Systematic Testing (Scratching the surface)

The art of economic testing...

What is reliability?

Definition: Reliability (ISO 9126)

The capability of the software product to maintain a specified level of performance when used under specifiied conditions.

If there is a defect, it may fail and is thus not reliable.

Thus:

- Reduce number of defects
- … will reduce number of failures
- … will increase reliability

Discussion

True?

- Find example of **removing a defect does not increase the system's reliability at all**

- Find example of **removing defect 1 increase reliability dramatically while removing defect 2 does not**

All defects are not equal!

So – given a certain amount of time to find defects (you need to sell things to earn money!):

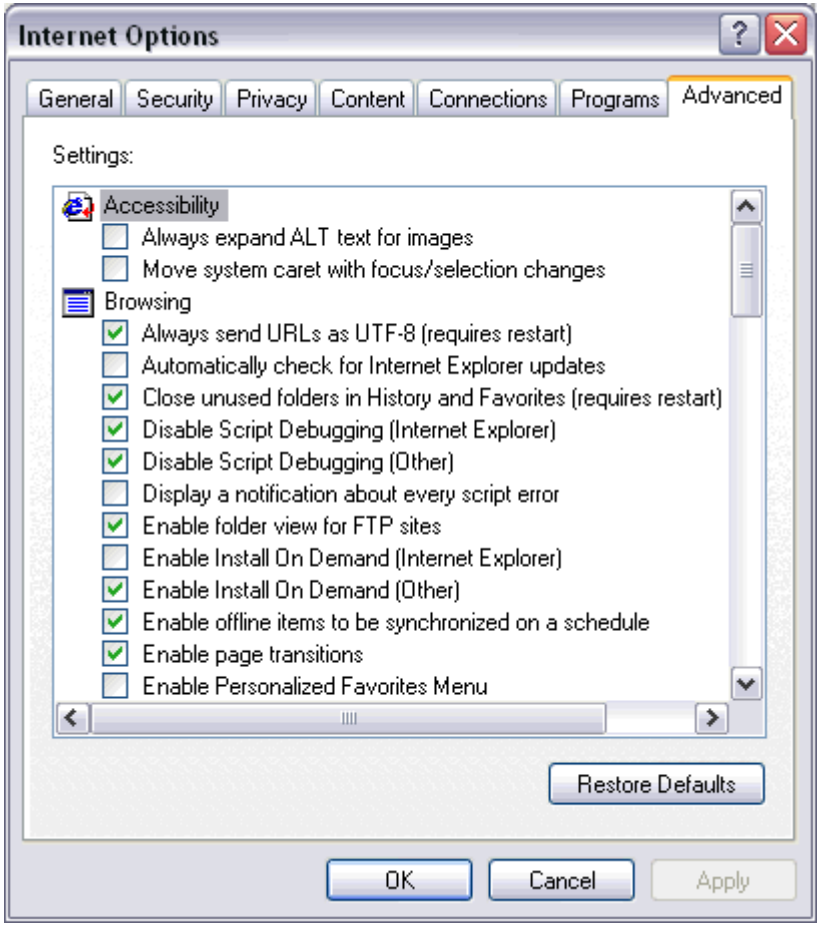
What kind of defects should you correct to get best *return on investment?*

Example

IE has an enormous amount of possible configurations!

Imagine testing *all possible combinations!*

Which one would you test most thoroughly?



Testing techniques

One viewpoint

The probability of defects is a function of the code complexity. Thus we may identify three different testing approaches:

- **No testing**. Complexity is so low that the test code will become more complex. Example: set/get methods
- **Explorative** testing: “gut feeling”, experience. TDD relies heavily on ‘making the smart test case’ but does not dictate any method.

Definition: **Systematic testing**

Systematic testing is a planned and systematic process with the explicit goal of finding defects in some well-defined part of the system.

Destructive!

Testing is a *destructive process!!!*

- In contrast to almost all other SW processes which are constructive!

Human psychology

- **I want to be a success**
  - **The brain will deliver!**
    - (ok, X-factor shows this is not always the case…)

I will prove my software works

I will prove my software is really lousy

Morale:

When testing, reprogram your brains

I am a success if I find a defect.
The more I find, the better I am!

Our focus

There are a lot of different testing techniques.

Types:

Definition: Black-box testing

The *unit under test* (UUT) is treated as a black box. The only knowledge we have to guide our testing effort is the specification of the UUT and a general knowledge of common programming techniques, algorithmic constructs, and common mistakes made by programmers.

Definition: White-box testing

The full implementation of the unit under test is known, so the actual code can be inspected in order to generate test cases.

Here – two black box techniques:

- Equivalence class partitioning
- Boundary value analysis

Equivalence Class Partitioning

Consider

Math.abs(x): Absolute value of x

- If x is not negative, return x.
- If x is negative, return the negation of x.

Will these five test cases ensure a reliable implementation?

Unit under test: Math.abs	
Input	Expected output
x = 37	37
x = 38	38
x = 39	39
x = 40	40
x = 41	41

Two problems

A) what is the probability that x=38 will find a defect that x=37 did not expose?

Unit under test: Math.abs	
Input	Expected output
x = 37	37
x = 38	38
x = 39	39
x = 40	40
x = 41	41

B) what is the probability that there will be a defect in handling negative x?

```
public static int abs(int x) { return x; }
```

Core insight

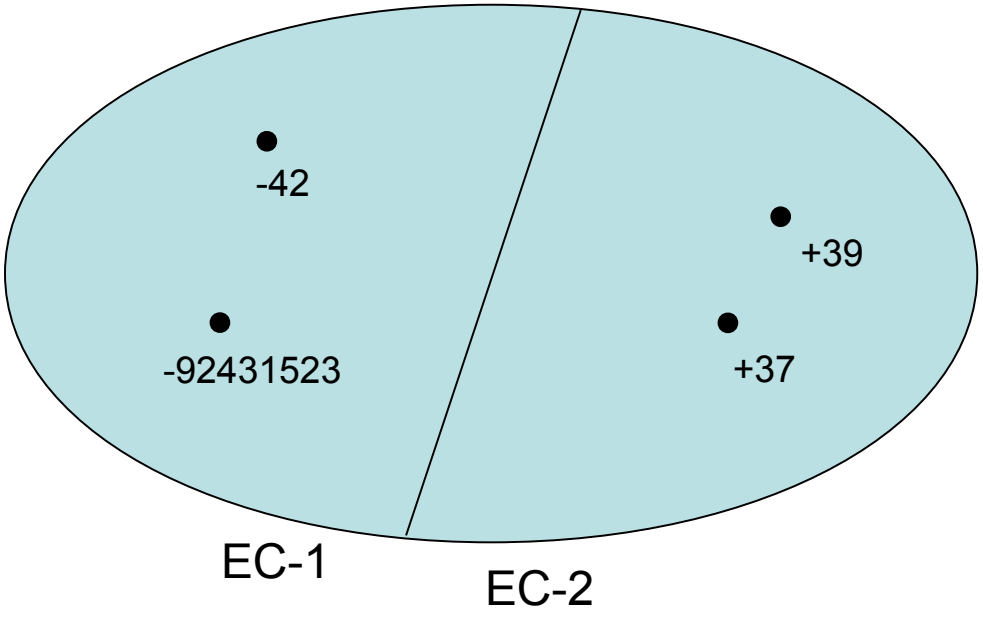
We can find a single input value that represents a large set of values!

Definition: **Equivalence class (EC)**

A subset of all possible inputs to the UUT that has the property that if one element in the subset demonstrates a defect during testing, then we assume that all other elements in the subset will demonstrate the *same* defect.

For Math.abs

ECs are subsets of the full input set.



Unit under test: Math.abs	
Input	Expected output
x = 37	37
~~x = 38~~	~~38~~
~~x = 39~~	~~39~~
~~x = 40~~	~~40~~
~~x = 41~~	~~41~~
X = - 42	42

The argumentation

The specification will force an implementation where (most likely!) all *positive* arguments are treated by one code fragment and all *negative* arguments by another.

- Thus we only need two test cases:
  - 1) one that tests the positive argument handling code
  - 2) one that tests the negative argument handling code

For 1) x=37 is just as good as x=1232, etc. Thus we simply *select a representative element* from each EC and generate a test case based upon it.

Note

Systematic testing ...

does *not* mean

- *Systematically find all defects and guaranty none are left!!!*

does mean

- Systematically derive a *small test case with high probability of finding many defects!!!*

Specifically

Systematic testing cannot in any way counter *malicious programming*

- *Virus, easter eggs, evil-minded programmers*
- *(really really lousy programmers)*

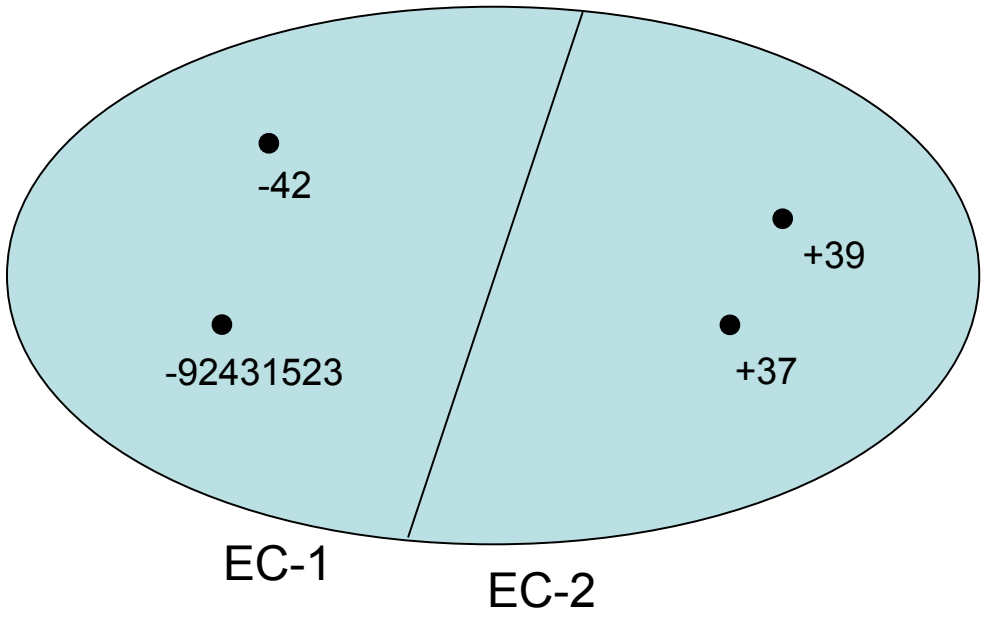
A sound EC partitioning

For our ECs to be *sound:*

- **Coverage:** Every possible input element belongs to at least one of the equivalence classes.
- **Representation:** If a defect is demonstrated on a particular member of an equivalence class, the same defect is assumed to be demonstrated by any other member of the class.

Exercise

Coverage? Representation?



- **Coverage:** Every possible input element belongs to at least one of the equivalence classes.
- **Representation:** If a defect is demonstrated on a particular member of an equivalence class, the same defect is assumed to be demonstrated by any other member of the class.

Exercise

The classic blunder at exams!

– *Representation = two values from the same EC will result in the **same behaviour** in the algorithm*

Argue why this is completely wrong!

– Consider for instance the Account class' deposit method…
  - account.deposit(100);
  - account.deposit(1000000);

Documenting ECs

Math.abs is simple. Thus the ECs are simple.

This is often **not** the case! Finding ECs require deep thinking, analysis, and iteration.

Document them!

Equivalence class table:

Condition	Invalid ECs	Valid ECs
absolute value of x	–	$x > 0$[1] $x \leq 0$[2]

Invalid/Valid ECs

Some input values make an algorithm *give up*, *bail out,* or *compute answer immediately:*

- Sqrt(0); file.open(“nonexisingfile”);division(4/0);

Input values that leads to *abnormal processing/giving up* we classify as belonging to ***invalid ECs*.**

Those input values that process normally we say belong to ***valid ECs.***

Finding the ECs

Often tricky…

Reality

Example: Backgammon move validation

- **validity = v (move, player, board-state, die-value)**
  - is Red move (B1-B2) valid on this board given this die?

- Problem:
  - multiple parameters: player, move, board, die
  - complex parameters: board state
  - coupled parameters: die couples to move!
    - EC boundary is not a constant!

A process

To find the ECs you will need to look carefully at the specification and especially all the conditions associated.

- Conditions express choices in our algorithms and therefore typically defines disjoint algorithm parts!

- And as the test cases should at least run through all parts of the algorithms, it defines the boundaries for the ECs.

… And consider typical programming techniques

- Will a program contain if's and while's here?

Partitioning Heuristics

1) If you have a *range of values* specification
   - make **3** ECs:
     - [1] in range — valid
     - [2] above range — invalid
     - [3] below range — invalid

Ex. Standard chess notation/ is “a8” or “x17” valid positions?

- Column range: a-h Row range: 1-8

Condition	Invalid ECs	Valid ECs
Column	< ′a′ [1]; > ′h′ [2]	′a′–′h′ [3]
Row	< 1 [4]; > 8 [5]	1–8 [6]

Partitioning Heuristics

2) If you have a *set, S, of values* specification
- make **|S|+1** ECs
  - [1]..[|S|] one for each member in S valid
  - [|S|+1 for a value outside S invalid

Ex. PayStation accepting coins
- Set of {5, 10, 25} cents coins

Condition	Invalid ECs	Valid ECs
Allowed coins	$\notin \{5, 10, 25\}[1]$	$\{5\}[2]; \{10\}[3]; \{25\}[4]$

Partitioning Heuristics

3) If you have a *boolean condition* specification
- make **2** ECs

Ex. the first character must be a letter

Condition	Invalid ECs	Valid ECs
Initial character of identifier	non-letter [1]	letter [2]

the object reference must not be null
- *you get it, right?☺*

Partitioning Heuristics

4) If you question the representation property of any EC, then repartition!

- Split EC into smaller ECs

Examples: shortly ☺

From ECs to Test cases

Test case generation

For disjoint ECs you simply pick an element from each EC to make a test case.

Extended test case table

ECs covered	Test case	Expected output
[2]	$x = -37$	$+37$
[1]	$x = 42$	$+42$

Augmented with a column showing which ECs are covered!

Condition	Invalid ECs	Valid ECs
absolute value of x	–	$x > 0$[1] $x \leq 0$[2]

Usual case

ECs are seldom disjoint – so you have to *combine* them to generate test cases.

Ex. Chess board validation

Condition	Invalid ECs	Valid ECs
Column	< 'a' [1]; > 'h' [2]	'a'–'h' [3]
Row	< 1 [4]; > 8 [5]	1–8 [6]

ECs covered	Test case	Expected output
[1], [4]	(' ',0)	illegal
[2], [4]	('i',-2)	illegal
[3], [4]	('e',0)	illegal
[1], [5]	(' ',9)	illegal
[2], [5]	('j',9)	illegal
[3], [5]	('f',12)	illegal
[1], [6]	(' ',4)	illegal
[2], [6]	('i',5)	illegal
[3], [6]	('b',6)	legal

Combinatorial Explosion

Umph! Combinatorial explosion of test cases ☹.

Ex.

- Three independent input parameters foo(x,y,z)
- Four ECs for each parameter
  - That is: x's input set divided into four ECs, etc.

Question:

- How many test cases?

Combinatorial Explosion

Answer: $4^3 = 64$ test cases…

TC1: [ECx1],[ECy1],[ECz1]
TC2: [ECx1],[ECy1],[ECz2] …
TC4: [ECx1],[ECy1],[ECz4] …
TC5: [ECx1],[ECy2],[ECz1] …
TC9: [ECx1],[ECy3],[ECz1] …
TC64: [ECx4],[ECy4],[ECz4]

Myers Heuristics

Often, generate test cases like this is better:

1. Until all valid ECs have been covered, define a test case that covers as many uncovered valid ECs as possible.
2. Until all invalid ECs have been covered, define a test case whose element only lies in a single invalid ECs.

Condition	Invalid ECs	Valid ECs
Column	< 'a' [1]; > 'h' [2]	'a'–'h' [3]
Row	< 1 [4]; > 8 [5]	1–8 [6]

ECs covered	Test case	Expected output
[1], [6]	(' ',5)	illegal
[2], [6]	('j',3)	illegal
[3], [4]	('b',0)	illegal
[3], [5]	('c',9)	illegal
[3], [6]	('b',6)	legal

Rule 2

Rule 1

Why Rule 2?

Due to **masking**

- One correct test *masks* a later incorrect test

Ex.

```
/** Demonstration of masking of defects.
*/
public class ChessBoard {
  public boolean valid(char column, int row) {
    if ( column < 'a' ) { return false; }
    if ( row < 0 ) { return false; }
    return true;
  }
}
```

Test case (‘ ‘,0) will pass which is expected

- Code deemed correct, but this is a **wrong** conclusion!

Why Rule 1?

You may combine as *many* valid ECs as possible and cover it with only a single test case until all valid ECs are exhausted…

Why?

Because I must assume that all elements from ECs are used to compute the final result. Any defects will thus most likely show up even if the defect only relate to one element.

Ex. bankdayNumberInYear(int month, int day)

- return 30*month+day

The Process

Revisited…

1. Review the requirements for the UUT and identify *conditions* and use the heuristics to find ECs for each condition. ECs are best written down in an *equivalence class table*.

2. Review the produced ECs and consider carefully the representation property of elements in each EC. If you question if particular elements are really representative then repartition the EC.

3. Review to verify that the coverage property is fulfilled.

4. Generate test cases from the ECs. You can often use Myers heuristics for combination to generate a minimal set of test cases. Test cases are best documented using a *test case table*.

An Example

Phew – let's see things in practice

Example

```
public interface weekday {

  /** calculate the weekday of the 1st day of the given month.
      @param year the year as integer. 2000 means year 2000 etc. Only
      years in the range 1900-3000 are valid. The output is undefined
      for years outside this range.
      @param month the month as integer. 1 means January, 12 means
      December. Values outside the range 1-12 are illegal.
      @return the weekday of the 1st day of the month. 0 means Sunday,
      1 means Monday etc. up til 6 meaning Saturday.
  */
  public int weekday(int year, int month)
     throws IllegalArgumentException;
}
```

Exercise

Which heuristics to use on the spec?

- **Range:** *If a condition is specified as a range of values*, select one valid EC that covers the allowed range, and two invalid ECs, one above and one below the end of the range.
- **Set:** *If a condition is specified as a set of values* then define an EC for each value in the set and one EC containing all elements outside the set.
- **Boolean:** *If a condition is specified as a "must be" condition* then define one EC for the condition being true and one EC for the condition being false.

Process step 1

Result

Condition	Invalid ECs	Valid ECs
year	< 1900 [1]; > 3000 [2]	$1900 - 3000$ [3]
month	< 1 [4]; > 12 [5]	$1 - 12$ [6]

Process step 2

Review and consider representation property?

Condition	Invalid ECs	Valid ECs
year	< 1900 [1]; > 3000 [2]	$1900 - 3000$ [3]
month	< 1 [4]; > 12 [5]	$1 - 12$ [6]

Damn – Leap years!

Nice to be an astronomer ☺

Condition	Invalid ECs	Valid ECs
year (y)		$\{y \mid y \in [1900; 3000] \wedge y\%400 = 0\}$ [3a] $\{y \mid y \in [1900; 3000] \wedge y\%100 = 0 \wedge y \notin [3a]\}$ [3b] $\{y \mid y \in [1900; 3000] \wedge y\%4 = 0 \wedge \notin [3a] \cup [3b]\}$ [3c] $\{y \mid y \in [1900; 3000] \wedge y\%4 \neq 0\}$ [3d]

What about the months? Let's play it safe…

Condition	Invalid ECs	Valid ECs
month		$1 - 2$ [6a]; $3 - 12$ [6b]

Process step 3

Coverage?

Process step 4

Generate, using Myers

ECs covered	Test case	Expected output
$[3a], [6a]$	$y = 2000; m = 2$	-
$[3b], [6b]$	$y = 1900; m = 5$	-
$[3c], [6b]$	$y = 2004; m = 10$	5
$[3d], [6a]$	$y = 1985; m = 1$	-
$[1]$	$y = 1844; m = 4$	[exception]
$[2]$	$y = 4231; m = 8$	[exception]
$[4]$	$y = 2004; m = 0$	[exception]
$[5]$	$y = 2004; m = 13$	[exception]

Conclusion: 8 test cases for a rather tricky alg.

Example 2

Formatting

```
/** format a string representing of a double. The string is always
    6 characters wide and in the form ###.##, that is the double is
    rounded to 2 digit precision. Numbers smaller than 100 have '0'
    prefix. Example: 123 -> '123.00'; 2,3476 -> '002.35' etc. If the
    number is larger or equal to 999.995 then '***.**' is output to
    signal overflow. All negative values are signaled with '---.--'
*/
public String format(double x);
```

Note! Most of the conditions do **not** really talk about x but on the output.

Exercise

What do we do?

```
/** format a string representing of a double. The string is always
    6 characters wide and in the form ###.##, that is the double is
    rounded to 2 digit precision. Numbers smaller than 100 have '0'
    prefix. Example: 123 -> '123.00'; 2,3476 -> '002.35' etc. If the
    number is larger or equal to 999.995 then '***.**' is output to
    signal overflow. All negative values are signaled with '---.--'
*/
public String format(double x);
```

Range? Boolean? Set?

Valid / Invalid ECs?

My analysis

Condition	Invalid ECs	Valid ECs
overflow / underflow	≥ 1000.0 [1]; < 0.0 [2]	0.0 <= x < 1000.0 [1a]
2 digit rounding		(,00x round up) [3]; (,00x round down) [4]
prefix		no '0' prefix [5]
		exact '0' prefix [6]
		exact '00' prefix [7]
		exact '000' prefix [8]
output suffix		'.yx' suffix ($x \neq 0$)[9]
		'.x0' suffix ($x \neq 0$)[10]
		exact '.00' suffix [11]

Test cases

ECs covered	Test case	Expected output
[1]	1234.456	'***.**'
[2]	-0.1	'—.–'
[3][5][9]	212.738	'212.74'
[4][6][10]	32.503	'032.50'
[3][7][11]	7.995	'008.00'
[4][8][9]	0.933	'000.93'

Boundary value analysis

Boundary value analysis

Experience shows that test cases focusing on *boundary conditions* have high payoff.

Some that spring into my mind is

- *iteration over a C array at its max size*
- *”off by one” errors in comparisons*
  - *if (x <= MAX_SIZE)* and not *if (x < MAX_SIZE)*
- *null as value for a reference/pointer*

Complements EP analysis

Definition: Boundary value

A boundary value is an element that lies right on or next to the edge of an equivalence class.

Ex. Formatting has a strong boundary between EC [1] and [1a]

- 0.0 (-> '000.00') and -0.000001 (-> '---.--')

It is thus very interesting to test x=0.0 as boundary.

Discussion

A few key points

Key Point: Observe unit preconditions

Do not generate ECs and test cases for conditions that a unit specifically cannot or should not handle.

Key Point: Systematic testing assumes competent programmers

Equivalence partitioning and other testing techniques rely on honest and competent programmers that are using standard techniques.

Key Point: Do not use Myers combination heuristics blindly

Myers heuristics for generating test cases from valid and invalid ECs can lead to omitting important test cases.

Summary

Equivalence Class Partitioning

- EC = set of input elements where each one will show same defect as all others in the same set (representation)
- Find ECs, use Myers to generate test cases.

Boundary analysis

- be sceptical about values at the boundaries
- Especially on the boundary between valid and invalid ECs