Command-form Coverage for Testing DB Applications

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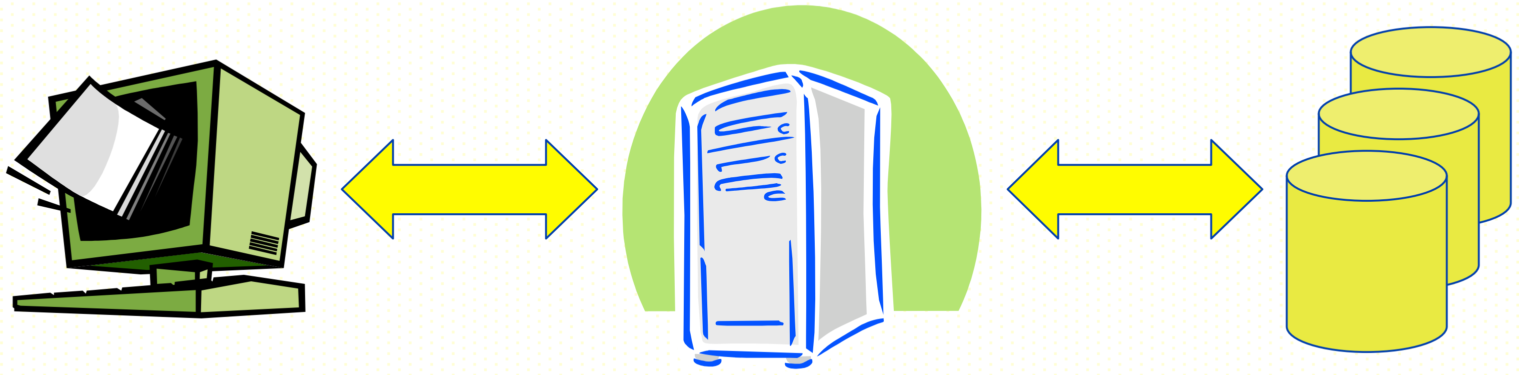
A Database Application



A Database Application

```
ResultSet srchBook(String searchString,
   int searchType, bool showRating,
   bool grpByRating, bool grpByISBN) {
 String[] srchFields =
   {"tiitle", "author", "isbn"};
 String queryStr =
   "SELECT title, author, description";
 if (showRating)
   queryStr += ", avg(rating) ";
 queryStr += "FROM books WHERE ";
 if (searchType==2)
   queryStr += srchFields[searchType] +
   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '" + searchString + "' ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
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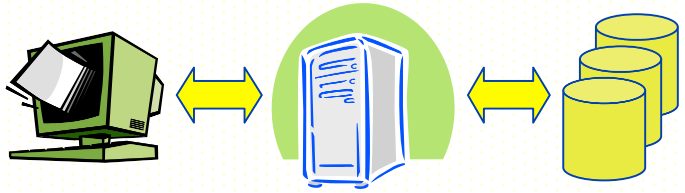
 return db.executeQuery(queryStr);
}
```



1) SELECT title, author, description, avg(rating) FROM books WHERE isbn = **<*>** GROUP BY isbn

2) SELECT title, author, description, avg(rating) FROM books WHERE author = '**<*>**'

:

18) SELECT title, author, description, avg(rating) FROM books WHERE author = '**<*>**' GROUP BY rating

Faults in Generated DB Commands

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ResultSet srchBook(String searchString,
   int searchType, bool showRating,
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 else
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   + " = ’“ + searchString + "’ ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
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1. Misspelled column name “tiitle,”
2. Missing delimiter for a concatenation
3. Lack of “GROUP BY” clause for grouping function
4. Missing delimiter unless one specific line is executed

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 else
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   + " = ’“ + searchString + "’ ";
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   queryStr += " GROUP BY isbn ";
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 String queryStr =
   "SELECT title, author, description";
 if (showRating)
   queryStr += ", avg(rating) ";
 queryStr += "FROM books WHERE ";
 if (searchType==2)
   queryStr += srchFields[searchType] +
   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '“ + searchString + "'  ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
```

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Traditional Testing

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 String queryStr =
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 queryStr += "FROM books WHERE ";
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   queryStr += searchFields[searchType]
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   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
```

Test Cases

Queries Generated

Faults Revealed

Traditional Testing

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ResultSet srchBook(String searchString,
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 String[] srchFields =
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   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '" + searchString + "' ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
```

Test Cases

1. ("0123", 2, false, false, true)

Queries Generated

1. SELECT title, author, descriptionFROM books WHERE isbn = 0123 GROUP BY isbn

Faults Revealed

1. #4

Traditional Testing

```
ResultSet srchBook(String searchString,
   int searchType, bool showRating,
   bool grpByRating, bool grpByISBN) {
 String[] srchFields =
   {"tiitle", "author", "isbn"};
 String queryStr =
   "SELECT title, author, description";
 if (showRating)
   queryStr += ", avg(rating) ";
 queryStr += "FROM books WHERE ";
 if (searchType==2)
   queryStr += srchFields[searchType] +
   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '" + searchString + "' ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
```

Test Cases

1. ("0123", 2, false, false, true)
2. ("Poe", 1, false, false, false)

Queries Generated

1. SELECT title, author, descriptionFROM books WHERE isbn = 0123 GROUP BY isbn
2. SELECT title, author, descriptionFROM books WHERE author = 'Poe'

Faults Revealed

1. #4
2. #4

Traditional Testing

```
ResultSet srchBook(String searchString,
   int searchType, bool showRating,
   bool grpByRating, bool grpByISBN) {
 String[] srchFields =
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 String queryStr =
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 if (searchType==2)
   queryStr += srchFields[searchType] +
   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '" + searchString + "' ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
 else if (grpByISBN)
   queryStr += " GROUP BY isbn ";
 return db.executeQuery(queryStr);
}
```

Test Cases

1. ("0123", 2, false, false, true)
2. ("Poe", 1, false, false, false)
3. ("Poe", 1, true, true, false)

Queries Generated

1. SELECT title, author, descriptionFROM books WHERE isbn = 0123 GROUP BY isbn
2. SELECT title, author, descriptionFROM books WHERE author = 'Poe'
3. SELECT title, author, description, avg(rating) FROM books WHERE author = 'Poe' GROUP BY rating

Faults Revealed

1. #4
2. #4
3. None

Traditional Testing

```
ResultSet srchBook(String searchString,
   int searchType, bool showRating,
   bool grpByRating, bool grpByISBN) {
 String[] srchFields =
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 String queryStr =
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 queryStr += "FROM books WHERE ";
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   " = " + searchString;
 else
   queryStr += searchFields[searchType]
   + " = '" + searchString + "' ";
 if (grpByRating)
   queryStr += "GROUP BY rating ";
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 return db.executeQuery(queryStr);
}
```

Test Cases

1. ("0123", 2, false, false, true)
2. ("Poe", 1, false, false, false)
3. ("Poe", 1, true, true, false)

Queries Generated

1. SELECT title, author, descriptionFROM books WHERE isbn = 0123 GROUP BY isbn
2. SELECT title, author, descriptionFROM books WHERE author = 'Poe'
3. SELECT title, author, description, avg(rating) FROM books WHERE author = 'Poe' GROUP BY rating

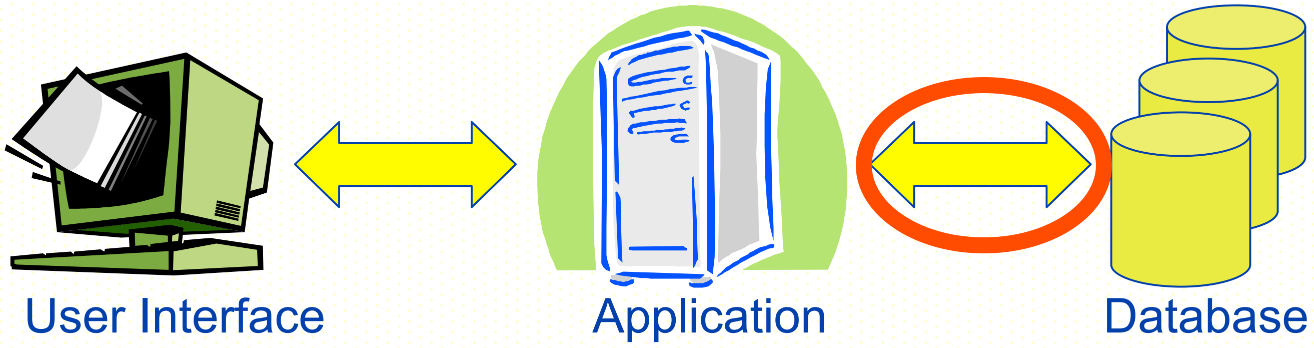
Faults Revealed

1. #4
2. #4
3. None

Outline

- Motivation and background
- Command-form coverage
- DITTO coverage tool
- Empirical evaluation
- Conclusion and future work

DB Command-form

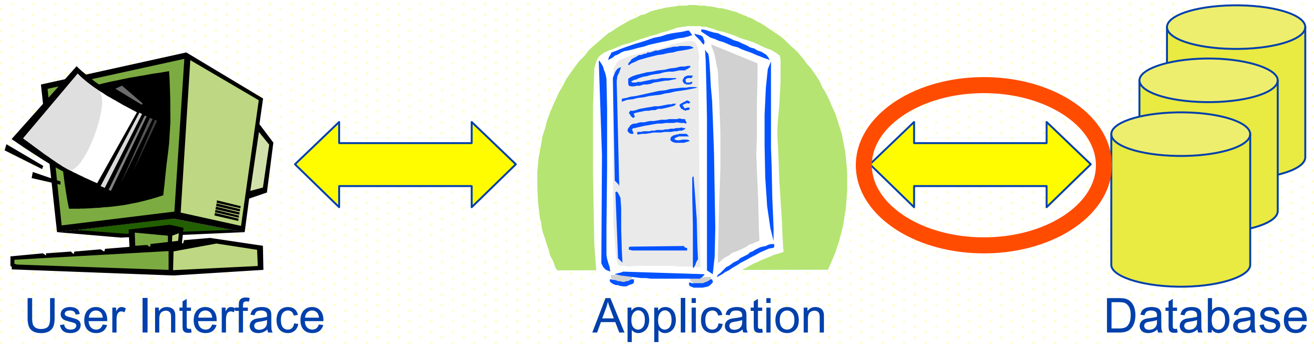


Given a DB application:

(Database) command form: Equivalence class that groups database commands, generated by the application, that differ only in the possible value of their indeterminate parts

Indeterminate part: Part of a command form that cannot be determined statically (substrings that correspond to user input)

DB Command-form



Given a DB application:

(Database) command form: Equivalence class that groups database commands, generated by the application, that differ only in the possible value of their indeterminate parts

Example:

*SELECT title, author, description FROM books WHERE author = '**Poe**'*

*SELECT title, author, description FROM books WHERE author = '**Capote**'*

*SELECT title, author, description FROM books WHERE author = '**Dante**'*

=> *SELECT title, author, description FROM books WHERE author = '**<*>**'*

Using the Criterion

1. Compute the command forms
2. Collect coverage information at runtime
3. Determine/report coverage information

1. Compute Command Forms

a. Perform string analysis on the application => char-level NFAs for each query string at each DB interaction point
b. Group SQL keywords and operators in NFAs and determinize
=> *SQL command-form models* (DFAs)
c. Assign unique ID to each command form

1. Compute Command Forms

a. Perform string analysis on the application
=> char-level NFAs for each query string at each DB interaction point

b. Group SQL keywords and operators in NFAs and determinize
=> *SQL command-form models* (DFAs)

c. Assign unique ID to each command form

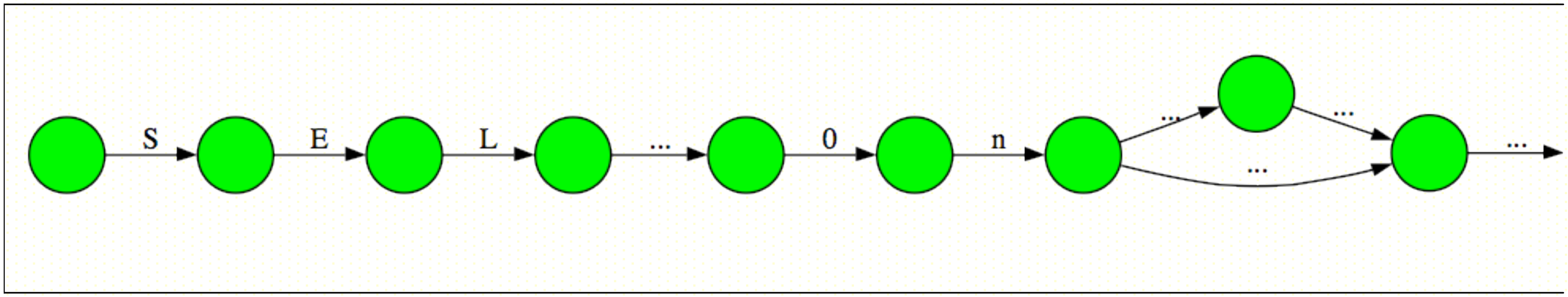
String Analysis

String analysis => NFAs for strings at DB interaction points

```
public ResultSet searchBooks(String searchString, int
    searchType, boolean showRating, boolean groupByRating,
    boolean groupByISBN) {

    String[] searchFields = {"tiitle", "author", "isbn"};
    String queryStr= "SELECT title, author, description";
    if (showRating)
        queryStr += ", avg(rating) ";
    ...
    return database.executeQuery(queryStr);
```

[Christensen, Møller, and Schwartzbach 2003]



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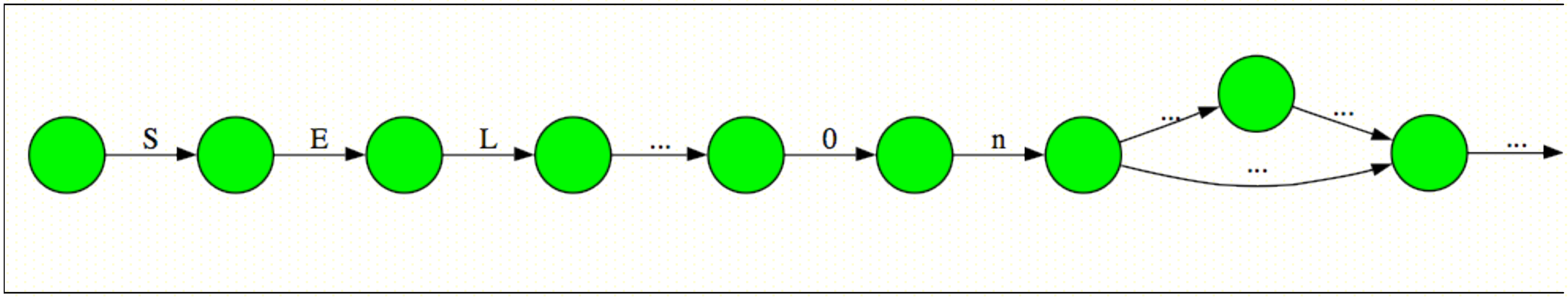
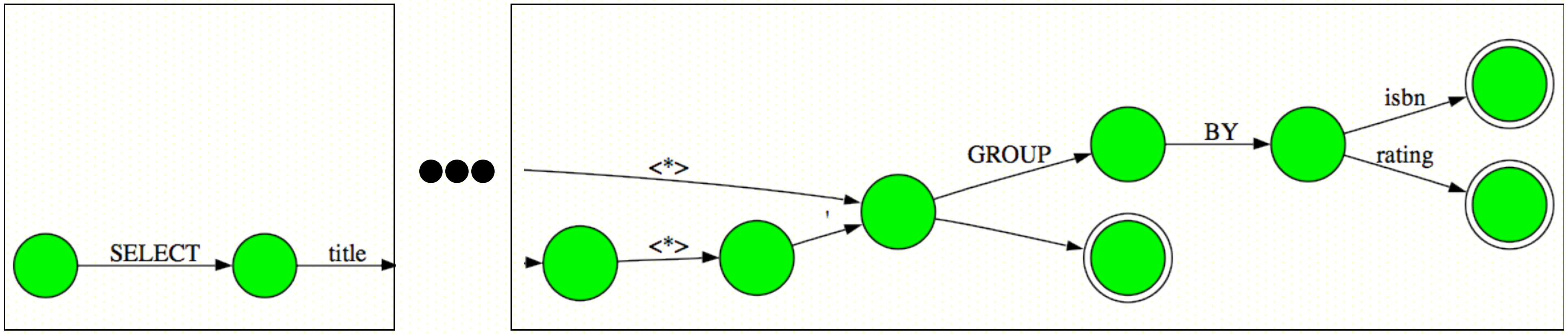
Build Command-form Models

Group SQL keywords/operators => SQL command-form models



Build Command-form Models

Group SQL keywords/operators => SQL command-form models



By construction, a path in the model identifies a command form (concatenation of transition labels)

=> The complete set of command forms (i.e., requirements) is given by the set of paths in all models

1. Compute Command Forms

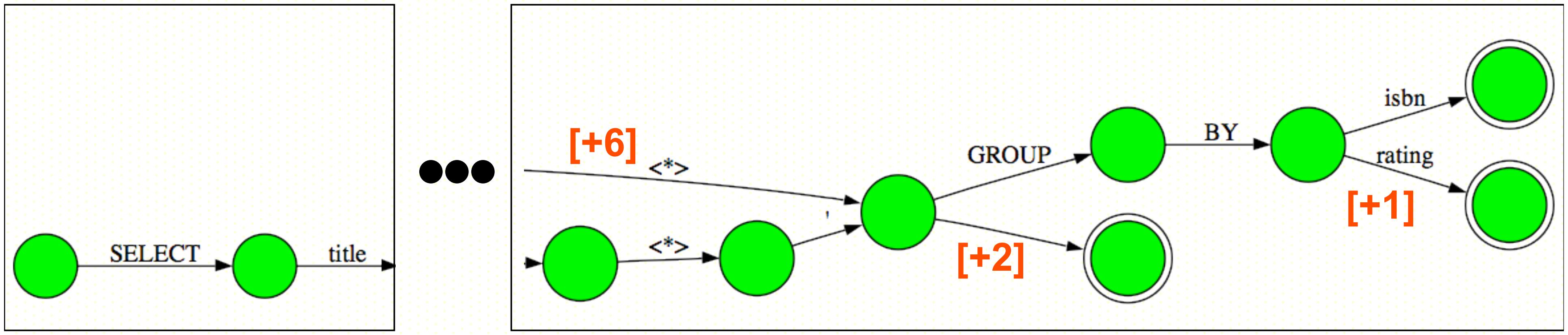
a. Perform string analysis on the application => char-level NFAs for each query string at each DB interaction point

b. Group SQL keywords and operators in NFAs and determinize => *SQL command-form models* (DFAs)

c. Assign unique ID to each command form

Assign Command-form IDs

Assign unique ID to each command form



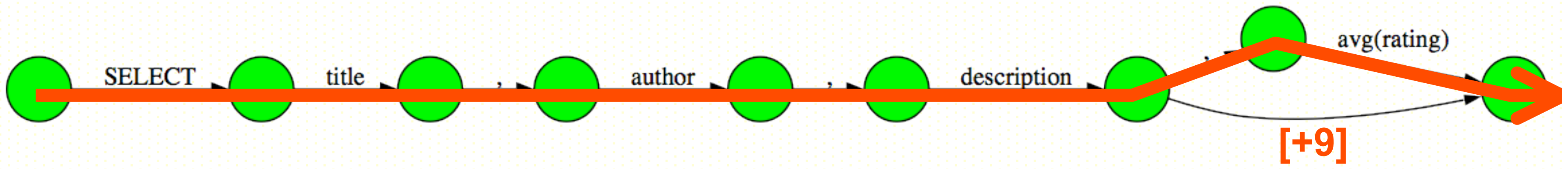
[Ball and Larus 1996]

- Efficient path-profiling technique => edge labels
- Sum of edge labels along a path gives unique ID for the path (i.e., for the corresponding command form)
  - No need to enumerate all forms
  - Straightforward computation of coverage

2. Collect Coverage Information

At runtime: Match dynamically-generated queries to command forms (i.e., to paths in the command-form models)

Query: SELECT title , author , description , avg(rating) FROM books WHERE author = ' **Poe** ' GROUP BY rating



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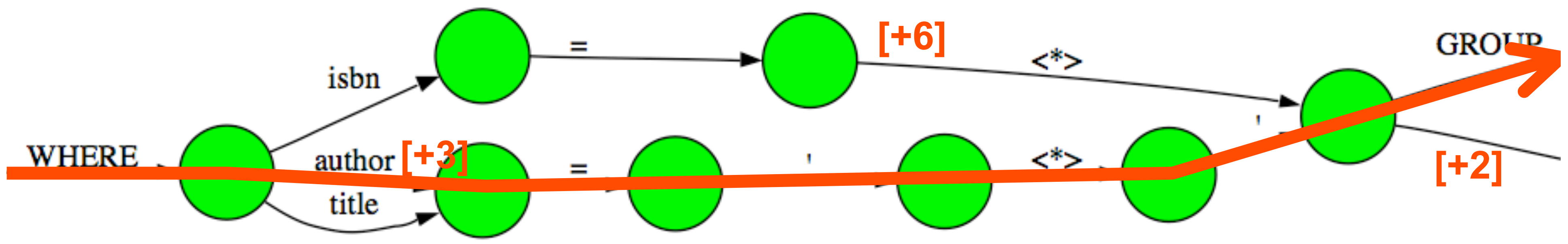


2. Collect Coverage Information

At runtime: Match dynamically-generated queries to command forms (i.e., to paths in the command-form models)

Query:

SELECT title , author , description , avg(rating) FROM books WHERE author = ' **Poe** ' GROUP BY rating

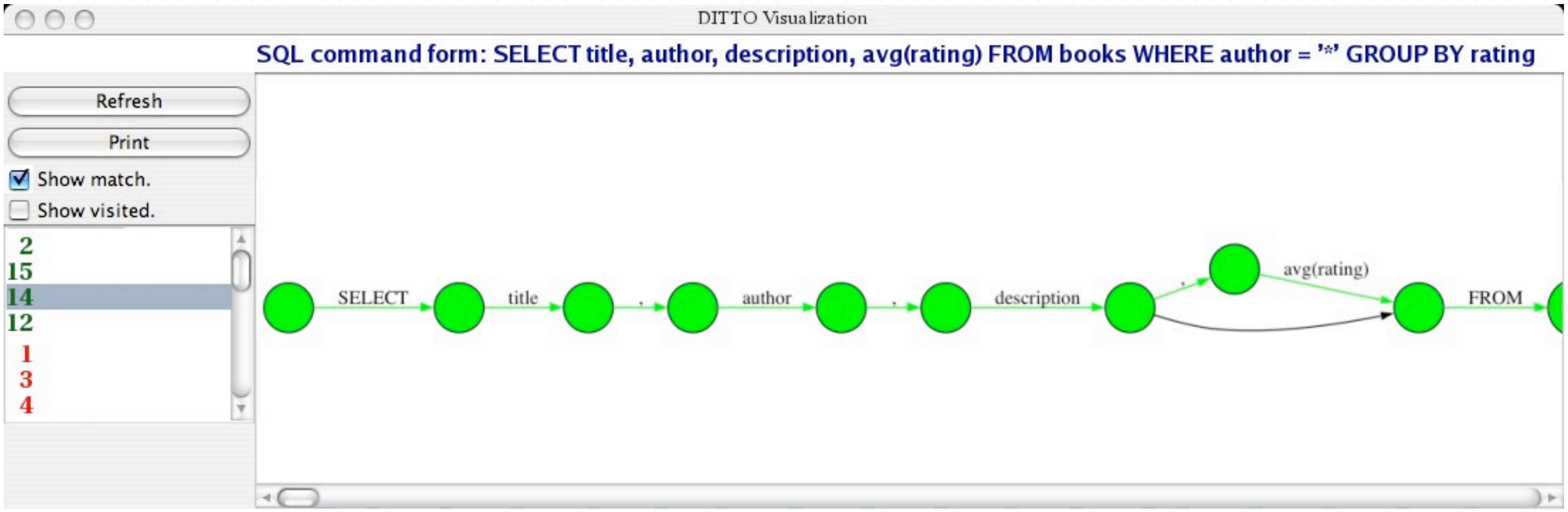
covers

Command form:

SELECT title, author, description, avg(rating) FROM books WHERE author = '**<*>**' GROUP BY rating

3. Coverage Analysis and Feedback

$$\text{Coverage} = \frac{\text{number of command forms covered}}{\text{total number of command forms}}$$

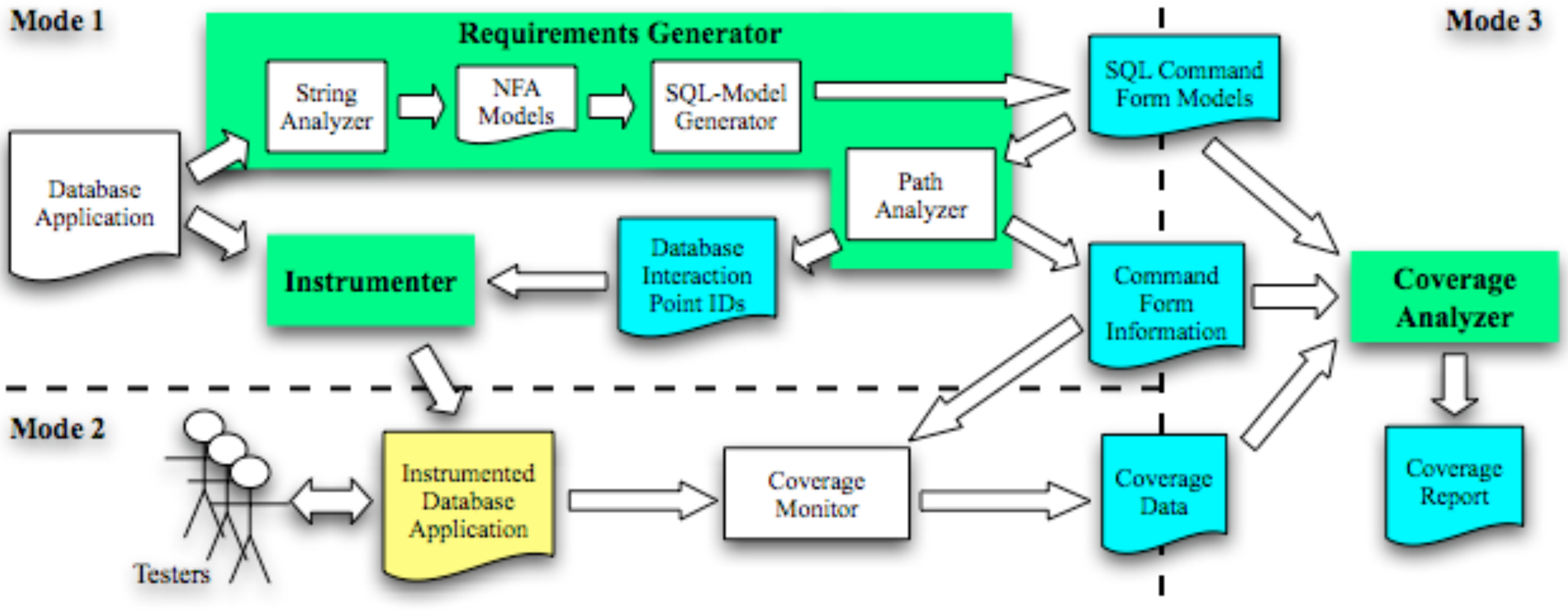


DITTO Visualization

SQL command form: SELECT title, author, description, avg(rating) FROM books WHERE author = '*' GROUP BY rating

The DITTO Coverage Tool

Database-Interaction Testing TOol



Empirical Evaluation

- **Study 1**: Perform a proof-of-concept evaluation on a commercial application and test suite
- **Study 2**: Investigate whether command-form coverage provides for a more thorough testing of database applications than traditional approaches

Study 1 — Feasibility

- Is the approach feasible?
- What is the command-form coverage achieved by the existing test suite?

Subject: Bookstore

- 27 servlets, ~17 KLOC

Test cases: Test suite from related work

- ~7,000 test cases

Results:

- DITTO was able to compute command forms and measure command-form coverage for the test suite
- Command-form coverage between 1% and 13%

=> Initial evidence that command-form coverage cannot be trivially achieved

Study 2 — Usefulness

- Is command-form coverage useful?
- Does it provide something more than traditional testing?

- Compare with a traditional criterion (branch coverage)
- Ideally, compare fault detection capability, but
  - few data points for real faults
  - difficult to seed faults in an unbiased way

=> Indirect comparison through estimation

Study 2: Protocol

Estimate number of command forms covered by a branch-adequate test suite for Bookstore (B)

- Compute total number of command forms for B
- Identify subset B' of B involved in building command forms; backward slices from DB interaction points
- Estimate the number of test cases needed to cover all branches in B'; cyclomatic complexity (overestimate)
- Assume each test case covers one command form (overestimate)
- Compare estimated number of command forms covered and total number of command forms

Results for Study 2

Servlet	*# DIP*	*# command forms*	*Estimated # comm. forms covered by branch-adequate test suite*
MyInfo	1	6	all
BookDetail	4	1583	150
AdminBooks	1	617	31
OrdersGrid	1	394	26
ShoppingCart	2	20	all
AdminMenu	1	1	all
MembersGrid	1	162	21

Related Work

Specific coverage for DB applications

- Chan and Cheung, 1999
- Kapfhammer and Soffa, 2003
- Suárez-Cabal and Tuya, 2004
- Willmor and Embury, 2005

Static checking of DB applications

- Christensen, Møller, and Schartzbachthe, 2003
- Gould, Su, and Devanbu, 2004

Other paradigms

- McClure and Krüger, 2005
- Cook and Rai, 2005

Test case generation for DB applications

- Frankl et al., 2000, 2004, 2005
- Zhang, Xu, and Cheung, 2001

Conclusion and Future Work

Conclusion

- Technique to adequately test DB applications (in particular, interactions application-DB)
- Approach based on command-form coverage
- DITTO tool that implements the approach
- Initial evaluation
  - Approach is feasible
  - Approach is potentially useful

Future work

- More extensive empirical studies
  - More subjects
  - Direct comparison with other criteria
- Improvement of the technique by leveraging info about the DB (e.g., DB schema)

Questions?