Practical Suggestions for Improving and Empirically Studying Greedy Test Suite Reduction and Prioritization Methods

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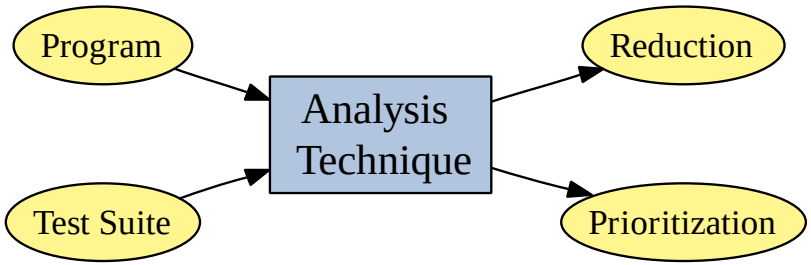
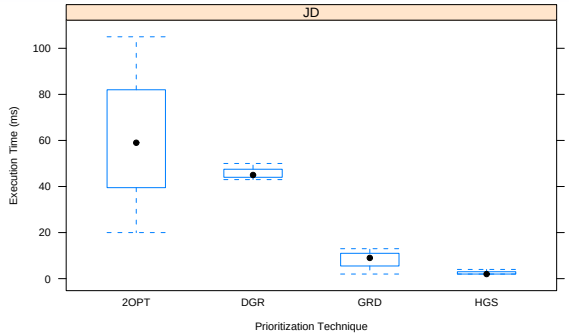
† In Conjunction with Adam M. Smith, Joshua J. Geiger, G. Elisabeta Mara (University of Pittsburgh)
Manos Renieris (Google)

Featuring an image from www.CampusBicycle.com

Important Contributions





Regression Testing Techniques

Detailed Empirical Study

Overview: Implement and evaluate the **efficiency** and **effectiveness** of cost-aware greedy methods for regression test suite **reduction** and **prioritization**

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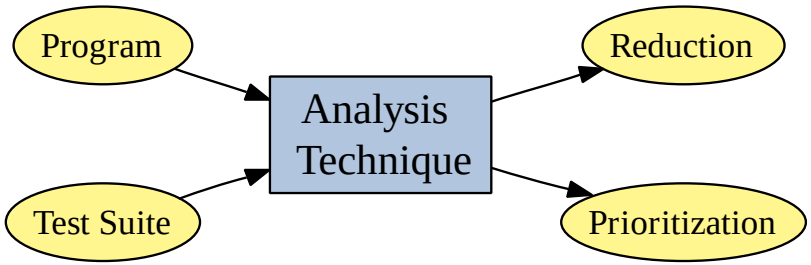

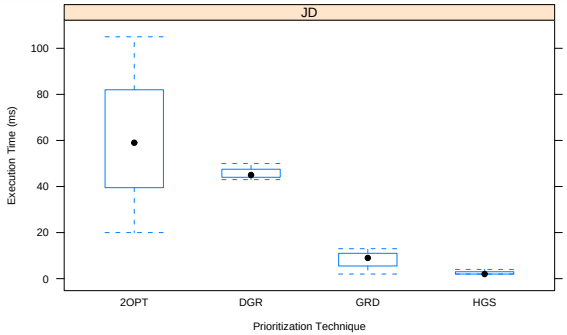

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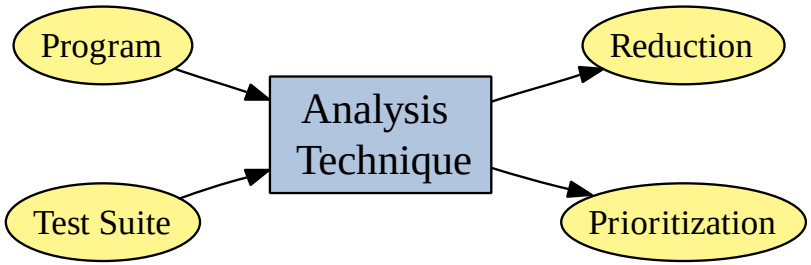

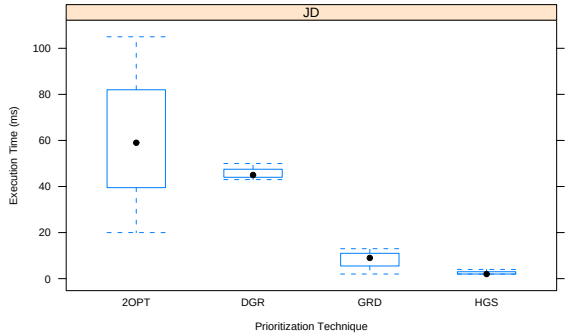

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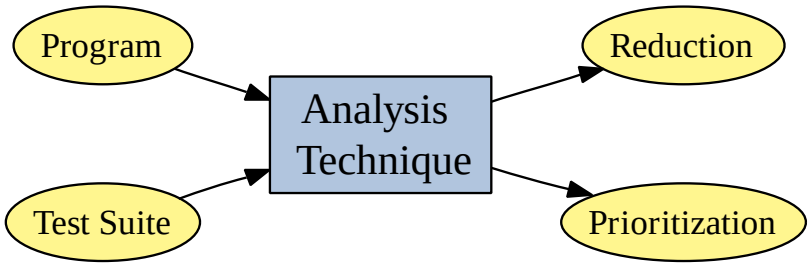

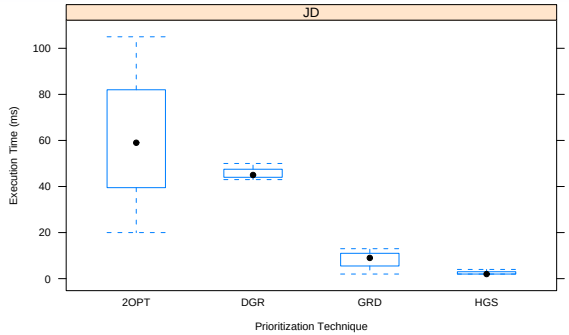

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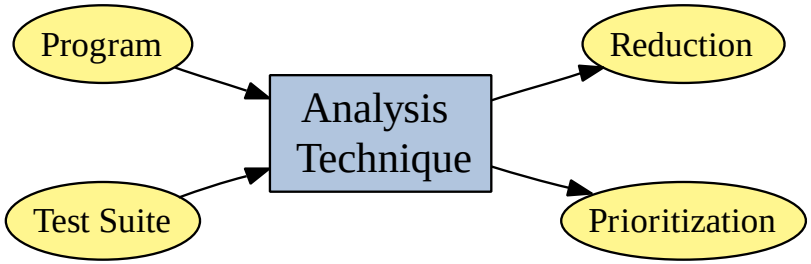

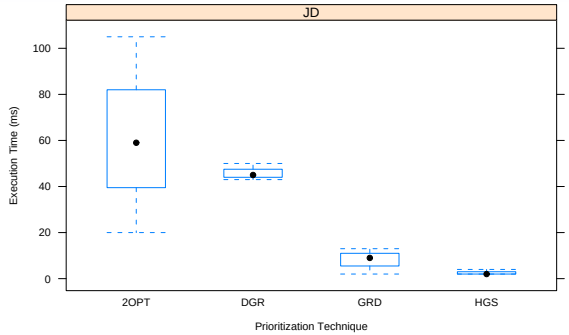

Regression Testing Techniques

Detailed Empirical Study

Experiments: Use automatically generated **synthetic** test suites and **real world** case study applications during the **empirical** study of greedy **regression testing** methods

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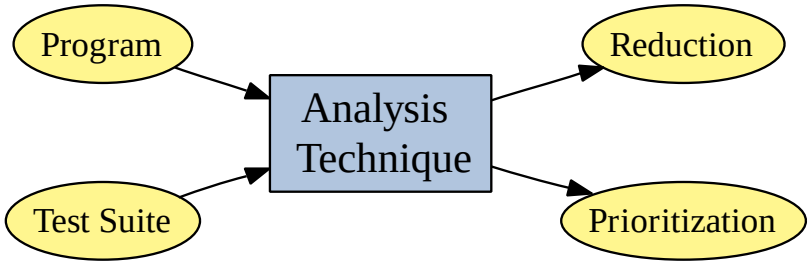
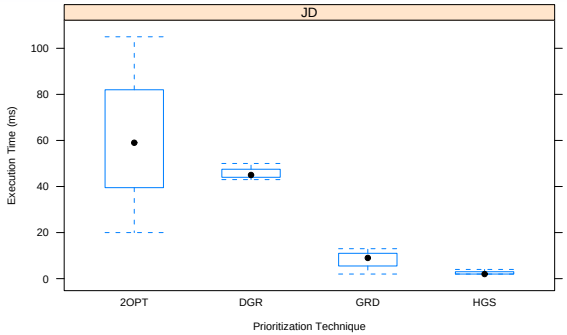


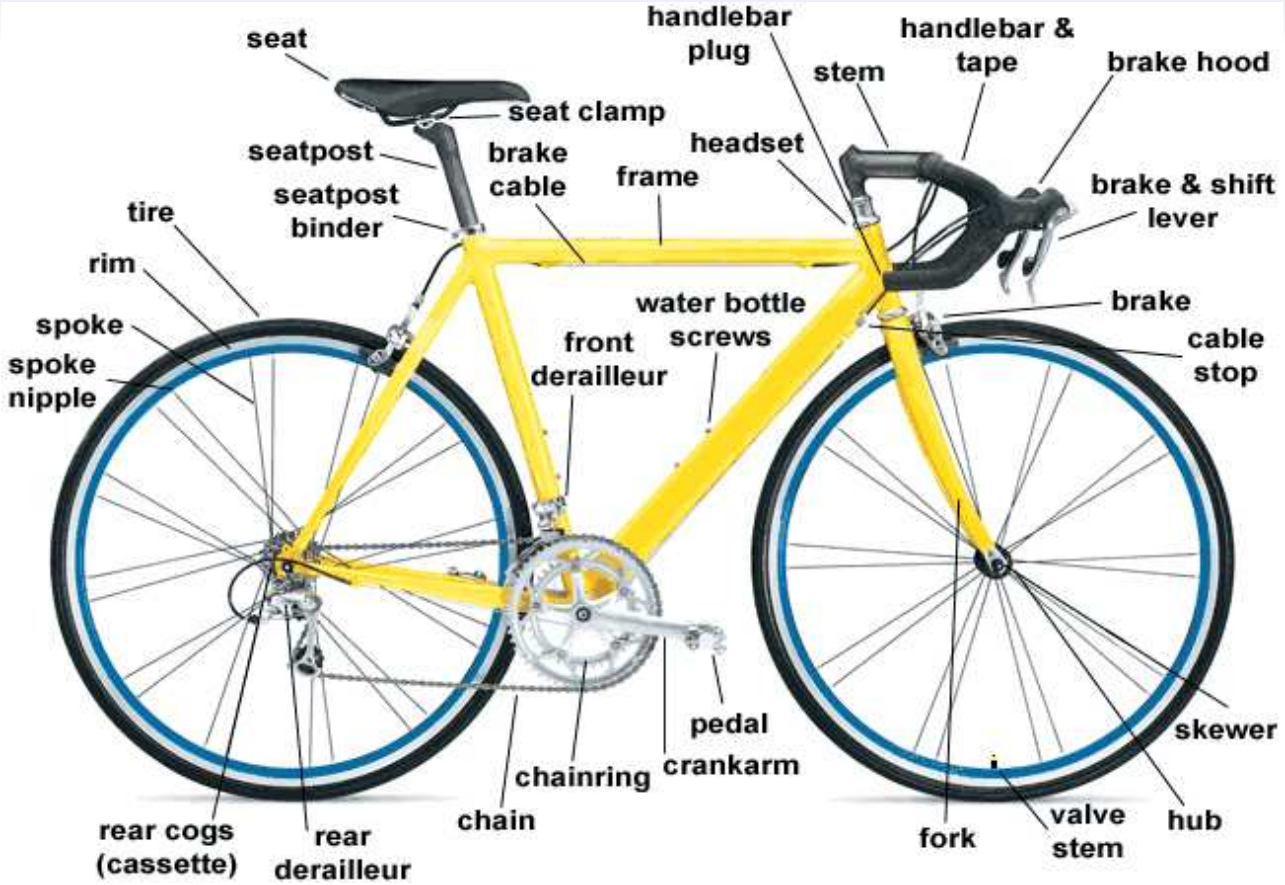


Regression Testing Techniques

Detailed Empirical Study

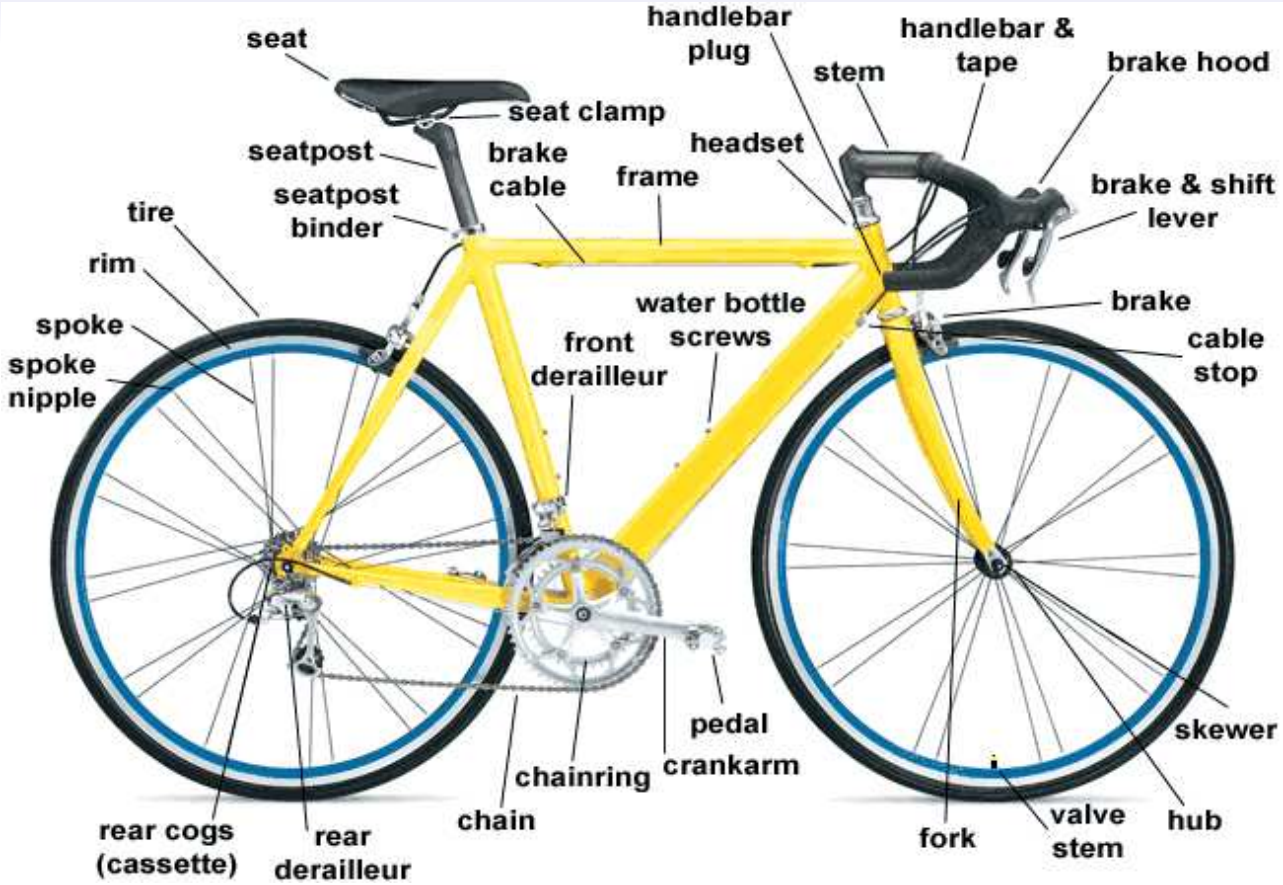
Analysis: Develop and use **tree** and **random forest** statistical models and interactive **visualization** techniques that help to **identify** efficiency and effectiveness **trade-offs** for testing

Regression Testing and Bicycles



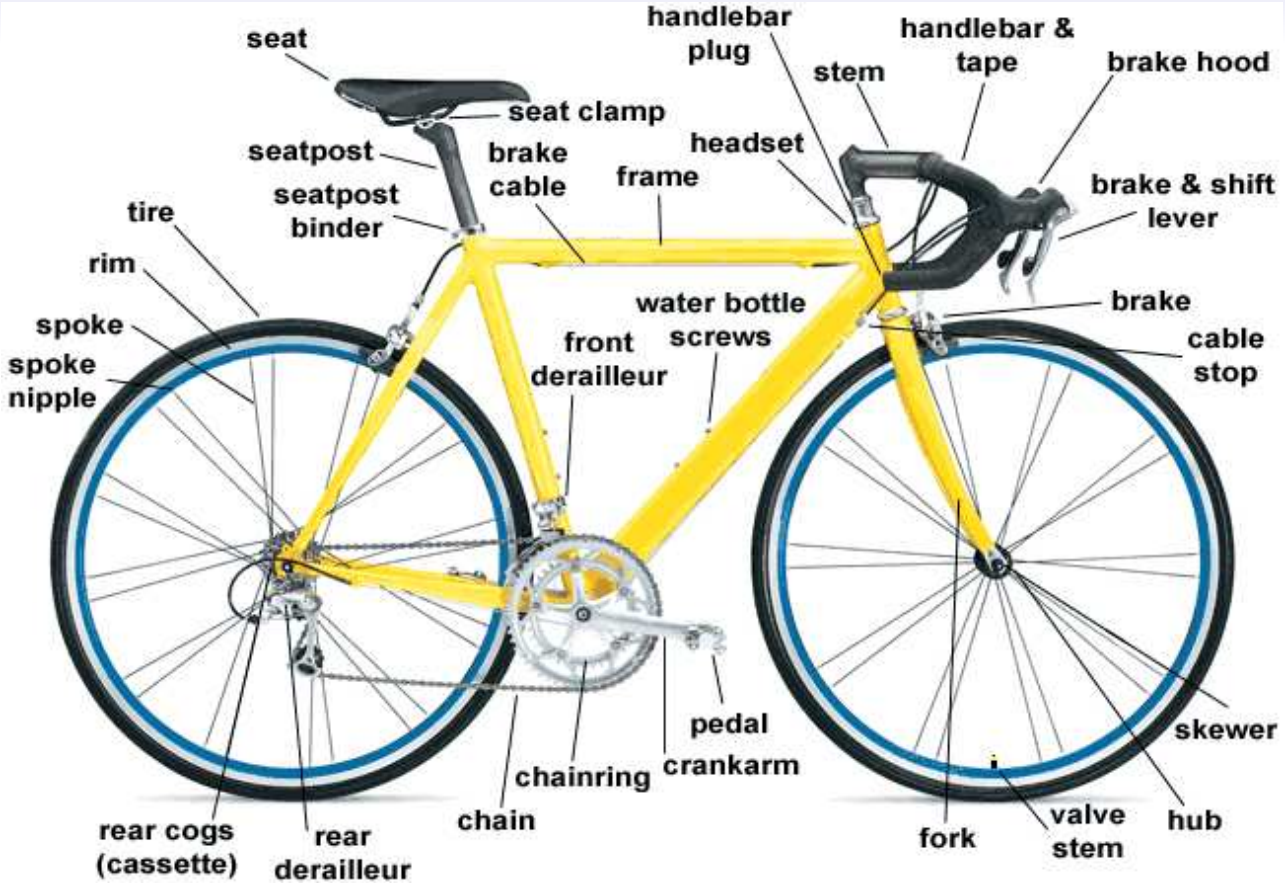
Effi ciency: Low wind resistance and time to destination

Regression Testing and Bicycles



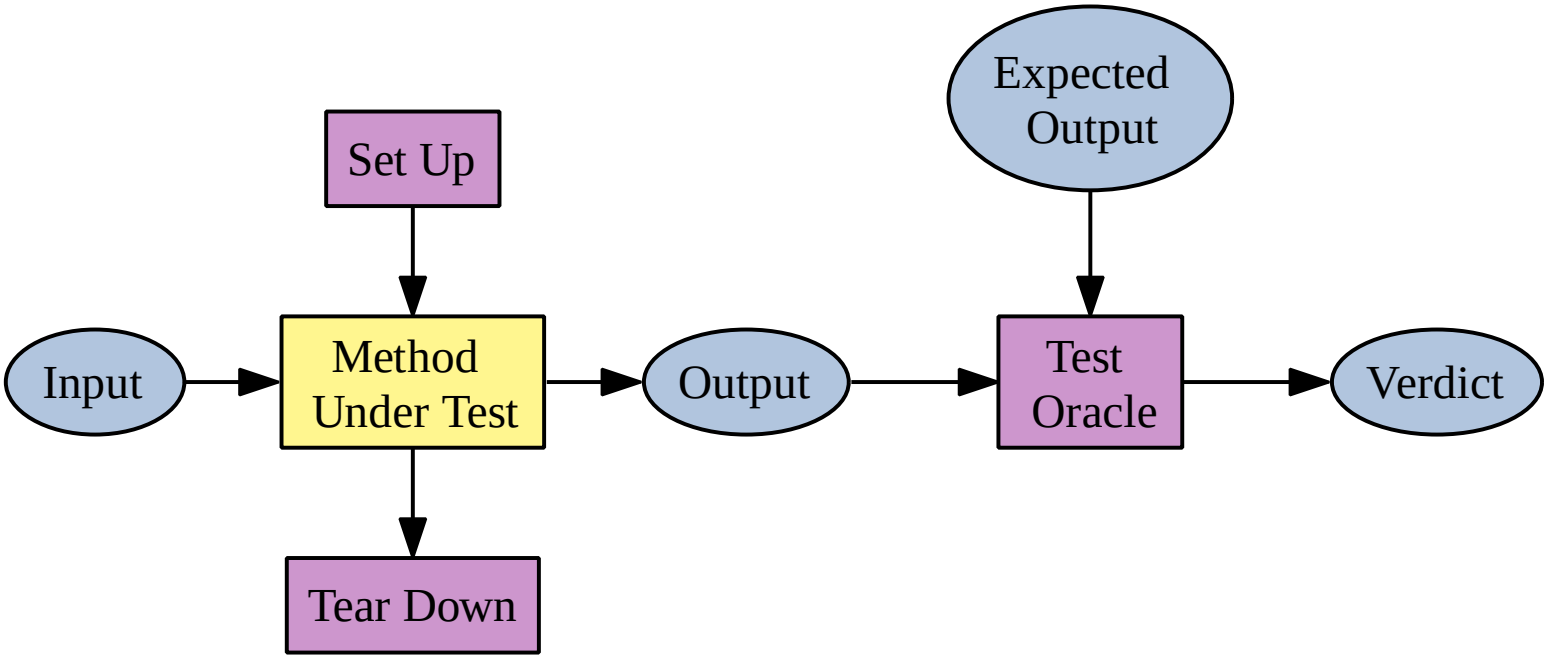
Effectiveness: Transports all required materials and no break downs

Regression Testing and Bicycles



Cost: Frame material and components cause price to vary considerably

What is a Test Case?



- Test suite **executor** runs each test case **independently**
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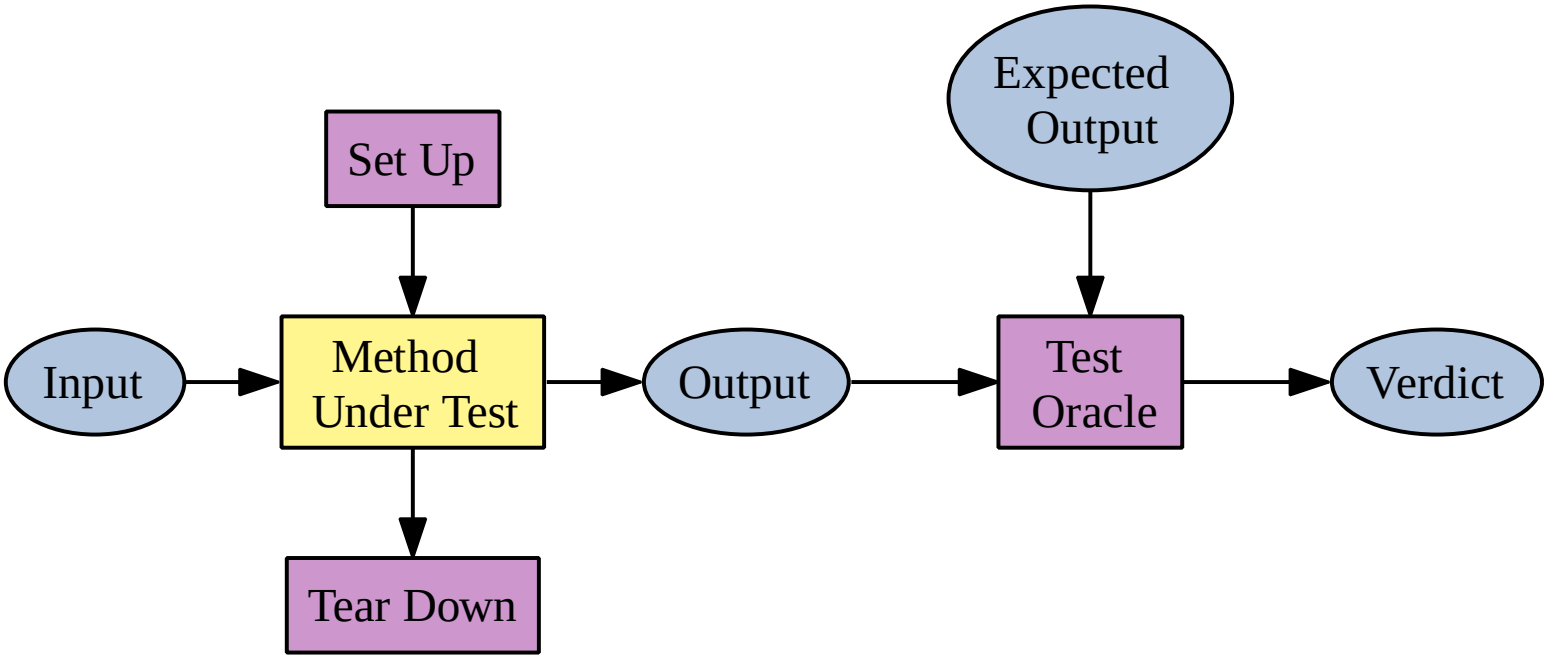

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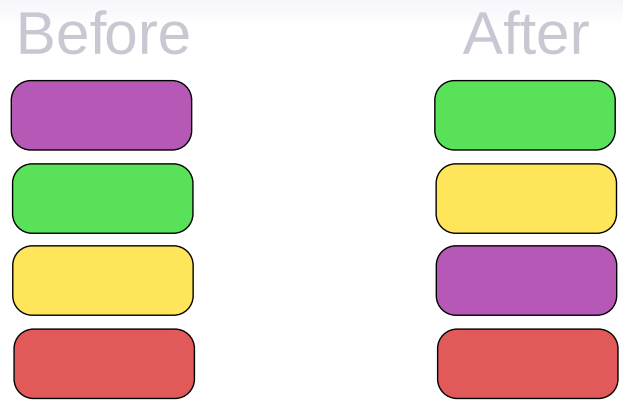

Reduction Prunes the Test Suite

Prioritization Reorders the Tests

It is **expensive** to run a test suite $T = \langle T_1, \ldots, T_n \rangle$. **Reduction** discards some of the n tests in an attempt to **decrease** testing time while still **preserving** objectives like **coverage** or **fault detection**.

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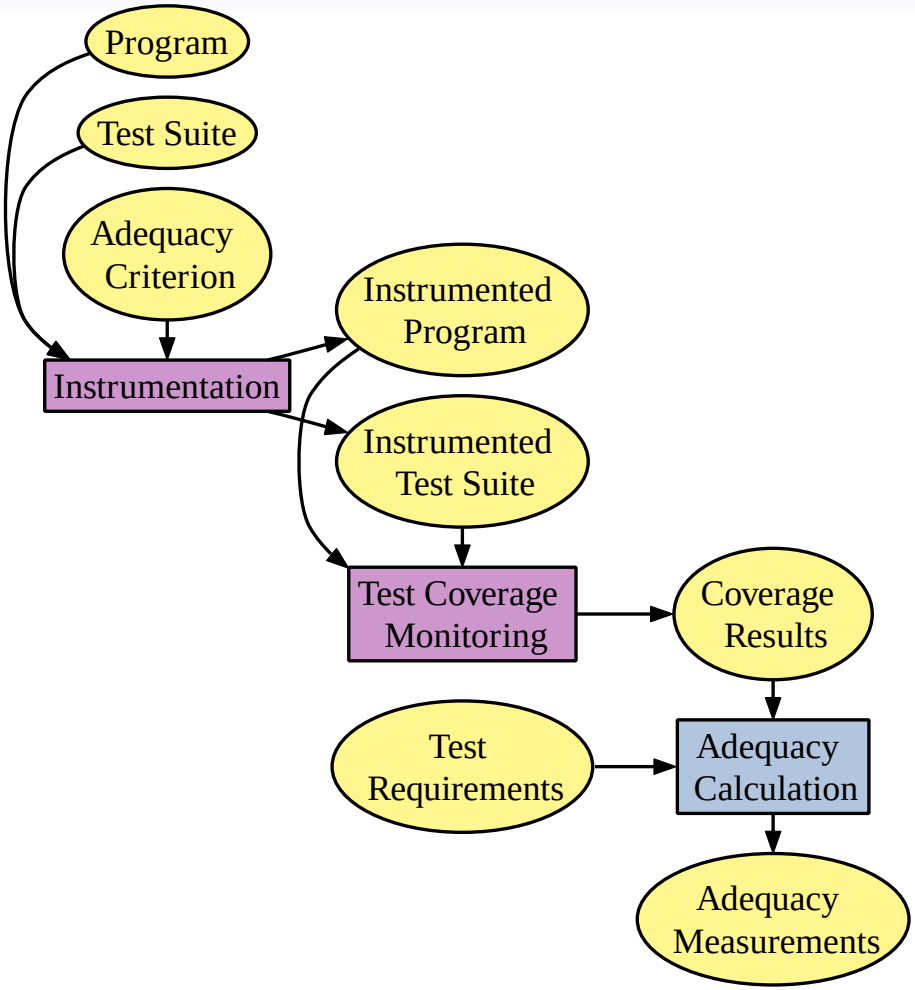
It is **expensive** to run a test suite $T = \langle T_1, \ldots, T_n \rangle$. **Prioritization** searches through the $n! = n \times n - 1 \times \ldots \times 1$ orderings for those that **maximize** an objective function like **coverage** or **fault detection**.

Calculating the Coverage of a Test Suite



Calculating Coverage

Use instrumentation probes to **capture** and **analyze** a test suite's coverage of the program state and structure

Regression Testing

The coverage results and adequacy measurements can support both test suite **reduction** and **prioritization**

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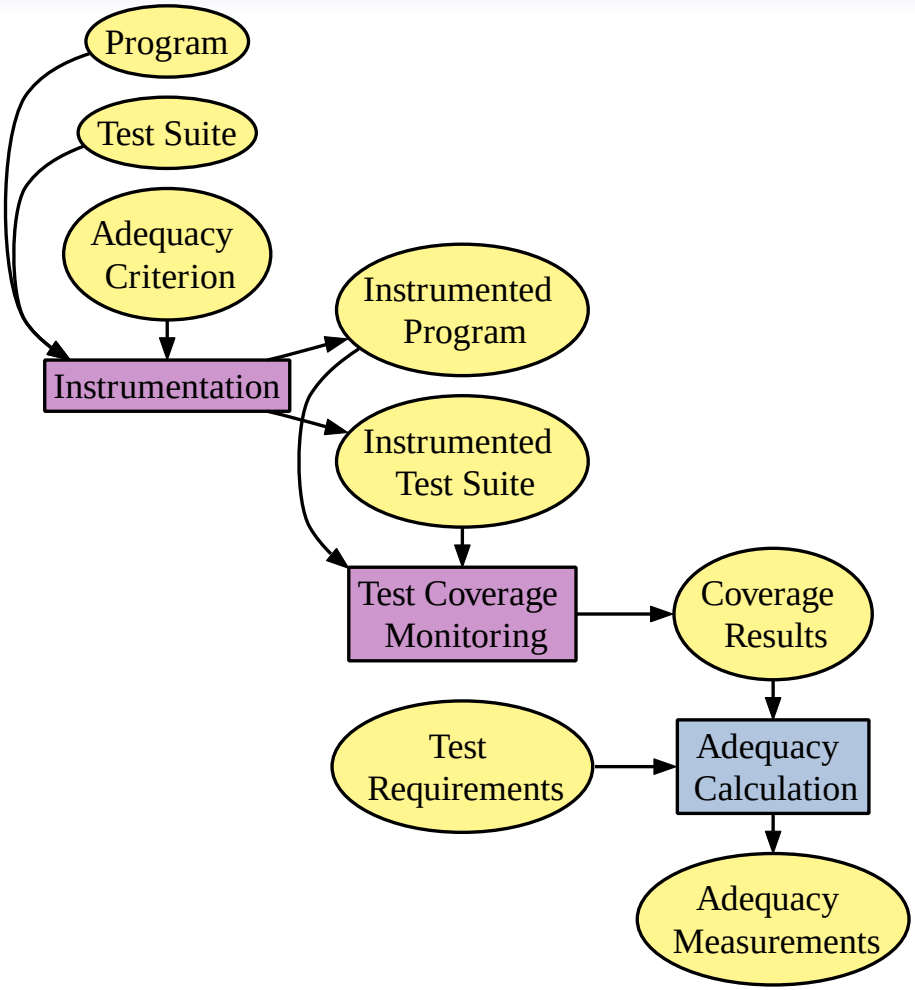

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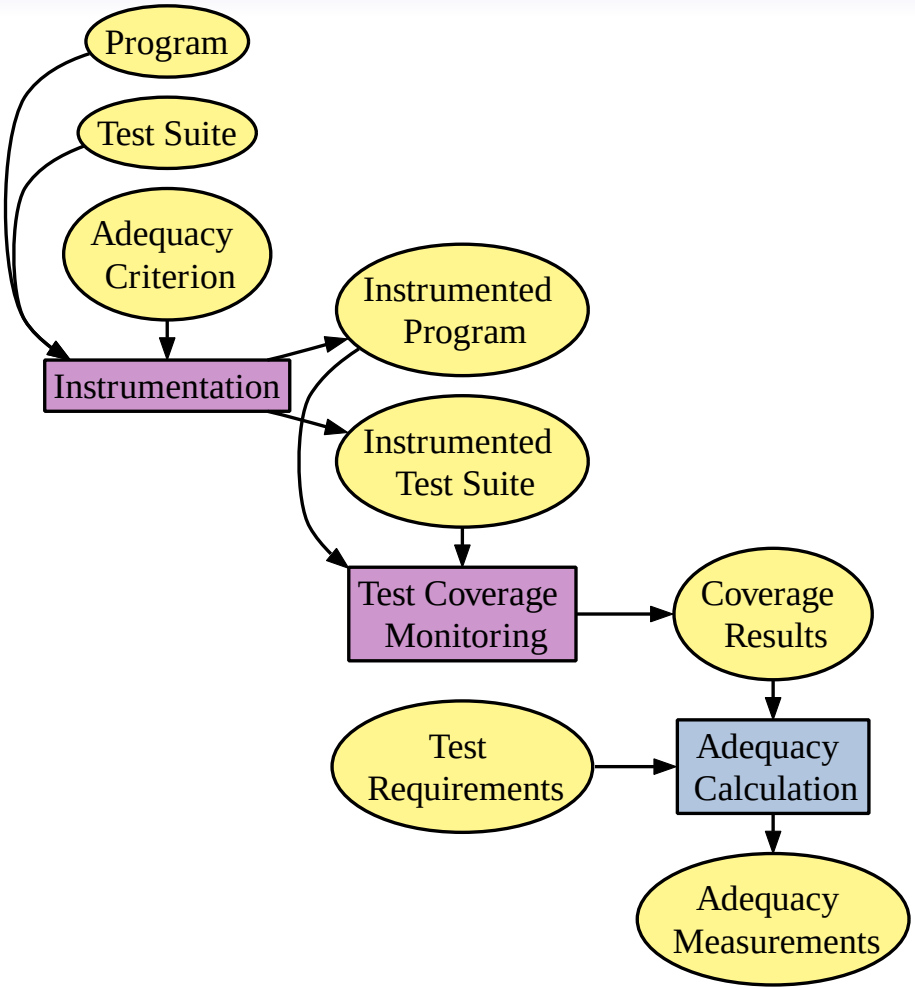

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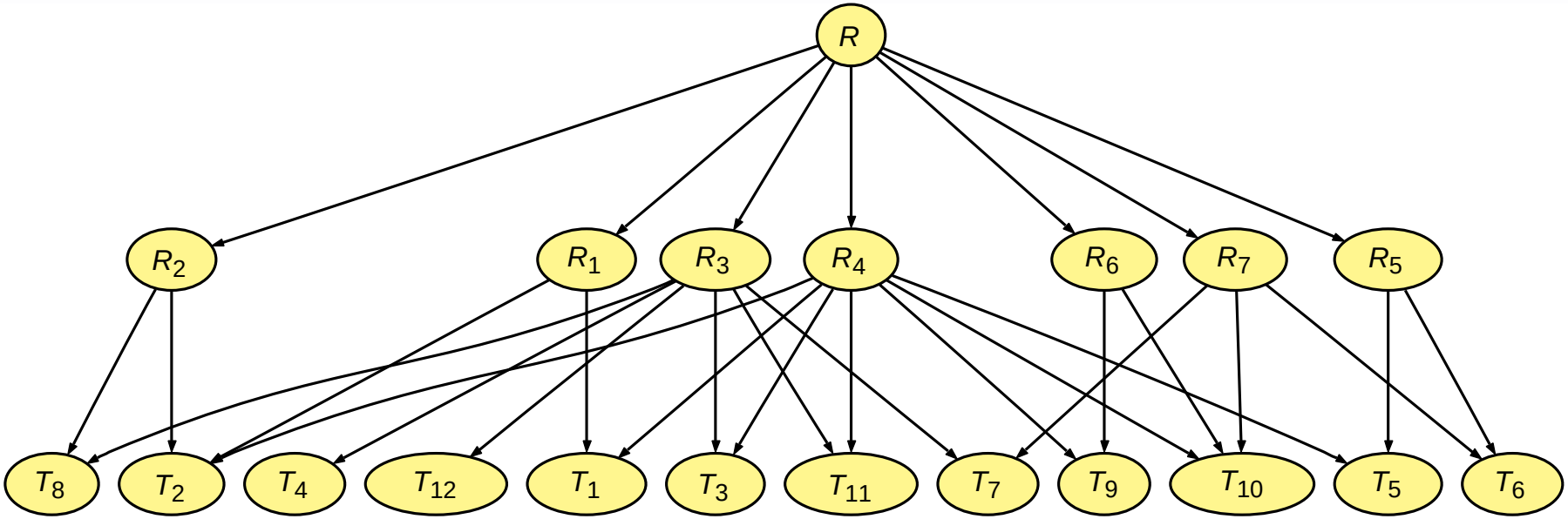

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- Test suite **reduction** discards the test cases that **redundantly** cover the test requirements
- $T = \langle T_2, T_3, T_6, T_9 \rangle$ covers **all** of the test requirements

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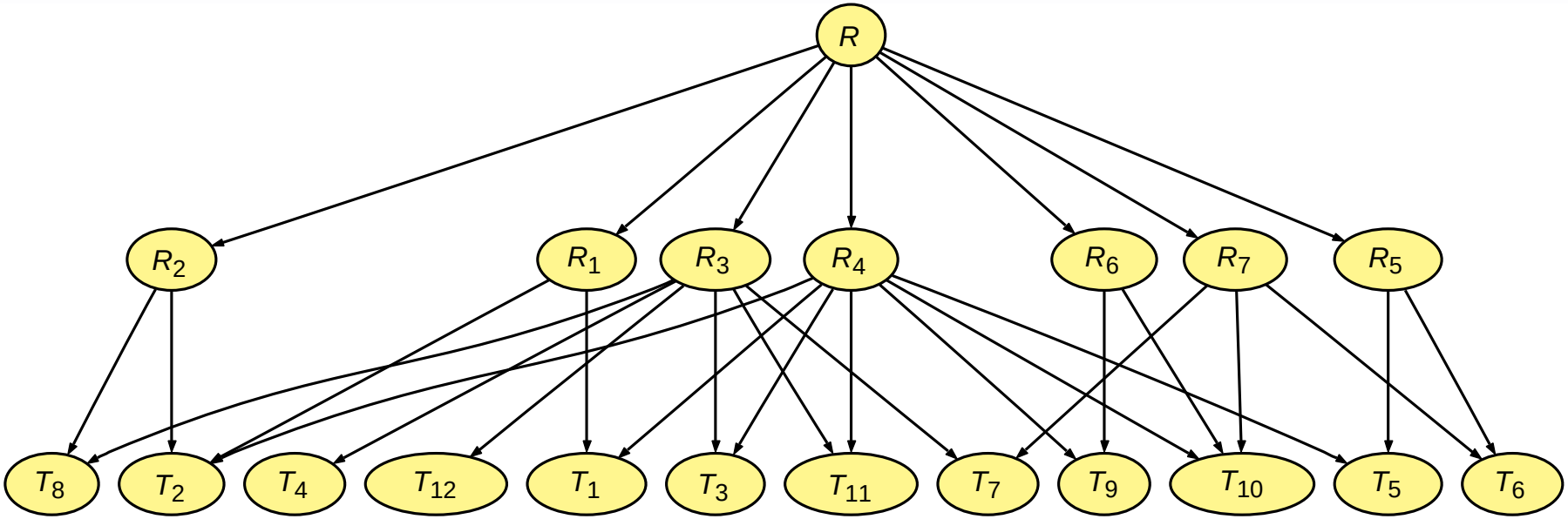

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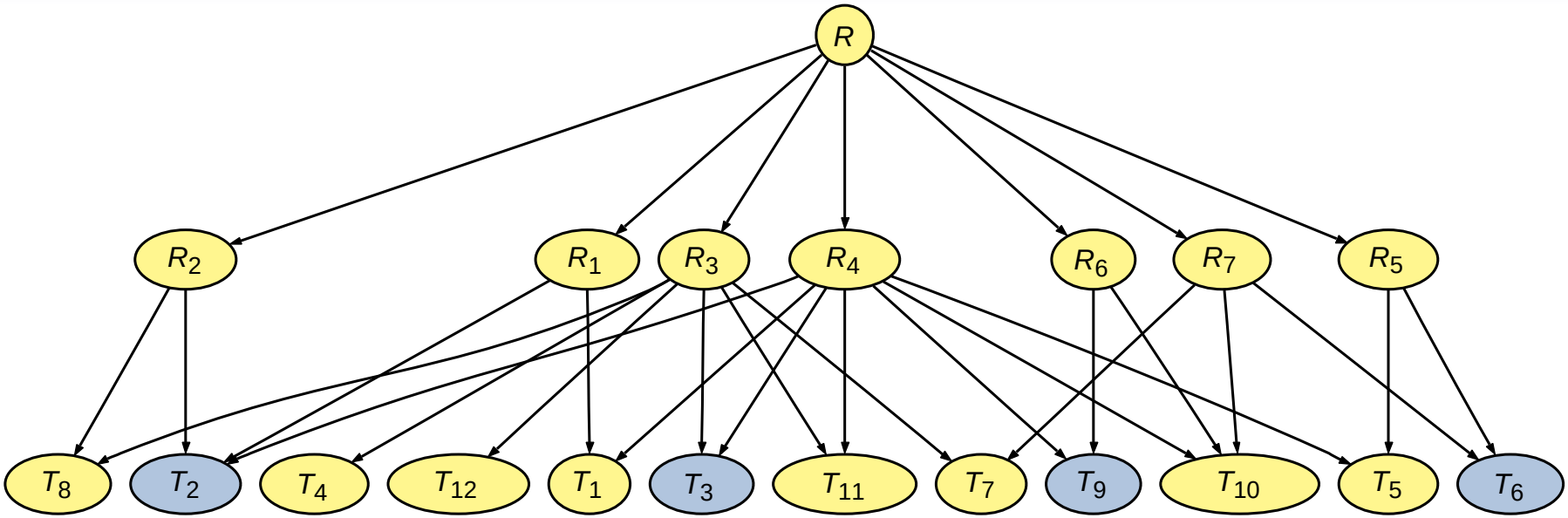

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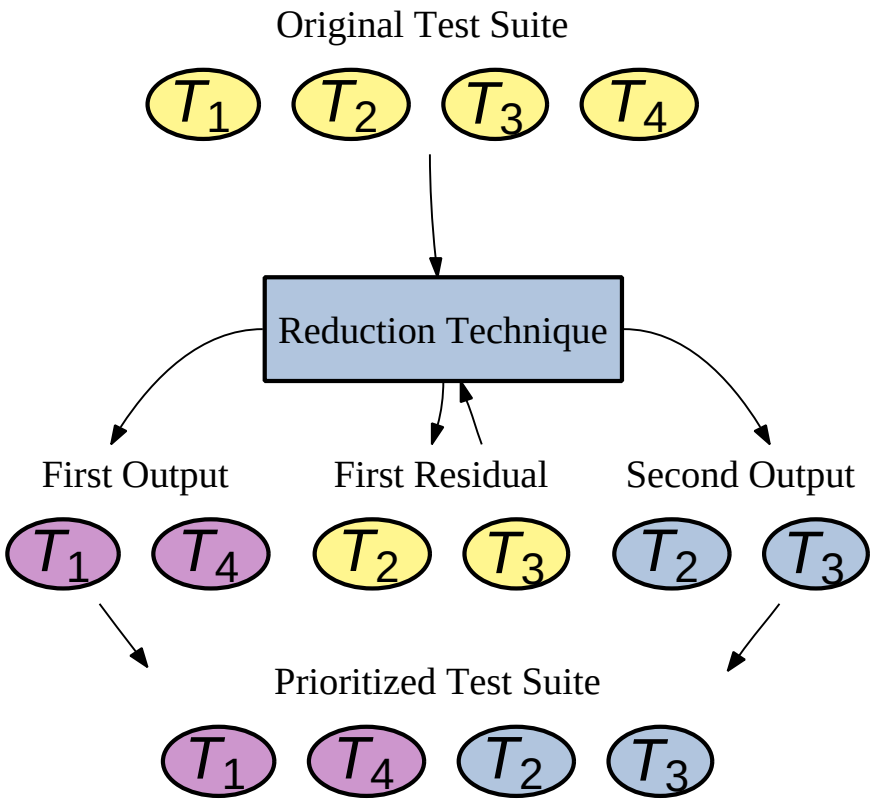

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Hypothesis: Using the execution **time** of a test case can **improve** the reduced and prioritized test suites

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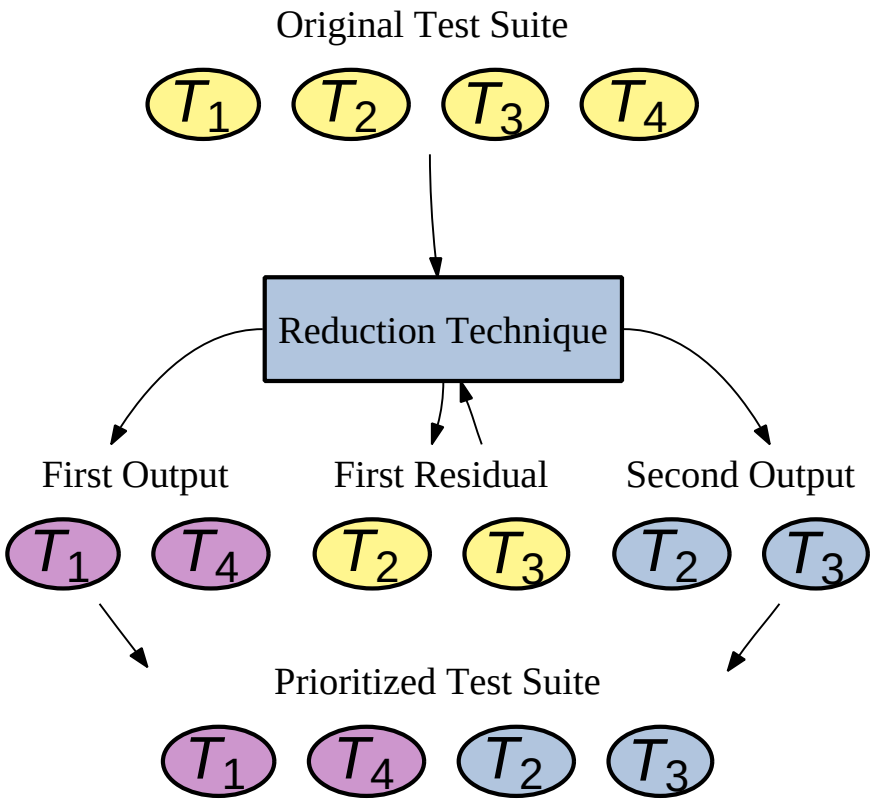

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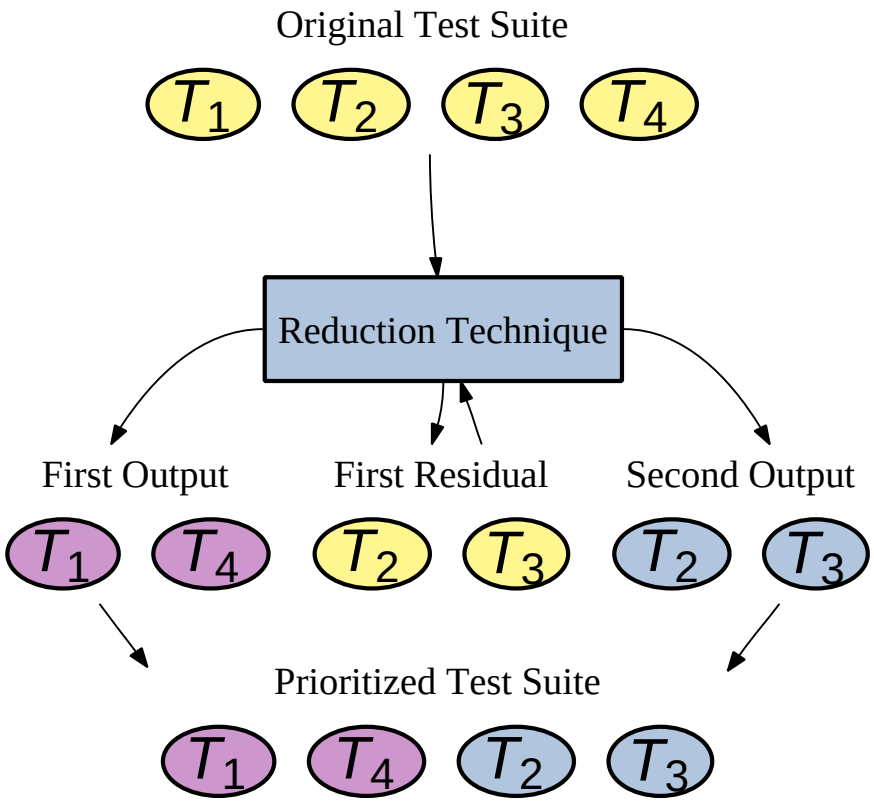

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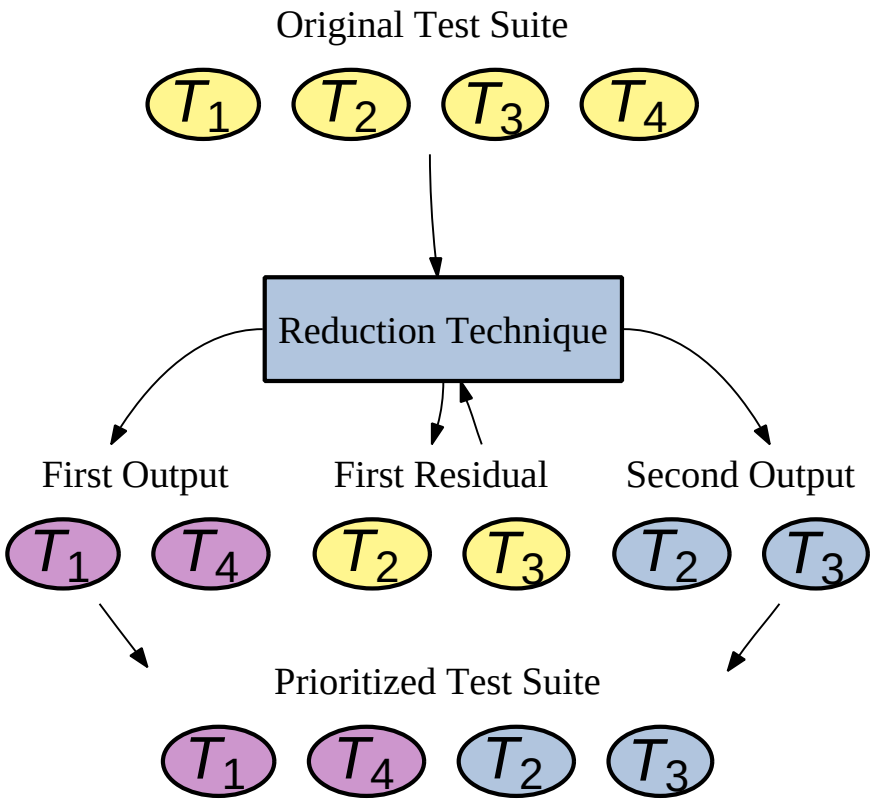

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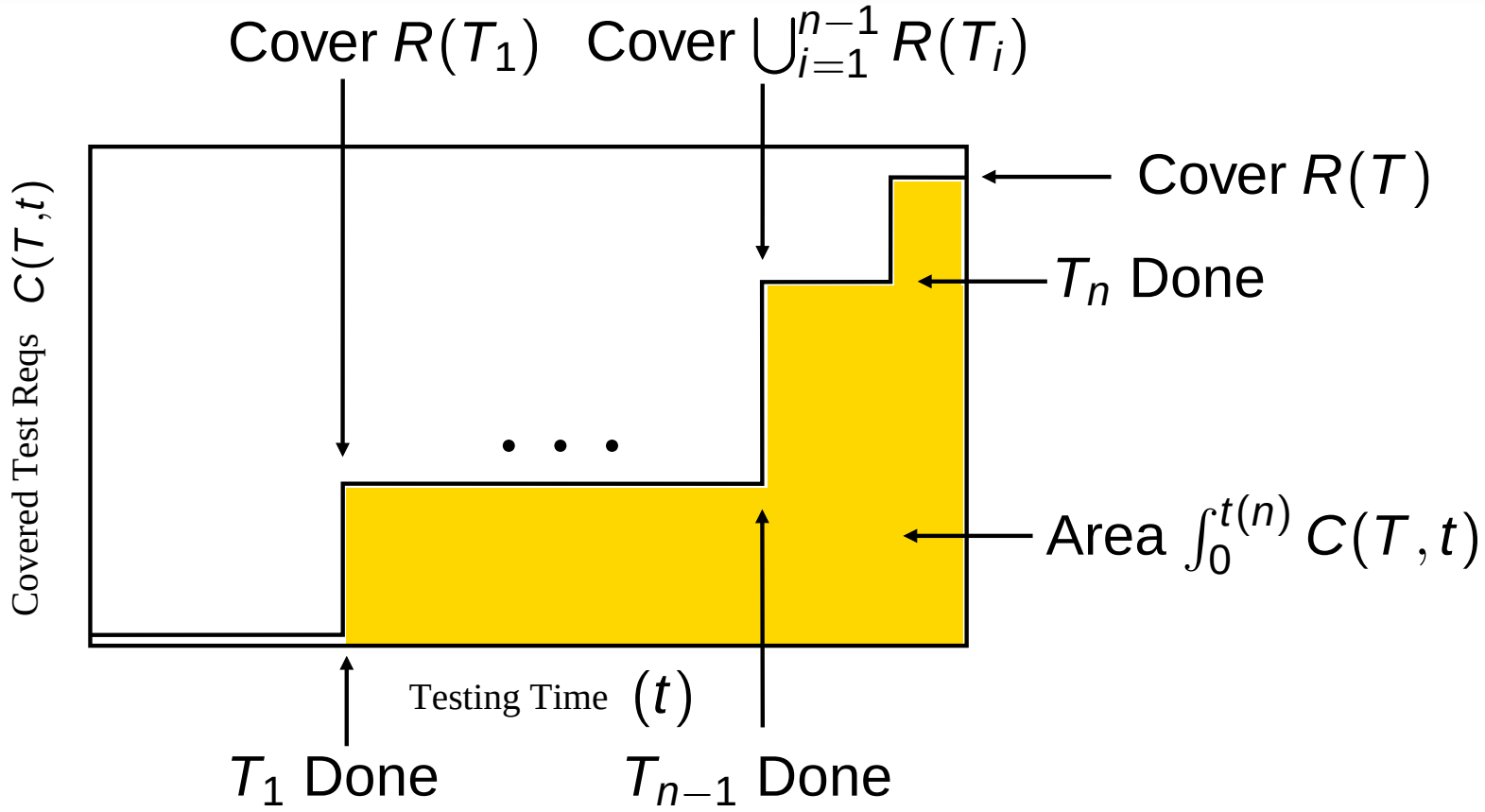

Prioritize to **increase** the CE of a test suite $CE = \frac{\text{Actual}}{\text{Ideal}} \in [0,1]$

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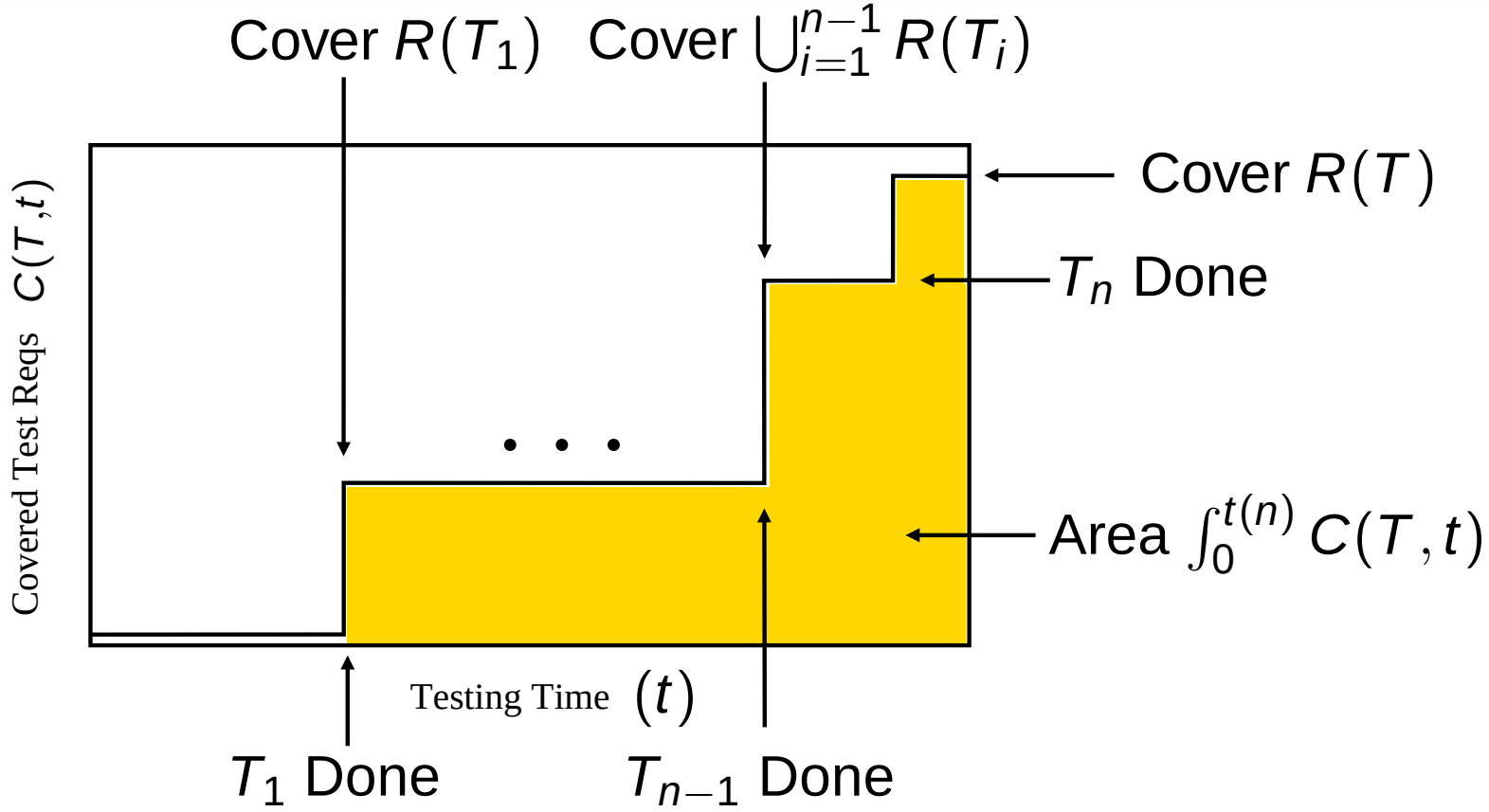

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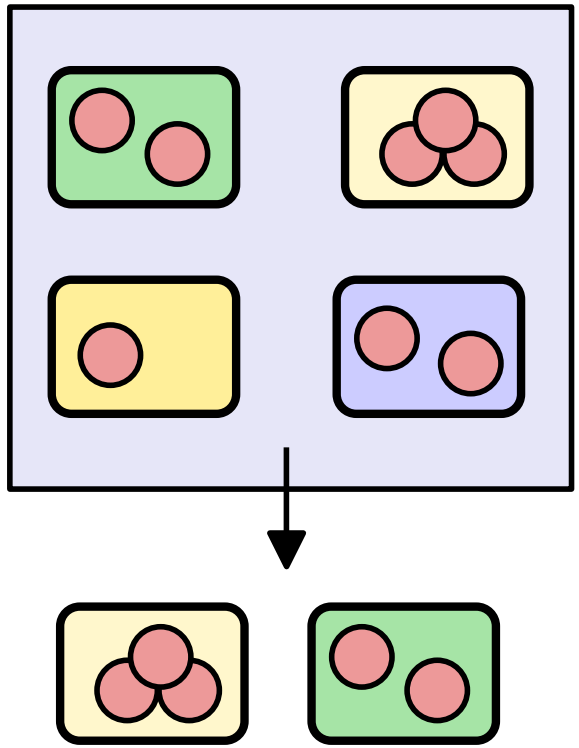
Evaluating Test Suite Reducers



Reduction Factor for Size (RFFS): How small is the reduced test suite?

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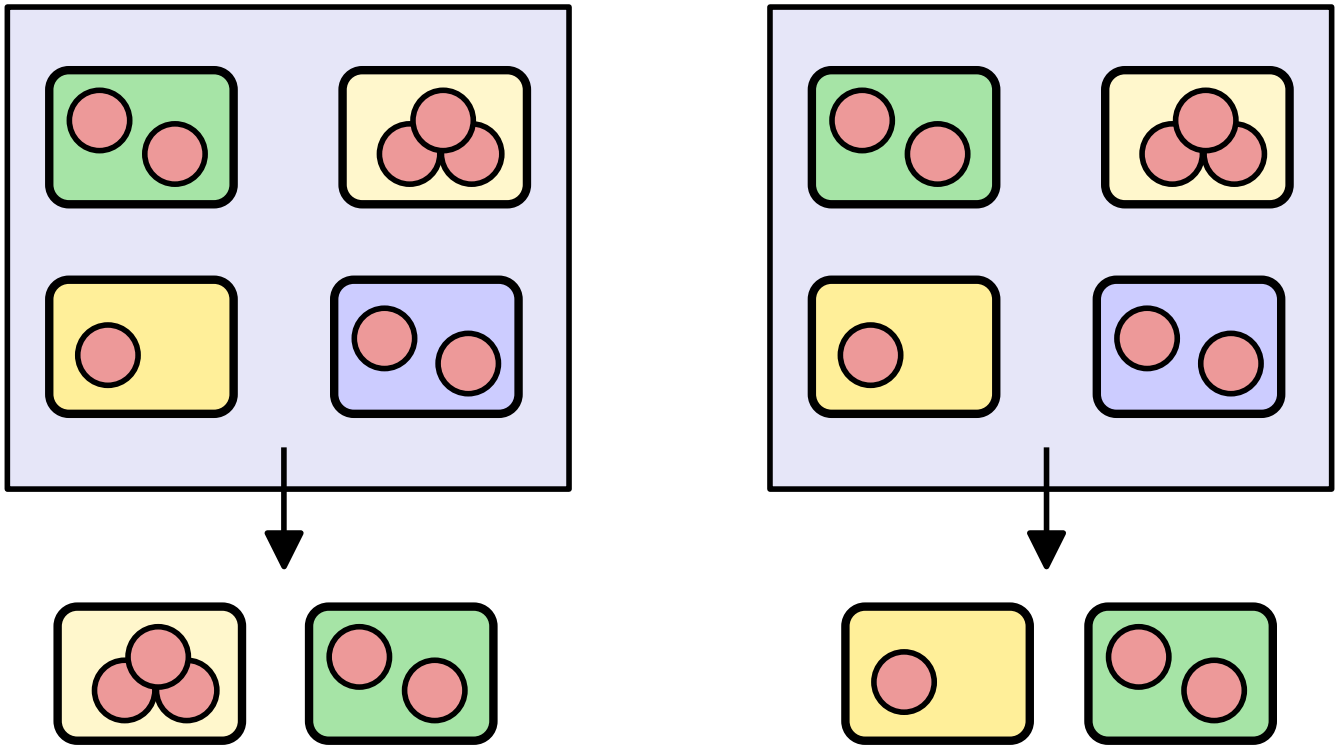
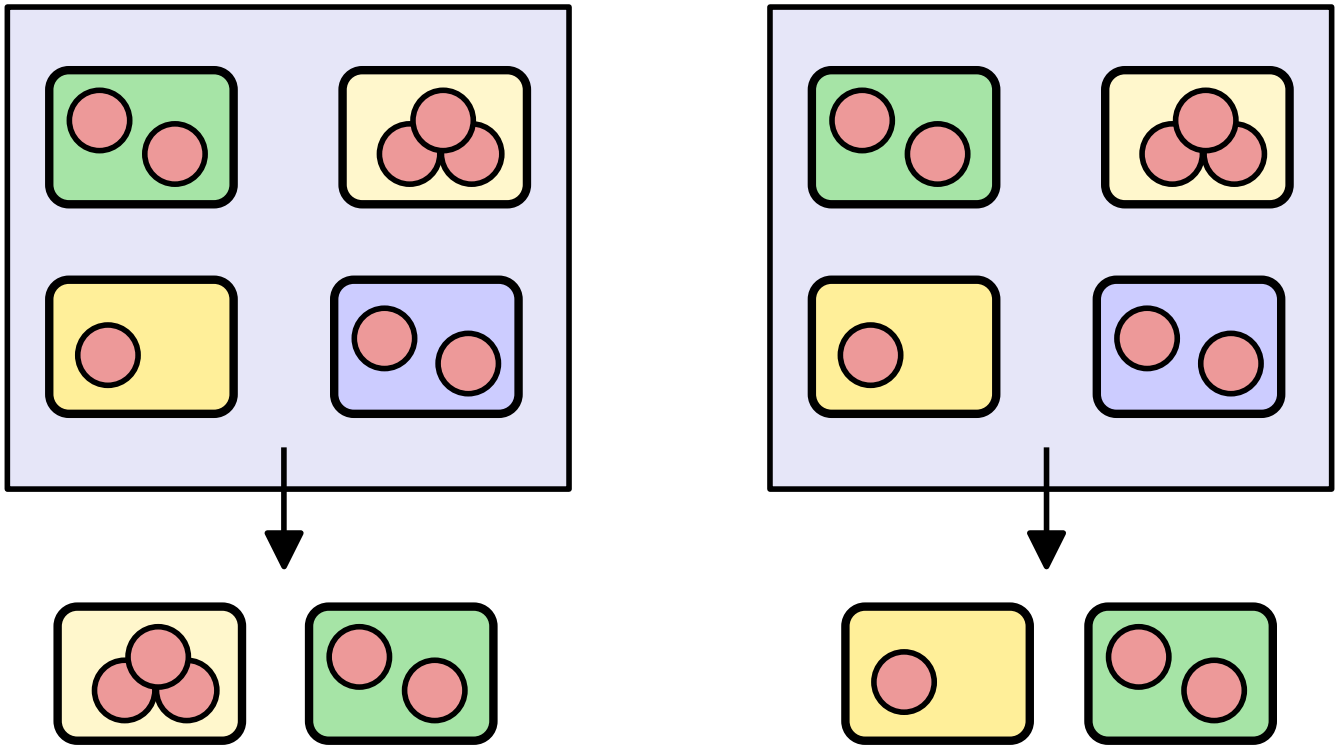


Reduction Factor for Time (RFFT): How fast is the reduced test suite?

Evaluating Test Suite Reducers



Common Rate (CR): How similar are differently reduced test suites?

Greedy Choices Impact Effectiveness

	R_1	R_2	R_3	R_4	R_5	Execution Time
T_1	✓	✓	✓	✓		4
T_2			✓	✓		1
T_3		✓				1
T_4	✓				✓	1

Greedy-by	T_r	$time(T_r)$	T_p	CE
coverage	$\langle T_1, T_4 \rangle$	5	$\langle T_1, T_4, T_2, T_3 \rangle$	0.400
time	$\langle T_2, T_3, T_4 \rangle$	3	$\langle T_2, T_3, T_4, T_1 \rangle$	0.714
ratio	$\langle T_2, T_4, T_3 \rangle$	3	$\langle T_2, T_4, T_3, T_1 \rangle$	0.743

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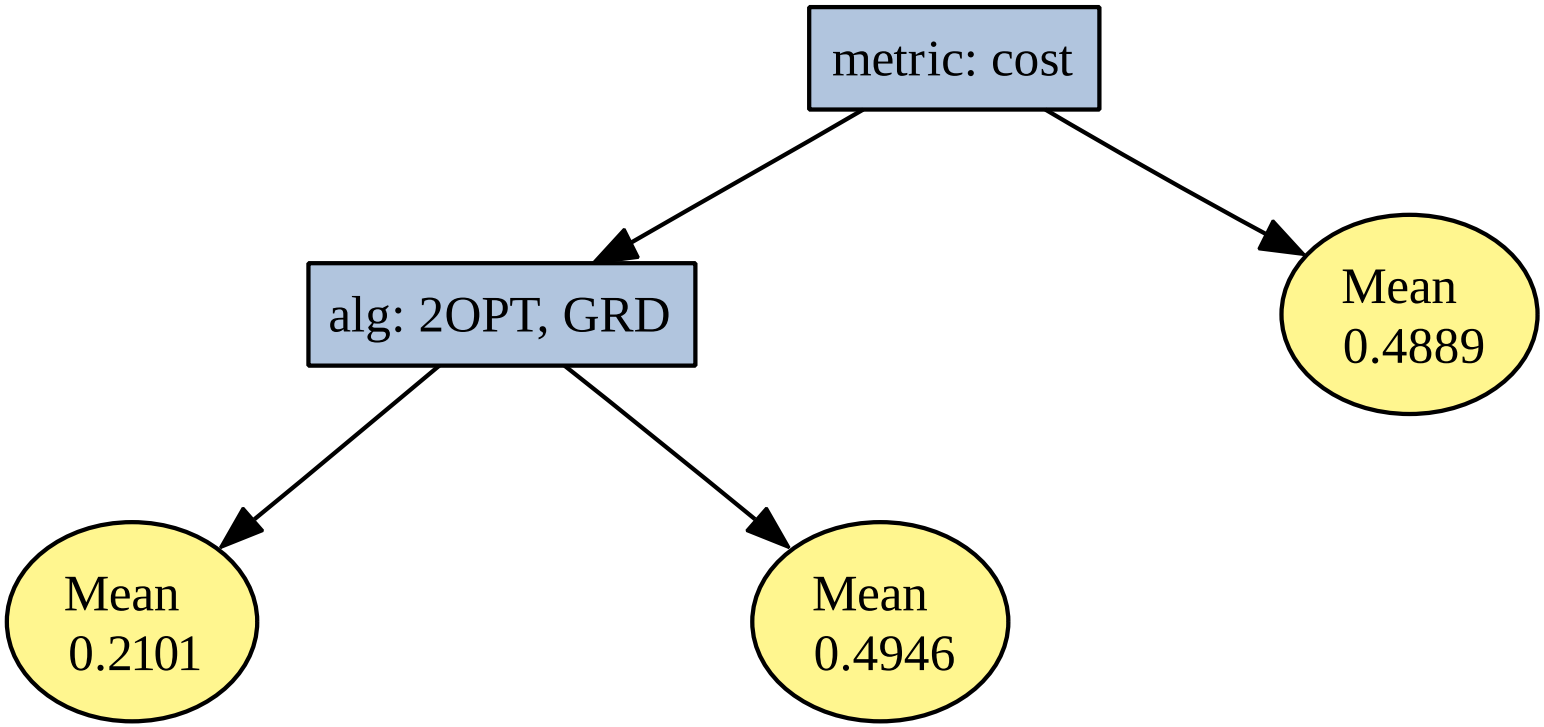
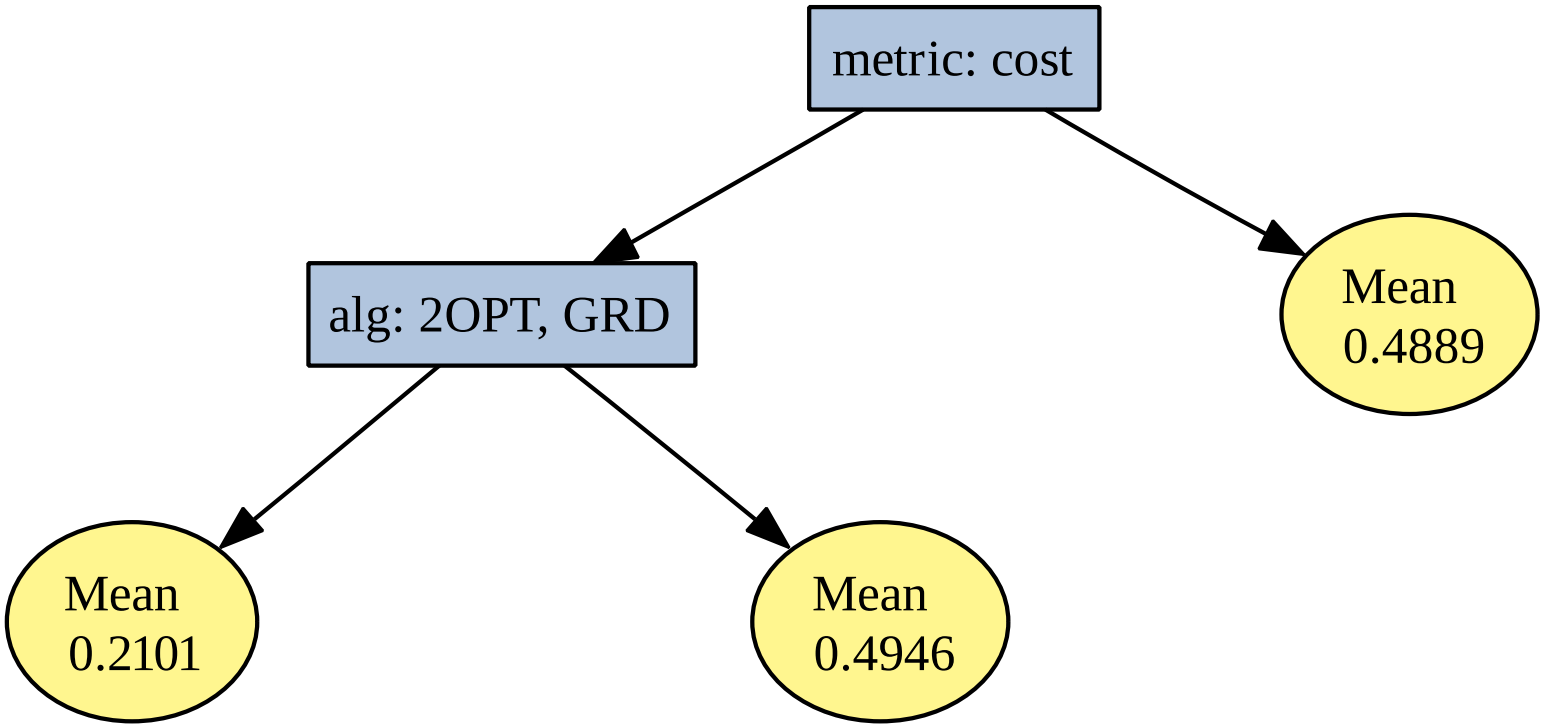
Analysis Method: Tree Models



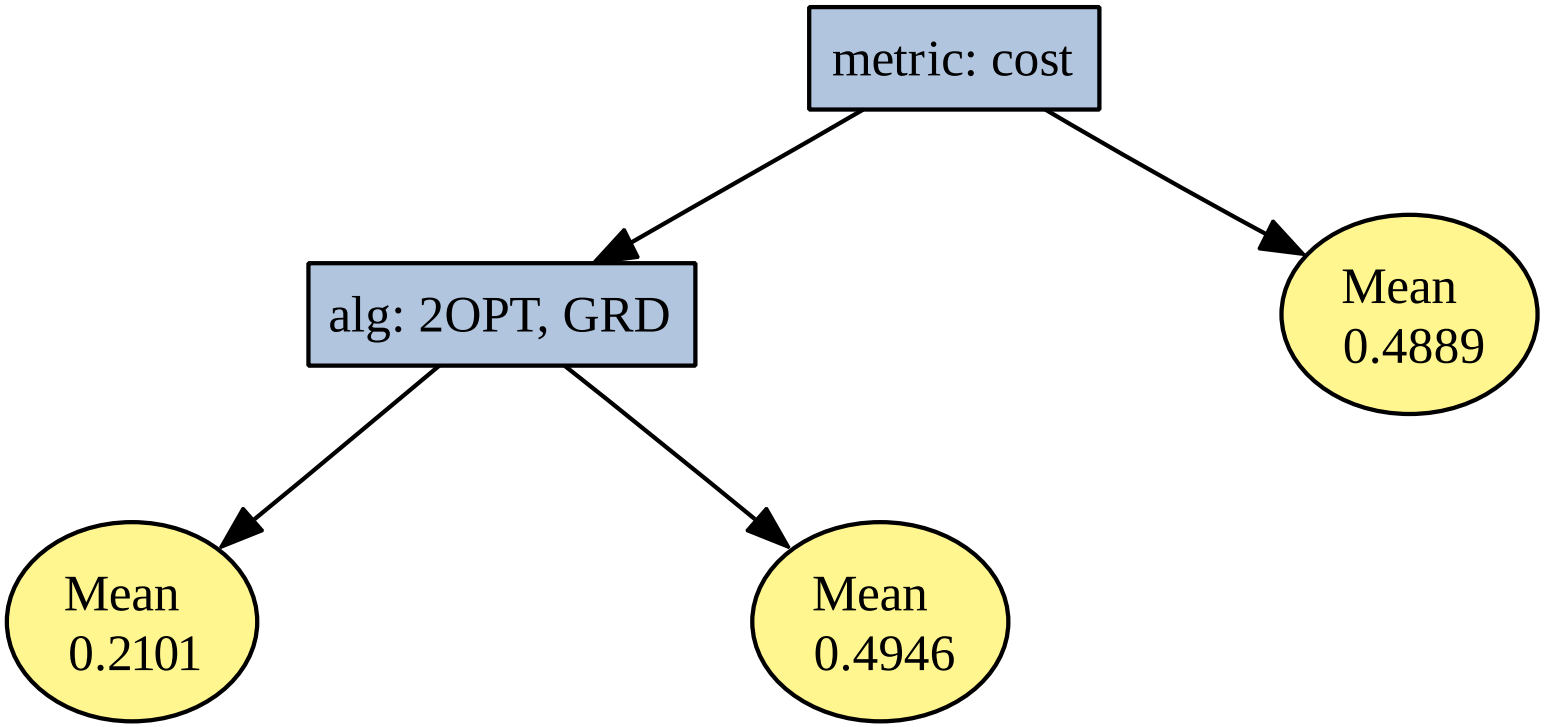
Tree Models: Use recursive partitioning to create hierarchical view of data

Analysis Method: Tree Models



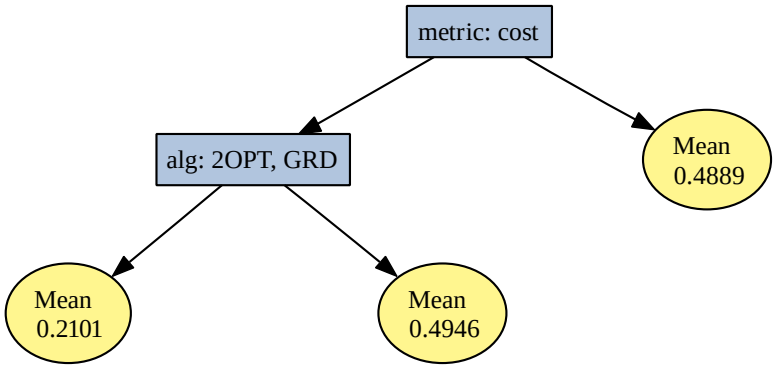
Explanatory Variable: Configuration of the testing methods (e.g., GCM)

Analysis Method: Tree Models



Response Variable: One of the evaluation metrics (e.g., CE or RFFT)

Analysis Method: Random Forests



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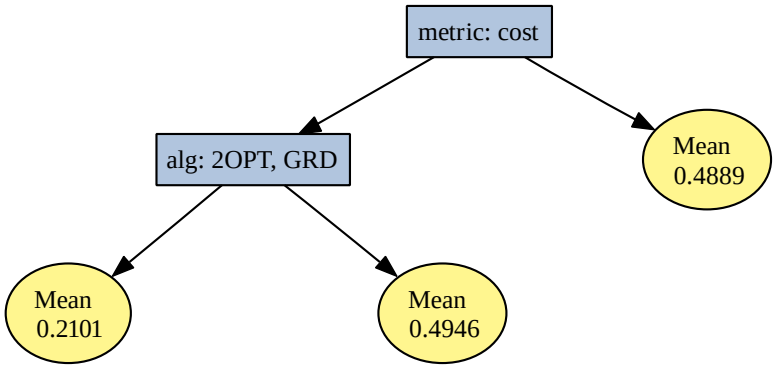

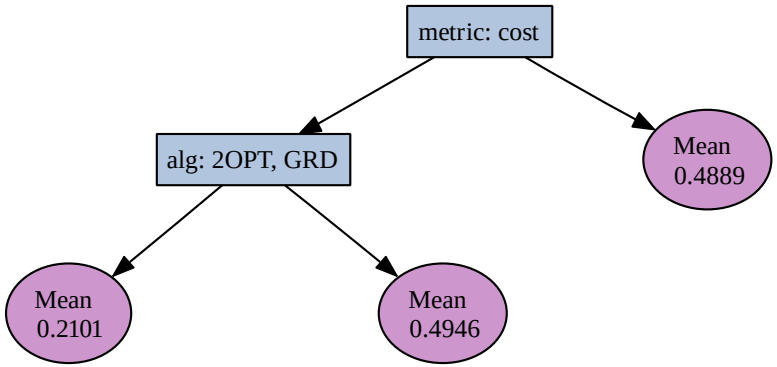

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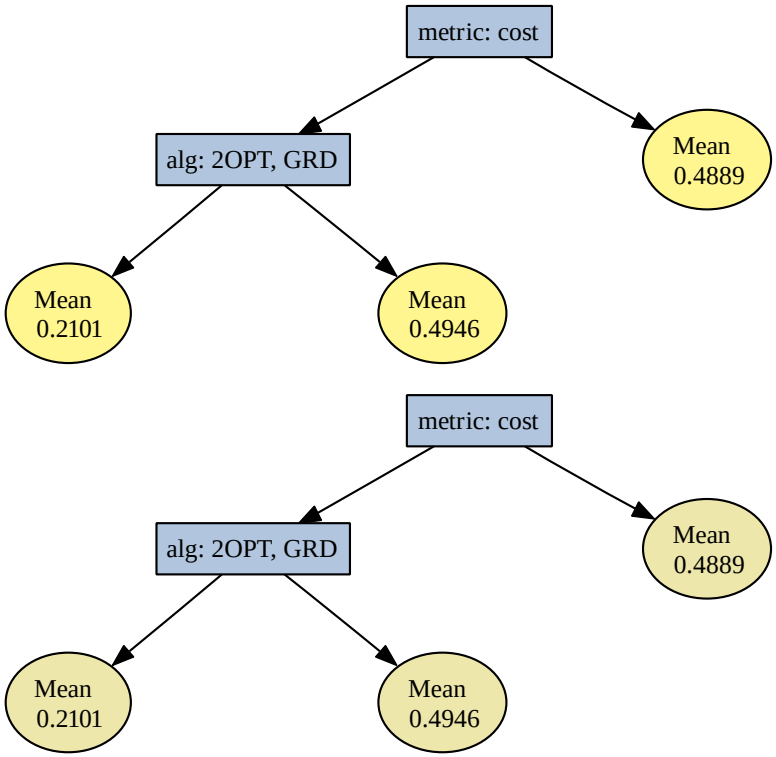

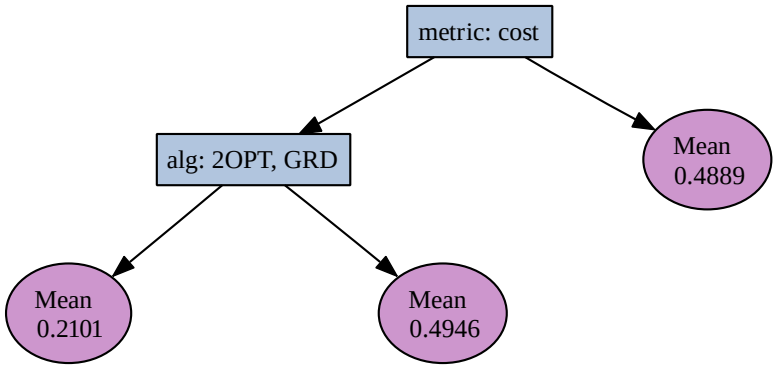

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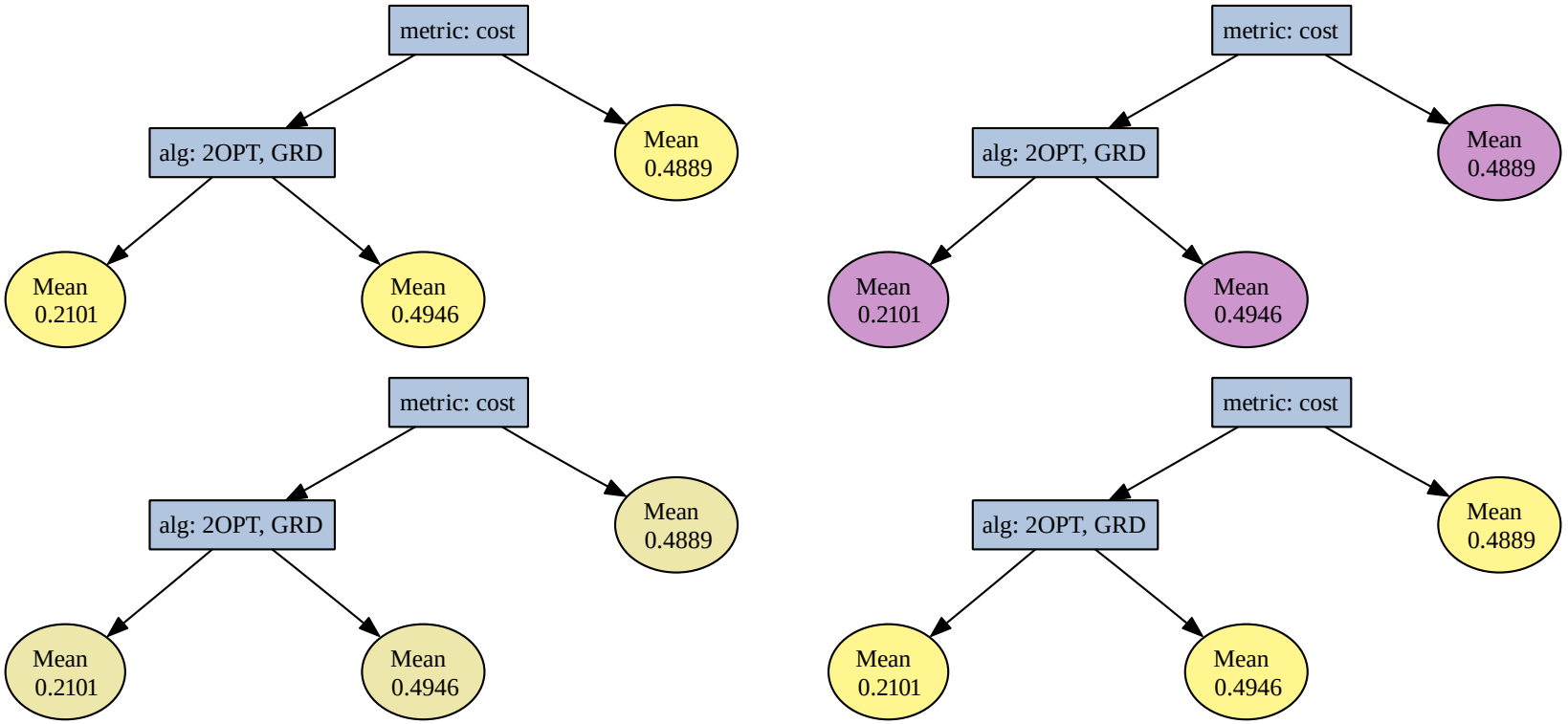

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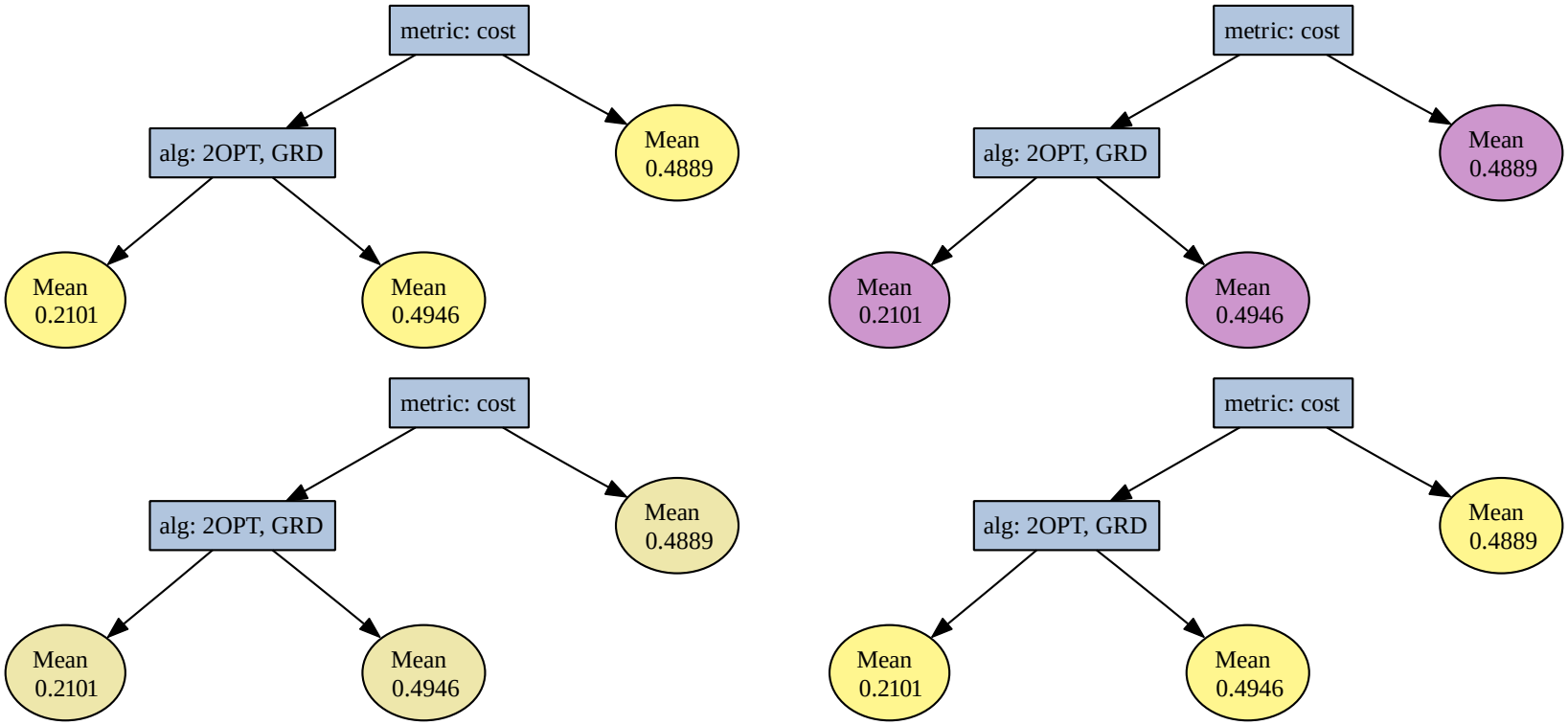

Many Trees: Randomly construct a large collection of trees in order to avoid bias and identify the most important explanatory variables

Case Study Applications

Name	$\|T\|$	$\|\mathcal{R}(T)\|$	CCN	NCSS
DS	110	40	1.35	1243.00
GB	51	88	2.60	1455.00
JD	54	783	1.64	2716.00
LF	13	6	1.40	215.00
RM	13	19	2.13	569.00
SK	27	117	2.00	628.00
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RP	76	221	2.65	6822.00

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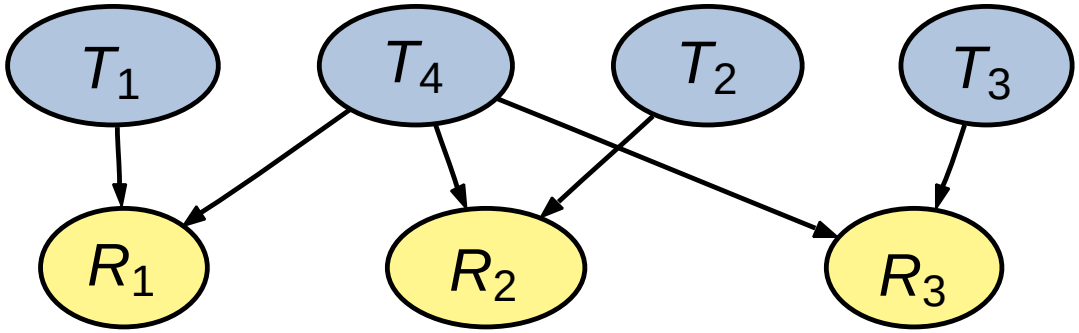
Do the **greedy** reducers and prioritizers efficiently identify test suites that **improve** effectiveness? What are the fundamental **trade-offs**?

"Greedy Fooling" Coverage Generation



Generation Procedure

- The **greedy** test prioritizer iteratively selects test cases according to the **(coverage / cost)** ratio
- **Goal**: generate coverage and timing information that will **fool** the greedy technique into creating $T_p = \langle T_n, \ldots, T_1 \rangle$ even though $CE(T_p) < CE(T)$ for $T = \langle T_1, \ldots, T_n \rangle$
- **Inspiration**: Vazirani's construction of a **tight example** for the greedy **minimal set cover** algorithm

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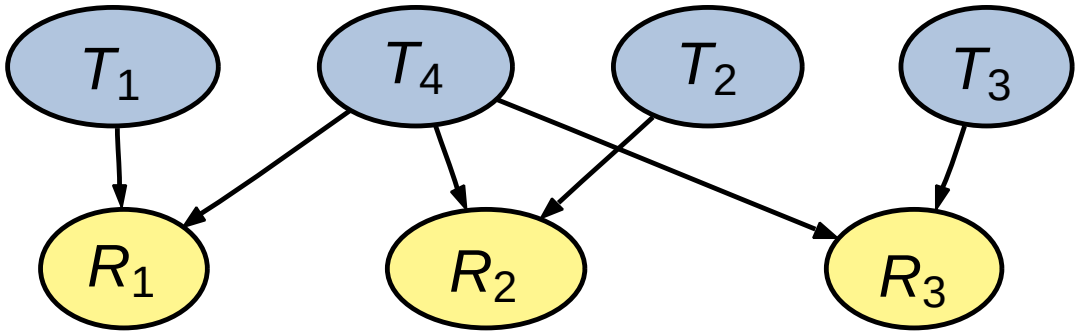

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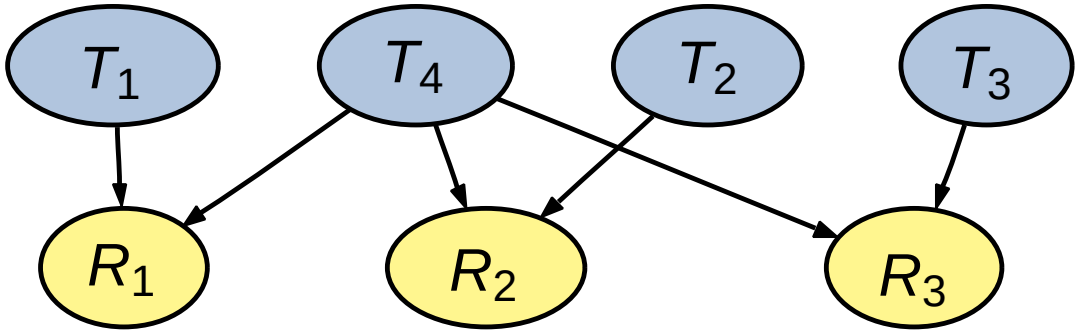

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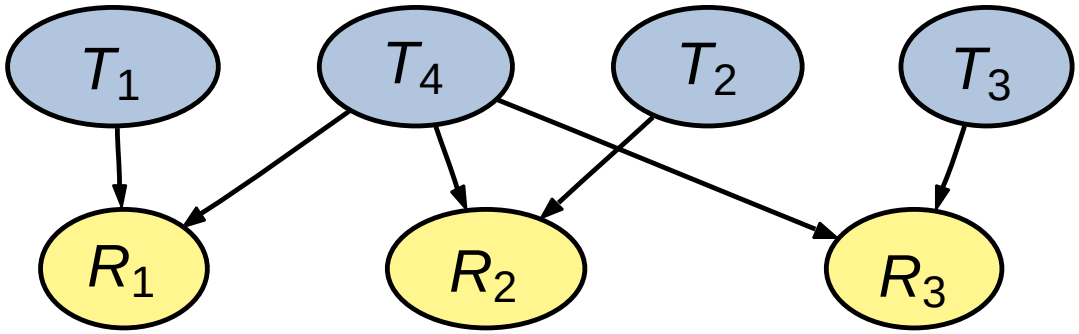
Constructing "Greedy Fooling" Test Suites



- **Approach**: use one dimensional **optimization** (e.g., golden section search and successive parabolic interpolation) to pick a value for $cost(T_n)$
- **Construction**: set $cost(T_1) = cost(T_2) = cost(T_3) = 1$ and then determine the bounds for $cost(T_4) \in [C_{min}, C_{max}]$
- **Example**: $cost(T_4) \in [2.138803, 2.472136]$ so that
  $CE_{min}(T_p) = .5838004 \quad CE_{min}(T) = .6108033$
  $CE_{max}(T_p) = .5482172 \quad CE_{max}(T) = .6345125$

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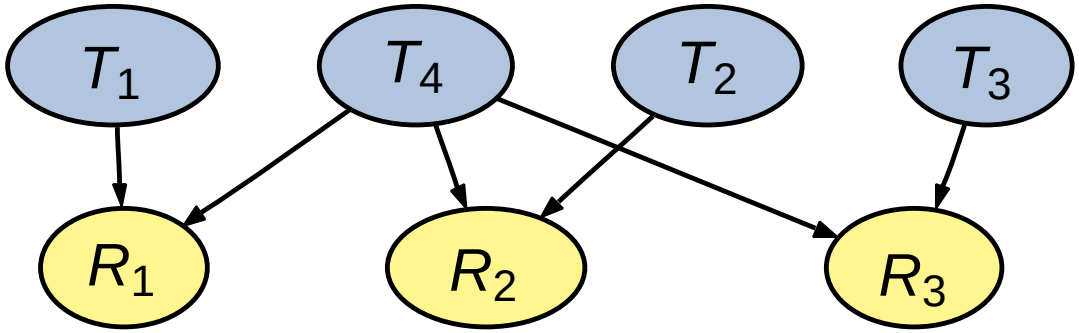

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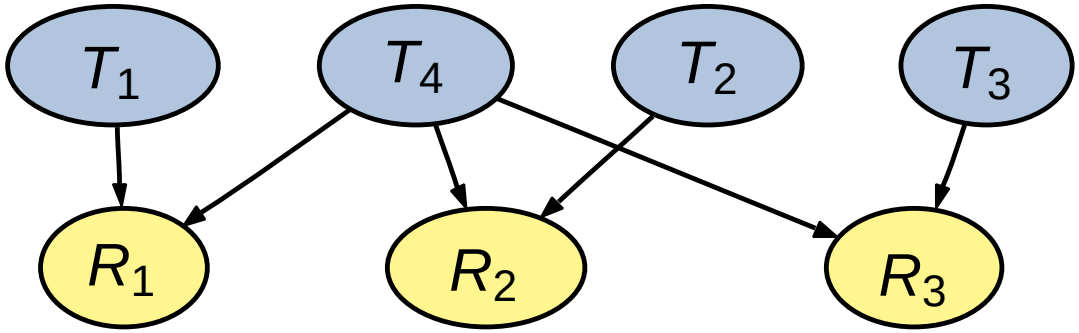

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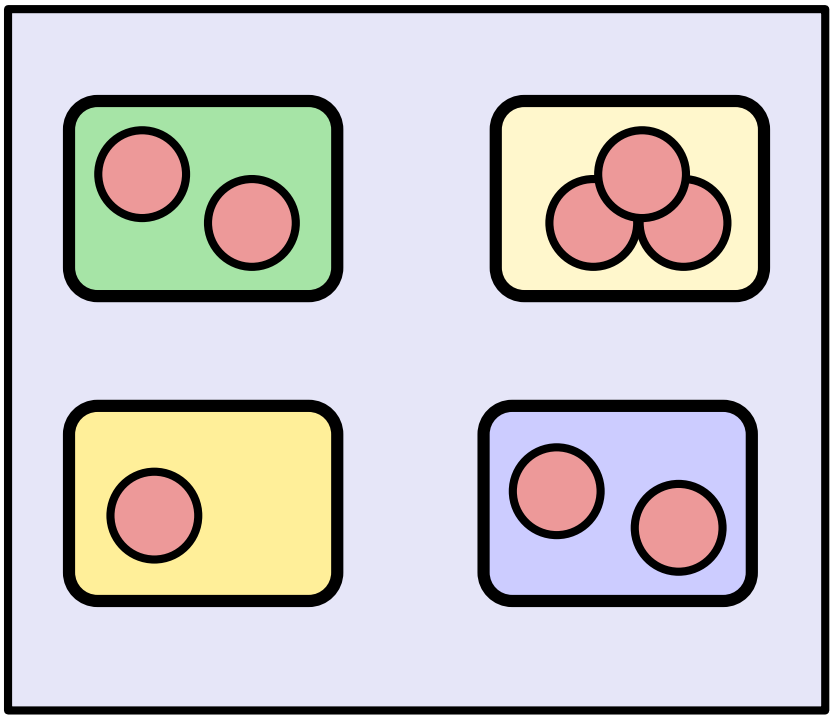
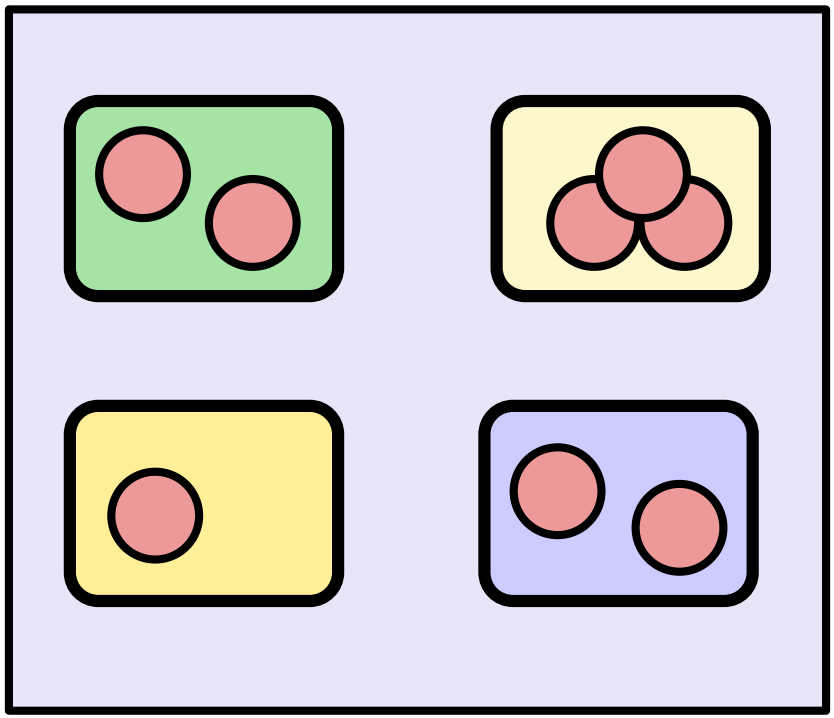
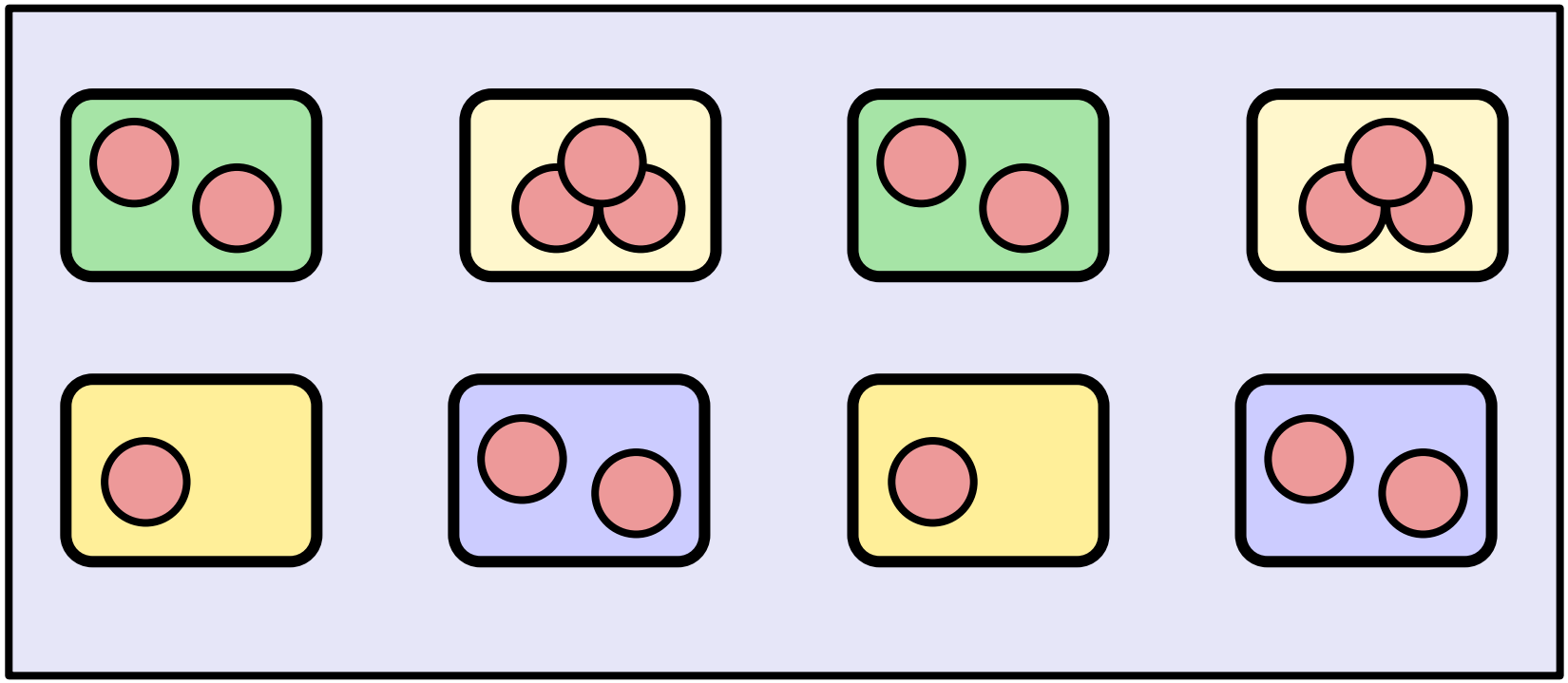
Constructing Build/Test Machine Suites





Objective: Simulate test suite execution on a centralized server

Constructing Build/Test Machine Suites



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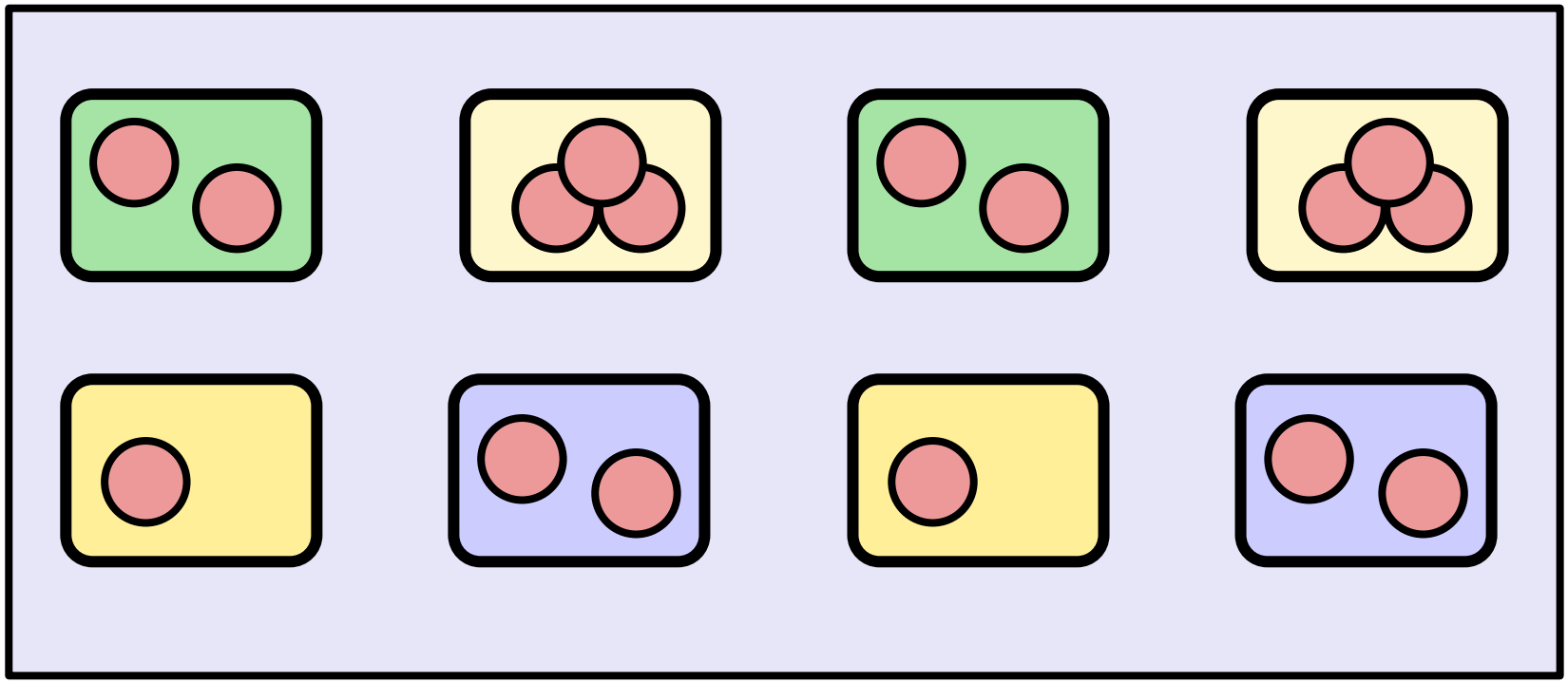

Construction: Combine all of the test suites and coverage reports

Random Test Suite Prioritization

Random Number	Input	Output
$\{1,2,3,4\}$ 2	$\langle t_1, t_2, t_3, \lvert t_4 \rangle$	$\langle t_1, t_4, t_3, t_2 \rangle$
$\{1,2,3\}$ 3	$\langle t_1, t_4, \lvert t_3, t_2 \rangle$	$\langle t_1, t_4, t_3, t_2 \rangle$
$\{1,2\}$ 1	$\langle t_1, \lvert t_4, t_3, t_2 \rangle$	$\langle t_4, t_1, t_3, t_2 \rangle$

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Importance: Random prioritization serves as a valuable experimental control and often produces orderings better than the initial suite

Random Test Suite Prioritization

Random Number	Input	Output
$\{1,2,3,4\}$ 2	$\langle t_1, t_2, t_3, \vert t_4 \rangle$	$\langle t_1, t_4, t_3, t_2 \rangle$
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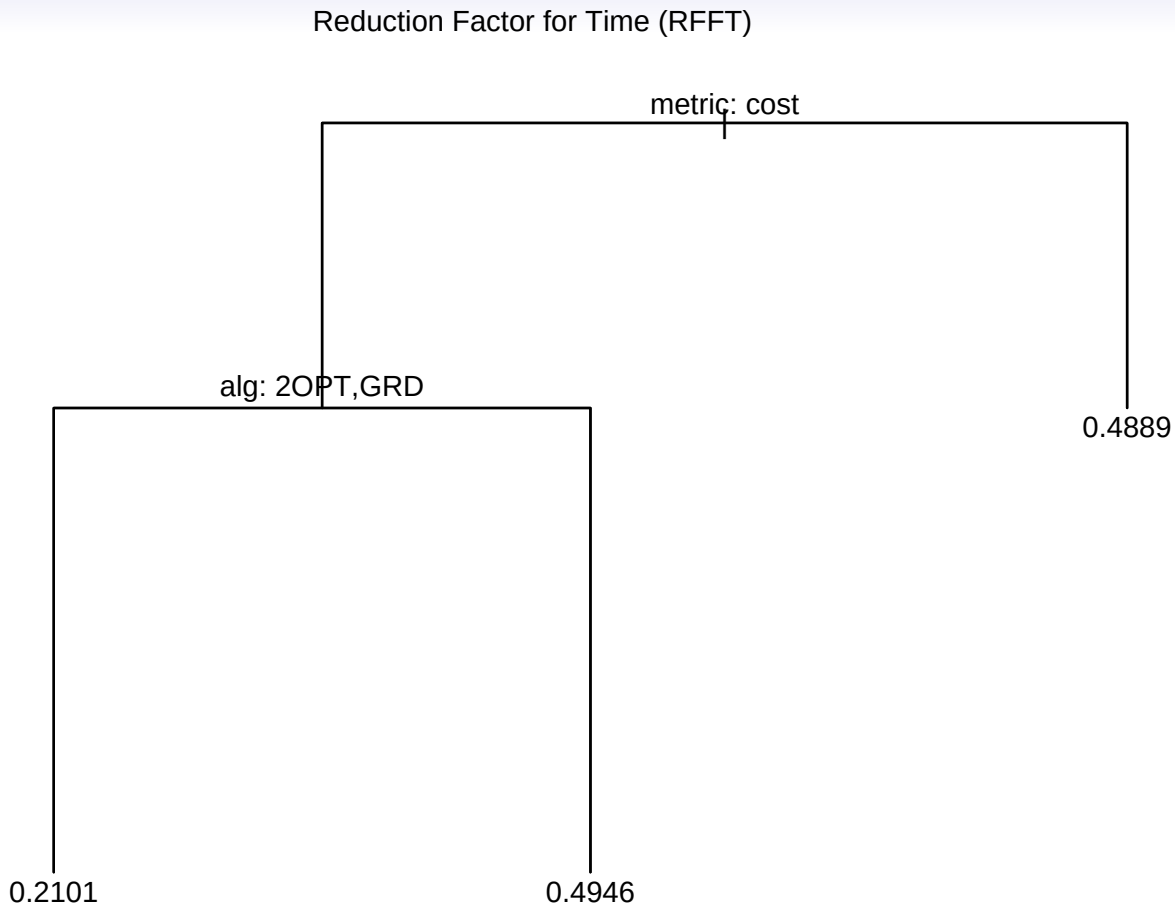
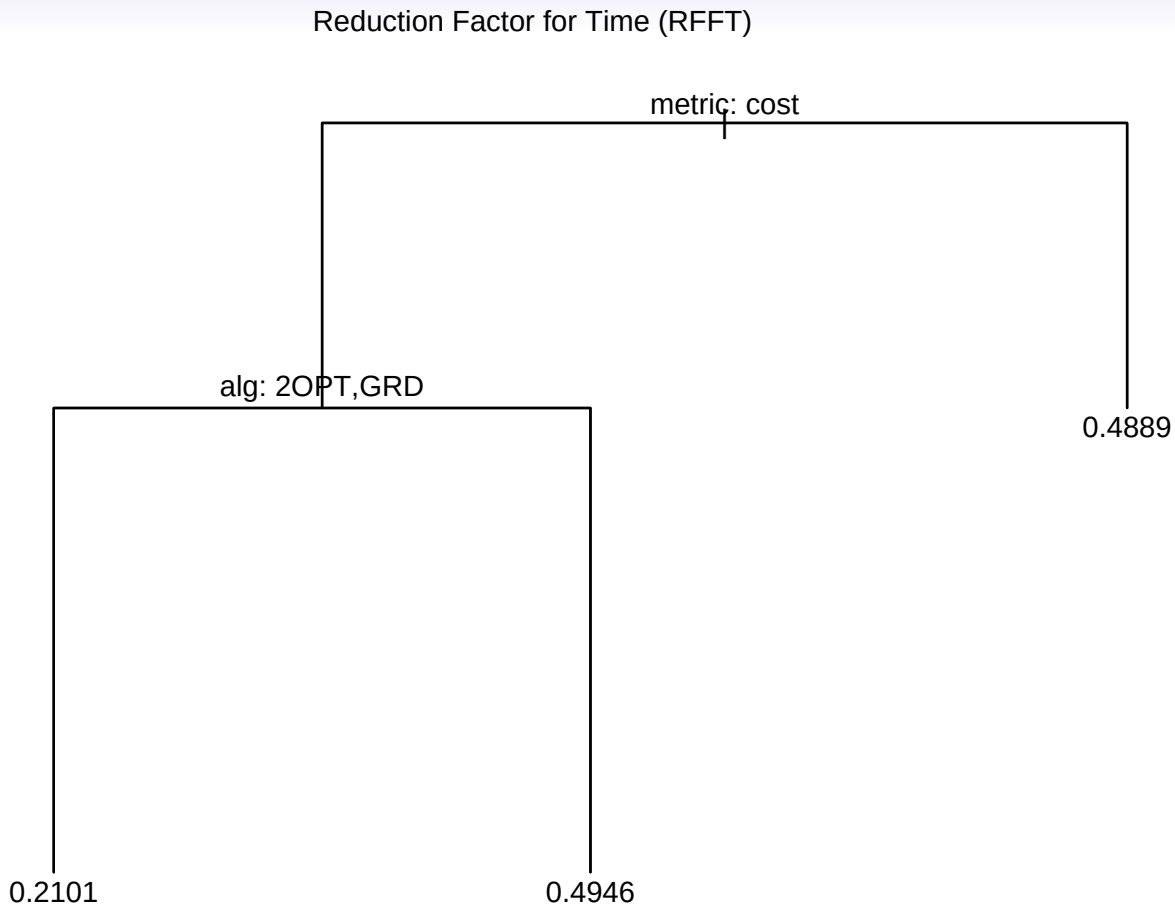
Strategy: Use the modern and efficient implementation of the Fisher-Yates shuffle to produce the reordered test suite $T_p = \langle t_4, t_1, t_3, t_2 \rangle$

Overview of RFFT Trends



The myopic focus on **cost** leads to **low** RFFT values for 2OPT and GRD

Overview of RFFT Trends



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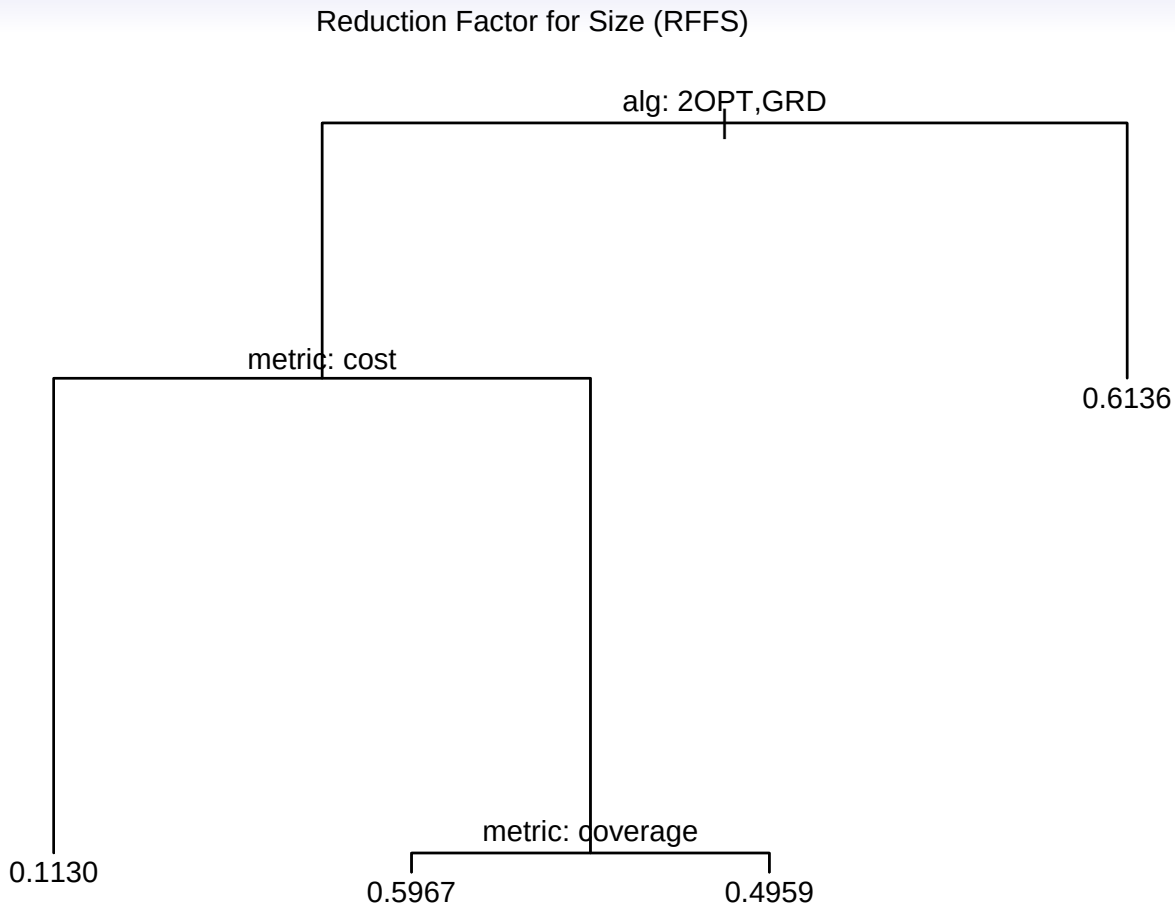
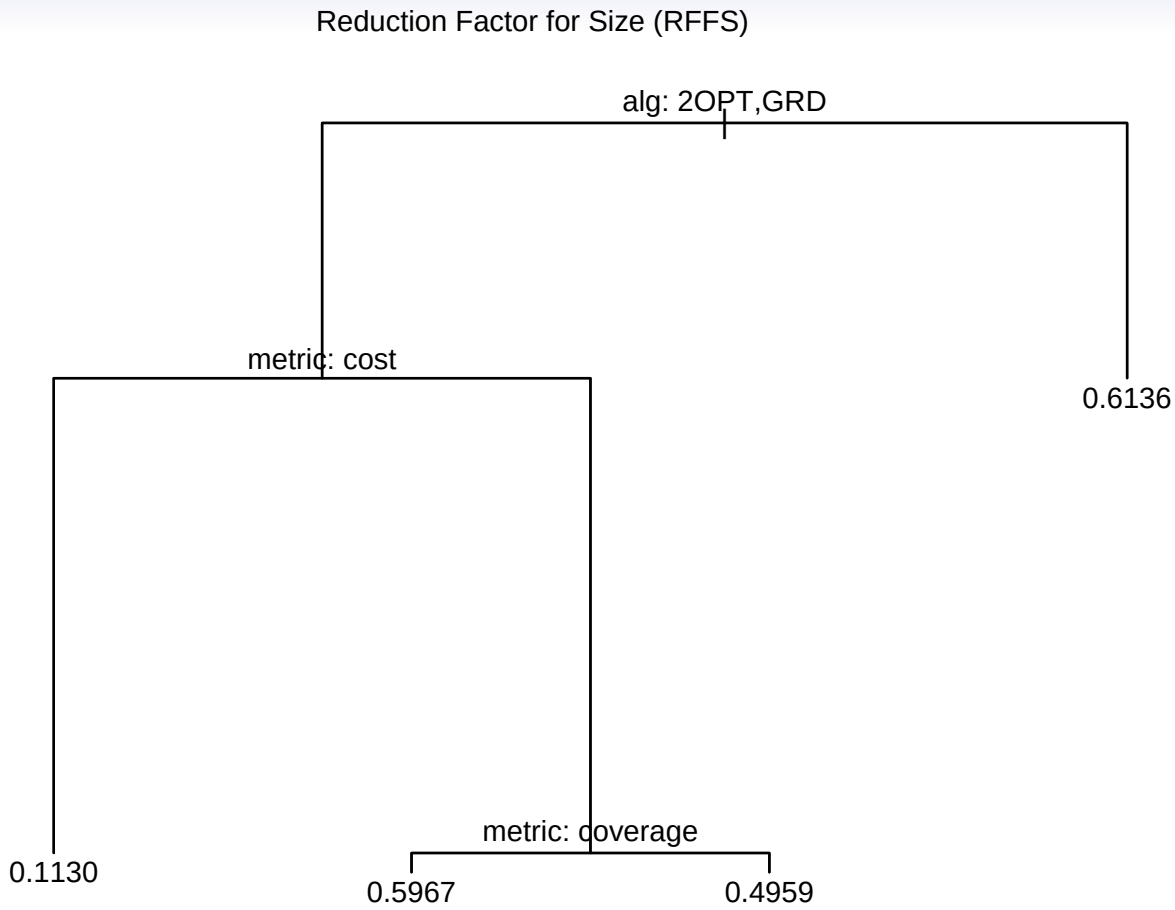
Overview of RFFS Trends



DGR and HGS are the **best** at creating test suites that **improve** RFFS

Overview of RFFS Trends



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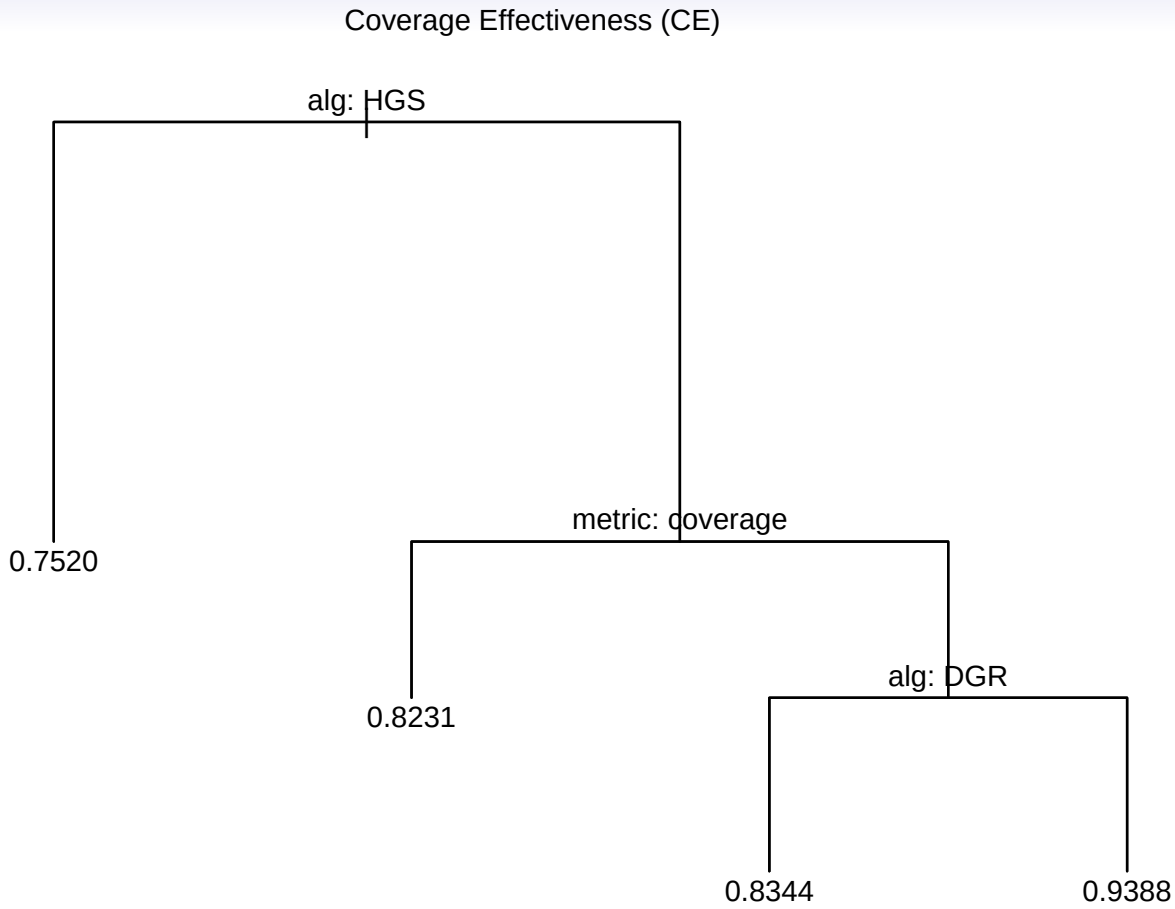
Overview of CE Trends



Using **ratio** and **cost** improves the CE of the prioritized test suite

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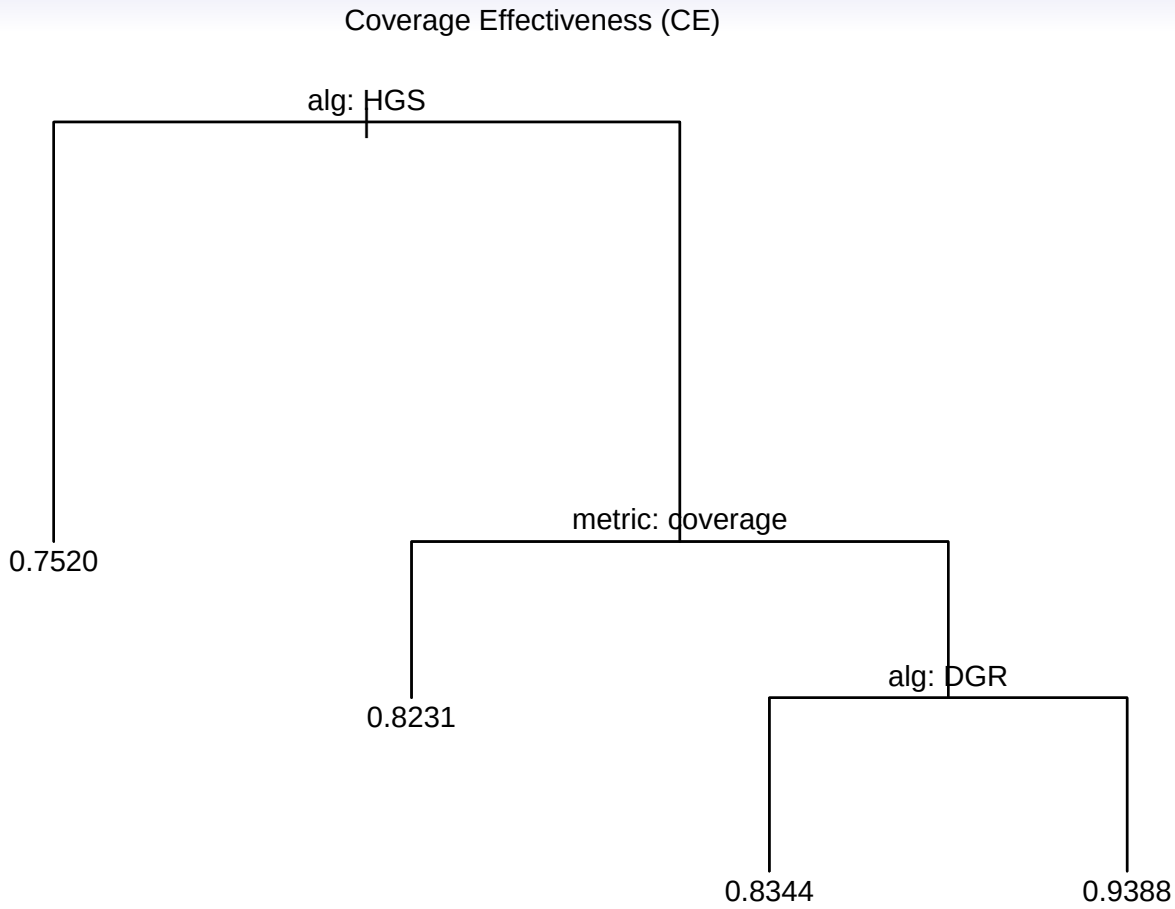

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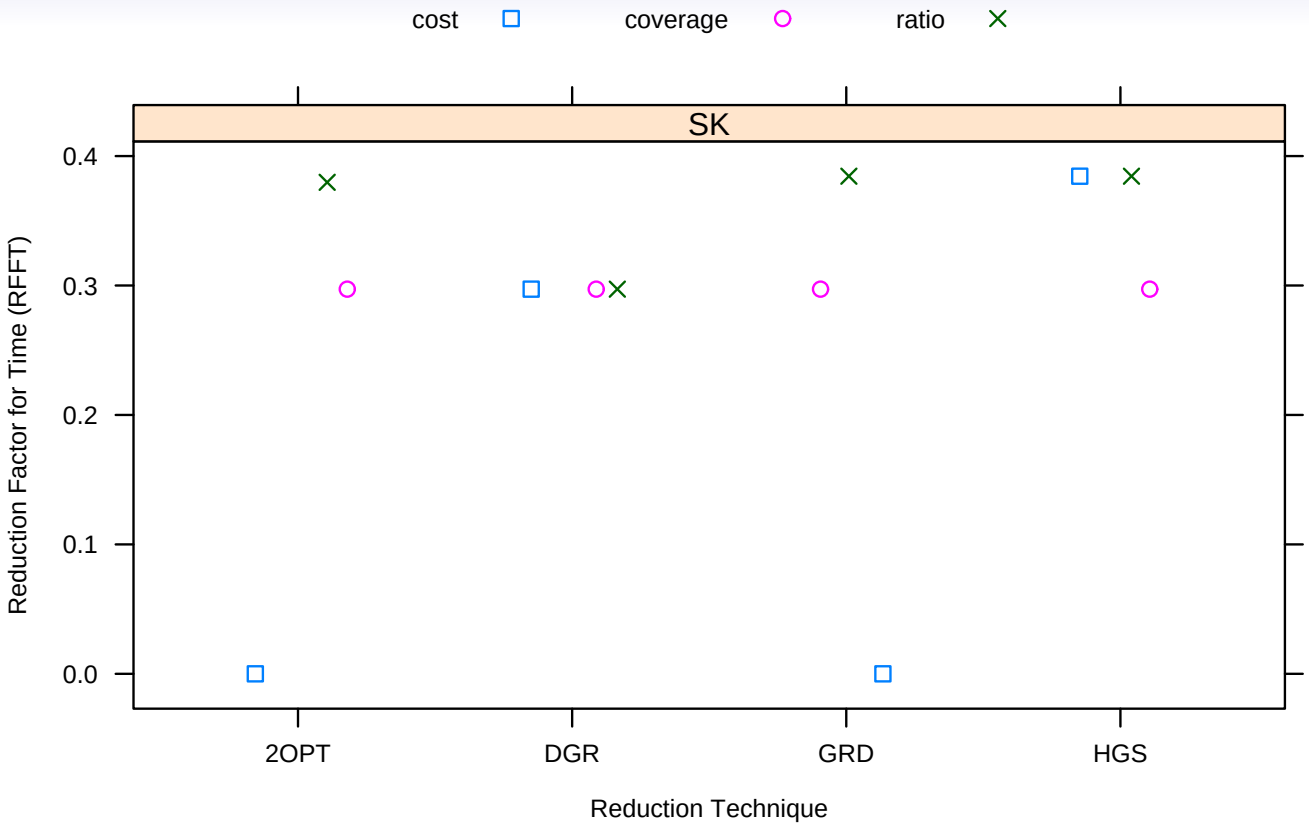
Reduction Factor for Time - SK



For 2OPT and GRD, **ratio** and **coverage** create the best test suites

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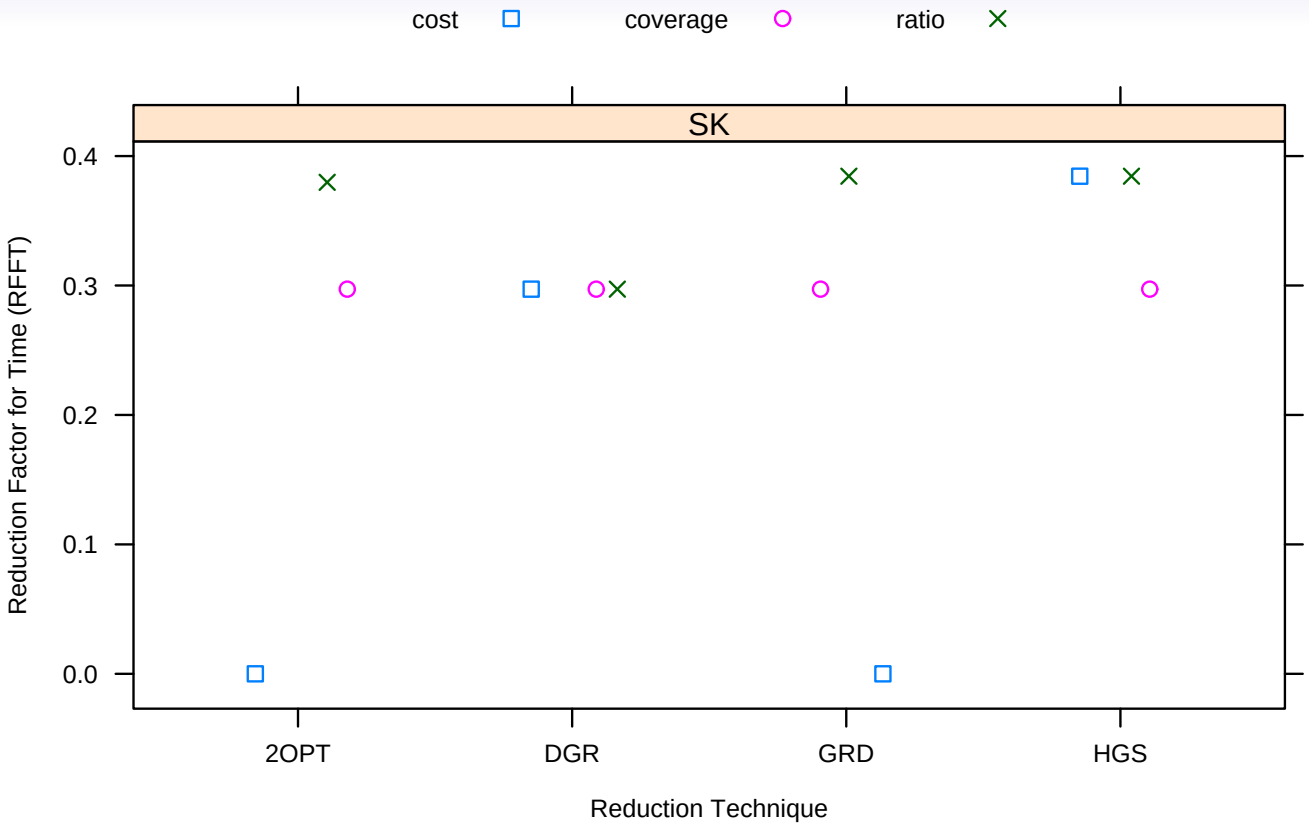

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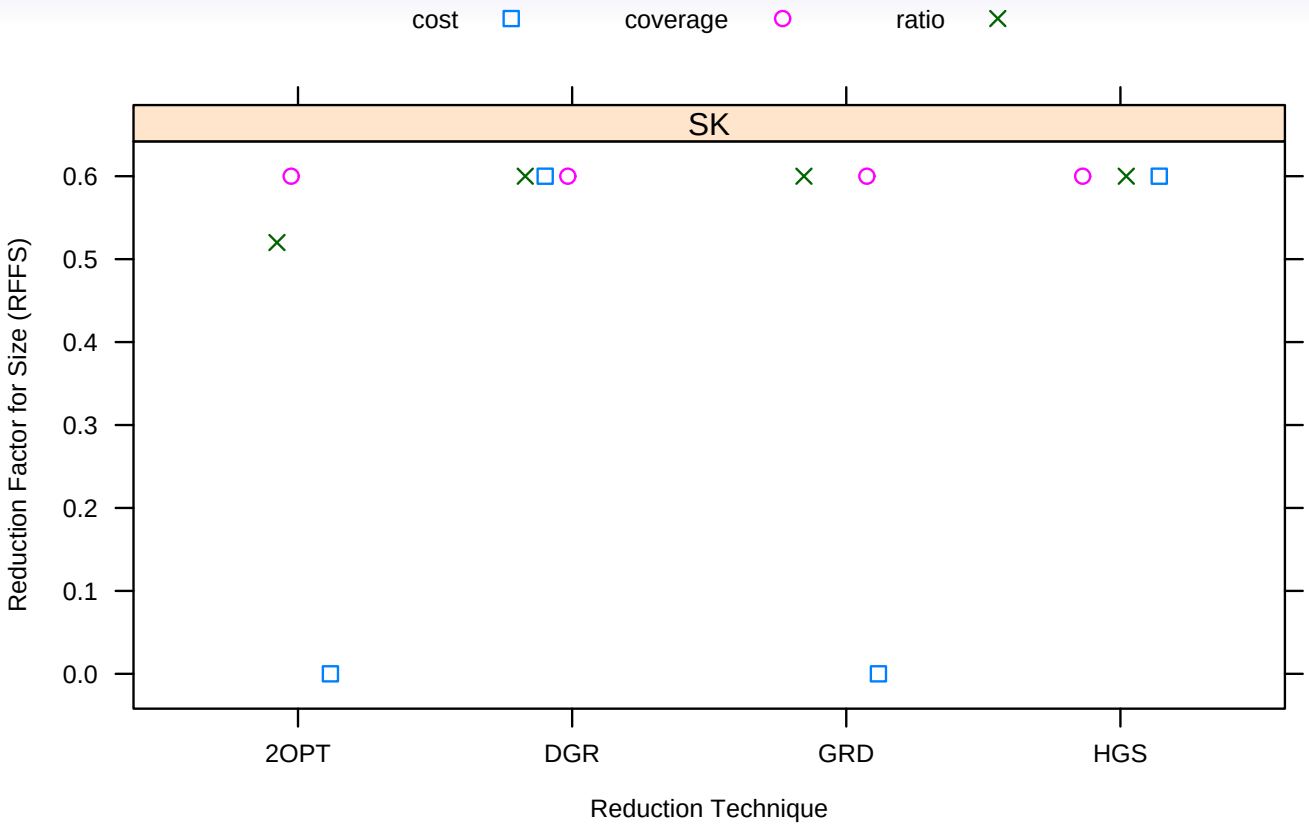

It is often **easy** to construct test suites with **high** RFFS values

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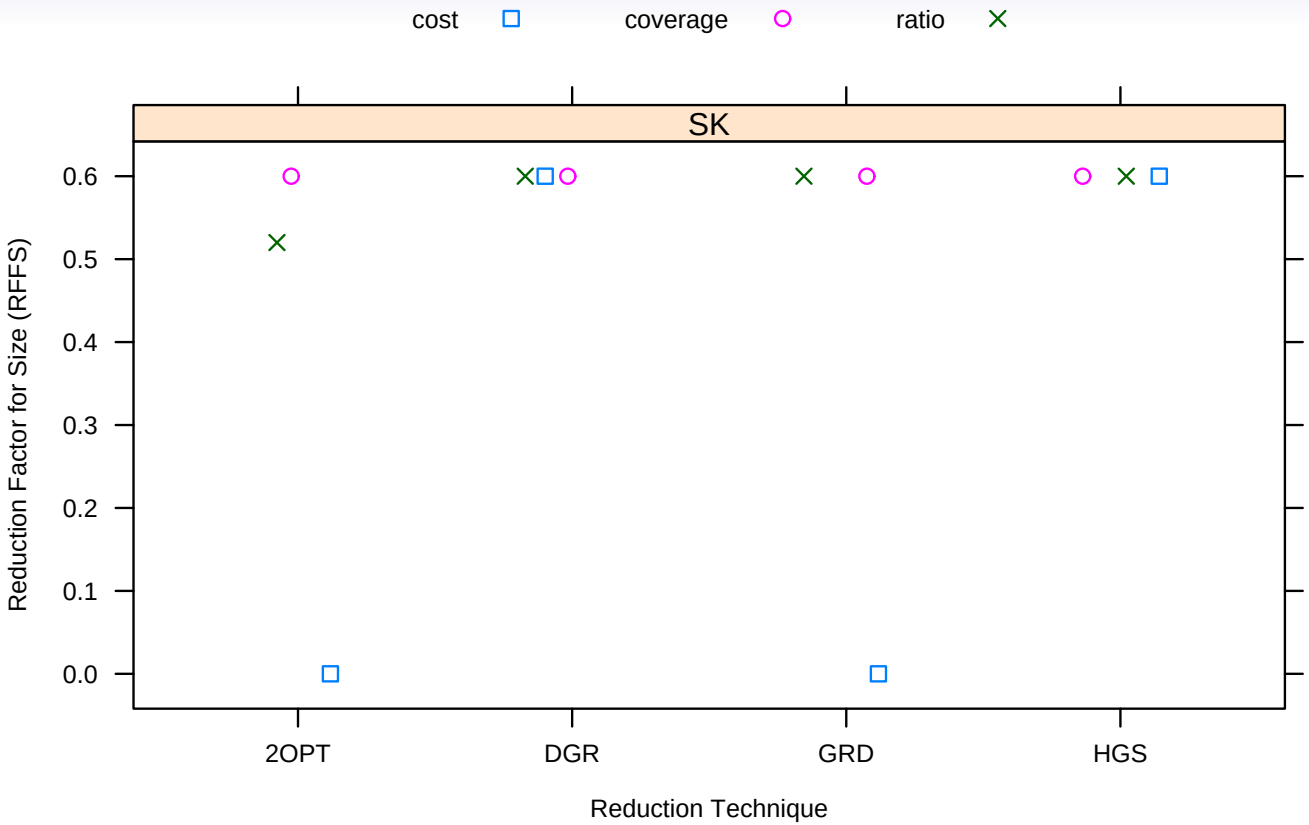

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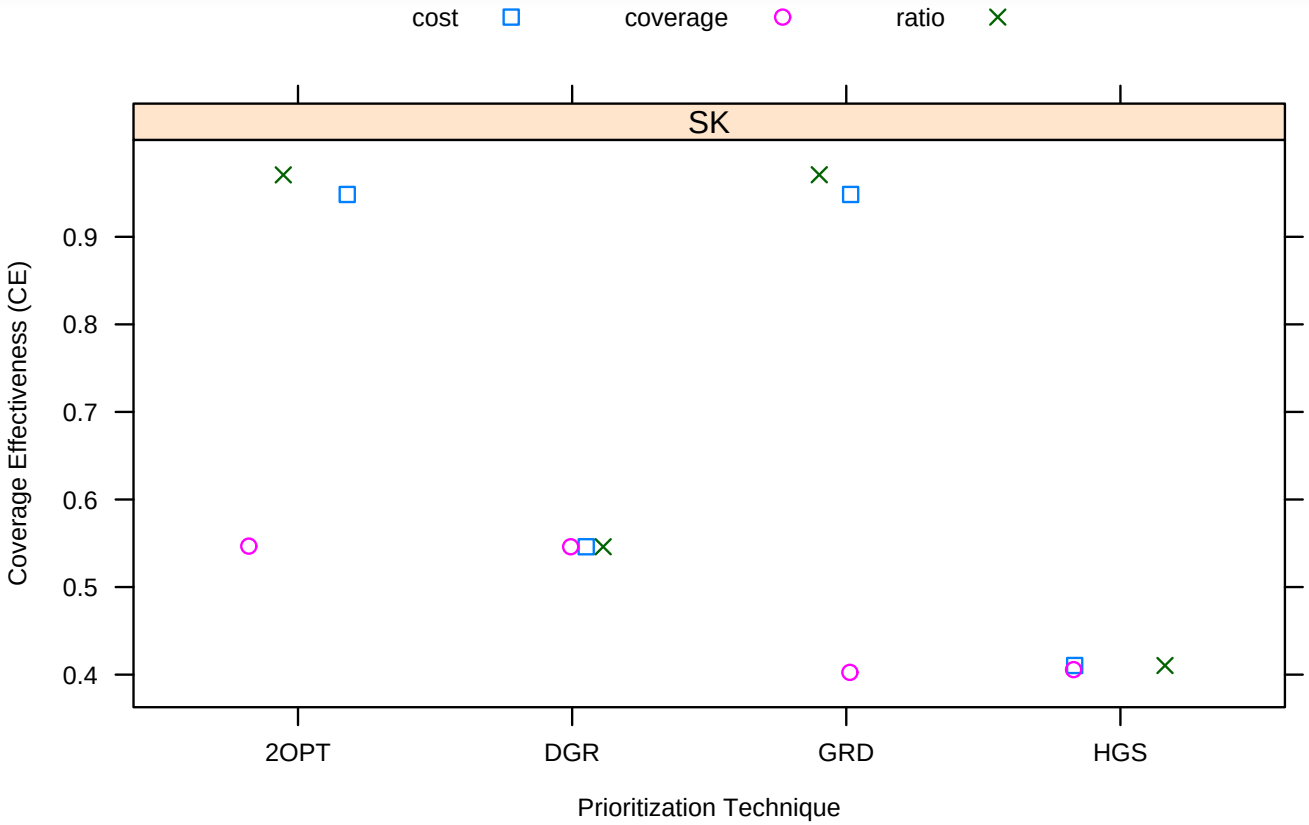
Coverage Effectiveness Results - RP



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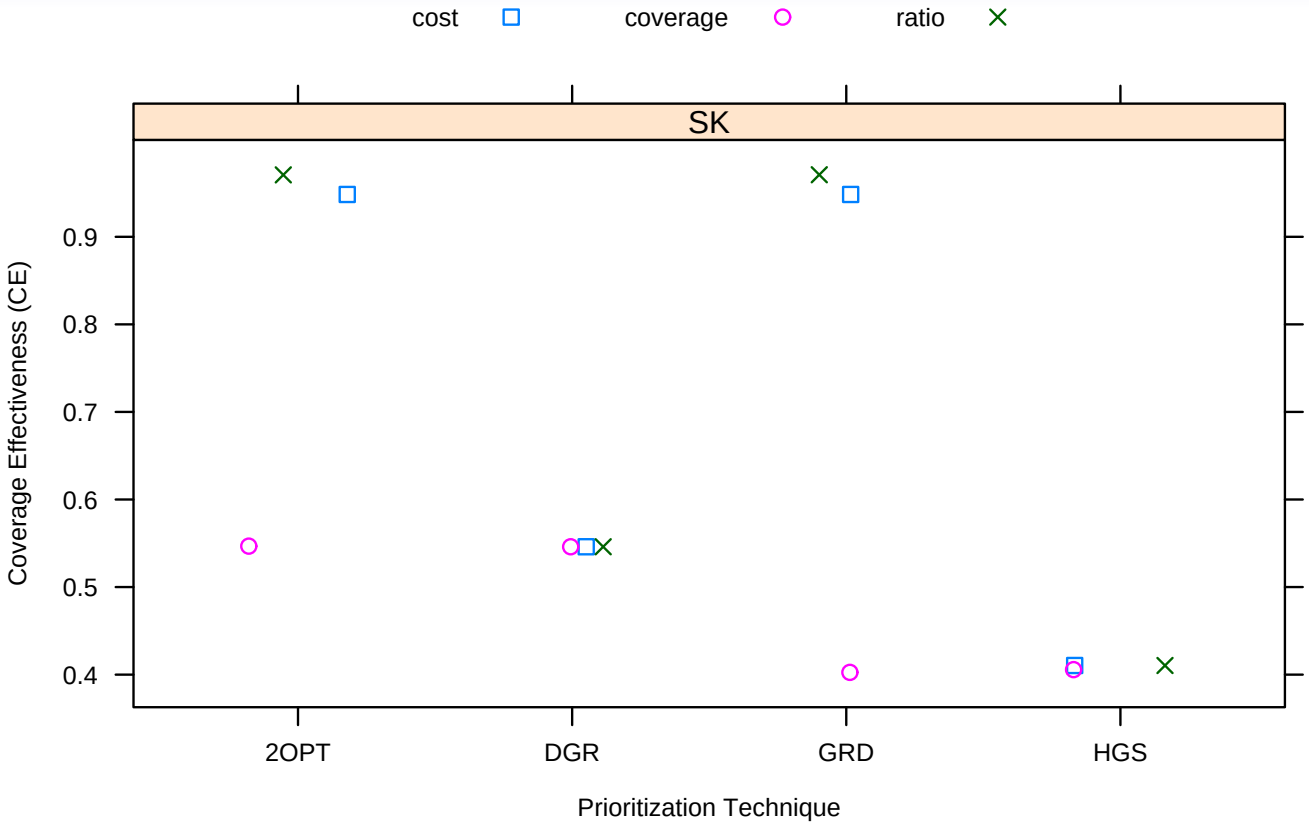
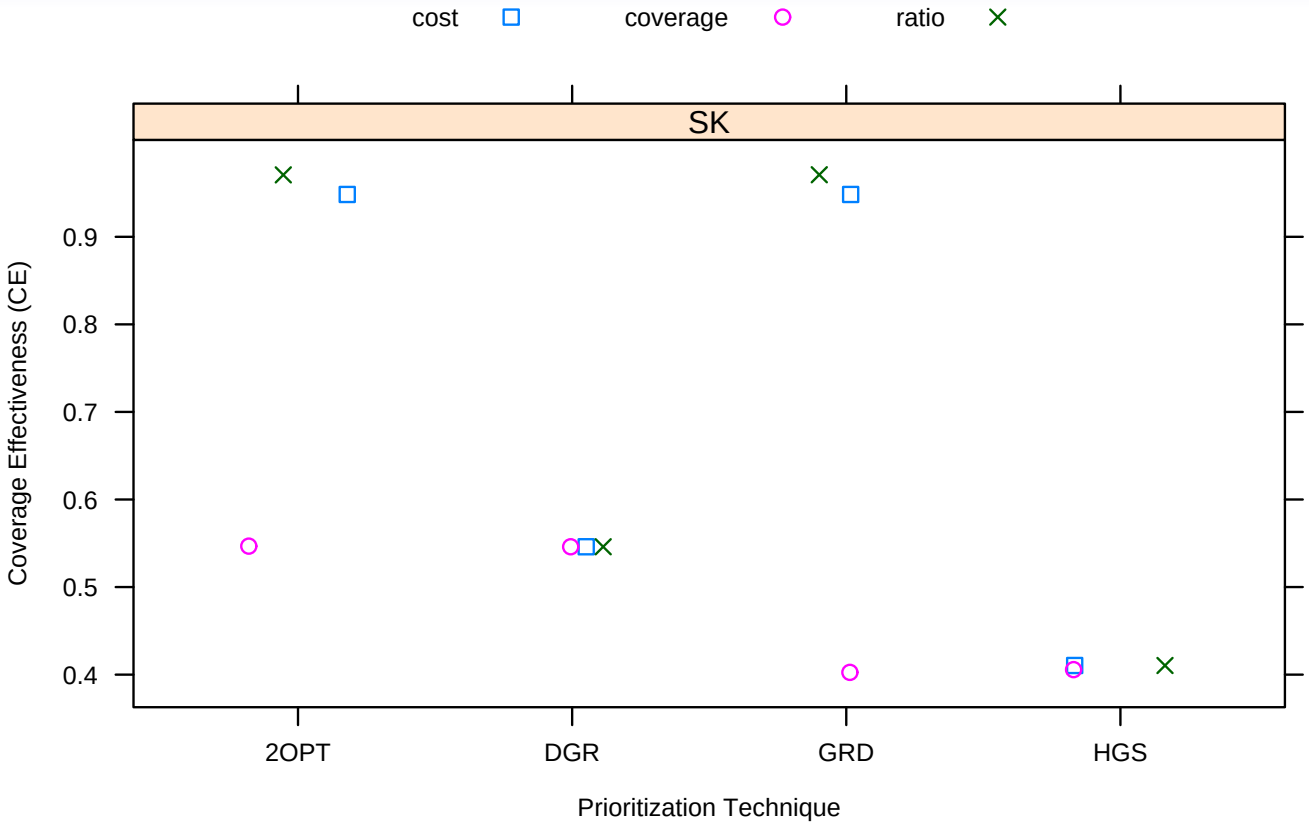


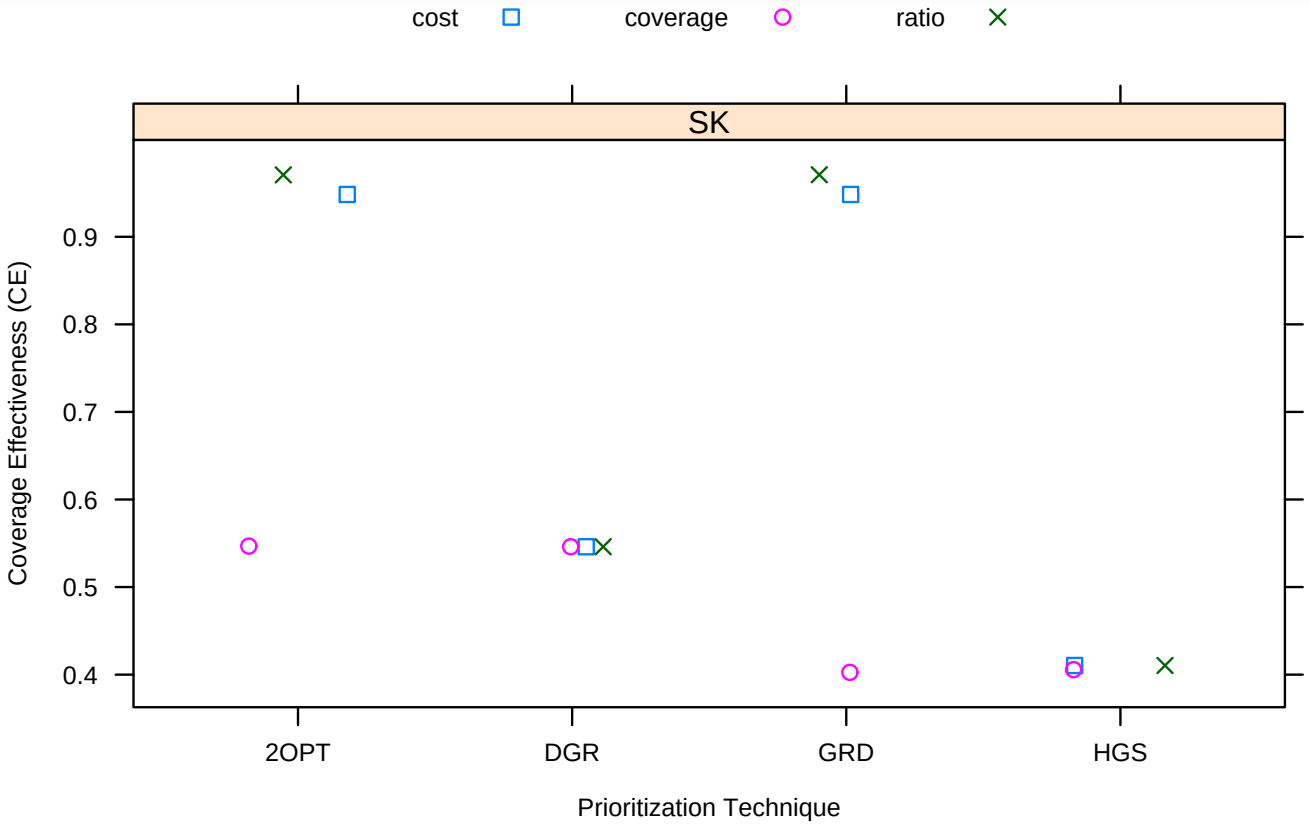
DGR and HGS exhibit **lackluster** performance when **reordering**

Coverage Effectiveness Results - RP



Greedily reordered test suites are **better** than randomly prioritized ones

Coverage Effectiveness Results - RP



Greedy fooling test suites cause GRD and DGR to make **low** CE suites

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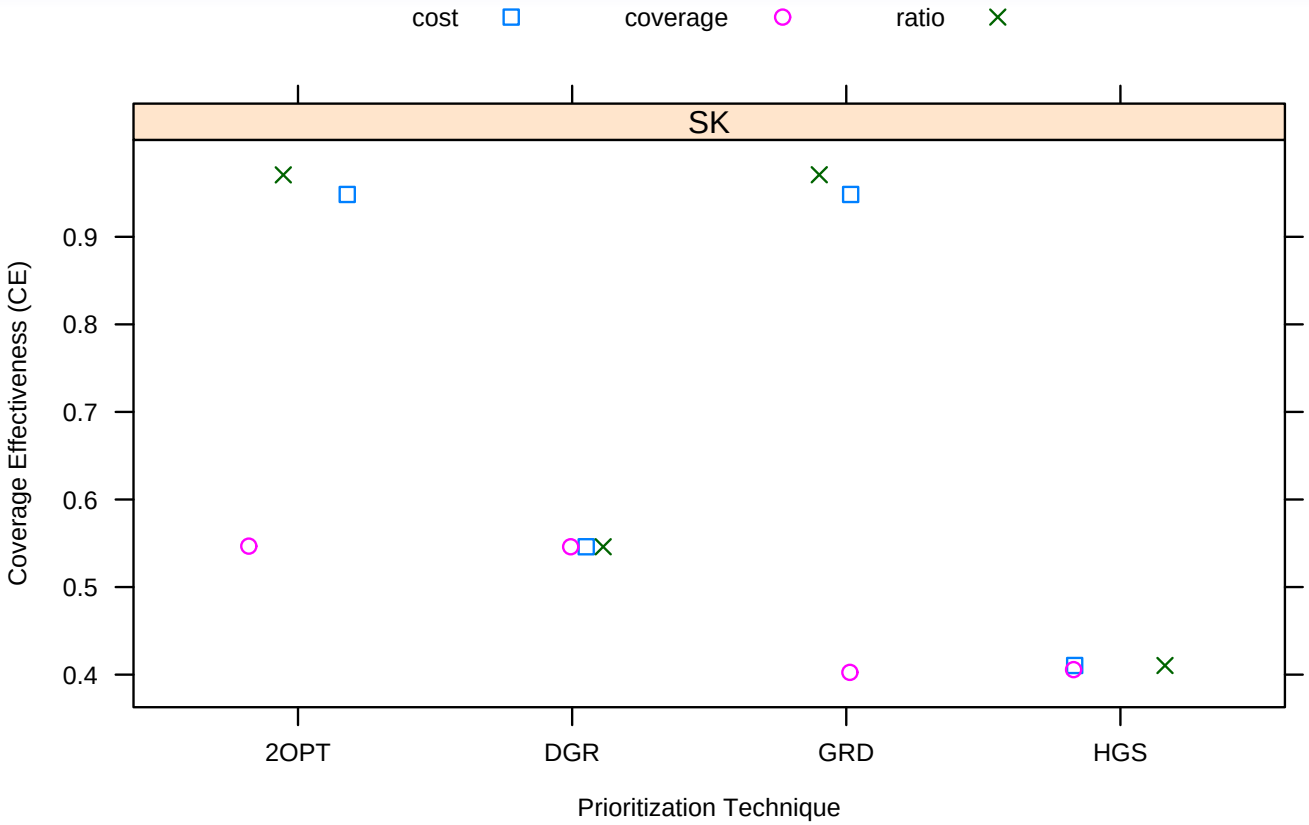

2OPT uses **lookahead** and can construct high CE test prioritizations

Common Rate Scores

Application	*CommonRate*(Υ)
Reminder	0.700
ReduceAndPrioritize	0.361
Sudoku	0.571
TransactionManager	0.450
DataStructures	0.171
GradeBook	0.747
JDepend	0.606
LoopFinder	0.500
Average	0.513

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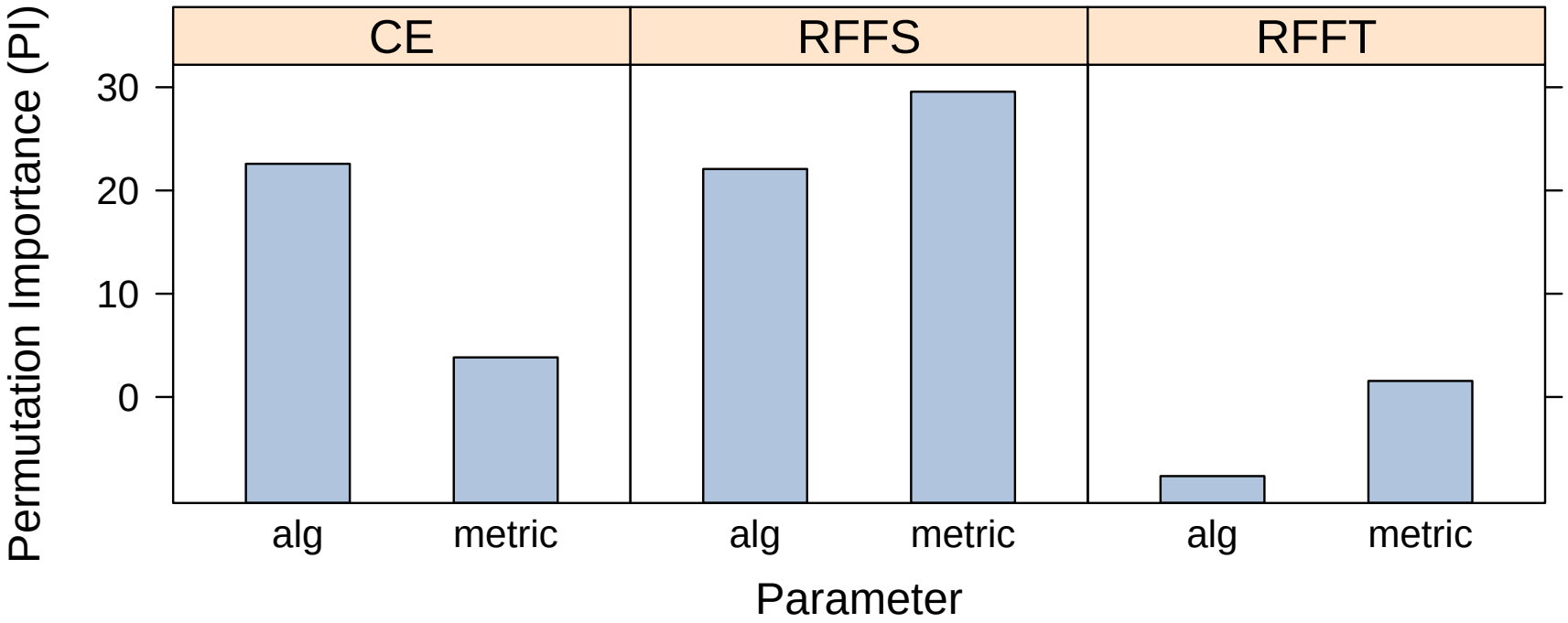
Value of the common rate is relatively **stable** across methods

Parameter Importance Values



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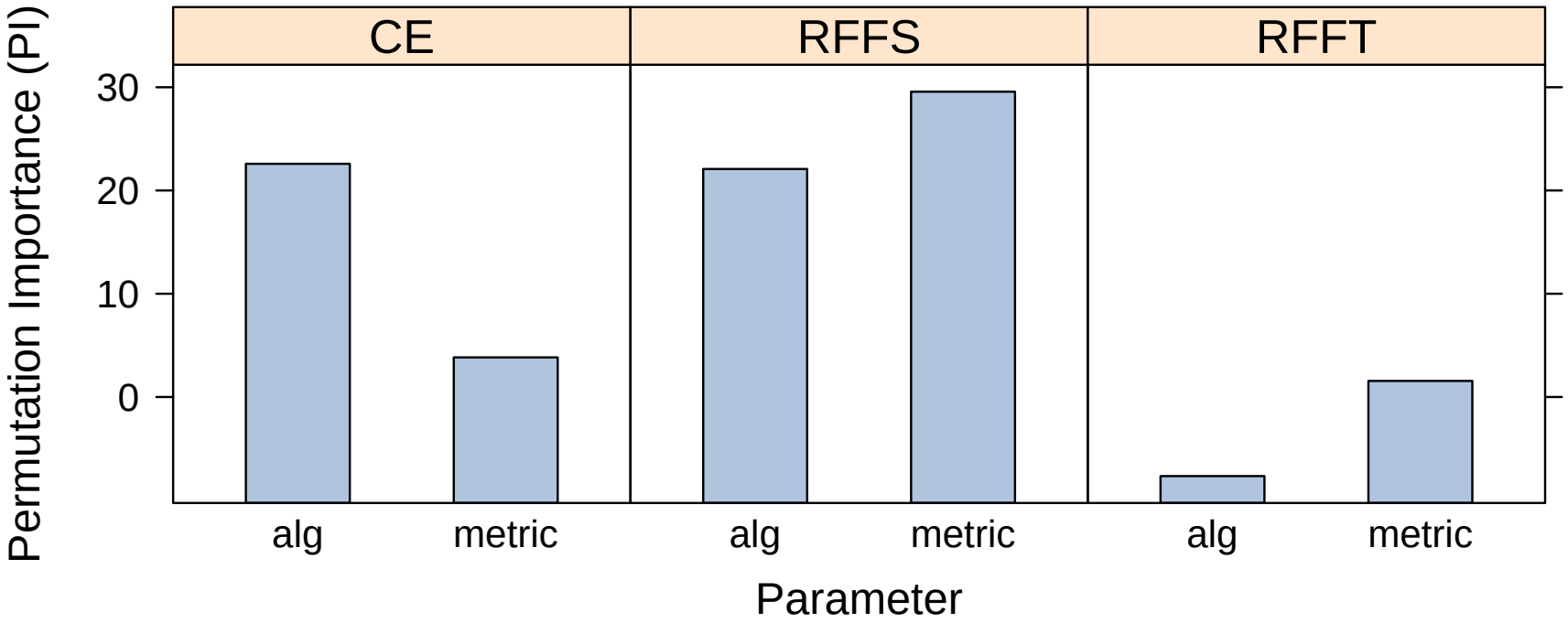

Algorithm choice is most important for improving the CE of ordering

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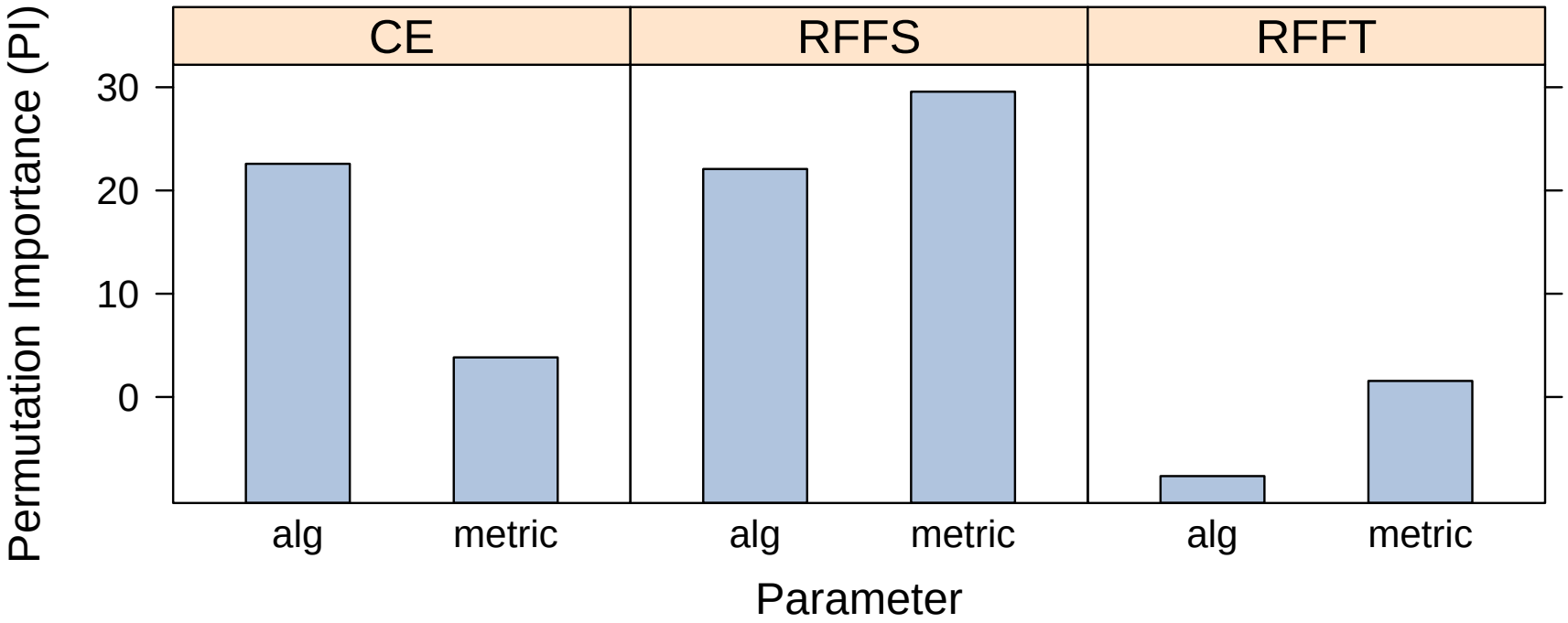
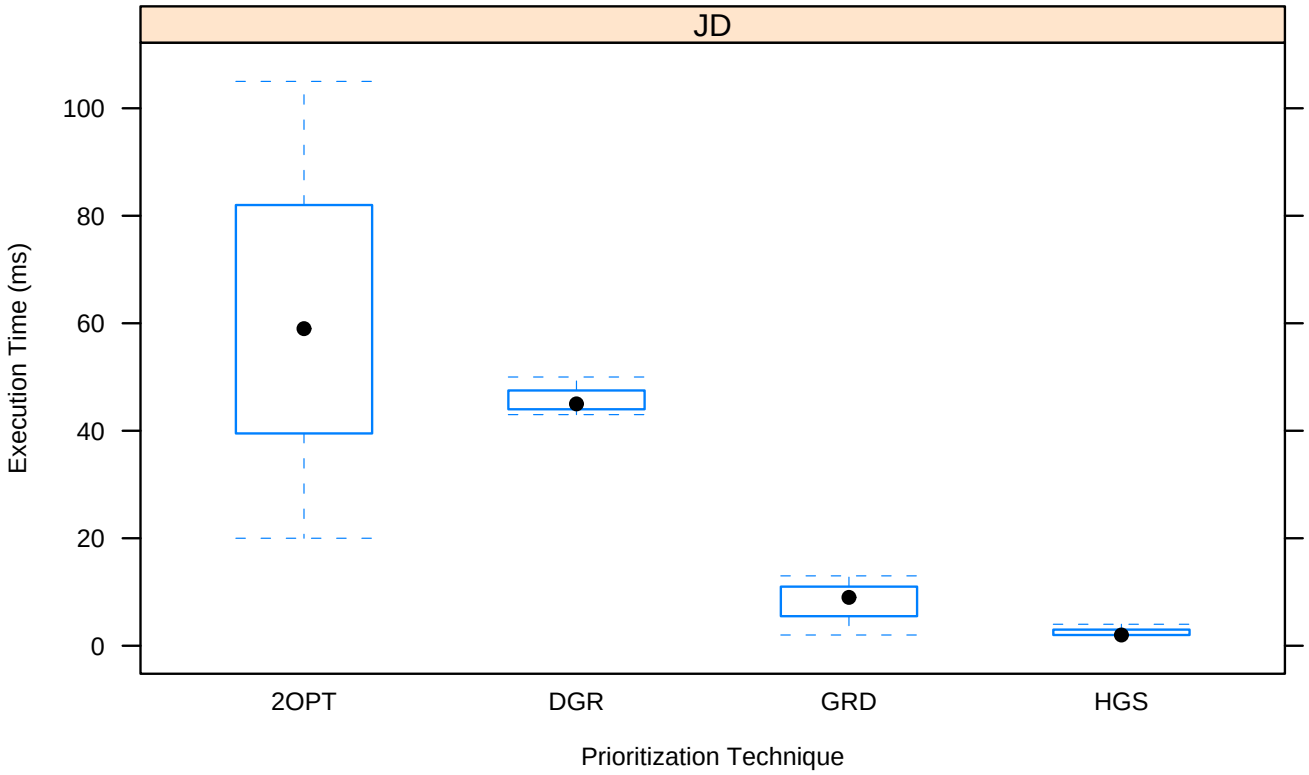


Greedy choice **metric** has the greatest impact on the test suite reducers

Efficiency Measurements



For the **chosen** case study applications, the techniques are **fast**

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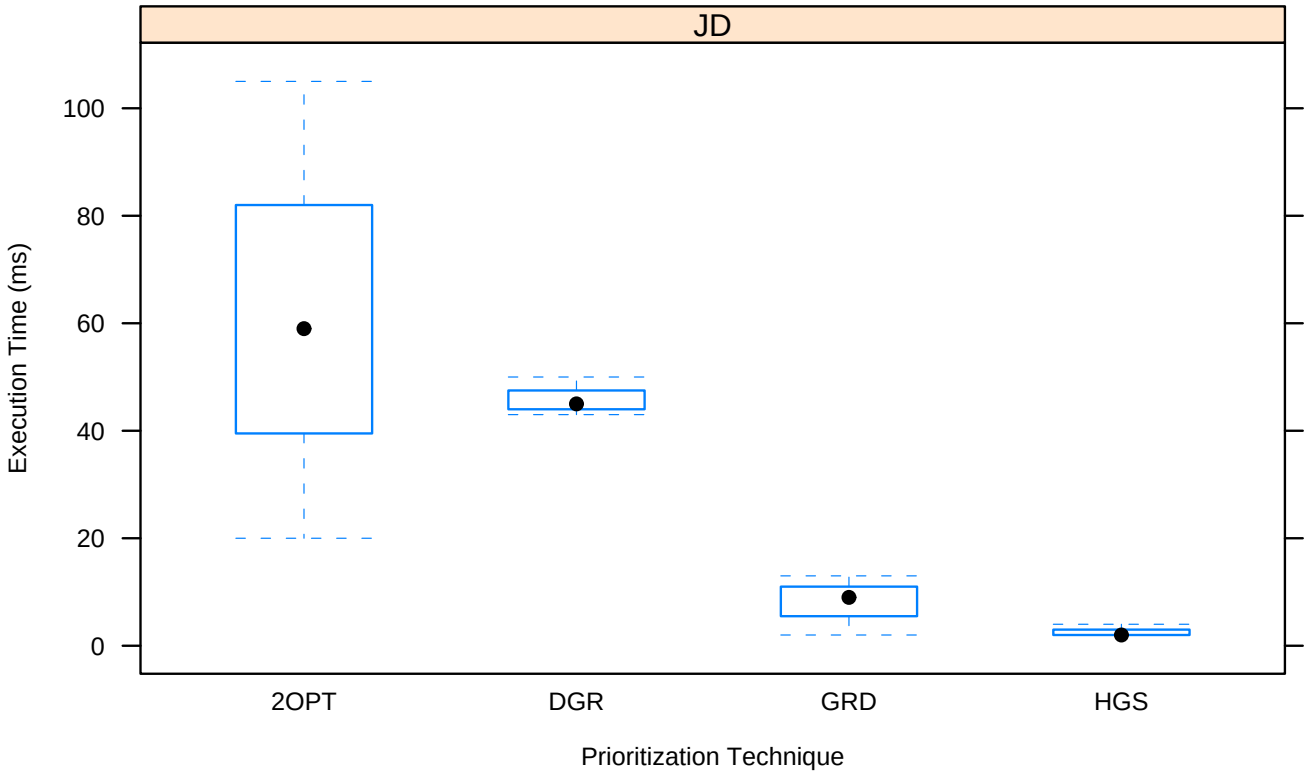

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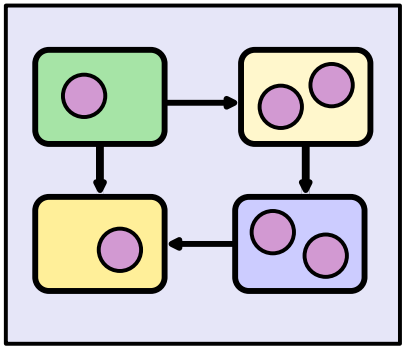
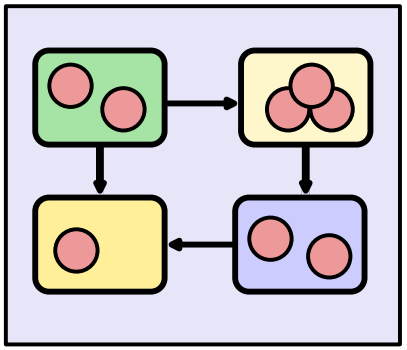
Alternative Evaluation Metrics Like APFD





Mutation Faults

Real Faults

Use **mutation** and **real** faults to support the calculation of fault detection effectiveness (**FDE**) and average percentage of faults detected (**APFD**). Consider **search-based** testing methods.

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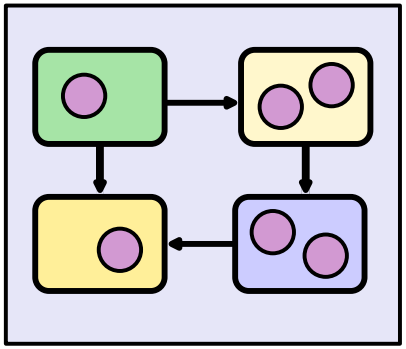

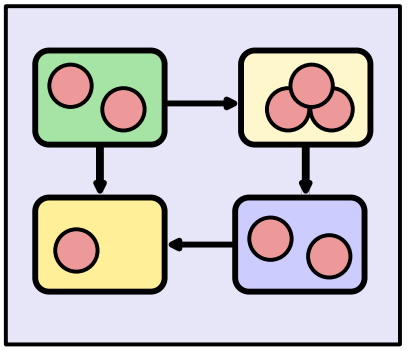

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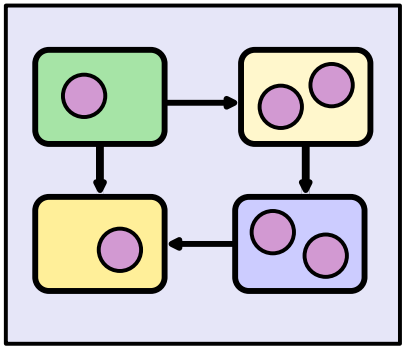

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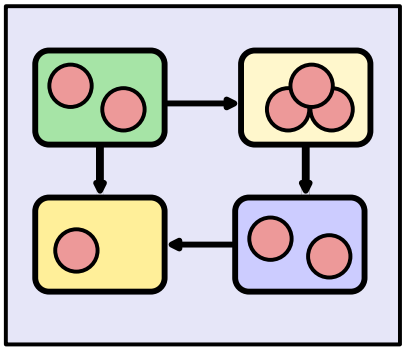

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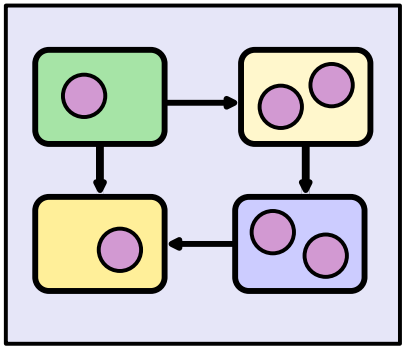

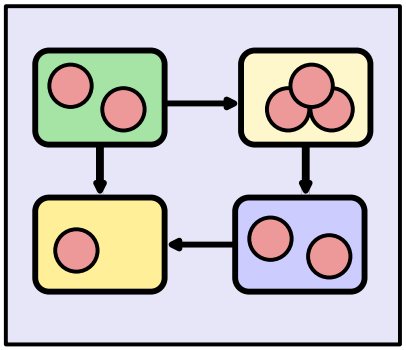

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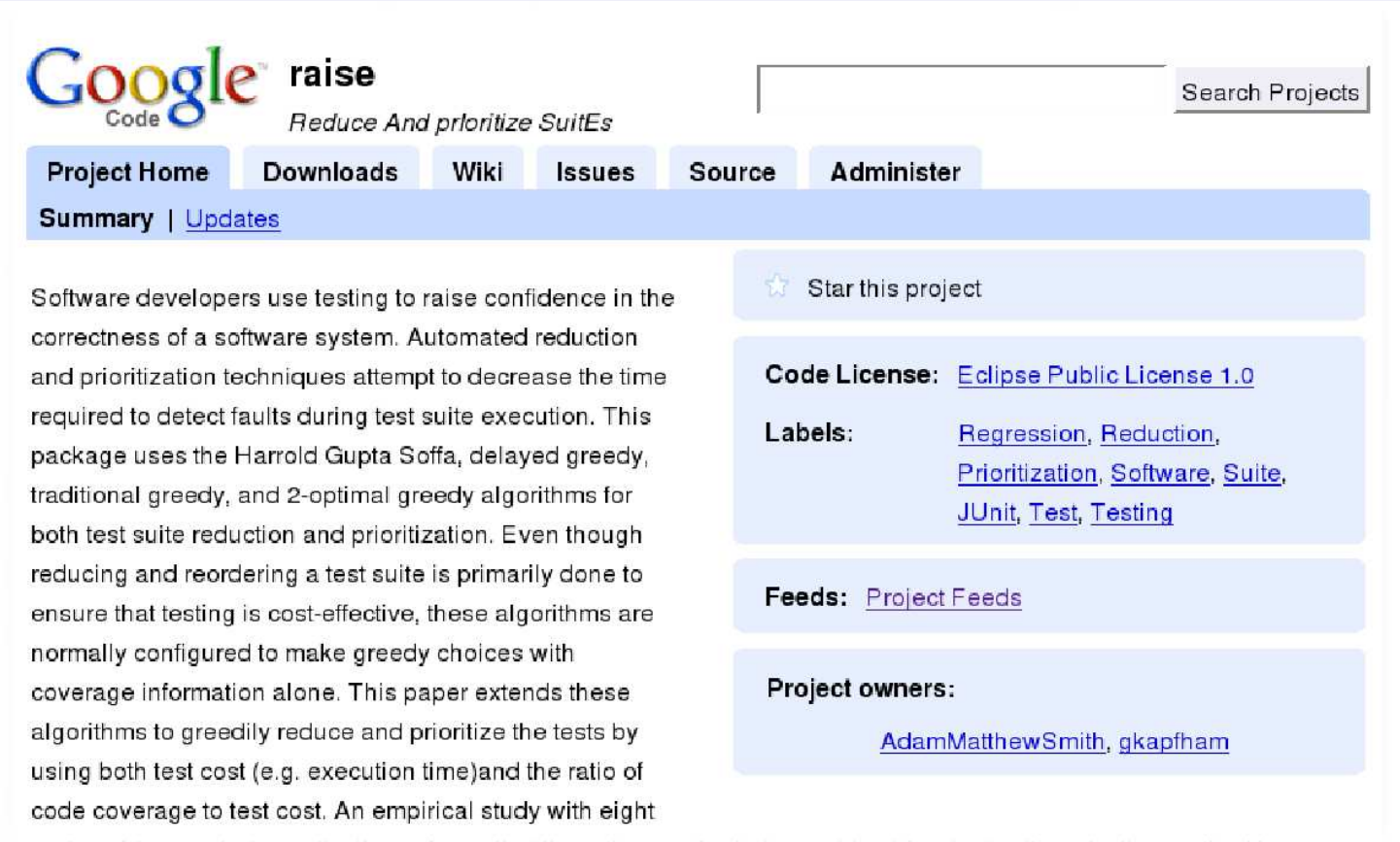
RAISE - *R*educe *A*nd pr*I*ortize Suit*E*s



http://raise.googlecode.com/ provides tools, data sets, and resources

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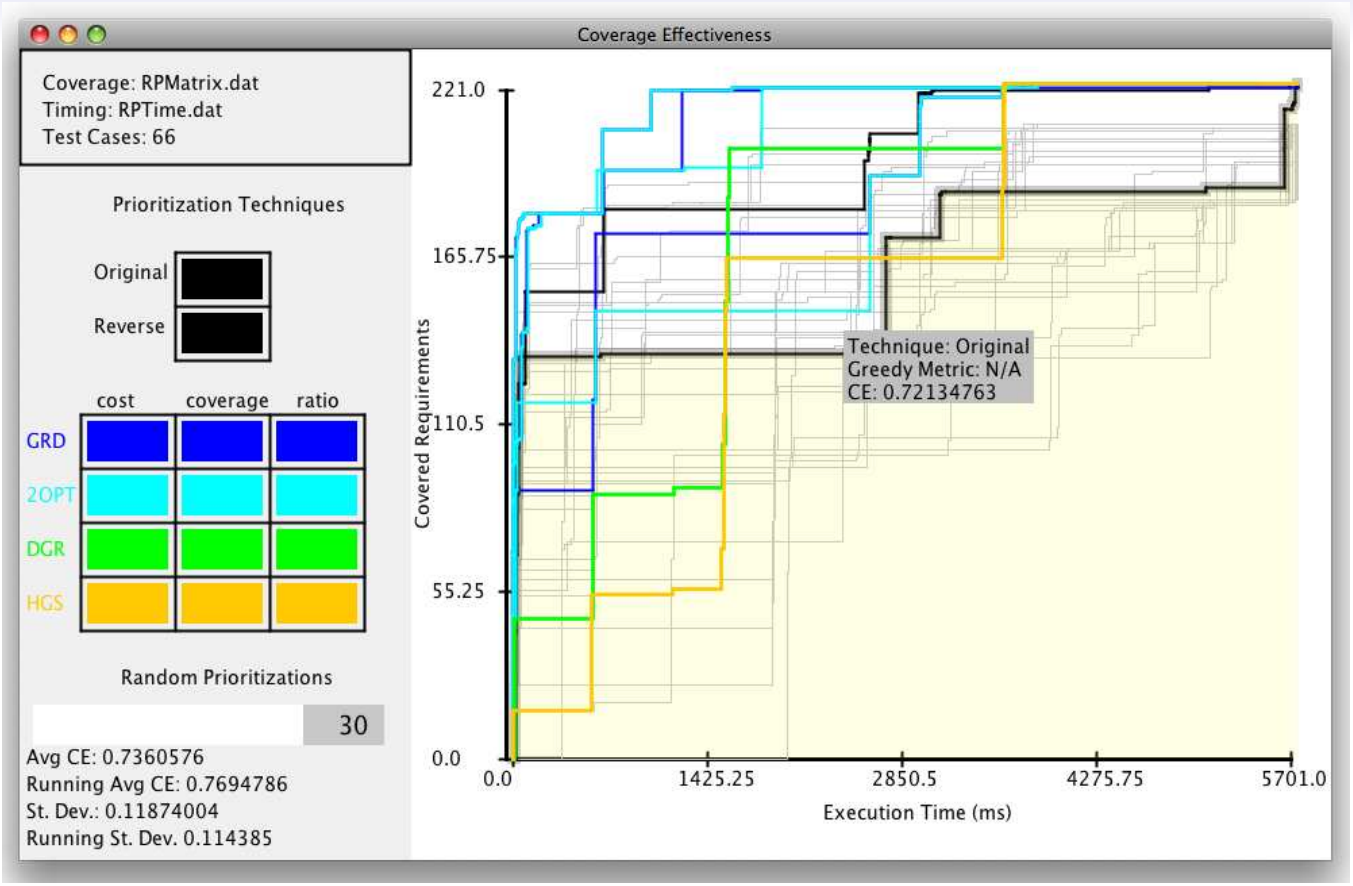
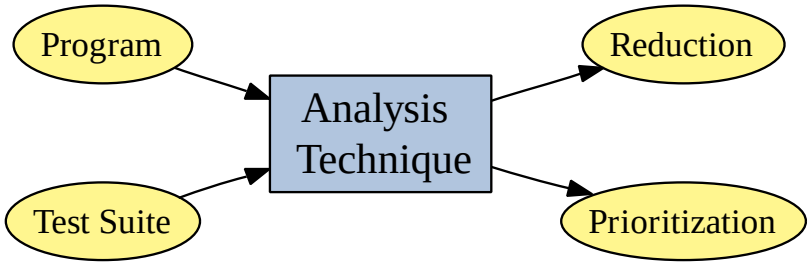
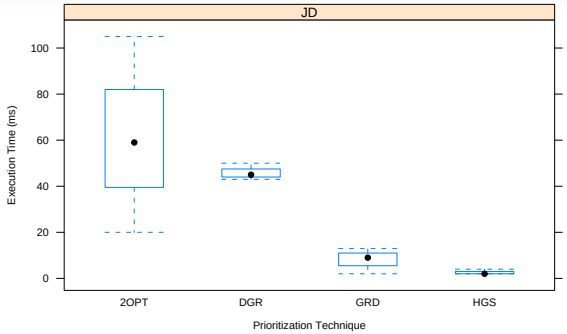


Interactive visualization methods enable testers to find **best** ordering

Concluding Remarks





Regression Testing Techniques

Detailed Empirical Results

- **Implementation** and empirical **evaluation** of methods for test suite reduction and prioritization
- Freely available **data sets** and free/open source **tools**

http://www.cs.allegheny.edu/~gkapfham/research/kanonizo/

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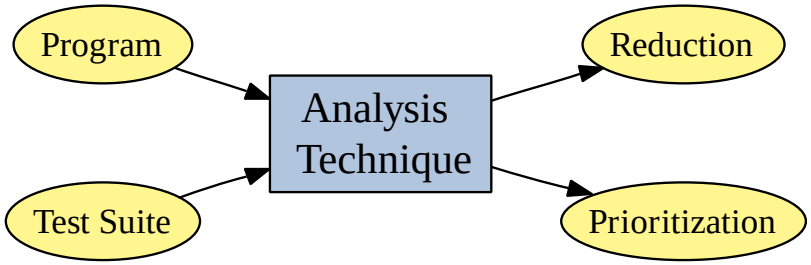

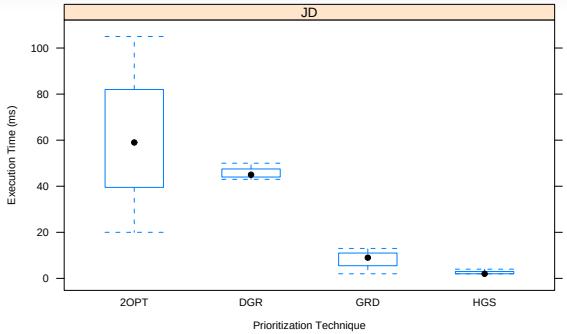

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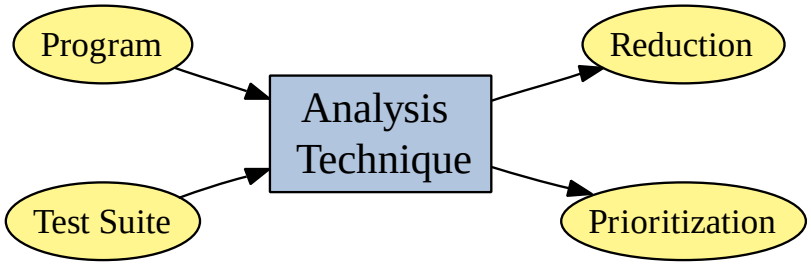

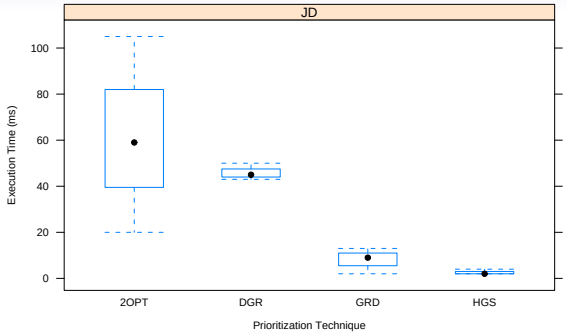

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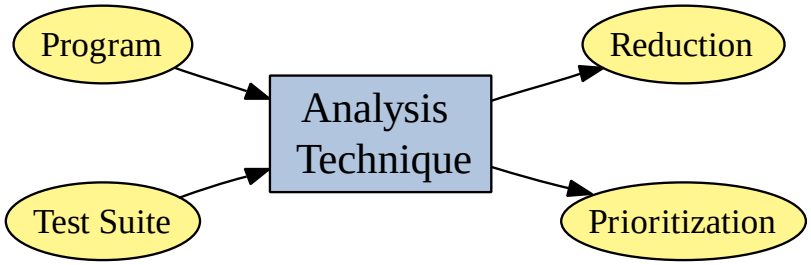

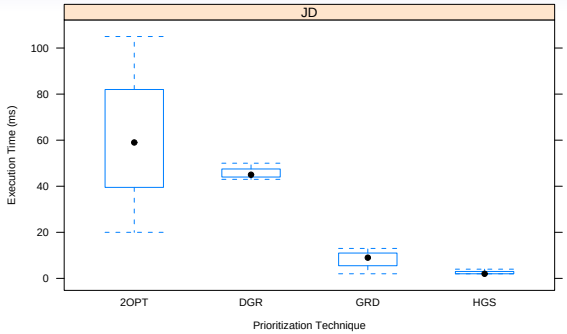

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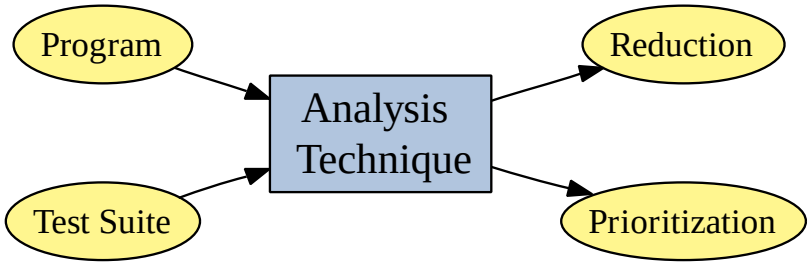

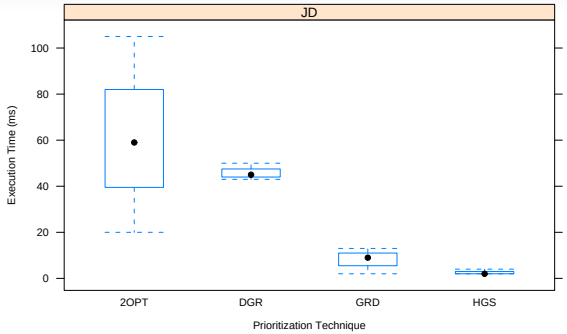

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