

## IV&V International Workshop 2013

# Evaluating the t-way Combinatorial Technique for Determining the Thoroughness of a Test Suite

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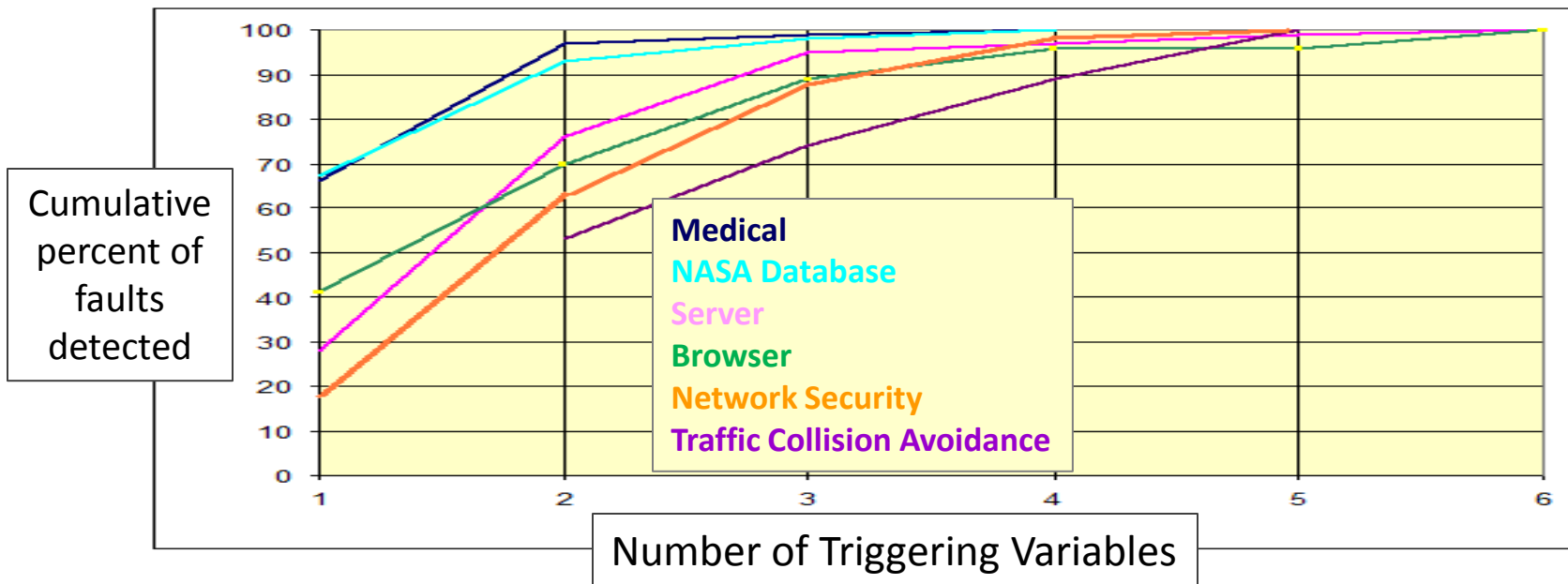
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# NIST Software Testing Work

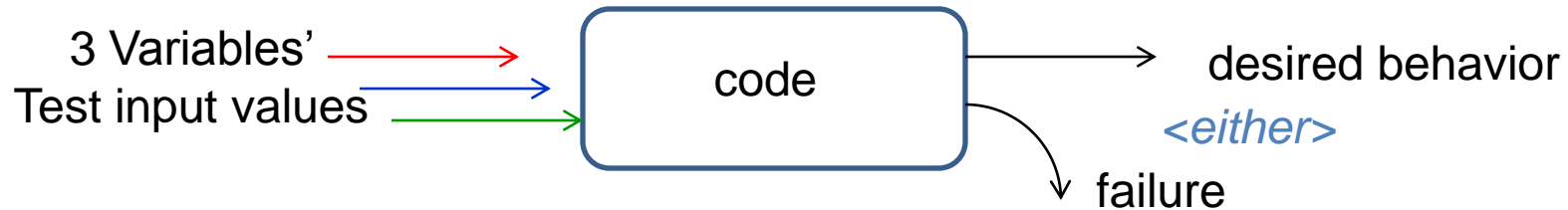
**Goal:** Reduce testing cost

- **Key finding:**

Most failures found are triggered by one or two variables, and progressively fewer by three, four, or more variables, and the maximum interaction degree is small.



# Examples of 't-way' Variable Value Interaction-Driven Failures



Variables >	Pressure	Volume	Velocity	Result	't-way' Interaction
Three possible failure scenarios	< 10			Failure	1 - Way
	< 10	> 300		Failure	2 - Way
	< 10	> 300	> 5	Failure	3 - Way

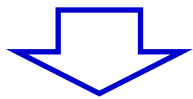
- The NIST Combinatorial Coverage Tool measures the capacity of a test suite for detecting faults due to t-way interactions.
- This is different from code coverage measures such as statement or branch coverage.

# NIST Tool Mechanics

In excel, define  
Input **Test Variables**  
and their Values  
for test cases:

**V1**      **V2**      **V3**

1	ENABLE	SIDE A	AVERAGE
2	ENABLE	SIDE A	MINIMUM
3	ENABLE	SIDE B	MINIMUM
4	DISABLE	SIDE A	AVERAGE
5	DISABLE	SIDE B	MINIMUM



Save Values in .csv file format

```
ENABLE, SIDE A, AVERAGE,
ENABLE, SIDE A, MINIMUM,
ENABLE, SIDE B, MINIMUM,
DISABLE, SIDE A, AVERAGE,
DISABLE, SIDE B, MINIMUM
```

Input .csv file into NIST Tool  
which compares the **Test Values**  
against all possible values:

**2-way (12)**

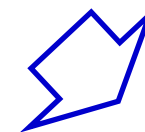
ENABLE	SIDE A
ENABLE	SIDE B
ENABLE	AVERAGE
ENABLE	MINIMUM
DISABLE	SIDE A
DISABLE	SIDE B
DISABLE	AVERAGE
DISABLE	MINIMUM
SIDE A	AVERAGE
SIDE A	MINIMUM
SIDE B	AVERAGE
SIDE B	MINIMUM

(11)

**3-way (8)**

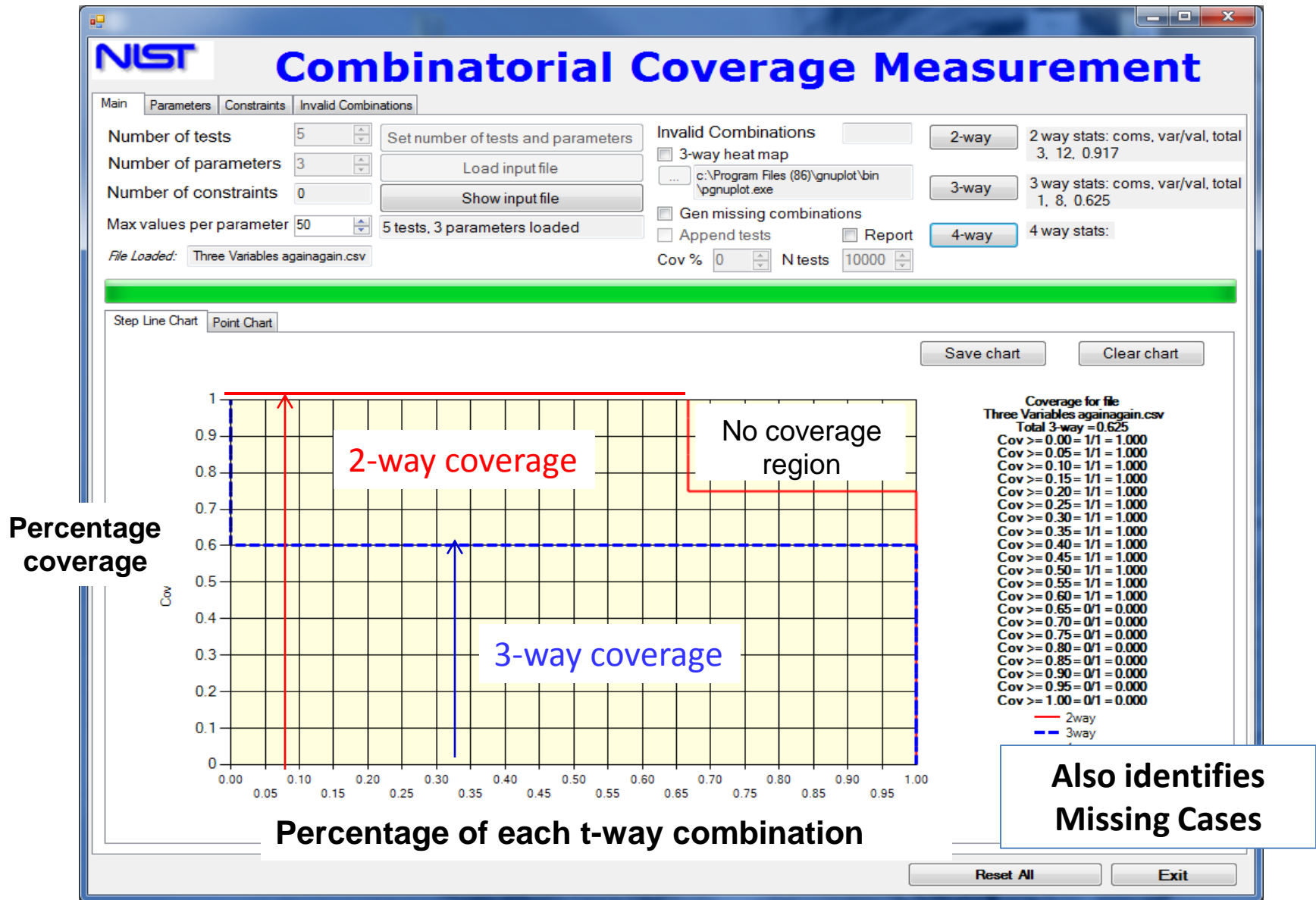
ENABLE	SIDE A	AVERAGE
ENABLE	SIDE A	MINIMUM
ENABLE	SIDE B	AVERAGE
ENABLE	SIDE B	MINIMUM
DISABLE	SIDE A	AVERAGE
DISABLE	SIDE A	MINIMUM
DISABLE	SIDE B	AVERAGE
DISABLE	SIDE B	MINIMUM

(5)



**NIST Tool  
Output Chart**

# NIST Tool Output Chart



## IV&V use of NIST Tool Conclusions:

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*“The NIST Tool provides a structure for recording and reporting test coverage.”*

1. As an inline IV&V analysis tool (including peer reviews):
  - 1) Example: analyze coverage/lack of coverage of developer tests
  - 2) Expect moderate overhead for worthwhile value added.
2. As an inline Verification tool in JSTAR/ITS:
  - 1) Example: identify the coverage of tests as they are defined
  - 2) Expect low overhead for high value added for test planning.
3. As an IV&V audit tool:
  - 1) Example: auditing completed IV&V analysis of developer tests
  - 2) Significant overhead for value added.
4. As a macroscopic IV&V tool:
  - 1) Example: analyze project or multi-project test plans
  - 2) Expect a moderate overhead for additional high level insight.

# IV&V use of NIST Tool Recommendations:

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***“The value of the NIST Tool must be proven in IV&V field trials.”***

1. Add the NIST Tool and Instructions for Use into the Catalog of Methods.
2. Use the Tool during active IV&V projects (including peer reviews)
  - 1) For evaluation of test coverage of developer's test plans.
  - 2) During analysis of developer test case scripts.
3. Implement Tool in JSTAR/ITC as verification test planning aid to measure coverage of tests as they are planned and before they are run
  - 1) During inhouse testing of developer flight software
  - 2) During inhouse development of test tools and other support software
  - 3) During development of simulators
4. Consider
  - 1) Use of Tool in comparing developer tests plans among projects.
  - 2) Collaboration with USAF and JHU/APL regarding Tool experiences
  - 3) Introducing Tool to software developers

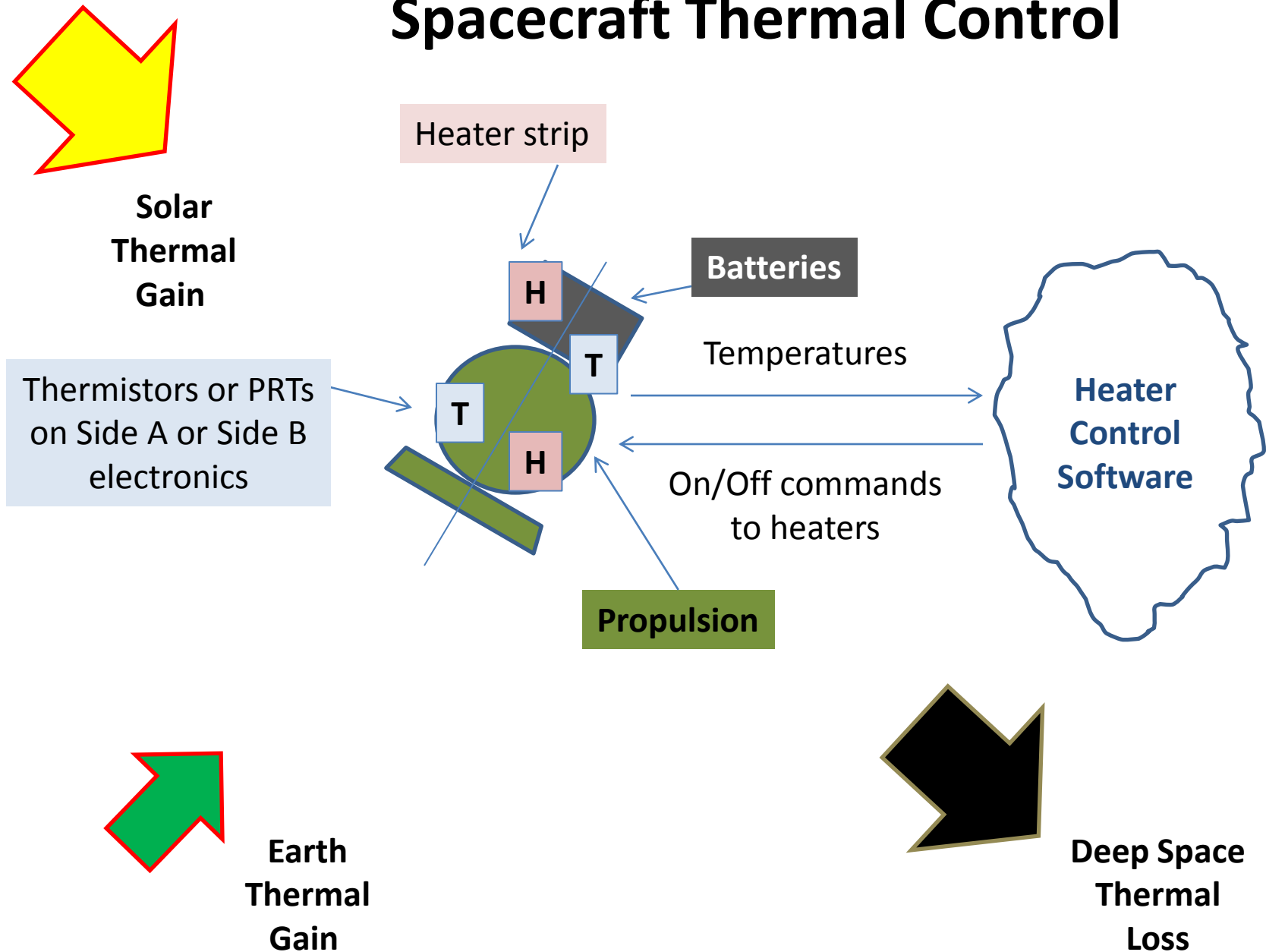
# Combinatorial Coverage Measurement Example

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# Spacecraft Thermal Control



# Tests Analyzed

## 14 tests from heater control test suite

Two sets of variables:

1) Flags:

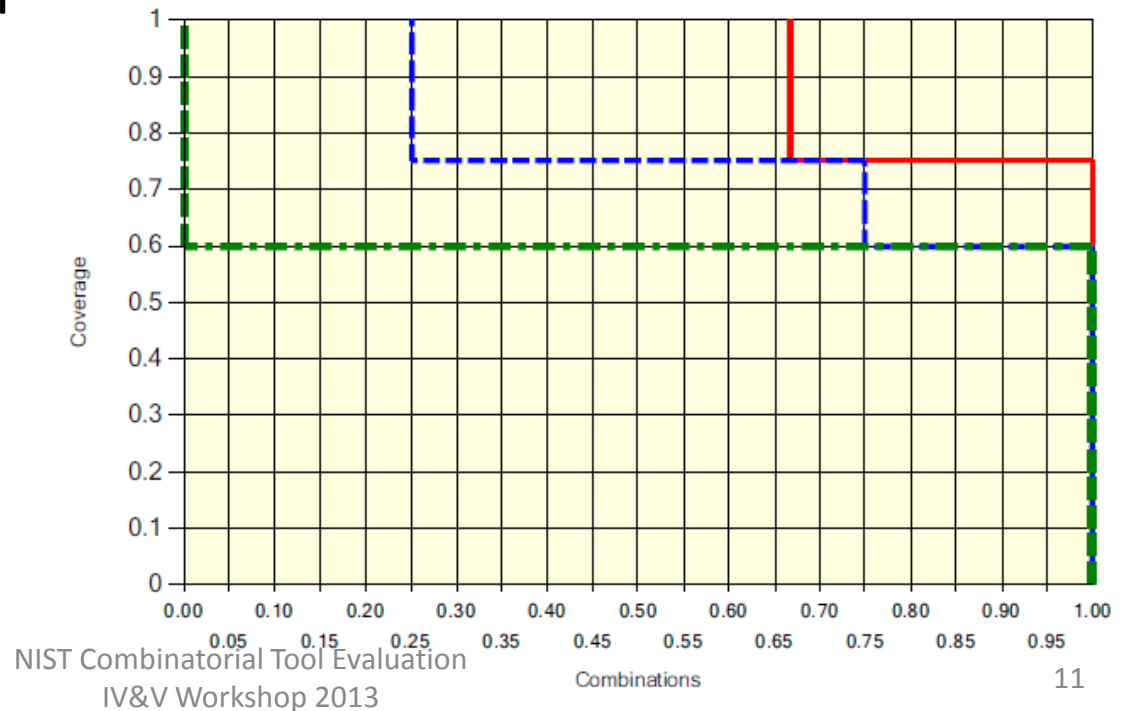
- a. Battery heater control enable/disable
- b. Battery heater control side a/b
- c. Battery heater telemetry side a/b
- d. Control flag (average/minimum)

2) Temperature sensors

- a. 16 thermistors,
- b. 18 PRTs (platinum resistance thermometers)

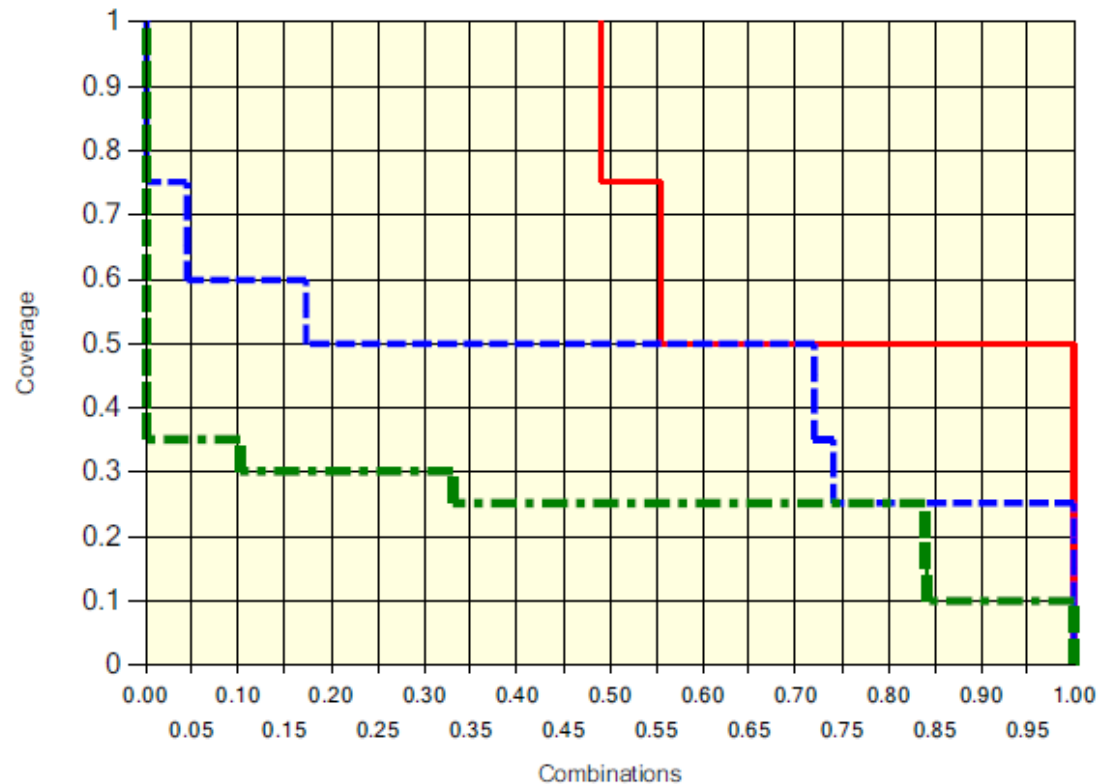
# Coverage of four flag combinations

- **Four flags: control enable/disable; control side; telemetry side; control flag (avg/min)**
- Reasonably good : 88.9% (2-way), 75% (3-way), 62.5% (4-way)
- Review of test values shows only one test for telemetry side B, so coverage would be higher if supplemented with more side B tests
- If flags affect execution sequence of software, combinations may be significant;
- Suggests need for additional tests



# Sensors: valid/invalid value combination coverage

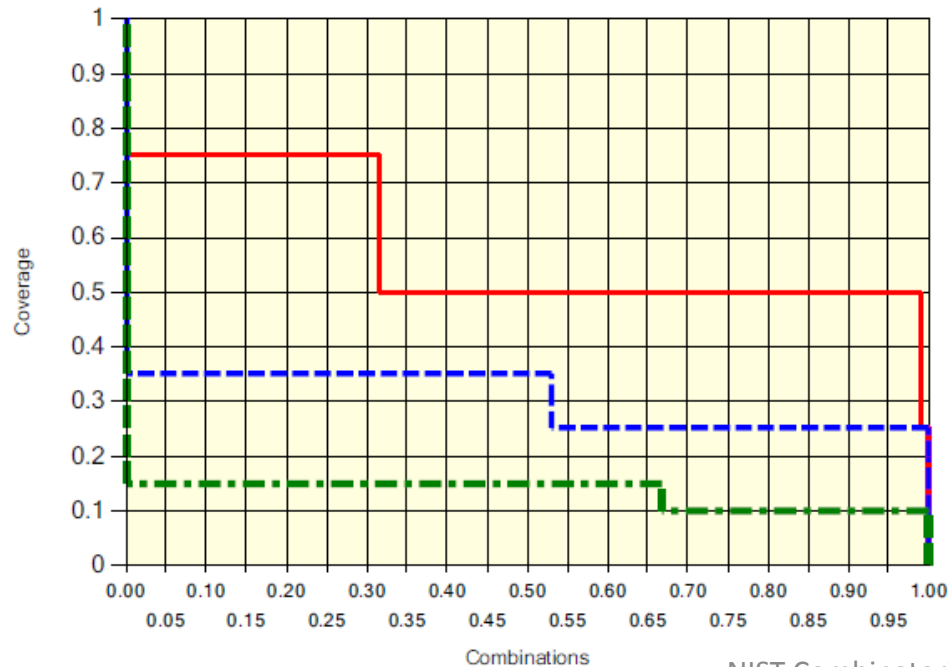
- 2, 3, 4-way coverage = 76.1%, 45.9%, 25.7%
- Combinations of values probably less significant than for flags that control s/w



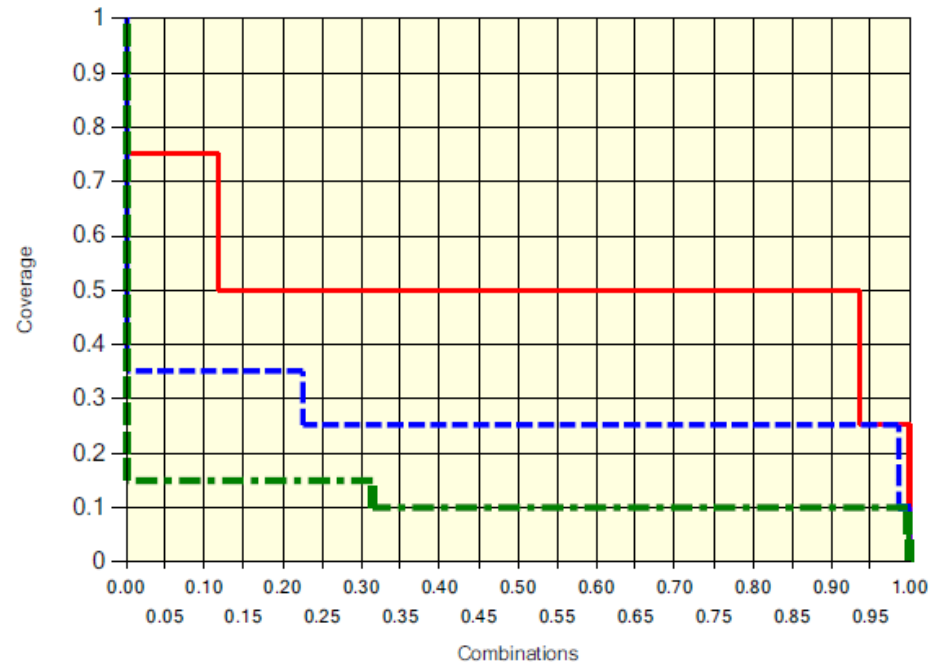
# Comparison of coverage: tests for MINIMUM and AVERAGE

- Coverage similar although 4 tests with MINIMUM flag, 10 with AVERAGE flag
- Coverage significantly lower than for flags

MINIMUM: 57.6%, 31.6%, 16.7%



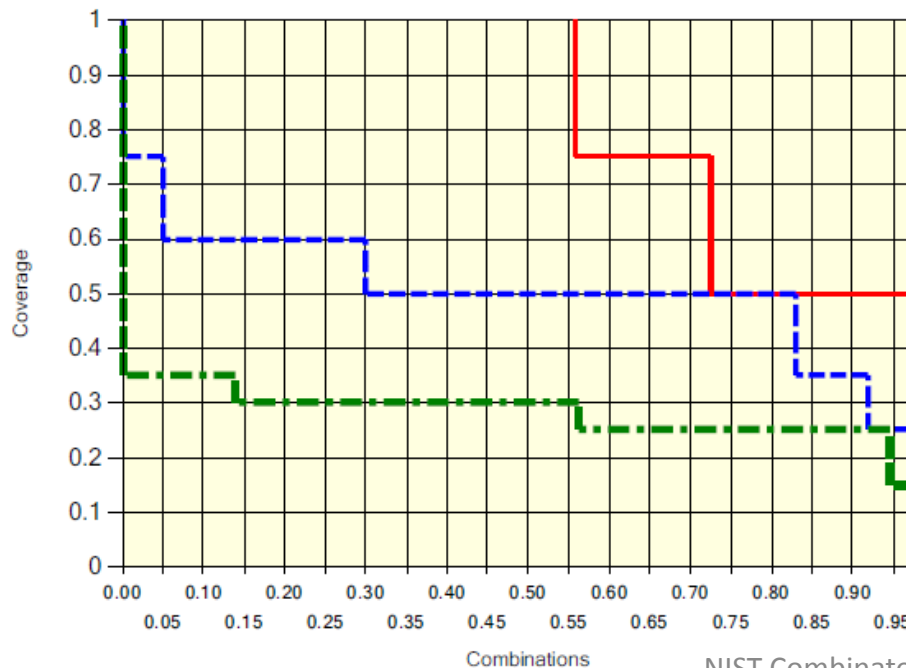
AVERAGE: 51.3%, 27.6%, 14.4%



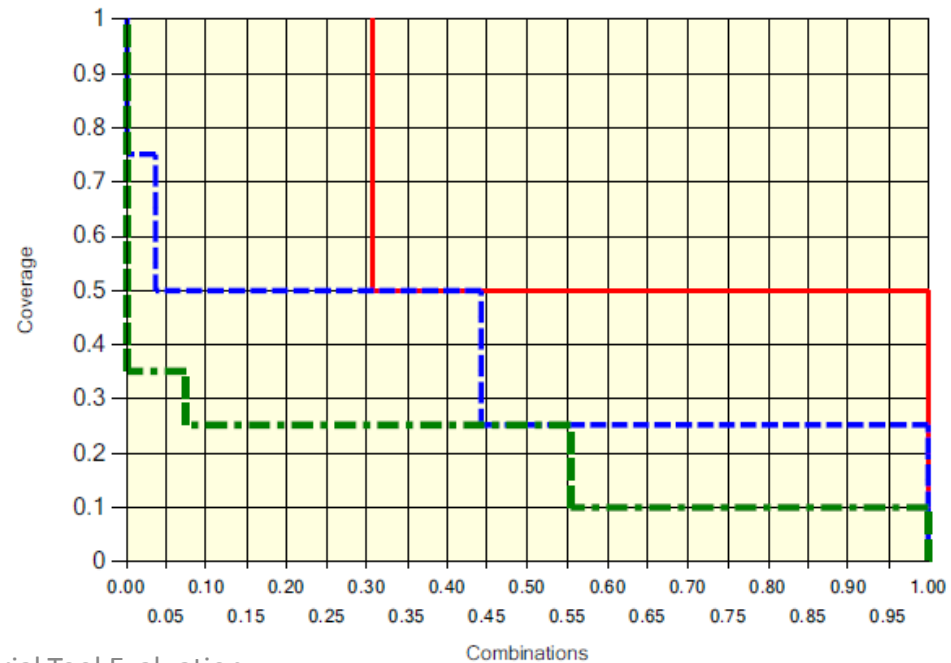
# Comparison of coverage: tests for Side A and B sensors

- Significant difference in coverage
- Suggests tests are more thorough for A side; higher risk of untested situations for B
- More tests for B may be helpful

A: 82.1%, 51.2%, 28.9%



B: 65.3%, 36.9%, 20.3%



# Difference in coverage for Side A and B not obvious

A:

1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1
1	0	1	0	0	0	1	0	1	0	1	0	1	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1
1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1
1	0	1	0	1	0	1	0	1	0	0	0	0	0	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

B:

1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0
0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

# CCM Tool

Parallel processing (optional)

Columns=parameters  
a,b,c,e,f  
c,b,e,a,b  
b,a,f,c,e

Rows=tests

Load input file

Main Screen

Random Tests

This feature gets an **input file** with all the parameters and their values and generates a random test file with the **number of tests specified**. It can be specified to **measure the coverage** from the test set obtained.

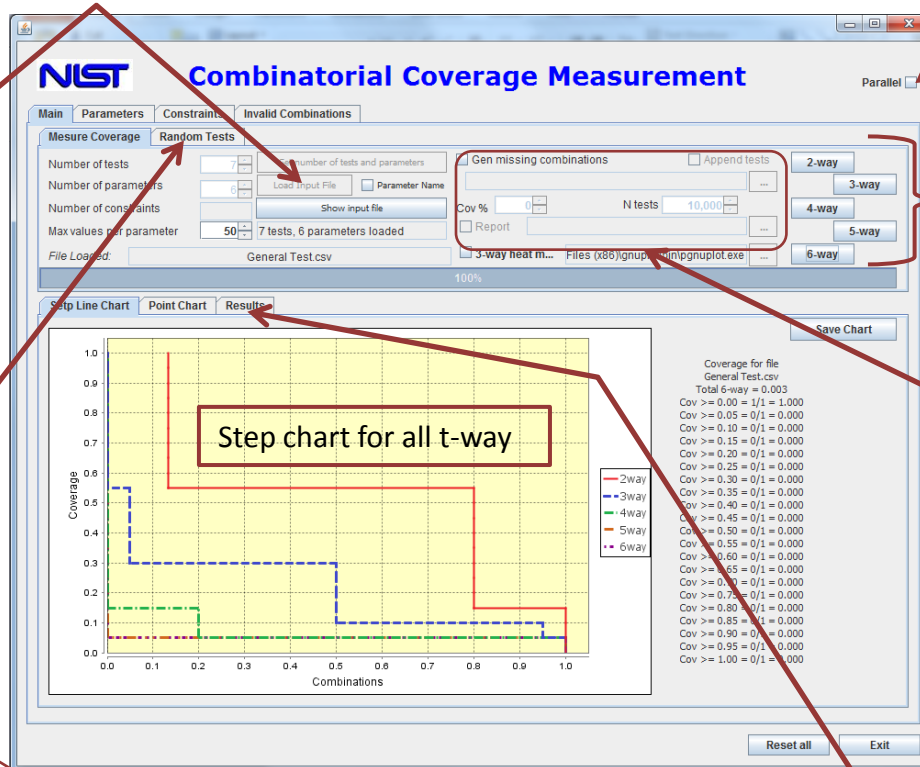
Measure Coverage Random Tests

Load File ☐ Parameter Name

File Loaded:

No. Tests:  ☐ Measure Coverage

Get Tests



t-way measurement

Results

t-way	Coms.	Var/Val	Var/Val Cov.	Invalid Tests	Total	Time Constraints	Time t-way	Total Time
2-way	15	285	94	0	32.9824561%	00:00:00.000000	00:00:00.000017	00:00:00.000017
3-way	20	1485	137	0	9.2255892%	00:00:00.000000	00:00:00.000001	00:00:00.000001
4-way	15	3990	105	0	2.6315789%	00:00:00.000000	00:00:00.000001	00:00:00.000001
5-way	6	5292	42	0	0.7936508%	00:00:00.000000	00:00:00.000002	00:00:00.000002
6-way	1	2744	7	0	0.255102%	00:00:00.000000	00:00:00.000002	00:00:00.000002



# CCM Tool

Parameters

**Combinatorial Coverage Measurement**

Main Parameters Constraints Invalid Combinations

Parameter P1 0

Value: [ ]

Add Remove Remove all

Boundaries/Groups

Number of classes: 3

Boundaries

Number Boundary Value Boundary

0 299.0

1 599.0

Load Remove

Boundaries

Parameter P3 2

Value: [ ]

Add Remove Remove all

Boundaries/Groups

Number of classes: 2

Boundaries

Values for this parameter

Number

0 1 2 3 4 5 6 7

Groups

Parameter P2 1

Value: [ ]

Add Remove Remove all

Boundaries/Groups

Number of classes: 2

Groups

Select Values

Num Group Values in Group

0 0

1 1,1,581,567,6

Groups

EXAMPLE, TCAS [Siemens suite], universe file

TCAS configuration:  
• Boundaries  
• Groups  
• Constraints

Parameter	Type	Boundaries/Groups/ Constraints
P1	Int	Cur_Vertical_Sep Cur_Vertical_Sep > MAXALTDIFF [600] Cur_Vertical_Sep > MINSEP [300]
P2	Bool	High_confidence
P3	Bool	Two_of_three_reports_valid
P4	Int	Own_Tracked_Alt Own_Tracked_Alt < Other_Tracked_Alt [own_below_threat] [bool] Other_Tracked_Alt < Own_Tracked_Alt [own_above_threat] [bool]
P5	Int	Own_tracked_alt_rate Own_tracked_alt_rate <= OLEV [600]
P6	Int	Other_tracked_alt Own_Tracked_Alt < Other_Tracked_Alt [own_below_threat] [bool] Other_Tracked_Alt < Own_Tracked_Alt [own_above_threat] [bool]
P7	Int	Alt_layer_value
P8	Int	Up_separation Up_Separation >= ALIM() [Positive_RA_Alt_Thresh[Alt_Layer_Value]] ~ 400,500,640,740 Up_Separation > NOZCROSS [100]
P9	Int	Down_separation Inhibit_Based_Climb() > Down_Separation Down_Separation >= ALIM() [Positive_RA_Alt_Thresh[Alt_Layer_Value]] ~ 400,500,640,740
P10	Int	Other_RAC Other_RAC == NO_INTENT [0]
P11	Int	Other_capability Other_Capability == TCAS_TA[1]
P12	Int	Climb_inhibit

Constraints

**Combinatorial Coverage Measurement**

Main Parameters Constraints Invalid Combinations

Parameters

P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
0	0	1	2597	574	4253	0	399	400	0	0	1
1	1	0	621	216	382	1	400	841	1	1	0
2	1	1	4398	133	1445	2	641	839	2	2	1
			581	3459	183	381	3	640	501	4	9
			567	3342	23	4657	1	499	741	3	3
			655	34	542	3514	9	500	401	1	4
			637	127	403	4616	4	401	740	9	
			906	698	499	2465	5	739	399		
			205	283	5056	637	741	499			
			5378	390	1000	906	740	500			
			136	576	2305	501	640				
			1945	376	2064	639	739				
			659	204	3825	605	931				

Symbols

Constraints

P7 <= 3

P7 >= 0

Reset all Exit

t-way	Coms.	Var/Val	Var/Val Cov.	Invalid Tests	Total
2-way	66	552	531	35	96.1956522%
3-way	220	4755	4359	35	91.6719243%
4-way	495	26462	21668	35	81.8834555%
5-way	792	105050	69101	35	65.7791528%
6-way	924	312451	145844	35	46.677399%

TCAS Results

Coverage

Step Chart

