Functional Testing

Mohammad Mousavi

Halmstad University, Sweden

http://ceres.hh.se/mediawiki/DT8021_Ed_2015

Testing and Verification of Embedded Systems (DT8021),
March 23, 2015

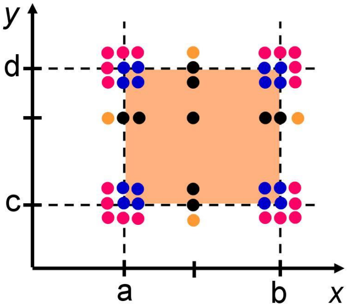
Outline

Functional Testing

- functional testing:
  program is an input from a certain domain to a certain range
- impossible to check all input/output combinations:
  defining a coverage criterion to choose some some

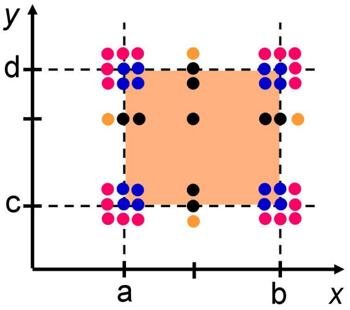
Boundary Value Testing

- boundary value testing: a test case for each combination of extreme (normal, out of bound) values



Boundary Value Testing: Pros and Cons

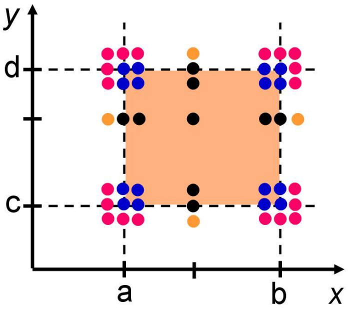
+ straightforward test-case generation
- no sense of covering the input domain
- awkward for logical vars.
- only independent input domains
- not using white-box information



Boundary Value Testing: Pros and Cons

+ straightforward test-case generation
- no sense of covering the input domain *
- awkward for logical vars. *
- only independent input domains *
- not using white-box information

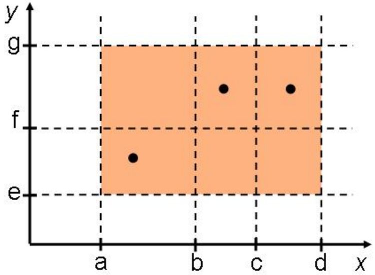
*: Today's order of business.



Outline

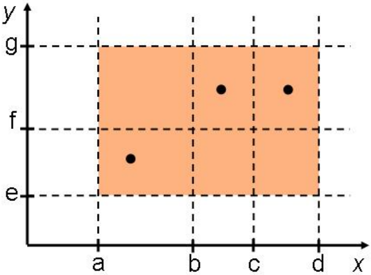
Weak Normal EC: Idea

- Define equivalence classes on the domain (range) of input (output) for each variable: (independent input)
- cover equivalence classes for the domain of each variable: single fault assumption
- how many test-cases are needed?
- also called: (equivalence, category) partition method



Little Puzzle

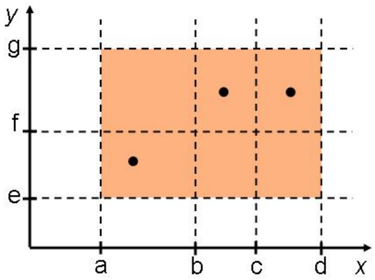
What is the minimal number of tokens that are needed to be put in an $m \times n$ grid such that each row and column contains at leats one token?



Little Puzzle

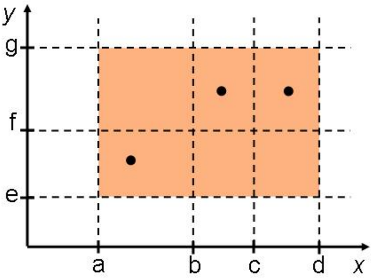
What is the minimal number of tokens that are needed to be put in an $m \times n$ grid such that each row and column contains at leats one token?

max(m,n):
Put token number i at $(max(i, m), max(i, n))$.



Weak Normal EC: Idea

- Define equivalence classes on the domain (range) of input (output) for each variable: (independent input)
- cover equivalence classes for the domain of each variable: single fault assumption
- how many test-cases are needed? $\max_x \mid S_x \mid$.



Mortgage Example (recap)

Spec. Write a program that takes
three inputs: gender (boolean), age([18-55]), salary ([0-10000])
and output the total mortgage for one person

Mortgage = salary * factor,
where factor is given by the following table.

Category	**Male**	**Female**
Young	(18-35 years) 75	(18-30 years) 70
Middle	(36-45 years) 55	(31-40 years) 50
Old	(46-55 years) 30	(41-50 years) 35

Weak Normal EC Testing

Category	Male	Female
Young	(18-35 years) 75	(18-30 years) 70
Middle	(36-45 years) 55	(31-40 years) 50
Old	(46-55 years) 30	(41-50 years) 35

- age: difficult!
- salary: [0-10000]
- male: as strange as boundary value!

Weak Normal EC Testing

Category	**Male**	**Female**
Young	(18-35 years) 75	(18-30 years) 70
Middle	(36-45 years) 55	(31-40 years) 50
Old	(46-55 years) 30	(41-50 years) 35

- age: difficult! [18-30], [31-35], [36-40], [41,45], [46-50], [51-55]
- salary: [0-10000]
- male: as strange as boundary value! true, false

Weak Normal EC Testing

if (male) **then return**

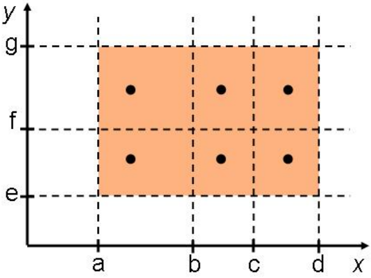
$((18 \leq age < 35)?(75 * salary) : (31 \leq age < 40)?(55 * salary) : (30 * salary))$

else return $((18 \leq age < 30)?(75 * salary) : (31 \leq age < 40)?(50 * salary) : (35 * salary))$

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	20	1000	75*1000	75*1000	P
female	32	1000	50*1000	50*1000	P
male	38	1000	55*1000	50*1000	P
female	42	1000	35*1000	35*1000	P
male	48	1000	30*1000	30*1000	P
female	52	1000	35*5000	too late!	F

Strong Normal EC Testing

- cover the all combinations of equivalence classes for the domain of all variables: multiple fault assumption
- number of test-cases? $\prod_x \mid S_x \mid$



Strong Normal EC Testing

Category	**Male**	**Female**
Young	(18-35 years) 75	(18-30 years) 70
Middle	(36-45 years) 55	(31-40 years) 50
Old	(46-55 years) 30	(41-50 years) 35

- age: [18-30], [31-35], [36-40], [41,45], [46-50], [51-55]
- salary: [0-10000]
- male: true, false

Strong Normal EC Testing

if (male) **then return**

$((18 \leq age < 35)?(75 * salary) : (31 \leq age < 40)?(55 * salary) : (30 * salary))$

else return $((18 \leq age < 30)?(75 * salary) : (31 \leq age < 40)?(50 * salary) : (35 * salary))$

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
female	20	1000	75*1000	70*1000	F
female	32	1000	50*1000	50*1000	P
female	38	1000	50*1000	50*1000	P
female	42	1000	35*1000	35*1000	P
female	48	1000	35*1000	35*1000	P
female	52	1000	35*5000	too late!	F

Strong Normal EC Testing

if (male) **then return**

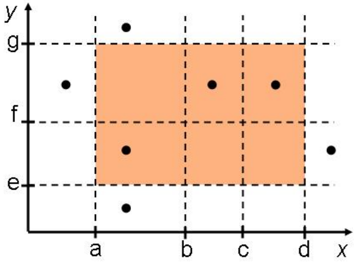
$((18 \leq age < 35)?(75 * salary) : (31 \leq age < 40)?(55 * salary) : (30 * salary))$

else return $((18 \leq age < 30)?(75 * salary) : (31 \leq age < 40)?(50 * salary) : (35 * salary))$

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	20	1000	75*1000	75*1000	P
male	32	1000	50*1000	75*1000	F
male	38	1000	55*1000	50*1000	P
male	42	1000	30*1000	55*1000	F
male	48	1000	30*1000	30*1000	P
male	52	1000	30*1000	30*1000	P

Weak Robust EC

- includes weak normal; adds out of range test-cases for each variable
- number of test-cases?
  $(\max_x \mid S_x \mid) + 2 * n$



Weak Robust EC Testing

if (male) **then return**

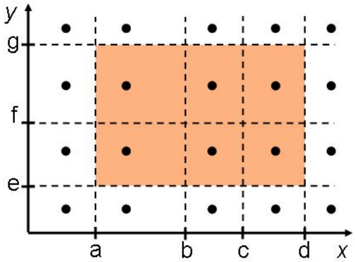
$((18 \leq age < 35)?(75 * salary) : (31 \leq age < 40)?(55 * salary) : (30 * salary))$

else return $((18 \leq age < 30)?(75 * salary) : (31 \leq age < 40)?(50 * salary) : (35 * salary))$

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	17	1000	30*1000	too young!	F
female	56	1000	35*1000	too late	F
male	36	-1	55*-1	0	F
female	36	10001	50*10001	50*10000	F

Strong Robust EC

- Same as strong normal but also checks for all out of range combinations
- number of test-cases? $\prod_x(\mid S_x \mid +2)$



Strong Robust EC

if (male) **then return**

$((18 \leq age < 35)?(75 * salary) : (31 \leq age < 40)?(55 * salary) : (30 * salary))$

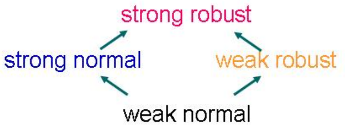
else return $((18 \leq age < 30)?(75 * salary) : (31 \leq age < 40)?(50 * salary) : (35 * salary))$

Mostly similar faults to Weak Robust EC:

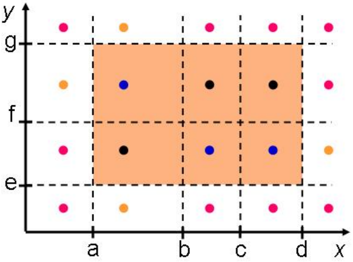
Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	17	1000	30*1000	too young!	F
female	56	1000	35*1000	too late	F
female	17	1000	35*1000	too young!	F
male	56	1000	30*1000	too late	F
male	36	-1	55*-1	0	F
female	36	10001	50*10001	50*10000	F

...

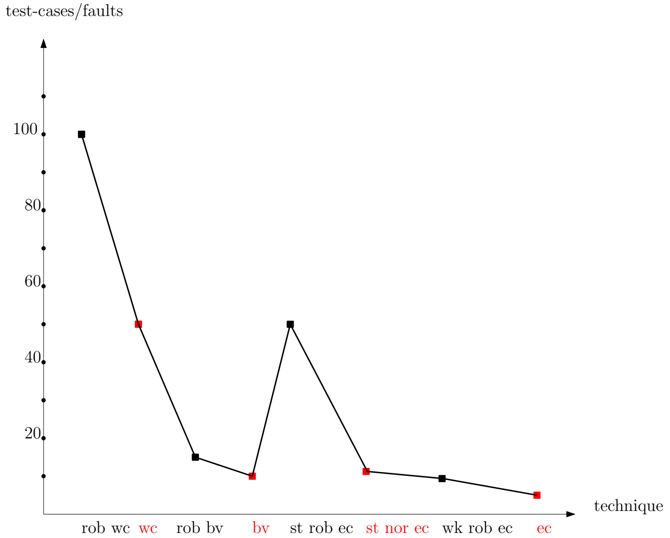
A Brief Comparison



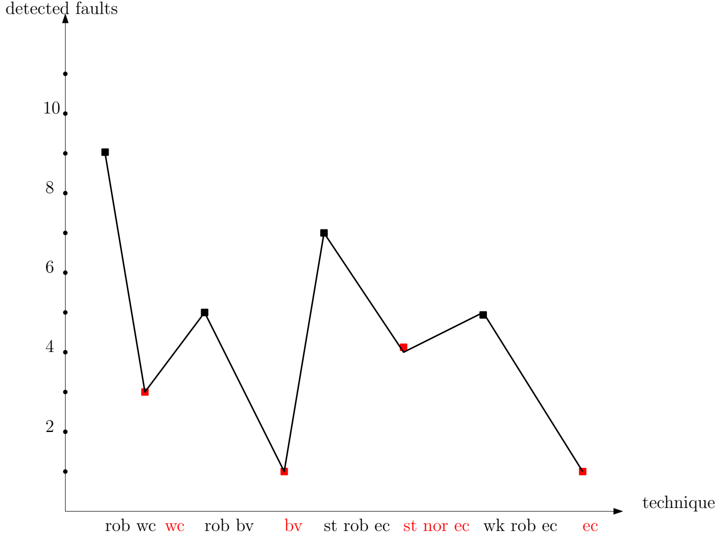
$A \rightarrow B$: Test-cases of A (faults detected by A) is a subset of those of B.



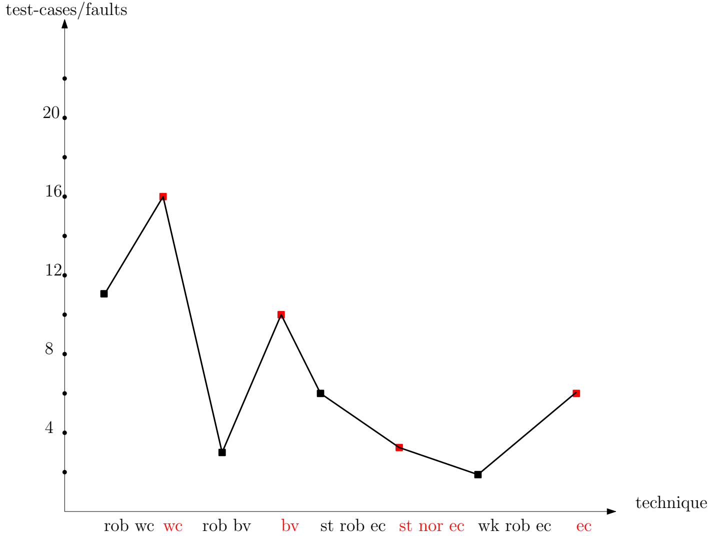
Mortgage Case: #Test-Cases



Mortgage Case: Detected Fault

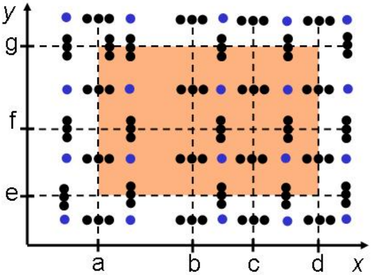


Mortgage Case: #Test-Cases/Fault



Idea

- Considering the boundaries of each partition relevant
- Example:
  Robust worst case testing of of partitions



Strong Robust EC + Robust BV

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	17	-1	30*-1	too young!	F 1
male	17	1000	30*1000	too young!	F 1
male	17	10001	30*10001	too young!	F 1
male	56 ‘	-1	30*-1	too late	F 2
male	56	1000	30*1000	too late	F 2
male	56	10001	30*10001	too late	F 2
female	17	-1	30*-1	too young!	F 3
female	17	1000	30*1000	too young!	F 3
female	17	10001	30*10001	too young!	F 3
female	56	-1	30*-1	too late	F 4
female	56	1000	30*1000	too late	F 4
female	56	10001	30*10001	too late	F 4

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
female	18	1000	75*1000	70*1000	F 5
female	19	1000	75*1000	70*1000	F 5
female	20	1000	75*1000	70*1000	F 5
female	29	1000	75*1000	70*1000	F 5
female	30	1000	35*1000	70*1000	F 6
female	31	1000	50*1000	50*1000	P
female	32	1000	50*1000	50*1000	P
female	34	1000	50*1000	50*1000	P
female	35	1000	50*1000	50*1000	P
female	36	1000	50*1000	50*1000	P
female	38	1000	50*1000	50*1000	P
female	39	1000	50*1000	50*1000	P
female	40	1000	35*1000	50*1000	F 7

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
female	41	1000	35*1000	35*1000	P
female	42	1000	35*1000	35*1000	P
female	44	1000	35*1000	35*1000	P
female	45	1000	35*1000	35*1000	P
female	46	1000	35*1000	35*1000	P
female	49	1000	35*1000	35*1000	P
female	50	1000	35*1000	35*1000	P
female	51	1000	35*1000	too late!	F 7
female	52	1000	35*1000	too late!	F 7
female	53	1000	35*1000	too late!	F 7
female	54	1000	35*1000	too late!	F 7
female	55	1000	35*1000	too late!	F 7

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	18	1000	75*1000	75*1000	P
male	19	1000	75*1000	75*1000	P
male	20	1000	75*1000	75*1000	P
male	29	1000	75*1000	75*1000	P
male	30	1000	75*1000	75*1000	P
male	31	1000	55*1000	75*1000	F 8
male	32	1000	55*1000	75*1000	F 8
male	34	1000	55*1000	75*1000	F 8
male	35	1000	55*1000	75*1000	F 9
male	36	1000	55*1000	55*1000	P
male	38	1000	55*1000	55*1000	P
male	39	1000	55*1000	55*1000	P
male	40	1000	55*1000	20*1000	F 10

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	41	1000	30*1000	30*1000	P
male	42	1000	30*1000	30*1000	P
male	44	1000	30*1000	30*1000	P
male	45	1000	30*1000	30*1000	P
male	46	1000	30*1000	30*1000	P
male	49	1000	30*1000	30*1000	P
male	50	1000	30*1000	30*1000	P
male	51	1000	30*1000	30*1000	P
male	52	1000	30*1000	30*1000	P
male	53	1000	30*1000	30*1000	P
male	54	1000	30*1000	30*1000	P
male	55	1000	30*1000	30*1000	P

Strong Robust EC + Robust BV (Cont'd)

Gender	**Age**	**Salary**	**Output**	**Correct Out.**	**Pass/Fail**
female	17	-1	35*-1	0	F 11
female	18	-1	75*-1	0	F 11

. . . . . .

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
female	17	10001	35*10001	too young!	F 11
female	18	10001	75*10001	75*10000	F 12

...

Strong Robust EC + Robust BV (Cont'd)

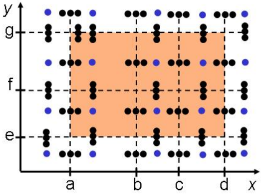
Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	17	-1	30*-1	0	F 12
male	18	-1	70*-1	0	F 12
...					

Strong Robust EC + Robust BV (Cont'd)

Gender	Age	Salary	Output	Correct Out.	Pass/Fail
male	17	10001	30*10001	too young!	F 12
male	18	10001	70*10001	75*10000	F 12
...					

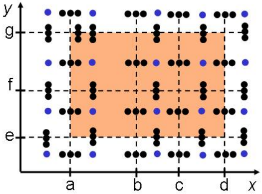
Problems

- Example:
  Strong EC + Robust BV
  number of test-cases:
  $\sim \prod_x 4(|\ S_x\ | + 1)$, whopping!



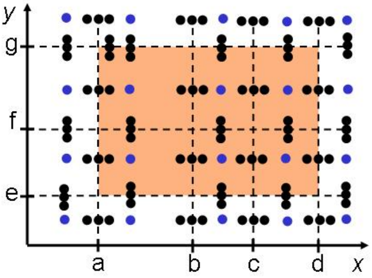
Problems

- >100 test-cases for the mortgage example
- too many for any real-life program
  e.g., 5 vars., each 5 partitions:
  $\sim$ 8 million test-cases
  1 sec. for each test-case:
  3 months testing!



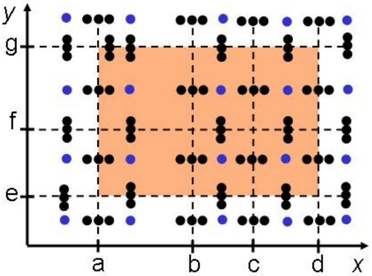
Problems

- Problems:
  1. No constraints on the equivalence classes
  2. Dependencies among different variables not taken into account
  3. No choice among relevant classes (e.g., apply worst-case testing on some and boundary values on others)
- Solutions: Attend the coming lecture!



Problems

- Problems:
  1. No constraints on the equivalence classes
  2. Dependencies among different variables not taken into account
  3. No choice among relevant classes (e.g., apply worst-case testing on some and boundary values on others)
- Solutions: Attend the coming lecture!



Possible Solution: Pairwise Testing

- Pairwise testing: for each two variables and each two partitions of their valuations, there is at least one test case
- T-wise testing: for each T variables and each T partitions of their valuations, there is at least one test case

Outline

Outline

Idea

- Goal: Summarize the logic of the program (à la Karnaugh maps)
- Find a few conditions on input determining the output behavior
  need not be independent
  relaxing the independence assumption in all previous techniques
- Determine the output actions
  for each combination of condition evaluations
- also called: cause-effect graph testing, or
  tableau testing

Basic Concepts

- Stub:
  - condition part
    the most dominating conditions first
    multi-valued conditions and special cases last
  - action part
    exceptions
    preferably combined actions as new rows

Stub	Entry		
c1	F	T	T
c2	-	F	T
c3	-	-	F
a1	X	-	-
a2	-	X	-
a1;a2	-	-	X

Basic Concepts

- Entry
  - columns are called rules
  - condition part: true, false, (possibly other values) or don't care
  - action part

Stub	Entry		
c1	F	T	T
c2	-	F	T
c3	-	-	F
a1	X	-	-
a2	-	X	-
a1;a2	-	-	X

Basic Concepts

- Completeness check for independent variables
  - each don't care counts for two rules
  - there must be $2^{|\{c_i\}|}$ rules (for n_i-valued conditions: $\prod_i n_i$)

c1	F	T	T
c2	-	F	T
c3	-	-	F
a1	X	-	-
a2	-	X	-
a1;a2	-	-	X

Basic Concepts

- Completeness check for independent variables
  - each don't care counts for two rules
  - there must be $2^{|\{c_i\}|}$ rules (for n_i-valued conditions: $\prod_i n_i$)

c1	F	T	T	T
c2	-	F	T	T
c3	-	-	F	T
a1	X	-	-	-
a2	-	X	-	-
a1;a2	-	-	X	-
error	-	-	-	X

Conditions/Actions									
c7: 0≤salary≤10000?	n	y	y	y	y	y	y	y	y
c1: male?	-	-	-	y	y	y	n	n	n
c2: too young? [..,18]	-	y	-	-	-	-	-	-	-
c3: young? m:[18,..,35], f:[18,..,30]	-	-	-	y	-	-	y	-	-
c4: mid? m:[36,..,45], f:[31,..,40]	-	-	-	-	y	-	-	y	-
c5: old? m:[46,..,55], f:[40,..,50]	-	-	-	-	-	y	-	-	y
c6: too old? m:[56,..], f:[51,..]	-	-	y	-	-	-	-	-	-
a1: wrong inputs	X	X	X	-	-	-	-	-	-
a2: 75*salary	-	-	-	X	-	-	-	-	-
a3: 70*salary	-	-	-	-	-	-	X	-	-
a4: 55*salary	-	-	-	-	X	-	-	-	-
a5: 50*salary	-	-	-	-	-	-	-	X	-
a6: 35*salary	-	-	-	-	-	-	-	-	X
a7: 30*salary	-	-	-	-	-	X	-	-	-

Decision Table for Testing

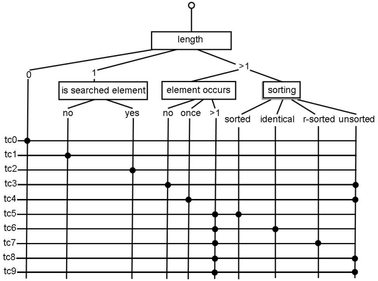
variables: Physical or Logical	P	P	P	P	P	L	L	L	L	L
Independent?	y	y	y	y	n	y	y	y	y	n
Single fault assum.?	y	y	n	n	-	y	y	n	n	-
Exception handling?	y	n	y	n	-	y	n	y	n	-
BV		X								
Robust	X									
WC				X						
Robust WC			X							
EC							X			
Strong (Normal) EC									X	
(Weak) Robust EC						X				
Strong Robust EC								X		
Decision Table					X					X

Outline

Basic Steps

Classification tree:

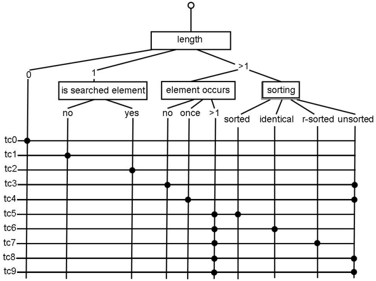
- Determine the aspects of specification influencing the logic
- Establish a hierarchy between aspects (the more global conditions first)
- Partition the input domain for each aspect
  cover the whole domain of the "parent" node



Basic Steps

Combination table:

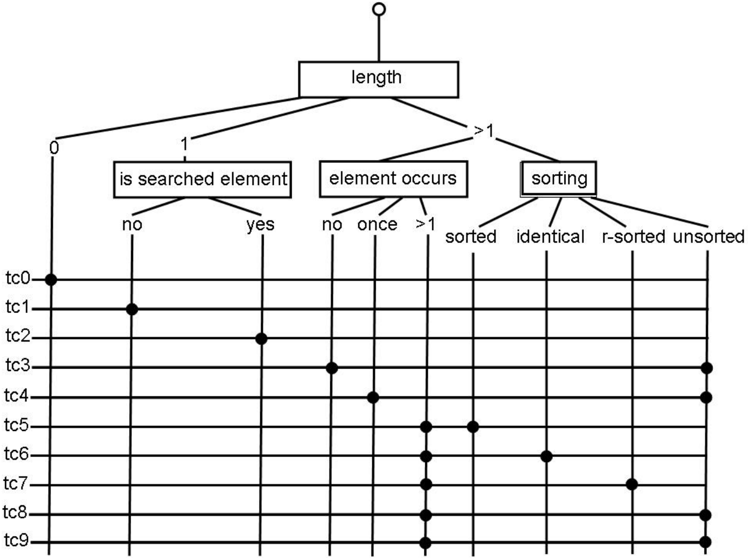
- Define a test-case for each relevant combination of inputs



Example

Informal Spec

Consider the function $count(list : List(El), el : El) : int$,
which takes a list of elements (with an order defined on them),
and an element
and output the number of occurrences of the element in the list.


length
0
1
>1
is searched element
element occurs
sorting
no
yes
no
once
>1
sorted
identical
r-sorted
unsorted
tc0
tc1
tc2
tc3
tc4
tc5
tc6
tc7
tc8
tc9

Mortgage Example

Classes

1. Salary: -1, [0..10000], >10000,
2. Gender: Male, Female,
3. Age: Too young, Young, Middle, Old, Too old (dependent on gender)

Outline

Functional Testing

- Equivalence testing forms the basis:
  - Strong variants are often practically infeasible
  - Robust techniques are very effective for PL's with weak typing
- Decision tables and classification trees, help us in:
  1. summarizing the logic
  2. identifying and documenting the effective methods and test-cases.

One Sentence to Take Home

No perfect functional testing technique exists:
combination of classification tree (or DT)
with others should provide an effective mix.