Software Development Project

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My Weekend (AKA Research Time!)

- Current project requires a Java parser (i.e., a tool that can interpret Java source code)
- Simple enough, there are plenty of existing parsers (for example, in Eclipse), so adapt
  - set of rules that describe the language (250ish)

```
rule AdditiveExpression
     MultiplicativeExpression ( ( PLUS / MINUS )
                    MultiplicativeExpression )*
end
```

Does it Work?

- All the rules are written (based on the spec), so how do we know if it works?
- Test it on a simple program!

```
public class hello {

    // method main(): ALWAYS the APPLICATION entry point
    public static void main (String[] args) {
        System.out.println ("Hello World!");
    }
}
```

Does it Work?

- All we know is whether it works with the given input or not?
  - no means more work
  - what about yes?
- Evaluate what yes means...

Does it Work?

- Further testing
  - tested on 60 selected Java programs
    - 4 worked
- Iterative fixes finally resulted in all 60 working
  - more testing?

Yes!

- Tried to parse 20,000 Java programs
  - 27 failed to parse
- A problem?
  - depends. All 27 relied on deprecated features in Java
- Does it work?
  - depends
  - `5 = a` parses

Some Truths About Testing

- It is impossible to completely test a program
- Testing cannot show that a program does not have any errors
- All errors will not be fixed
- It can be difficult to determine if something is an error or not
- Requirements and specifications will change

Not New

- *"an analyzing process must equally have been performed in order to furnish the Analytical Engine with the necessary operative data; and that herein may also lie a possible source of error. Granted that the actual mechanism is unerring in its processes, the cards may give it wrong orders"* (Ada Lovelace, 1815-1852)
- *"It has been just so in all of my inventions. The first step is an intuition, and comes with a burst, then difficulties arise—this thing gives out and [it is] then that 'Bugs' — as such little faults and difficulties are called — show themselves and months of intense watching, study and labor are requisite..."* (Thomas Edison, 1847-1931)

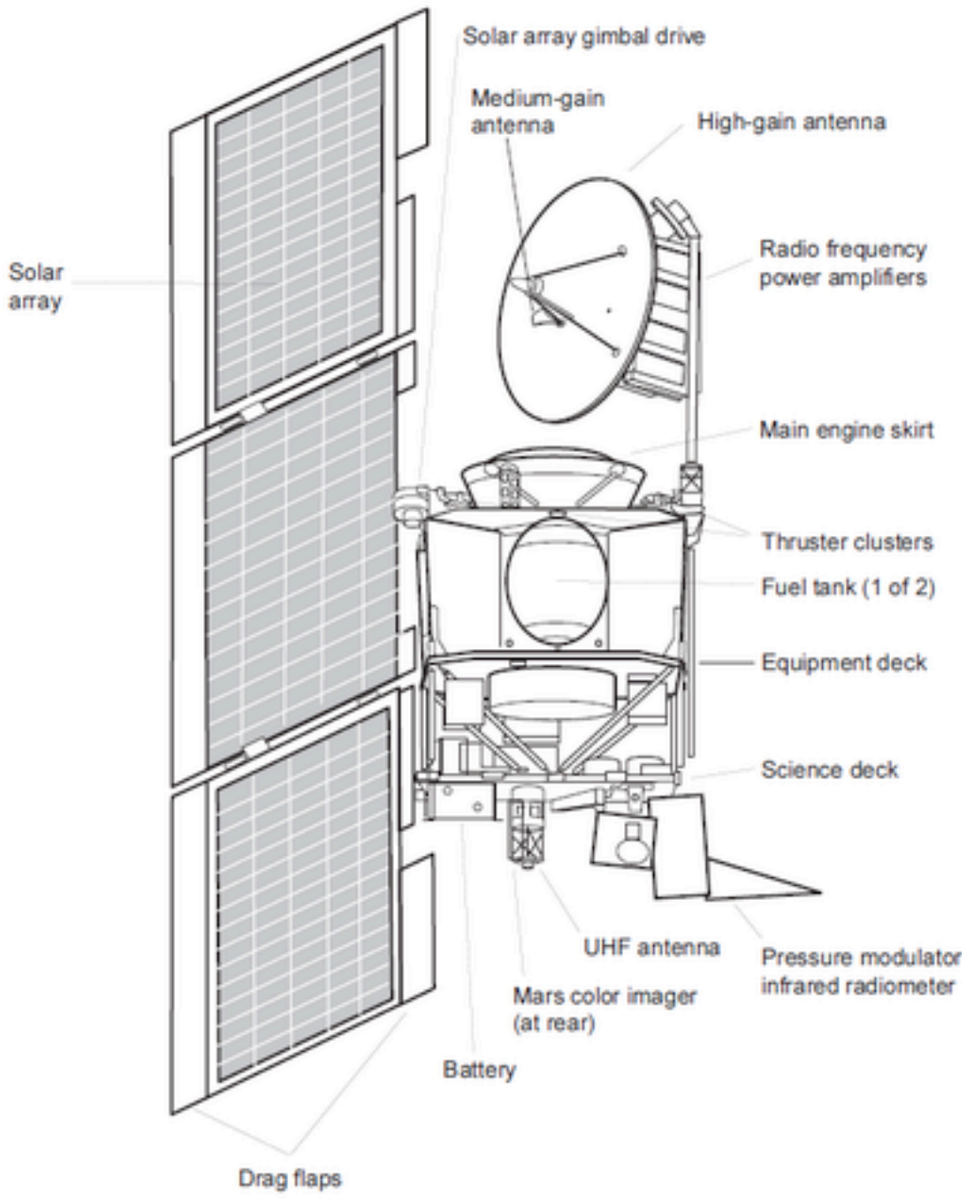
Why Should We Care?

- NIST (National Institute for Standards and Technology) determined that software errors cost $60B / year (2002)
- Industry average, 15-50 errors / KLOC (release)
- Microsoft, 0,5 errors / KLOC (release)
  - Windows Vista, 50 000 KLOC

Pentium FDIV

- Certain inputs result in the wrong result / precision
- On average 1 error per 9^10*9 operations (random data)
- 5 out of 1066 rows in a table where wrong due to incorrect loop conditions
- intel spent about $500M (estimate) to replace CPUs

Mars Climate Orbiter



- Navigation errors resulted in an approach at too low orbit, and was destroyed on entry
- Two systems used different units
  - Pounds-seconds
  - Newton-seconds
- Approx. $330M

Ariane 5 (flight 501)

- Exploded 37s after launch
- Software from Ariane 4 was reused
  - Changed requirements
  - Different trajectory
- 64bit numbers converted to 16bit (overflow exception)
- But, exceptions were not handled for performance reasons...

Is a Program Correct?

- Prove it
- Show that a model (that is presumably implemented by the program) has certain properties
- Test if the program has certain properties

Prove Correctness

- Use formal methods (maths) to prove that a program is correct
- Quite difficult and involved, even for small programs
- Generally not practical, even for safety-critical programs

Test a Model

- Extract an abstract model from a program and show that the model is correct
- Shows properties for all executions
- In practice,
  - difficult to show non-trivial properties
  - for programs with non-trivial structure

Example

- seL4, an operating system kernel
  - 7,500 lines of C code
  - 200,000 lines of proof
  - 25-30 man years (research project)
  - Due to project contributions, they claim a similar proof can be done in about 10 man years

So, Testing...

- "Execute" the program and see if it behaves correctly
  - static: read, inspect, analyse
  - dynamic: run
- Realistic and always necessary
- *"Beware of bugs in the above code; I have only proved it correct, not tried it"* (Donald Knuth)

Static Testing

- Read the code and look for (common) errors
  - are all variables initialized?
  - are loop conditions correct?
  - are array indices within bounds?
  - ...
- Tools can help

Example

```
public int countPositive(int[] x) {
   int count;
      for (int i=1; i<=x.length; i++) {
         if (x[i]>=0) count++;
      }
      return count;
}
```

Dynamic Testing

- Run the program (incl. compilations) and see what happens
- Test different inputs, check outputs
- One run tests one set of inputs!

Example

```
public int countPositive(int[] x) {
   int count=0;
     for (int i=1; i<x.length; i++) {
       if (x[i]>=0) count++;
     }
     return count;
  }

a=countPositive([1,2,3,4]);       //a==3
b=countPositive([-1,2,-3,4]);      //b==2
c=countPositive([-1,-2,-3,-4]); //c==0
```

Verification/Validation

- Often used incorrectly
  - Verification, check according to specification
  - Validation, check according to initial requirements
- Verification: You implemented it correctly
- Validation: You implemented the correct thing

Test Cases and Suites

- A test case represents an execution of a program
  - input and expected output
  - e.g., ([-1,2,-3,4], 2)
- A test suite is a set of test cases.

Black Box Testing

- Consider the program that is tested as a black box (impenetrable)
- Testing does not consider source code or internal properties
- Provides input, checks output
- Useful to test systems or when there is no available source code

White Box Testing

- Look inside the box
- Use source code to create test cases

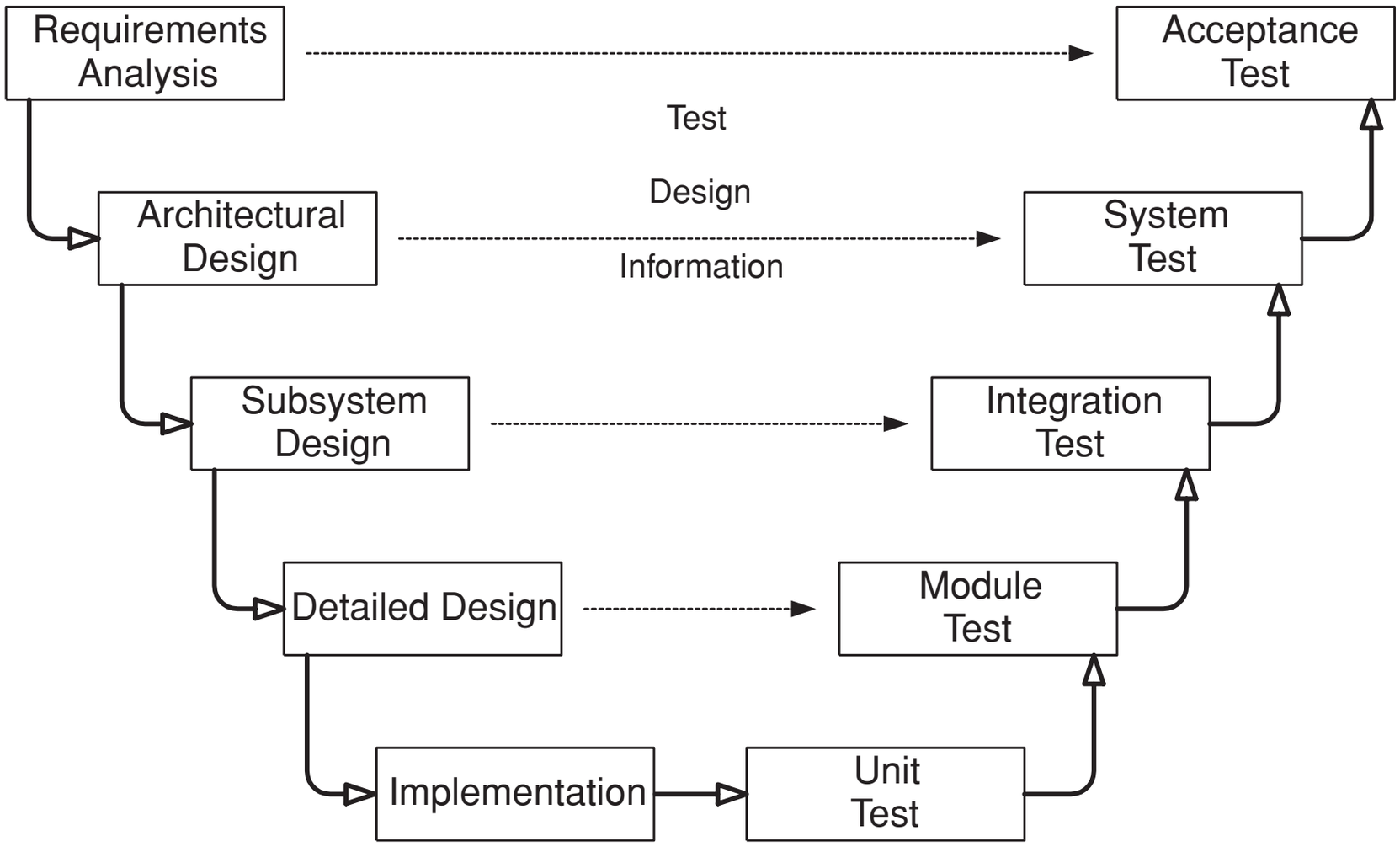
Coverage

- Measures what a test suites tests, based on structural properties, e.g.
  - which lines of code are executed
  - which boolean expressions are evaluated to both true and false during a test
  - which control flows are tested?

Coverage

- Often used as a quality measure of the testing / test suite
  - higher coverage is better
  - not a very good measure, but...
  - easy to understand and reason about (when white box testing)

When / What Do We Test?



Pass or Fail?

- Test-to-Pass, tests if the program works
  - simple test cases
    - that should work
- Test-to-Fail, tries to break the program
  - evil test cases
  - that might not work

Initial Example

- Black box testing
  - I had the source, but did not consider it
  - First 60 cases, test to pass
  - Next 20,000 cases, test to fail (approx).
  - Why start with test to pass?

A Good Approach?

- 60 + 20,000 randomly selected Java programs
  - so, in a sense, double black box
- Reasonable?
  - quite slow (1 test / second = 5+ hours)
  - all 27 problems were "identical" ("so 1 told me something, 26 did not")

A Better Approach?

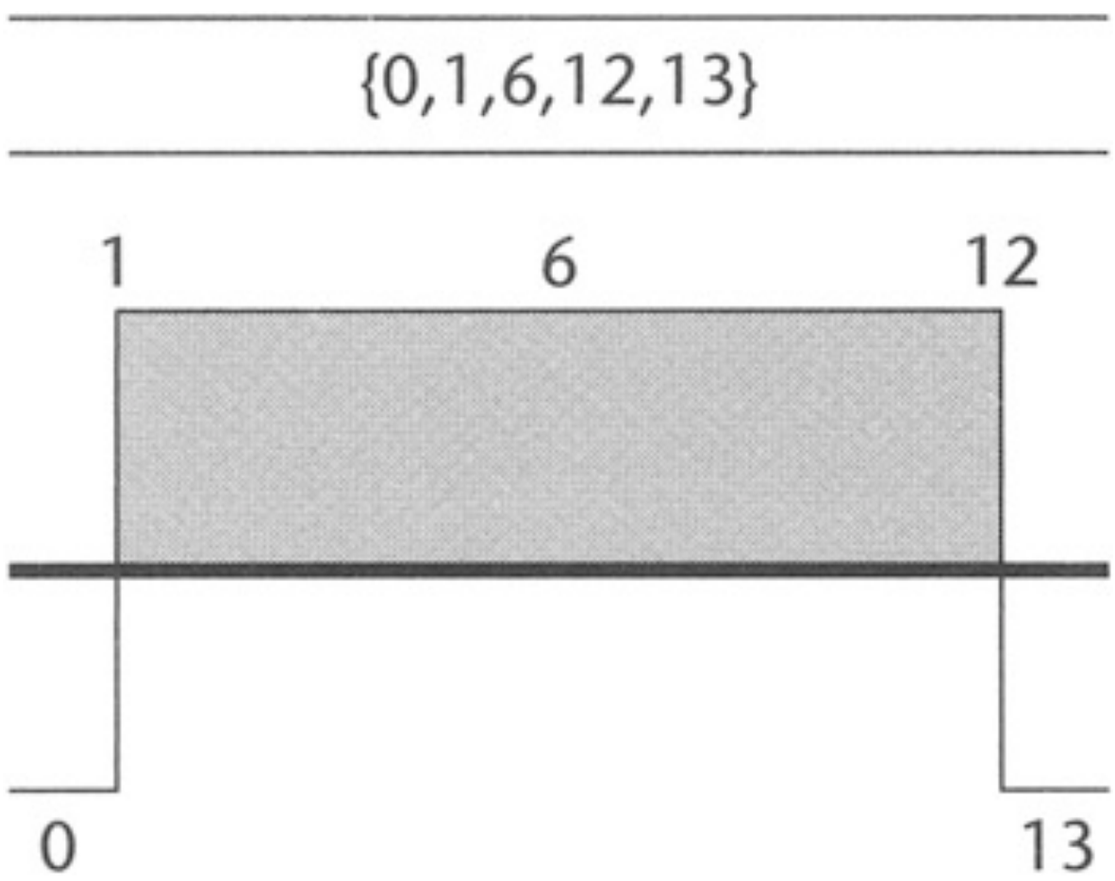
- Consider the program a function
  - with a domain and a range
  - Partition the domain into blocks with similar properties
    - test a block
    - test between blocks (edges)

Example

P_1: x<y	P_2: x=y	P_3: x>y
<(1,2), 2>	<(1,1),1>	<(3,2),3>
<(3,9), 9>	<(3,3),3>	<(3,2),3>
...	...	...

Testing a function that determines the larger of two integers

Example

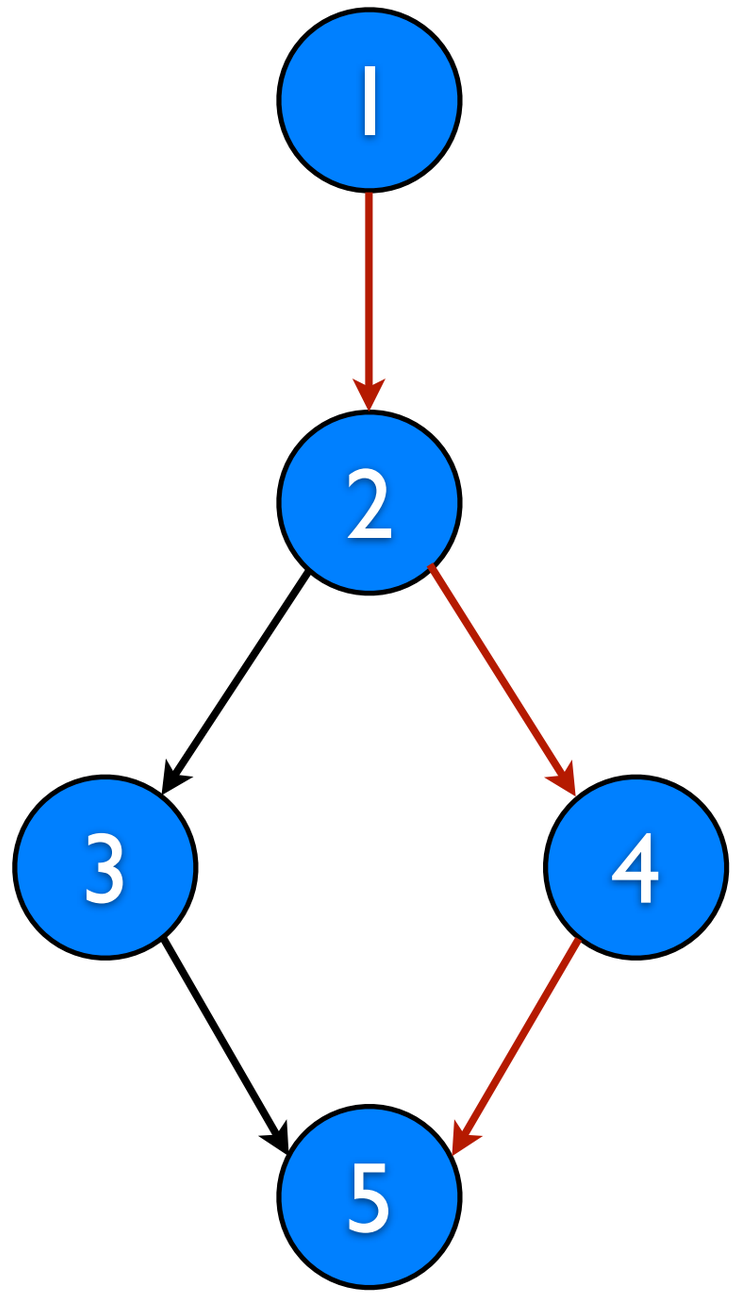


White Box

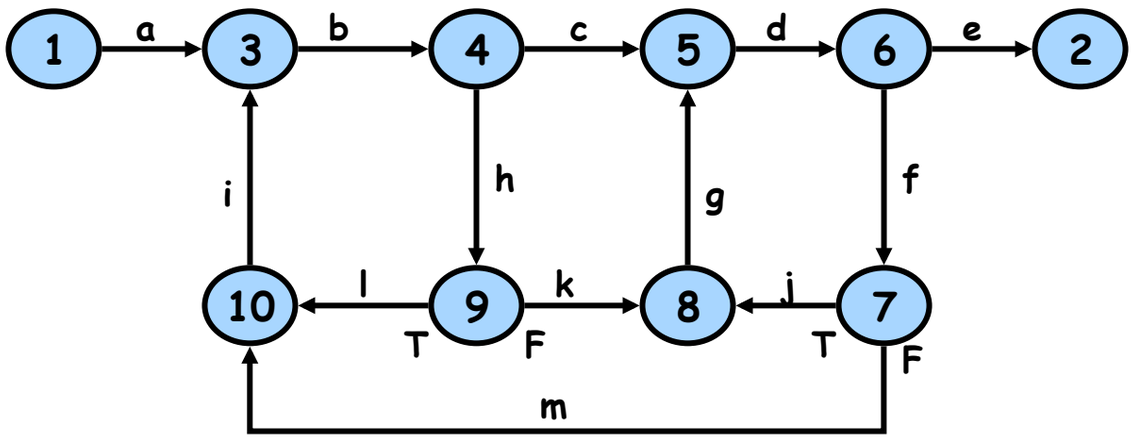
- Find paths through the program ...
- ... and make sure you cover these
- Statement coverage
- Branch coverage

Example

```
   int max(int x, int y)
   {
1:    int max;
2:    if(x>y)
3:       max=x;
      else
4:       max=y
5:    return max;
   }
```



Example



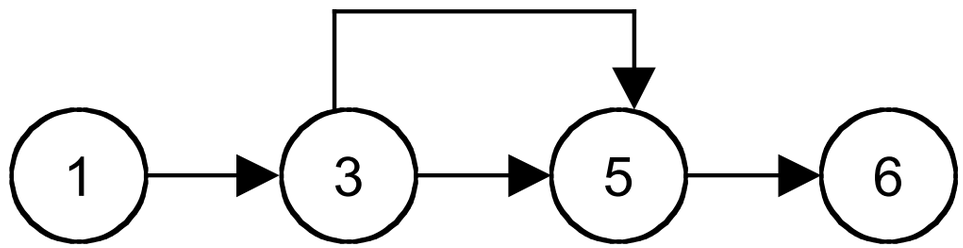
PATHS	DECISIONS				PROCESS LINKS											
	4	6	7	9	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
abcde	*T*	*T*			*	*	*	*	*								
abhkgde	*F*	*T*		*F*	*	*		*	*		*	*			*		
abhlibcde	*TF*	*T*		*T*	*	*	*	*	*		*	*	*			*	
abcdfjgde	*T*	*TF*	*T*		*	*	*	*	*	*	*			*			
abcdfmibcde	*T*	*TF*	*F*		*	*	*	*	*	*		*	*				*

Sunt förnuft

"The more we learn about testing, the more we realize that statement and branch coverage are minimum floors below which we dare not fall, rather that ceilings to which we should aspire." (B. Beizer)

Example: ABS

```
/* ABS
This program function returns the absolute value of
the integer passed to the function as a parameter.
    INPUT: An integer.
    OUTPUT: The absolute value if the input integer.
*/
1   int ABS(int x)
2   {
3     if(x < 0)
4       x = -x;
5     return x;
6   }
```

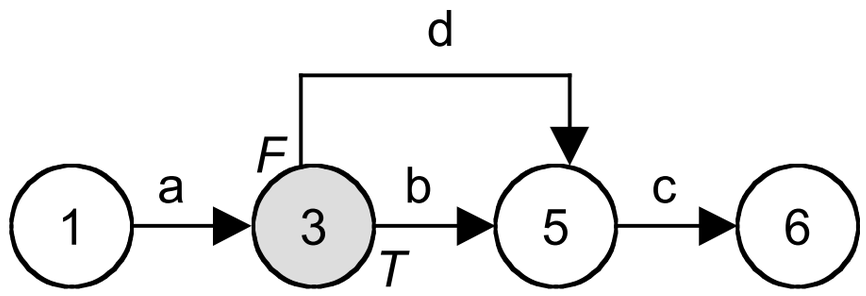


Example: ABS

- Possible to completely test ABS
- Since there is a maximum integer
- However, not practical since since we often use either 32-bit or 64-bit integers
  - so, best case, 2^32 test cases

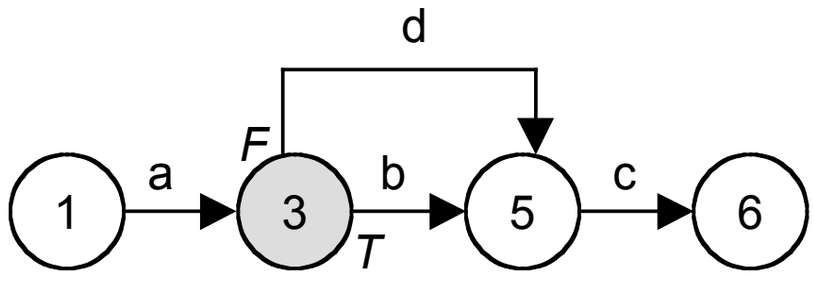
Statement Coverage

PATHS	PROCESS LINKS				TEST CASES	
	a	b	c	d	INPUT	OUTPUT
abc	√	√	√		A Negative Integer, x	-x
adc	√		√	√	A Positive Integer, x	x



Branch Coverage

PATHS	DECISIONS	TEST CASES	
		INPUT	OUTPUT
abc	T	A Negative Integer, x	-x
adc	F	A Positive Integer, x	x



Unit Testing

“If code has no automated test cases to show it works, then the assumption must be that it doesn't”

Unit Testing

- Parts of the source code (s.k. units) are tested
- A unit is the smallest testable entity
  - Often procedure / method
- White box
- Often written by the developer (TDD)
- Often automated

Benefits

- Makes it easier to change the code
  - test checks so everything still works
- Supports integration testing
  - shows that each unit works
  - (but not the same thing)

Benfits (more later)

- Living documentation
  - Shows how the API/methods should be used
  - Illustrates cases that are important
- Design
  - If (and they should) the test cases are written before implementation, they can guide the implementation

Form

- Unit tests call or executes part of the source code
- The result is validated by asserting facts
  - e.g. assertNotEqual(“apple”,“orange”)

Acceptance Testing (XP)

- Tests a user story
  - from a "customer" perspective
  - The customer can accept or reject
  - Testing should be at least modeled by the customer
  - AKA functional testing or customer testing