

Localizing SQL Faults in Database Applications

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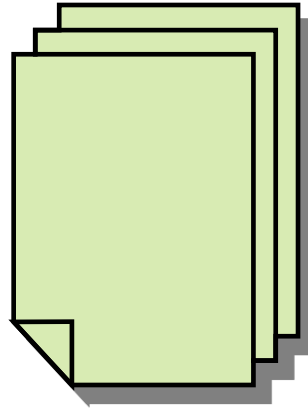
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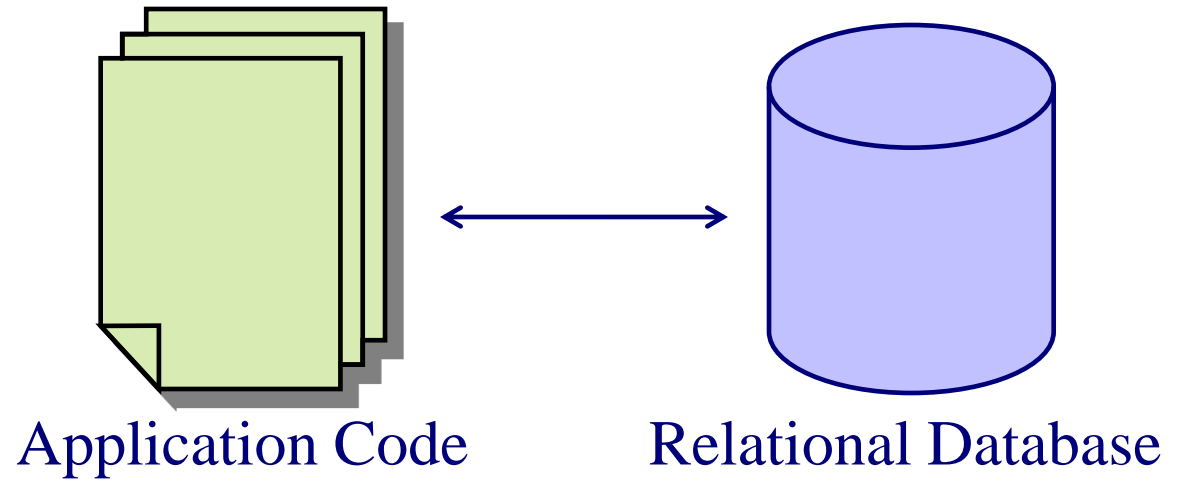
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Real-World Software Applications

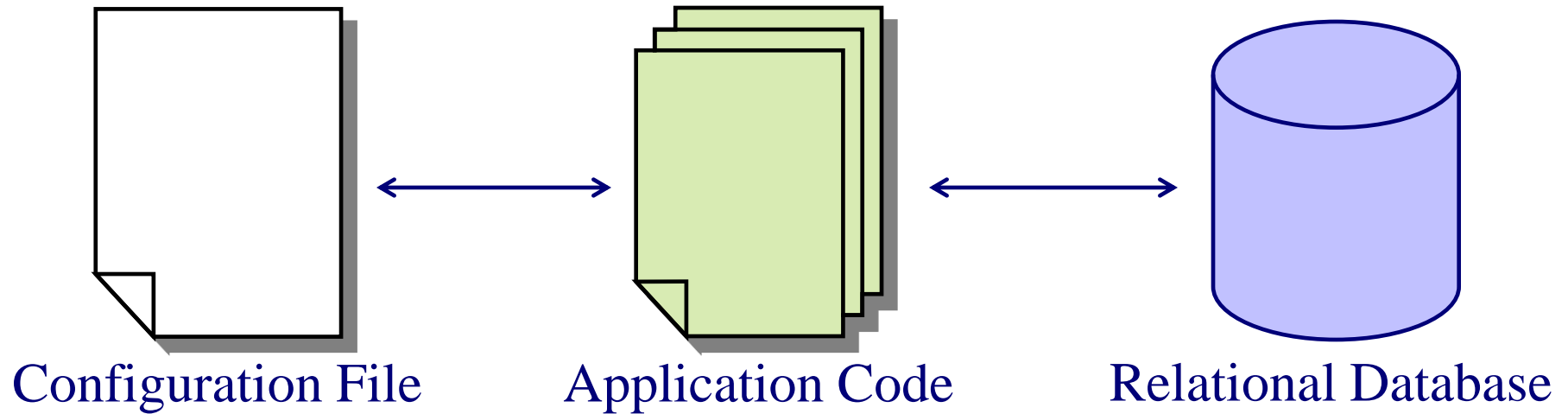


Application Code

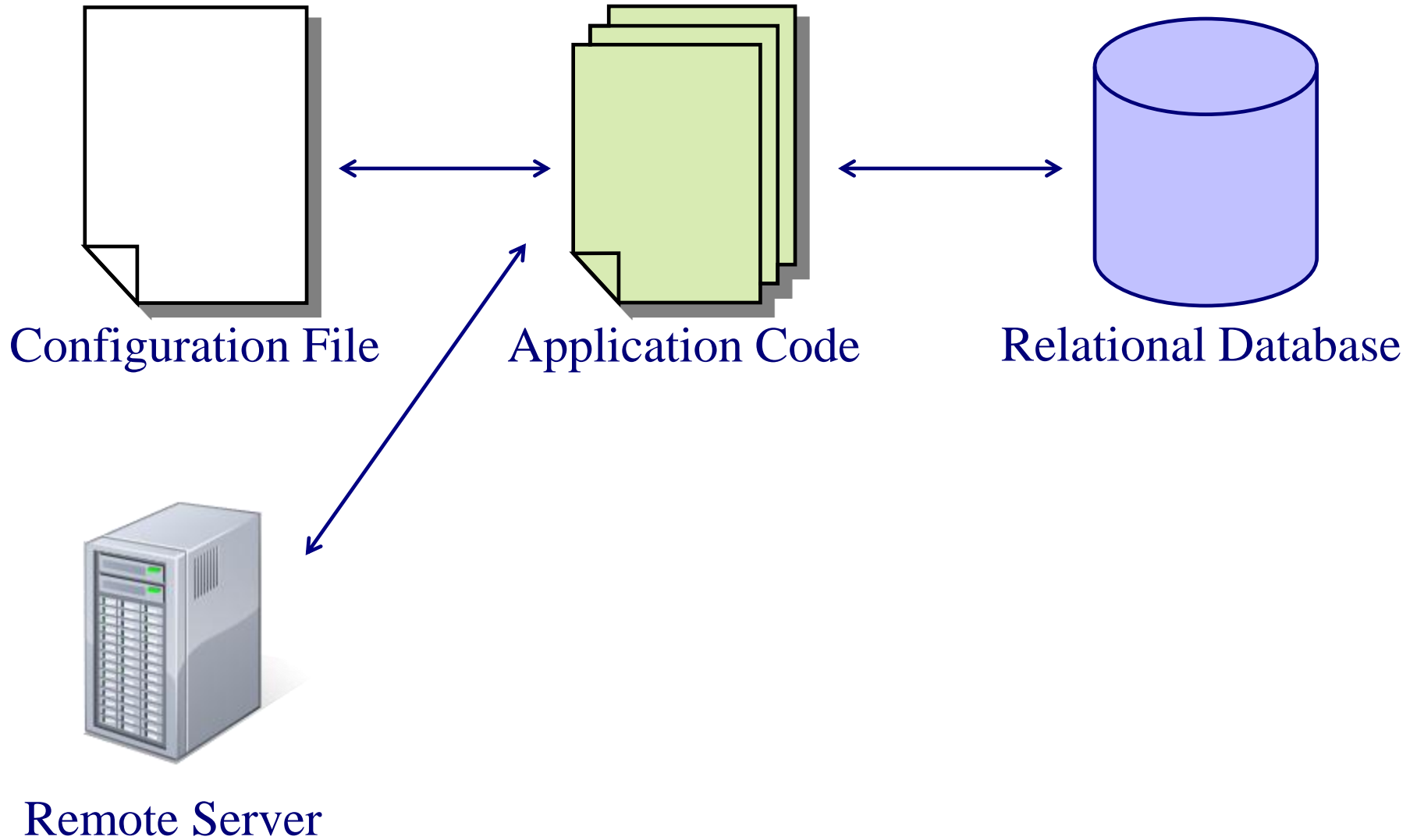
Real-World Software Applications



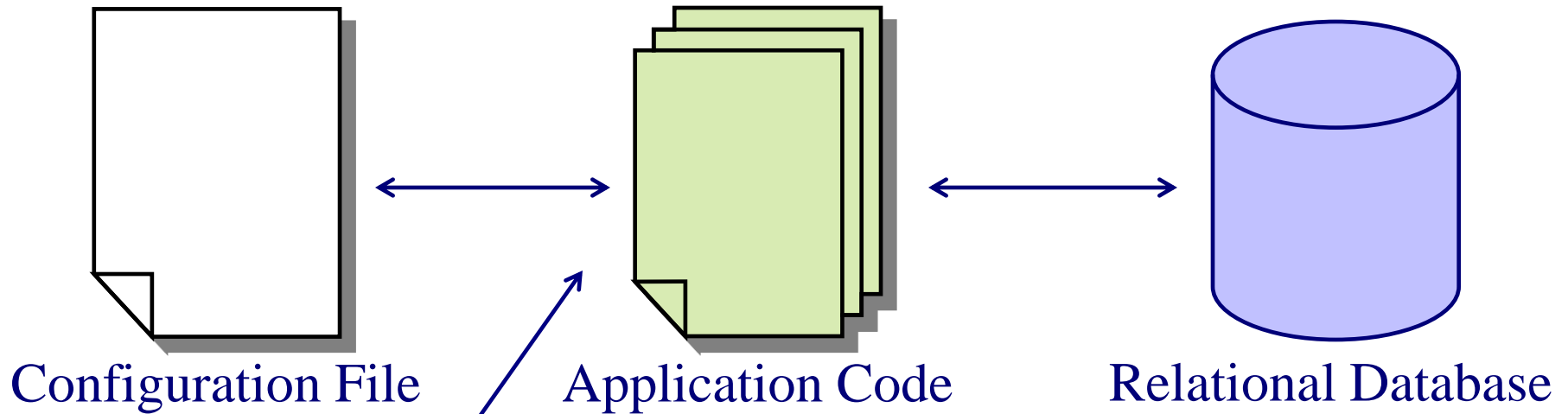
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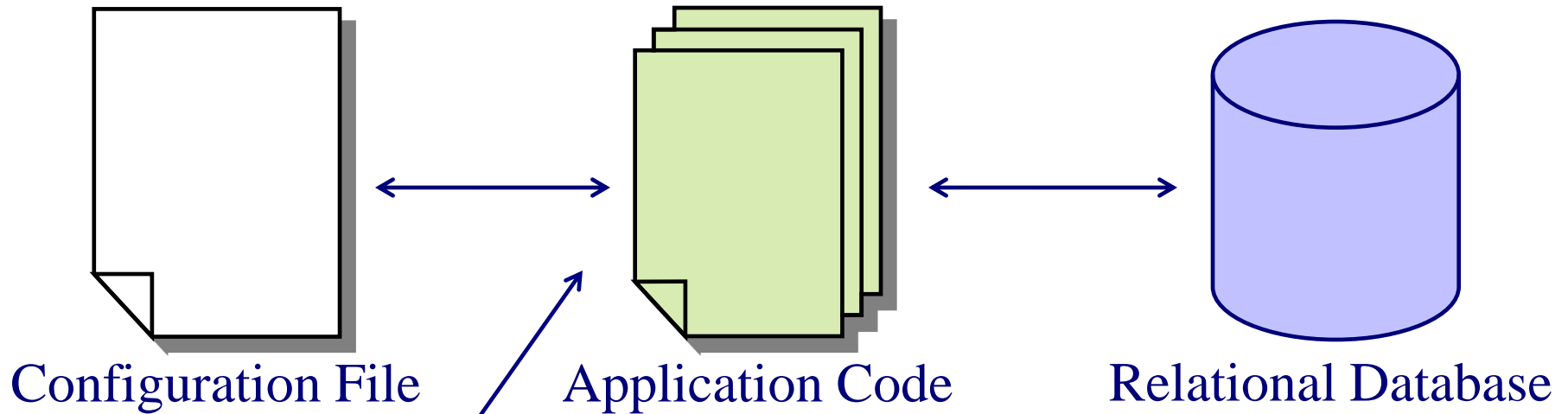


Remote Server

Key Observations

- The database is an essential component of real-world software
- Brooks and colleagues report that the most common errors in three real-world industrial systems involve database interactions (ICST 2009)

Real-World Software Applications



Remote Server

Important Questions

- How well do existing fault-localization techniques perform for commonly implemented database applications?
- Does the use of additional information about the database improve the effectiveness of these methods?

Motivating Example

```
printProdsold(String uType, String uID) {  
1:String attr=conf.getAttr(uType,uID) ;  
2:String whereClause=conf.getWhere(uType,uID) ;  
3:String SQL="SELECT "+attr+  
           "FROM Sale Where "+whereClause;  
4:PreparedStatement ps=new PreparedStatement() ;  
5:ResultSet rs=ps.executeQuery(SQL) ;  
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}
```


Motivating Example

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```

MID	CID	PROD	PRICE
1	1	Soda	\$0.99
1	3	Cheese	3.99
2	2	Hammer	5.00
2	3	Nails	0.50

Database Table

Motivating Example

```
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uType	Merchant (M)
attr	PRODUCT, PRICE
whereClause	MID>=uID
uType	Customer (C)
attr	PRODUCT, PRICE
whereClause	CID=uID

Configuration File

Motivating Example

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```

Error in the
whereClause!

>=

should be

=

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Statistical Fault Localization

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```

Techniques use:

Dynamic information

- statements executed
- outcome (pass/fail)

Statistical analysis

- computes suspiciousness of each statement

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Pass/Fail Status	F	P	P	P	P

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```

M,1	M,2	C,1	C,2	C,3
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
F	P	P	P	P

suspiciousness

Pass/Fail Status

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<code>printProdsold(String uType, String uID) {</code>	M,1	M,2	C,1	C,2	C,3	suspiciousness
<code>1:String attr=conf.getAttr(uType,uID);</code>	•	•	•	•	•	0.45
<code>2:String whereClause=conf.getWhere(uType,uID);</code>	•	•	•	•	•	0.45
<code>3:String SQL="SELECT "+attr+</code>	•	•	•	•	•	0.45
<code> "FROM Sale Where "+whereClause;</code>	•	•	•	•	•	0.45
<code>4:PreparedStatement ps=new PreparedStatement();</code>	•	•	•	•	•	0.45
<code>5:ResultSet rs=ps.executeQuery(SQL);</code>	•	•	•	•	•	0.45
<code>6:printResultSet(rs);</code>	•	•	•	•	•	0.45
<code>}</code>						
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```

printProdsold(String uType, String uID) {
1:String attr=conf.getAttr(uType,uID);
2:String whereClause="MID>=uID";
3:String SQL="SELECT * FROM PRODUCT WHERE "+whereClause;
4:PreparedStatement stmt=conn.prepareStatement(SQL);
5:ResultSet res=stmt.executeQuery();
6:printResults(res);
}
    
```

	M,1	M,2	C,1	C,2	C,3	suspiciousness
1	•	•	•	•	•	0.45
2	•	•	•	•	•	0.45
3	•	•	•	•	•	0.45
4	•	•	•	•	•	0.45
5	•	•	•	•	•	0.45
6	•	•	•	•	•	0.45
					P	

Important Challenges to Overcome

- Statistical fault-localization assigns the same suspiciousness scores to all of the statements
- Existing methods do not consider the state or structure of the database

MID	CID	PRODUCT	PRICE
1	1	Soda	0.99
1	3	Cheese	3.99
2	2	Hammer	5.00
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whereClause	MID>=uID
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Statistical Fault Localization

	M,1	M,2	C,1	C,2	C,3	suspiciousness
<code>printProdsold(String uType, String uID) {</code>						
<code>1:String attr=conf.getAttr(uType,uID);</code>	•	•	•	•	•	0.45
<code>2:String whereClause=conf.getWhereClause(uType,uID);</code>				•	•	0.45
<code>3:String SQL=conf.getSQL(uType,uID,whereClause);</code>					•	0.45
<code>4:PreparedStatement stmt=conn.prepareStatement(SQL);</code>					•	0.45
<code>5:ResultSet rs=stmt.executeQuery();</code>					•	0.45
<code>6:printResults(rs);</code>					•	0.45
<code>}</code>					P	

Our database-aware fault-localization technique has two goals for SQL faults

- 1. Localize on the faulty statement-SQL or statement-attribute tuple**
- 2. Provide extra information about the SQL commands executed by tests**

MID	CID	PRODUCT	PRICE
1	1	S	1.99
1	3	Cheese	3.99
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uType	whereClause	SQL
Customer (C)	MID>=uID	SELECT * FROM PRODUCT WHERE MID>=uID
PRODUCT, PRICE	CID=uID	SELECT * FROM PRODUCT WHERE MID>=uID AND CID=uID

Outline for the Rest of the Presentation

- Our Technique
 - Definitions
 - Algorithm
- Empirical Studies
- Conclusion

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Our Technique—Definitions

Database Interaction Point

Location in the source code where control and data transfer from the application to the database and back

```
printProdsold(String uType,  
1:String attr=conf.getAttr(uT  
2:String whereClause=conf.get  
3:String SQL="SELECT "+attr+  
        "FROM Sale Where "+whereClause;  
4:PreparedStatement ps=new PreparedStatement();  
5:ResultSet rs=ps.executeQuery(SQL);  
6:printResultSet(rs);  
}
```

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Our Technique—Definitions

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1	3	Cheese	3.99
2	2	Hammer	5.00
2	3	Nails	0.50

uType	Merchant (M)
attr	PRODUCT, PRICE
whereClause	MID>=uID
uType	Customer (C)
attr	PRODUCT, PRICE
whereClause	CID=uID

Our Technique—Definitions

Statement-SQL Tuple

- $\langle s, c \rangle$ where c is an SQL command executed by a statement s
- Record the set of $\langle s, c \rangle$ executed by each test case t in test suite T

```

printProdsold(String uType, String attr,
1:String whereClause,
2:String SQL="SELECT * FROM Sale WHERE " + whereClause,
3:PreparedStatement ps=new PreparedStatement();
4:ResultSet rs=ps.executeQuery(SQL);
5:printResultSet(rs);
}

```

MID	CID	PROD	PRICE
1	1	Soda	\$0.99
1	3	Cheese	3.99
2	2	Hammer	5.00
2	3	Nails	0.50

uType	Merchant (M)
attr	PRODUCT, PRICE
whereClause	MID>=uID
uType	Customer (C)
attr	PRODUCT, PRICE
whereClause	CID=uID

Our Technique—Definitions

```

printProdsold(String attr, String whereClause, String SQL) {
1: String attr=conf.attr;
2: String whereClause=conf.whereClause;
3: String SQL="SELECT PRODUCT, PRICE
    FROM Sale WHERE MID=?";
4: PreparedStatement ps=new PreparedStatement();
5: ResultSet rs=ps.executeQuery(SQL);
6: printResultSet(rs);
}

```

Statement-SQL Tuple

- $\langle s, c \rangle$ where c is an SQL command executed by a statement s
- Record the set of $\langle s, c \rangle$ executed by each test case t in test suite T

MID	attr	whereClause	PRODUCT, PRICE
1			
1			
2	2	Hammer	5.00
2	3	Nails	0.50

$\langle 5, \text{SELECT PRODUCT, PRICE FROM Sale WHERE MID}=? \rangle$

$\langle 5, \text{SELECT PRODUCT, PRICE FROM Sale WHERE CID}=? \rangle$

attr
whereClause
PRODUCT, PRICE
CID=uid

Our Technique—Definitions

Statement-Attribute Tuple

- $\langle s, a \rangle$ where a is an attribute appearing in one or more commands c executed at statement s
- Record the set of $\langle s, a \rangle$ executed by each test case t in test suite T
- Saved only when multiple unique SQL commands are executed at statement s

```

1
2
3
4
5:
6:printResultSet(rs);
}

```

MID	CID	PROD	PRICE
1	1	Soda	\$0.99
1	3	Cheese	3.99
2	2	Hammer	5.00
2	3	Nails	0.50

uType attr whereClause	Merchant (M) PRODUCT, PRICE MID>=uID
uType attr whereClause	Customer (C) PRODUCT, PRICE CID=uID

Our Technique—Definitions

Statement-Attribute Tuple

- $\langle s, a \rangle$ where a is an attribute appearing in one or more commands c executed at statement s
- Record the set of $\langle s, a \rangle$ executed by each test case t in test suite T
- Saved only when multiple unique SQL commands are executed at statement s

1
2
3
4
5:
6:
}

```
printResultSet(rs);
```

MID	CID	PROD	PRICE
1	1	Soda	\$0.99
1	3	Cheese	3.99
2	2	Hammer	5.00
2	3	Nails	0.50

uType attr whereClause	M P M
uType attr whereClause	Customer (C) PRODUCT, PRICE CID=uID

$\langle 5, \text{PRODUCT} \rangle$
 $\langle 5, \text{PRICE} \rangle$
 $\langle 5, \text{MID} \rangle$
 $\langle 5, \text{CID} \rangle$

Our Technique—Algorithm

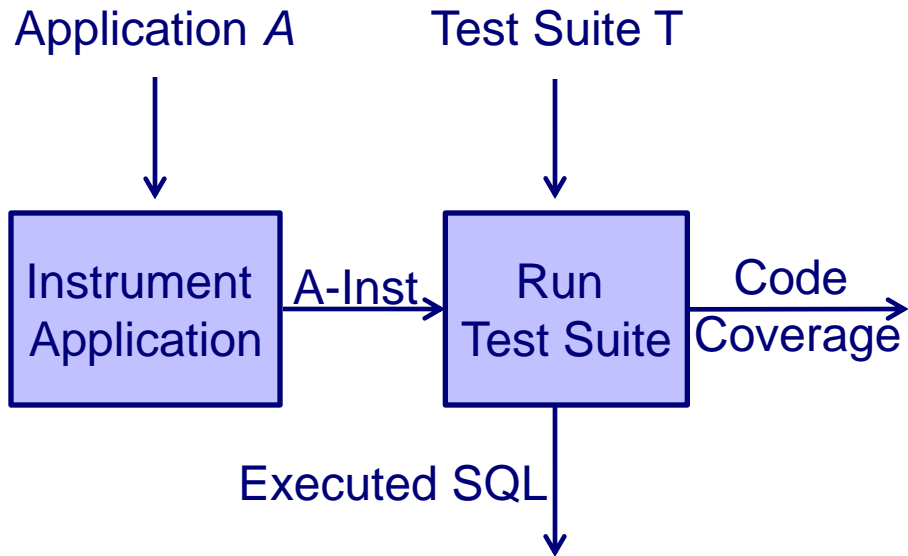
Application A



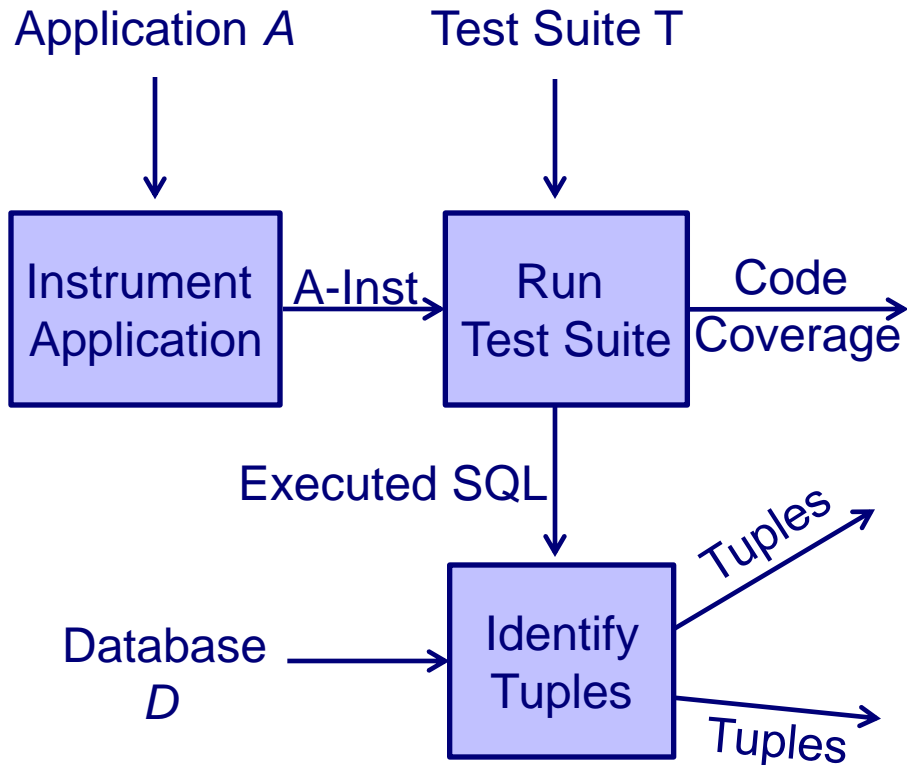
Instrument
Application

A-Inst

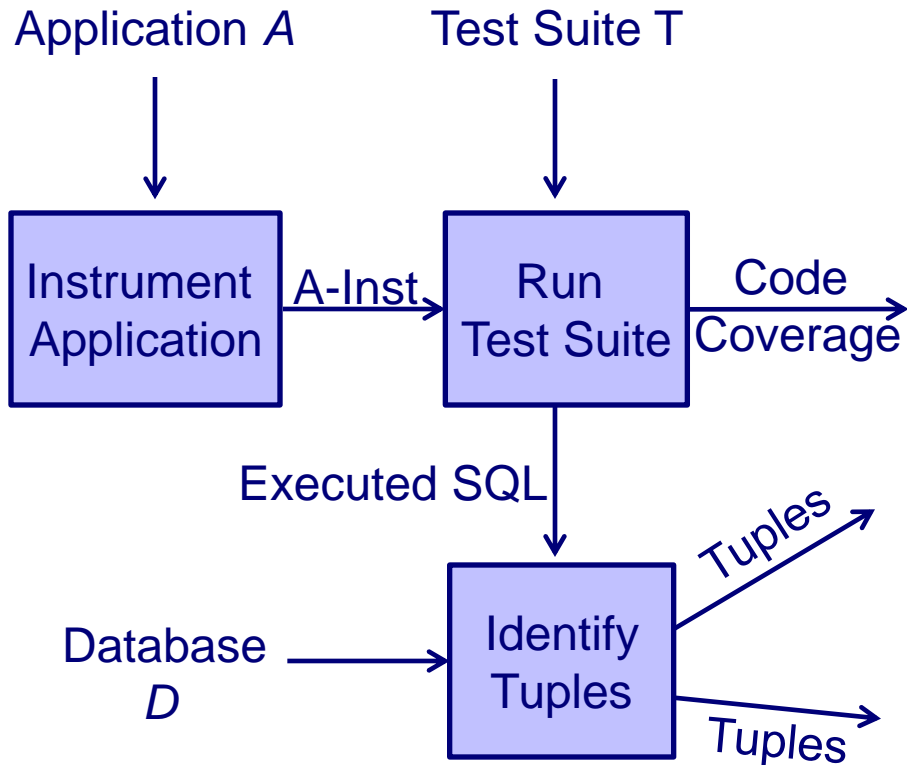
Our Technique—Algorithm



Our Technique—Algorithm



Our Technique—Algorithm



Revisiting the Example

Our Technique—Algorithm Example

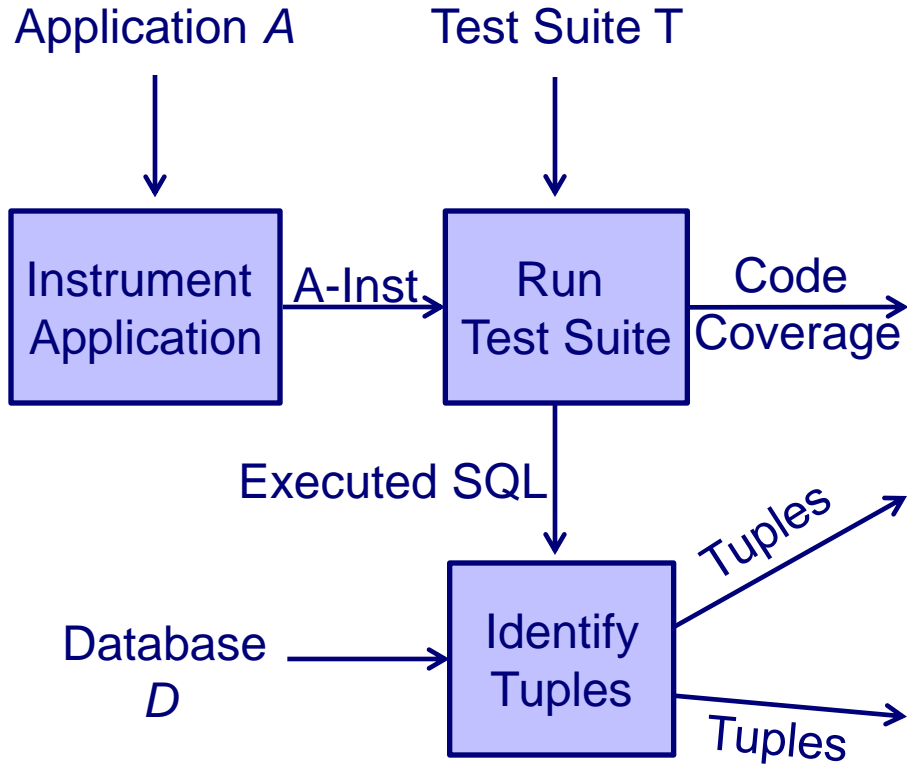
	M,1	M,2	C,1	C,2	C,3
<code>printProdsold(String uType, String uID) {</code>					
<code>1:String attr=conf.getAttr(uType,uID) ;</code>	•	•	•	•	•
<code>2:String whereClause=conf.getWhere(uType,uID) ;</code>	•	•	•	•	•
<code>3:String SQL="SELECT "+attr+</code>	•	•	•	•	•
<code> "FROM Sale Where "+whereClause;</code>	•	•	•	•	•
<code>4:PreparedStatement ps=new PreparedStatement() ;</code>	•	•	•	•	•
<code>5:ResultSet rs=ps.executeQuery(SQL) ;</code>	•	•	•	•	•
<code> <5,SELECT..WHERE MID>=?></code>	•	•			
<code> <5,SELECT..WHERE CID=?></code>			•	•	•
<code> <5,PRODUCT></code>	•	•	•	•	•
<code> <5,PRICE></code>	•	•	•	•	•
<code> <5,MID></code>	•	•			
<code> <5,CID></code>			•	•	•
<code>6:printResultSet(rs) ;</code>	•	•	•	•	•
<code>}</code>					
Pass/Fail Status	F	P	P	P	P

Identify Statement-SQL and Statement-Attribute Tuples

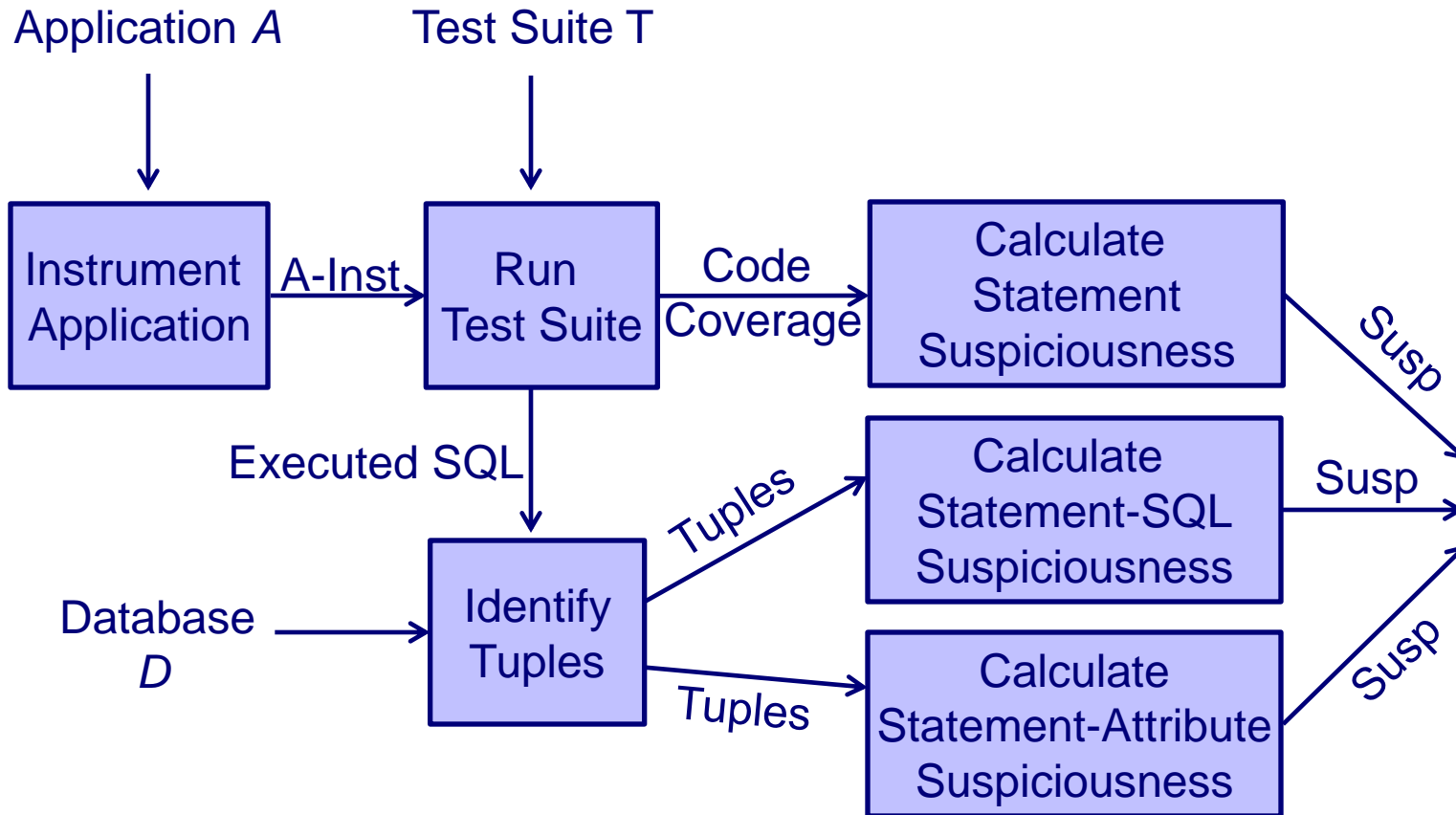
<5, SELECT PRODUCT, PRICE FROM Sale WHERE MID>=?>

<5, PRODUCT>, <5, PRICE>, <5,MID>, <5,CID>

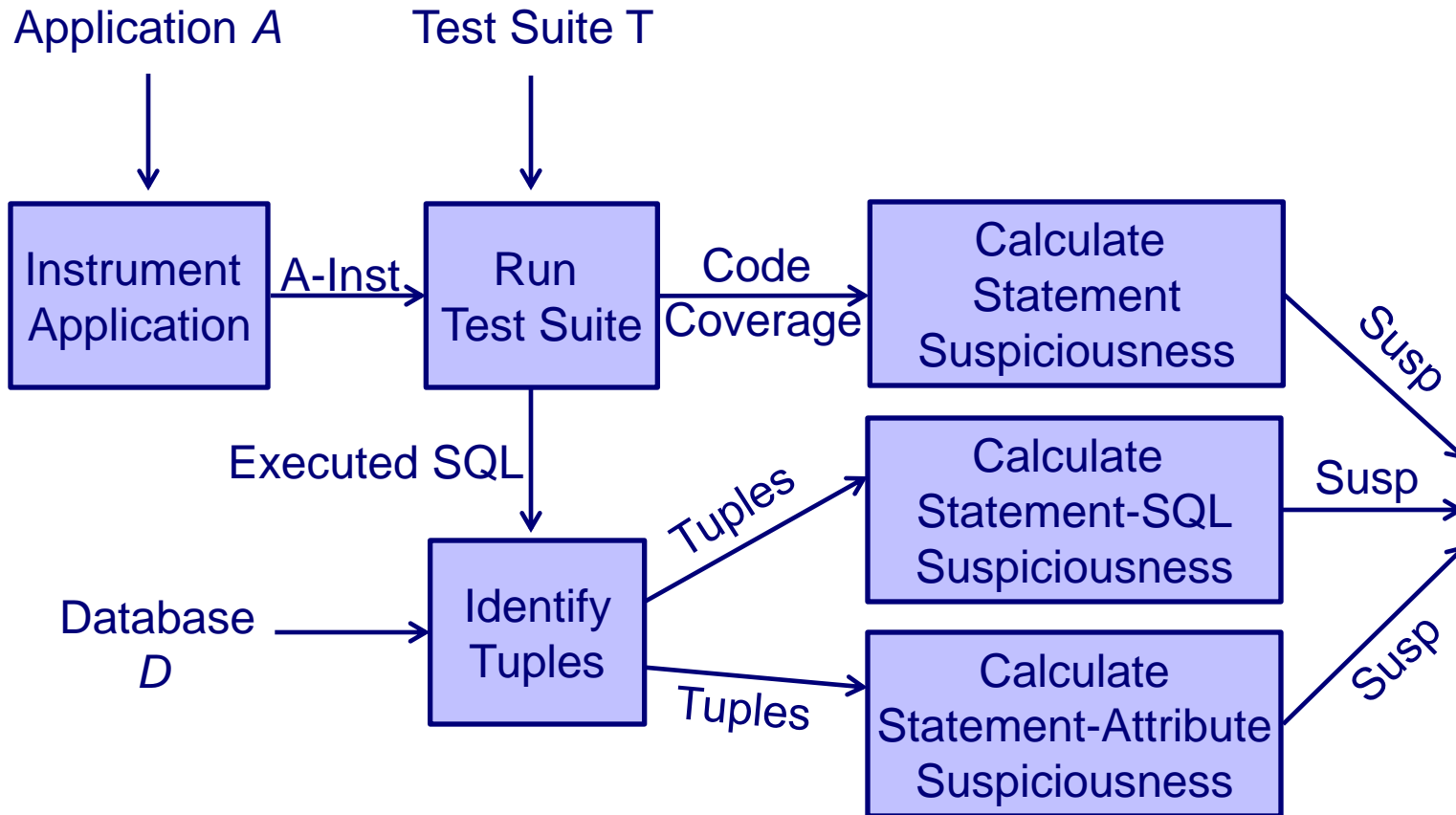
Our Technique—Algorithm



Our Technique—Algorithm



Our Technique—Algorithm



Revisiting the Example

Our Technique—Algorithm Example

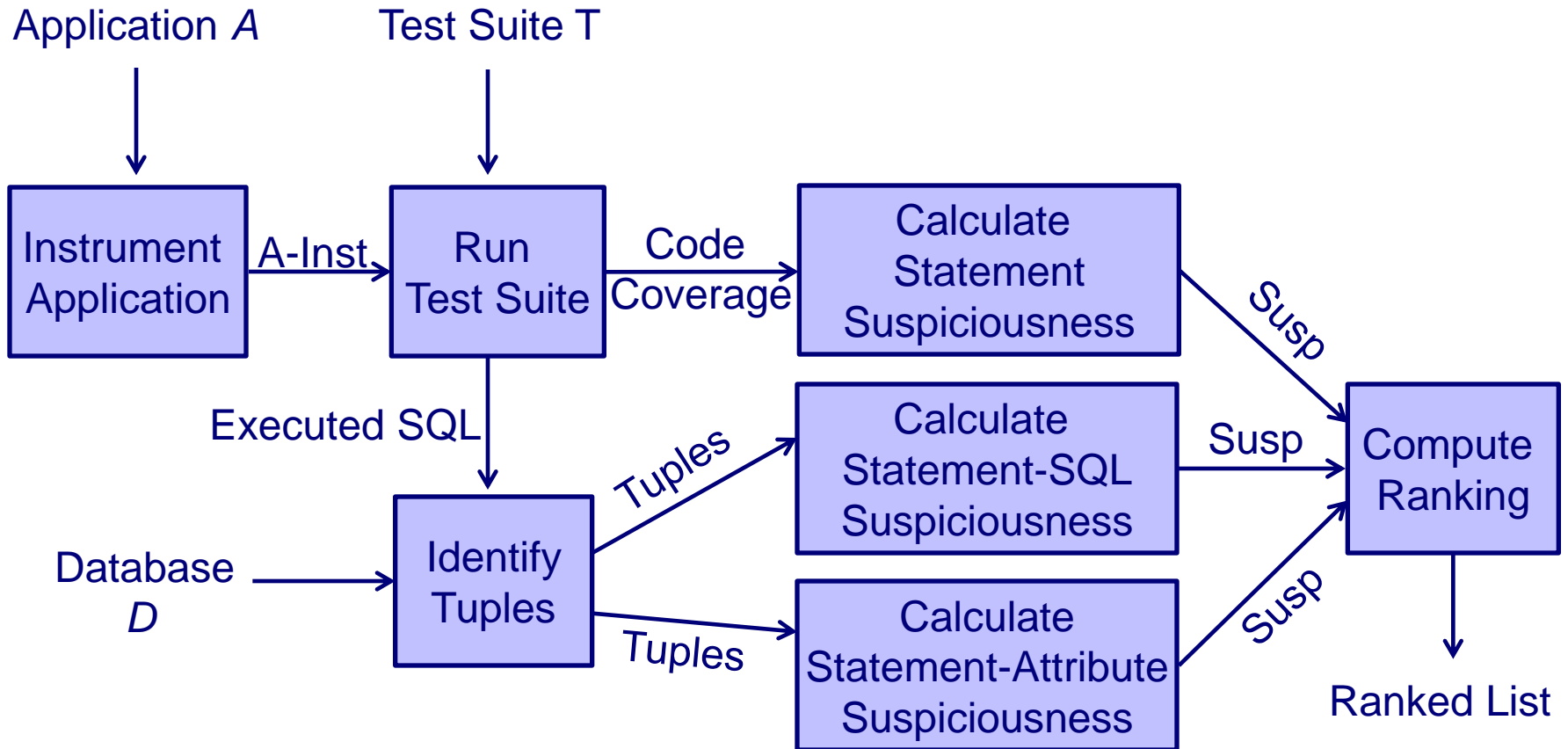
	M,1	M,2	C,1	C,2	C,3	suspiciousness
<code>printProdsold(String uType, String uID) {</code>						
<code>1:String attr=conf.getAttr(uType,uID) ;</code>	•	•	•	•	•	0.45
<code>2:String whereClause=conf.getWhere(uType,uID) ;</code>	•	•	•	•	•	0.45
<code>3:String SQL="SELECT "+attr+</code>	•	•	•	•	•	0.45
<code> "FROM Sale Where "+whereClause;</code>	•	•	•	•	•	0.45
<code>4:PreparedStatement ps=new PreparedStatement();</code>	•	•	•	•	•	0.45
<code>5:ResultSet rs=ps.executeQuery(SQL) ;</code>	•	•	•	•	•	0.45
<code><5,SELECT..WHERE MID=?></code>	•	•				0.71
<code><5,SELECT..WHERE CID=?></code>			•	•	•	0.00
<code><5,PRODUCT></code>	•	•	•	•	•	0.45
<code><5,PRICE></code>	•	•	•	•	•	0.45
<code><5,MID></code>	•	•				0.71
<code><5,CID></code>			•	•	•	0.00
<code>6:printResultSet(rs) ;</code>	•	•	•	•	•	0.45
<code>}</code>						
	F	P	P	P	P	

Calculate Suspiciousness

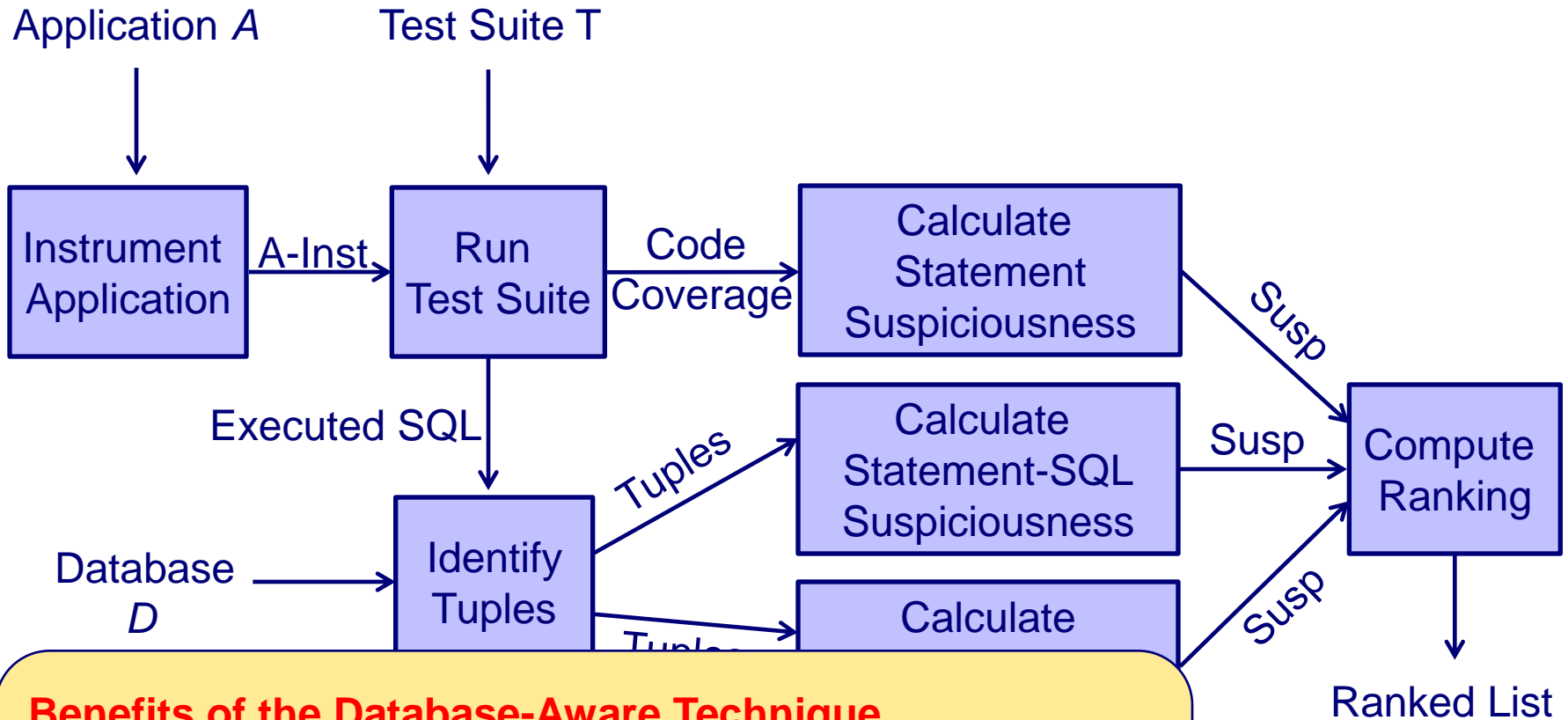
`<5, MID>`: Passed=1, Failed=1, Total Failed=1

Suspiciousness=1/sqrt(1(1+1))=0.71

Our Technique—Algorithm



Our Technique—Algorithm



Benefits of the Database-Aware Technique

Finds the faulty

1. Database interaction point
2. SQL command
3. Attribute in the SQL clause

Outline for the Rest of the Presentation

- Our Technique
 - Definitions
 - Algorithm
- Empirical Studies
- Conclusion

Empirical Studies

Implementation

- Cobertura: Collect per-test case coverage reports
- P6Spy: Record the executed SQL statements
- Unity: Parse statements in multiple versions of SQL

Empirical Studies

Implementation

- Cobertura: Collect per-test case coverage reports
- P6Spy: Record the executed SQL statements
- Unity: Parse statements in multiple versions of SQL

Subjects	Java LOC	Test Cases	Tables (DB)	Interaction Points (DB)	Type (DB)	Description
MessageSwitch	3672	80	15	16	Oracle	Transaction processing system
JWhoisServer	6684	79	10	2	HSQLDB	Open source WHOIS server
iTrust	25517	802	30	157	MySQL	Medical application (NC State)

Empirical Studies

Setup

- Identified types of mutants
 - Code mutants—code faults in the application
 - SQL mutants—SQL faults in the application
- Created the mutants manually
 - Existing tools couldn't process our subjects
 - Followed an established approach (*IST* 49(4), 2007)

Empirical Studies

Setup

- Identified types of mutants
 - Code mutants—code faults in the application
 - SQL mutants—SQL faults in the application
- Created the mutants manually
 - Existing tools couldn't process our subjects
 - Followed an established approach (*IST* 49(4), 2007)
- Resulting mutants

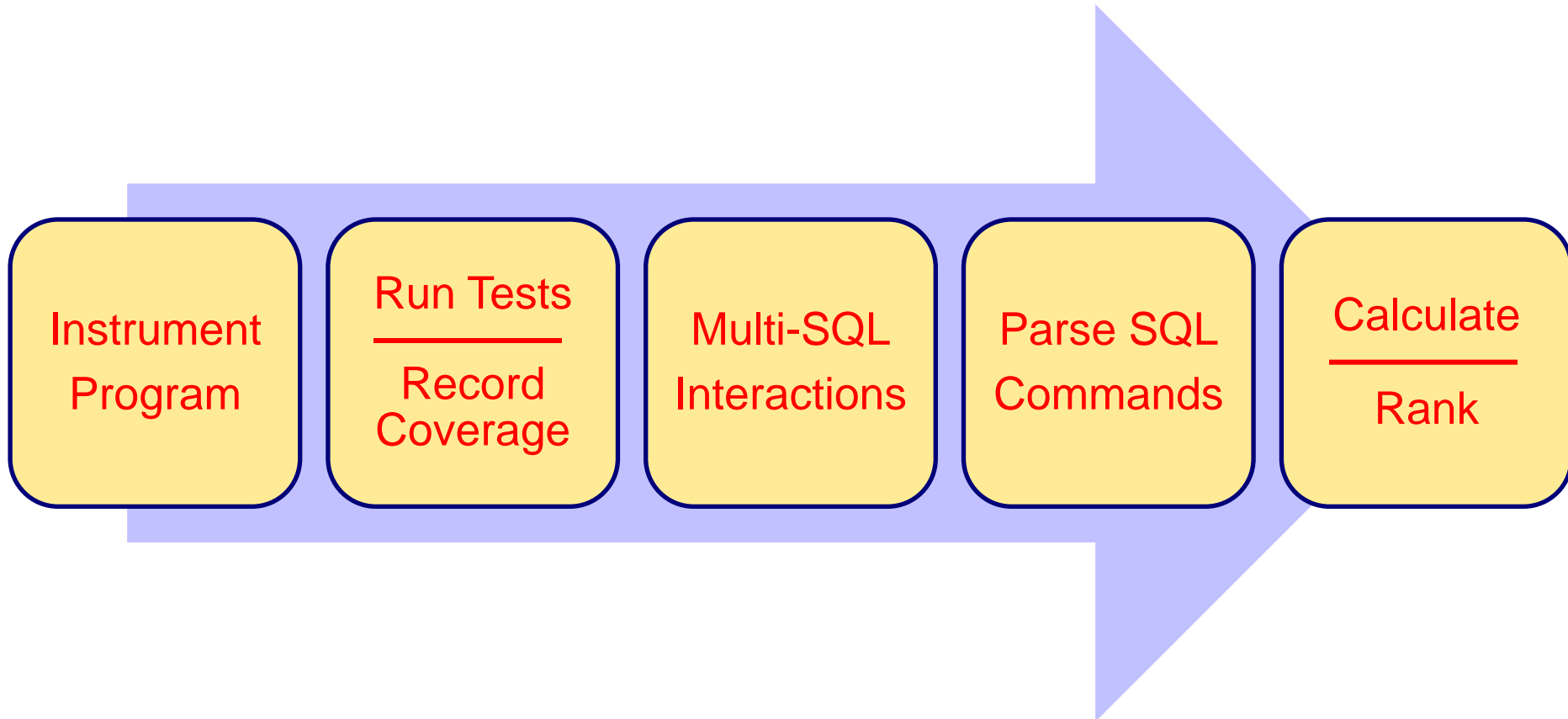
Subjects	Code Mutants	SQL Mutants
MessageSwitch	100	15
JWhoisServer	50	10
iTrust	25	30

Study 1—Effectiveness

- **Goal** Compare the database-aware approach to statement-based fault localization for SQL and code faults

Study 1—Effectiveness

- **Goal** Compare the database-aware approach to statement-based fault localization for SQL and code faults
- **Method** For each mutant in the program



Study 1—Results

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Study 1—Results

Subject	Fault Type	Statement	Database	Statement	Database
MessageSwitch	SQL	50%	67%	100%	100%
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	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

For each case study application, measure fault localization effectiveness for SQL and code faults

Study 1—Results

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Measured the percentage of faults found without examining 99% and 90% of the subject's source code

Study 1—Results

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
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	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Higher values indicate a more effective fault localization method

Study 1—Discussion

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Statement-based fault localization finds 0% of the SQL faults without examining 99% of statements

Study 1—Discussion

Subject	Fault Type	Statement	Database	Statement	Database
MessageSwitch	SQL	50%	67%	100%	100%
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	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Database-aware fault localization finds 95% of the SQL faults without examining 99% of statements

Study 1—Discussion

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

Statement-based fault localization works well for applications with static database interactions

Study 1—Discussion

Subject	Fault Type	Statement 99%	Database 99%	Statement 90%	Database 90%
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

When improvement is unlikely, database-aware fault localization does not degrade effectiveness

Study 1—Discussion

Subject	Fault Type	Statement	Database	Statement	Database
MessageSwitch	SQL	50%	67%	100%	100%
	Code	26%	26%	68%	68%
	All	32%	36%	76%	76%
JWhoisServer	SQL	0%	95%	87%	100%
	Code	17%	13%	61%	61%
	All	7%	63%	77%	85%
iTrust	SQL	94%	94%	100%	100%
	Code	98%	98%	98%	100%
	All	97%	97%	98%	100%

The database-aware technique is most useful for database applications with dynamic interactions

Study 2—Qualitative Case Study

- **Goal** Evaluate the additional benefits of our technique that are difficult to quantify

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- **Method**
 - Assume developer has found suspicious code
 - Select one mutant for each subject

Study 2—Qualitative Case Study

- **Goal** Evaluate the additional benefits of our technique that are difficult to quantify
- **Method**
 - Assume developer has found suspicious code
 - Select one mutant for each subject
 - For each mutant, provide



Code
Sample

Mutant
Description

Additional
Details

Study 2 – JWhoisServer

```
private final synchronized ResultSet  
    execPST(PreparedStatement pst)  
    throws SQLException {  
    ResultSet res = pst.executeQuery();  
    return res;  
}
```

Fault Localization Challenge

**Database interaction point does not
contain the faulty SQL command**

Study 2 – JWhoisServer

```
protected final String getWherePart() {
    Vector<String> qv = this.getQfield();
    final String qf = this.getQfield().get(0);
    StringBuilder ret = new StringBuilder(
        "WHERE "+qf+" <= ? "
        +"AND inetnumend >= ? "
        +"AND "+this.bytelengthField+" = ? ");
    if (this.getWhereaddition().length() > 0) {
        if(!this.getWhereaddition().startsWith(" ")) {
            ret.append(" ");
        }
        ret.append(this.getWhereaddition());
    }
    ret.append("ORDER BY "+qf+" ASC, inetnumend ASC");
    return ret.toString();
}
```

Study 2 – JWhoisServer

```
protected final String getWherePart() {  
    Vector<String> qv = this.getQfield();  
    final String qf = this.getQfield().get(0);  
    StringBuilder ret = new StringBuilder(  
        "WHERE "+qf+" <= ? "  
        +"AND inetnumend >= ? "  
        +"AND "+this.bytelelengthField+" = ? ");  
    if (this.getWhereaddition().length() > 0) {  
        if(!this.getWhereaddition().startsWith(" ")) {  
            ret.append(" ")  
        }  
        ret.append(this.getWhereaddition());  
    }  
    ret.append(" OR ");  
    return ret.toString();  
}
```

Fault Localization Challenge

JWhoisServer constructs the SQL command in a dynamic fashion

Study 2 – JWhoisServer

External Configuration File

```
db.inetnum.table=inetnum
db.inetnum.objectlookup=inetnum;inet
db.inetnum.qfield=inetnumstart
db.inetnum.key=descr
db.inetnum.bytelength=bytelength
db.inetnum.display=netname AS network;
bytelength;inetnumstart;inetnumend;descr;source
db.inetnum.recurse.person=admin_c;tech_c
```

Study 2 – JWhoisServer

External Configuration File

```
db.inetnum.table=inetnum
db.inetnum.objectlookup=inetnum;inet
db.inetnum.qfield=inetnumstart
db.inetnum.key=descr
db.inetnum.bytelength=bytelength
db.inetnum.display=netname AS network;
bytelength;inetnumstart;inetnumend;descr;source
db.inetnum.recurse.person=admin_c;tech_c
```

Suspicious Database Interaction Point

Statement: dbpool.java:631

SQL Command: select descr, netname as network, bytelength,
inetnumstart, inetnumend, source from inetnum
where inetnumstart <= ? and inetnumend >= ?
and bytelength = ?
order by inetnumstart asc, inetnumend asc

Suspiciousness: 0.91

Study 2 – JWhoisServer

External Configuration File

```
db.inetnum.table=inetnum
db.inetnum.objectlookup=inetnum;inet
db.inetnum.qfield=inetnumstart
db.inetnum.key=descr
db.inetnum.bytelength=bytelength
db.inetnum.display=netname AS network;
bytelength;inetnumstart;inetnumend;descr;source
db.inetnum.recurse.person=admin_c;tech_c
```

Additional Information

The SQL command connected to a specific test case and its pass/fail status

Suspicious Database Interaction Point

Statement: dbpool.java:631

SQL Command: select descr, netname as network, bytelength, inetnumstart, inetnumend, source from inetnum where inetnumstart <= ? and inetnumend >= ? and bytelength = ? order by inetnumstart asc, inetnumend asc

Suspiciousness: 0.91

Study 2 – JWhoisServer

- **Standard method** *does not*
 - Identify the faulty database interaction point as highly suspicious
 - Extract the complete SQL command
- **Database-aware technique** provides a precise ranking *and* the full SQL command, thereby eliminating manual developer effort

Outline for the Rest of the Presentation

- Our Technique
 - Definitions
 - Algorithm
- Empirical Studies
- **Conclusion**

Future Work

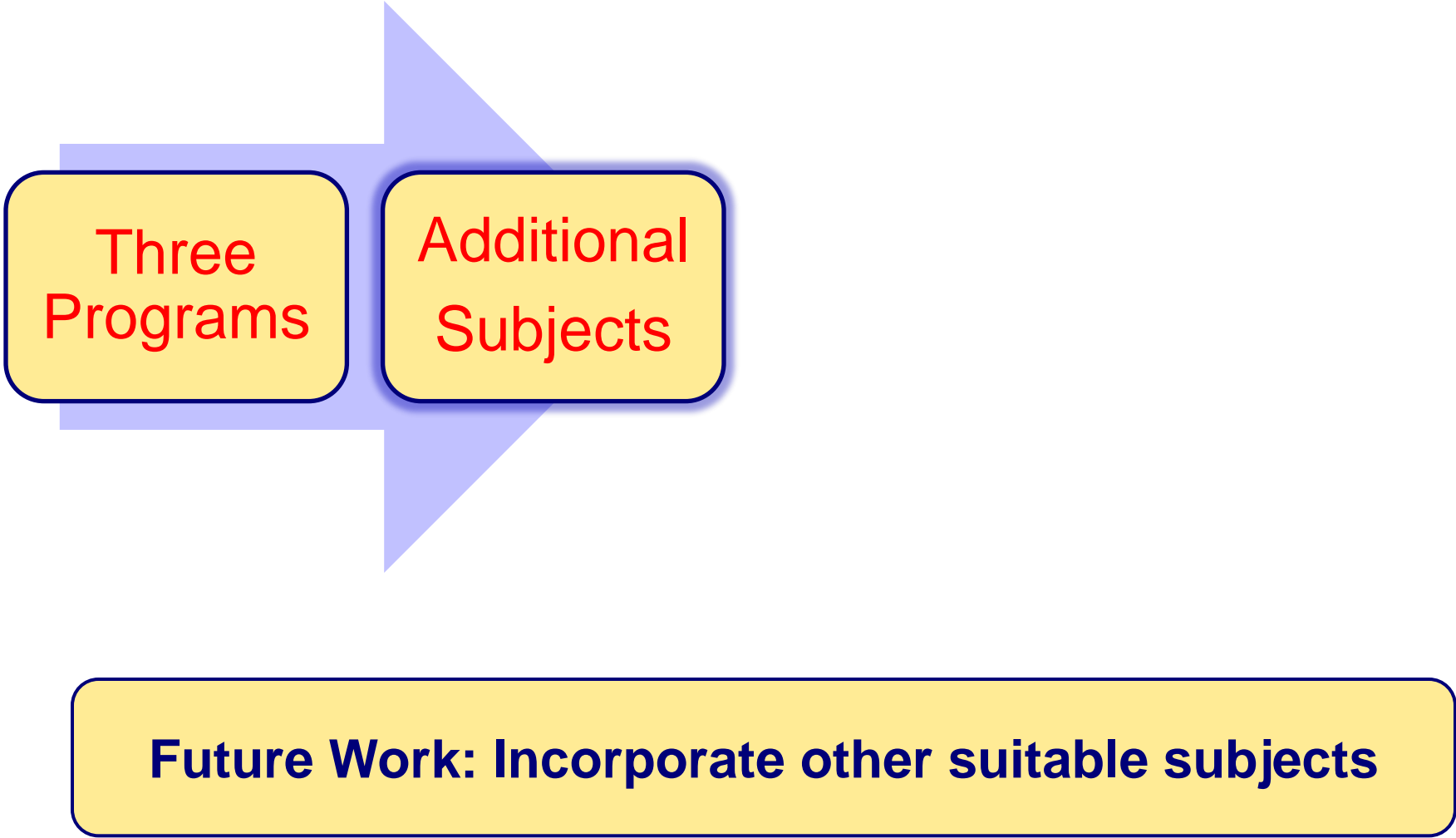


Three
Programs

Additional
Subjects

Used three subject programs – (1) from previous research, (2) open source, and (3) industrial

Future Work



Three
Programs

Additional
Subjects

Future Work: Incorporate other suitable subjects

Future Work

Three
Programs

Additional
Subjects

Command
Attributes

More
Entities

Future Work

Three Programs

Additional Subjects

Command Attributes

More Entities

Focused on entities involving an SQL command and the attributes found in the relational database

Future Work

Three
Programs

Additional
Subjects

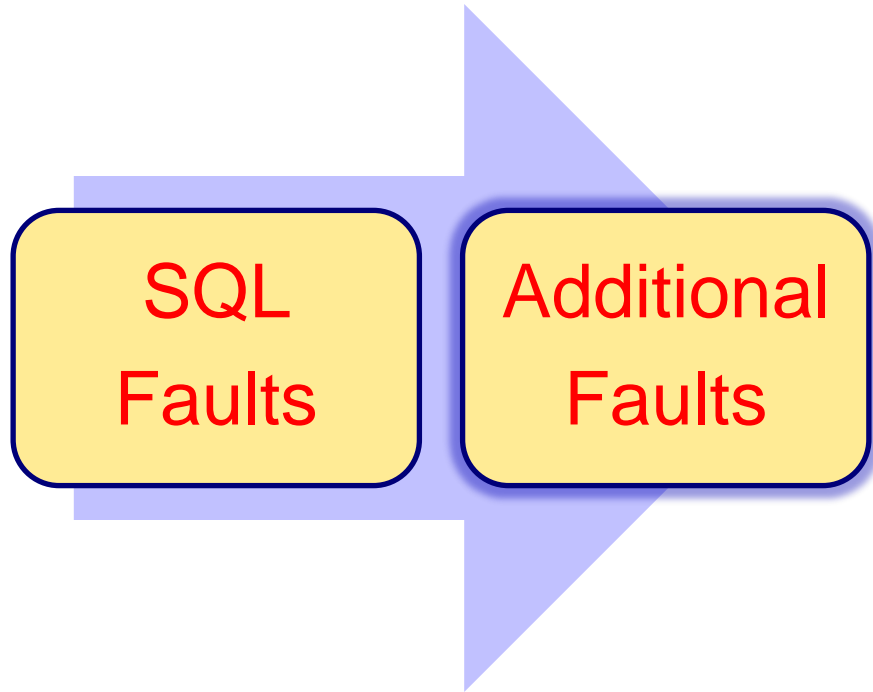
Command
Attributes

More
Entities

Future Work: WHERE and GROUP BY clauses

Future Work

Future Work



Localizing SQL faults that involve mistakes in querying and modifying the database

Future Work

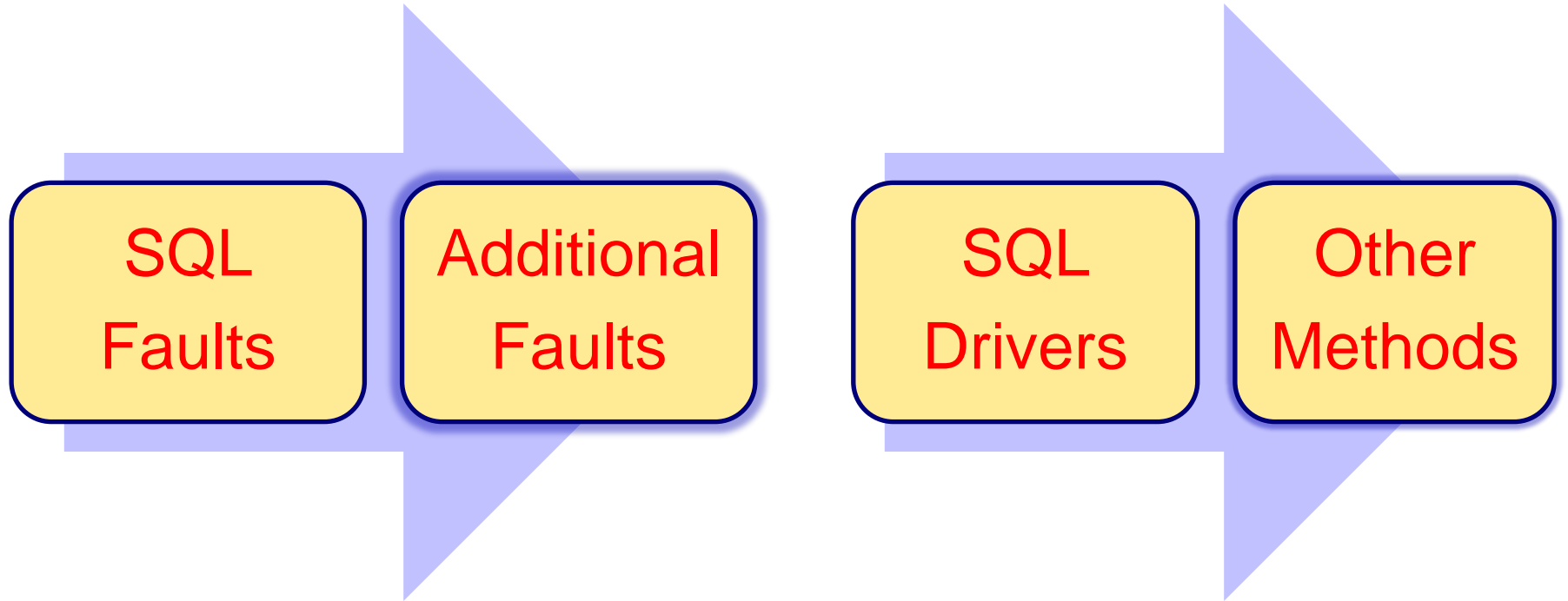


SQL
Faults

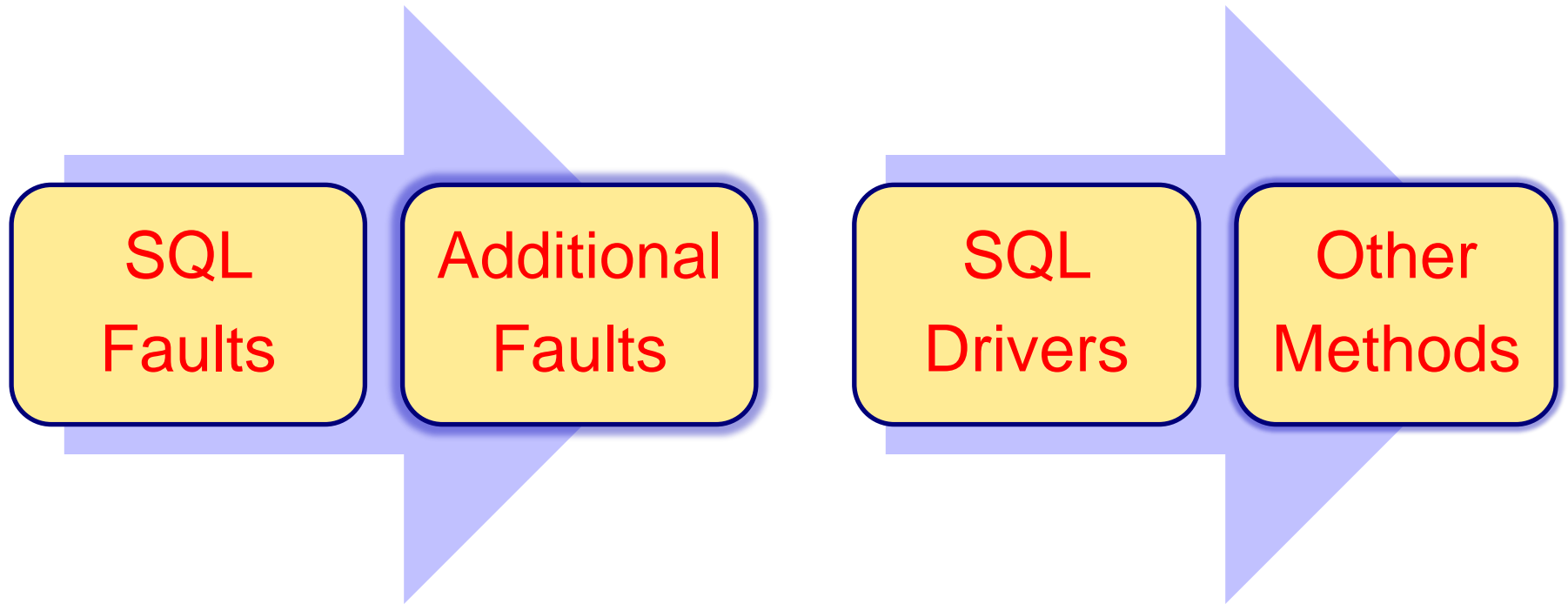
Additional
Faults

Future Work: Consider data and schema faults

Future Work

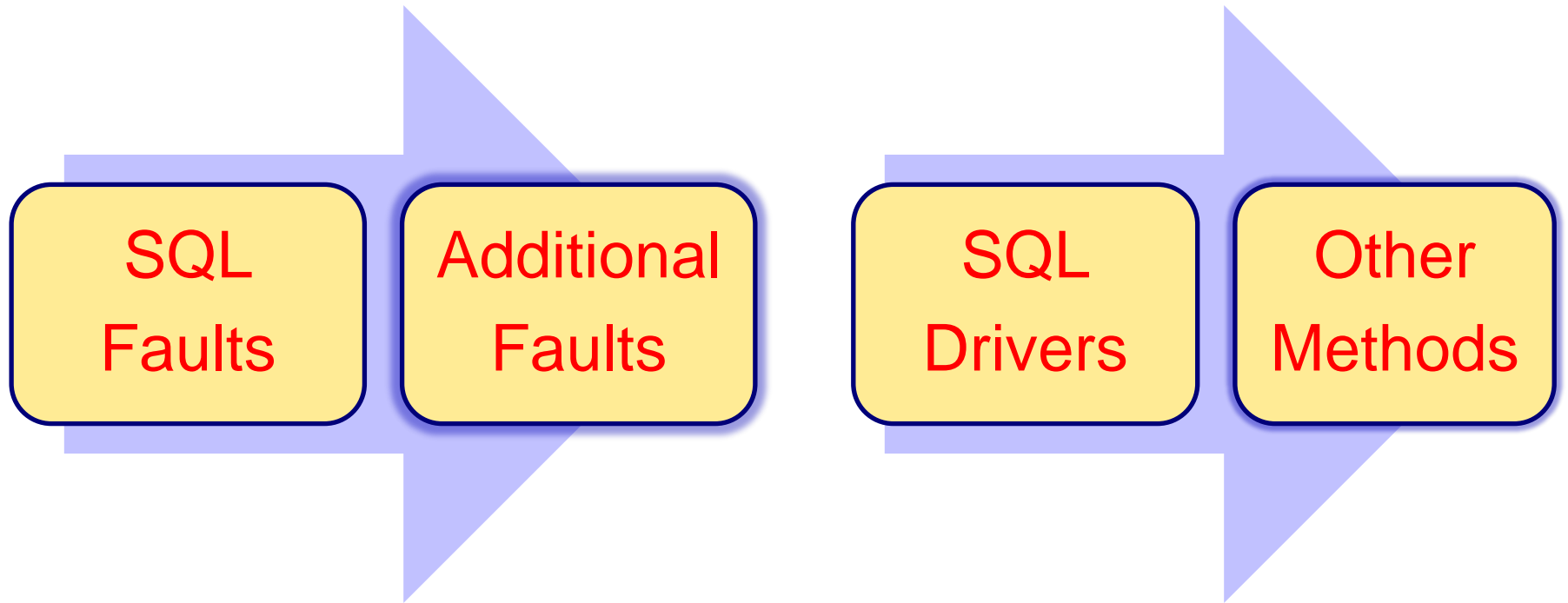


Future Work



Considered SQL commands that are encoded as strings and submitted through a database driver

Future Work



Future Work: Localize faults in stored procedures

Summary of Contributions

Key Motivators

- **Databases are an essential component of many software applications**
- **Real-world industrial faults result from incorrect interaction with a database**

Summary of Contributions

- Database-aware fault localization method that uses database-related information
- Prototype database-aware fault localization system that provides a ranking as well as the executed SQL commands

Summary of Contributions

- Database-aware fault localization method that uses database-related information
- Prototype database-aware fault localization system that provides a ranking as well as the executed SQL commands
- Empirical studies revealing that:
 - Statement-based methods work well for database applications with static interactions
 - Database-aware approach markedly improves fault localization for dynamic applications

Summary of Contributions

In summary, this paper

- **Shows the need for database-aware fault-localization methods**
- **Describes the first approach that calculates suspiciousness for program and database entities**

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In summary, this paper

- Shows the need for database-aware fault-localization methods
- Describes the first approach that calculates suspiciousness for program and database entities

The experimental study

- Quantitatively and qualitatively evaluates the presented technique
- Shows improvements in the effectiveness of finding SQL faults by as much as 95% over existing methods

Localizing SQL Faults in Database Applications

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Sarah R. Clark^{*}, Jake Cobb^{*},

James A. Jones[‡], and Mary Jean Harrold^{*}

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