# Detecting Logical Bugs of DBMS with Coverage-based Guidance

Yu Liang Song Liu Hong Hu


# Memory Bugs in DBMS: Well Studied


- Generation-based testing
  - *SQLsmith, QAGen [SIGMOD'07], QGEN [VLDB'04] …*
- Mutation-based fuzzing
  - *Squirrel [CCS'20], PolyGlot [Oakland'21], RATEL [ICSE-SEIP'21] …*

# Logical Bugs in DBMS: Limited Exploration


DISCARD TEMP results in "ERROR: cache lookup failed for type 0"

COLLATE nocase index on a WITHOUT ROWID table malfunctions

Title: Incorrect result on a table scan of a partial index

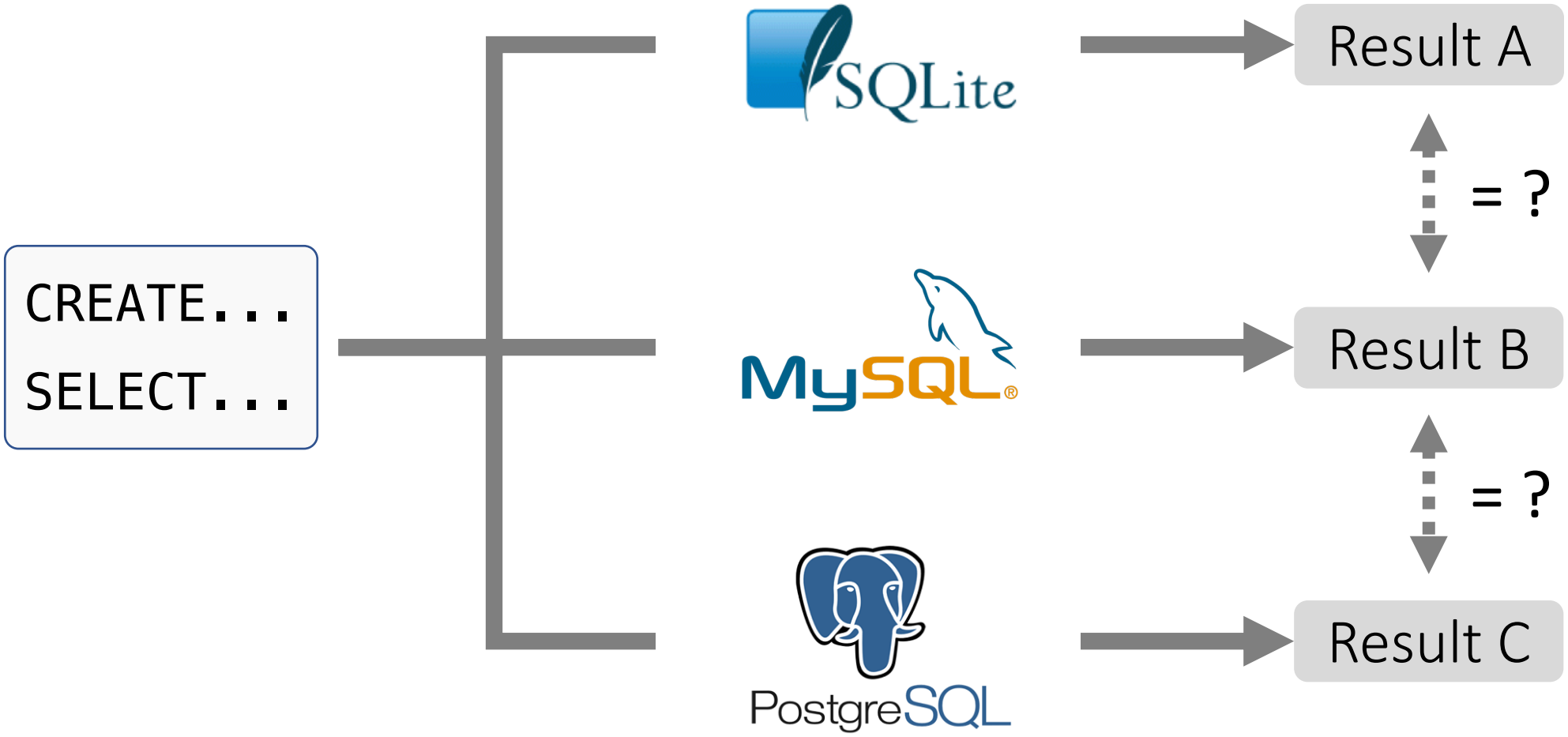
MariaDB Server / MDEV-21065

UNIQUE constraint causes a query with string comparison to omit a row in the result set

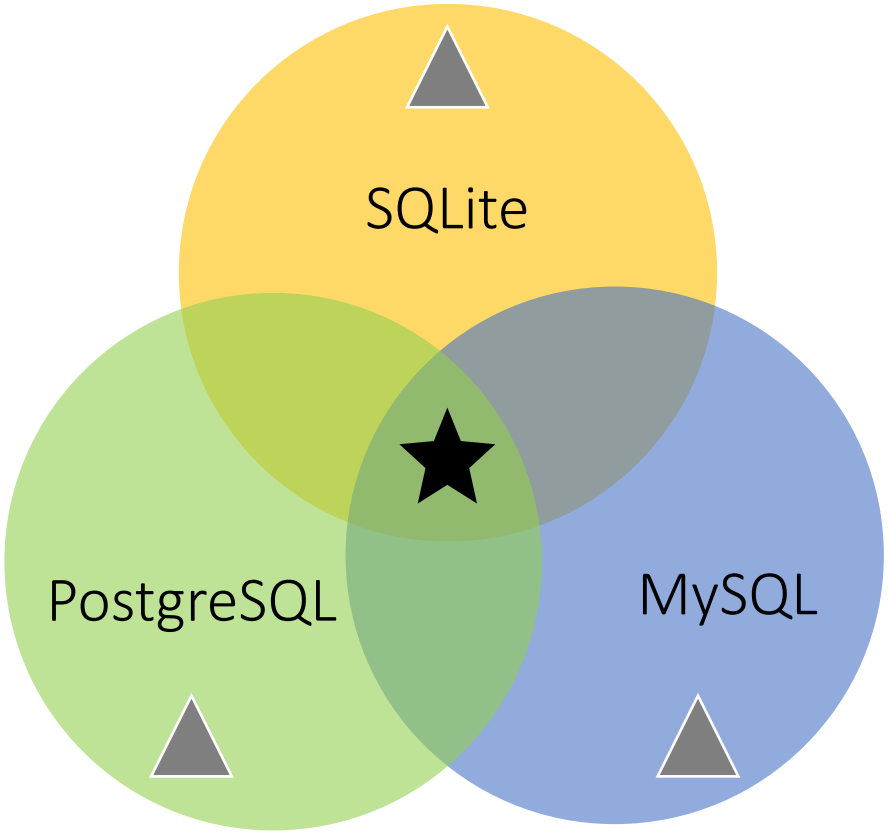
Double negation causes incorrect result #15725

| | |
|---|---|
| **Bug #95889** | **Functional index seems to malfunction with UNSIGNED column** |

# Existing Works: Differential Testing



# Existing Works: Differential Testing




- SQLite dialects

```
without rowid; fts5; ...
```

- PostgreSQL dialects

```
pg_catalog; integer[]; ...
```

- MySQL dialects

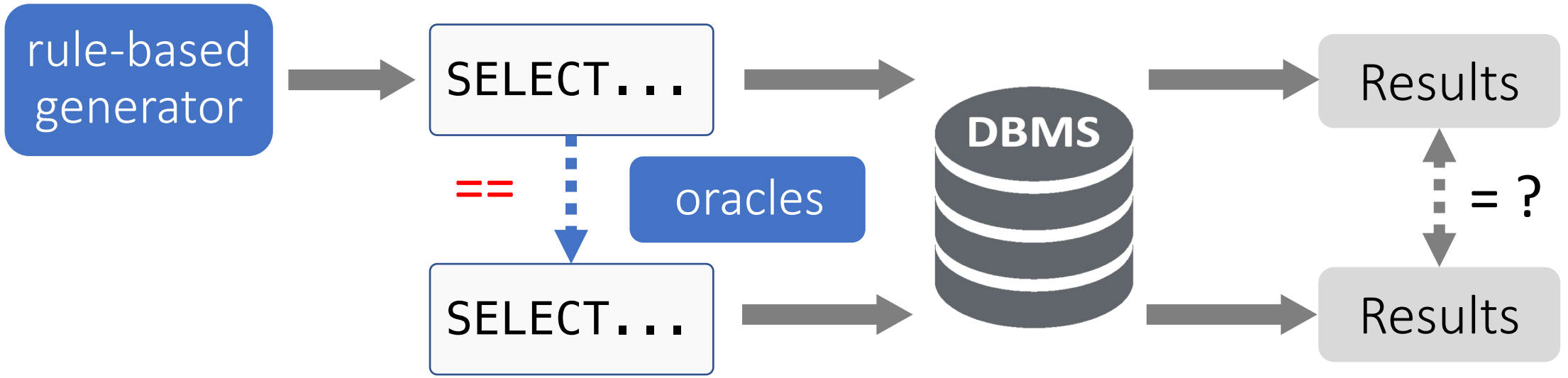
```
datetime; json_set(); ...
```

★ Limited common syntax → Low coverage

▲ Various dialects/features → Low correctness rate (validity)

# Existing Works: SQLancer

- Use oracles to find logical bugs
  - compare results from function-equivalent queries
- Cons: rely on rule-based query generator
  - limited to explore deep program logic

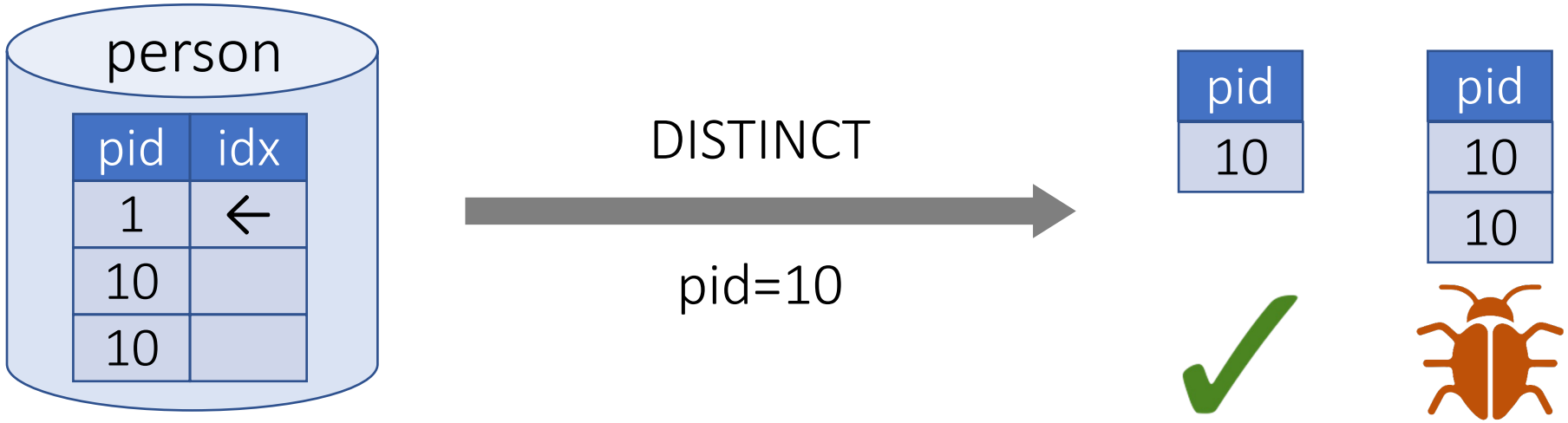


# Contributions

- SQLRight: a general platform to test DBMS logical bugs
  - coverage-guided fuzzing
  - validity-oriented mutation
  - general interfaces for DBMS oracles
- Found 18 logical bugs in SQLite and MySQL
- https://github.com/psu-security-universe/sqlright

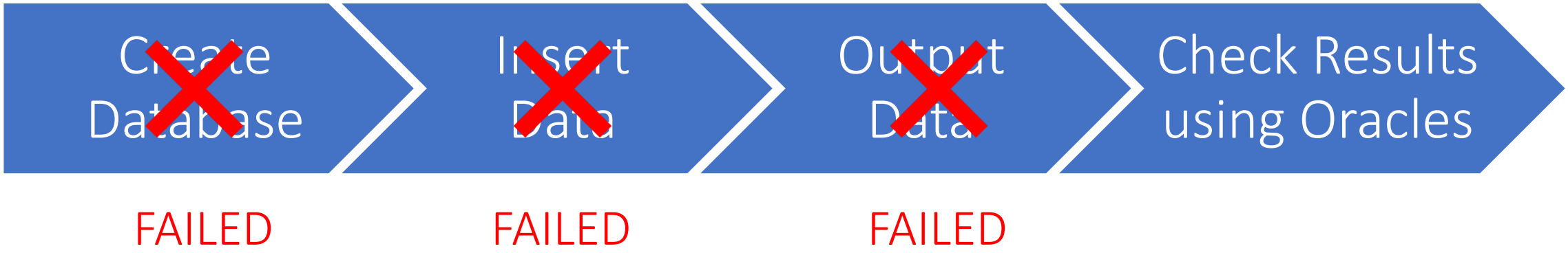
# Motivating Example (SQLite)

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
SELECT DISTINCT pid FROM person WHERE pid=10;
```



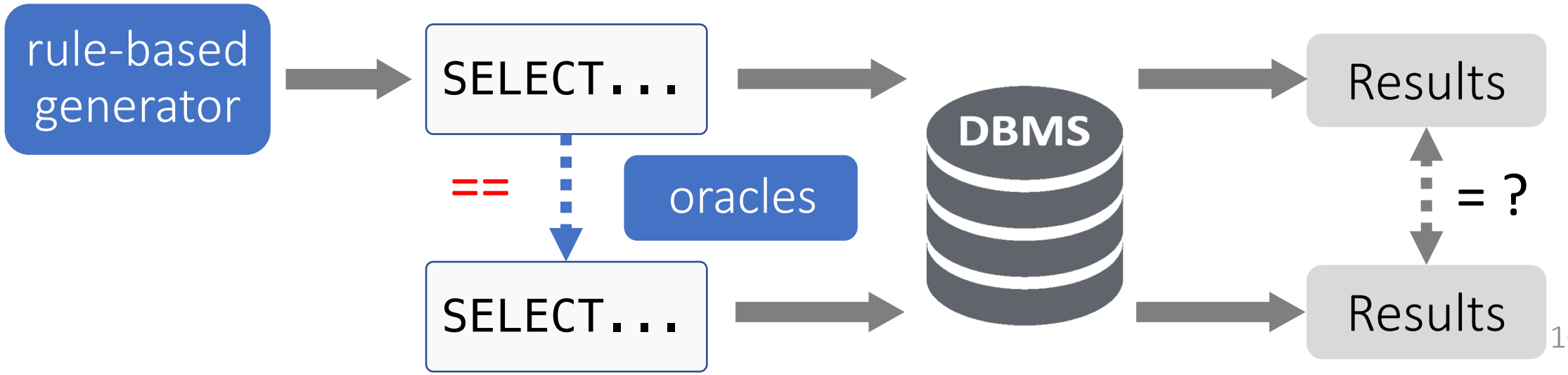
# Challenges to Detect Logical Bugs


- Generating valid queries
  - invalid queries cannot trigger logical bugs



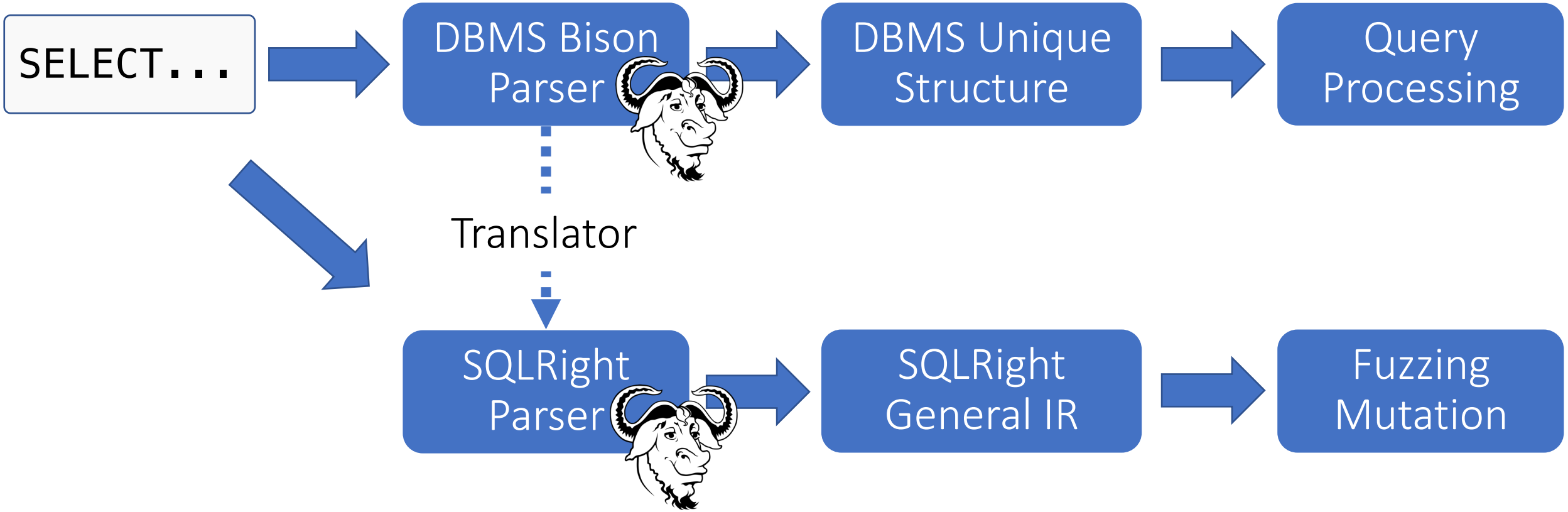
# Challenges to Detect Logical Bugs


- Implementing DBMS oracles
  - no platform for easy oracle development
  - no easy integration with existing techniques
- SQLancer: non-trivial manual efforts



# Validity-oriented Query Mutation


- Dedicated Parsing



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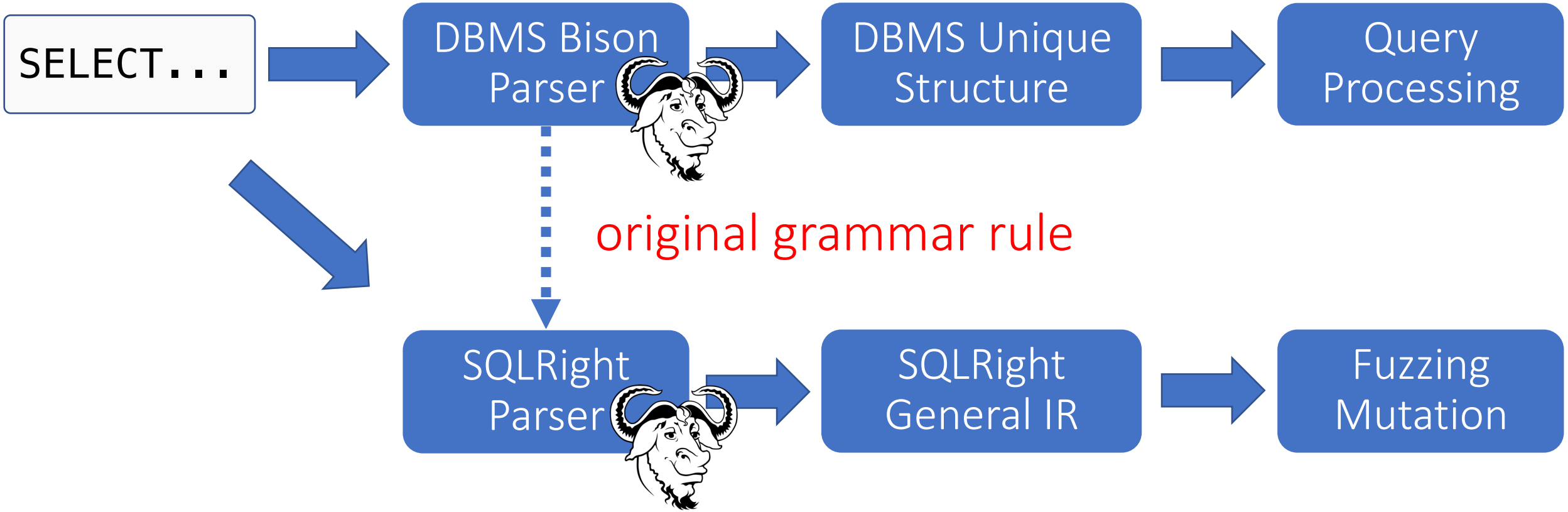


# Validity-oriented Query Mutation


```
CREATE TABLE x ( x INT, x INT, x INT);
INSERT INTO x VALUES (x), ( x ), ( x );
ALTER TABLE x RENAME x TO x ;
SELECT x FROM x WHERE x = x ;
```

- Context-based IR Instantiation
  - fill in concrete query operands

# Validity-oriented Query Mutation


```
CREATE TABLE v0 ( c1 INT, c2 INT, c3 INT);
INSERT INTO v0 VALUES (0), (10), (10);
ALTER TABLE v0 RENAME c3 TO c4 ;
SELECT * FROM v0 WHERE c1 = c4 ;
```

rename c3 to c4

use c4 not c3

- Context-based IR Instantiation
  - fill in concrete query operands

# Validity-oriented Query Mutation


- Two other techniques (details in paper)
  - cooperative mutation
  - non-deterministic behaviors removal

# General Interfaces for DBMS Oracles


- Easy development for new oracles
- Four general APIs

# General Interfaces for DBMS Oracles


- remove improper queries

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
INSERT INTO person VALUES (RANDOM());
```

random results

# General Interfaces for DBMS Oracles


- remove improper queries

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
INSERT INTO person VALUES (RANDOM());
```

random results

# General Interfaces for DBMS Oracles


- append oracle-compatible SELECT statements

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
- INSERT INTO person VALUES (RANDOM());
+ SELECT DISTINCT COUNT(*) FROM person WHERE pid=10;
```

NoREC oracle

# General Interfaces for DBMS Oracles


seed input → preprocess → append output → **transform** → compare

- transform query to functional equivalent forms

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
INSERT INTO person VALUES (RANDOM());
SELECT DISTINCT COUNT(*) FROM person WHERE pid=10;
SELECT DISTINCT pid=10 FROM person;
```

NoREC oracle

# General Interfaces for DBMS Oracles


- comparison method to identify unexpected result

```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
- INSERT INTO person VALUES (RANDOM());
+ SELECT DISTINCT COUNT(*) FROM person WHERE pid=10;
+ SELECT DISTINCT pid=10 FROM person;
```

matched

res: {1}

res: {0, 1}

# General Interfaces for DBMS Oracles


- comparison method to identify unexpected result

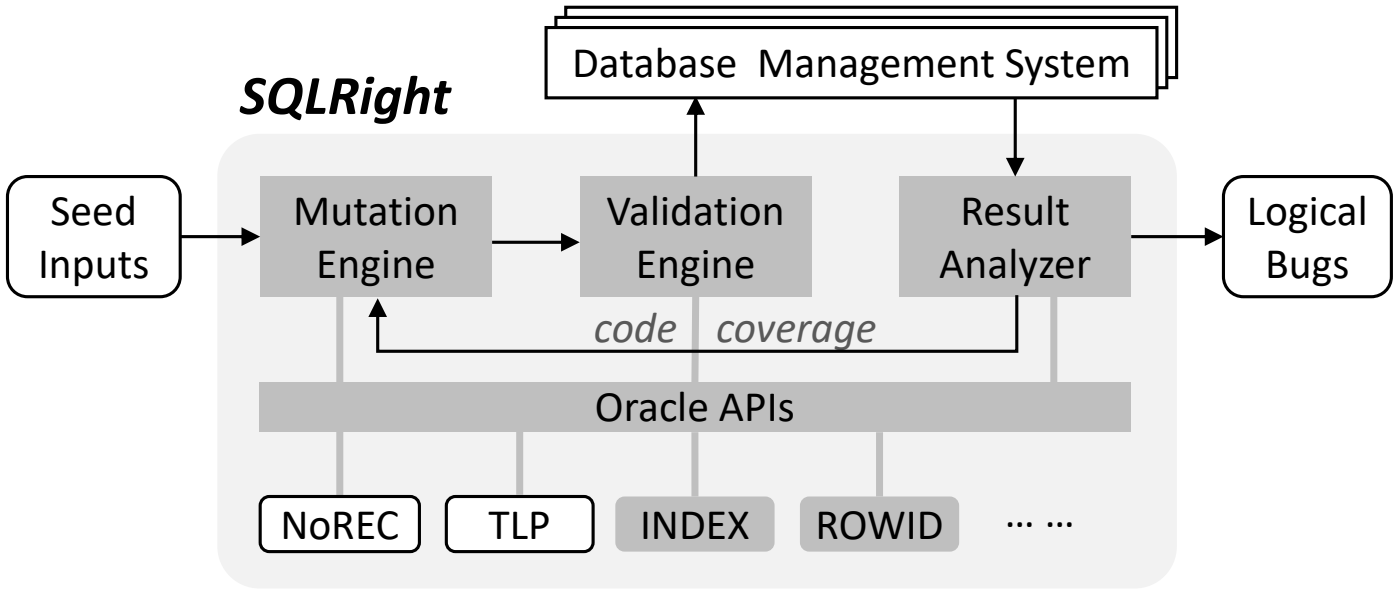
```
CREATE TABLE person (pid INT);
INSERT INTO person VALUES (1), (10), (10);
CREATE UNIQUE INDEX idx ON person (pid) WHERE pid=1;
- INSERT INTO person VALUES (RANDOM());
+ SELECT DISTINCT COUNT(*) FROM person WHERE pid=10;
+ SELECT DISTINCT pid=10 FROM person;
```

not matched

res: {2}

res: {0, 1}

# SQLRight Overview




- Coverage-guided fuzzer
- Validity-oriented mutation
- General interfaces for oracles

# Evaluation

- Can SQLRight detect real-world logical bugs?
- Can SQLRight find more bugs than existing tools?
- Contribution of different SQLRight components?



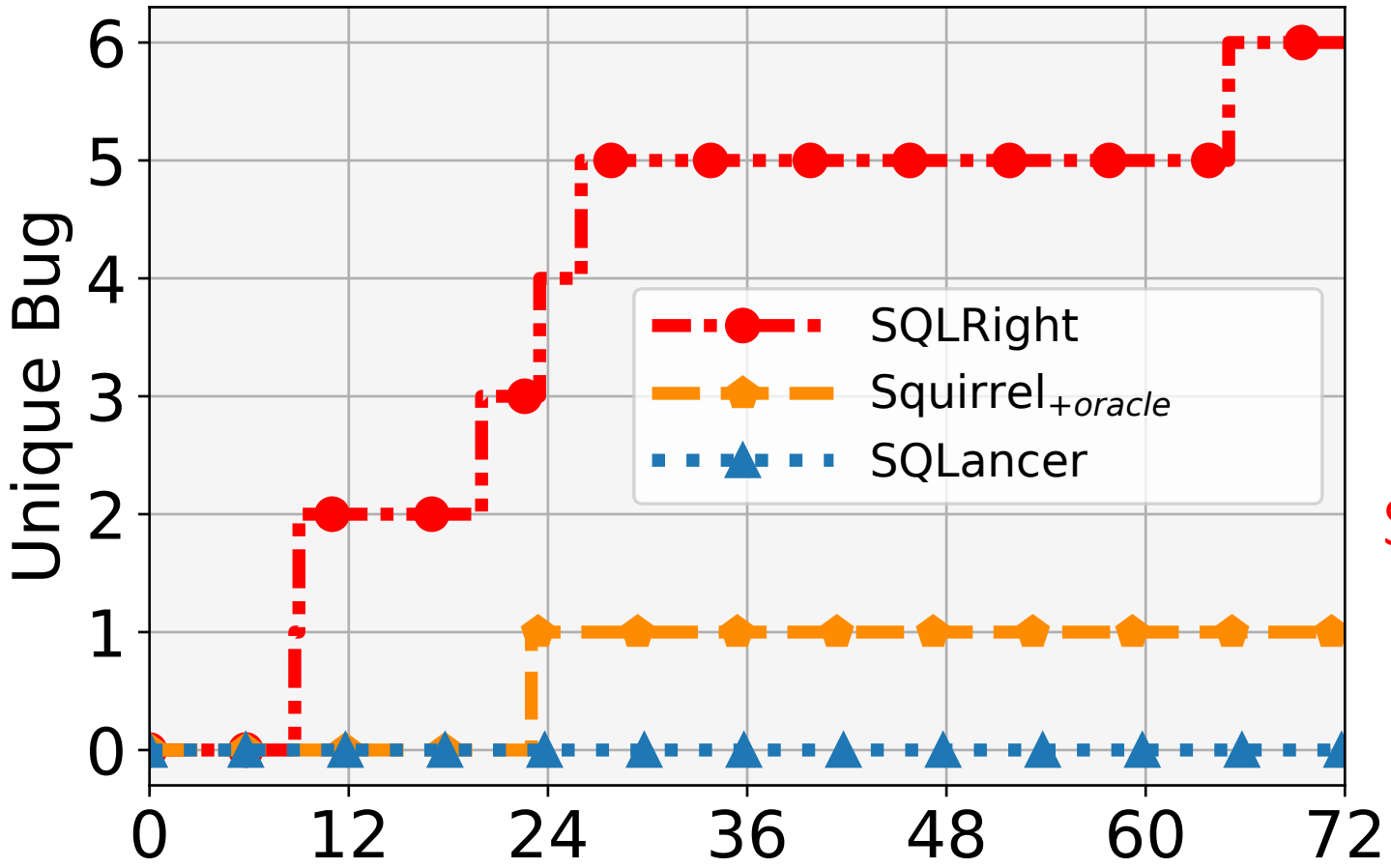
# Detect Real-world Logical bugs

| Oracle \ DBMS | SQLite | MySQL | PostgreSQL | Total |
|---|---|---|---|---|
| NoREC | 11 | 3 | 0 | 14 |
| TLP | 1 | 1 | 0 | 2 |
| ROWID | 1 | 0 | 0 | 1 |
| INDEX | 1 | 0 | 0 | 1 |
| TOTAL | 14 | 4 | 0 | 18 |

- 18 logical bugs
  - 14 SQLite
  - 4 MySQL
- 15 bugs fixed
- 2 from new oracles

# Comparison regarding *Detected Bugs* (NoREC)

- SQLite




SQLRight: 6 bugs

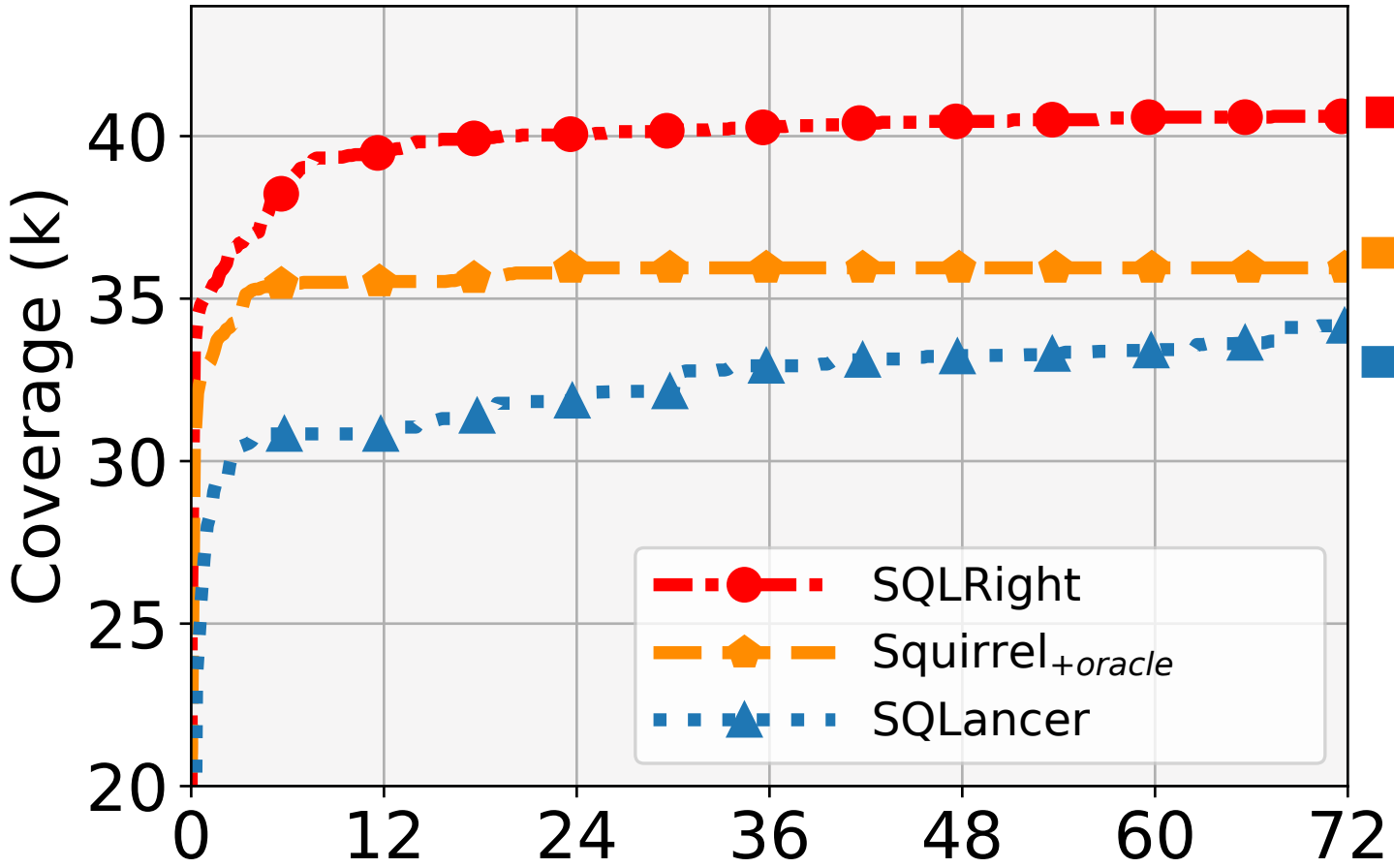
Squirrel: mem corrupt detector

Squirrel$_{+oracle}$: 1 bug

SQLancer: 0 bug

# Comparison regarding *Branch Coverage* (NoREC)

- SQLite




SQLRight: 40.6K

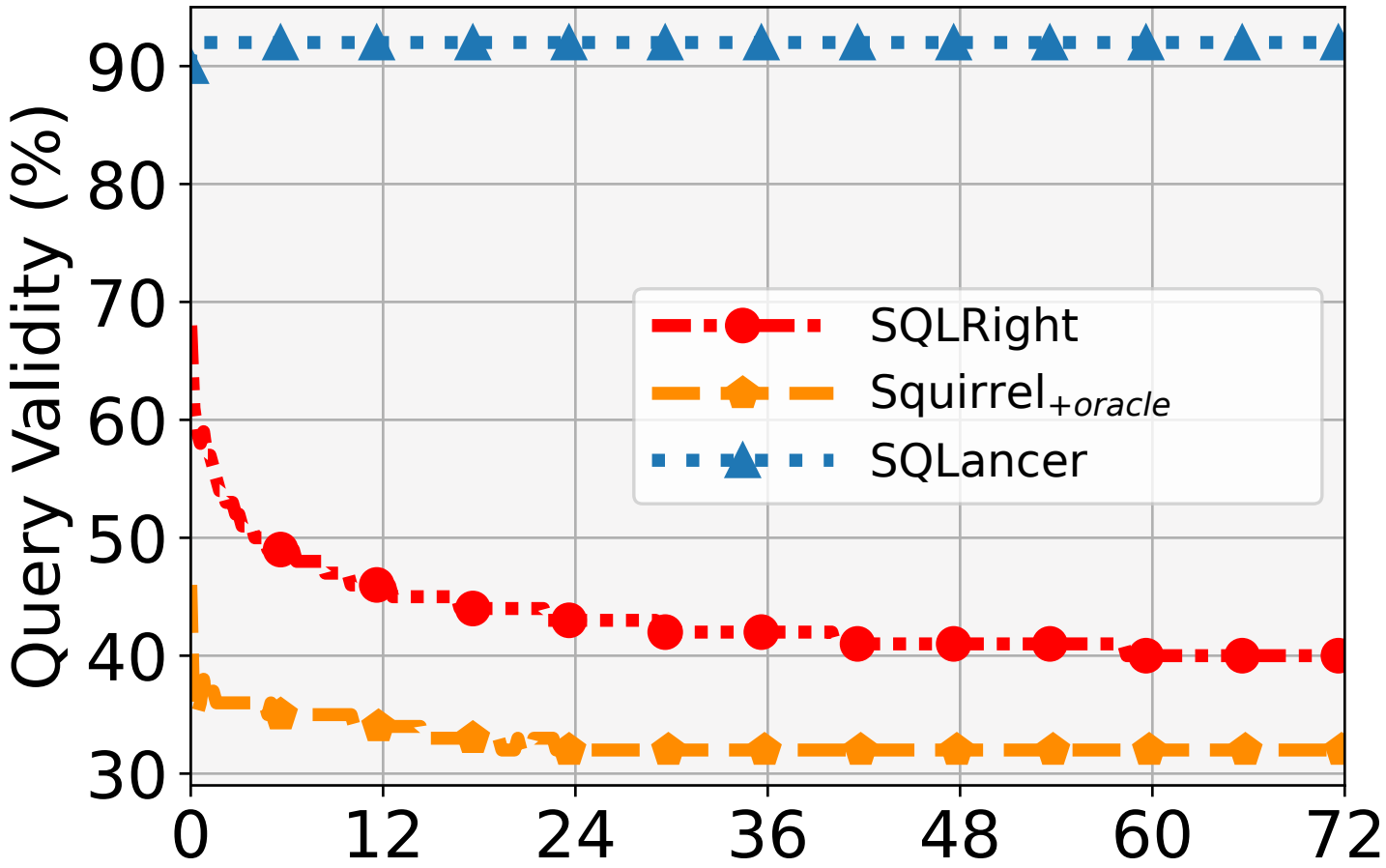
Squirrel$_{+oracle}$: 35.9K

SQLancer: 34.2K

12.97% more coverage than best baseline

# Comparison regarding *Query Validity* (NoREC)

- SQLite



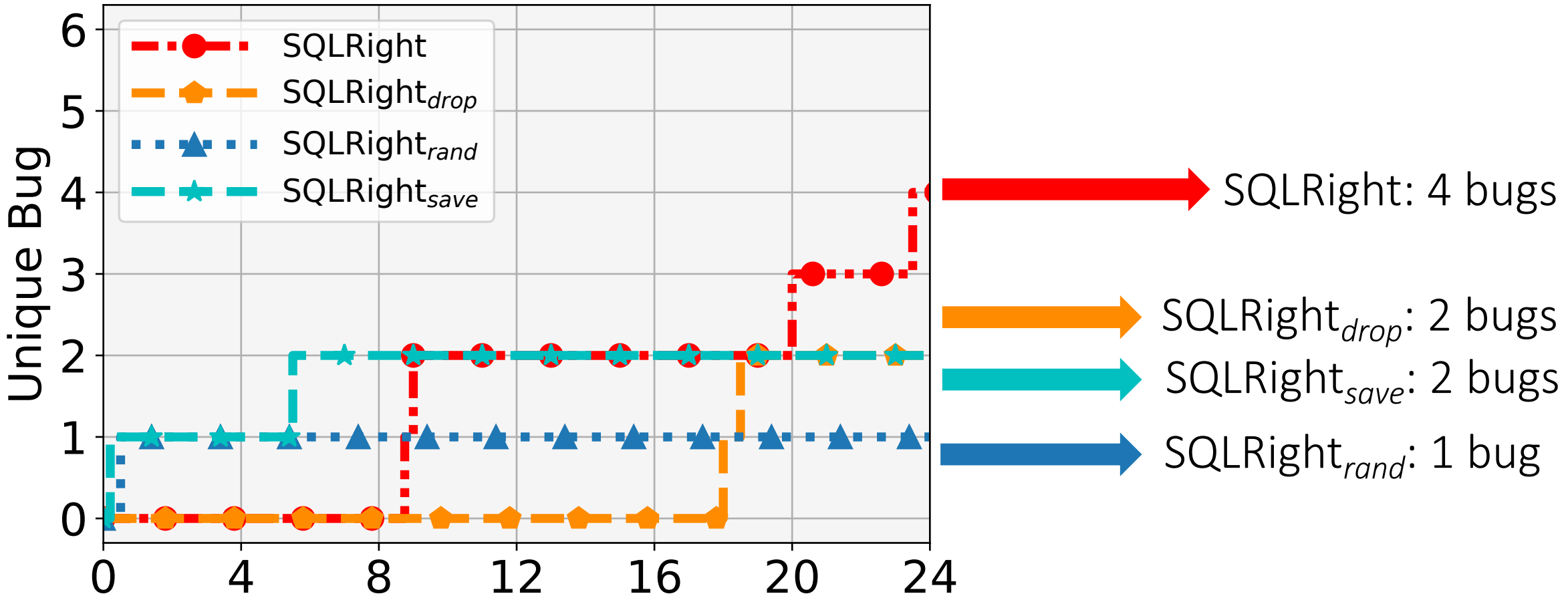

SQLancer: 92.0%
rule-based

SQLRight: 40.0%

Squirrel$_{+oracle}$: 32.0%

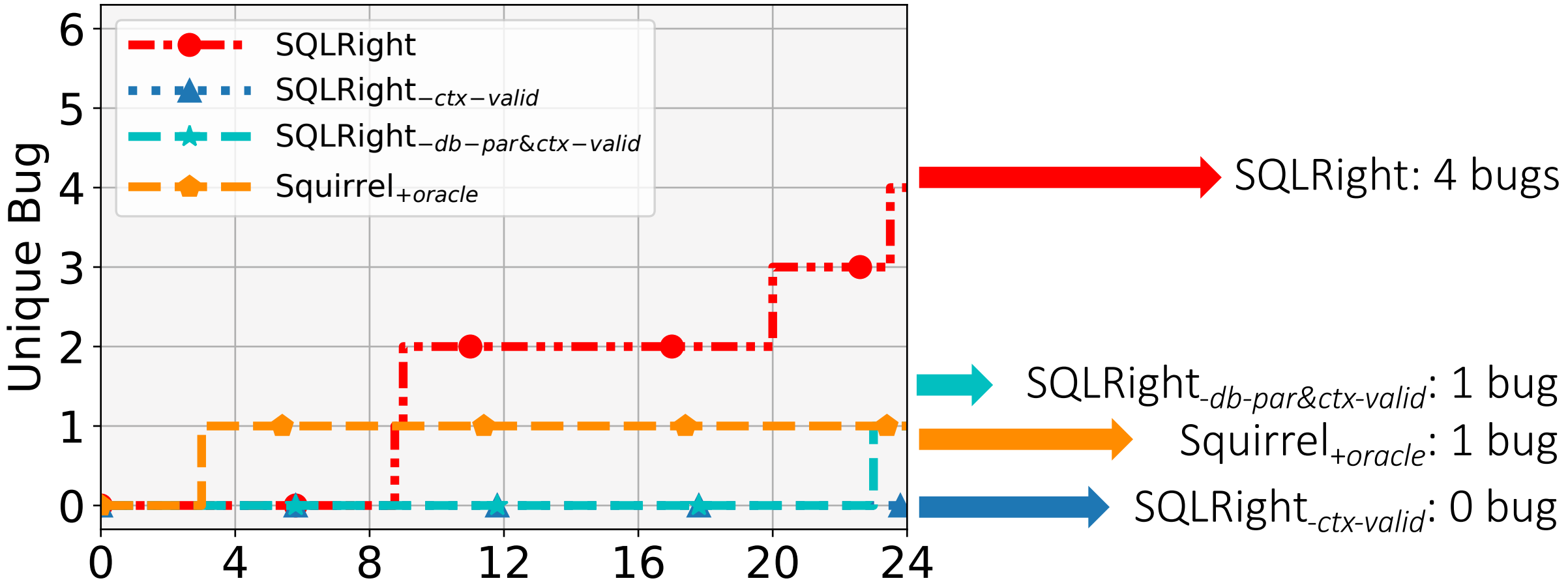
# Contribution of *Coverage Feedback* (NoREC)

- SQLite

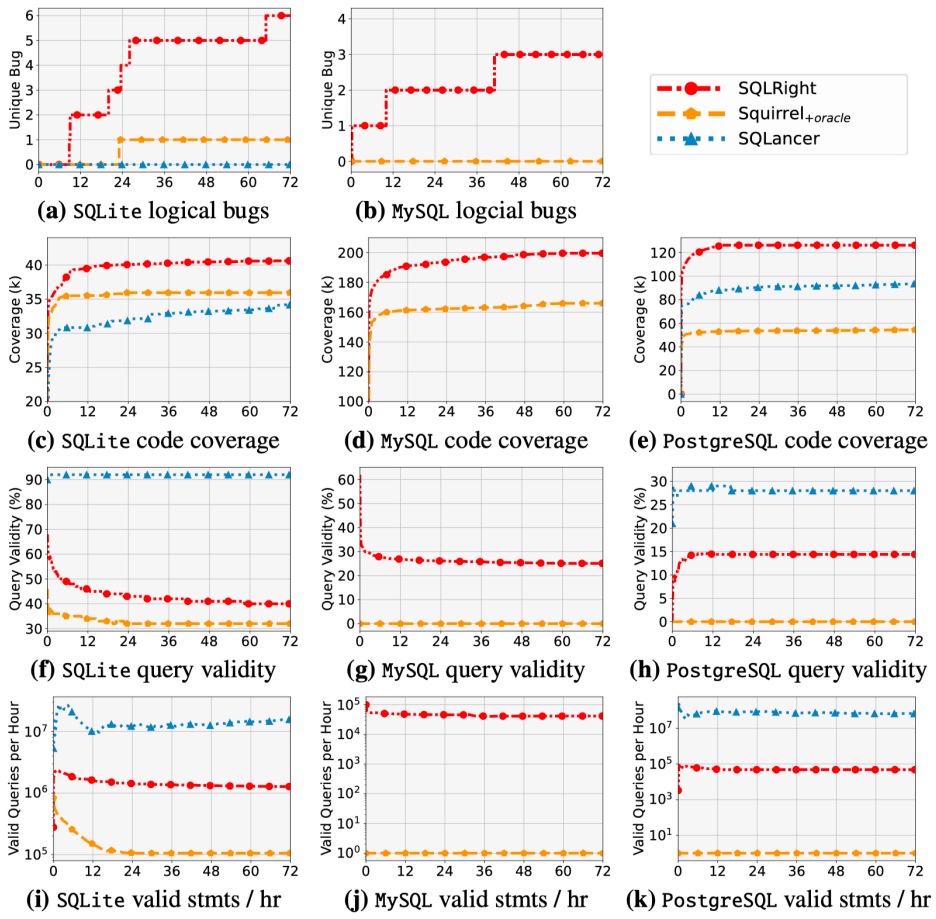


# Contribution of *Validity* (NoREC)

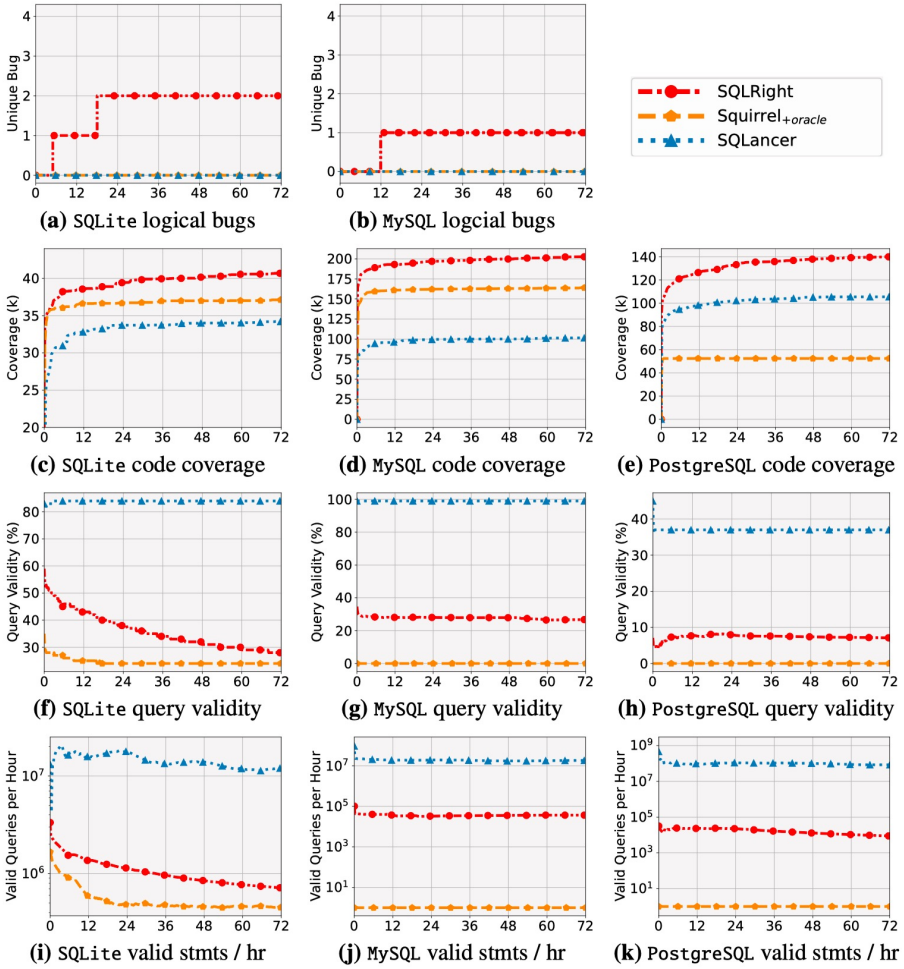
- SQLite



# More Evaluations in the Paper




NoREC




TLP

# Conclusion

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# Thank You

Question?

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