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# Combinatorial Testing

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# What is NIST?

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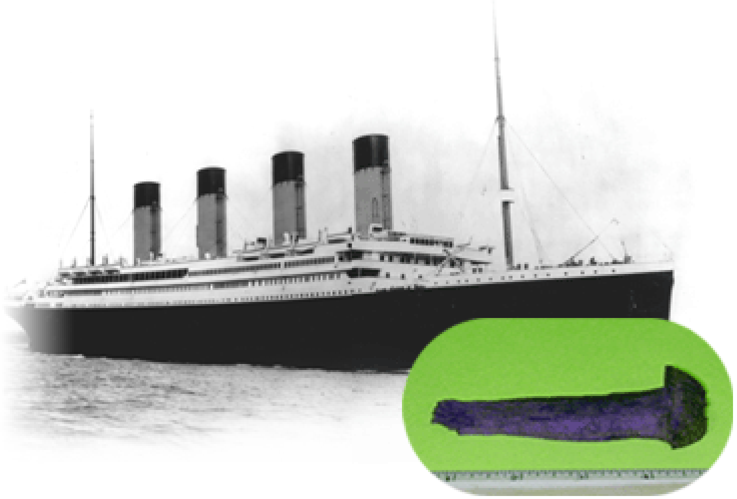
- A US Government agency
- The nation's measurement and testing laboratory – 3,000 scientists, engineers, and support staff including 3 Nobel laureates
- Research in physics, chemistry, materials, manufacturing, computer science

Among other topics,
**analysis of engineering failures**, including buildings, materials, and ...



# Software Failure Analysis

- NIST studied software failures in a variety of fields including 15 years of FDA medical device recall data
- What causes software failures?
    - logic errors?
    - calculation errors?
    - inadequate input checking?   Etc.
- What testing and analysis would have prevented failures?
- Would all-values or all-pairs testing find all errors, and if not, then how many interactions  would we need to test to find all errors?

e.g., failure occurs if

| | |
|---|---|
| pressure < 10 | (1-way interaction) |
| pressure < 10 & volume > 300 | (2-way interaction) |

# Pairwise testing is popular, but when is it enough?

- Pairwise testing commonly applied to software
- Intuition: some problems only occur as the result of an interaction between parameters/components
- Pairwise testing finds about 50% to 90% of flaws
  - Cohen, Dalal, Parelius, Patton, 1995 – 90% coverage with pairwise, all errors in small modules found
  - Dalal, et al. 1999 – effectiveness of pairwise testing, no higher degree interactions
  - Smith, Feather, Muscetolla, 2000 – 88% and 50% of flaws for 2 subsystems

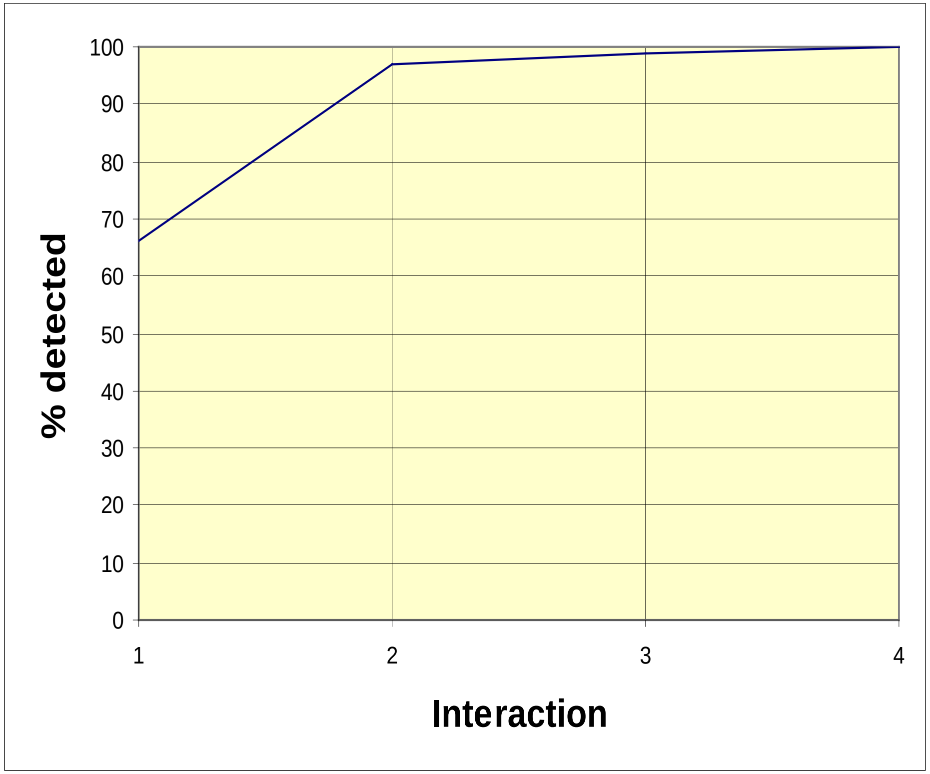
What if finding 50% to 90% of flaws is not good enough?

# When is pairwise testing not enough?

"Relax, our engineers found
90 percent of the flaws."

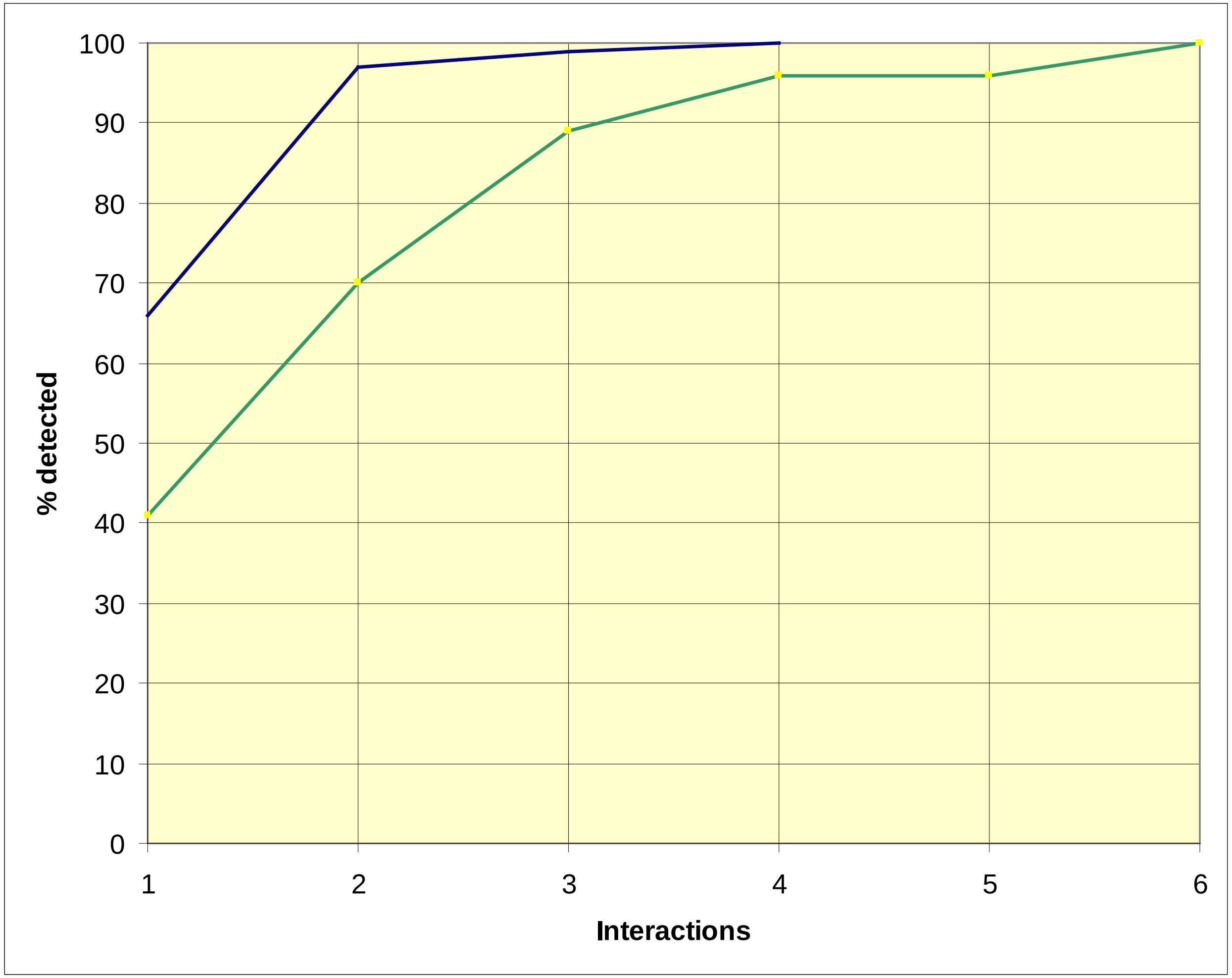
# How about hard-to-find flaws?

- Interactions e.g., failure occurs if
- pressure < 10 (1-way interaction)
- pressure < 10 & volume > 300 (2-way interaction)
- pressure < 10 & volume > 300 & velocity = 5 (3-way interaction)
- The most complex failure reported required 4-way interaction to trigger




# How about other applications?

Browser (green)

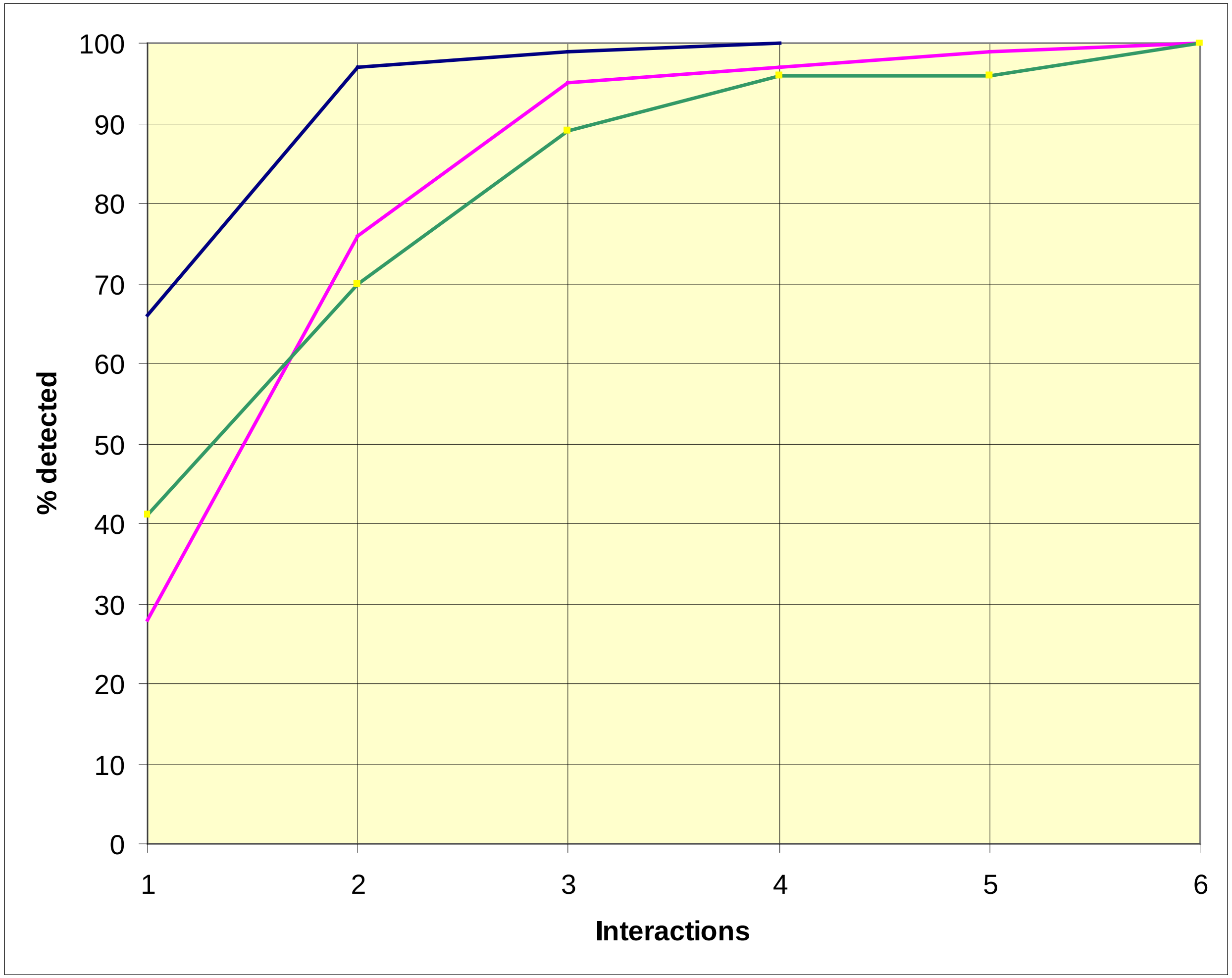



These faults more complex than medical device software!!

Why?

# And other applications?

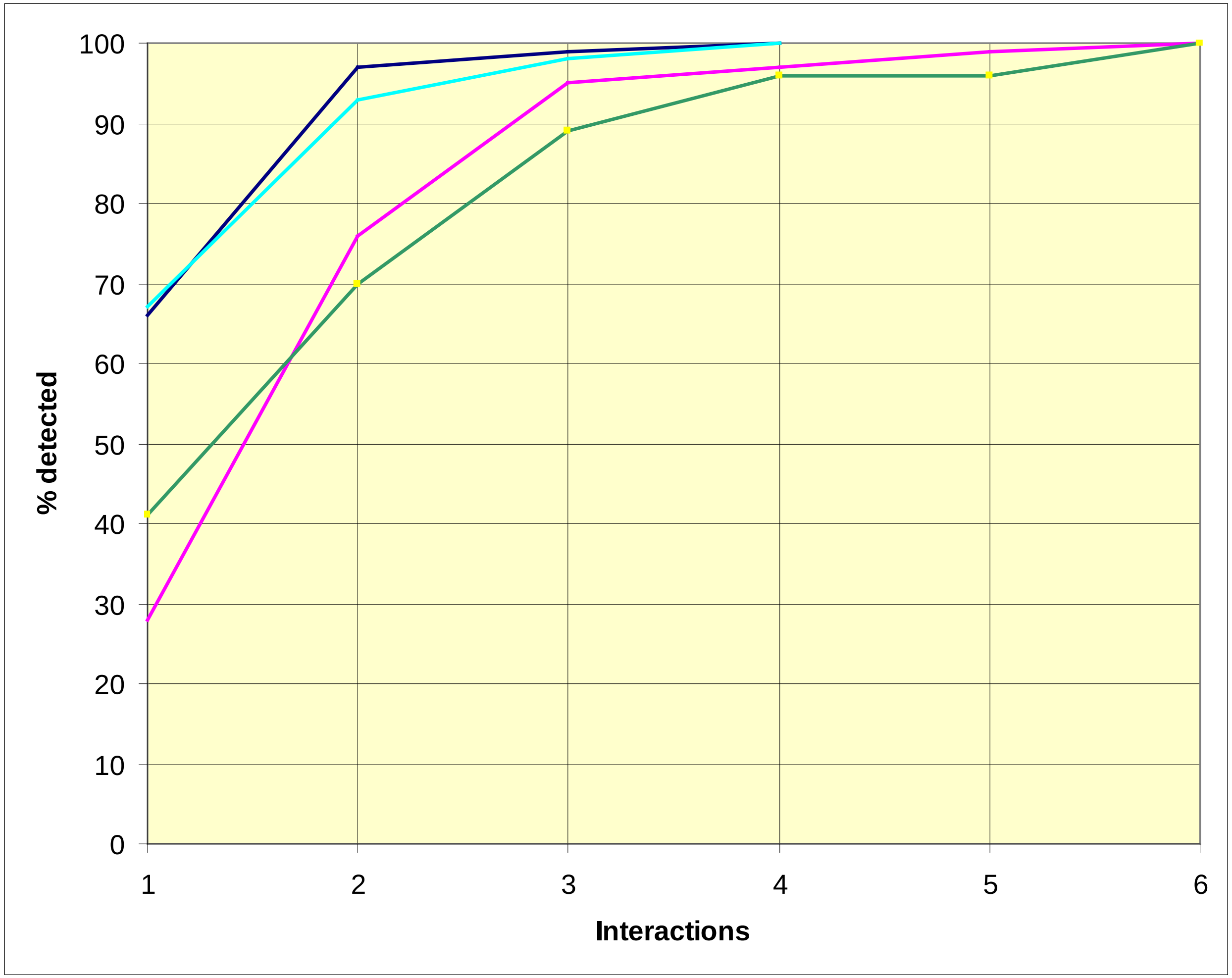
## Server (magenta)



# Still more?

NASA distributed database

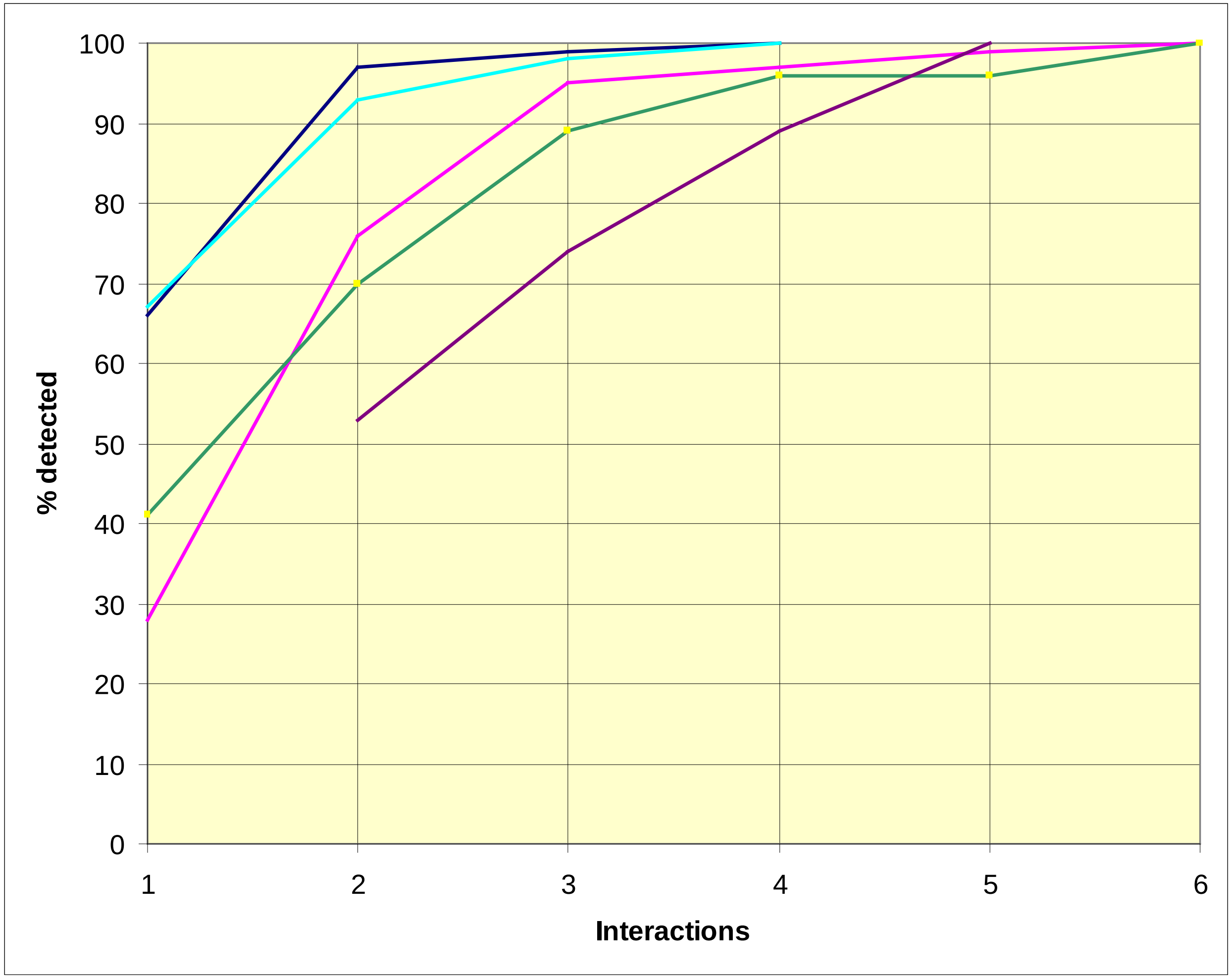
(light blue)



# Even more?

## TCAS module (seeded errors)

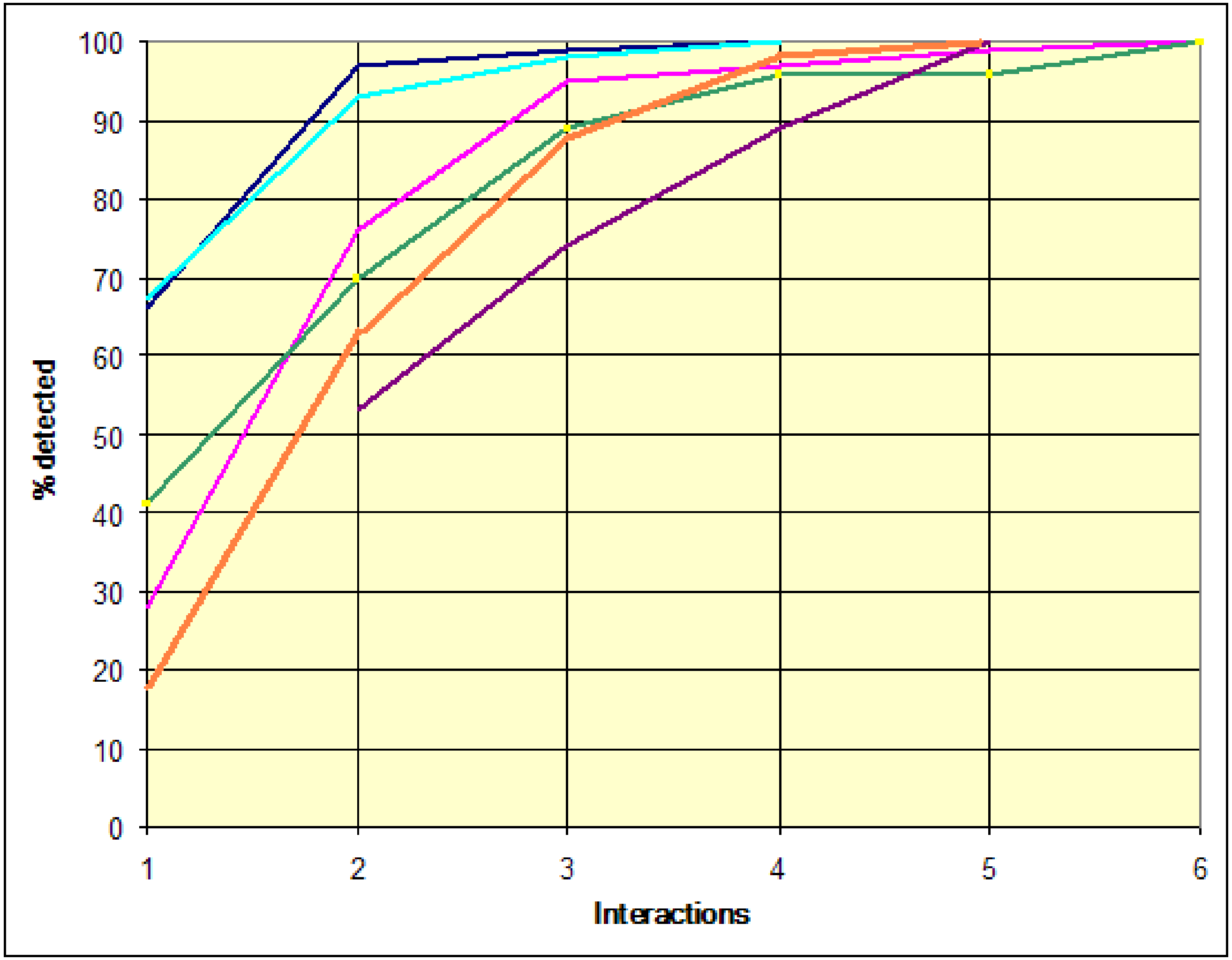
(purple)



# Finally

Network security (Bell, 2006)

(orange)




These are most complex faults of all.

Why?

# So, how many parameters are involved in really tricky faults?

- Maximum interactions for fault triggering for these applications was 6
- Much more empirical work needed
- Reasonable evidence that maximum interaction strength for fault triggering is relatively small

How is this knowledge useful?

# How is this knowledge useful?

- Suppose we have  a system with on-off switches: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# How do we test this?

- 34 switches = $2^{34}$ = $1.7 \times 10^{10}$ possible inputs = $1.7 \times 10^{10}$ tests


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# What if we knew no failure involves more than 3 switch settings interacting?

- 34 switches = $2^{34}$ = $1.7 \times 10^{10}$ possible inputs = **$1.7 \times 10^{10}$** tests
- If only 3-way interactions, need only **33** tests
- For 4-way interactions, need only **85** tests


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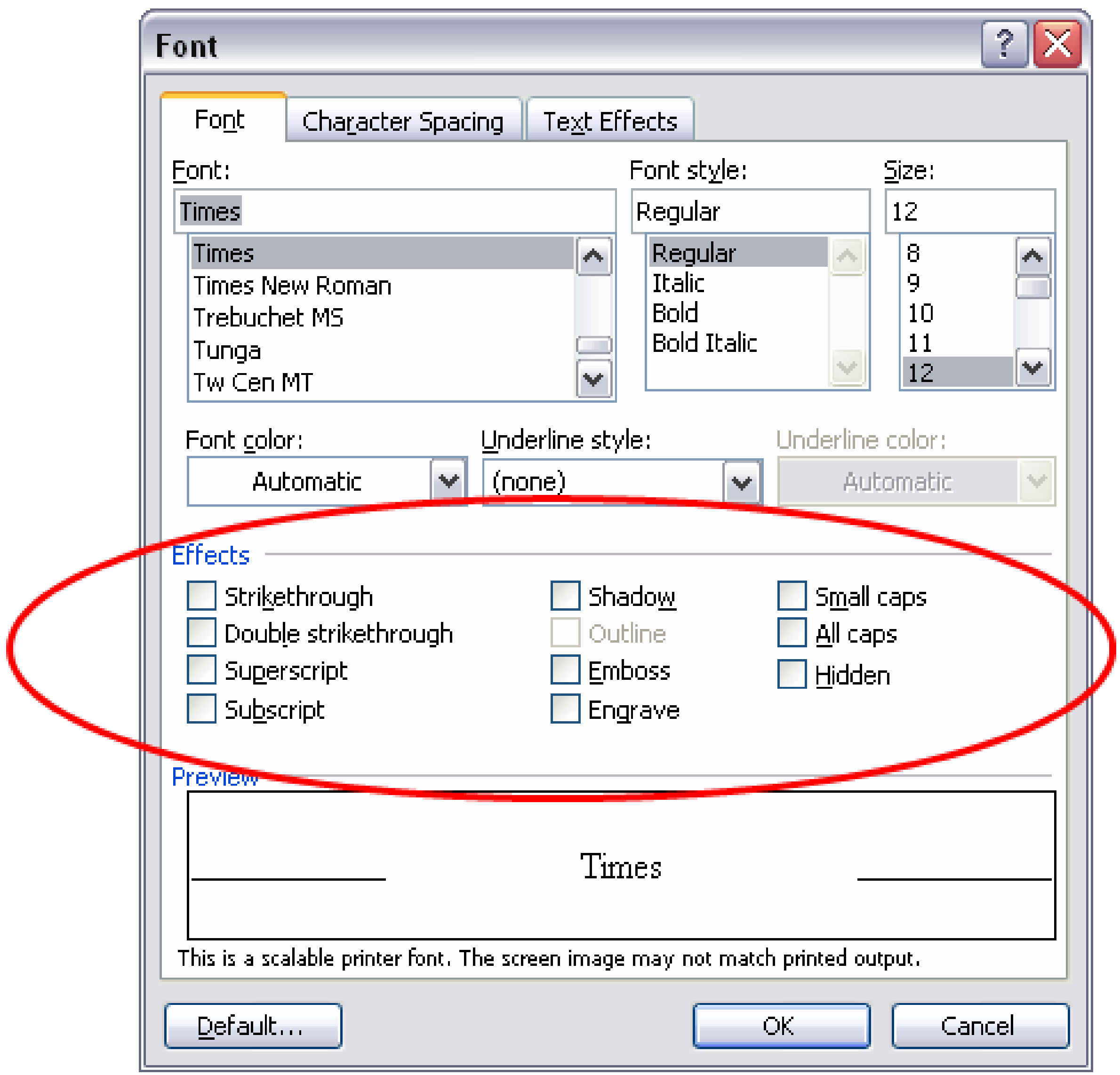
# What is combinatorial testing? A simple example

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# How Many Tests Would It Take?

- There are 10 effects, each can be on or off
- All combinations is $2^{10}$ = 1,024 tests

  too many to visually check …

- Let’s look at all 3-way interactions …

# Now How Many Would It Take?

- There are $\binom{10}{3}$ = 120 3-way interactions.
- Naively 120 x $2^3$ = 960 tests.
- Since we can pack 3 triples into each test, we need no more than 320 tests.
- Each test exercises many triples:

0 0 0 1 1 1 0 1 0 1

We oughtta be able to pack a lot in one test, so what's the smallest number we need?

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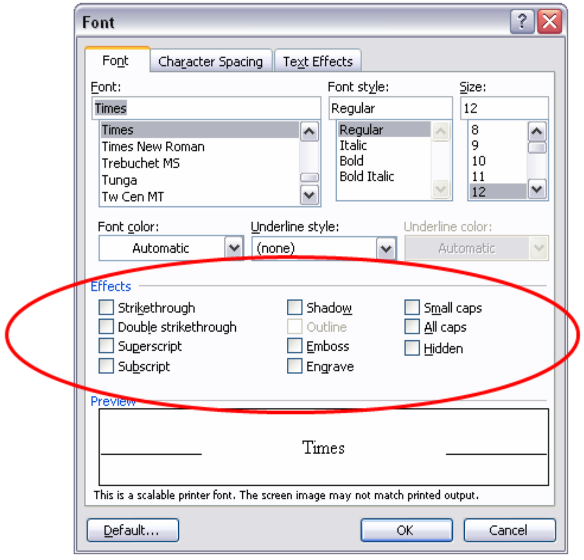
# A Covering Array

Each row is a test:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |

Each column is a parameter:




**All triples in only 13 tests**

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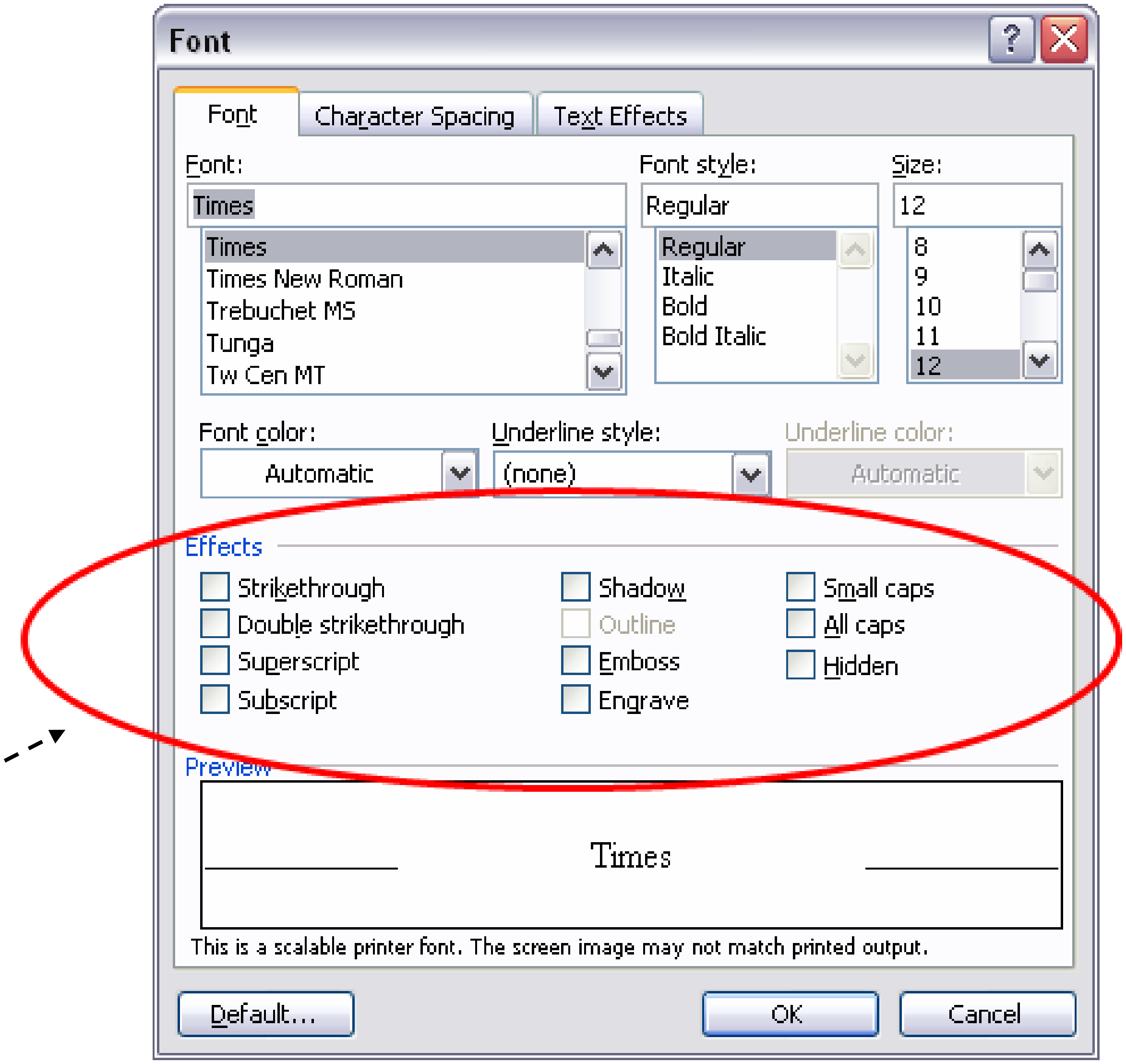
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |




0 = effect off
1 = effect on

**13** tests for **all 3-way combinations**

$2^{10}$ = **1,024** tests for **all combinations**

# New algorithms to make it practical

- **Tradeoffs to minimize calendar/staff time:**
- FireEye (extended IPO) – Lei – roughly optimal, can be used for most cases under 40 or 50 parameters
    - Produces minimal number of tests at cost of run time
    - Currently integrating algebraic methods
- Adaptive distance-based strategies – Bryce – dispensing one test at a time w/ metrics to increase probability of finding flaws
    - Highly optimized covering array algorithm
    - Variety of distance metrics for selecting next test
- PRMI – Kuhn –for more variables or larger domains
    - Randomized algorithm, generates tests w/ a few tunable parameters; computation can be distributed
    - Better results than other algorithms for larger problems

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# New algorithms

- Smaller test sets faster, with a more advanced user interface
- First parallelized covering array algorithm
- More information per test

**IPOG**

**(Lei, 06)**

| T-Way | IPOG | | ITCH (IBM) | | Jenny (Open Source) | | TConfig (U. of Ottawa) | | TVG (Open Source) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Size | Time | Size | Time | Size | Time | Size | Time | Size | Time |
| 2 | 100 | 0.8 | 120 | 0.73 | 108 | 0.001 | 108 | >1 hour | 101 | 2.75 |
| 3 | 400 | 0.36 | 2388 | 1020 | 413 | 0.71 | 472 | >12 hour | 9158 | 3.07 |
| 4 | 1363 | 3.05 | 1484 | 5400 | 1536 | 3.54 | 1476 | >21 hour | 64696 | 127 |
| 5 | 4226 | 18.41 | NA | >1 day | 4580 | 43.54 | NA | >1 day | 313056 | 1549 |
| 6 | 10941 | 65.03 | NA | >1 day | 11625 | 470 | NA | >1 day | 1070048 | 12600 |

Traffic Collision Avoidance System (TCAS): $2^7 3^2 4^1 10^2$

**PRMI**

**(Kuhn, 06)**

| | 10 | | 15 | | 20 | |
|---|---|---|---|---|---|---|
| | **tests** | **sec** | **tests** | **sec** | **tests** | **sec** |
| **1 proc.** | 46086 | 390 | 84325 | 16216 | 114050 | 155964 |
| **10 proc.** | 46109 | 57 | 84333 | 11224 | 114102 | 85423 |
| **20 proc.** | 46248 | 54 | 84350 | 2986 | 114616 | 20317 |
| **FireEye** | 51490 | 168 | 86010 | 9419 | ** | ** |
| **Jenny** | 48077 | 18953 | ** | ** | ** | ** |

Table 6. 6 way, $5^k$ configuration results comparison
** insufficient memory

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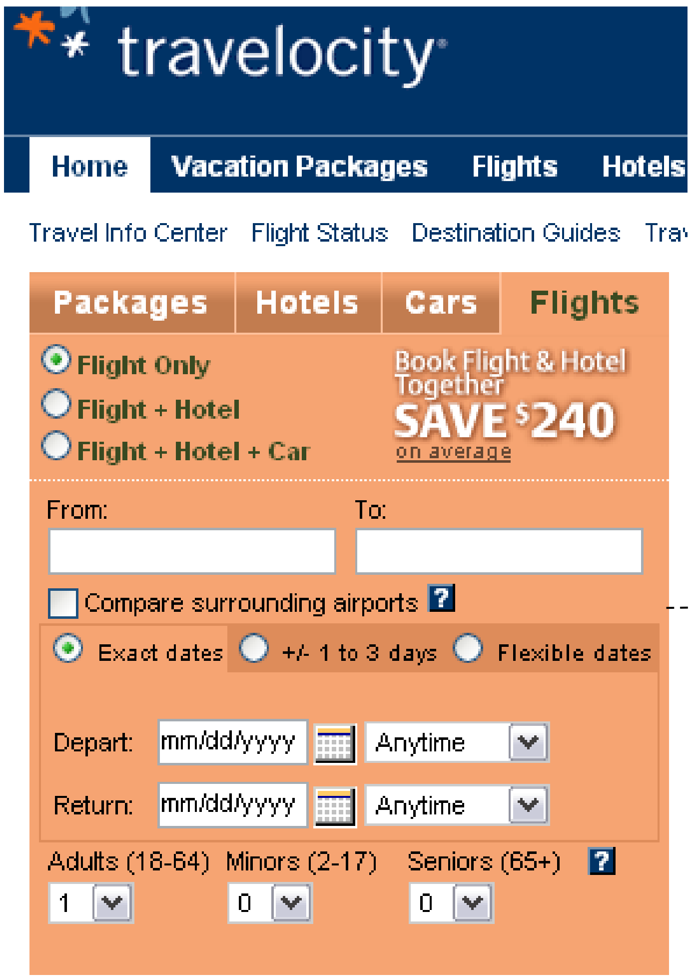
# A Real-World Example




**No silver bullet** because:

Many values per variable

Need to abstract values

But we can still increase information per test

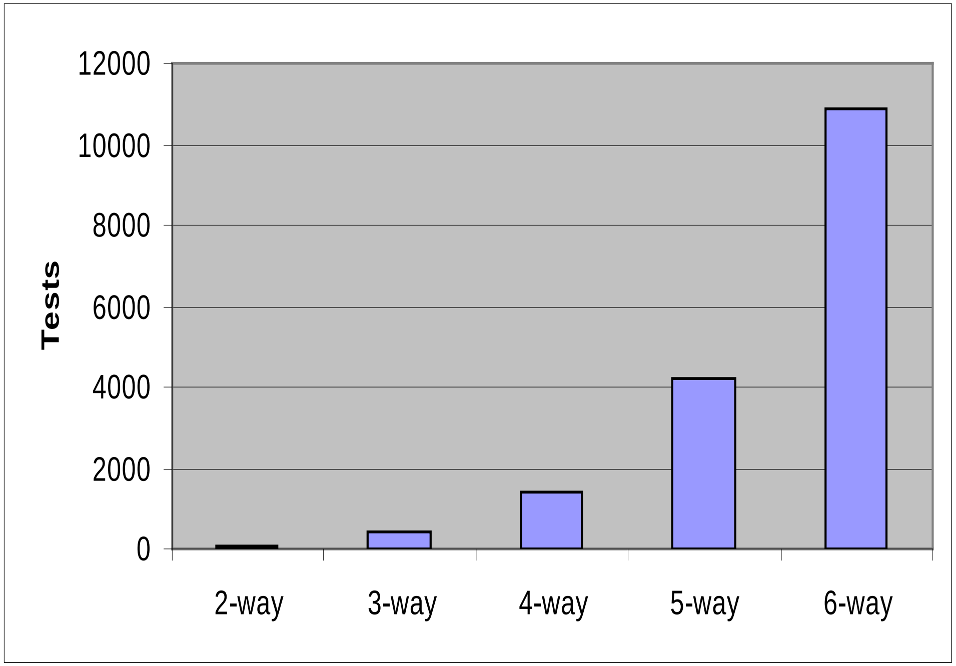
Plan: flt, flt+hotel, flt+hotel+car
From: CONUS, HI, Europe, Asia …
To: CONUS, HI, Europe, Asia …
Compare: yes, no
Date-type: exact, 1to3, flex
Depart: today, tomorrow, 1yr, Sun, Mon …
Return: today, tomorrow, 1yr, Sun, Mon …
Adults: 1, 2, 3, 4, 5, 6
Minors: 0, 1, 2, 3, 4, 5
Seniors: 0, 1, 2, 3, 4, 5

# Example

- Traffic Collision Avoidance System (TCAS) module
  - Used in previous testing research
  - 41 versions seeded with errors
  - 12 variables: 7 boolean, two 3-value, one 4-value, two 10-value
  - All flaws found with 5-way coverage
  - Thousands of tests - generated by model checker in a few minutes

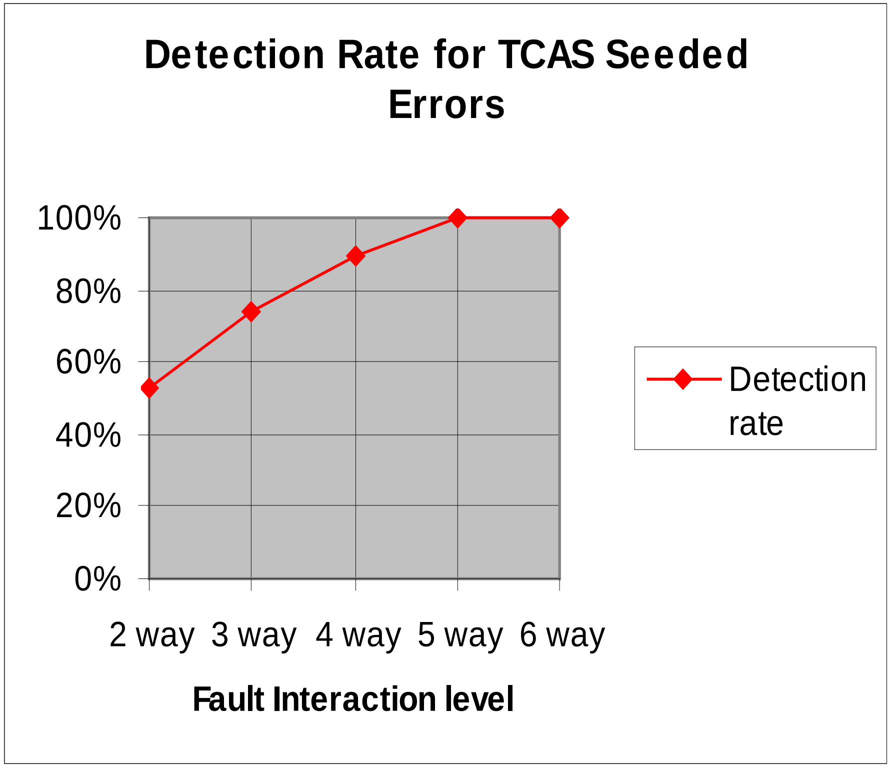
# Tests generated

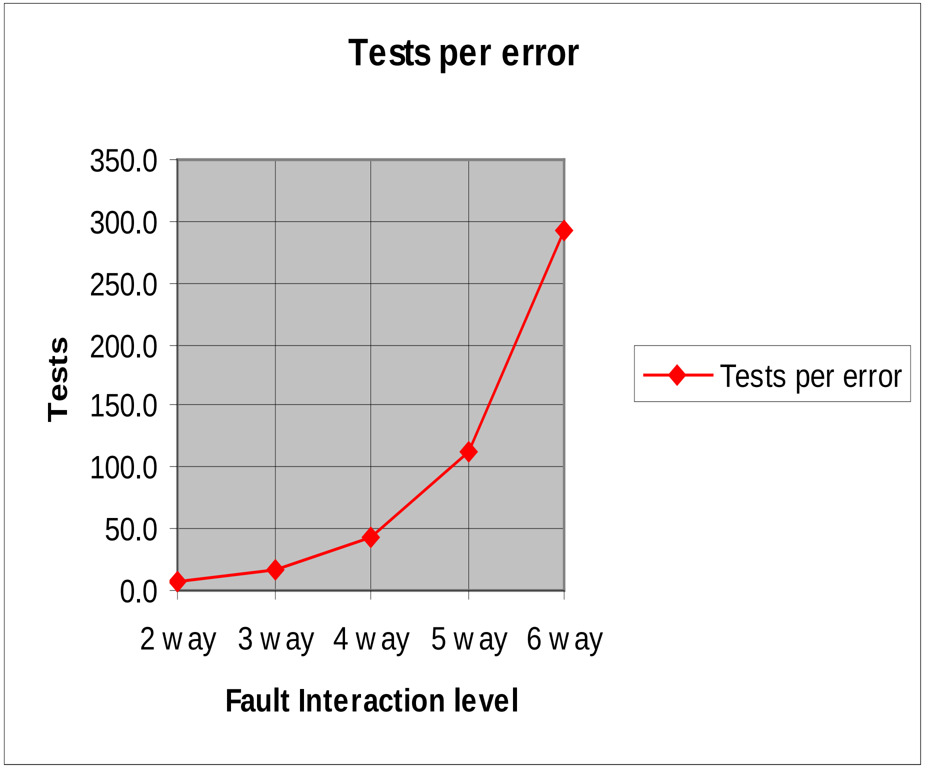
| *t* | Test cases |
|---|---|
| 2-way: | 156 |
| 3-way: | 461 |
| 4-way: | 1,450 |
| 5-way: | 4,309 |
| 6-way: | 11,094 |



# Results

- Roughly consistent with data on large systems
- But errors harder to detect than real-world examples




**Bottom line for model checking based combinatorial testing:**
**Expensive but can be highly effective**

# Where does this stuff make sense?

- More than (roughly) 7 or 8 parameters and less than 300, depending on interaction strength desired
- Processing involves interaction between parameters (numeric or logical)

# Where does it not make sense?

- Small number of parameters, where exhaustive testing is possible
- No interaction between parameters, so interaction testing is pointless   (but we don't usually know this up front)

# Modeling & Simulation Application

- “Simured” network simulator
  - Kernel of ~ 5,000 lines of C++ (not including GUI)
- Objective: detect configurations that can produce deadlock:
  - Prevent connectivity loss when changing network
  - Attacks that could lock up network
- Compare effectiveness of random vs. combinatorial inputs
- Deadlock combinations discovered
- Crashes in >6% of tests w/ valid values (Win32 version only)

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# Simulation Input Parameters

| Parameter | | Values |
|---|---|---|
| 1 | DIMENSIONS | 1,2,4,6,8 |
| 2 | NODOSDIM | 2,4,6 |
| 3 | NUMVIRT | 1,2,3,8 |
| 4 | NUMVIRTINJ | 1,2,3,8 |
| 5 | NUMVIRTEJE | 1,2,3,8 |
| 6 | LONBUFFER | 1,2,4,6 |
| 7 | NUMDIR | 1,2 |
| 8 | FORWARDING | 0,1 |
| 9 | PHYSICAL | true, false |
| 10 | ROUTING | 0,1,2,3 |
| 11 | DELFIFO | 1,2,4,6 |
| 12 | DELCROSS | 1,2,4,6 |
| 13 | DELCHANNEL | 1,2,4,6 |
| 14 | DELSWITCH | 1,2,4,6 |

5x3x4x4x4x4x2x2
x2x4x4x4x4x4
= 31,457,280
configurations

Are any of them dangerous?

If so, how many?

Which ones?

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# Combinatorial vs. Random

**Deadlocks Detected - combinatorial**

| t | Tests | 500 pkts | 1000 pkts | 2000 pkts | 4000 pkts | 8000 pkts |
|---|---|---|---|---|---|---|
| 2 | 28 | 0 | 0 | 0 | 0 | 0 |
| 3 | 161 | 2 | 3 | 2 | 3 | 3 |
| 4 | 752 | 14 | 14 | 14 | 14 | 14 |

**Average Deadlocks Detected – random**

| t | Tests | 500 pkts | 1000 pkts | 2000 pkts | 4000 pkts | 8000 pkts |
|---|---|---|---|---|---|---|
| 2 | 28 | 0.63 | 0.25 | 0.75 | 0. 50 | 0. 75 |
| 3 | 161 | 3 | 3 | 3 | 3 | 3 |
| 4 | 752 | 10.13 | 11.75 | 10.38 | 13 | 13.25 |

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# Network Deadlock Detection

Detected 14 configurations that can cause deadlock:

$14/ 31,457,280 = 4.4 \times 10^{-7}$

Combinatorial testing found one that very few random tests could find:

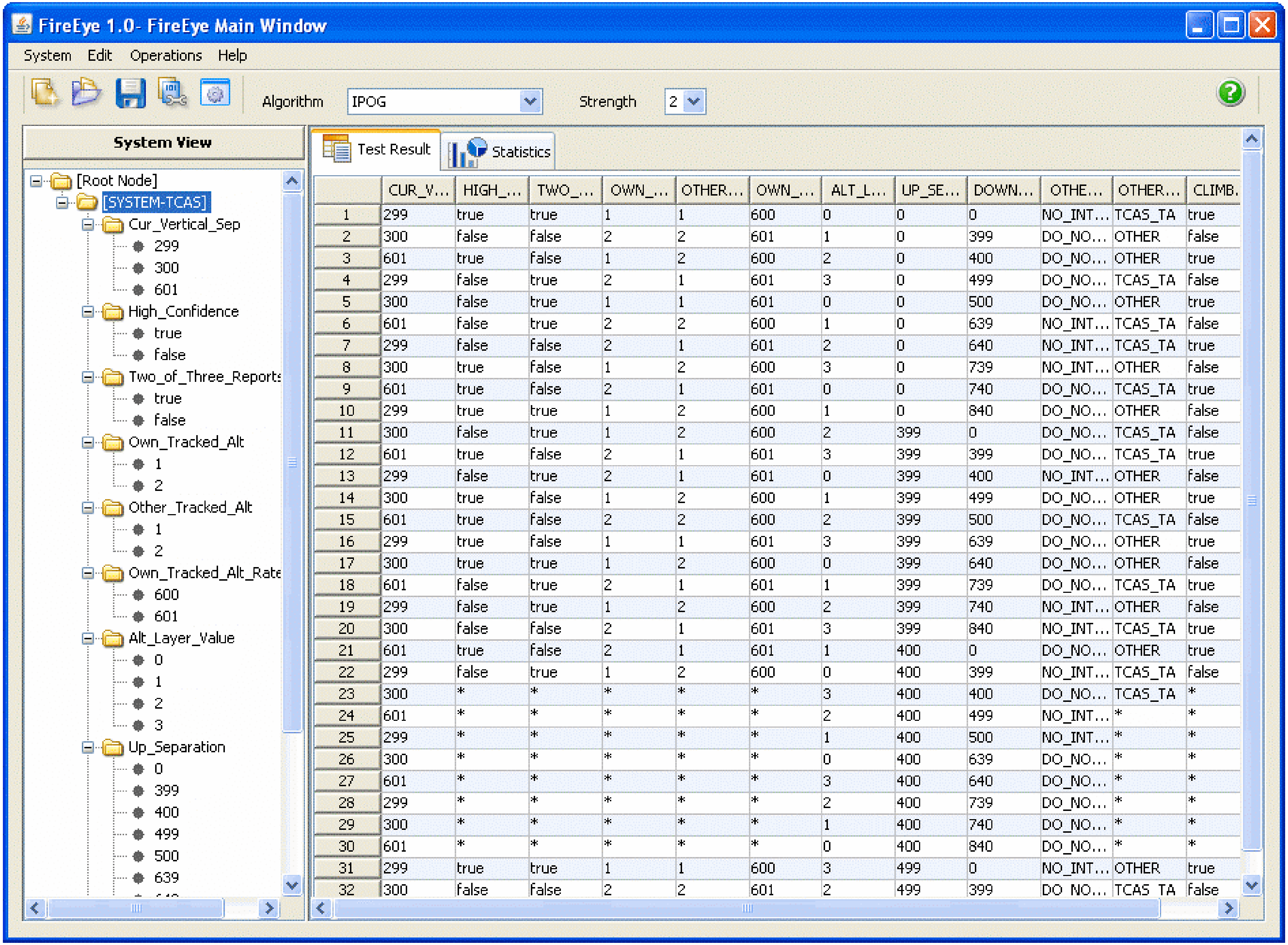
$1/ 31,457,280 = 3.2 \times 10^{-8}$

Combinatorial testing found more deadlocks than random, including some that might never have been found with random testing

Risks:

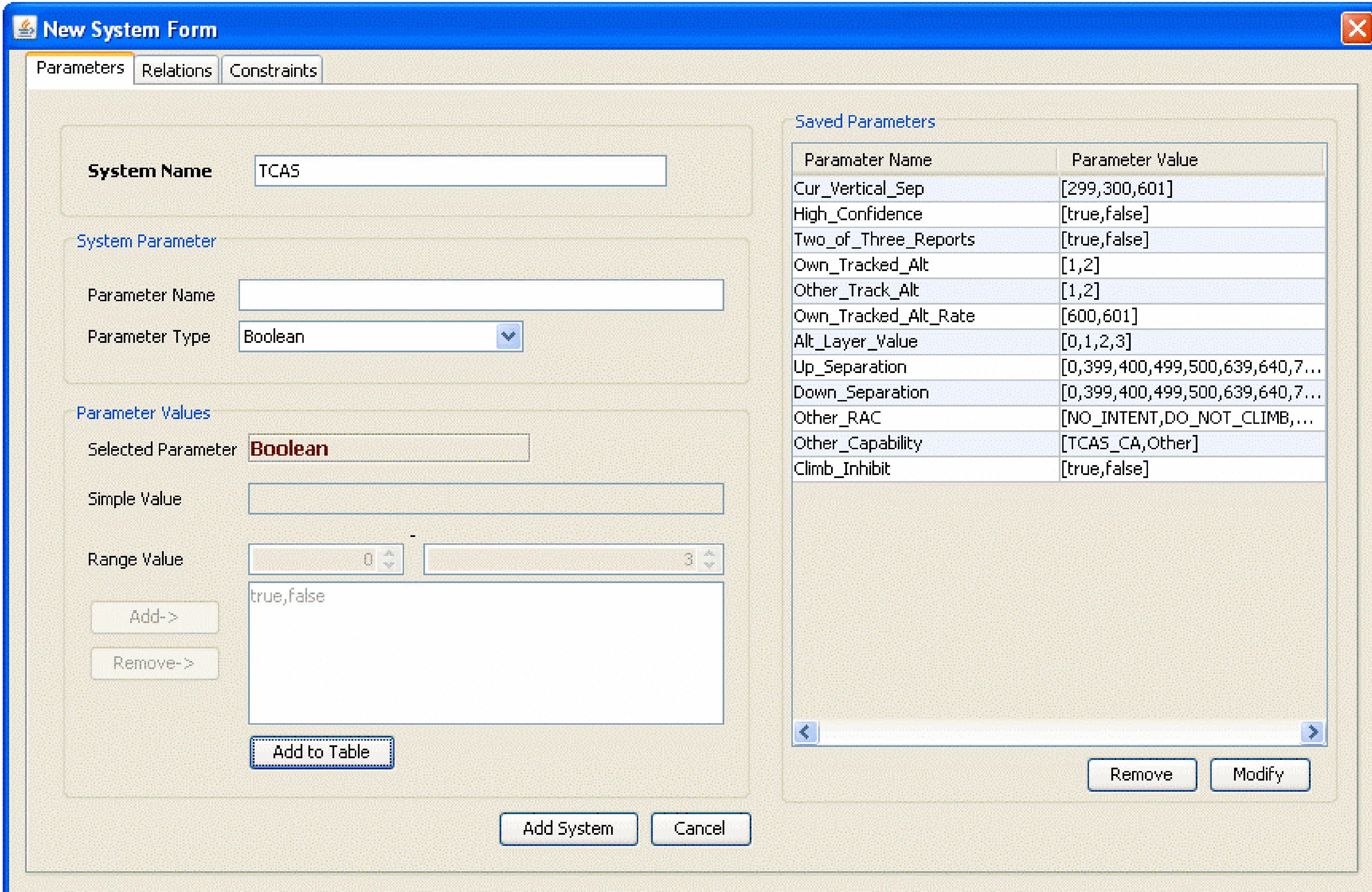
- accidental deadlock configuration: low
- deadlock configuration discovered by attacker: **high**

# ACTS Tool
# (NIST & UT Arlington)

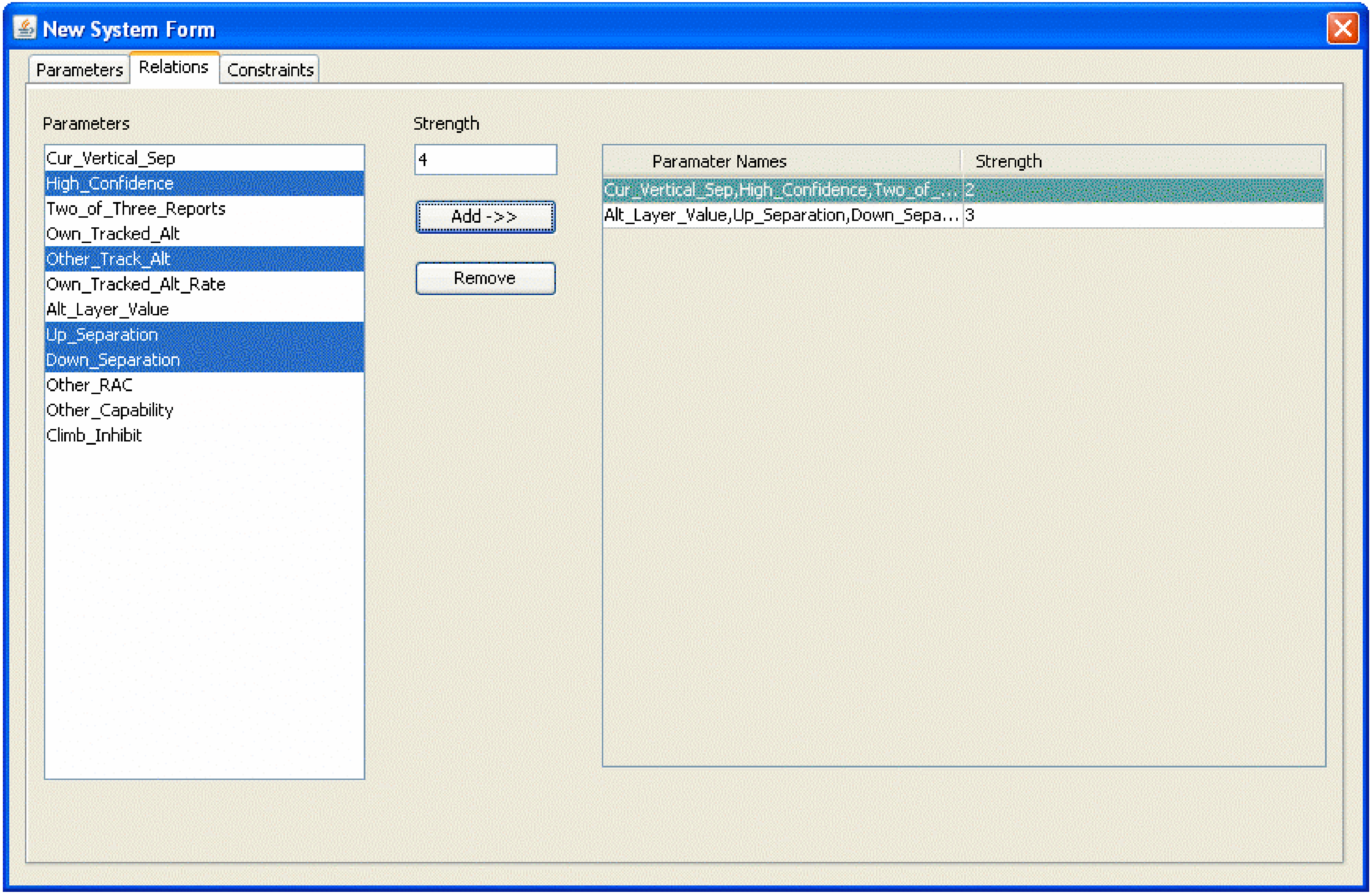



| | CUR_V... | HIGH_... | TWO_... | OWN_... | OTHER... | OWN_... | ALT_L... | UP_SE... | DOWN... | OTHE... | OTHER... | CLIMB. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 299 | true | true | 1 | 1 | 600 | 0 | 0 | 0 | NO_INT... | TCAS_TA | true |
| 2 | 300 | false | false | 2 | 2 | 601 | 1 | 0 | 399 | DO_NO... | OTHER | false |
| 3 | 601 | true | false | 1 | 2 | 600 | 2 | 0 | 400 | DO_NO... | OTHER | true |
| 4 | 299 | false | true | 2 | 1 | 601 | 3 | 0 | 499 | DO_NO... | TCAS_TA | false |
| 5 | 300 | false | true | 1 | 1 | 601 | 0 | 0 | 500 | DO_NO... | OTHER | true |
| 6 | 601 | false | true | 2 | 2 | 600 | 1 | 0 | 639 | NO_INT... | TCAS_TA | false |
| 7 | 299 | false | false | 2 | 1 | 601 | 2 | 0 | 640 | NO_INT... | TCAS_TA | true |
| 8 | 300 | true | false | 1 | 2 | 600 | 3 | 0 | 739 | NO_INT... | OTHER | false |
| 9 | 601 | true | false | 2 | 1 | 601 | 0 | 0 | 740 | DO_NO... | TCAS_TA | true |
| 10 | 299 | true | true | 1 | 2 | 600 | 1 | 0 | 840 | DO_NO... | OTHER | false |
| 11 | 300 | false | true | 1 | 2 | 600 | 2 | 399 | 0 | DO_NO... | TCAS_TA | false |
| 12 | 601 | true | false | 2 | 1 | 601 | 3 | 399 | 399 | DO_NO... | TCAS_TA | true |
| 13 | 299 | false | true | 2 | 1 | 601 | 0 | 399 | 400 | NO_INT... | OTHER | false |
| 14 | 300 | true | false | 1 | 2 | 600 | 1 | 399 | 499 | DO_NO... | OTHER | true |
| 15 | 601 | true | false | 2 | 2 | 600 | 2 | 399 | 500 | DO_NO... | TCAS_TA | false |
| 16 | 299 | true | false | 1 | 1 | 601 | 3 | 399 | 639 | DO_NO... | OTHER | true |
| 17 | 300 | true | true | 1 | 2 | 600 | 0 | 399 | 640 | DO_NO... | OTHER | false |
| 18 | 601 | false | true | 2 | 1 | 601 | 1 | 399 | 739 | DO_NO... | TCAS_TA | true |
| 19 | 299 | false | true | 1 | 2 | 600 | 2 | 399 | 740 | NO_INT... | OTHER | false |
| 20 | 300 | false | false | 2 | 1 | 601 | 3 | 399 | 840 | NO_INT... | TCAS_TA | true |
| 21 | 601 | true | false | 2 | 1 | 601 | 1 | 400 | 0 | DO_NO... | OTHER | true |
| 22 | 299 | false | true | 1 | 2 | 600 | 0 | 400 | 399 | NO_INT... | TCAS_TA | false |
| 23 | 300 | * | * | * | * | * | 3 | 400 | 400 | DO_NO... | TCAS_TA | * |
| 24 | 601 | * | * | * | * | * | 2 | 400 | 499 | NO_INT... | * | * |
| 25 | 299 | * | * | * | * | * | 1 | 400 | 500 | NO_INT... | * | * |
| 26 | 300 | * | * | * | * | * | 0 | 400 | 639 | DO_NO... | * | * |
| 27 | 601 | * | * | * | * | * | 3 | 400 | 640 | DO_NO... | * | * |
| 28 | 299 | * | * | * | * | * | 2 | 400 | 739 | DO_NO... | * | * |
| 29 | 300 | * | * | * | * | * | 1 | 400 | 740 | DO_NO... | * | * |
| 30 | 601 | * | * | * | * | * | 0 | 400 | 840 | DO_NO... | * | * |
| 31 | 299 | true | true | 1 | 1 | 600 | 3 | 499 | 0 | NO_INT... | OTHER | true |
| 32 | 300 | false | false | 2 | 2 | 601 | 2 | 499 | 399 | DO_NO... | TCAS_TA | false |

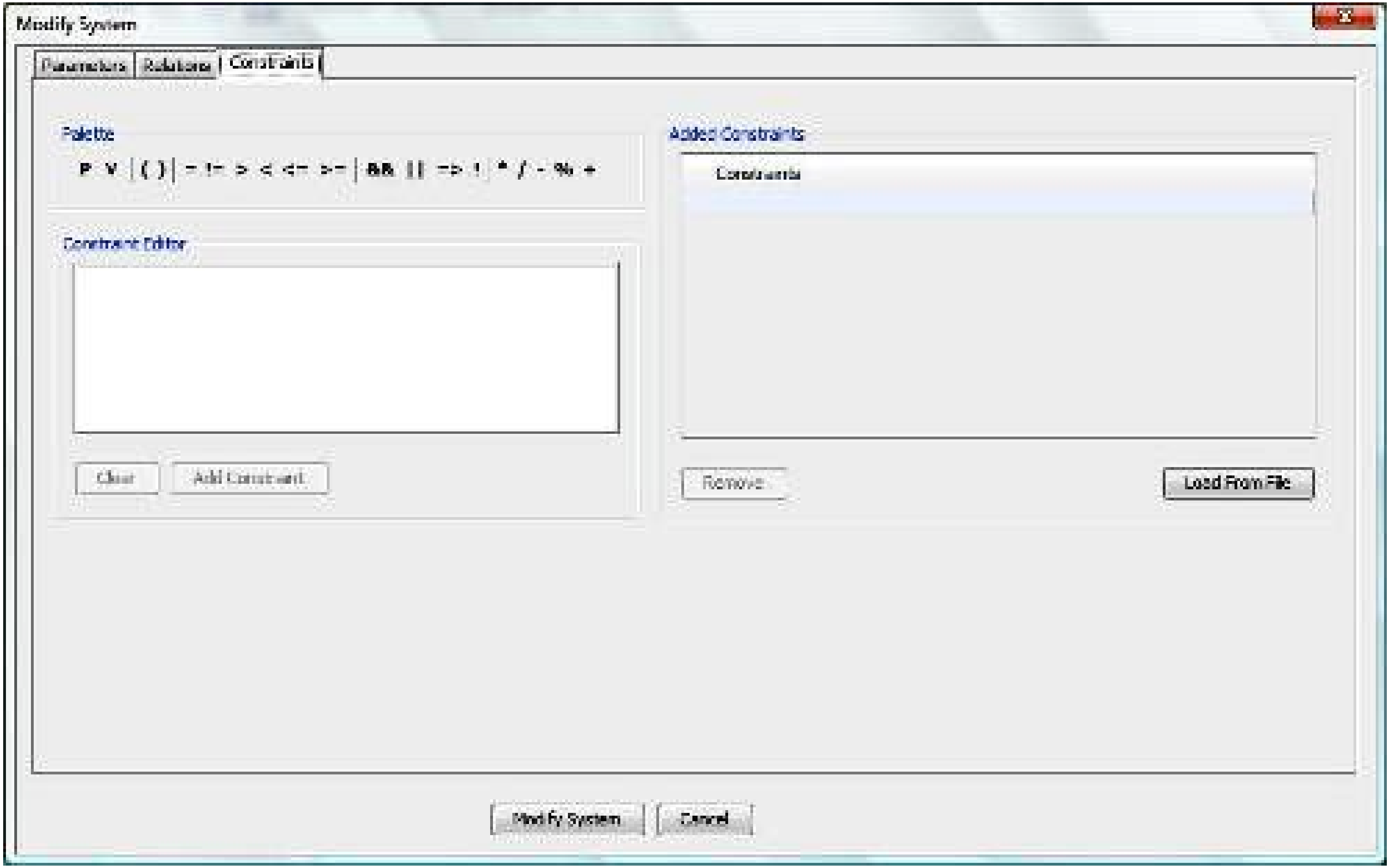
# Defining a new system



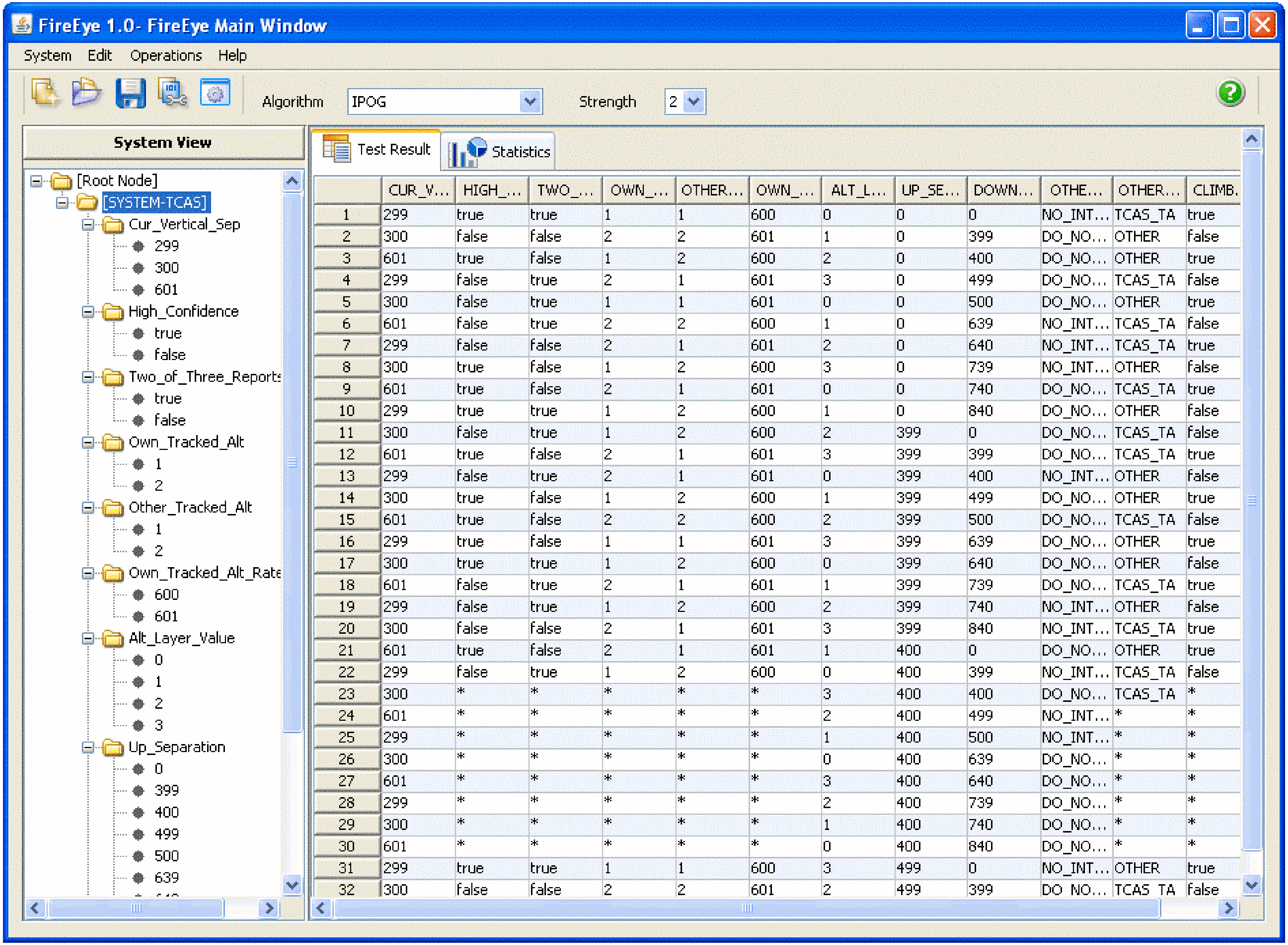
# Variable interaction strength



# Constraints



# ACTS Tool – covering array




| | CUR_V... | HIGH_... | TWO_... | OWN_... | OTHER... | OWN_... | ALT_L... | UP_SE... | DOWN... | OTHE... | OTHER... | CLIMB. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 299 | true | true | 1 | 1 | 600 | 0 | 0 | 0 | NO_INT... | TCAS_TA | true |
| 2 | 300 | false | false | 2 | 2 | 601 | 1 | 0 | 399 | DO_NO... | OTHER | false |
| 3 | 601 | true | false | 1 | 2 | 600 | 2 | 0 | 400 | DO_NO... | OTHER | true |
| 4 | 299 | false | true | 2 | 1 | 601 | 3 | 0 | 499 | DO_NO... | TCAS_TA | false |
| 5 | 300 | false | true | 1 | 1 | 601 | 0 | 0 | 500 | DO_NO... | OTHER | true |
| 6 | 601 | false | true | 2 | 2 | 600 | 1 | 0 | 639 | NO_INT... | TCAS_TA | false |
| 7 | 299 | false | false | 2 | 1 | 601 | 2 | 0 | 640 | NO_INT... | TCAS_TA | true |
| 8 | 300 | true | false | 1 | 2 | 600 | 3 | 0 | 739 | NO_INT... | OTHER | false |
| 9 | 601 | true | false | 2 | 1 | 601 | 0 | 0 | 740 | DO_NO... | TCAS_TA | true |
| 10 | 299 | true | true | 1 | 2 | 600 | 1 | 0 | 840 | DO_NO... | OTHER | false |
| 11 | 300 | false | true | 1 | 2 | 600 | 2 | 399 | 0 | DO_NO... | TCAS_TA | false |
| 12 | 601 | true | false | 2 | 1 | 601 | 3 | 399 | 399 | DO_NO... | TCAS_TA | true |
| 13 | 299 | false | true | 2 | 1 | 601 | 0 | 399 | 400 | NO_INT... | OTHER | false |
| 14 | 300 | true | false | 1 | 2 | 600 | 1 | 399 | 499 | DO_NO... | OTHER | true |
| 15 | 601 | true | false | 2 | 2 | 600 | 2 | 399 | 500 | DO_NO... | TCAS_TA | false |
| 16 | 299 | true | false | 1 | 1 | 601 | 3 | 399 | 639 | DO_NO... | OTHER | true |
| 17 | 300 | true | true | 1 | 2 | 600 | 0 | 399 | 640 | DO_NO... | OTHER | false |
| 18 | 601 | false | true | 2 | 1 | 601 | 1 | 399 | 739 | DO_NO... | TCAS_TA | true |
| 19 | 299 | false | true | 1 | 2 | 600 | 2 | 399 | 740 | NO_INT... | OTHER | false |
| 20 | 300 | false | false | 2 | 1 | 601 | 3 | 399 | 840 | NO_INT... | TCAS_TA | true |
| 21 | 601 | true | false | 2 | 1 | 601 | 1 | 400 | 0 | DO_NO... | OTHER | true |
| 22 | 299 | false | true | 1 | 2 | 600 | 0 | 400 | 399 | NO_INT... | TCAS_TA | false |
| 23 | 300 | * | * | * | * | * | 3 | 400 | 400 | DO_NO... | TCAS_TA | * |
| 24 | 601 | * | * | * | * | * | 2 | 400 | 499 | NO_INT... | * | * |
| 25 | 299 | * | * | * | * | * | 1 | 400 | 500 | NO_INT... | * | * |
| 26 | 300 | * | * | * | * | * | 0 | 400 | 639 | DO_NO... | * | * |
| 27 | 601 | * | * | * | * | * | 3 | 400 | 640 | DO_NO... | * | * |
| 28 | 299 | * | * | * | * | * | 2 | 400 | 739 | DO_NO... | * | * |
| 29 | 300 | * | * | * | * | * | 1 | 400 | 740 | DO_NO... | * | * |
| 30 | 601 | * | * | * | * | * | 0 | 400 | 840 | DO_NO... | * | * |
| 31 | 299 | true | true | 1 | 1 | 600 | 3 | 499 | 0 | NO_INT... | OTHER | true |
| 32 | 300 | false | false | 2 | 2 | 601 | 2 | 499 | 399 | DO_NO... | TCAS_TA | false |

# Output

Output formats:

- XML
- Numeric
- CSV
- Excel

Post-process output using Perl scripts, etc.

# Output options

Degree of interaction coverage: 2
Number of parameters: 12
Number of tests: 100

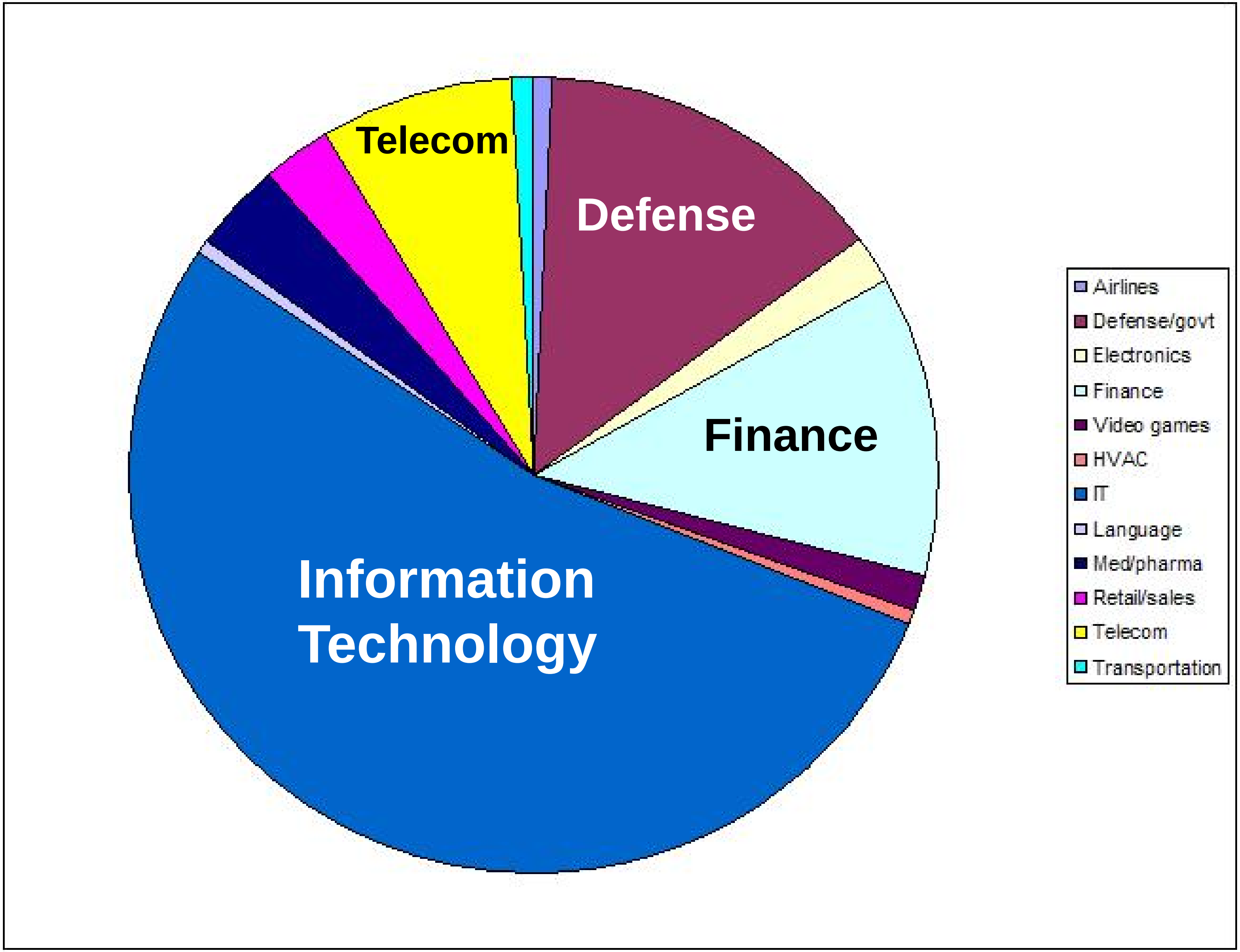
-----------------------------------------

0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 0 1 1 1 1
2 0 1 0 1 0 2 0 2 2 1 0
0 1 0 1 0 1 3 0 3 1 0 1
1 1 0 0 0 1 0 0 4 2 1 0
2 1 0 1 1 0 1 0 5 0 0 1
0 1 1 1 0 1 2 0 6 0 0 0
1 0 1 0 1 0 3 0 7 0 1 1
2 0 1 1 0 1 0 0 8 1 0 0
0 0 0 0 1 0 1 0 9 2 1 1
1 1 0 0 1 0 2 1 0 1 0 1
Etc.

Degree of interaction coverage: 2
Number of parameters: 12
Maximum number of values per parameter: 10
Number of configurations: 100
-----------------------------------------
Configuration #1:

1 = Cur_Vertical_Sep=299
2 = High_Confidence=true
3 = Two_of_Three_Reports=true
4 = Own_Tracked_Alt=1
5 = Other_Tracked_Alt=1
6 = Own_Tracked_Alt_Rate=600
7 = Alt_Layer_Value=0
8 = Up_Separation=0
9 = Down_Separation=0
10 = Other_RAC=NO_INTENT
11 = Other_Capability=TCAS_CA
12 = Climb_Inhibit=true

# ACTS Users



Telecom
Defense
Finance
Information Technology
Airlines
Defense/govt
Electronics
Finance
Video games
HVAC
IT
Language
Med/pharma
Retail/sales
Telecom
Transportation

# Summary

NIST National Institute of Standards and Technology

- Empirical research suggests that all software failures caused by interaction of few parameters
- Combinatorial testing can exercise all t-way combinations of parameter values in a very tiny fraction of the time needed for exhaustive testing
- New algorithms and faster processors make large-scale combinatorial testing possible
- Project could produce better quality testing at lower cost
- Beta release of tools available, to be open source

**Please contact us if you are interested!**

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http://csrc.nist.gov/acts (Or just search “combinatorial testing” !)