Time-Aware Test Suite Prioritization

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Regression Testing

- Software is constantly modified
  - Bug fixes
  - Addition of functionality
- After making changes, test using regression test suite
  - Provides confidence in correct modifications
  - Detects new faults
- High cost of regression testing
  - More modifications › larger test suite
  - May execute for days, weeks, or months
  - Testing costs are very high

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Reducing the Cost

- Cost-saving techniques
  - Selection: Use a subset of the test cases
  - Prioritization: Reorder the test cases
- Prioritization methods
  - Initial ordering
  - Reverse ordering
  - Random ordering
  - Based on fault detection ability

Ordering Tests with Fault Detection

- Idea: First run the test cases that will find faults first
- Complications:
  - Different tests may find the same fault
  - Do not know which tests will find faults
- Use coverage to estimate fault finding ability

Prioritization Example

Prioritized Test Suite (with some fault information)

T2	T1	T4	T5	T6	T3
1 fault	7 faults	3 faults	3 faults	3 faults	2 faults
1 min.	9 min.	4 min.	4 min.	4 min.	3 min.

Faults found / minute

1.0	0.778	0.75	0.75	0.75	0.667

- Retesting generally has a time budget
- Is this prioritization best when the time budget is considered?

Contribution: A test prioritization technique that intelligently incorporates a time budget

Fault Aware Prioritization

FAULTS/ TEST CASE	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
T1	X	X		X	X	X	X	X
T2	X							
T3	X				X			
T4		X	X				X	
T5				X		X		X
T6		X		X		X		

TESTING GOAL: Find as many faults as soon as possible

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Time Budget: 12 minutes

T1	f_1	f_2		f_4	f_5	f_6	f_7	f_8
T2	f_1							
T3	f_1				f_5			
T4		f_2	f_3				f_7	
T5				f_4		f_6		f_8
T6		f_2		f_4		f_6		

Fault-based Prioritization

T1	T4	T5	T6	T3	T2
7 faults	3 faults	3 faults	3 faults	2 faults	1 fault
9 min.	4 min.	4 min.	4 min.	3 min.	1 min.

Finds 7 unique faults in 9 minutes

Time Budget: 12 minutes

T1	f_1	f_2		f_4	f_5	f_6	f_7	f_8
T2	f_1							
T3	f_1				f_5			
T4		f_2	f_3				f_7	
T5				f_4		f_6		f_8
T6		f_2		f_4		f_6		

Naïve Time-based Prioritization

T2	T3	T4	T5	T6	T1
1 fault	2 faults	3 faults	3 faults	3 faults	7 faults
1 min.	3 min.	4 min.	4 min.	4 min.	9 min.

Finds 8 unique faults in 12 minutes

Time Budget: 12 minutes

T1	f_1	f_2		f_4	f_5	f_6	f_7	f_8
T2	f_1							
T3	f_1				f_5			
T4		f_2	f_3				f_7	
T5				f_4		f_6		f_8
T6		f_2		f_4		f_6		

Average-based Prioritization

T2	T1	T4	T5	T6	T3
1 fault	7 faults	3 faults	3 faults	3 faults	2 faults
1 min.	9 min.	4 min.	4 min.	4 min.	3 min.

Finds 7 unique faults in 10 minutes

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Time Budget: 12 minutes

T1	f_1	f_2		f_4	f_5	f_6	f_7	f_8
T2	f_1							
T3	f_1				f_5			
T4		f_2	f_3				f_7	
T5				f_4		f_6		f_8
T6		f_2		f_4		f_6		

Intelligent Time-Aware Prioritization

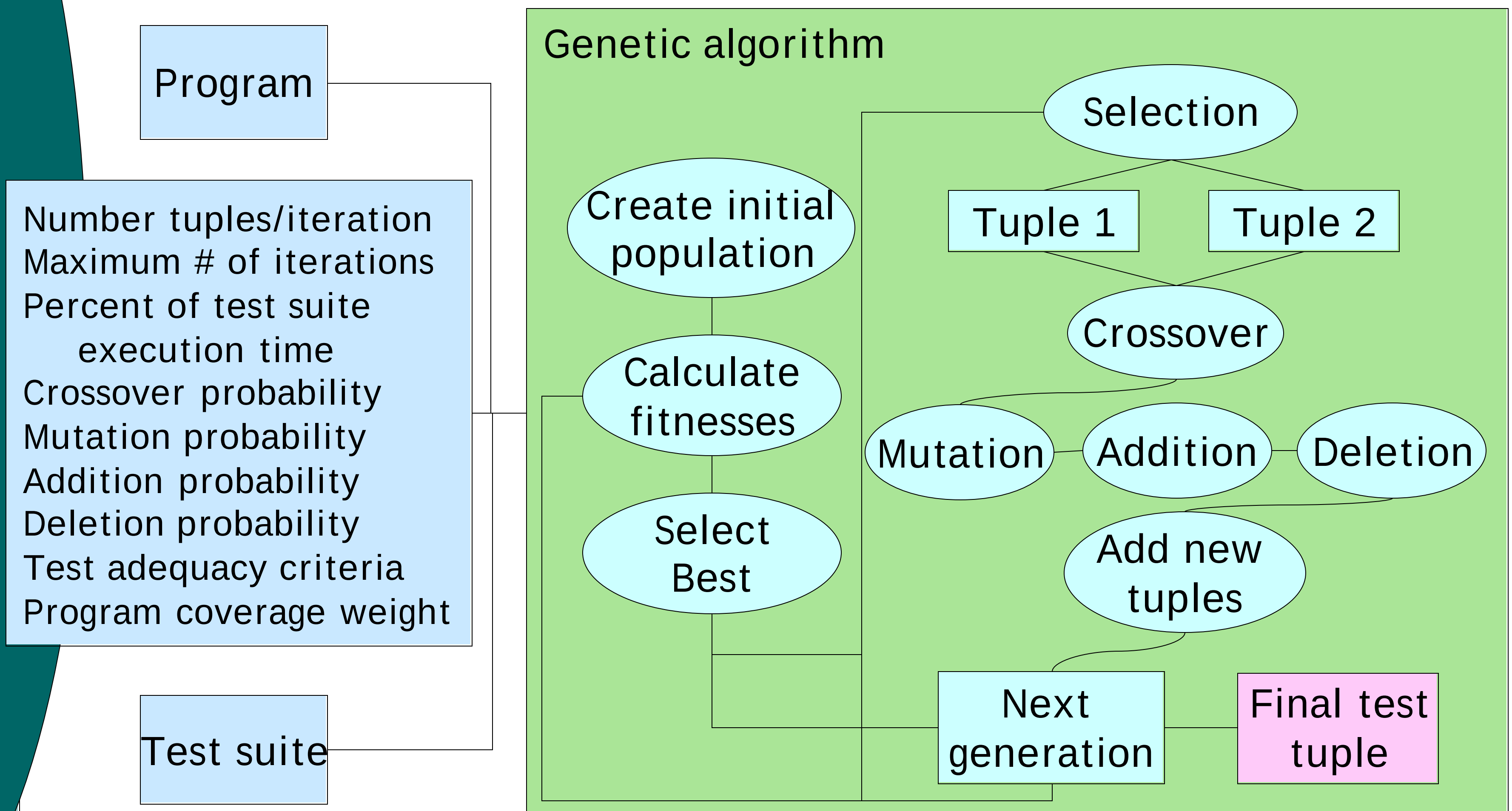
T5 3 faults 4 min.	T4 3 faults 4 min.	T3 2 faults 3 min.	T1 7 faults 9 min.	T2 1 fault 1 min.	T6 3 faults 4 min.

Finds 8 unique faults in 11 minutes

Time-Aware Prioritization

- Time-aware prioritization (TAP) combines:
  - Fault finding ability (overlapping coverage)
  - Test execution time
- Time constrained test suite prioritization problem   0/1 knapsack problem
  - Use genetic algorithm heuristic search technique
  - Genetic algorithm
    - Fitness ideally calculated based on faults
    - A fault cannot be found if code is not covered
    - Fitness function based on test suite and test case code coverage and execution time

Prioritization Infrastructure



Fitness Function

Primary Fitness
Secondary Fitness

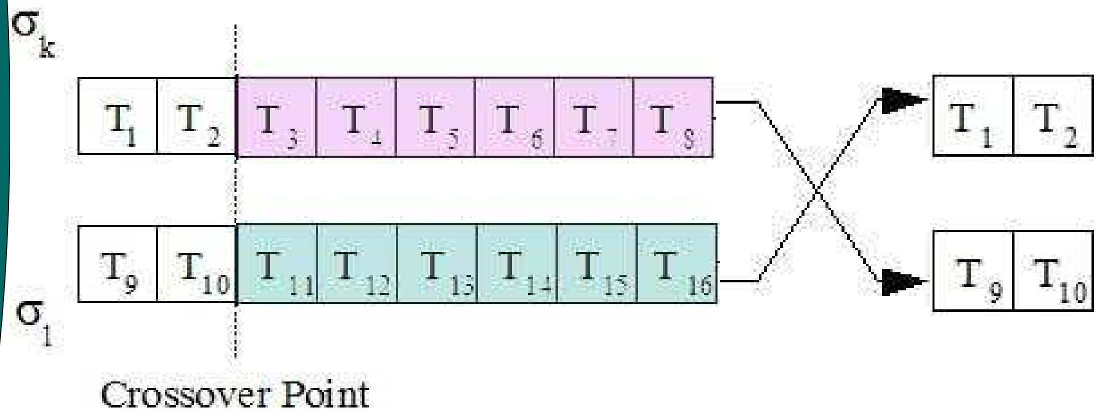
Test Suite 1: 70% coverage ← Preferred!

Test Suite 2: 40% coverage

- Fitness function components
  1. Overall coverage
  2. Cumulative coverage of test tuple
  3. Time required by test tuple
     - If over time budget, receives very low fitness

Creation of New Test Tuples

Crossover



- Vary test tuples using recombination
- If recombination causes duplicate test case execution, replace duplicate test case with one that is unused

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Creation of New Test Tuples

- Mutation
  - For each test case in tuple
    - Select random number, R
    - If R < mutation probability, replace test case
- Addition- Append random unused test case
- Deletion- Remove random test case

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Experimentation Goals

- Analyze trends in average percent of faults detected (APFD)
- Determine if time-aware prioritizations outperform selected set of other prioritizations
- Identify time and space overheads

Experiment Design

- GNU/Linux workstations
  - 1.8 GHz Intel Pentium 4
  - 1 GB main memory
- JUnit test cases used for prioritization
- Case study applications
  - Gradebook
  - JDepend
- Faults seeded into applications
  - 25, 50, and 75 percent of 40 errors

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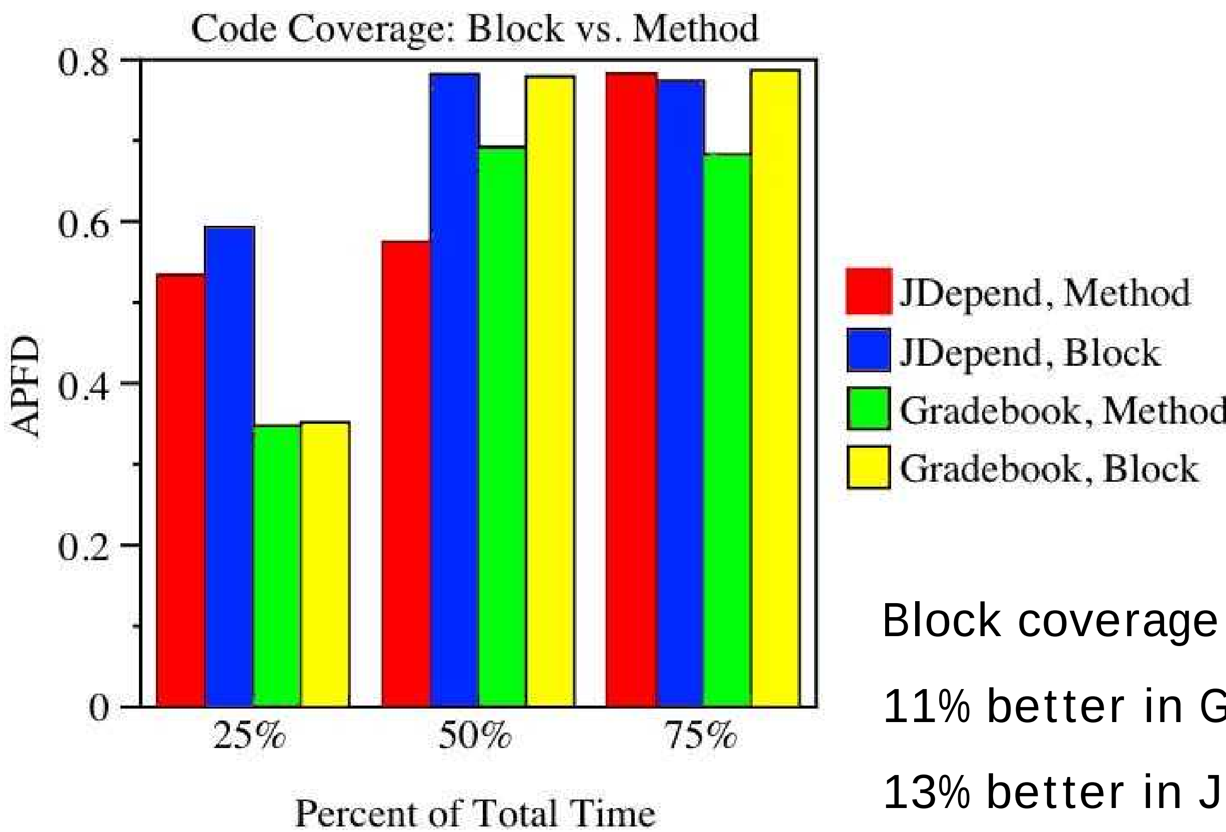
Evaluation Metrics

- Average percent of faults detected (APFD)
  - T = test tuple
  - g = number of faults in program under test
  - n = number of test cases
  - *reveal(i, T)* = position of the first test in T that exposes fault i

$$APFD(T,P) = 1 - \frac{\sum_{i=1}^{g} reveal(i,T)}{ng} + \frac{1}{2n}$$

- Peak memory usage
- User and system time

TAP APFD Values

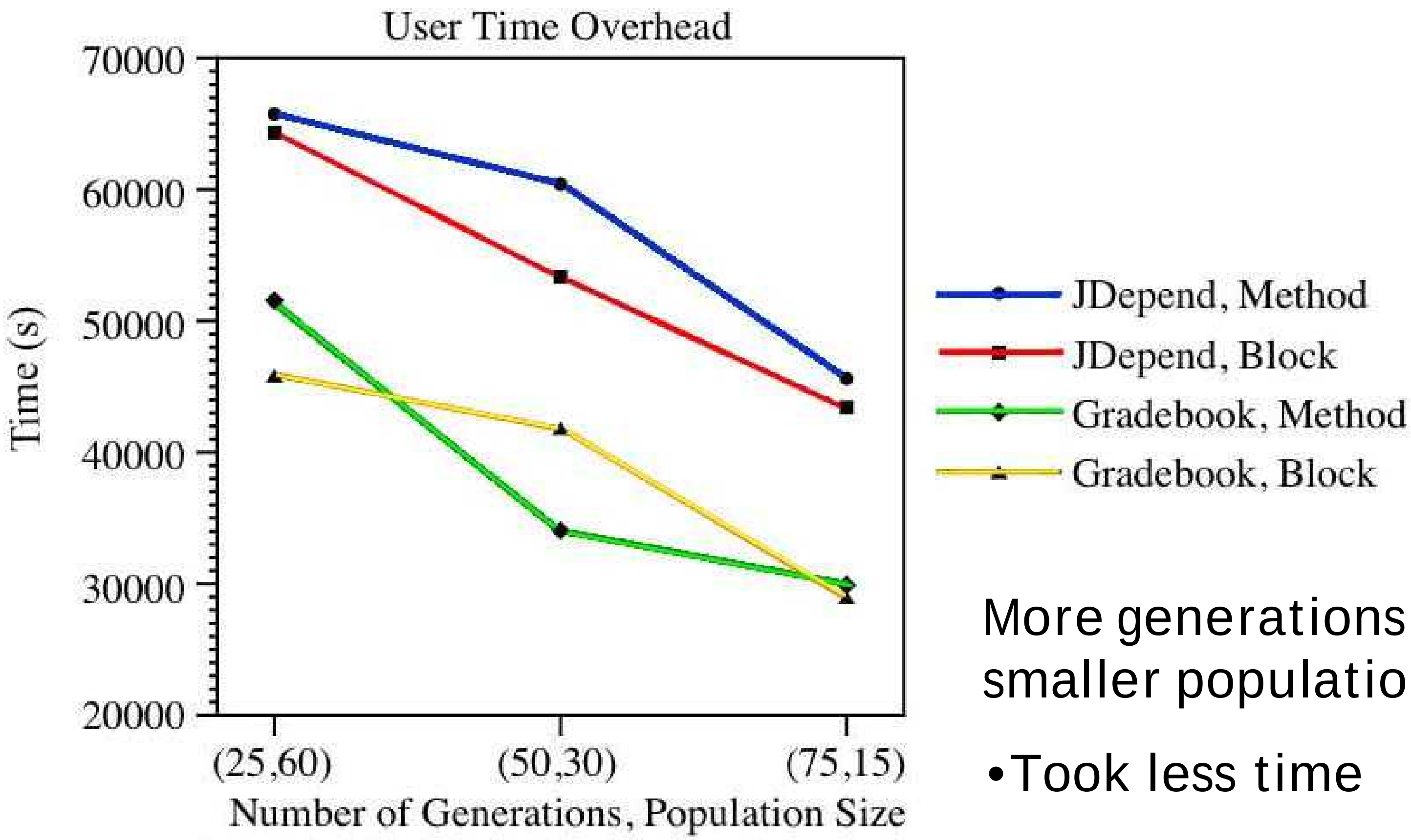


Block coverage preferred:

11% better in Gradebook

13% better in JDepend

TAP Time Overheads



More generations with smaller populations:

- Took less time
- Same quality results

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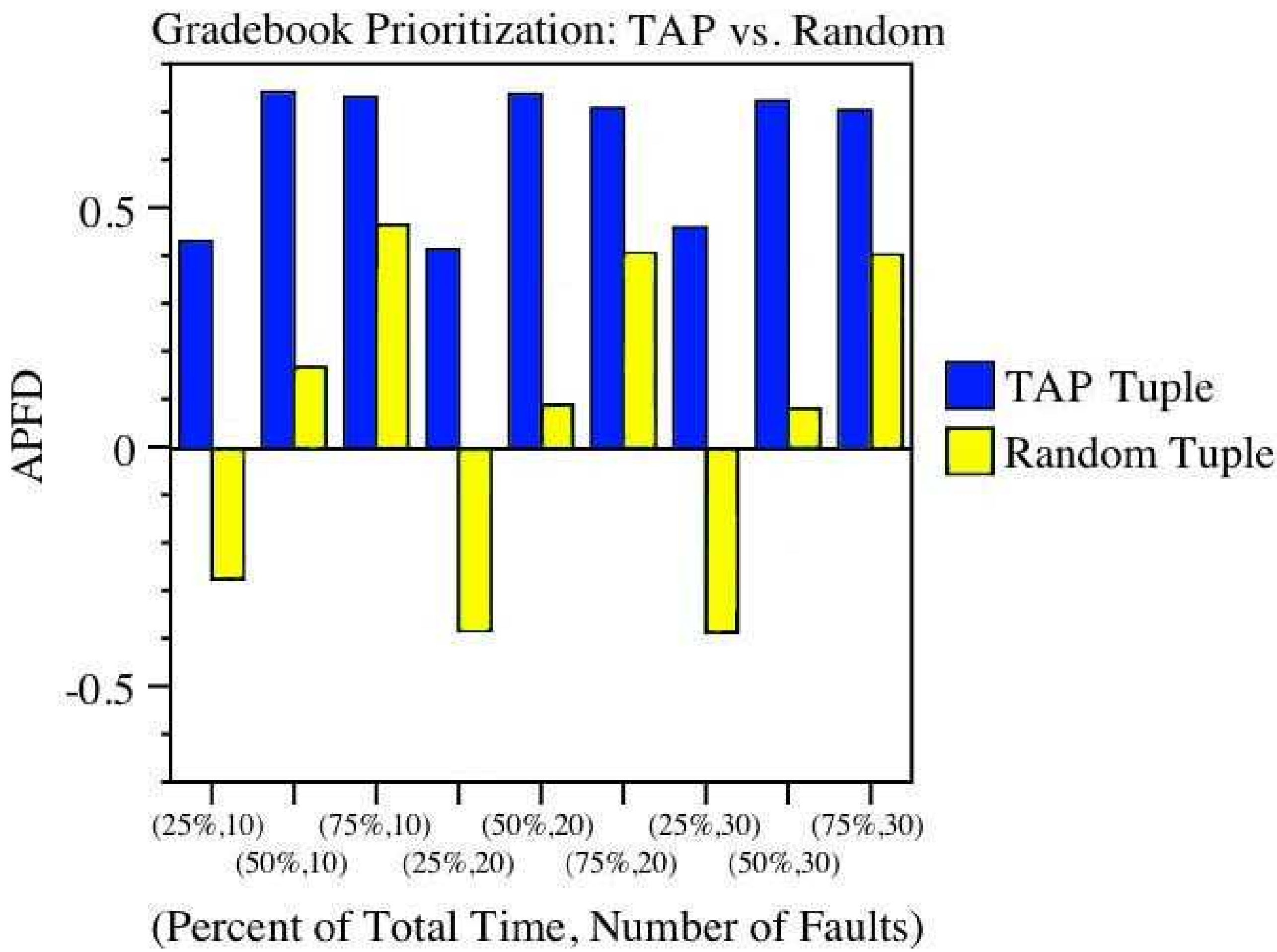
Gradebook: Intelligent vs Random



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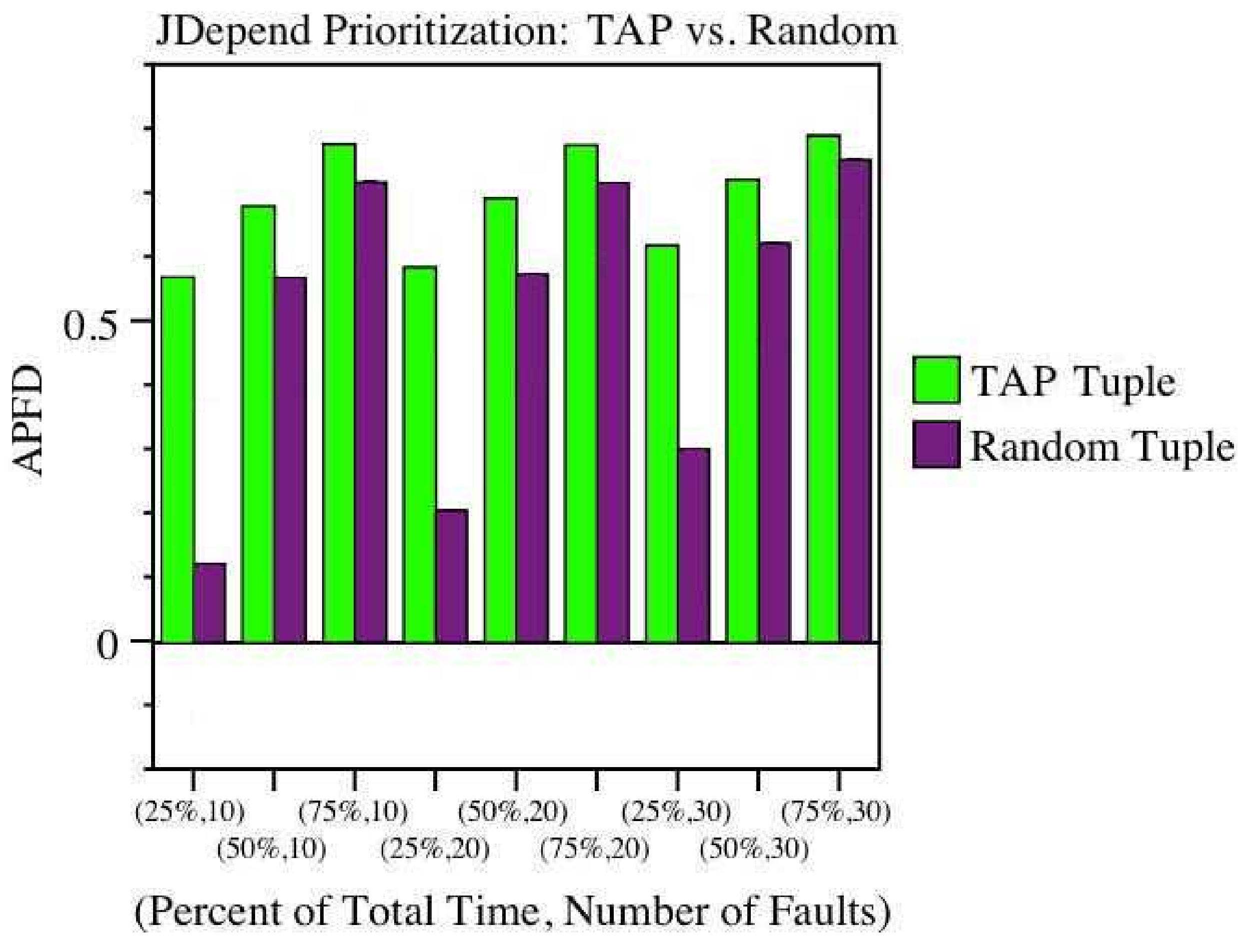
JDepend: Intelligent vs. Random



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Other Prioritizations

- Random prioritizations redistribute fault-revealing test cases
- Other prioritizations
  - Initial ordering
  - Reverse ordering
  - Fault-aware
    - Impossible to implement
    - Good watermark for comparison

Gradebook: Alternative Prioritizations

% total time	# Faults	Initial	Reverse	TAP	Fault aware
0.25	10	-0.6	-0.2	0.43	0.7
0.25	20	-0.9	-0.2	0.41	0.7
0.25	30	-0.9	-0.0	0.46	0.5
0.50	10	-0.04	0.1	0.74	0.9
0.50	20	-0.2	0.2	0.74	0.9
0.50	30	-0.3	0.3	0.72	0.8
0.75	10	0.3	0.5	0.73	0.9
0.75	20	0.1	0.4	0.71	0.9
0.75	30	0.04	0.5	0.70	0.9

- Time-aware prioritization up to 120% better than other prioritizations

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Conclusions and Future Work

- Analyzes a test prioritization technique that accounts for a testing time budget
- Time intelligent prioritization had up to 120% APFD improvement over other techniques

- Future Work
  - Make fitness calculation faster
  - Distribute fitness function calculation
  - Exploit test execution histories
  - Create termination condition based on prior prioritizations
  - Analyze other search heuristics

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Thank you!

Time-Aware Prioritization (TAP) Research:

- http://www.cs.virginia.edu/~krw7c/TimeAwarePrioritization.htm

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