

# Automated Seed Selection Algorithm for an Arbitrary Test Suite

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# Agenda

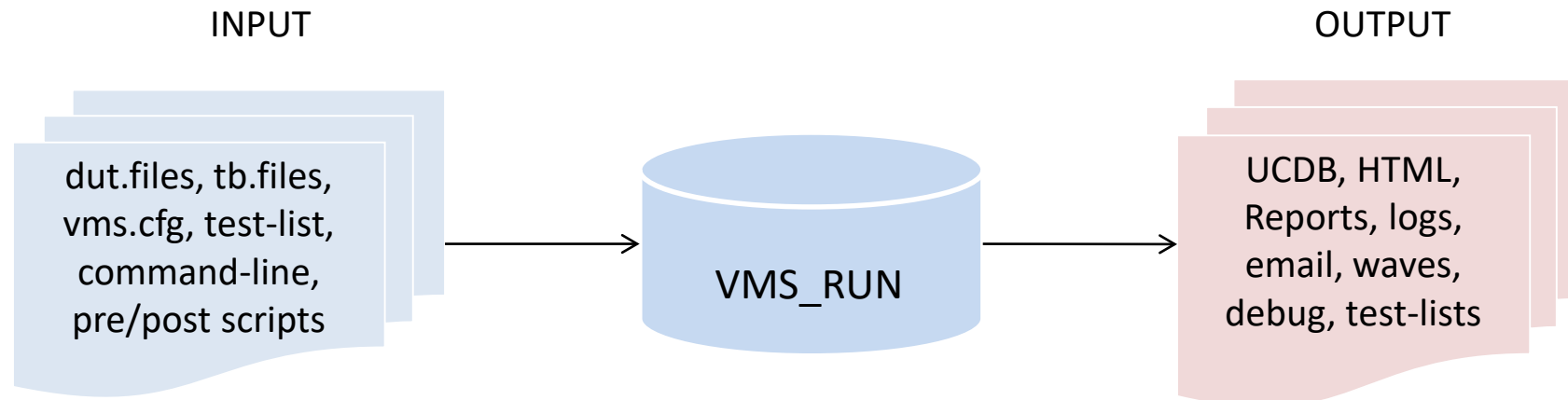
- Randomizable Test Benches and Coverage
- Verification Management System and Randomization
- Test Ranking
- Blindly Choosing Seeds
- Proposed Algorithm
- Results (the good and the bad)
- Future Work

# Randomizable Test Benches and Coverage

- Constrained Random Verification
  - Methodology to apply pseudo-random stimulus to the DUT
- SystemVerilog provides coverage construct to measure completeness
  - Pseudo-random stimulus applied until 100% of coverage metrics met
- SystemVerilog seed used as start value of randomization
- Random stability is not guaranteed
  - Coverage from seeds can change due to many factors
    - New/Modified constraints, DUT changes, Simulator versions
- Large regressions require a methodology to efficiently select seeds

# Verification Management System and Randomization

- VMS – Verification Management System
- Established a standard approach to:
  - Design and test bench organization
  - Specification of tools arguments
  - Test list creation
  - Regression status / coverage



# Verification Management System and Randomization

- VMS SV seed control and randomization

Option	Description
-num_seeds	Specifies the number of SV seeds to generate
-rand_seed	Use this argument to seed the random number generator
-sv_seed	Specifies explicitly which SV seed to use (no generation)

```
test1  -num_seeds 10 -rand_seed random           //10 random seeds
test2  -num_seeds 3 -rand_seed 1000           //seed generator with 1000
test3  -sv_seed 12345678                     //SV seed of 12345678
```

# Test Ranking

- Mentor Questa stores coverage in UCDB (Unified Coverage DataBase)
- UCDB for each test => merged UCDB
- UCDBs ranked for coverage by Questa VM (Verification Management)
  - Separated into contributing and non-contributing

## **ranktest.contrib**

```
<path>/test1_203493581.ucdb  
<path>/test1_2301405129.ucdb  
<path>/test1_271092741.ucdb  
<path>/test2_3359947225.ucdb  
<path>/test2_4247070545.ucdb
```

## **ranktest.noncontrib**

```
<path>/test1_2055117863.ucdb  
<path>/test1_1637509452.ucdb  
<path>/test2_3444222990.ucdb  
<path>/test3_12345678.ucdb
```

# Blindly Choosing Seeds

- Little thought put into test contribution to coverage
- Just choose X number of seeds per test for each regression
  - Shotgun approach
  - Leads to large coverage redundancy among test-seed pairs
  - Wastes licenses and hardware resources

## Regression 1 test list

```
test1 -num_seeds 10 -rand_seed random  
test2 -num_seeds 10 -rand_seed random  
test3 -num_seeds 10 -rand_seed random
```

## Regression 2 test list

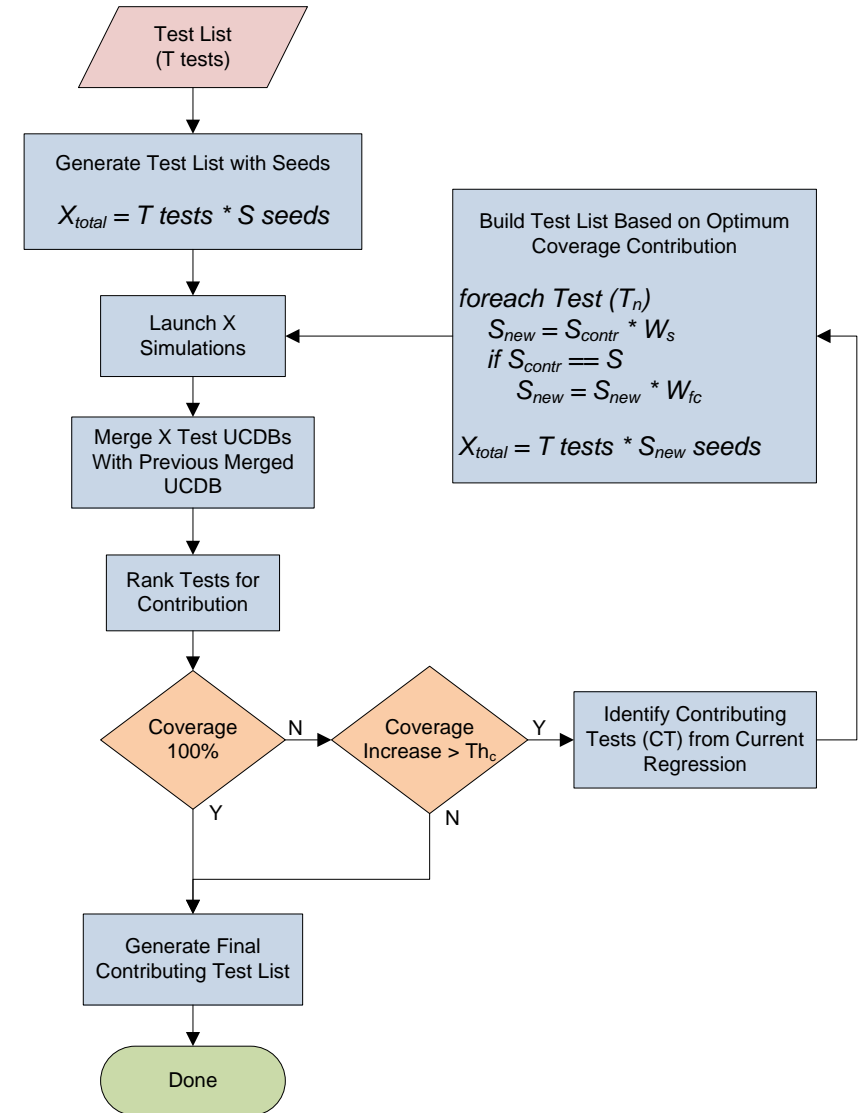
```
test1 -num_seeds 10 -rand_seed random  
test2 -num_seeds 10 -rand_seed random  
test3 -num_seeds 10 -rand_seed random
```

## Regression 3 test list

```
test1 -num_seeds 10 -rand_seed random  
test2 -num_seeds 10 -rand_seed random  
test3 -num_seeds 10 -rand_seed random
```

# Proposed Algorithm

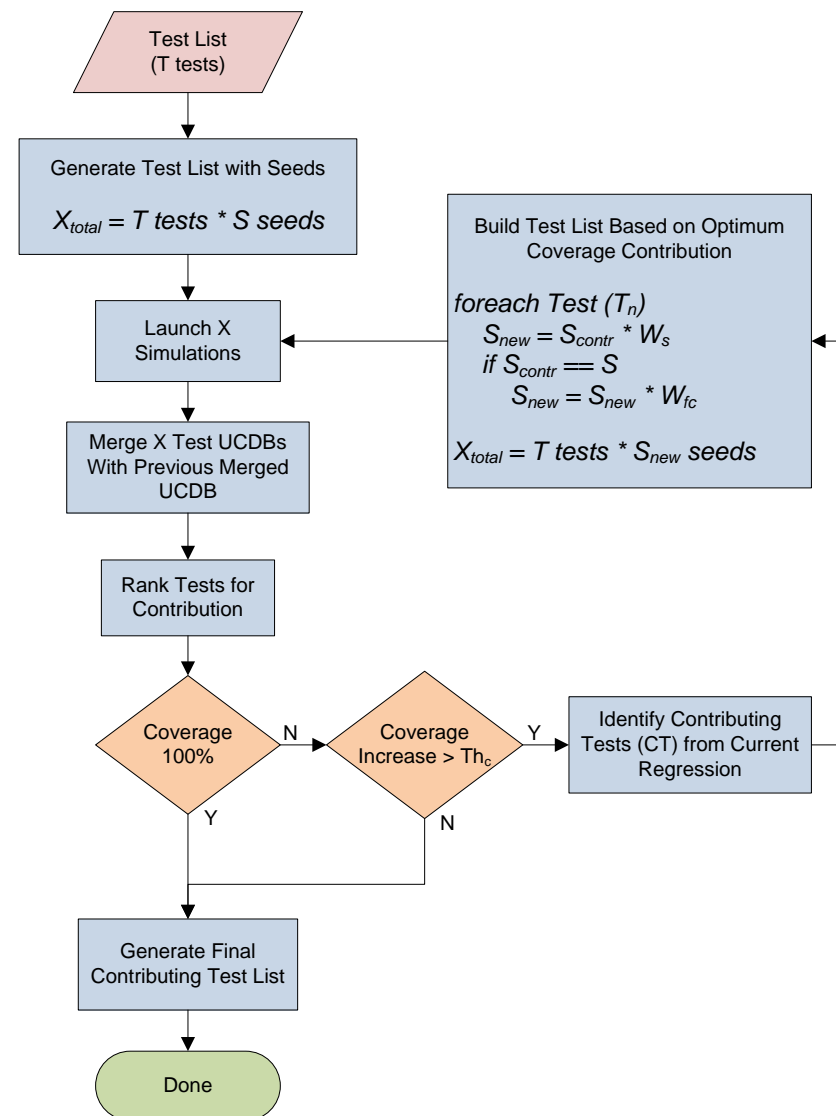
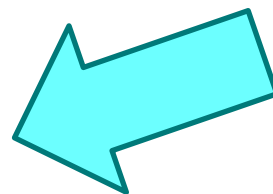
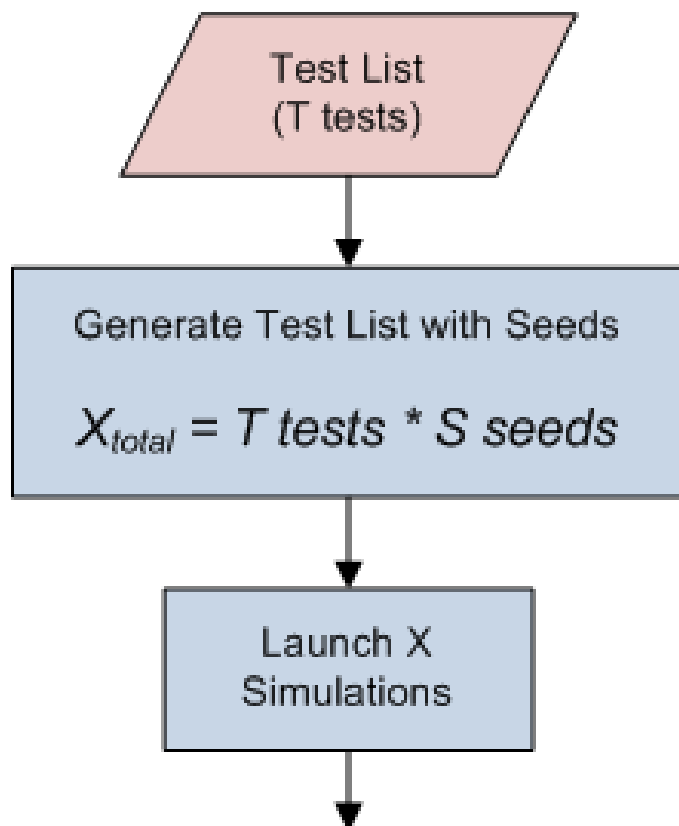
- Key Components:
  - Eliminate tests that don't contribute
  - Reward tests with more seeds in proportion to their contribution
  - Low contributing tests provide diminishing returns over time





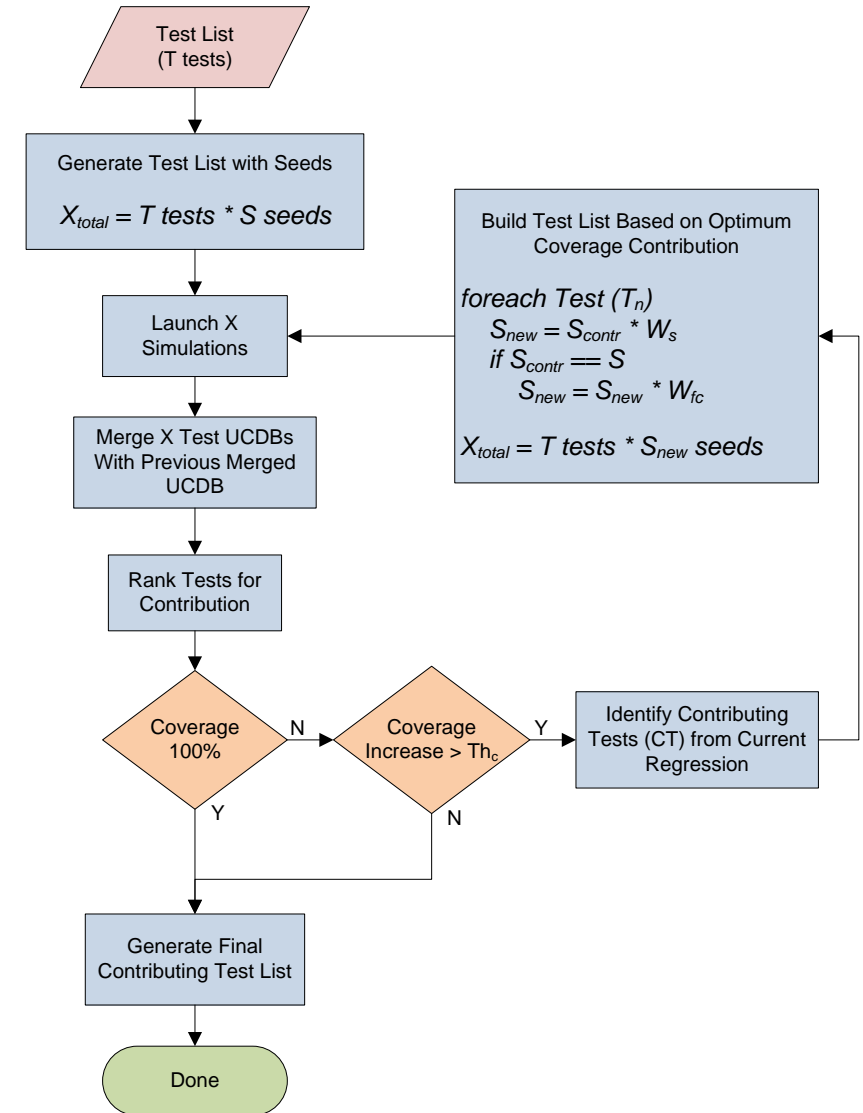
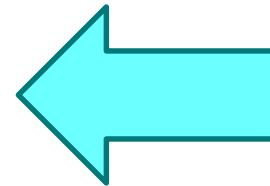
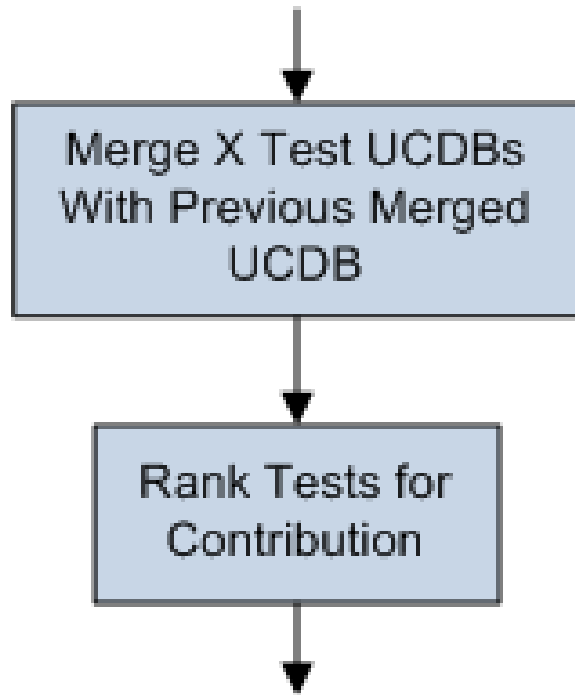
# Proposed Algorithm

- Initial test list with initial seed count



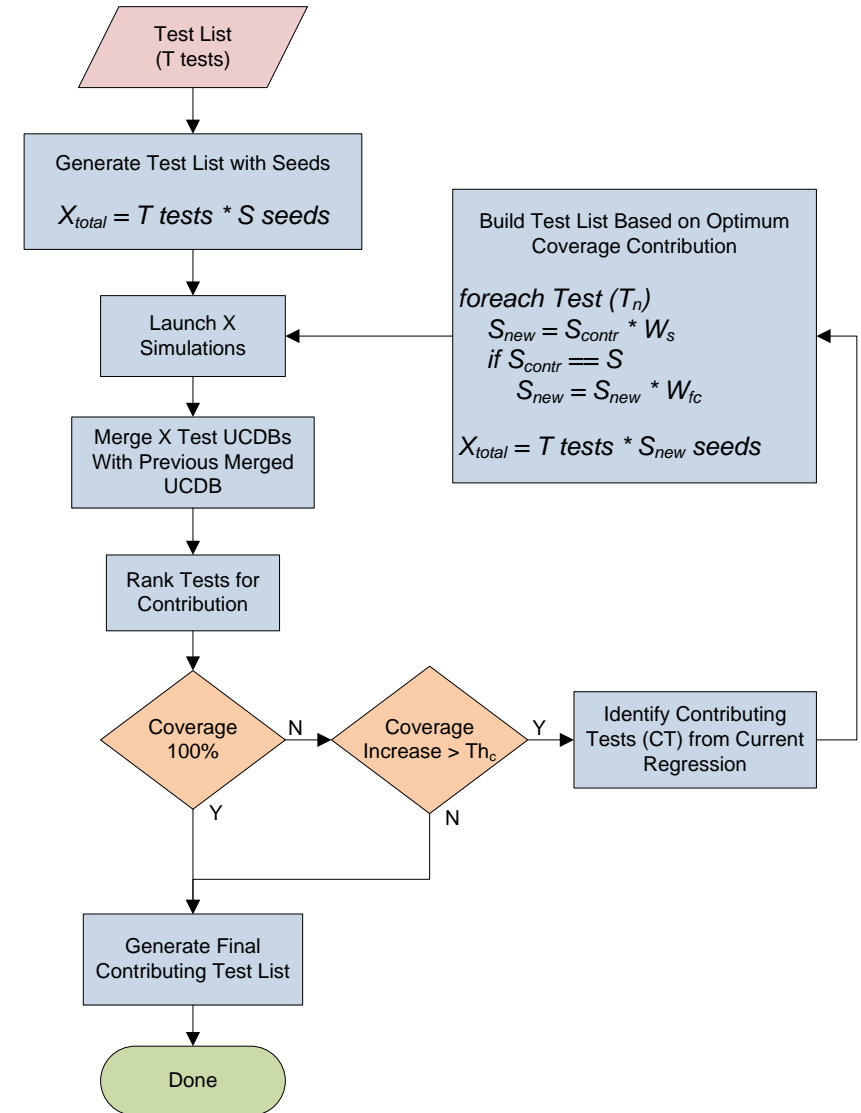
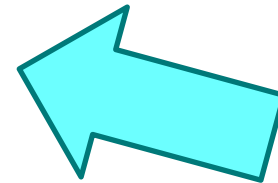
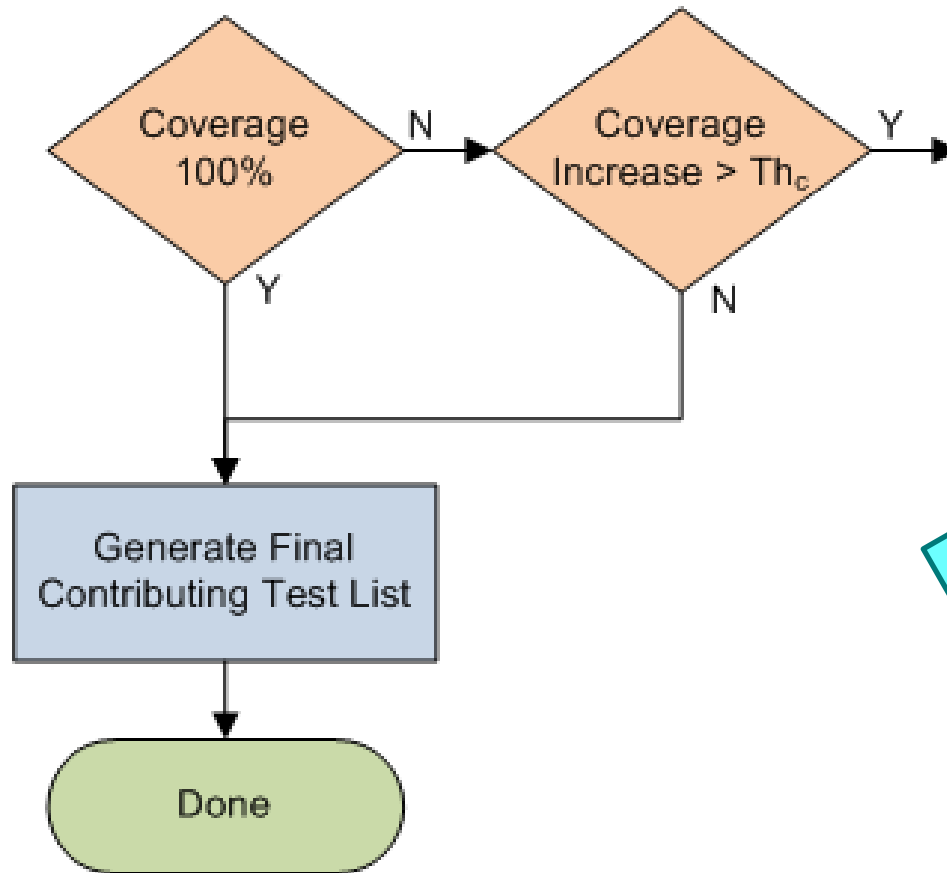
# Proposed Algorithm

- Test UCDBs are Merged and Ranked

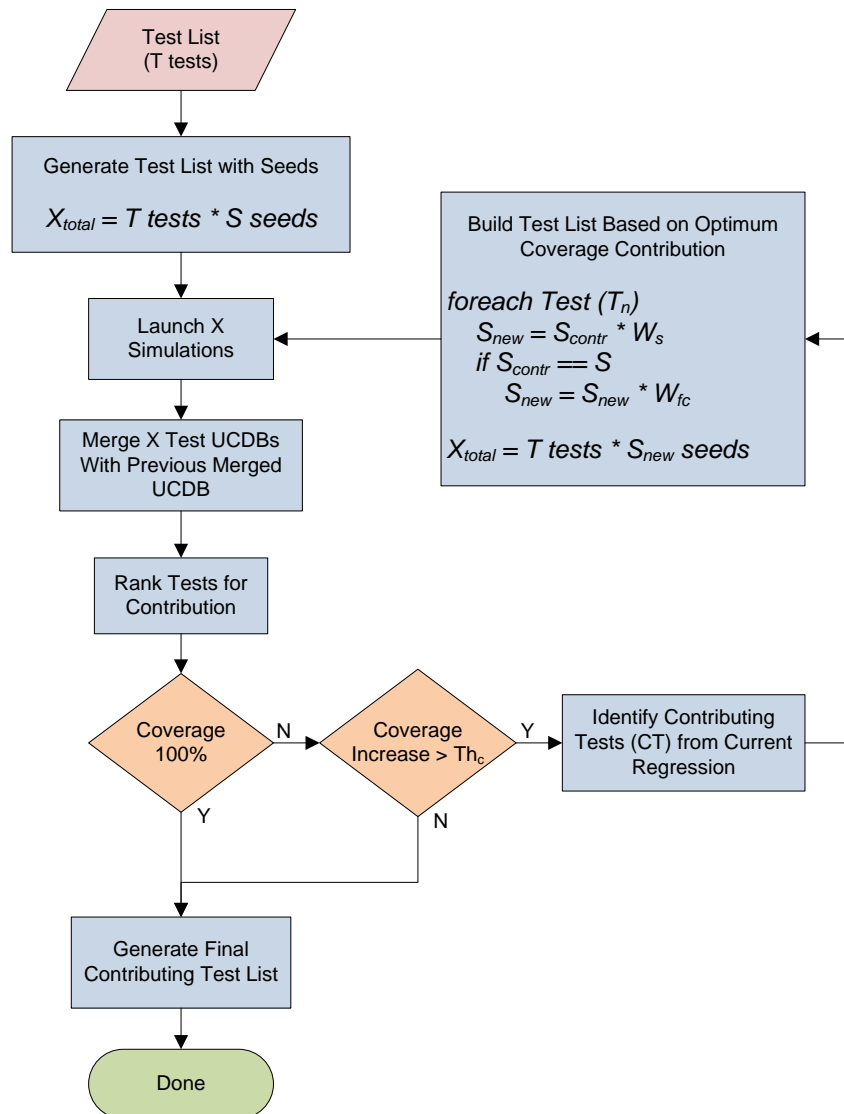


# Proposed Algorithm

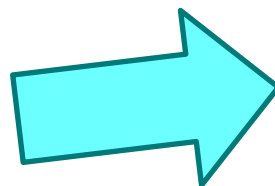
- Quit when Coverage Target or Threshold is met



# Proposed Algorithm

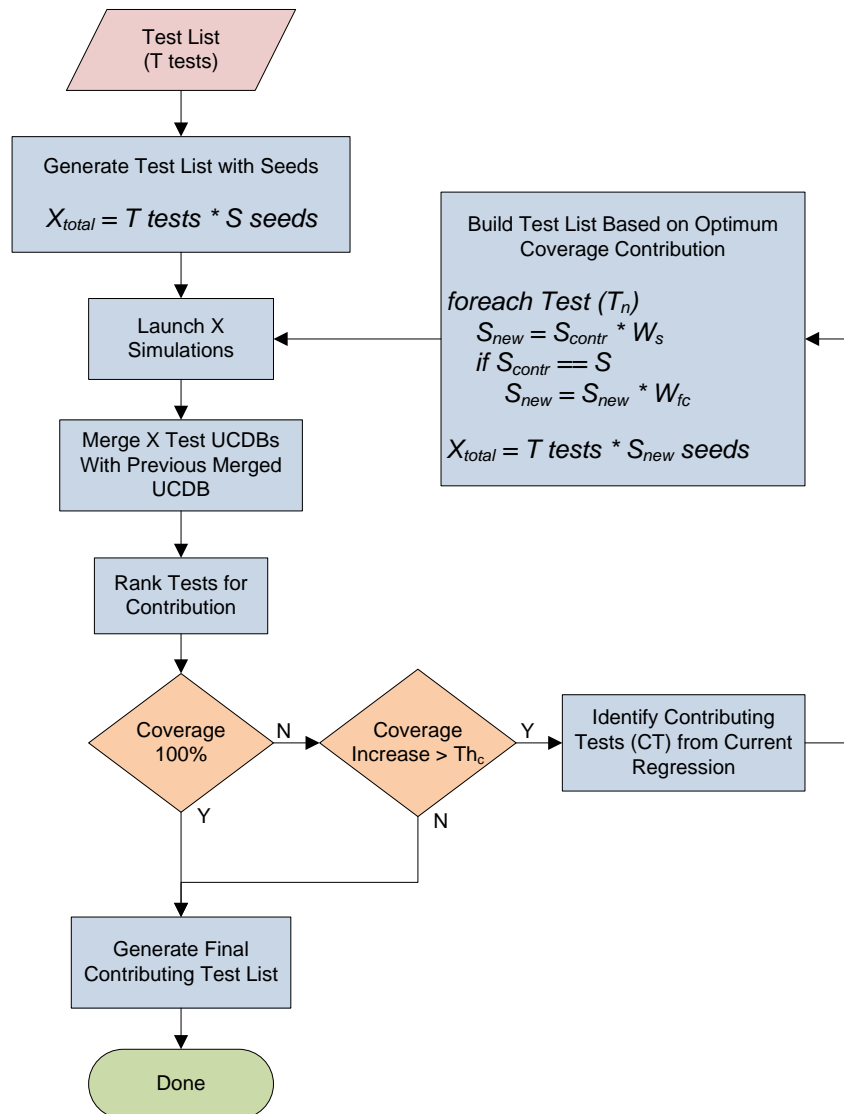


- Based on Ranking Results identify only Contributing Tests
- Start with this for new test list

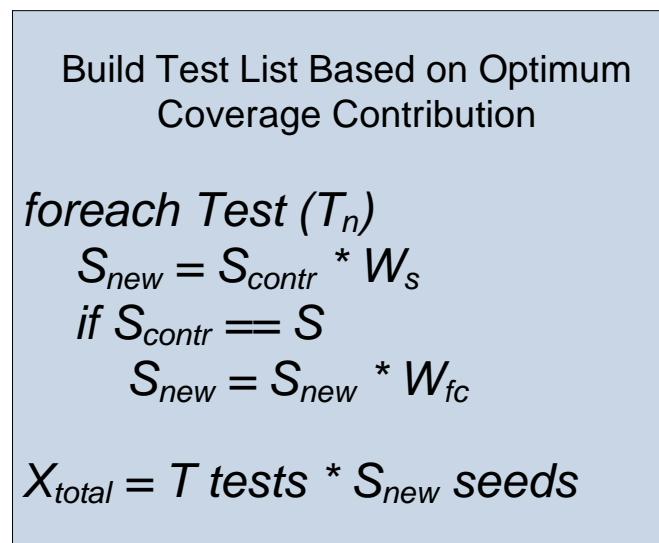
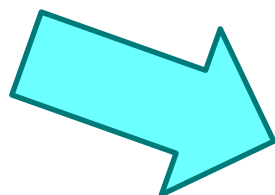


Identify Contributing Tests (CT) from Current Regression

# Proposed Algorithm



- Reward based on Contribution
- What should Reward be?
- For paper, Reward is multiplied if maximum Contribution, “Double Down”



# Results (Methods Tried)

- Two different test benches tried with 10 tests each
- Methods tried
  - Shotgun
    - Ask for ten random seeds per test for each regression
  - Algorithm with weighting factors;  $W_s=2$ ,  $W_{fc}=1$  (no double down)
    - Reward all contributing tests by giving them 2x more seeds
  - Algorithm with weighting factors;  $W_s=2$ ,  $W_{fc}=2$  (double down)
    - Reward all contributing tests by giving them 2x more seeds
    - Reward all maximum contribution tests with 2x more seeds
- $T_{hc}=0$  for all methods (Run until incremental coverage is 0)

# Results TB1 – Shotgun

- 100 tests each regression, regardless of contribution
- 900 total tests executed

Test #	Reg 1	Reg 2	Reg 3	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8	Reg 9	Totals	Seeds Kept Per Test
T <sub>1</sub>	10	10	10	10	10	10	10	10	10	90	13
T <sub>2</sub>	10	10	10	10	10	10	10	10	10	90	41
T <sub>3</sub>	10	10	10	10	10	10	10	10	10	90	8
T <sub>4</sub>	10	10	10	10	10	10	10	10	10	90	38
T <sub>5</sub>	10	10	10	10	10	10	10	10	10	90	20
T <sub>6</sub>	10	10	10	10	10	10	10	10	10	90	6
T <sub>7</sub>	10	10	10	10	10	10	10	10	10	90	8
T <sub>8</sub>	10	10	10	10	10	10	10	10	10	90	9
T <sub>9</sub>	10	10	10	10	10	10	10	10	10	90	6
T <sub>10</sub>	10	10	10	10	10	10	10	10	10	90	11
<b>Totals</b>	100	100	100	100	100	100	100	100	100	900	160

# Results TB1 – Shotgun

- 160 seeds kept
- 77.47% coverage after 51 hours

Regr #	Coverage %	Tests Run	Contributing Tests per Iteration	Final Rank Contribution	Total Wall Clock Time (s)	Total Kept Seeds
1	76.05	100	69	19	22612.77	69
2	76.26	100	52	16	44114.21	101
3	76.74	100	33	17	65462.10	120
4	76.98	100	30	16	86872.50	135
5	76.99	100	30	19	107173.24	146
6	77.04	100	28	22	128018.57	158
7	77.24	100	27	24	147417.34	159
8	77.47	100	14	12	166907.69	158
9	<b>77.47</b>	100	15	15	<b>186266.24</b>	<b>160</b>



# Results TB1 – $W_s=2$ , $W_{fc}=1$

- Tests per regression depends on contribution
- Stopped after Reg 6
- 600 total tests executed

Test #	Reg 1	Reg 2	Reg 3	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8	Reg 9	Totals	Seeds Kept Per Test
T <sub>1</sub>	10	16	14	2	2	2	N/A	N/A	N/A	46	13
T <sub>2</sub>	10	20	34	38	30	16	N/A	N/A	N/A	148	41
T <sub>3</sub>	10	10	6	2	0	0	N/A	N/A	N/A	28	8
T <sub>4</sub>	10	20	30	36	32	20	N/A	N/A	N/A	148	38
T <sub>5</sub>	10	16	18	14	6	4	N/A	N/A	N/A	68	20
T <sub>6</sub>	10	6	2	0	0	0	N/A	N/A	N/A	18	6
T <sub>7</sub>	10	10	6	2	0	0	N/A	N/A	N/A	28	8
T <sub>8</sub>	10	14	4	2	0	0	N/A	N/A	N/A	30	9
T <sub>9</sub>	10	14	8	4	4	0	N/A	N/A	N/A	40	6
T <sub>10</sub>	10	12	12	8	2	2	N/A	N/A	N/A	46	11
<b>Totals</b>	100	138	134	108	76	44	0	0	0	600	160

# Results TB1 – $W_s=2$ , $W_{fc}=1$

- 160 seeds kept
- 78.00% coverage after 40 hours
- Shotgun coverage of 77.47% met after Reg 3 (24 hours)

Regr #	Coverage %	Tests Run	Contributing Tests per Iteration	Final Rank Contribution	Total Wall Clock Time (s)	Total Kept Seeds
1	76.05	100	69	27	22612.77	69
2	76.68	138	67	35	54187.42	114
3	77.55	134	54	37	87251.37	134
4	77.78	108	38	25	113711.20	148
5	78.00	76	22	23	133868.65	152
6	<b>78.00</b>	44	13	13	<b>144371.49</b>	<b>160</b>
7	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A	N/A

# Results TB1 – $W_s=2$ , $W_{fc}=2$

- Tests per regression depends on contribution
- Stopped after Reg 6
- 666 total tests executed

Test #	Reg 1	Reg 2	Reg 3	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8	Reg 9	Totals	Seeds Kept Per Test
T <sub>1</sub>	10	16	12	8	4	6	N/A	N/A	N/A	56	12
T <sub>2</sub>	10	40	48	40	34	20	N/A	N/A	N/A	192	51
T <sub>3</sub>	10	10	4	2	0	0	N/A	N/A	N/A	28	6
T <sub>4</sub>	10	40	58	44	24	10	N/A	N/A	N/A	186	45
T <sub>5</sub>	10	16	10	6	2	0	N/A	N/A	N/A	44	14
T <sub>6</sub>	10	6	6	2	0	0	N/A	N/A	N/A	24	5
T <sub>7</sub>	10	10	2	0	0	0	N/A	N/A	N/A	22	6
T <sub>8</sub>	10	14	6	6	2	0	N/A	N/A	N/A	38	7
T <sub>9</sub>	10	14	6	2	0	0	N/A	N/A	N/A	32	7
T <sub>10</sub>	10	12	12	6	4	2	N/A	N/A	N/A	46	10
<b>Totals</b>	100	178	164	116	70	38	0	0	0	666	163

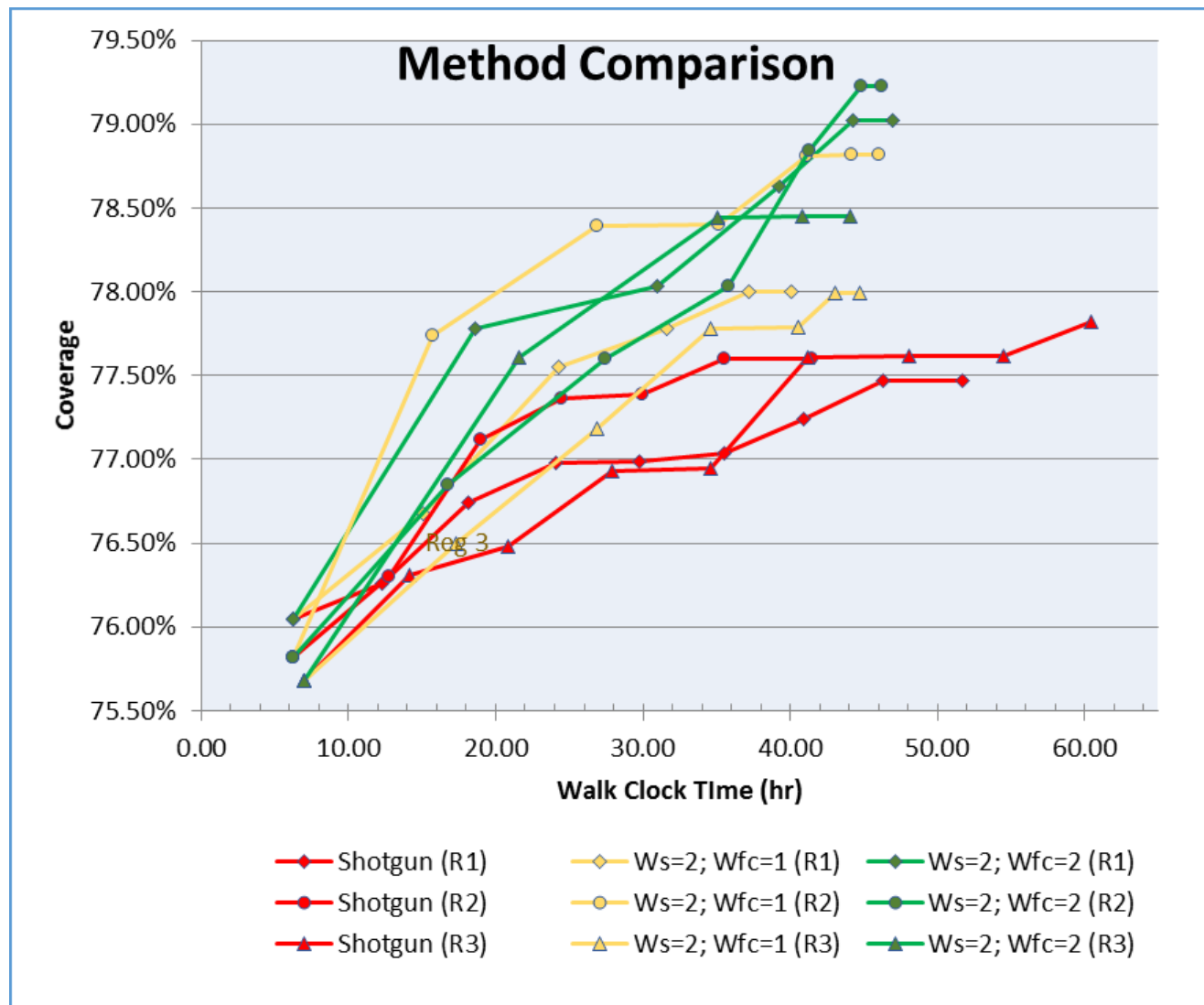
# Results TB1 – $W_s=2$ , $W_{fc}=2$

- 163 seeds kept
- 79.02% coverage after 47 hours
- Shotgun coverage of 77.47% met after Reg 2 (19 hours)

Regr #	Coverage %	Tests Run	Contributing Tests per Iteration	Final Rank Contribution	Total Wall Clock Time (s)	Total Kept Seeds
1	76.05	100	69	28	22612.77	69
2	77.78	178	82	41	67125.55	126
3	78.03	164	58	35	111433.47	142
4	78.63	116	35	29	141276.32	151
5	79.02	70	20	19	159551.93	156
6	<b>79.02</b>	38	11	11	<b>169013.31</b>	<b>163</b>
7	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A	N/A

# Results TB1

- Graph of three trials
- Algorithm always better than shotgun (coverage and runtime)



# Results TB2 – Shotgun

- 100 tests each regression, regardless of contribution
- 900 total tests executed
- 159 seeds kept
- 73.94% coverage after 321 hours

Regr #	Coverage %	Tests Run	Contributing Tests per Iteration	Final Rank Contribution	Total Wall Clock Time (s)	Total Kept Seeds
1	72.88%	100	50	20	112214.64	50
2	73.20%	100	32	17	245781.12	65
3	73.35%	100	29	19	407193.75	91
4	73.43%	100	29	15	554897.93	105
5	73.89%	100	25	19	665679.11	123
6	73.90%	100	24	13	780300.98	134
7	73.93%	100	24	21	895211.77	147
8	73.94%	100	20	19	1005816.78	154
9	<b>73.94%</b>	100	16	16	<b>1154565.67</b>	<b>159</b>

# Results TB2 – $W_s=2$ , $W_{fc}=1$

- Tests per regression depends on contribution
- Stopped after Reg 9
- 818 total tests executed

Test #	Reg 1	Reg 2	Reg 3	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8	Reg 9	Totals	Seeds Kept Per Test
T <sub>1</sub>	10	20	30	34	28	18	8	2	2	152	44
T <sub>2</sub>	10	20	24	12	6	0	0	0	0	72	16
T <sub>3</sub>	10	14	10	2	0	0	0	0	0	36	6
T <sub>4</sub>	10	6	2	0	0	0	0	0	0	18	3
T <sub>5</sub>	10	4	0	0	0	0	0	0	0	14	0
T <sub>6</sub>	10	2	0	0	0	0	0	0	0	12	0
T <sub>7</sub>	10	10	8	2	2	0	0	0	0	32	5
T <sub>8</sub>	10	20	36	62	90	82	66	54	38	458	131
T <sub>9</sub>	10	2	0	0	0	0	0	0	0	12	1
T <sub>10</sub>	10	2	0	0	0	0	0	0	0	12	1
<b>Totals</b>	100	100	110	112	126	100	74	56	40	818	207

# Results TB2 – $W_s=2$ , $W_{fc}=1$

- 207 seeds kept
- 74.39% coverage after **1392 hours!**
- Shotgun coverage of 73.94% met after Reg 4 (409 hours)

Regr #	Coverage %	Tests Run	Contributing Tests per Iteration	Final Rank Contribution	Total Wall Clock Time (s)	Total Kept Seeds
1	72.88%	100	50	17	112214.64	50
2	73.56%	100	55	25	327634.83	88
3	73.68%	110	56	37	773717.09	124
4	74.12%	112	63	30	1471147.61	166
5	74.16%	126	50	35	2587410.89	184
6	74.19%	100	37	24	3378029.35	202
7	74.38%	74	28	24	3954061.21	203
8	74.39%	56	20	18	4614303.64	202
9	<b>74.39%</b>	40	7	7	<b>5009957.93</b>	<b>207</b>



# Future Work

- Understand the right reward
  - Proportional to coverage?
  - Should length of test be a factor?
  - Proportional to coverage / length of test?
- Build statistical data from more regressions