Combinatorial Coverage as an Estimator of Residual Risk After Testing

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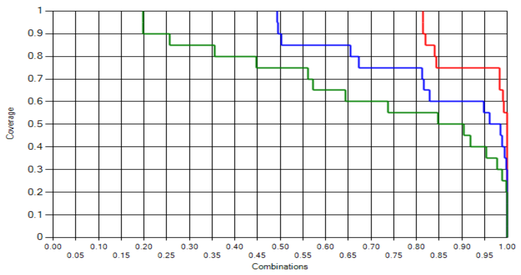
Problem: an existing test set has a large number of tests.

- Not designed as a covering array
- Does it provide 2-way coverage? 3-way coverage? More?
- How can we evaluate combinatorial coverage?

Definition. *Variable-value configuration:* For a set of *t* variables, a variable-value configuration is a set of *t* valid values, one for each of the variables.

Definition. *Simple t-way combination coverage:* the proportion of *t*-way combinations of variables for which all valid variable-values configurations are fully covered.

Definition. *Total t-way combination coverage:* the proportion of valid *t*-way variable-values configurations covered.



Combinatorial coverage for 7,489 tests
$1^3 2^{75} 4^2 6^2$ configuration
red = 2-way; blue=3-way; green=4-way

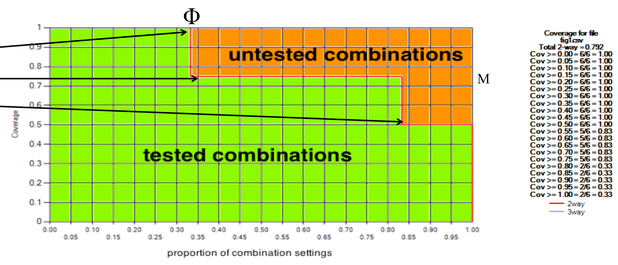
J.R. Maximoff, M.D. Trela, D.R. Kuhn, R. Kacker, "A Method for Analyzing System State-space Coverage within a t-Wise Testing Framework", IEEE International Systems Conference 2010, Apr. 4-11, 2010, San Diego.

Test #	a	b	c	d
1	0	0	0	0
2	0	1	1	0
3	1	0	0	1
4	0	1	1	1

Vars	Configurations covered	Config coverage
a b	00, 01, 10	.75
a c	00, 01, 10	.75
a d	00, 01, 11	.75
b c	00, 11	.50
b d	00, 01, 10, 11	1.0
c d	00, 01, 10, 11	1.0

- Tests contain four binary variables: a, b, c, d
- What can we say about coverage?
  - Tests have $\binom{4}{2}$ 2-way combinations with 4 values each: 00, 01, 10, 11
  - Measure the coverage of each combination
  - Φ = % of combinations w/ full 100% value coverage
  - M = minimum value coverage

2/6 covered to 100%
3/6 covered to 75%
6/6 covered to ≥ 50%
total 2-way coverage
= 19/24 = .79
(area under curve)



Evaluating Test Strategies

- Combinatorial coverage is an important consideration for all test strategies
- Helps us understand why some strategies are effective

Some properties of test criteria

M_t (*all-values*) ≥ $\frac{1}{v^{t-1}}$

M_t (*base-choice*) = $\frac{1+t(v-1)}{v^t}$

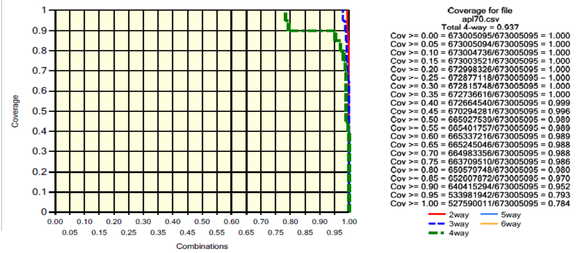
(*t*+1)-way total coverage: $S_{t+1} \geq 1/v$

S_t = total variable-value coverage, the proportion of variable-value configurations that are covered by at least one test
M_t = minimum coverage of *t*-way settings among combinations

Very Large Test Sets

- Some problems are too large for covering array algorithms
- Random tests naturally cover a high proportion of combinations
- Measure random test set coverage

Example:
coverage for 70 tests, $2^{35}3^2 4^1 5^2 1^4 1^1$ design:



MEASURING TLS CIPHER SUITES

- combination of key exchange, authentication, encryption and MAC algorithms
- interactions between components may be sources of problems
- useful to consider what interactions exist in already implemented code; what may need more extensive testing if suite is extended
- Examples
  - IANA - input model of $5^1 6^2 10^1 28^1$ = 8400 possible implementations; small proportion covered
  - Mozilla – smaller input model; larger proportion covered
- Combinatorial coverage provides a measure of one aspect of assurance complexity