Test Prioritization

Related reading: ***Effectively Prioritizing Tests in Development Environment***

15-819M: Program Analysis

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Test Prioritization: Motivation

- Goal: find and eliminate newly introduced defects
- Regression Testing for Windows
  - Many tests
  - Many platform configurations to run them on
  - Full tests take weeks to run
- Test Prioritization
  - Want to run tests likely to fail first
  - Day 1 after internal release, not day 21!
- Test Selection
  - What tests should I run before checking in code?
  - What tests should be run before releasing a critical fix?
  - Special case of prioritization

Observation: New defects are introduced from changed code

Challenges in Test Prioritization

- Detecting change and affected parts of the program
- Scalability to handle complex systems
  - Tens of millions of tests
  - Thousands of developers and testers
  - Tens of millions lines of source code
  - Acceptable response times
- Integrating seamlessly into development process

Scout (Echelon): Test Prioritization System

New Image

Old Image

Image Change Analysis

What changed?
Detect impacted *blocks*
(new + old changed)

Old Image Coverage

Coverage Impact Analysis

What can be leveraged?
Detect impacted blocks likely to be covered by existing tests

Test Prioritization

What order should tests be run?
Detect minimal set of test cases likely to cover the impacted blocks

Output 1
Prioritized list of test cases based on coverage of the impacted blocks

Output 2
List of impacted blocks not covered by the existing tests

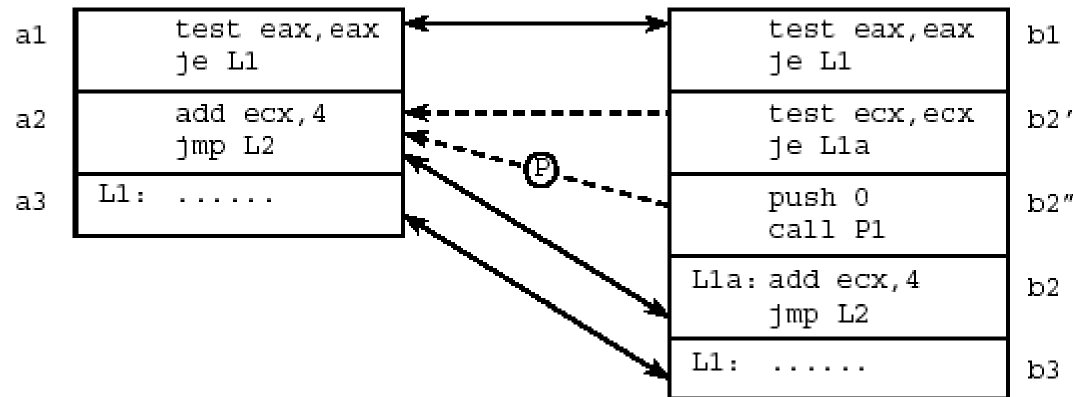
BMAT – Binary Matching

- Goal: detect corresponding blocks in old and new versions of a program
  - [Wang, Pierce, and McFarling JILP 2000]
- Matches basic blocks in binary code
  + don’t need source code
  – must ignore changes in address space
- Algorithm considers similarities in code and in its uses

BMAT – Matching Procedures

- Match procedures if names match
  - Qualified by package, scope, etc.
  - If ambiguous, extend to include argument types
- Check for similar names
  - Verify match if blocks are similar (see below)
- Look for function bodies hashing the same
- Perform pair-wise comparison of blocks otherwise
- *Conclude function is new if no matches are found*

BMAT – Matching Blocks



- Match blocks based on hash of contents
  - Look for exact match first, then apply fuzzy hashing algorithm
    - Fuzzy algorithms ignore information that is likely to change due to innocuous changes: offsets, registers, block addrs, opcodes
- Control-flow match
  - Build CFG, look for node pairs with the same connectivity
  - May match many new blocks to one old block
  - Partial match: new block not always executed (e.g. b2'')

Detecting Impacted Blocks

- Old blocks
  - Identical (modulo address changes)
- Impacted blocks
  - Old modified blocks
  - New blocks

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Computing Coverage

- Computed for each test T
- Old block b
  - Covered if T covered b in old binary
- New block
  - Covered if at least one predecessor and successor were covered in old binary
  - Heuristic: predict branches taken
  - Heuristic: don’t check predecessors for indirect call targets

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Prioritization Algorithm

Input:
TestList: set of tests
Coverage (t) : set of blocks covered by test t
ImpactedBlkSet: set of new and old modified blocks

Output: a set of sequences Seq

Algorithm:

```
while (any t in TestList covers any block in ImpactedBlkSet )
{
   CurrBlkSet = ImpactedBlkSet
    Start a new sequence Seq
   while (any t in TestList covers any block in CurrBlkSet }
    {
       for each t in TestList  compute
       {
            Weight(t) = count[CurrBlkSet ∩ Coverage(t)]
       }
       Select test  t in TestList with maximum weight
       Add t to current sequence Seq
       Remove t from TestList
       CurrBlkSet = CurrBlkSet – Coverage (p)
     }
}
Put all remaining tests in TestList in a new sequence Seq
```

Test	Blocks
t1	b2,b7
t2	b1,b2,b3,b8
t3	b7
t4	b6
t5	b1,b2,b5
t6	b4,b5

Impacted: b1,b2,b4,b7,b8

Seq1: t2 t1 t6
Seq2: t5 t3
Seq3: t4

Prioritization Algorithm Improvement

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- "As we keep a sorted list of tests by weight, ***we terminate the search*** for a test when the ***new computed weight is greater than the [previous] weight of the next test***. This helps the algorithm to converge faster." [Srivastava 02]

if (Seq ≠ ∅) then
  if Weight(t) > Weight(s) then
    break

Where:
  s is the next element of TestList after t
  Weight(s) holds its old value

Prioritization Algorithm Improvement

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Non-increasing cardinality per iteration

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Prioritization Algorithm Extensions

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Test Features:

- Contextual coverage
- Execution Time
- Overall coverage
- Rate of fault detection
- …

[Srivastava 02] mentions using other features when ties occur on the main feature

Alternatively, the features can be weighted and combined

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Weight(t)

$$= w_{coverage} * \textbf{count[CurrBlkSet} \cap \textbf{Coverage(t)]} + w_{exec_time} * [\text{ExecTime (t)}]^{-1}$$

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(The line "Weight(t) = count[CurrBlkSet ∩ Coverage(t)]" is struck through, with an arrow pointing from it to Weight(t) below.)

Test Features:

- Contextual coverage
- Execution Time
- Overall coverage
- Rate of fault detection
- …

Weight(t)

$= w_{coverage}$

$*$ count[CurrBlkSet ∩ Coverage(t)]

$+ w_{exec_time} * [ExecTime(t)]^{-1}$

Caveat:
Must normalize units

Echelon Performance: ProductX.EXE

Image Info

	Build 2411.1	Build 2529.0
Date	12/11/2000	01/29/2001
Functions	31,020	31,026
Blocks	668,068	668,274
File size	8,880,128	8,880,128
PDB size	22,602,752	22,651,904
Number of Traces	3,128	3,128

1.8 million lines of source code

Results

Impacted Blocks	378 (220 New, 158 OC)
Likely Covered by existing tests (LC)	176 Blocks
Traces needed to cover LC (Set 1)	16 Traces
Number of sets in prioritized list	1,225

Scout took about 210 seconds

Test Sequence Characteristics

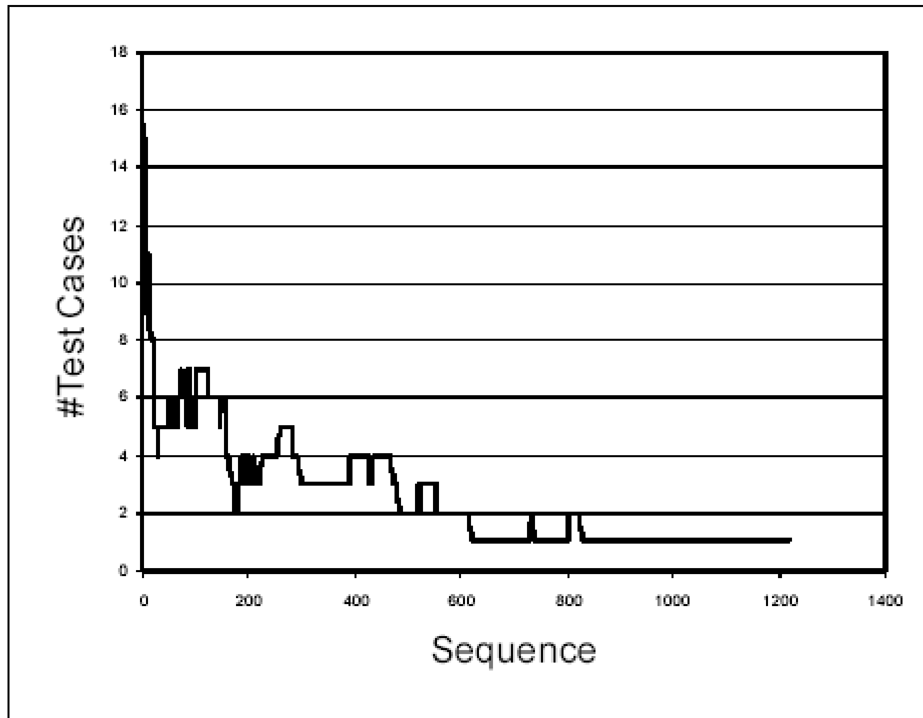

Figure 3. Number of tests in each sequence

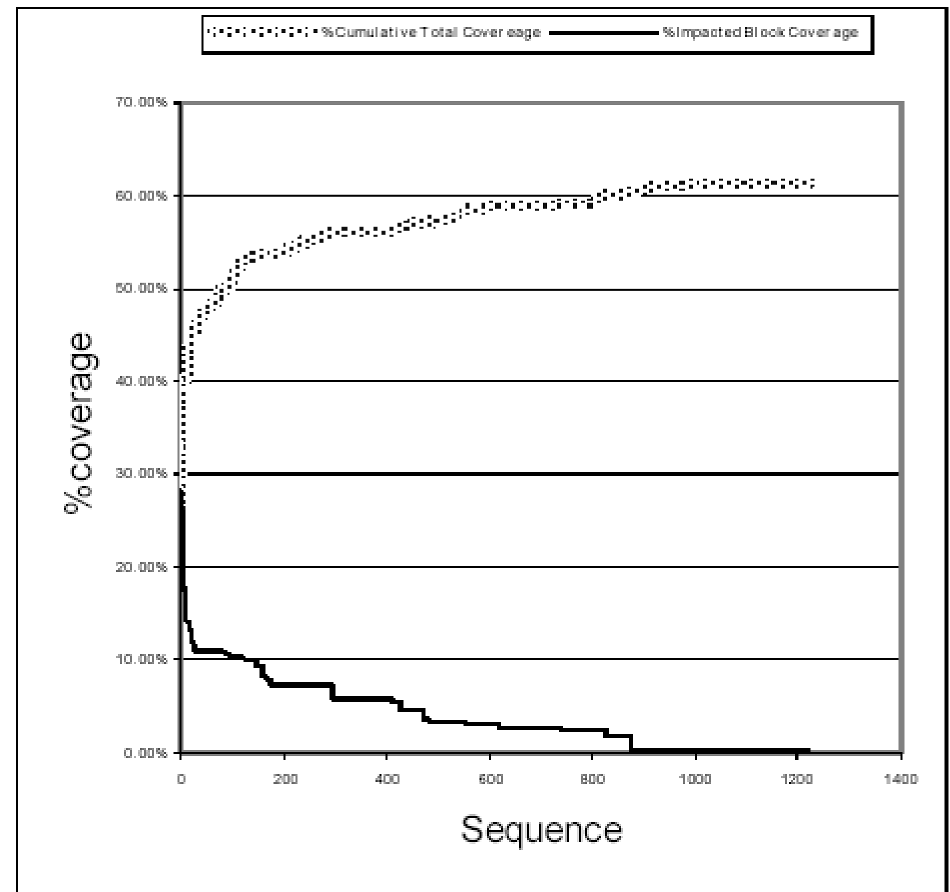

Figure 5. Cumulative coverage and impacted coverage

Prediction Errors

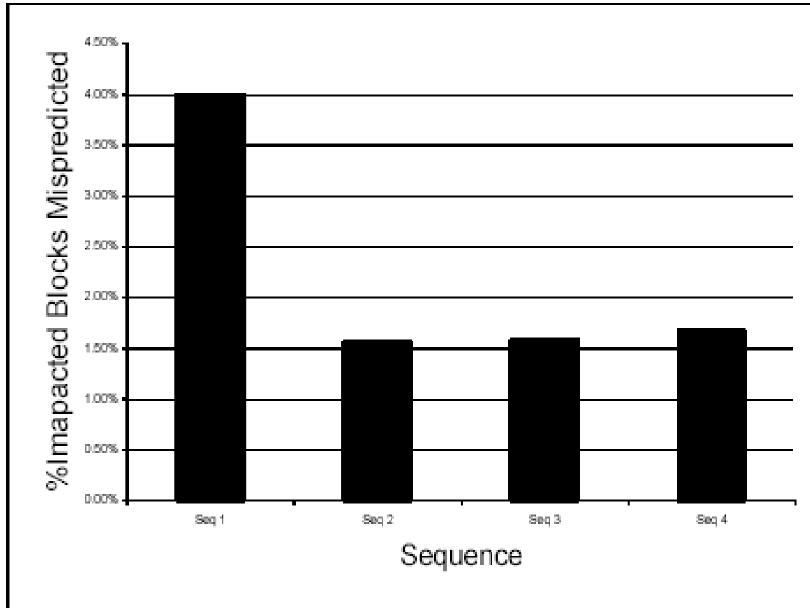

Figure 6. Predicted blocks not covered

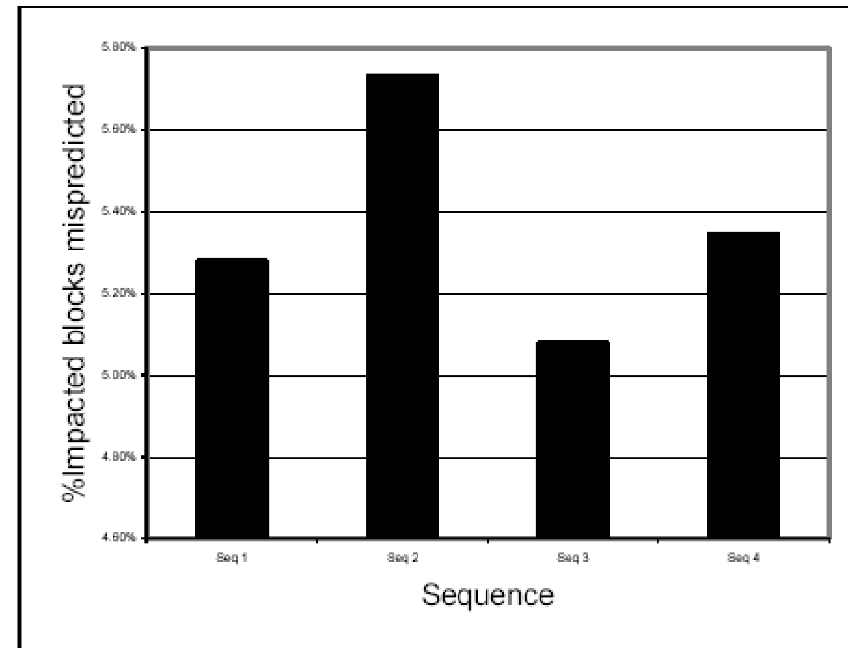

Figure 7. Blocks covered but not predicted

1-4% False Positives

4-5% False Negatives

Defect Detection

Program A

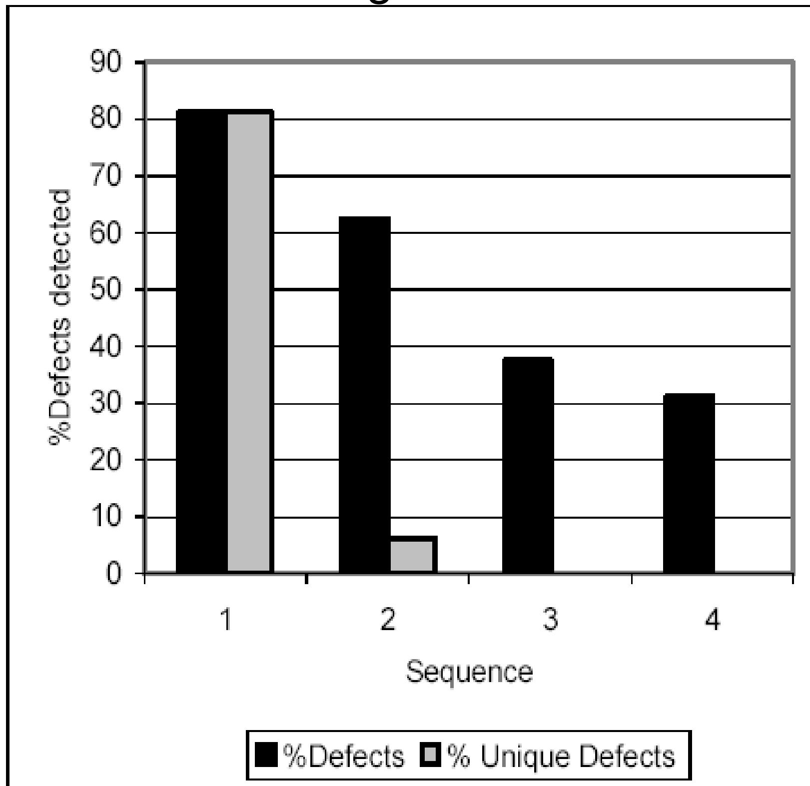

Figure 12. Defects detected in each sequence

Program B

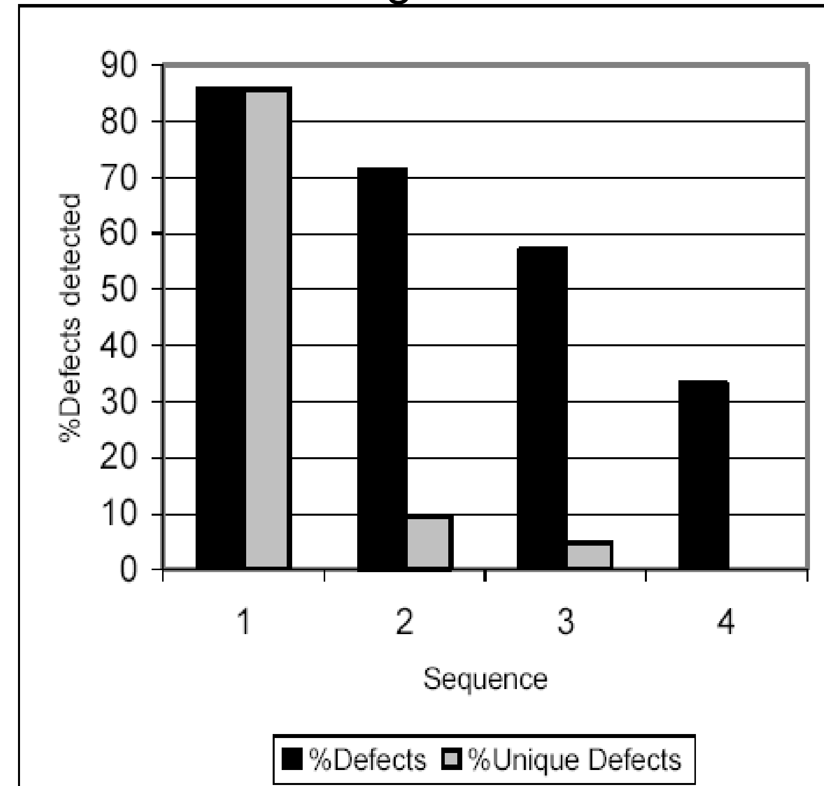

Figure 13. Defects detected in each sequence

Summary: Test Prioritization

- Effectively being used in MS Windows, SQL, and Exchange development process
  - Quickly identifies tests most likely to detect errors
- Scales to production environments - millions of tests and thousands of binaries
- Combination of approximations and static analysis to eliminate manual methods
- Collect information about development process