Fault Tolerant Computing

CS 530

Test Coverage & Defects

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Test Coverage Measures

• Statement or Block coverage
• Branch or decision coverage
• P-use coverage: p-use pair: variable defined/modified - use as predicate
• C-use coverage: similar - use for computation
• Subsumption hierarchy:
  ▪ Covering all branches cover all statements
  ▪ Covering all p-uses cover all branches
Modeling: Defects, Time, & Coverage

Malaiya, Li, Bieman, Karcich, Skibbe, 1994
Li, Malaiya, Denton, 1998
Coverage Based Defect Estimation

• Coverage is an objective measure of testing
  ▪ Directly related to test effectiveness
  ▪ Independent of processor speed and testing efficiency
• Lower defect density requires higher coverage to find more faults
• Once we start finding faults, expect coverage vs. defect growth to be linear
Logarithmic-Exponential Coverage Model

• Hypothesis 1: defect coverage growth follows logarithmic model

\[ C^0(t) = \frac{\beta_0}{N_0} \ln(1 + \beta_1^0 t), \quad C^0(t) \leq 1 \]

• Hypothesis 2: test coverage growth follows logarithmic model

\[ C^i(t) = \frac{\beta_0}{N_i} \ln(1 + \beta_1^i t), \quad C^i(t) \leq 1 \]
Log-Expo Coverage Model (2)

- Eliminating \( t \) and rearranging,
  \[
  C^0 = a^i_0 \ln[1 + a^i_1 (\exp(a^i_2 C^i) - 1)], \quad C^0 \leq 1
  \]
  where \( C^0 \) : defect coverage, \( C^i \) : test coverage
  \( a^i_0, a^i_1, a^i_2 \) : parameters; \( i \) : branch cov, p - use cov etc.

- For “large” \( C^i \), we can approximate
  \[
  C^0 = -A^i + B^i C^i
  \]
Coverage Model, Estimated Defects

\[ C^0 = -A^i + B^i C^i, \quad C^i > C^i_{knee} \]

- Only applicable after the knee
- Assumptions : Stable Software
Location of the knee

\[ C_{knee} = 1 - \left( \frac{E_{\text{min}}}{D_{\text{min}} E_0} \right) D_0 \]

- Based on interpretation through logarithmic model
- Location of knee based on initial defect density
- Lower defect densities cause knee to occur at higher coverage
- Parameter estimation: Malaiya and Denton (HASE ‘98)
Data Sets Used
Vouk and Pasquini

• Vouk data
  ▪ from N version programming project to create a flight controller
  ▪ Three data sets, 6 to 9 errors each

• Pasquini data
  ▪ Data from European Space Agency
  ▪ C Program with 100,000 source lines
  ▪ 29 of 33 known faults uncovered
Defects vs. Branch Coverage

Data Set: Pasquini

Defects Expected

Fitted Model

Branch Coverage

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Estimation of Defect Density

- Estimated defects at 95% coverage, for Pasquini data (assume 5% dead code)
- 28 faults found, and 33 known to exist

<table>
<thead>
<tr>
<th>Measure</th>
<th>Coverage Achieved</th>
<th>Expected Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>82%</td>
<td>36</td>
</tr>
<tr>
<td>Branch</td>
<td>70%</td>
<td>44</td>
</tr>
<tr>
<td>P-uses</td>
<td>67%</td>
<td>48</td>
</tr>
</tbody>
</table>
Defects vs. P-Use Coverage
Data Set: Vouk 3

Defects Expected
Fitted Model

Defects vs. P-Use Coverage
Data Set: Vouk 3

Defects
P-Use Coverage

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Coverage Based Estimation

Data Set: Pasquini et al

Estimates are stable
Current Methods

• Development process based models allow for *a priori* estimates
  - Not as accurate as methods based on test data
• Sampling methods often assume faults found as easy to find as faults not found
  - Underestimates faults
• Exponential model
  - Assume applicability of exponential model
  - We present results of a comparison
The Exponential Model

Data Set: Pasquini et al

Estimate rises as new defects found

Estimates very close to actual faults

Test Cases
Defects
Defects Found
Estimate

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Related articles

• Frankl & Iakouneno, Proc. SIGSOFT ‘98
  ▪ 8 versions of European Space Agency program, 10K LOC, Single fault reinsertion
• Williams, Mercer, Mucha, Kapur, 2001
  ▪ "Code coverage, what does it mean in terms of quality?,“
  ▪ analysis from first principles
• Peter G Bishop, SAFECOMP 2002
  ▪ A related model, unreachable code
Related articles


• Avaya lab data

• “The test effort increases exponentially with test coverage, but the reduction in field problems increases linearly with test coverage.”
Observations and Conclusions

• Estimates with new method are very stable
  ▪ Visual confirmation of earlier projections
• Which coverage measure to use?
  ▪ Stricter measure will yield closer estimate
• Some code may be dead or unreachable
  ▪ Found with compile or link time tools
  ▪ May need to be taken into account