Model-Based Testing

(DIT848 / DAT260)

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Lecture 3
White Box Testing - Coverage

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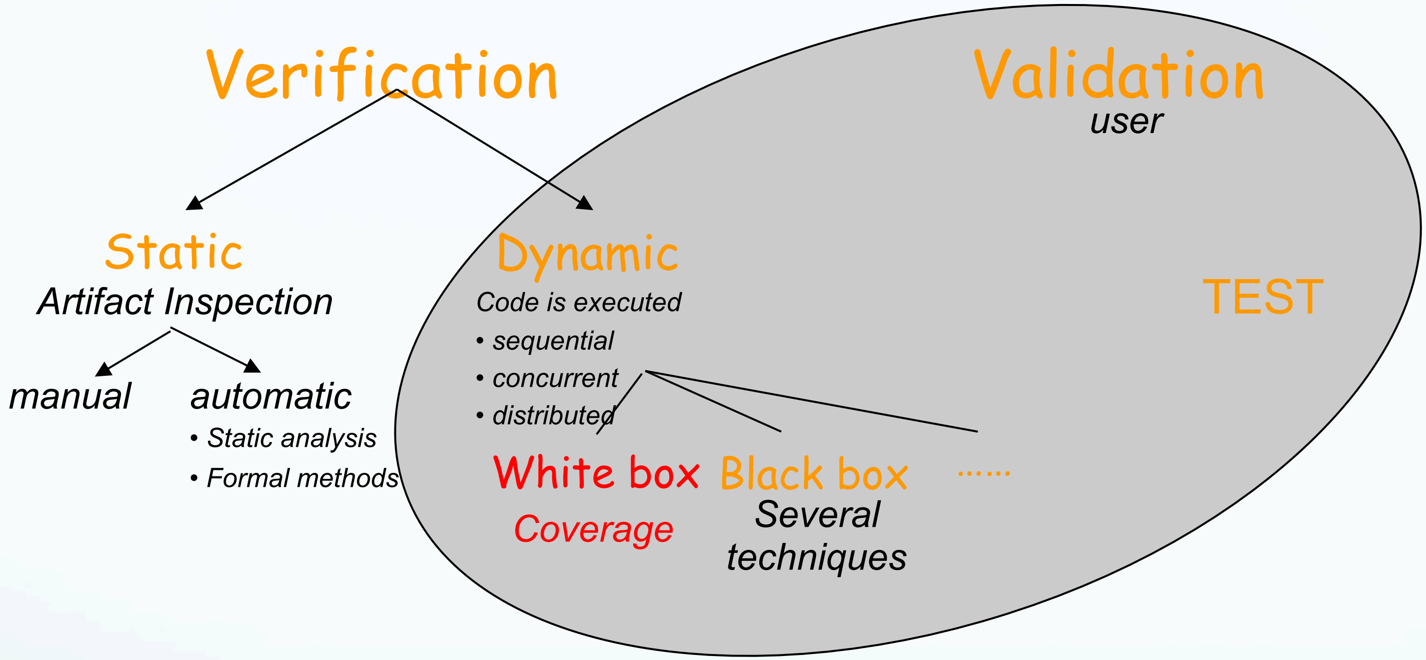
Some slides based on material by Magnus Björk, Thomas Arts and Ian Somerville

What have we seen so far?

- V&V: Validation & Verification
- The V model
  - Test levels
- Black box testing
- (Extended) Finite State Machines

Any question?

Today's topic



White box testing

Do I need more test cases?

- I think I have test cases for all aspects of the specification,
- I've added test cases for boundary values,
- …guessed error values,
- …and performed 10.000 random test cases.

Is that enough?

Do I need more test cases?

- The bad:
  - There is no way to know for certain

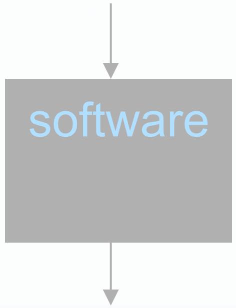
- The good:
  - There are techniques that can help us
    - Identify some aspects that may otherwise go unnoticed
    - Give some criteria for "enough"

Coverage techniques

Black box and White box testing

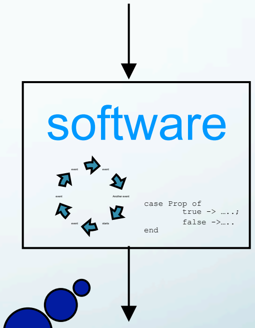
Black box testing: Test tactic in which the test object is addressed as a box one **cannot** open.

A test is performed by sending **a sequence of input values** and observing the output *without using any knowledge about the test object internals.*



White box testing: Test tactic in which the test object is addressed as a box one **can** open

A test is performed by sending a **sequence of input values** and observing the output and internals while explicitly *using knowledge about the test object internals*



Also called
Structural testing or
Glass box testing

What white box testing is not

- White box testing is (typically) **NOT**:
  - Black box test cases that refer to internal constructs

Id: calc.h/pressPlus/1
Purpose: verifying that the correct operation is stored
Precondition: state is a CalcStatePtr pointing to a valid calculator state
Action: call pressPlus(state)
Expected outcome: state->op = Plus

Refers to internal representation, not interface

- Drawbacks of test cases like this:
  - Test properties not in specification
  - Fail if internal representation is changed
  - And when they fail, it may be hard to understand why/where
- …but sometimes they may be necessary
  - Unit testing of internal functions

What white box testing is

- 'Normal' white box testing is:
  - Black box testing, combined with tools that analyze implementation specific properties
- White box techniques covered in this lecture
  - Code coverage analysis
    - Are there parts of the code that are not executed by any test cases?
    - Used to find inadequacies in the test suite
  - Assignment: EclEmma (Java)
  - In this lecture: Some examples in C (GCov) and functional programming

Coverage checking

Coverage checking

The structure of the software is used to determine whether a set of tests is a sufficient/adequate one

Thus:

1) Decide which structure to consider
2) Decide upon coverage criteria
3) Find a set of tests such that this structure is covered according to the decided criteria

Common structures

- **Function coverage**
  - All functions have been executed
- **Entry/exit coverage**
  - All entry and exit points of all functions have been executed
    - *Entry* points: all calls to a function
    - *Exit* points: each return statement
- **Statement coverage** (lines of code)
  - All lines of code have been executed
- **Branch coverage** (condition coverage)
  - If: both "if" and "else" part, even if no else part
  - While loop: both with true and false conditions
  - Lazy logical ops (&& and ||): first arguments both true and false
- **Path coverage**
  - All possible routes through the code (combination of branches)
  - Infinitely many if there are while loops (only feasible for small functions)
- More on later lecture…

How to cover exceptions?

Not easy, due to their dynamicity

Example (Coverage in Functional Prog.)

- Function from (pretended) ATM system

- Representation of amount of cash in machine:
  - [(100,23),(500,11)] means that machine contains:
    - 23 100kr bills
    - 11 500kr bills
  - We call it "pair-notes"

- Function to look at: *subtract*
  - subtract a number of notes - notes remaining in the ATM
  - `subtract(<list_of_pair-notes_to_withdraw>, <list_of_pair-notes_in_Bank>)`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

Expected output: `[{100,100},{500,1}]`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

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  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

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Example (Coverage in Functional Prog.)

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  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

`subtract([],subtract2(`**`500`**`,2,[{`**`100`**`,100},{500,3}])).`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

`subtract([],subtract2(500,2,[{100,100},{500,3}])).`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

`subtract([],subtract2(`**`500`**`,2,[{`**`100`**`,100},{500,3}])).`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

```
subtract([],[{100,100}|subtract2(500,2,[{500,3}])]).
```

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

```
subtract([],[{100,100}|subtract2(500,2,[{500,3}])]).
```

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

`subtract([],[{100,100}|subtract2(500,2,[{500,3}])]).`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

```
subtract([],[{100,100}|[{500,3-2}]]).
```

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

Evaluates to

`subtract([],[{100,100}|[{500,1}]]).`

Example (Coverage in Functional Prog.)

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Test case: `subtract([{500,2}],[{100,100},{500,3}]).`

output: `[{100,100},{500,1}]`

All statements and all branches have been executed. Matches expected output.

Example (Coverage in Functional Prog.)

Are we happy? Is the program correct?

What happen with the following?

Test case: `subtract([{500,2}],[{100,5},{500,3}]).`

It will **not** work!! The case [100,100] was a particular case; we inverted values!

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{V,M}|subtract2(Value,N,Notes)].
```

Example (Coverage in Functional Prog.)

Are we happy now? Is the program correct?

What happen with the following?

Test case: `subtract([{100,2}],[{100,100},{500,3}]).`

It will **not** work!! We are "loosing" the suffix of the list!

```
subtract([],Notes) ->
  Notes;
subtract([{Value,Nr}|Rest],Notes) ->
  subtract(Rest,subtract2(Value,Nr,Notes)).

subtract2(Value,N,[{Value,M}|Notes]) when M>=N ->
  [{Value,M-N}|Notes];
subtract2(Value,N,[{V,M}|Notes]) ->
  [{M,V}|subtract2(Value,N,Notes)].
```

Coverage (example in C)

```
void printPos(int n) {
   printf("This is ");
   if (n < 0)
      printf("not ");
   printf("a positive integer.\n");
   return;
}
```

Should be: <=

Actually: else { }

Code originally from Wikipedia

Are we happy with coverage?

Test case 1

Action: call printPos(-1)

Expected outcome:

”This is not a positive integer” (printed on stdout)

Coverage: 100% statement, 50% branch, 50% path

Test case 2

Action: call printPos(1)

Expected outcome:

”This is a positive integer” (printed on stdout)

Coverage: 100% statement, branch & path (including previous)

Test case 3

Action: call printPos(0)

Expected outcome:

”This is not a positive integer” (printed on stdout)

Fails!

Boundary value

Group exercise

- Come up with pieces of code (in any language) and a few test cases such that following conditions are met, or motivate why it is impossible:

1. 100% branch coverage, less than 100% path coverage
2. 100% path coverage, less than 100% statement coverage
3. 100% function coverage, less than 100% exit point coverage

Groups 2-5 persons: 10 min

Suggestions

1: 100% branch coverage, less than 100% path coverage

```
void foo(int n) {
 if(n>0)
  printf("Positive\n");
 else
  printf("Not positive\n");
 if(n % 2)
  printf("Odd\n");
 else
  printf("Even\n");
}
```

Id: Test case 1: pos/odd
Action: call foo(1)
Expected outcome:
 "Positive" and "Odd"

Id: Test case 2: neg/even
Action: call foo(-2)
Expected outcome:
 "Not positive" and "Even"

Path positive/even
not covered!

Suggestions

2: 100% path coverage, less than 100% statement coverage

Id: Test case 1
Action: run main
Expected outcome: "Hello world" printed

```
int main(void) {
  printf("Hello world\n");
  return 0;
  printf("Unreachable code\n");  }
```

This statement is **not** covered!

Suggestions

3: 100% function coverage, less than 100% exit point coverage

```
int abs(int n) {
  if(n < 0)
    return -n;
  return n;
}
```

Id: abs/1

Action: call abs(-17)

Expected outcome:
returns 17

Didn't cover this exit point

White box test design

Strategy for using coverage measure:

1. Design test cases using *black box test design* techniques
2. Measure code coverage
3. Design test cases by inspecting the code to cover unexecuted code

100% coverage does **not** mean there are no errors left!

So, code coverage should be seen as complementary method – It cannot do the thinking for you

However, coverage analysis catches aspects that are otherwise easily forgotten

Adding test cases after coverage analysis

- The new test cases should still be black box test cases, not referring to the code

Good test case:

Id: abs/2
Purpose: Execute abs on negative integer
Action: call abs(-17)
Expected outcome: Call returns 17

Bad test case:

Id: abs/2
Purpose: Cover line 3 of abs
Action: call abs(-17)
Expected outcome: Line 3 executed

Refers to code

Practical coverage analysis

In order to measure coverage, most languages require a compile flag to enable keeping track of line numbers during execution

Consequences:

- Performance changes, hence **timing related faults** may be *undiscoverable*
- Memory requirements change, hence one may experience problems running in embedded devices

There are a lot of tools available for many languages

Coverage vs Profiling

Both methods count executions of entities, but purpose is different

- Coverage tool: find out which entities have been executed, to establish confidence in verification
- Profiler: identify bottlenecks and help programmer improve performance of software

Example: Gcov (C)

The program **avg** (short for "average") reads a text file, whose name is given as a command line argument, containing a number of integers, and reports the average value of all the integers. The program has been implemented in C (see below and next page), and the following small test suite has been developed by a programmer to start testing the system:

Test case avg.1: Normal integers

Prerequisites: The file avgtest1.txt contains "10 15 35"

Action: Run ./avg avgtest1.txt

Expected outcome: The program prints "The average is 20"

Test case avg.2: Negative numbers

Prerequisites: The file avgtest2.txt contains "-2 2 -6"

Action: Run ./avg avgtest2.txt

Expected outcome: The program prints "The average is -2"

Executing this test suite together with gcov reveals that there is untested code, the tool giving the message "Lines executed: 63.33% of 30". The actual output from gcov can be seen in next slide.

NOTE: The uncovered statements are those lines preceded with ####

Example: GCov

```
-:    1:#include <stdio.h>
-:    2:#include <stdlib.h>
-:    3:
-:    4:// readInts: read a file containing integers, and return their
-:    5://           sum and the number of integers read.
-:    6:
-:    7:#define READINTS_SUCCESS 0     // Indicates success
-:    8:#define READINTS_FILEERR 1     // the file could not be read
-:    9:#define READINTS_SYNTAXERR 2  // syntax error in file
-:   10:
2:   11:int readInts(const char* filename, int* sumRslt, int* lengthRslt){
2:   12:  FILE* file = fopen(filename, "r");
2:   13:  if(!file)
#####:   14:    return READINTS_FILEERR;
-:   15:
2:   16:  *sumRslt=0;
2:   17:  *lengthRslt=0;
-:   18:  while(1) {
-:   19:    int theInt;
8:   20:    if(fscanf(file, "%d", &theInt) == 1) {
-:   21:      // Successfully read integer
6:   22:      (*sumRslt) += theInt;
6:   23:      (*lengthRslt)++;
-:   24:    } else {
-:   25:      // Could not read integer. End of file or syntax error?
2:   26:      if(feof(file)) {
-:   27:        // End of file
2:   28:        fclose(file);
2:   29:        return READINTS_SUCCESS;
-:   30:      } else {
-:   31:        // Syntax error
#####:   32:        fclose(file);
#####:   33:        return READINTS_SYNTAXERR;
-:   34:      }
-:   35:    }
6:   36:  }
-:   37:}
-:   38:
2:   39:int main(int argc, char**argv) {
-:   40:  int sum, length;
-:   41:  const char* filename;
-:   42:
2:   43:  if(argc < 2) {
#####:   44:    printf("Error: missing argument\n");
#####:   45:    exit(EXIT_FAILURE);
-:   46:  }
2:   47:  filename = argv[1];
-:   48:
2:   49:  switch(readInts(filename, &sum, &length)) {
-:   50:  case READINTS_FILEERR:
#####:   51:    printf("Error reading file %s\n", filename);
#####:   52:    exit(EXIT_FAILURE);
-:   53:
-:   54:  case READINTS_SYNTAXERR:
#####:   55:    printf("Syntax error in file %s\n", filename);
#####:   56:    exit(EXIT_FAILURE);
-:   57:
-:   58:  case READINTS_SUCCESS:
-:   59:  default:
-:   60:    break;
-:   61:  }
-:   62:
2:   63:  if(length==0) {
#####:   64:    printf("Error: no integers found in file %s\n",
filename);
#####:   65:    exit(EXIT_FAILURE);
-:   66:  }
-:   67:
2:   68:  printf("The average is %d\n", sum / length);
-:   69:
2:   70:  return EXIT_SUCCESS;
-:   71:}
```

Group exercise

- Provide additional test cases so that all cases together yield 100% statement coverage

- Write complete test cases as shown in the test cases above, and indicate which lines each test case cover

Groups 2-5 persons: 10 min

Exercise: Proposed solution

-To cover l.64-65 (avgtest3.txt is an empty file - Test case avg3:

Prerequisites: The file avgtest3.txt exists but is empty

Action: ./avg avgtest3.txt

Expected outcome: An error is reported, stating that the input is empty

- To cover l.32-33 and 55-56 - Test case avg4:

Prerequisites: avgtest4.txt contains a list of non-integers

Action: ./avg avgtest4.txt

Expected outcome: An error message is given that there is a syntax error

- To cover l.14 and 51-52 - Test case avg5:

Prerequisites: Call the function with an argument, not a file

Action: -./avg "asdfdf" (or ./avg non_existing_file.txt)

Expected outcome: An error reading file could be given

- To cover l.44-45 Test case avg5:

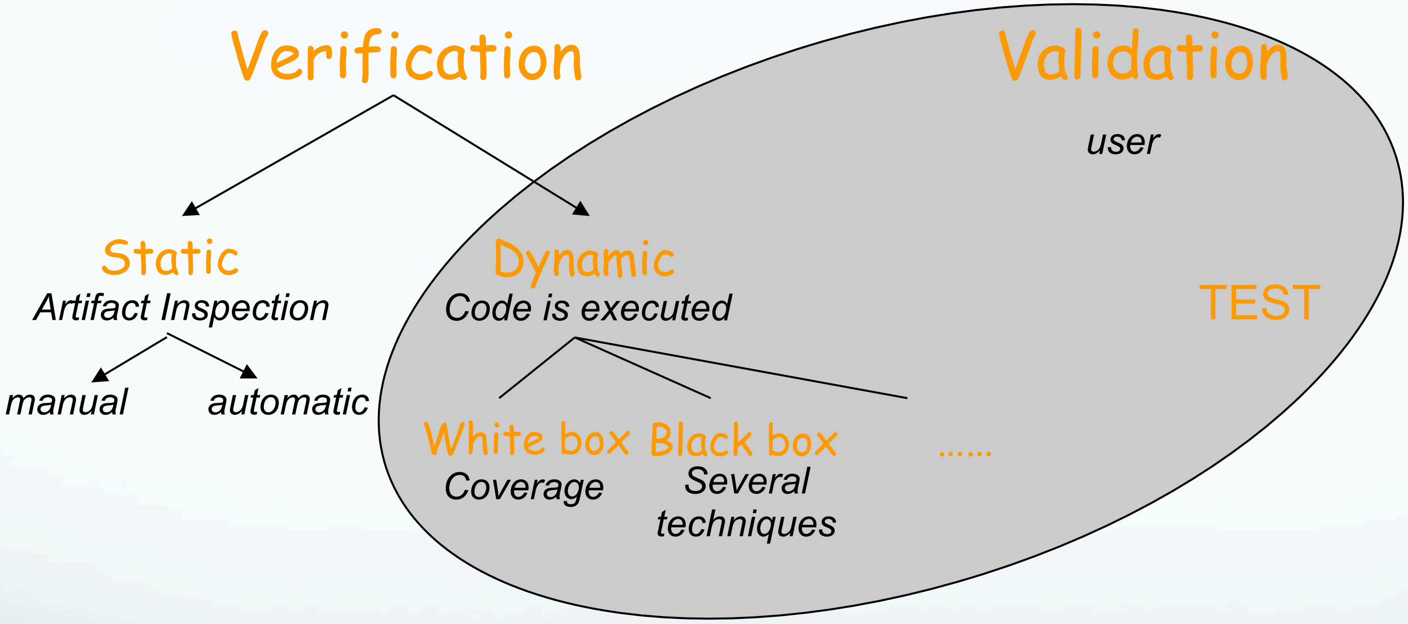
Prerequisites: None

Action: ./avg

Expected outcome: Error missing argument is given

Any problem understanding the solution? **Try it yourself with GCoV!**

Terminology



Next lecture

Testing: The Bigger Picture