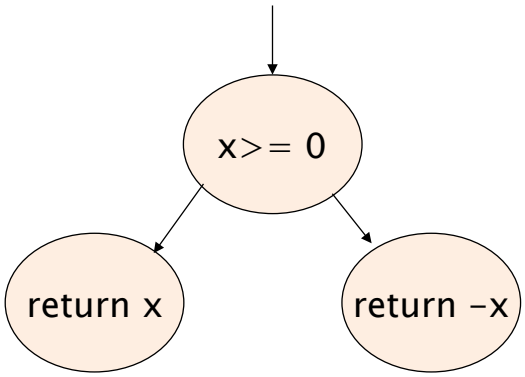
T1 (1; 1)

T2 (-1; 1)

Statement coverage = node coverage

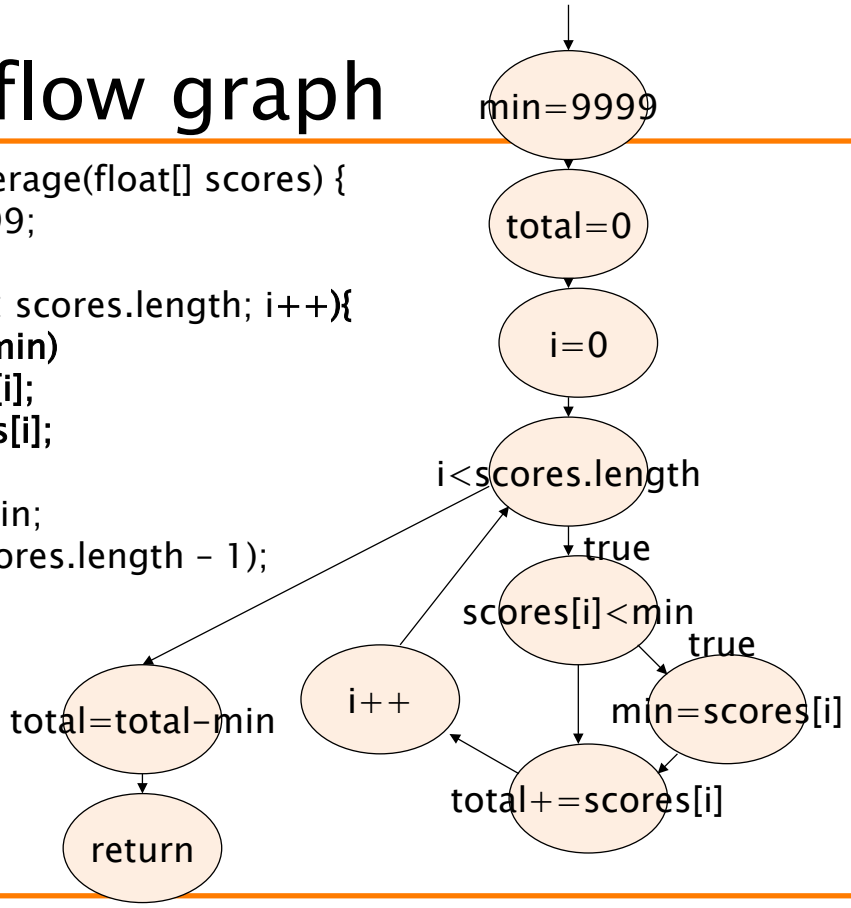
Control flow graph

```
double abs(double x){
if (x>=0) then return x;
          else return -x;
             }
```



Control flow graph

```
float homeworkAverage(float[] scores) {
  float min = 99999;
   float total = 0;
   for (int i = 0; i < scores.length; i++){
     if (scores[i] < min)
       min = scores[i];
     total += scores[i];
   }
   total = total - min;
  return total / (scores.length - 1);
}
```



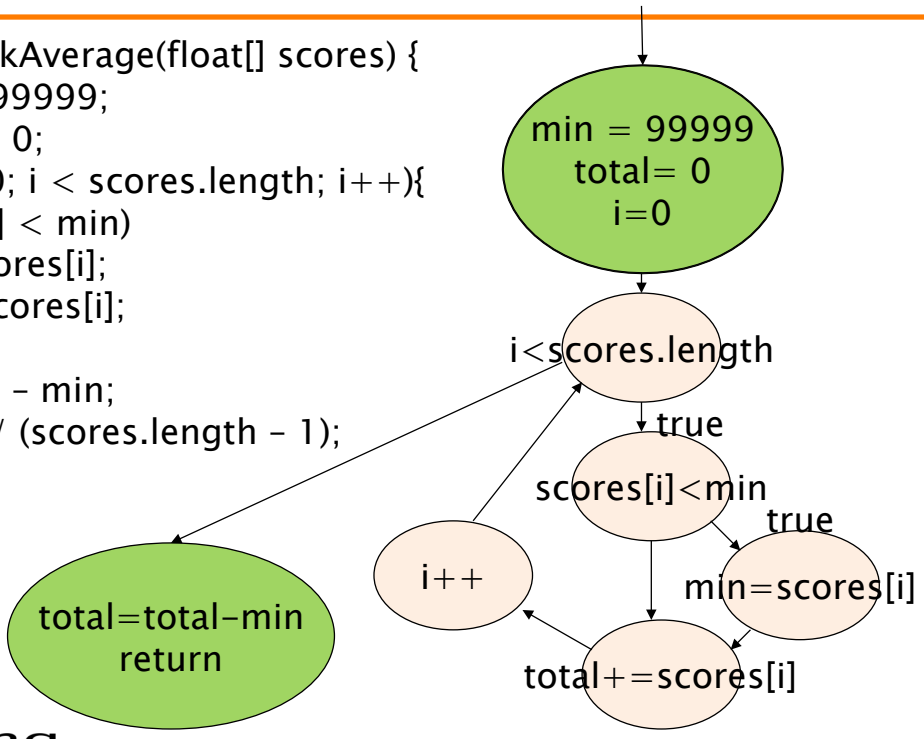
Measure: Node coverage

- Node coverage = number of nodes executed / total number of nodes

- For each test
- Cumulative: for a test suite

Basic blocks

```
float homeworkAverage(float[] scores) {
  float min = 99999;
   float total = 0;
   for (int i = 0; i < scores.length; i++){
     if (scores[i] < min)
       min = scores[i];
     total += scores[i];
   }
   total = total - min;
  return total / (scores.length - 1);
}
```



Statement coverage

- Node covergage ⇔ Statement coverage
- Basic block cov ⇔ Statement coverage

Decision coverage

Try to cover all decisions in the program with true and false

Measure:

decision coverage =

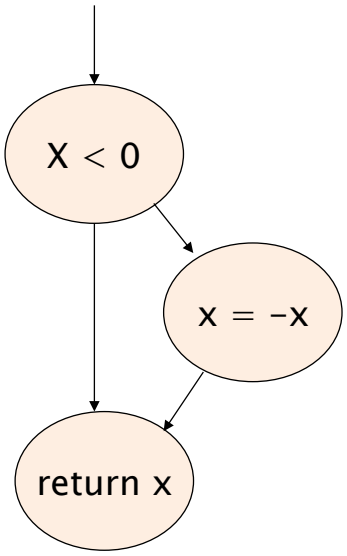
#decisions covered/ #decisions

Decision coverage

- Edge coverage ⇔ Decision coverage

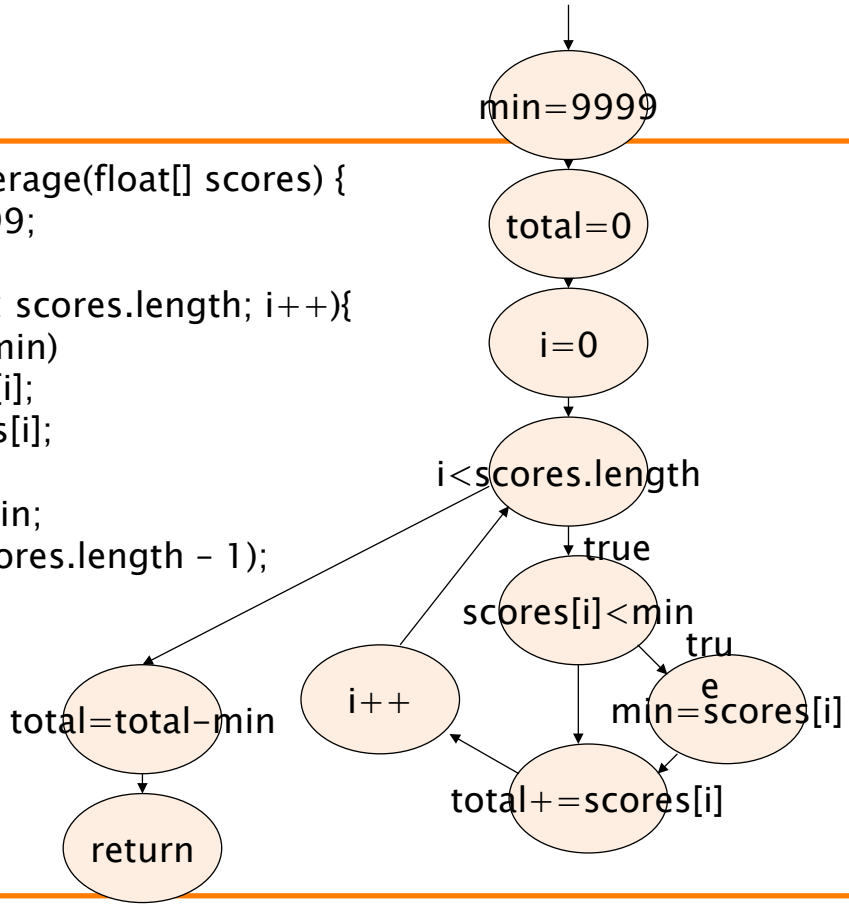
Edge coverage

```
double abs(double x){
  if (x < 0) then x = -x;
  return x;
}
```



T1 (1 ;1)
T2 (-1; 1)


```
float homeworkAverage(float[] scores) {
  float min = 99999;
   float total = 0;
   for (int i = 0; i < scores.length; i++){
     if (scores[i] < min)
       min = scores[i];
     total += scores[i];
   }
   total = total - min;
  return total / (scores.length - 1);
}
```



T1({1}; 1)

T2({1,2}; 1.5)

Relations

Edge coverage implies node coverage

not viceversa

Condition coverage

```
{
  boolean isMarried;
  boolean isRetired;
  int age;
  if (age>60 and isRetired or isMarried)
        discountRate = 30;
  else  discountRate = 10;
}
```

- Simple

Test case	age>60	isRetired	isMarried
T1	T	T	T
T2	F	F	F

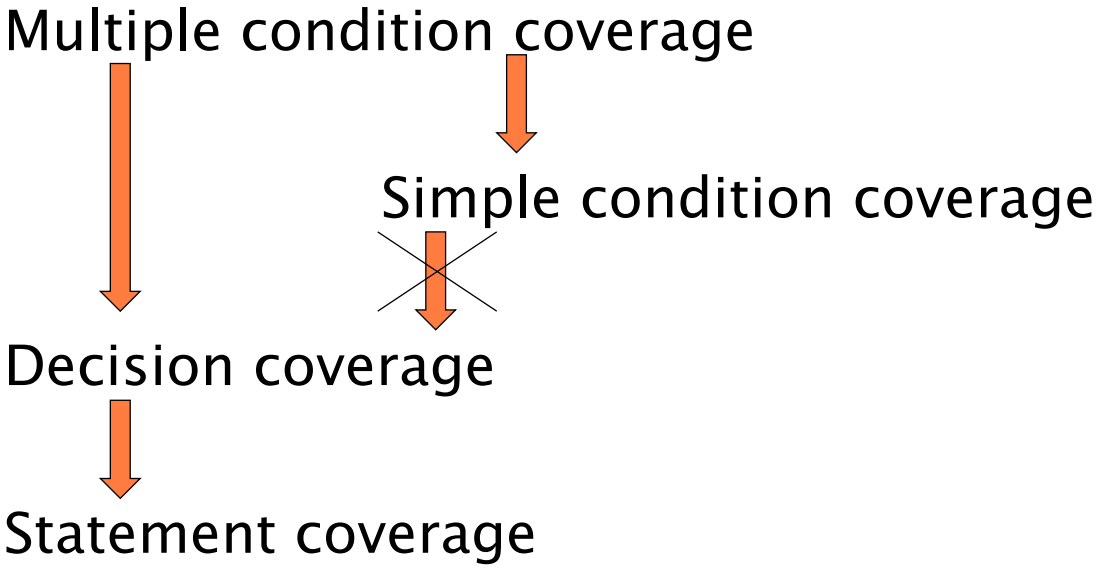
Condition coverage multiple

```
{
  boolean isMarried;
  boolean isRetired;
  int age;
  if (age>60 and isRetired or isMarried)
        discountRate = 30;
  else  discountRate = 10;
}
```

- Multiple

Test case	age>60	isRetired	isMarried	Decisio
T1	T	T	T	T
T2	T	T	F	T
T3	T	F	T	T
T4	T	F	F	F
T5	F	T	T	T
T6	F	T	F	F
T7	F	F	T	T
T8	F	F	F	F

Relations



Test case	age>60	isRetired	isMarried	Decision
T1	T	T	T	T
T2	T	T	F	T
T3	T	F	T	T
T4	T	F	F	F
T5	F	T	T	T
T6	F	T	F	F
T7	F	F	T	T
T8	F	F	F	F

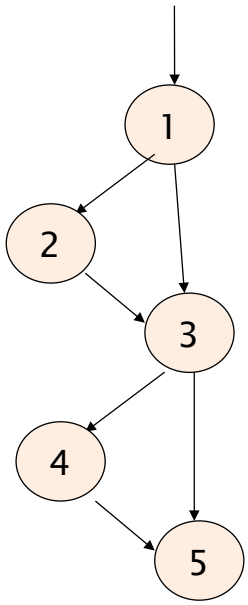
- T2 and T7 provide simple condition coverage, but no decision coverage

Path coverage

- Path = sequence of nodes in a graph
- select test cases such that every path in the graph is visited

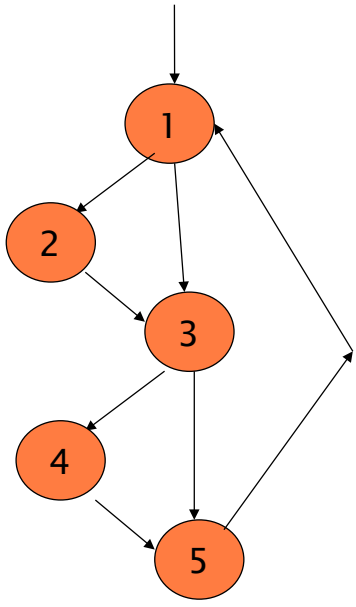
Path coverage

- Ex. 4 paths in this simple graph
  - 1,2,3,4,5
  - 1,3,5
  - 1,3,4,5
  - 1,2,3,5



Path coverage

- Combinatorial explosion with cycle
  - 1,3,5
  - 1,3,5,1,3,5
  - 1,3,5,1,3,5,1,3,5
  - Etc ..
  - Npaths = 4^{nloops}



Path coverage

- In most cases unfeasible if graph is cyclic
- Approximations
  - Path-n
    - Path-4 == loop 0 to 4 times in each loop
  - Loop coverage
    - In each loop cycle 0, 1 , >1 times

Loop coverage

- select test cases such that every loop boundary and interior is tested
  - Boundary: 0 iterations
  - Interior: 1 iteration and > 1 iterations
  - Coverage formula: x/3

Loop coverage

- Consider each loop (for, while) separately
- Write 3 test cases
  - No enter the loop
  - Cycle once in the loop
  - Cycle more than once

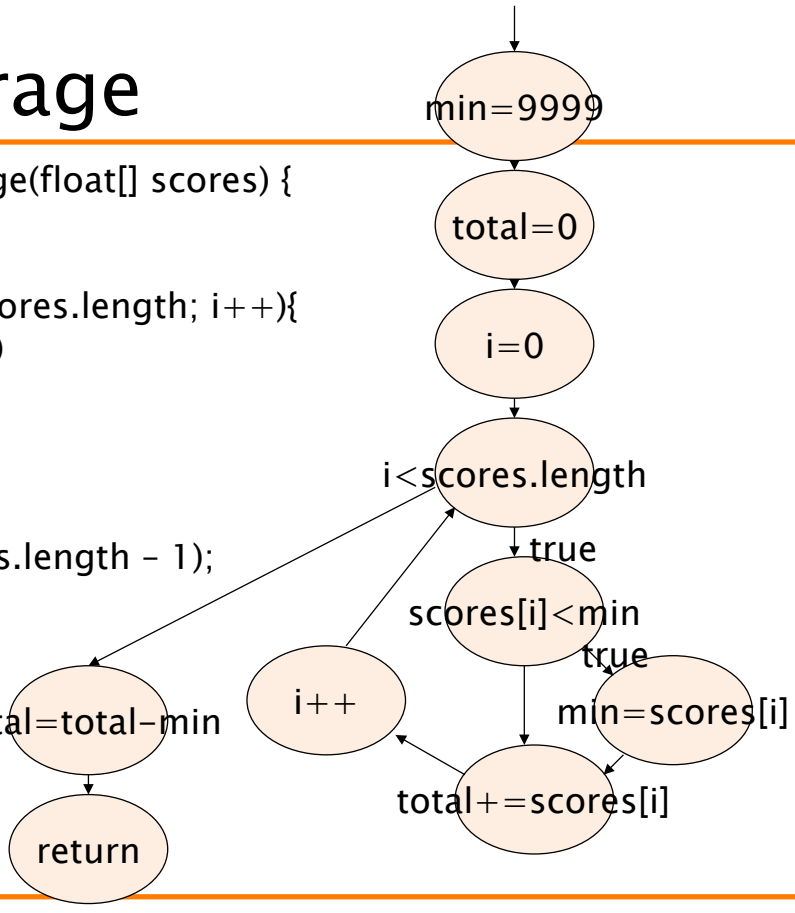
Loop coverage

```
float homeworkAverage(float[] scores) {
   float min = 99999;
    float total = 0;
    for (int i = 0; i < scores.length; i++){
      if (scores[i] < min)
        min = scores[i];
      total += scores[i];
    }
    total = total – min;
   return total / (scores.length – 1);
 }
```

T1({1}; 1) loops 1

T2({1,2,3}; 2) loops 2

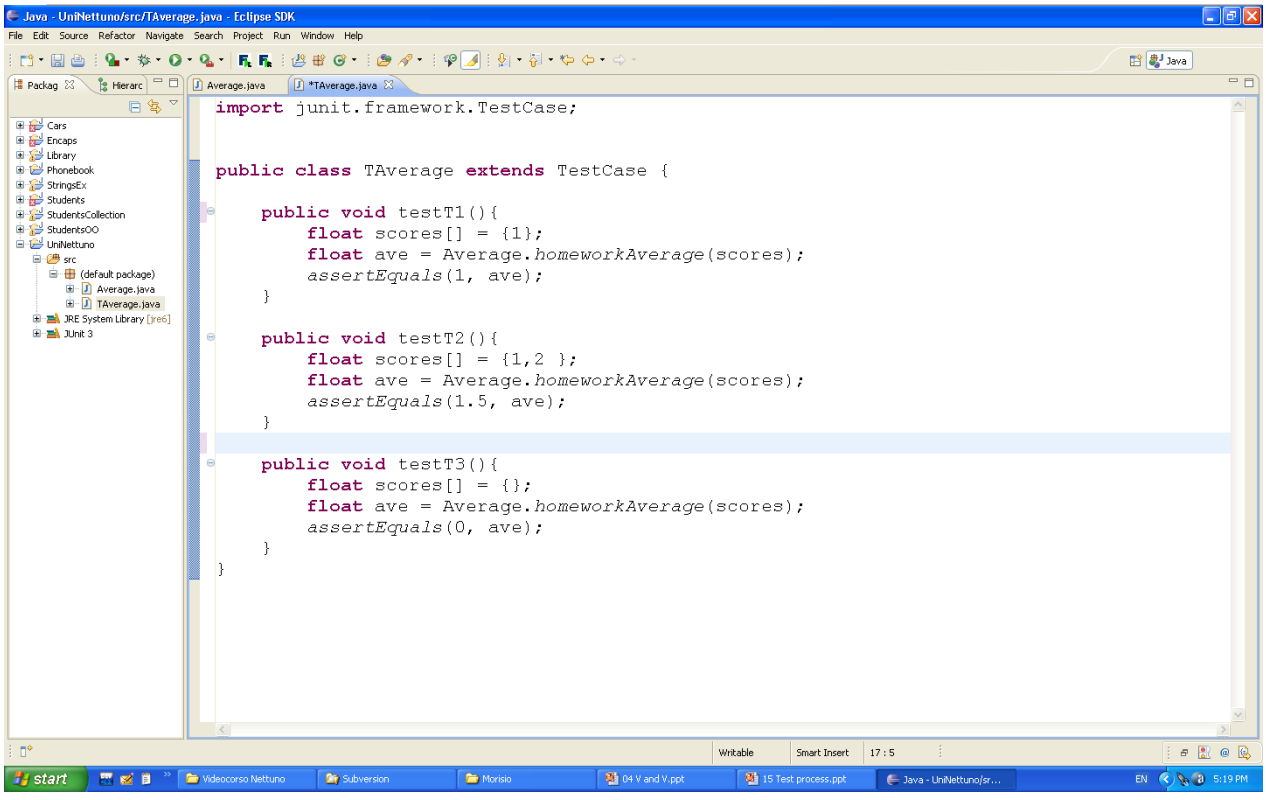
T3({}; ?) loops 0



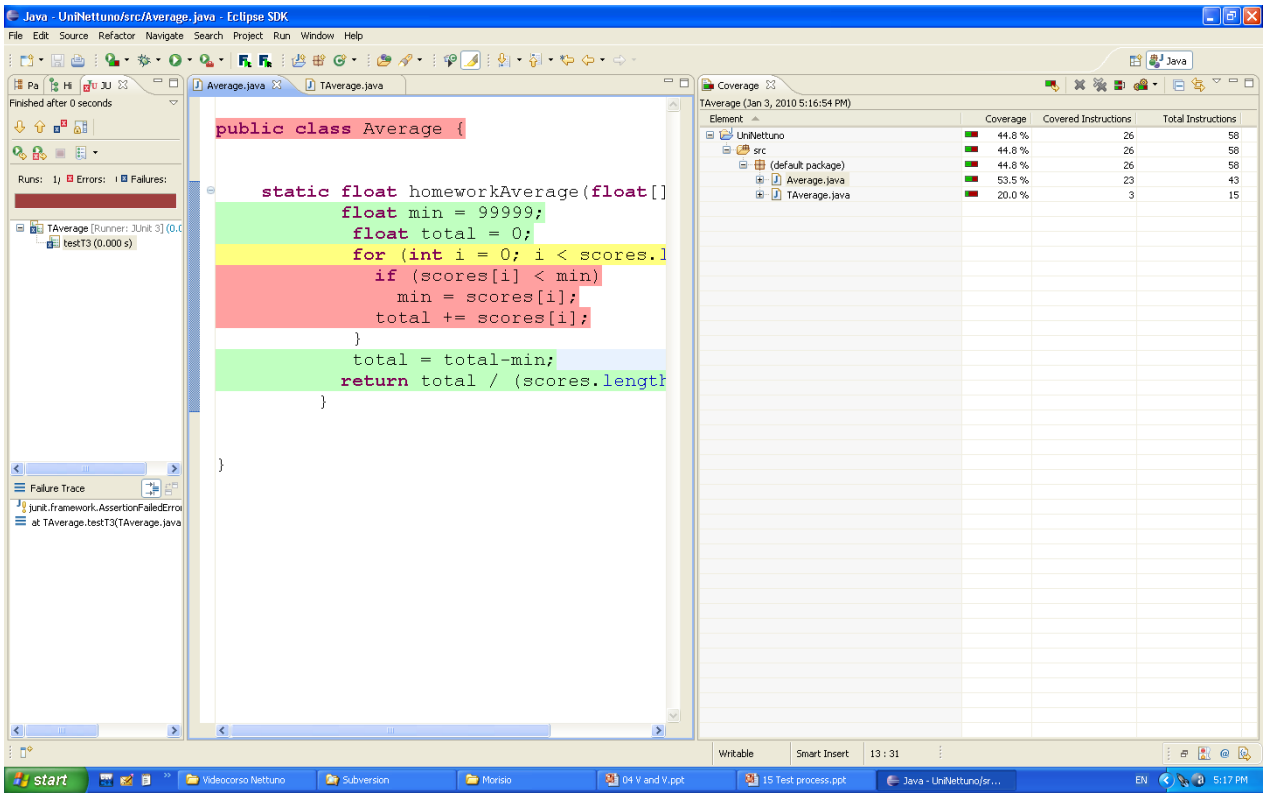
Tools

- To write and run test cases
  - Ex JUnit
- To compute coverage
  - Ex. Cobertura

JUnit



Cobertura



Summary

- Structural / white box testing starts from the code, and uses several coverage objectives
  - Statements
  - Decisions
  - Conditions (simple, multiple)
  - Path
  - Loop

Summary

- White box testing is typically made in the development environment and supported by tools to compute coverage

Mutation testing

Mutation testing

- Are our test cases ‘good’?
- Idea:
  1. write test cases
  2. inject errors in program (single small change)
  3. verify if test cases catch the errors injected

Mutation Testing

- Mutation Testing (a.k.a., Mutation analysis, Program mutation)
  - Introduced in early 1970s
  - Used in software/hardware

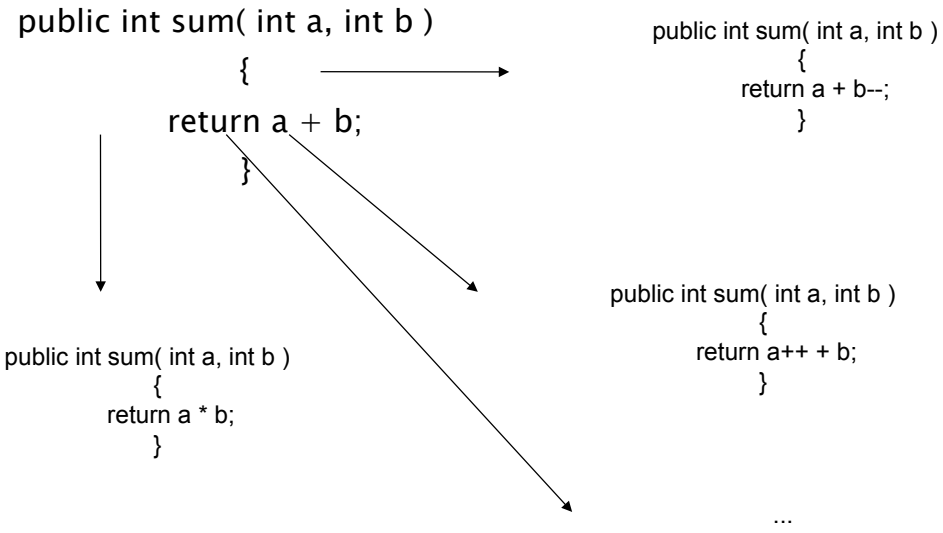
Terms

- *Mutant*: program with one change
- *Killable mutant*: non functionally equivalent. A test case can kill it
- *Equivalent mutant*: functionally equivalent to program. No test case can kill it.
- *Mutation score*:
  - property of a test suite (goal: 100%)
  - Killed non equivalent mutants / all non equivalent mutants

Mutations

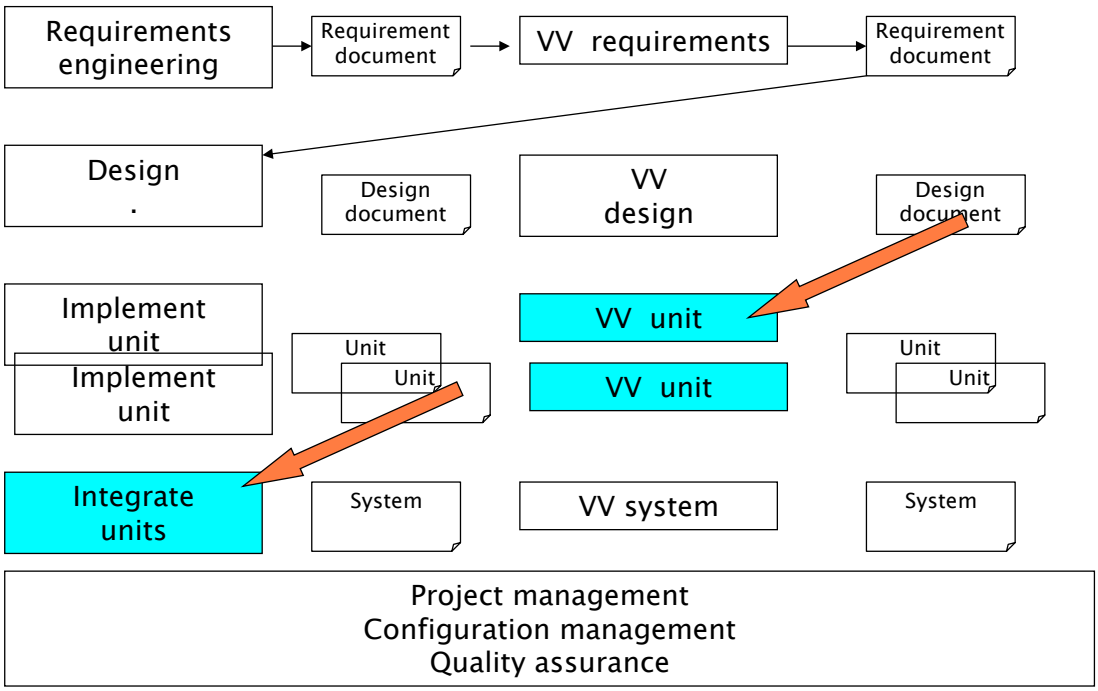
- Common mutations
  - Delete a statement
  - Swap two statements
  - Replace arithmetic operation
  - Replace boolean relation
  - Replace a variable
  - Replace boolean subexpression with constant value

Mutation examples



Integration test

Integration test

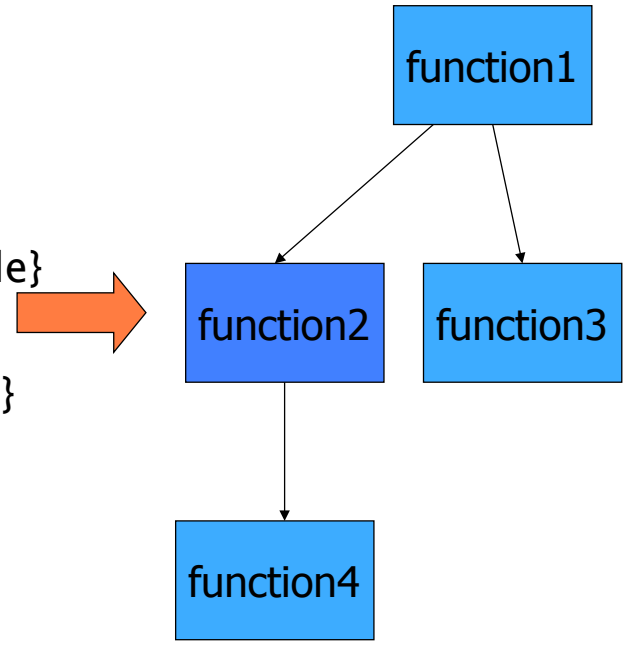


The problem

- Some units need others. How to test them?

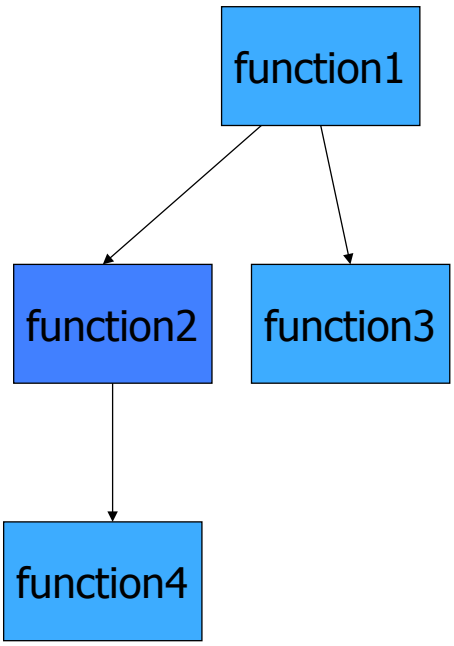
The dependency graph

```
function1() {  //some code
                  call function2();
                  call function3();
               // some other code}
function2() {  //some code
                  call function4();}
```



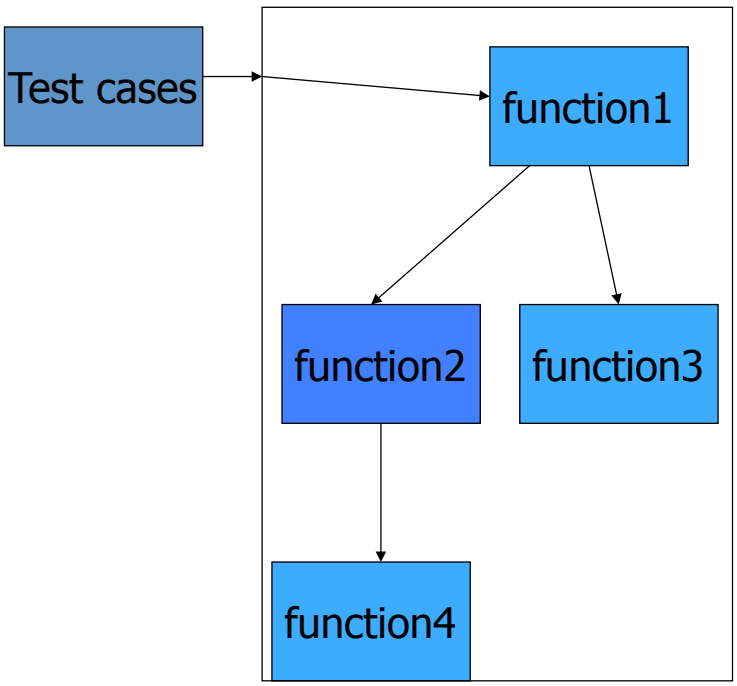
The problem -2

- Function3, function4 have no dependency
  - Unit test techniques can be applied
- Function1, function2 have dependencies, how to test them?
  - Option1: test everything together (big bang integration)
  - Option2: incremental (top down, bottom up, mixed)



Big bang integration

- All functions are developed
- Test is applied directly to the aggregate as-if it were a single unit



Problems

- When a defect is found, how to locate it?
  - Could be generated
    - by any function
      - function1, 2, 3, 4
    - by any interaction
      - function1 to function2, function1 to function3, function2 to function4
      - Interaction problems: bad parameter passed, parameter passed in wrong order, in wrong timing

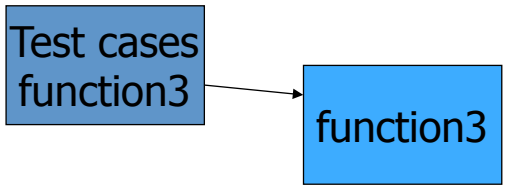
Ex. Integration problems

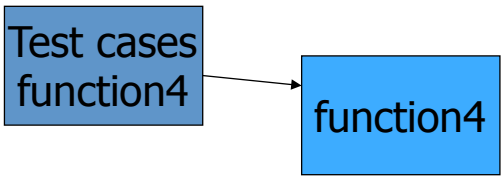
```
triangleSurface( float height, float base){}
Class Person{
    public Person(String surname, String name){}
    }

main() {
 triangleSurface(10, 4); // int instead of float
 triangleSurface(3.1, 4.2); // exchanged base (3.1)
                            // and height  (4.2)
 new Person("John", "Wright")
}
```


Incremental integration

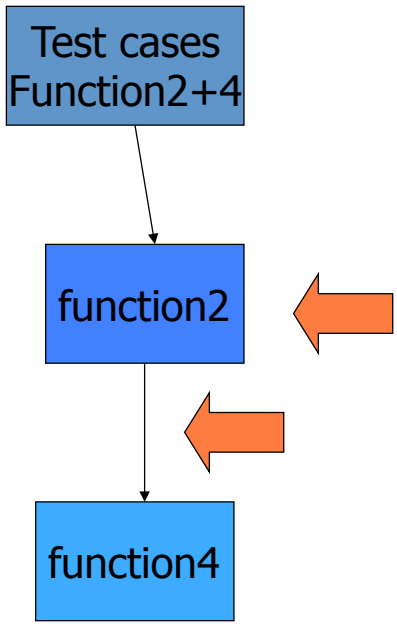
- Goal:
  - Add one unit at a time, test the partial aggregate
- Pro:
  - Defects found, most likely, come by last unit/interaction added
- Con:
  - More tests to write, stubs/drivers to write

- Step 1
  - function4, function3 have no dependencies. Test them in isolation (unit test)

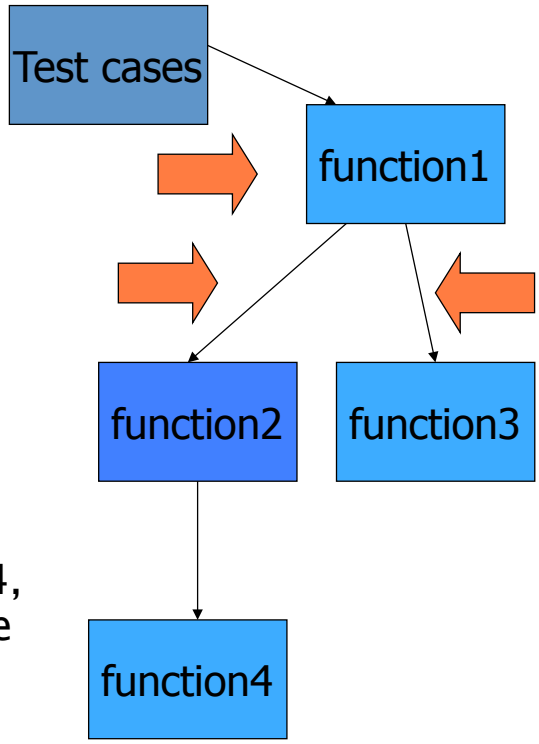




- Step 2
  - Test function2+function4 as-if they were one unit
  - if defect is found, it should come
    - from function2 or
    - from interaction function1-function4
    - Not from function 4, that is now 'trusted'



- Step 3
  - Test all
  - if defect is found, it should come
    - from function1 or
    - from interaction function1–function2
    - from interaction function1–function3
    - Not from function 2+4, and function3, that are now ‘trusted’



SOftEng http://softeng.polito.it

Stub, driver

- Driver
  - Unit (function or class) developed to pilot another unit
- Stub
  - Unit developed to substitute another unit (fake unit)
- Also called mock ups

SOftEng http://softeng.polito.it

Ex. driver (JUnit)

```
public class ConverterTest extends TestCase {

    public void testOne(){
            Converter c = new Converter();
            char [] str = {'1', '2','3','4','5','6', '7'};
            try {
                        c.convert(str);
                        fail();
            } catch (Exception e) {
               assertTrue(true);
            }
    }       }
```

```
public class Converter {

    public int convert(char[] str) throws Exception {
            if (str.length > 6)
                        throw new Exception();
            int number = 0;
            int digit;
            int i = 0;
            if (str[0] == '-')
                        i = 1;
            for (; i < str.length; i++) {
                        digit = str[i] - '0';
                        number = number * 10 + digit;
            }
            if (str[0] == '-')
                        number = -number;
            if (number > 32767 || number < -32768)
                        throw new Exception();
            return number;
    }
}
```

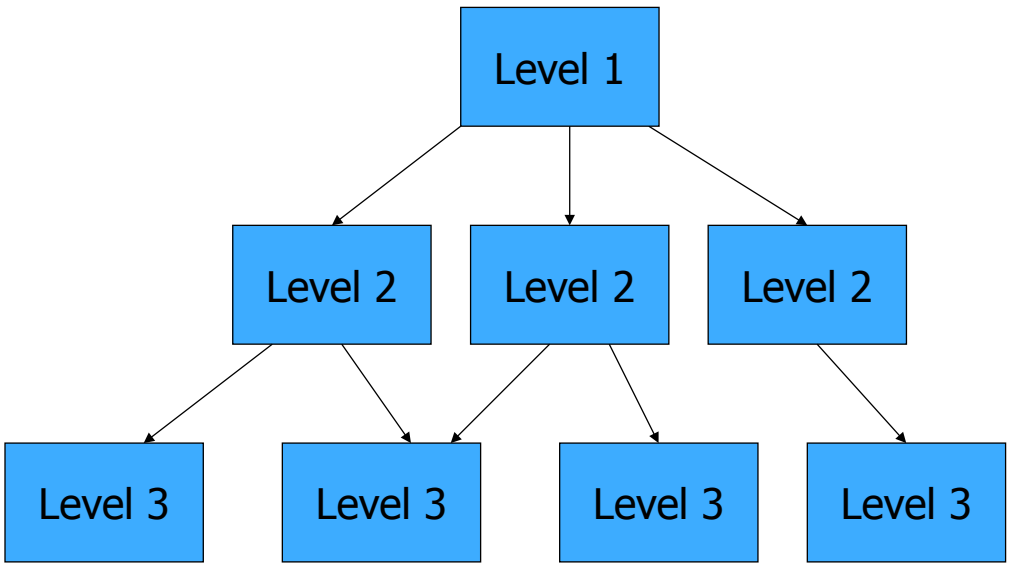

Stub

- Must be simpler than unit substituted (trade off between simplicity and functionality)
  - Ex. unit = function to compute social security number from name/family name etc.
  - Stub = returns always same ssn
  - Ex. unit = catalog of products, contains thousands of them
  - Stub. Contains 3 products, returns them randomly

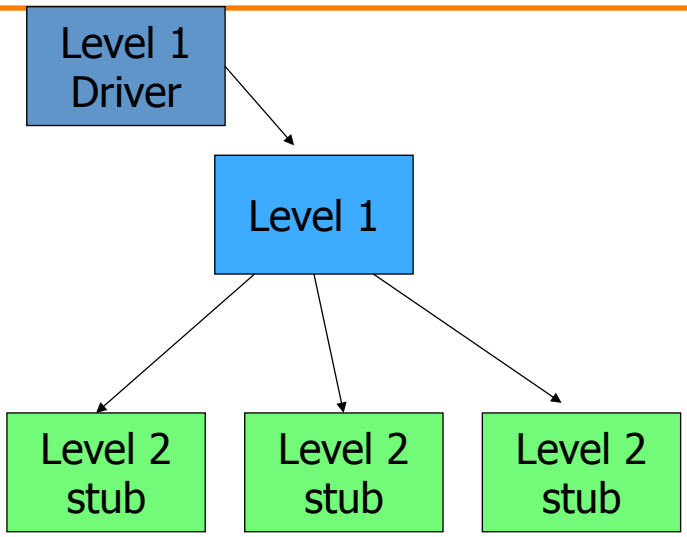
Incremental integration

- Top down
- Bottom up
  - Defined relatively to the dependency graph

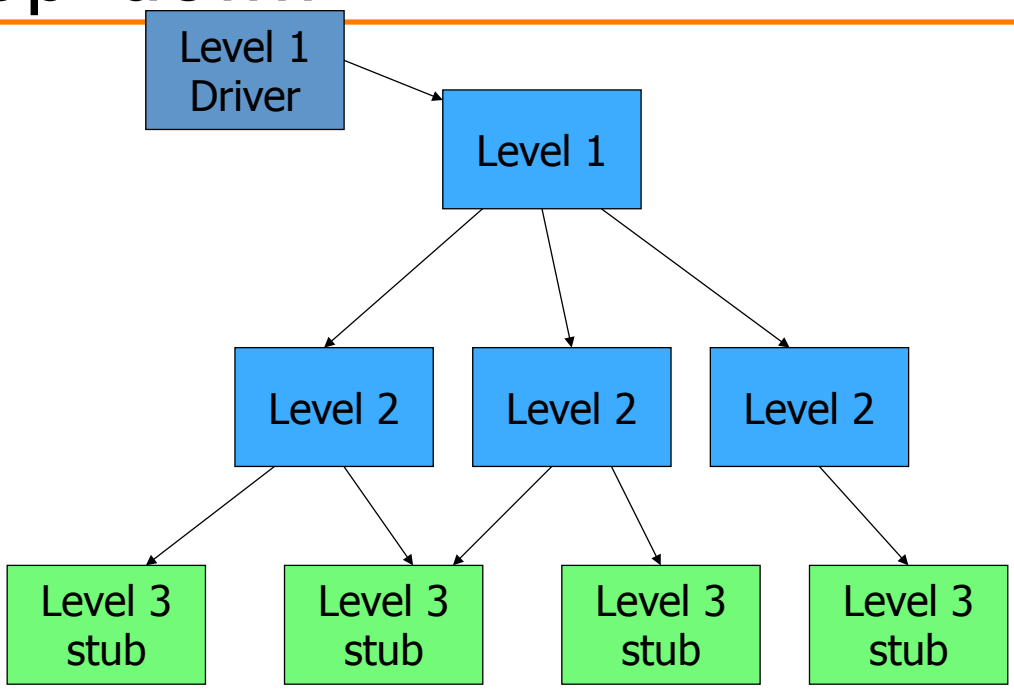
A system



Top-down



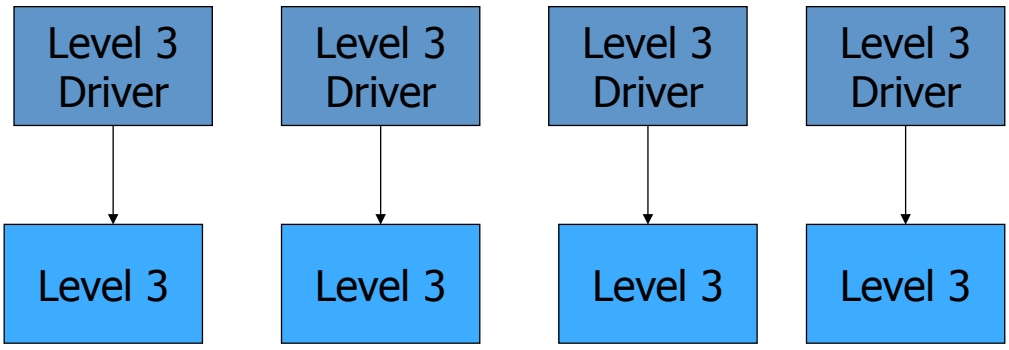
Top-down



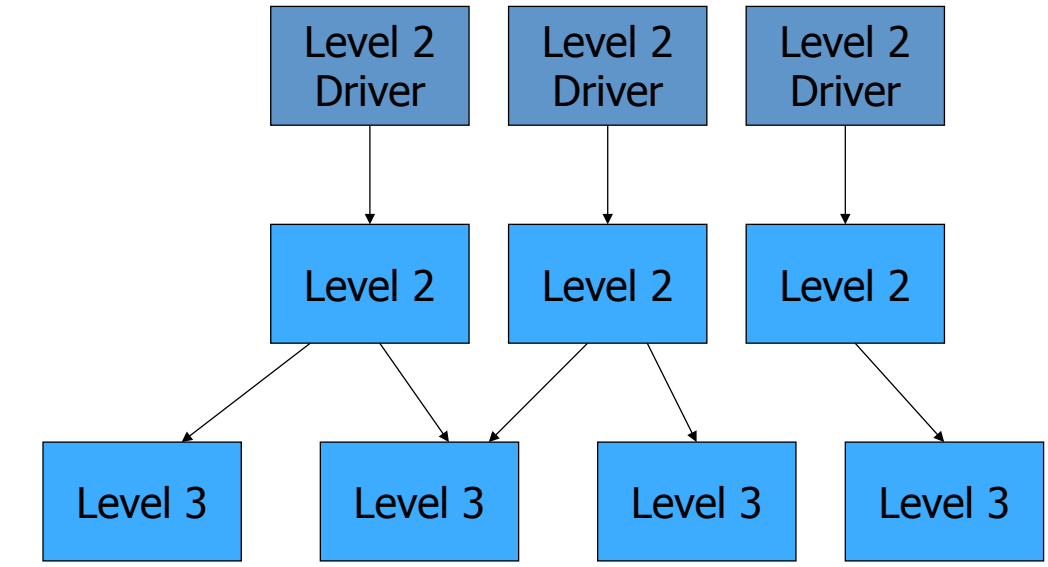
Top-down

- Pros
  - Allows early detection of architectural flaws
  - A limited working system is available early
- Cons
  - Requires the definition of stubs for all lower level units
  - Suitable only for top-down development
  - Lower levels not directly observable

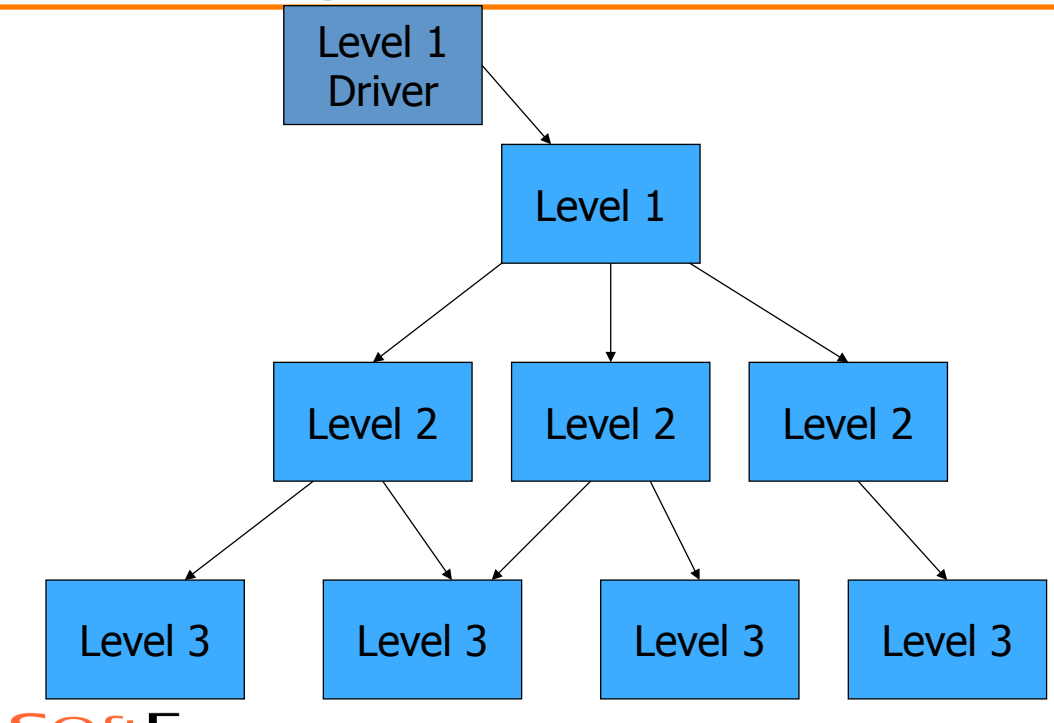
Bottom-up



Bottom-up



Bottom-up



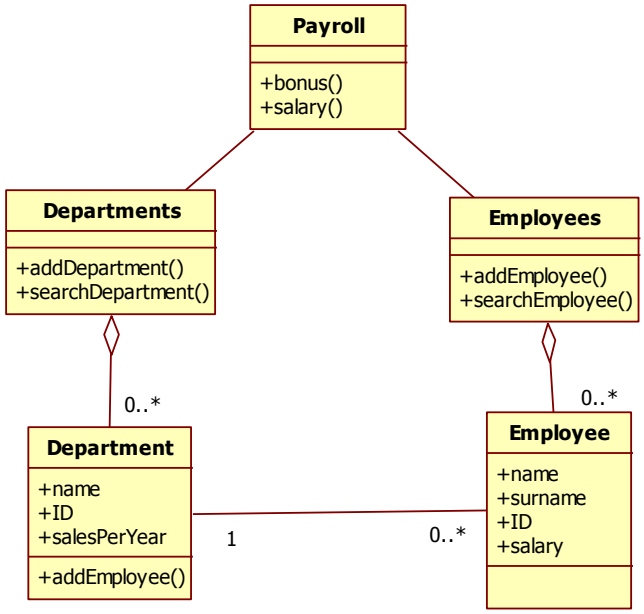
Bottom-up

- Pros
  - Testing can start early in the development process
  - Lower levels are directly observable
- Cons
  - Requires the definition of drivers for all lower level units

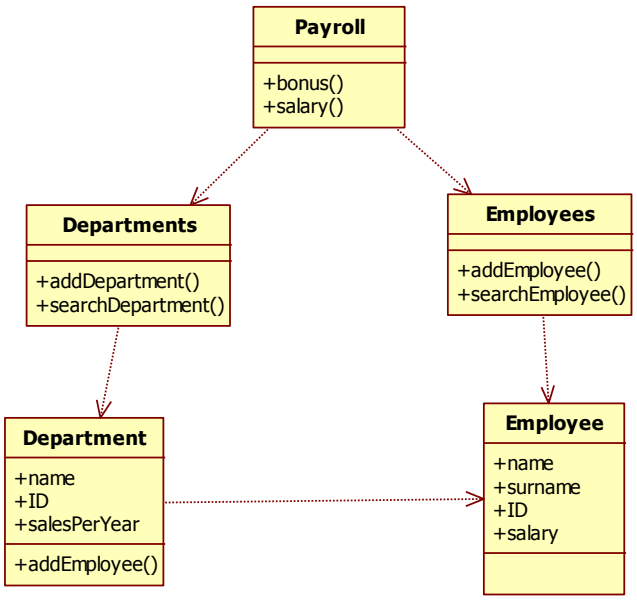
Example

- A company has employees and departments, each employee belongs to a department
- Payroll
  - salary(ID) – returns salary given employee ID
  - bonus(amount) – gives bonus 'amount' to employees with higher sales record
- Employee
  - name, surname, ID, salary
- Department
  - name, id, salesPerYear
  - addEmployee
- Employees
  - add employee
  - search employee, returns employee given ID
- Departments
  - add department
  - search department, returns department given ID

Class diagram (1)



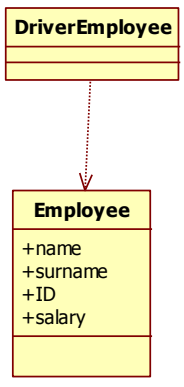
Dependencies (1)



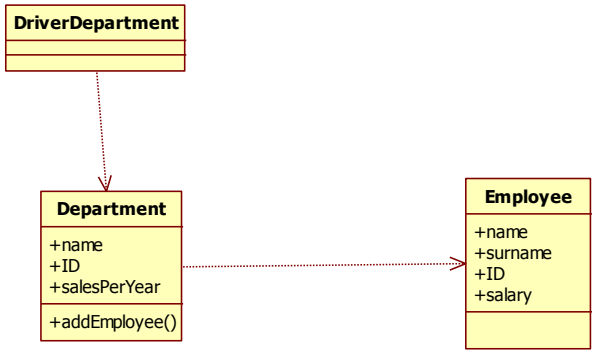
Integration

- Bottom up
  - Employee
  - Employees Department
  - Departments
  - Payroll
- Top Down
  - Payroll
  - Departments, Employees

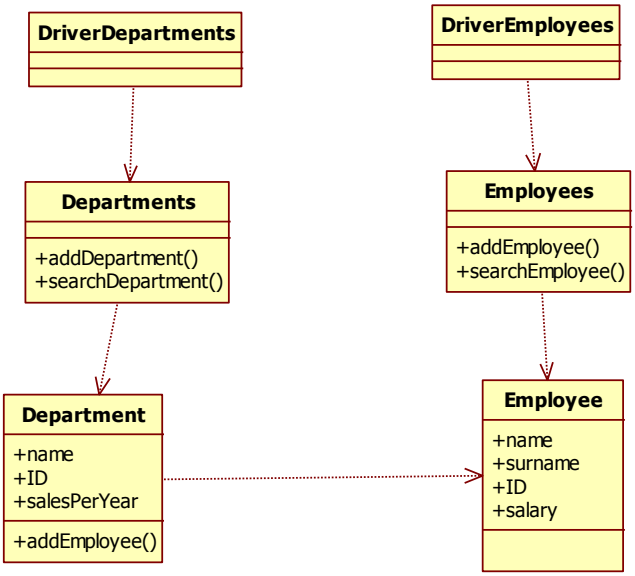
BU – 1



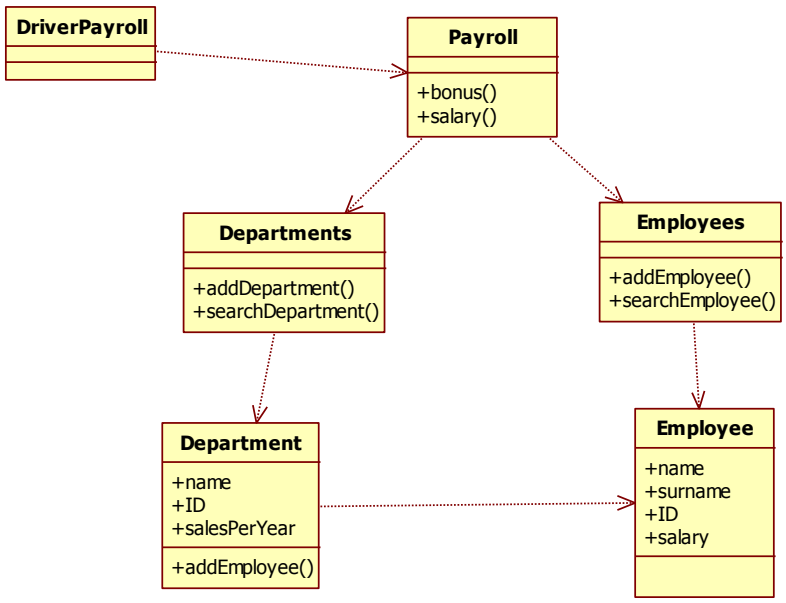
BU – 2


DriverDepartment
Department
+name
+ID
+salesPerYear
+addEmployee()
Employee
+name
+surname
+ID
+salary

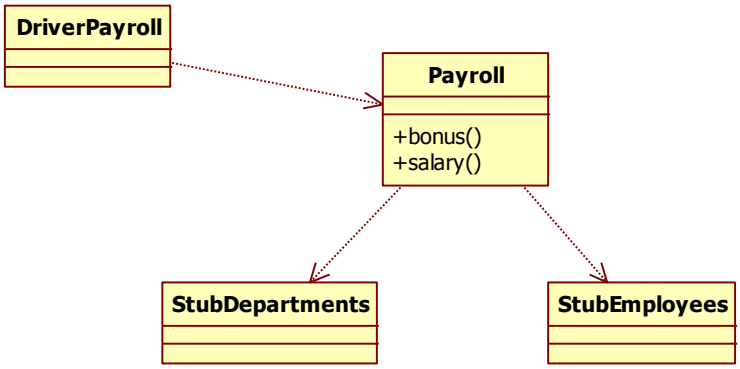
BU – 3


DriverDepartments
DriverEmployees
Departments
+addDepartment()
+searchDepartment()
Employees
+addEmployee()
+searchEmployee()
Department
+name
+ID
+salesPerYear
+addEmployee()
Employee
+name
+surname
+ID
+salary

BU – 4

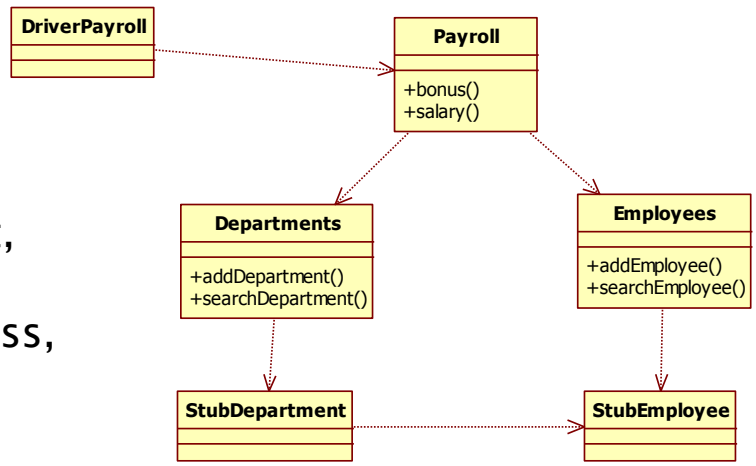

DriverPayroll
Payroll
+bonus()
+salary()
Departments
+addDepartment()
+searchDepartment()
Employees
+addEmployee()
+searchEmployee()
Department
+name
+ID
+salesPerYear
+addEmployee()
Employee
+name
+surname
+ID
+salary

TD – 1

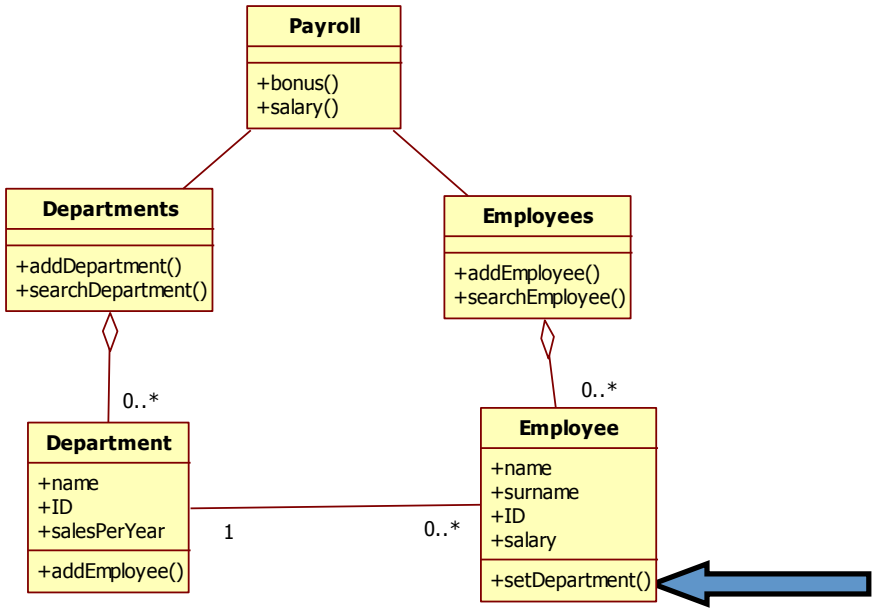

DriverPayroll
Payroll
+bonus()
+salary()
StubDepartments
StubEmployees

TD – 2

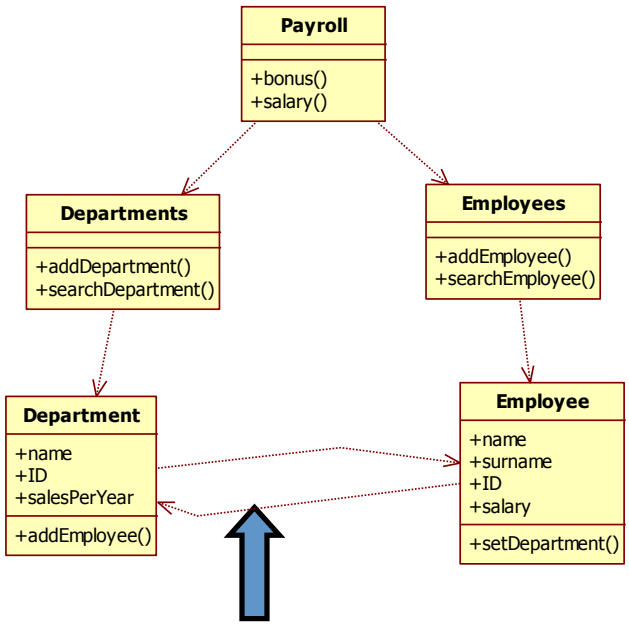
StubDepartment, StubEmployee probably useless, have similar complexity of Department and Employee



Class Diagram (2)



Dependencies (2)

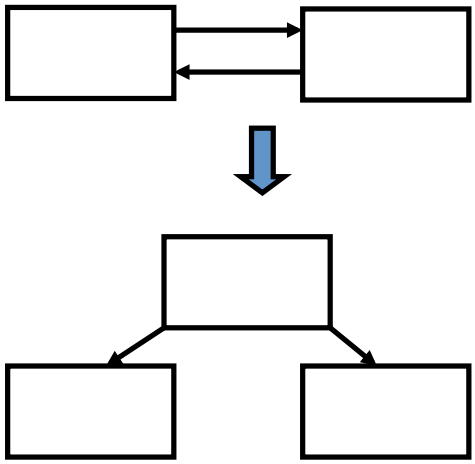


Integration

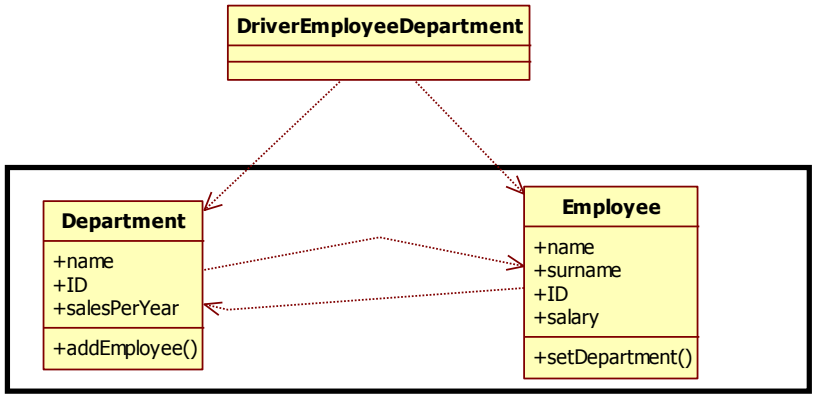
1. Consider classes with dependency loop as single class

   Not feasible if large/complex classes

2. Change design, split loop



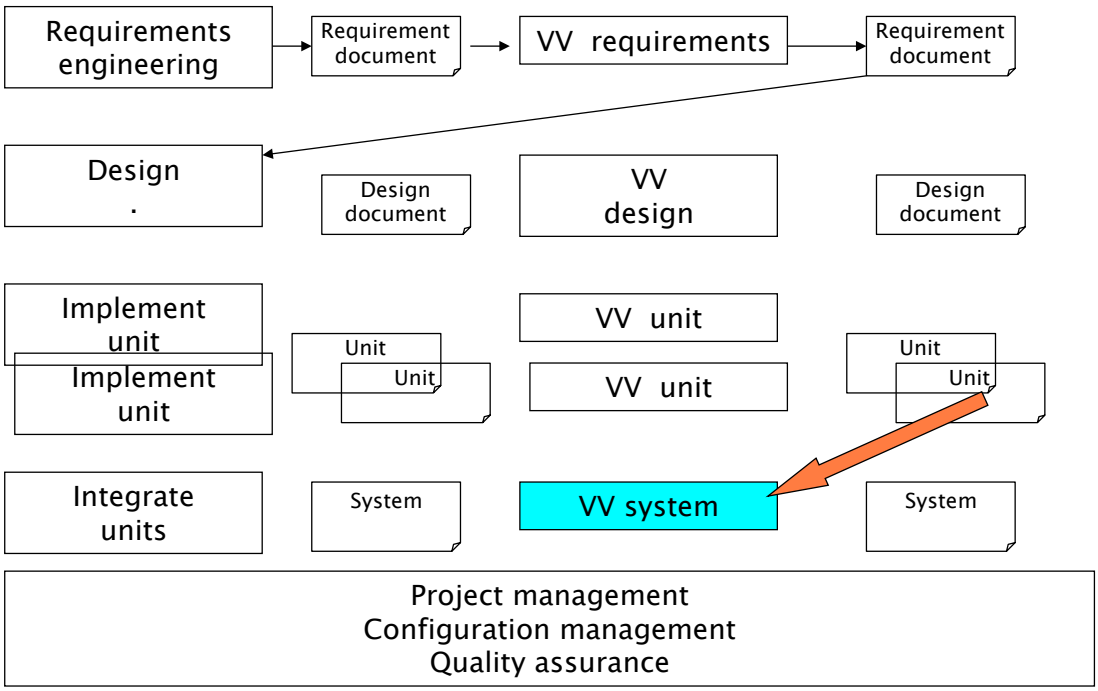
Case 1 – BU



- Next steps as for BU case

System test

System test



System test

- Is applied to the software system as a whole
- Aims at verifying the correspondence of the system to the requirements
- Is performed by a test team (typically not the development team)

System test

- Test of functional requirements
  - Coverage of uses cases/scenarios as listed in requirement document
  - Consider usage profile (the most common, typical ways of using the system)
    - Cfr. Unit and integration test, goal is coverage, using all functions, all code.
- Test in conditions as far as possible close to working conditions
  - Cfr. Acceptance test performed by user
  - Cfr. Platform

The platform

- Environment where an application runs, defined by
  - Operating system
  - Database
  - Network
  - Memory
  - CPU
  - Libraries
  - Other applications installed
  - Other users
  - …

Platform and test

- An element (system, unit, ..) can be tested on
  - Target platform
    - Where the element will run for day by day use
    - **Cannot** be used for production
      - Risk of corrupting data
      - Availability
  - Production platform
    - Where the element is produced
    - Cannot be (in most cases) equal to the target platform

Platforms, examples

- Embedded system
  - ABS for car, heating control system, mobile phone
    - Production platform is typically PC, external devices simulated/emulated
- Information system
  - Bank account management, student enrollment management
    - Production platform is PC or workstation, database replicated in simplified form

System test variants

- Developer, production platform
- Developer, target platform
- Acceptance testing
  - User, developer platform
  - User, target platform

System test

- Test of non functional requirements
  - Non functional properties are usually system, (emerging) properties. In many cases only testable when system is available
    - See efficiency, reliability

Non functional properties

- **Usability, reliability, portability, maintainability, efficiency (see ISO 9126)**
- **Configuration**: the commands and mechanisms to change the system
- **Recovery**: the capability of the system to react to catastrophic events
- **Stress**: reliability of the system under limit conditions
- **Security**: resilience to non authorized accesses

System test - variants

- Acceptance testing
  - Data and test cases provided by the customer, on target platform
- Beta-testing
  - Selected group of potential customers

Test, in summary

	Functional/ non functional	Who tests	Platform	Techniques
Unit test	Functional	Developer or test group	Production	BB, WB
Integration test	Functional	Developer or test group	Production	Incremental TD or BU
System test	Functional + non functional	Developer or test group or user	Production, target	Requirement coverage Scenarios, profiles

Testing classification (2)

	Phase		
	Unit	Integration	System
Functional / black box	X	X	X
Structural / white box	X		
Reliability			X
Risks			X

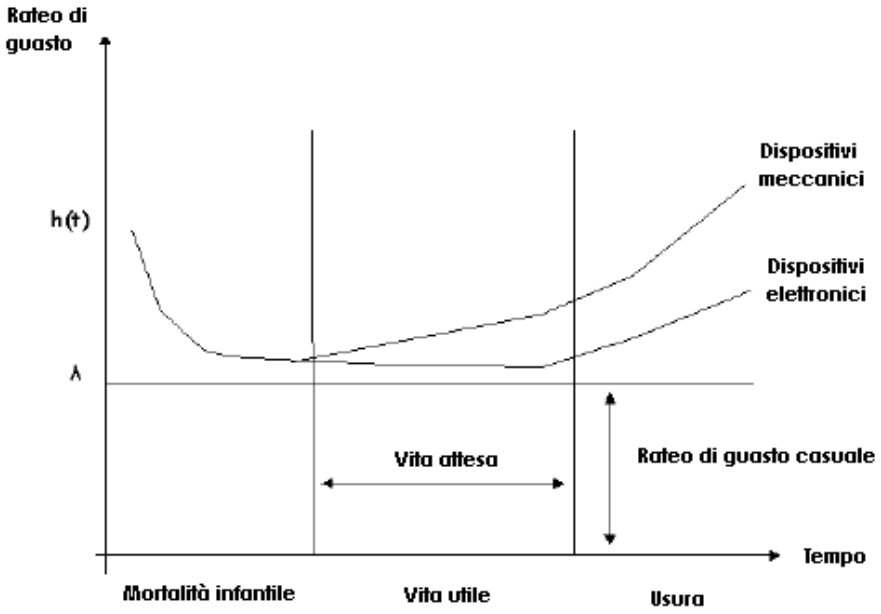
Reliability testing

- Aims at providing estimate of reliability
  = P(failure over period of time)

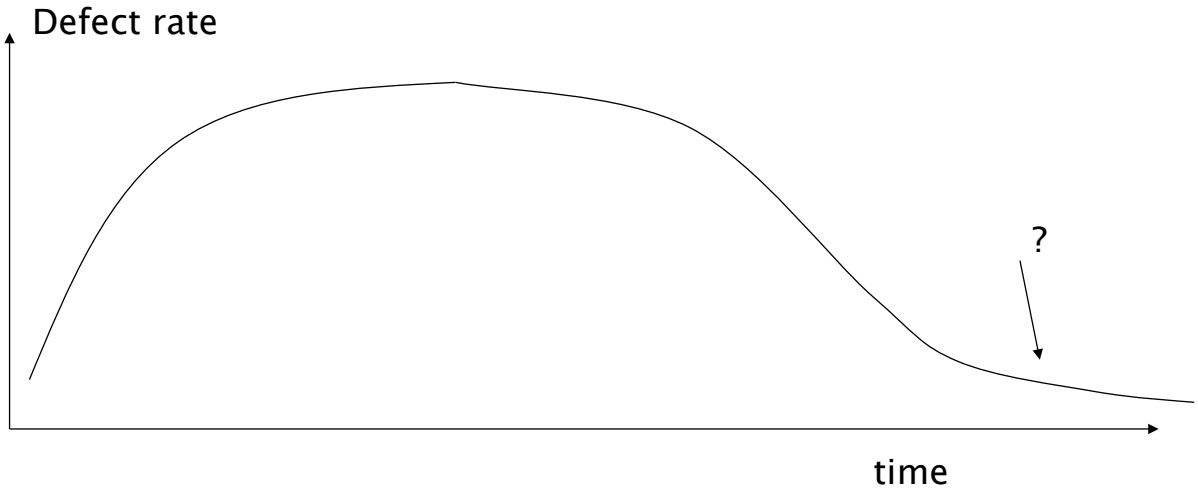
- Other measures of reliability:
  - defect rate = defect/time
  - MTBF = time between defects

- Constraints
  - Large number of test cases
  - Independent
  - Defect fix does not introduce other defect

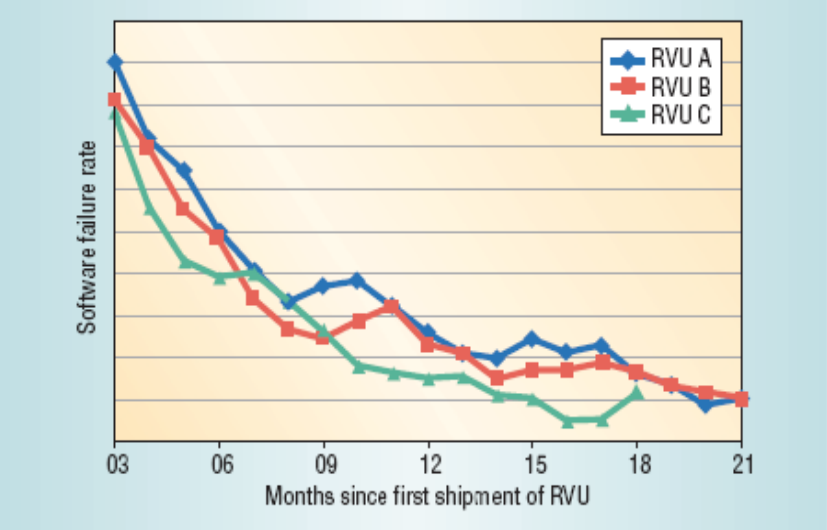
Hw reliability



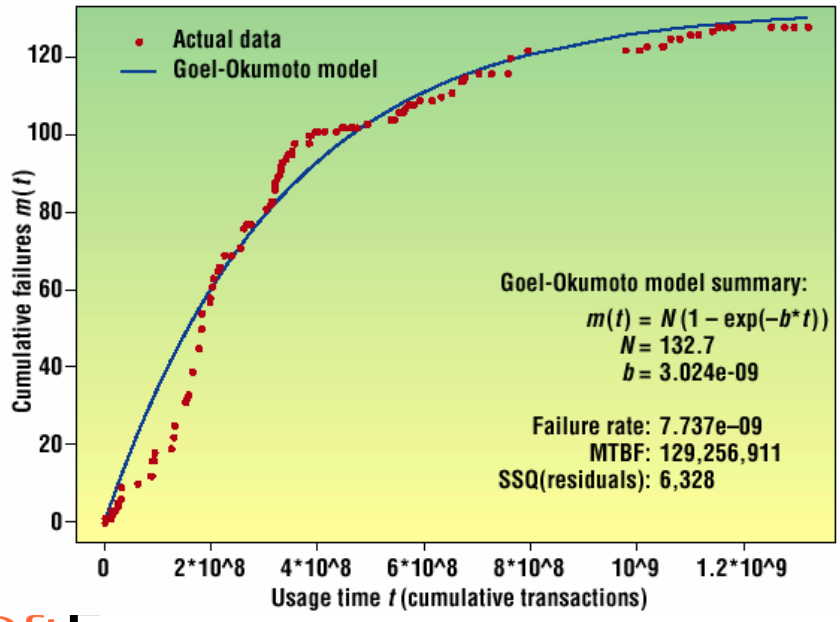
Sw reliability



HP



IBM application



Risk based testing / safety

- Identify risks
- Characterize risks: probability, effect
- Rank risks
- Handle risks

- Int x; typed language
- x = 12
- x = “good” // error syntax
- char x = 12; loosely typed language;
- Variable x; x=12; x= ‘good’

Regression testing

- Regression testing
  - Tests previously defined are repeated after a change
  - To assure that the change has not introduced defects
    - Time0
      - Element (unit, system) in v0, test set t0 is defined and applied, all tests pass
    - Time1
      - Element is changed to v1
      - Test set t0 is re-applied, do all tests still pass?

Test, documentation and automation

Representing test cases

- Informally
  - i.e. Word document
- Formally
  - Word/excel document + translator to programming language
    - FIT, Fitnesse
  - Programming language
    - Java, Eclipse + JUnit
    - (similar for C, C#, http, perl,..)

Test automation

The problem

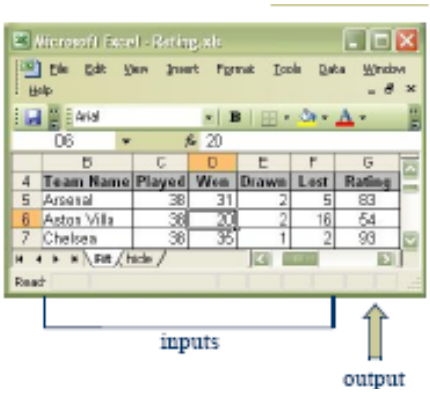
- Test cases should be not only documented
  - So that they are not lost, and can be reapplied
    - Cfr. Test cases are just invented and applied
- But also automated
  - So that application of test cases is fast and error free
    - Cfr manual application of test cases

Testing tools

- Table based testing
  - FIT, Fitnesse
- Documentation and application
  - Junit
- Capture replay
- Coverage
- Profiling

Table based testing

- Test cases are written as tables (word/ excel), and linked to application to be tested
- Pro:
  - Allows end users to write tests (especially acceptance tests, black box tests)
  - Independent of GUI
  - Allows automation
- Cons
  - Requires fixtures



FIT Framework for Integrated Test

- Open source implementation of table based testing
  - User specifies tests in HTML tables
  - Developers defines *fixtures* to parse tables and execute tests
  - Fit compares tables and actual results

FITnesse

- Standalone wiki that's hooked to FIT
- Allows group to easily edit test files without worrying about ensuring the correct versions propagate out to all locations
- http://fitnesse.org

Capture replay

- Capture tool: captures end user test as sequence of events on the GUI
  - Mouse clicks, keyboard inputs, screen outputs
- Replay tool: reapplies any captured sequence
- Pros:
  - End user write test case, seamlessly
  - Allows automation
- Cons:
  - Depends on GUI structure: if changed, captured test cases may not be replayed

Coverage

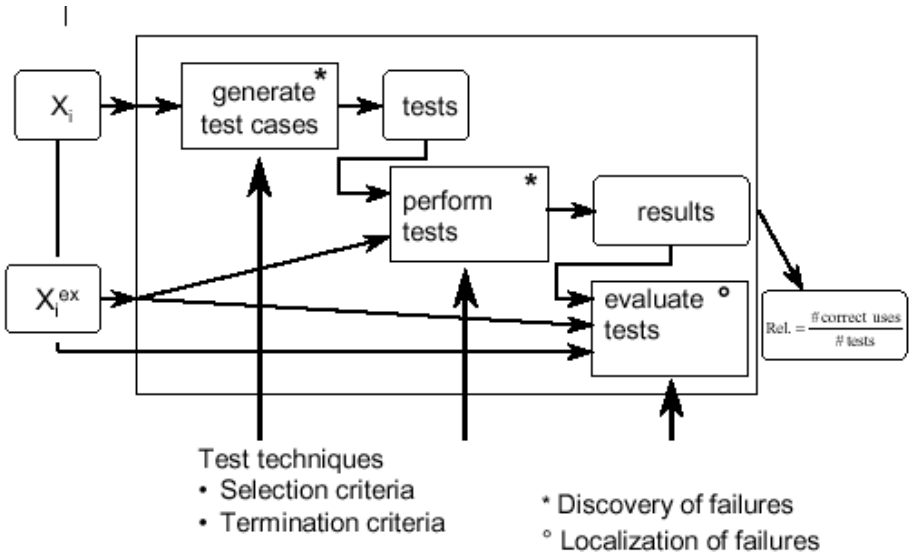
- Show graphically and numerically coverage (statements, branches, conditions) on source code
- Ex., Clover, Jcoverage, Cobertura, Eclemma

Profilers

- Trace time spent per function, given specific test execution
  - Performance test

Test documentation

Test process



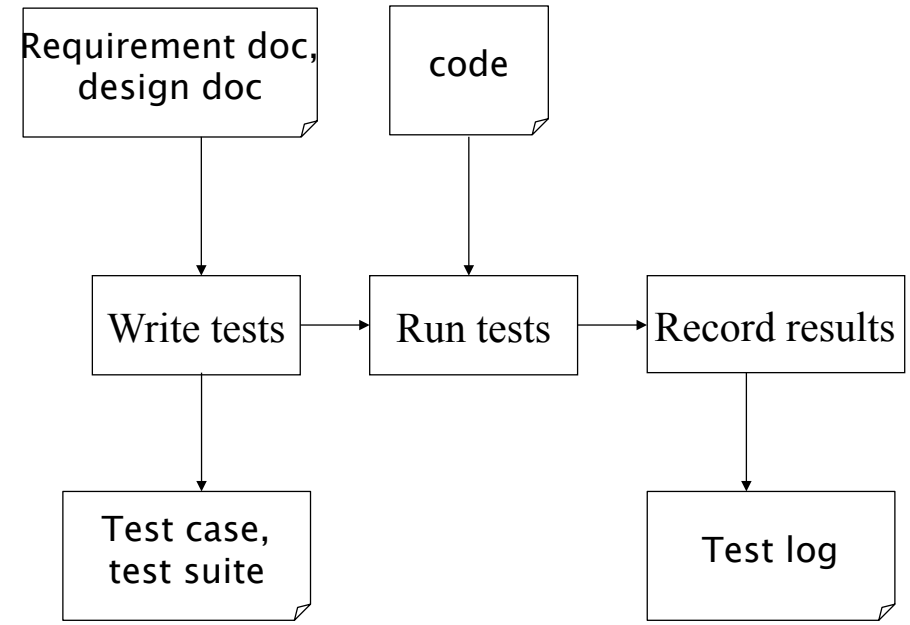
Test Process Standard

- IEEE Standard for Software Test Documentation (Std. 829-2008, revised Std. 829-1998, revised Std. 829 1983).
- Defines the deliverables to be produced by the testing process
- Avoid duplication between documents and between documents and tools

Integrity levels

- Catastrophic
- Critical
- Marginal
  - Software must execute correctly or an intended function will not be realized causing minor consequences. Complete mitigation possible.
- Negligible
  - Software must execute correctly or intended function will not be realized causing negligible consequences. Mitigation not required.

Test activities



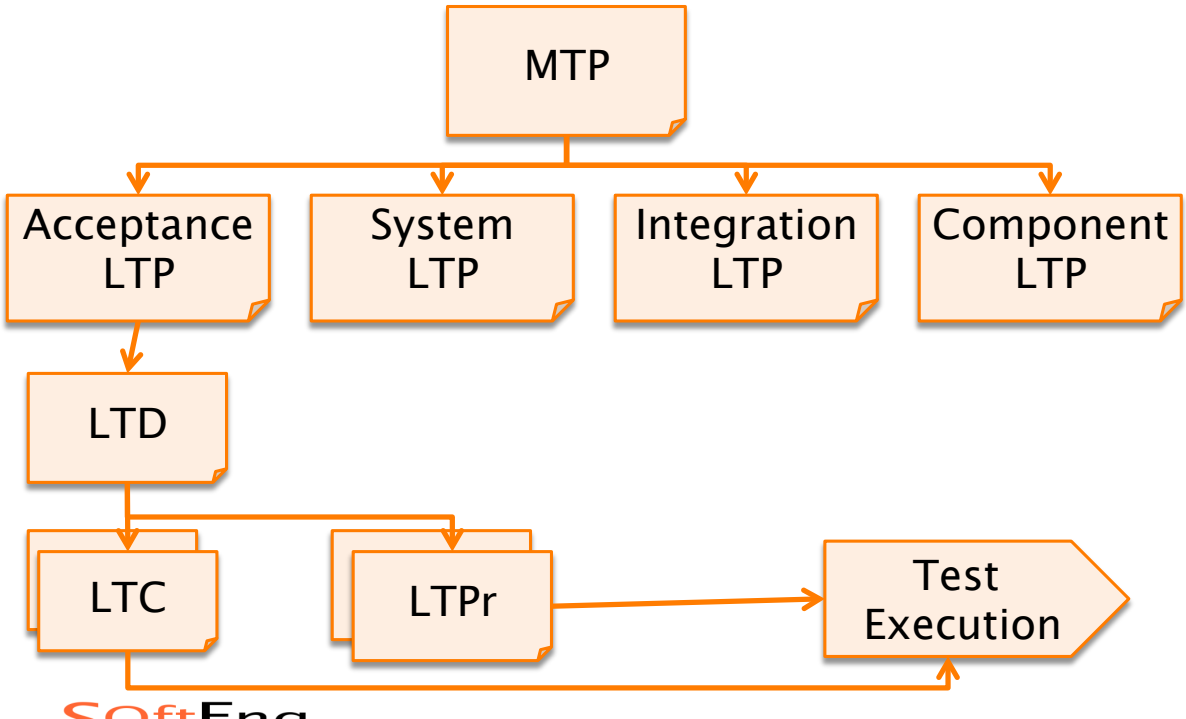
Test levels

- Specific for each company, e.g.
  - Component
  - Component Integration
  - System
  - Acceptance

Deliverables

- Planning and specification documents
  - MTP Master Test Plan
  - **LTP** Test Plan
  - **LTD** Test Design
  - **LTC** Test Case
  - **LTPr** Test Procedure
- Enactment documents
  - **LTL** Test Log
  - AR Anomaly Report
  - ITSR Interim Test Status Report
  - LTR Test Report
  - **TSR** Master Test Report

Relationship among deliverables



Master Test plan

- Guide the management of testing
- Establish a plan and schedule
- Define the required resources
- Define the generic pass/fail criteria
- Identify the test items
- Explain the nature and extent of each test

Level Test Plan

- Define testing activities:
  - scope, approach, resources, and schedule
- Identify
  - items being tested,
  - features to be tested,
  - testing tasks to be performed,
  - personnel responsible for each task,
  - associated risk(s).

Deliverables

- Planning and specification documents
  - **TP** Test Plan
  - **TDS** Test Design Specification
  - **TCS** Test Case
  - **TPS** Test Procedure Specification
- Enactment documents
  - **TTR** Test –item Transmittal Report
  - **TL** Test Log
  - **TIR** Test Incident Report
  - **TSR** Test –Summary Report

Test plan

- Guide the management of testing
- Establish a plan and schedule
- Define the required resources
- Define the generic pass/fail criteria
- Identify the test items
- Explain the nature and extent of each test

Traceability matrix

- Map tests to requirements
- May be part of test plan or in some other place

	Req x.1	Req x.2	Req y.1
Test 1	X	X	
Test 2	X		
Test 3			X

Test-to-requirement Correspondence Table

Test design specification

- Specifies, for one or more features to be tested the details of the approach
  - Testing techniques
  - Analysis of results
  - List of test cases and motivation
  - Generic attributes

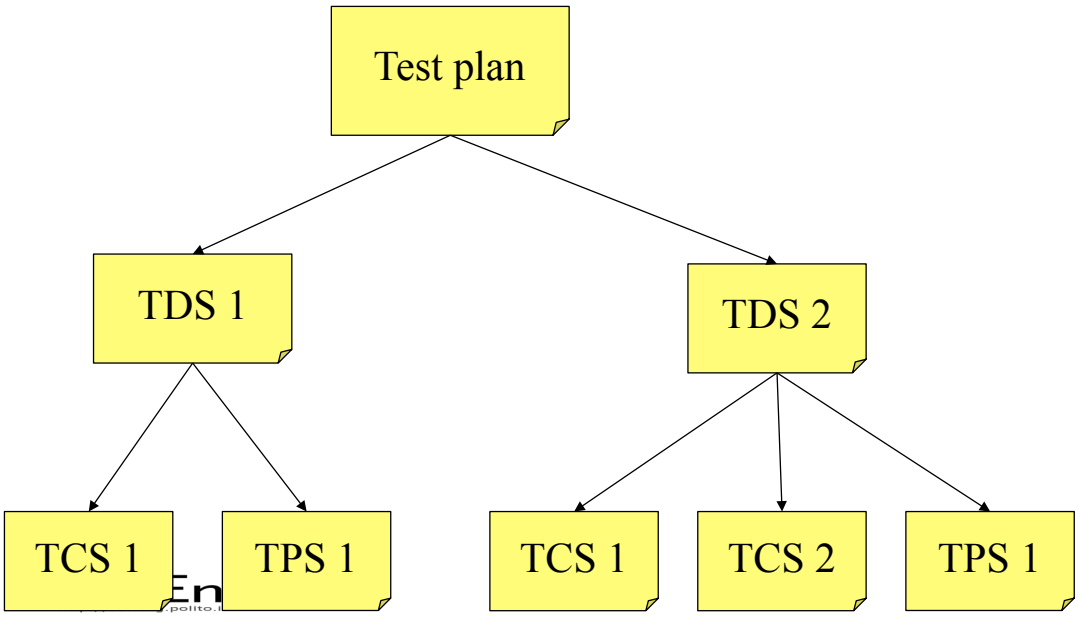
Test case specification

- Specifies a test case in terms of
  - Goal
  - Input data
  - Expected output (oracle)
  - Test conditions
    - Required HW and SW
  - Special procedural requirements
  - Inter-test dependencies
- The test case is listed in a TDS document

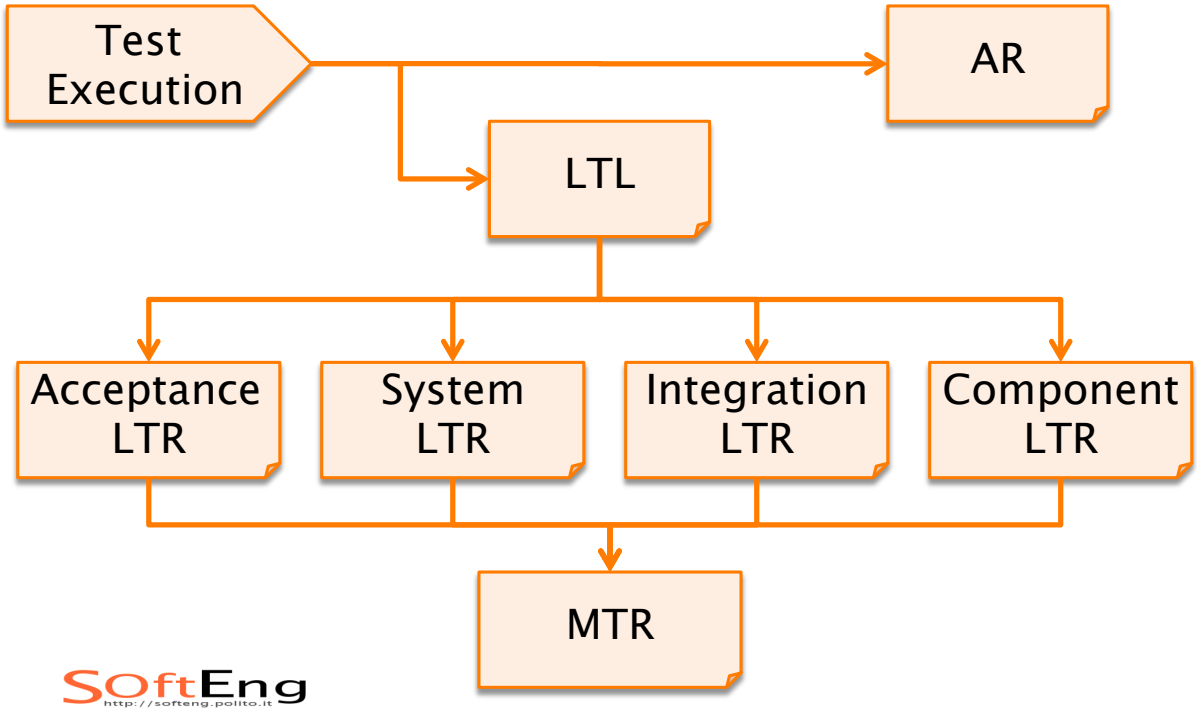
Test procedure specification

- Specifies how to execute one o more test cases
- The test procedure defines:
  - How to prepare the execution of the test
  - How to start and conduct the execution
  - Which measurements to collect
  - How to suspend the test in presence of unforeseen events
  - How to resume a suspended test

Relationship among deliverables



Execution Deliverables



Execution deliverables

- Test item transmittal report
  - Describes a test item delivered for test
  - Includes at least
    - Identification of sw item
    - Its status
    - Its physical location
- Test log
  - Complete, systematic, chronological records of all details relative to test execution

Test-Incident Report

- Test incident:
  - Any event occurred during testing requiring further investigation
- TIR documents all test-incidents
  - Input
  - Expected output
  - Actual output
  - Anomalies
  - Time
  - Attempts to re-execute the test
  - Personnel

Test summary report

- Summarizes the result of a testing session
- Includes
  - List of solved incidents
  - Solutions applied
  - List of unsolved incidents
  - Evaluation of test limitations

Level Test Log

- Provides a chronological record of relevant details about test execution
  - An automated tool may capture all or part of this information
- Relevant info:
  - Execution description
  - Procedure results (success or failure)
  - Environment (deviation)
  - Anomalies

Anomaly Report

- Document any event that occurs during the testing process that requires investigation.
- Time and context
- Description
  - Input
  - Expected output
  - Actual output
  - Anomalies
- Impact

Interim Test Status Report

- Summarizes the results of testing activities
  - Test status summary
  - Changes from plans
  - Test status metrics

Level Test Report

- Summarizes the results of the designated testing activities
  - Overview of results
  - Detailed results
    - Open and resolved anomalies
    - Test executed and collected metrics
    - Test assessment (e.g. coverage metrics)
  - Recommendations
    - Test items evaluation
    - Suitability for production use

Master Test Report

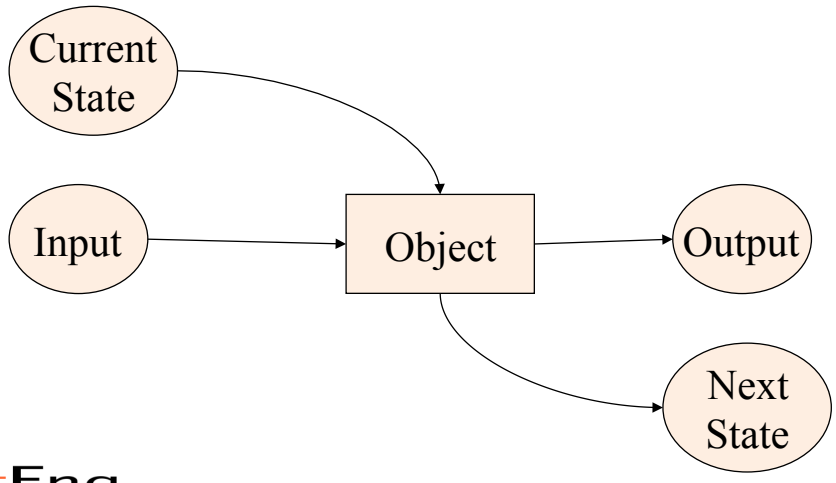
- Summarizes the result of all testing activities
  - Test activities
  - Test tasks results
  - List of anomalies and resolutions
  - Assessment of release quality
  - Summary of collected metrics

Object-oriented sw test

- Procedural
  - Basic component: procedure
  - Test method: procedure I/O
  - A procedure call is statically bound to a code
  - Procedures keep the same context
- OO
  - Basic components: class (data+operation), object
  - Test methods: several levels
  - Polymorphism and dynamic binding can change it at run-time
  - Methods can be inherited by several classes

OO sw test

- The behavior depends on the state too
- It may be difficult to observe the state



Static analysis

- Static
  - inspections
  - source code analysis 
- Dynamic
  - testing

Static analysis techniques

- Compilation static analysis
- Control flow analysis
- Data flow analysis
- Symbolic execution
- Inspections

Compilation analysis

- Compilers analyze the code checking for
  - Syntax correctness
  - Types correctness
  - Semantic correctness
- The errors detected by a compiler strongly depend on the language
  - Loose vs. strongly typed languages
  - Static vs. dynamic visibility

MISRA-C

- MISRA: Motor Industry Software Reliability Association
- Issues Misra-C, guidelines for C programs
  - Issue1, 1998
    - 127 rules, 93 compulsory
  - Issue2, 2004
    - 141 rules, 121 compulsory

Rules, examples

5 Use only characters in the source character set. This excludes the characters $ and @, among others.

22 Declarations of identifiers denoting objects should have the narrowest block scope unless a wider scope is necessary.

34 The operands of the && and || operators shall be enclosed in parenthesis unless they are single identifiers.

67 Identifiers modified within the increment expression of a loop header shall not be modified inside the block controlled by that loop header.

103 Relational operators shall not be applied to objects of pointer type except where both operands are of the same type and both point into the same object.

Rule 5

signed char dollar = '$';

- not accepted

signed char esc_m = '\m';

- not accepted (what would be the associated behaviour to this escape sequence?)

Rule 34

```
if ((var++) || (num == 11)){...} /* OK */
if (var++ || num == 11){...} /* NOT OK */
if ((vect[num]) && (num == 11)){...} /* OK */
if ((structure.field != 0) && (num < 11)){...} /*
   OK */
if (vect[num] == 4 && (num == 11)){...} /* NOT
   OK */
```


Rule 67

```
for (int i = 0; i< max; i++){

  i=i+1;  // NO
}
```

Misra static analyzers

- Parse source code and check if rules are violated
  - QA-C by Programming Research, is a full featured MISRA C1 and C2 validator.
  - Testbed by LDRA, offers a static and dynamic analysis.
  - PC-Lint by Gimpel, is one of the fastest and least expensive validtors.
  - DAC by Ristan-CASE, provides a reverse engineering, documentation and code analyzer.

Bad Smells (Fowler)

- Fowler et al., Refactoring, Improving quality of existing code

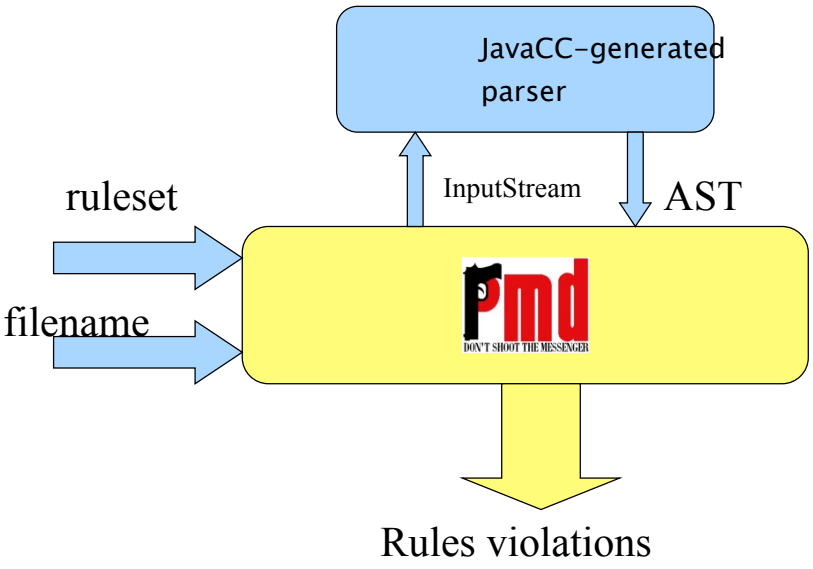
Bad smells

- Duplicated code
- Long method
- Large class
- Long parameter list
- Divergent change
- Shotgun surgery
- Feature envy
- Data clumps
- Primitive obsession
- Switch statements
- Parallel inheritance hierarchies
- Lazy class
- Speculative generality
- Temporary field
- Message chain
- Middle man
- Inappropriate intimacy
- Alternative classes with different interfaces
- Incomplete Library class
- Data class
- Refused bequest
- Comments

Java analyzers

- PMD
  - pmd.sourceforge.net
- Findbug
  - findbug.sourceforge.net

PMD



For each rule

PMD, rules

- empty try/catch/finally/switch statements...
- Dead code – unused local variables, parameters and private methods...
- Suboptimal code – wasteful String/ StringBuffer usage...
- Overcomplicated expressions – unnecessary if statements, for loops that could be while loops...
- Duplicate code – copied/pasted code means copied/pasted bugs

Findbug, rules

- Correctness bug:
  - Probable bug – an apparent coding mistake resulting in code that was probably not what the developer intended.
- Bad Practice
  - Violations of recommended and essential coding practice. Examples include hash code and equals problems, cloneable idiom, dropped exceptions, serializable problems, and misuse of finalize.
- Dodgy
  - Code that is confusing, anomalous, or written in a way that leads itself to errors. Examples include dead local stores, switch fall through, unconfirmed casts, and redundant null check of value known to be null.

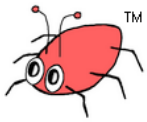
PMD and FIND BUGS: let's try!

- Let's run the plugins with the following piece of code

SmellChallenger.java

```
1  package it.polito.softeng;
2
3  public class SmellChallenger {
4
5      private int unread;
6
7      public void print_a_null_string(){
8
9          String s = new String("I'm not null...yet");
10         s=null;
11         System.out.println(s.length());
12
13     }
14
```

Results comparison



Avoid unused private fields → `private int unread;` ← Unused field

Methods names should not contain underscores → `public void print_a_null_string(){`

Avoid instantiating String objects: it's usually unnecessary

Avoid variables with short names

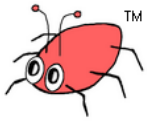
`String s = new String ("I'm not null...yet");`

Dead store to variable s

Invokes inefficient new String(String) constructor

SOftEng http://softeng.polito.it

Results comparison



Anomaly: A recently defined variable is redefined. This is ominous but don't have to be a bug.

Assigning an Object to null is a code smell. Consider refactoring. → `s=null;`

System.(out|err).print is used, consider using a logger.

```
System.out.println
(s.length());

}
```

Null point deference of s

Load of known null value

SOftEng http://softeng.polito.it

Data flow analysis

- Analyzes the values of variables during execution to find out anomalies
- Looks like dynamic but some information can be collected statically
- Three operations on variables
  - Definition: – write– a new value is assigned
  - Use: – read– the value of the variable is read
  - Nullification: the variable has no significant value

Data flow analysis

- Correct sequences
- D U
  - The use of a variable must be always preceded by a definition of the same variable
- Suspect (forbidden) sequences
- D D
- N U
  - A use of a variable not preceded by a definition corresponds to the use of an undefined value

Data flow analysis

- Tools recover the sequence and recognize suspect ones

	x1	x2	x
`void swap(float*x1, float* x2){`	D	D	–
`int float x;`	–	–	N
`*x2 = x;`	–	D	U
`*x2 = *x1;`	U	D	–
`*x1 = x;`	D	–	U
`}`			

`x = *x2;`

Symbolic execution

- The program is executed with symbolic values instead of actual values
- Output variables are expressed as symbolic formulas of input variables
- Symbolic execution may be extremely complex even for simple programs

Symbolic execution

```
1 integer product (int x, int y, int z){
2   int tmp1, tmp2;
3   tmp1 = x*y;
4   tmp2 = y*z;
5   return tmp1 * tmp2 / y;
6 }
```

Stmt	*x*	*y*	*z*	*tmp1*	*tmp2*	*product*
2	X	Y	Z	?	?	?
3	X	Y	Z	X*Y	?	?
4	X	Y	Z	X*Y	Y*Z	?
5	X	Y	Z	X*Y	Y*Z	X*Y*Y*Z / Y