A Test Adequacy Infrastructure with Database Interaction Awareness

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(in collaboration with Mary Lou Soffa)
Motivation

The Risks Digest, Volume 22, Issue 64, 2003

Jeppesen reports airspace boundary problems

About 350 airspace boundaries contained in Jeppesen NavData are incorrect, the FAA has warned. The error occurred at Jeppesen after a software upgrade when information was pulled from a database containing 20,000 airspace boundaries worldwide for the March NavData update, which takes effect March 20.
Looking Ahead

- Test adequacy infrastructure that can find faults and establish confidence in the correctness of a database-centric application
  - Model of database interaction faults
  - Unified application representation
  - Family of test adequacy criteria
- Experiments with real applications that measure the number of test requirements and the time and space overheads incurred by enumeration
  - Foundation for a comprehensive methodology for testing database-centric applications
Testing Challenges

- Must consider the environment in which software applications actually execute
- Should test a program and its interaction with a database
- Database-centric application’s state space is well-structured, but essentially infinite (Chays et al.)
- Need to show program does not violate database integrity, where integrity = consistency + validity (Motro)
- Must locate program and database coupling points that vary in granularity
Program $P$ interacts with two relational databases $D_k$ and $D_l$.
Program $P$ can view and/or modify the state of the database
Database Interaction Faults: (1-v)

$P$ uses **update** or **insert** to incorrectly modify items within database.

- Commission fault that violates database validity.
- Structural adequacy criteria can support fault isolation.
Database Interaction Faults: (1-c)

- $P$ uses `delete` to remove incorrect items from database.
- Commission fault that violates database completeness.
- Structural adequacy criteria can support fault isolation.
Database Interaction Faults: (2-v)

$P$ does not submit delete to remove items from database

Commission or omission fault that violates database validity

Structural adequacy criteria cannot easily support omission fault isolation
Database Interaction Faults: (2-c)

- $P$ does not submit update or insert to database
- Commission or omission fault that violates database completeness
- Structural adequacy criteria cannot easily support omission fault isolation
A program can interact with a relational database at different levels of granularity.
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**Database Interaction Levels**

**UserInfo**

<table>
<thead>
<tr>
<th>card_number</th>
<th>pin_number</th>
<th>user_name</th>
<th>acct_lock</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32142</td>
<td>Brian Zorman</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>41601</td>
<td>Robert Roos</td>
<td>0</td>
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<tr>
<td>3</td>
<td>45322</td>
<td>Marcus Bittman</td>
<td>0</td>
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<tr>
<td>4</td>
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A program can interact with a relational database at different levels of granularity.

### Database Interaction Levels

#### P

#### D₁

#### Dₙ

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#### Attribute Level
A program can interact with a relational database at different levels of granularity.
Database Interaction Points: DML

\[
\text{select } A_1, A_2, \ldots, A_q \\
\text{from } r_1, r_2, \ldots, r_m \\
\text{where } Q
\]

\[
\text{delete from } r \\
\text{where } Q
\]

\[
\text{insert into } r(A_1, A_2, \ldots, A_q) \\
\text{values}(v_1, v_2, \ldots, v_q)
\]

\[
\text{update } r \\
\text{set } A_l = F(A_l) \\
\text{where } Q
\]
Analyzing Database Interaction Points

- Database interaction point \( I_r \in I \) corresponds to the execution of a SQL DML statement.
- Consider the relevant portions of SQL that are parsed by HSQLDB (http://hsqldb.sf.net).
- Interaction points are normally encoded within Java programs as dynamically constructed Strings.
- Select uses \( D_k \), delete defines \( D_k \), insert defines \( D_k \), update defines and/or uses \( D_k \).
select * from $R_1$
where $A < (select \ \text{avg}(G) \ \text{from} \ R_2)$

update $R_3$
set $J = 500$
where $L < 1000$
Test Adequacy Concepts

- $P$ violates a database $D_k$’s validity when it:
  - (1-v) inserts entities into $D_k$ that do not reflect real world

- $P$ violates a database $D_k$’s completeness when it:
  - (1-c) deletes entities from $D_k$ that still reflect real world

- In order to verify (1-v) and (1-c), $T$ must cause $P$ to define and then use entities within $D_1, \ldots, D_n$!
Data Flow Information

- Interaction point:
  "UPDATE UserInfo SET acct_lock = 1 WHERE card_number =” + card_number + “;”;
  
  - Database Level: define(BankDB)
  - Attribute Level: define(acct_lock) and use(card_number)

- Data fbw information varies with respect to the granularity of the database interaction
## Database Entities

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\[ A_v(I_r) = \{ 1, 32142, \ldots, \text{Geoffrey Arnold}, 0 \} \]

→ Enumerate database entities at the attribute value level
Application Types

- Testing methodology relevant to all types of applications
- Current tool support focuses on Interface-Outside applications

**Example:** Java application that submits SQL Strings to HSQLDB relational database using JDBC drivers
The DICFG: A Unified Representation

"Database-enhanced" CFG for lockAccount

Automatically constructed with tool support

Define temporaries to represent the program's interaction at the levels of database and attribute
Database interaction graphs (DIGs) are placed before interaction point $I_r$.

- Multiple DIGs can be integrated into a single CFG.

- String at $I_r$ is determined in a control-flow sensitive fashion using enhanced BRICS JSA.
Iteratively construct a database aware CFG to support data flow analysis and enumerate test requirements.
Database interaction association (DIA) involves the \textit{def} and \textit{use} of a database entity.

- DIAs can be located in the DICFG with data flow analysis.
- \textit{all-database-DUs} requires tests to exercise all DIAs for all of the accessed databases.
Generating Test Requirements

- Measured time and space overhead when computing family of test adequacy criteria
- Modified ATM and mp3cd to contain appropriate database interaction points
- Soot 1.2.5 to calculate intraprocedural associations
- GNU/Linux workstation with kernel 2.4.18-smp and dual 1 GHz Pentium III Xeon processors
Experiment Goals and Design

- **Research Question One**: Does the incorporation of database interactions yield more test requirements?

- **Research Question Two**: Can test requirement enumeration be performed efficiently if database interactions are included?

- **Experiment Metrics**: Number of test requirements ($\mathcal{TR}$), time overhead ($\mathcal{T}$), and space overhead ($\mathcal{S}$)

- **Applications**: ATM (1732 NCSS and 136 methods) and mp3cd (2913 NCSS and 452 methods)
Number of Test Requirements: ATM

80.7% increase in number of test requirements from $D$ to $A_v$
92.5\% increase in number of test requirements from $D$ to $A_v$
Time Overhead: ATM

→ 2.7% increase in time overhead from $P$ to $P + A_v$

A Test Adequacy Infrastructure with Database Interaction Awareness, UCSB, November 7, 2005 – p. 26/35
Time Overhead: mp3cd

14.4% increase in time overhead from $P$ to $P + A_v$
Space Overhead: ATM

Average number of {DI}CFG nodes and edges is stable
mp3cd has more database interactions and larger database
## Average Increase in CFG Nodes

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<thead>
<tr>
<th></th>
<th>$SN_I^% (R, D)$</th>
<th>$SN_I^% (R_c, R)$</th>
<th>$SN_I^% (A, R)$</th>
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<tr>
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<td>.6</td>
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<tr>
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<table>
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<tr>
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<th>$SN_I^% (A_v, A)$</th>
<th>$SN_I^% (A_v, D)$</th>
<th>$SN_I^% (A_v, P)$</th>
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<td>7.5</td>
<td>5.8</td>
<td>10.4</td>
<td>12.2</td>
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<tr>
<td>mp3cd</td>
<td>15.5</td>
<td>10.2</td>
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## Average Increase in CFG Edges

<table>
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<th></th>
<th>( SE_T% (R, D) )</th>
<th>( SE_T% (R_c, R) )</th>
<th>( SE_T% (A, R) )</th>
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<tbody>
<tr>
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<tr>
<td>mp3cd</td>
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<th></th>
<th>( SE_T% (A_v, R_c) )</th>
<th>( SE_T% (A_v, A) )</th>
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<td>16.7</td>
<td>11.0</td>
<td>22.1</td>
<td>23.8</td>
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Related Work

- Jin and Offutt and Whittaker and Voas have suggested that the environment of a software system is important.
- Chan and Cheung transform SQL statements into C code segments.
- Chays et al. and Chays and Deng have created the category-partition inspired AGENDA tool suite.
- Neufeld et al. and Zhang et al. have proposed techniques for database state generation.
- Dauo et al. focused on the regression testing of database-driven applications.
Ongoing Research

- Test suite execution that minimizes number of costly database restarts and initializations
- Test coverage monitoring through a database interaction calling context tree (DICCT)
- Regression test suite reduction and prioritization that incorporates database aware adequacy and test case cost
- Detailed empirical studies with ten case study applications of varying code and database size
- Comprehensive tool support to assist the testing of database-centric applications
Conclusions

- Must test the program’s interaction with the database
- Test adequacy infrastructure provides: (i) database interaction fault model, (ii) unified application representation, (iii) family of test adequacy criteria
- Unique family of test adequacy criteria to detect all type (1) and some type (2) violations of database validity and completeness
- Intraprocedural database interactions can be computed from a DICFG with minimal time and space overhead
- Foundation for a complete testing methodology
Further Resources


http://cs.allegheny.edu/~gkapfham/research/diatoms/