Software Testing

1. Introduction

Universiteit Antwerpen

1. Introduction

(Based on "Part I: Preliminaries" of Testing Object-Oriented Systems)

- Challenge
- Test Adequacy (vs. Test Inadequacy)
- The V model
- Terminology
- Limits of testing
- What is special about object-oriented testing ?
- Challenge revisited

Challenge

Devise a test plan (i.e. a set of test cases) for a program that ...

> … reads three integer values from a card(*). The three integer values are interpreted as representing the lengths of the side of a triangle. The program prints a message that states whether the triangle is scalene, isosceles, or equilateral.
>
> From "The Art of Software Testing" (Myers, 1978)

(*) A "Card" was common input medium in 1978, interpret as "File".

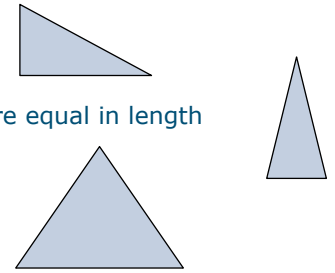
Challenge (help)

A valid triangle must meet two conditions

- No sides may have a length of zero
- each side must be shorter than the sum of all sides divided by 2

A triangle is

- scalene: no sides are equal in length
- isosceles: there exist two sides which are equal in length
- equilateral: all sides are equal in length



Challenge (solution)

- 3 one valid for each scalene, isosceles, or equilateral
- 3 permutations for equal sides (all isosceles)
- 1 one side a zero length
- 1 one side negative length
- 3 permutations for equal sides (all invalid)
- 6 permutations (one side smaller than sum of all sides divided by 2)
- 1 all sides zero
- 3 non-integer inputs
- 3 missing inputs
- 6 permutations (one side equals the sum of the other two)
- 3 three, two and one sides at maximum value (MAXINT)

  - 33 test cases are possible !
  - Highly experienced programmers score on the average 7.8/14

What is Testing ?

Testing = design and implementation of a special software system:
exercises another software system with the intent of finding bugs

Test Design = analyze system under test and decide where bugs are likely to occur

Test Implementation = automate as much as possible; i.e. apply test cases and evaluate results

- Test Models = abstraction to conquer astronomical complexity.
- Fault Model = Focus on places where bugs are likely to occur

Test Adequacy vs. Test Inadequacy

The "Test Adequacy Utopia"

- If a system passes an ADEQUATE suite of test cases, then it must be correct
  - impossible: provable undecidable

Weaker proxies for adequacy

- Design rules to highlight INADEQUACY of test suites
  - If a given suite of test cases does not satisfy the design rules … reconsider carefully
  - compare: "due diligence"

Testing is risk assessment !

Risk Projection (2 dimensions)

likelihood \ impact	Low	Medium	High
High	low	medium	high
Medium	low	medium	medium
Low	low	low	low

Risk = impact * likelihood

likelihood \ impact	insignificant	minor	moderate	major	catastrophic
almost certain	moderate	high	high	critical	critical
likely	moderate	moderate	high	high	critical
possible	low	moderate	high	high	critical
unlikely	low	moderate	moderate	high	high
rare	low	low	moderate	moderate	high

Risk Projection (3 dimensions)

Sometimes a 3rd item is added to the equation

- urgency
  = the time left before measures or responses would need to be implemented
- less time available ⇒ risk becomes more critical

Risk = impact * likelihood * urgency

Good testing …

- reduces likelihood (provided sufficient test coverage)
- should reduce urgency (provided test strategy is in place)
  - When should which tests be executed ?
  - What actions should be taken if tests fail ?
- does *not* affect impact (⇒ fall-back plans, disaster scenarios)

V-Model

Risk Assessment (example)

Risk ?

- probability: extremely unlikely
  (however, 3 independent e-mails)
- urgency: extremely urgent
  (potential explosion within hours)
- impact … infinite
  (potential life loss of students)

Deze mededeling werd online verspreid om de studenten en het personeel op de hoogte te brengen:

Beste studenten, Beste medewerkers

Er liep maandagochtend een bommelding binnen voor de Universiteit Antwerpen. De politie onderzoekt de melding momenteel en maakt een dreigingsanalyse. Reden tot paniek is er geenszins, maar uit voorzorg vraagt de politie dat alle studenten de campussen van de universiteit zouden verlaten voor de rest van de dag. Neem best ook alle materiaal mee. Deze maatregel geldt dus voor alle campussen van de Universiteit Antwerpen. Iedereen gaat best naar huis of naar zijn of haar kot. Blijven hangen in de straten rond de verschillende campussen heeft weinig zin. Wie deze boodschap leest, vragen we om op een rustige manier ook andere studenten op de hoogte te brengen. Wie dringende vragen heeft, kan bellen met het callcenter van de universiteit op 03 265 54 54. Bedankt voor de medewerking!

Van zodra we meer info lees je het hier. Het nieuws houdt de Antwerpse studenten op Twitter alvast in de ban. (DR)

ALLE CAMPUSSEN UNIVERSITEIT ANTWERPEN DOORZOCHT

18.000 studenten Universiteit Antwerpen geëvacueerd na bommelding

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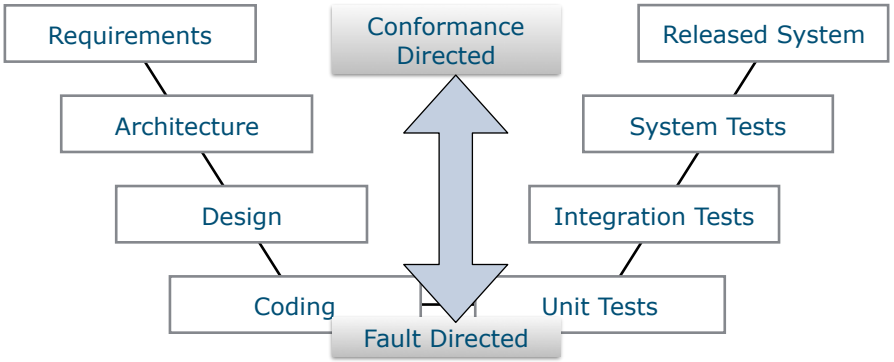
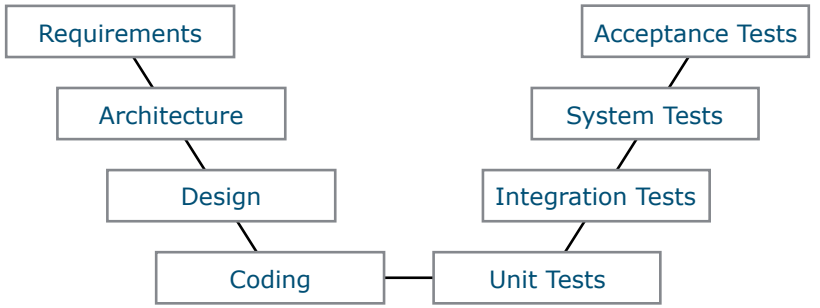
Test Strategy = The V-model

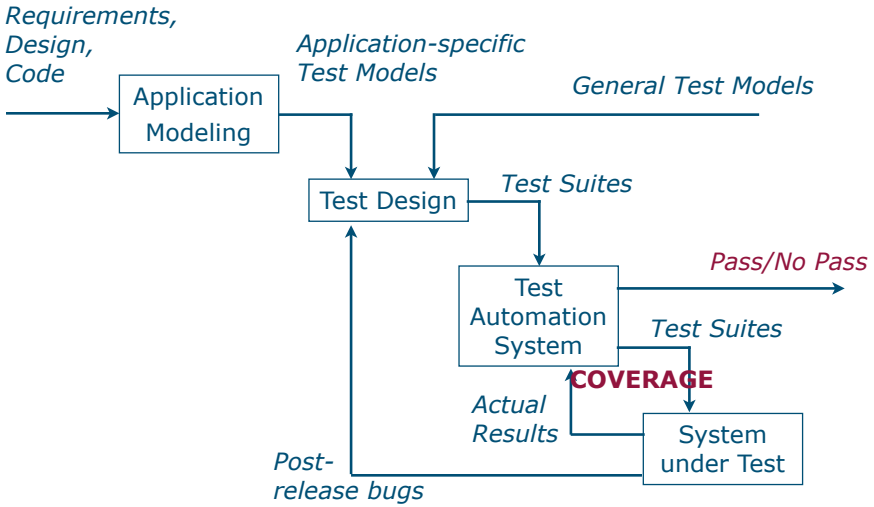


The V-model: Test Design vs. Test Execution



Requirements	Architecture	Design	Coding	Testing			
Test Design				Test Execution			
Acceptance Test Cases	System Test Cases	Integration Test Cases	Unit Test Cases	Unit Tests	Integration Tests	System Tests	Acceptance Tests

Testing: systems engineering view



Terminology (1/4)

- software testing = execution of code using combinations of input and state to reveal bugs
  (not requirements validation ! not code/design/… reviews !)
- component (under test) = any software aggregate that has visibility in the development environment (method, class, object, function, module, executable, task, subsystem, ...)
- scope of test = collection of components to be verified

implementation	under test = IUT
method	under test
object	under test = OUT
class	under test
component	under test = CUT
system	under test = SUT

Perspective of a forensic investigator dissecting suspicious samples

Terminology (2/4)

- **unit test** = test scope is small executable (object of a class, method)
- **integration test** = test scope is complete system or subsystem (software AND hardware)
- **system test** = test scope is a complete and integrated application

- **fault-directed testing**: intent is to reveal faults through failures
- **conformance-directed testing**: intent is to demonstrate conformance to required capabilities

- confidence = assessment of the likelihood of unrevealed bugs
- (estimated) failure rate = the probability that a failure will occur after a certain period of usage
  ➡ both are external quality attributes !

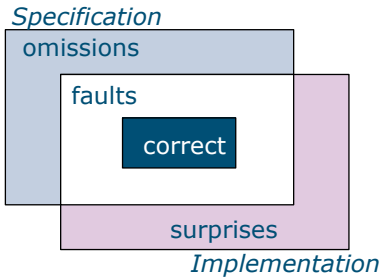
Terminology (3/4)

- **test case** = pretest state of implementation under test + test inputs or conditions + expected results
  - expected results: generated messages + thrown exceptions + returned values + resultant state
  - oracle = means to produce expected result
  - test point = specific value for test case input and state variables

- **domain** = a set of values that input or state variables of the implementation under test may take
- **domain analys**is: places constraints on input/state/output to select test points
  - equivalence classes (partition testing)
  - boundary value analysis, special values testing

Terminology (4/4)

- failure = manifested inability of a system
- software fault = missing or incorrect code
- error = human action that produces a fault
- bug = error or fault
- omission = required capability that is not present
- surprise = code that does not support any required capability



Limits of Testing: State space explosion

Input space is surprisingly large

- Simplified case
  - Triangle example with points in coordinate system [1..10, 1..10]
  - 10^2 = 100 possible end-points; 10^4 = 10.000 possible lines; $10^{4*3} = 10^{12}$ possible triangles
- Less simplified
  - display of 1024 x 768 pixels; 786.432^2 possible lines; 786.432^6 possible triangles = 2,36574 x 10^{35}
- Full integer coordinate system
  - $2^{16 \times 4}$ possible lines; $2^{16 \times 4 \times 3} = 2^{192} = 6.277 \times 10^{57}$ possible triangles (number of particles in the universe = +-10^{80})

Limits of Testing: Loops

```
for (int i = 0; i < n; i++) {
      if (a.get(i) == b.get(i))
          x[i] = x[i] + 100;
      else
          x[i] = x[i] / 2;
}
```

Without iteration:
- 3 entry exit paths

With two iterations:
- 5 possible paths

For n iterations
- 2^n + 1 possible paths

Limits of Testing: Coincidental Correctness

- Coincidental correctness: buggy code may produce correct results under some circumstances
  - example: write x + x instead of x * x will produce correct result for x = 2 !
  - example 2:

```
int scale(int j) {
    j = j -1 ;   // should be j = j + 1;
    j = j / 30000;
    return j;
}
```

out of 65.536 possible values for j, only six will reveal the fault ! (-30001, - 30000, -1, 0, 29999 and 30000)

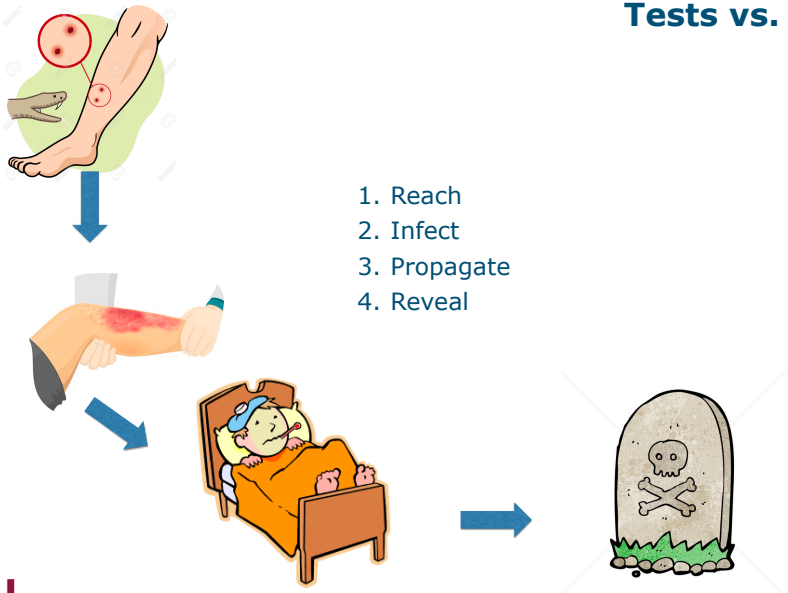
Coincidental Correctness in Inheritance

```
public class Account extends Object {
      protected Date lastTxDate, today;
      // ...
      int quartersSinceLastTx () {
            return (90 / daysSinceLastTx ());
      }
      int daysSinceLastTx () {
            return (today.day() - lastTxDay.txDate + 1);
            // Correct - today's transactions return 1 day elapsed
}}
public class TimeDepositAccount extends Account {
      // ...
      int daysSinceLastTx () {
            return (today.day() - lastTxDay.txDate);
            // Incorrect - today's transactions return 0 days
      }
}
```

quartersSinceLastTx will produce "divide by zero" exception when last transaction occurs on the current day

proverbial "Needle in a haystack"

Tests vs. Faults



1. Reach
2. Infect
3. Propagate
4. Reveal

Where is the fault?

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

i>0 ⟼ i >= 0

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

Input that does not reach the fault

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

x = null; y = 5

Coverage = 0

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```


Input = reaches the fault

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

x = [2,3,5]; y = 3

Coverage = Complete for loop

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```


Input = infects the program state

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

x = [2,3,5]; y = 25

Coverage = All except “return i;”

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```


Together we have 100% coverage

```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

Input: reach / infect / propagate ⇒ reveal?

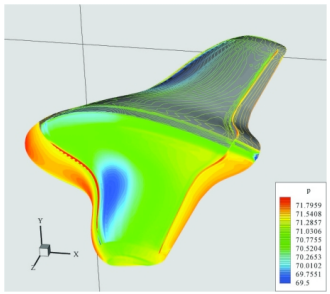
```
/**
 * Find last index of element
 * @param x array to search
 * @param y element to look for
 * @return last index of y in x, if absent -1
 * @throws NullPointerException if x is null
*/

public static int findLast(int [] x, int y)
{
for (int i=x.length-1; i>0; i--)
   if (x[i] == y)
      return i;
return -1;
}
```

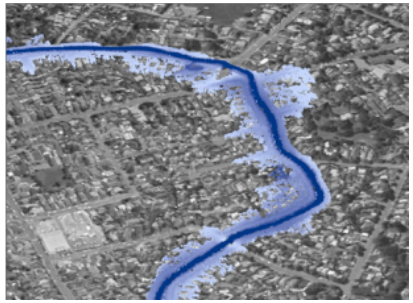
x = [2,3,5]; y = 2

Fault Model

Predict where defects are likely to occur based on past experience

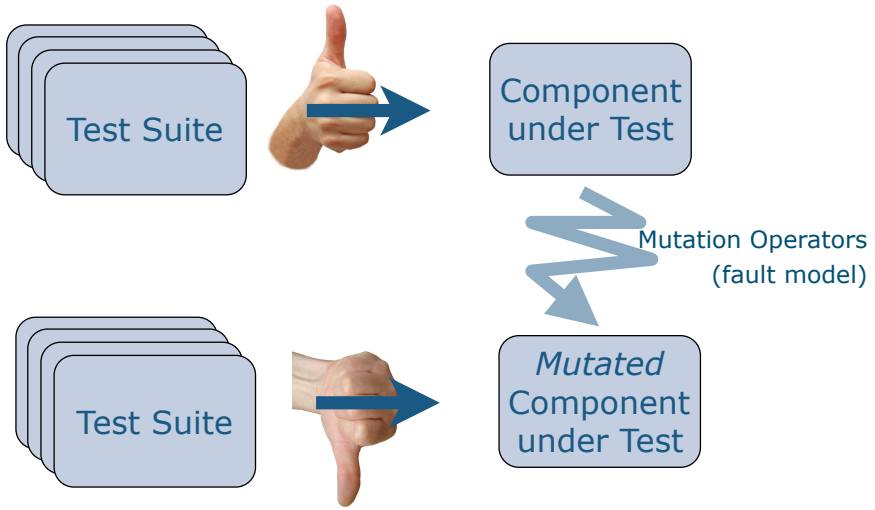


Simulation of pressure



Flood depth and extend

Mutation Testing




```
int method(int v1, int v2)
{
    if (v1 < v2)
        return 1;
    return -1;
}
```

```
int method(int v1, int v2)
{
    if (v1 >= v2)
        return 1;
    return -1;
}
```

Operator	Description	Example	
		Before	After
CBM	Mutates the boundary conditions	a > b	a >= b
IM	Mutates increment operators	a++	a––
INM	Inverts negation operator	–a	a
MM	Mutates arithmetic & logical operators	a & b	a | b
NCM	Negates a conditional operator	a == b	a != b
RVM	Mutates the return value of a function	return true	return false
VMCM	Removes a void method call	voidCall(x)	–

Competent Programmer Hypothesis
(Program is close to correct)

Coupling Effect
(Test suites capable of detecting simple errors will also detect complex errors)

Fault Models for Object-Oriented Programming

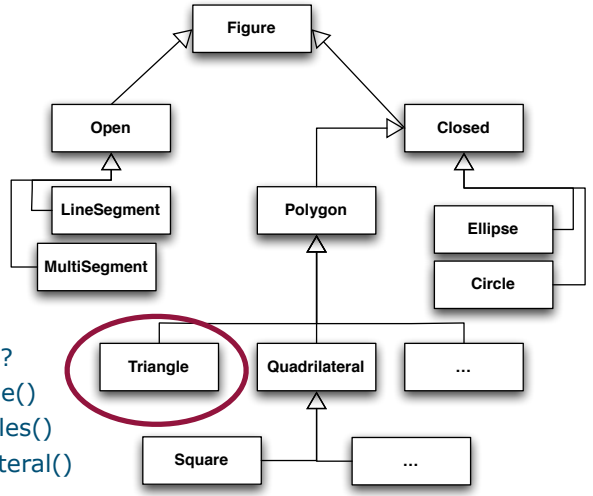
Object-oriented programming is based on powerful constructs
- easy to use, easy to abuse

- dynamic binding + complex inheritance
  - faults due to unanticipated bindings and misinterpretations
- many small components with lots of interfaces
  - interface programming are a known cause of faults
- objects preserve state, but state control is distributed over program
  - state control errors are likely

Object-Oriented Testing ≠ Traditional testing

- Encapsulation:
  - difficult to bring an object in desired state
  - difficult to verify whether it is in a desired state
- Inheritance:
  - Weakens encapsulation
  - Subtle interactions (initialize & new, copy & isEqual, == & hash)
  - type/subtype relationship (Liskov's substitution principle)
  - multiple inheritance: even more possibilities for subtle interactions
  - abstract classes: some methods are intentionally empty
  - generic classes: interaction between type parameter and the generic class
- Polymorphism
  - should be considered if- or switch statement (branch testing !)
  - subtle interactions (double dispatch of + on Number hierarchy)

Challenge revisited (class diagram)



How to test ?
- is_scalene()
- is_isosceles()
- is_equilateral()

Challenge revisited (java code)

```
class Polygon extends Figure {
    abstract void draw (int r, int g, int b);
    abstract void erase ();
    abstract float area (); abstract float perimeter (); abstract float center ();
}
class Triangle extends Polygon {
    public Triangle (LineSegment a, LineSegement b, LineSegement c);
     public void setA(LineSegment a);
       … setB … ; … setC …;… getA …;… getB …;… getC …;
    public boolean is_scalene(); … is_isosceles(); …is_equilateral()
}
class LineSegment extends Figure {
    public LineSegment (int x1, int y1, int x2, int y2);
       … setx1 … ; … sety1 …;… setx2 …;… sety2 …;… getx1 …;… gety1 …; …
}
```


Challenge (object-oriented - solution 1/2)

- constructor faithfully creates line segments
- only one of the predicates (is_*) is true at a given time
- minimum/maximum values for each LineSegment parameter
- repeat a result
- repeat result after permuting line lengths
- repeat result after sending erase, draw, …
- repeat result more than 2 times
- 1 single point line, 2 single point lines, 3 single point lines
- three lines: 1 minimum length + 2 maximum lengths
- two nonintersecting single lines
- two overlapping lines of different lengths
- three overlapping lines of different lengths
- two intersecting lines
- two parallel lines
- three nonintersecting parallel lines
- three lines intersecting at one point
- three parallel lines
- three non intersecting, non parallel lines
- three lines that form an interior triangle but extend beyond the intersections

Challenge (object-oriented - solution 2/2)

- three lines with two intersections (“open” triangle)
- three lines with one intersections (“open” triangle)
- three lines, each of maximum length
- three lines, each of maximum length
- a figure with one line entirely on each boundary of the coordinate space
- above for two and three lines
- two lines that intersect and originate from the same boundary of the coordinate space

➡ 62 test cases in total

Original Myers Tests

- 33 test cases
  - 6 not possible (non integer input & missing input)
- 62 + 27 = 89 test cases !

Inheritance & Polymorphism

- All methods defined in *Figure* inherited or overridden by Triangle provide a response that is consistent with the original definition
- above for *Closed*
- above for *Polygon*

➡ 3 x other tests with a substituted triangle

Conclusion

(Based on “Part I: Preliminaries” of Testing Object-Oriented Systems)

- Challenge
- *Test Adequacy (vs. Test Inadequacy)*
  - Risk reduction
- *The V model*
- Terminology
- Limits of testing
- *What is special about object-oriented testing ?*
- Challenge revisited