Using Parse Tree Validation to Prevent SQL Injection Attacks

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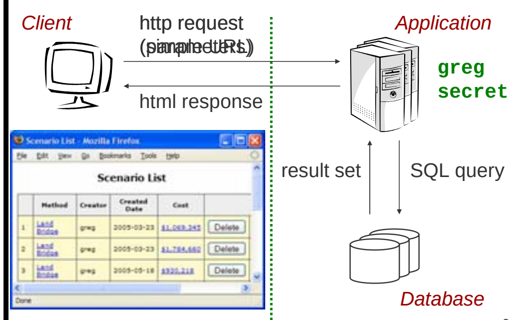
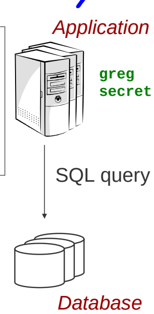
Web Application Architecture



SQL Injection: Anatomy of a Vulnerability

```
. . .
Statement s = conn.createStatement();
String q = "SELECT * FROM scenarios "
       + "WHERE username='" + user
       + "' AND password='" + pass
       + "';";
ResultSet RS = s.execute(q);
. . .
```




```
SELECT * FROM scenarios
       WHERE username='greg'
       AND password='secret';
```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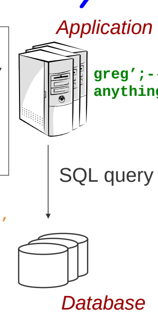



```
SELECT * FROM scenarios
       WHERE username='greg';--'
       AND password='anything';
```

```
SELECT * FROM scenarios
       WHERE username='greg';
```


Many Forms of SQL Injection

- Add comment character
  - `--`, `#`
  - Remove end of query
- Add a tautology
  - `OR 1=1`, `OR ''=''`, …
  - All table rows satisfy the query
- Add a statement
  - `;DROP TABLE scenarios`
- Can be complicated, multi-step
  - Insert unexpected value in table
    - eg `admin'--` as a username
  - Exploit this value in subsequent query

Preventing SQL Injection (1)

- "Sanitize" the input, removing all bad characters
  - Remove ' - =
  - Flag occurrence of valid SQL keywords (DROP, OR,…)
  - Problem: sometimes these characters are ok! (e.g., O'Reilly)
- Replace ' in user input with ''
  - SQL treats '' as a single quote literal
  - SELECT * FROM users WHERE name='O' 'Reilly'
  - Problem 1: undermined by other ways to escape input
  - Example: backslash also yields literal: \'
    - username passed in: \'; DROP TABLE users; --
    - Double quotes to get: \' '; DROP TABLE users; --
    - SELECT * FROM users WHERE name='\' '; DROP TABLE users; --'
  - Problem 2: other encodings (e.g., unicode)
  - Problem 3: integer fields do not have quotes
    - SELECT * FROM users WHERE userid=23 OR 1=1;

Preventing SQL Injection (2)

- "Sanitize" the input, confirming it contains only good characters
  - Regular expressions, static analysis
  - Problems: hard to get right, a lot to ask of programmers
- SQLRand
  - Replace SQL tokens with secret random values
  - Attacker can not write syntactically correct SQL
  - Problem: easy to leak secret (e.g., error messages)
- Prepared statements
  - Create query as a parameterized statement

```
String q = "SELECT * FROM scenarios WHERE username=?
  AND password=?";
PreparedStatement ps = conn.prepareStatement(q);
ps.setObject(1,user);
```

  - The best solution, really the right way to do things
  - Problems:
    - Annoying to use (syntax for replacing ?'s can be awkward)
    - Dynamic length queries

Our Approach: Best of Both Worlds

- Benefits of prepared statements
  - Guarantee preservation of parse tree
- Benefits of dynamic string concatenation
  - Easy, natural programming style
  - Consistent with state-of-the-practice

Parse Tree Validation

- Assume the existence of a special character, ♣
  - Never part of user input, never part of an SQL query
- Use this character to demarcate user input

```
SELECT * FROM scenarios WHERE username='♣greg♣'
  AND password='♣secret♣';
```

- Compare the parse trees of two strings:
  1. The string with all text between pairs of ♣ replaced by a literal token (i.e., a special leaf in the parse tree)

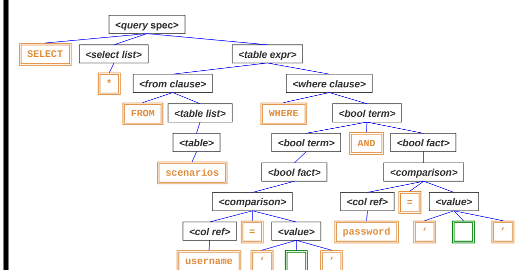
```
SELECT * FROM scenarios WHERE username='?'
  AND password='?';
```

  2. The string with all occurrences of ♣ removed

```
SELECT * FROM scenarios WHERE username='greg'
  AND password='secret';
```

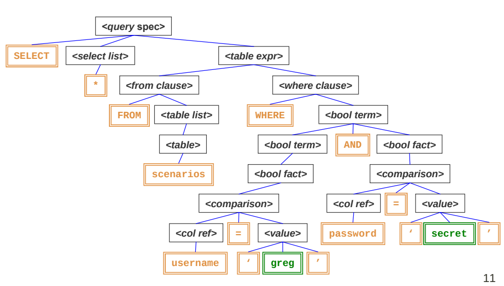

Parse Tree Comparison

```
SELECT * FROM scenarios WHERE username='?'
  AND password='?';
```



Parse Tree Comparison

```
SELECT * FROM scenarios WHERE username='greg'
  AND password='secret';
```



Parse Tree Validation Rule

- Accept the SQL query if
  - The *structures* of the two parse trees are exactly the same (node types), and
  - The values of corresponding nodes in the two parse trees are exactly the same, except for the special (green) leaf nodes.
- Otherwise, reject the query as insecure

Revisiting our Assumption

- Technique is predicated on a reliable way to demarcate user input
  - Special character (♣) that can not be part of user input
  - Otherwise, attacker could circumvent
    - input: `secret♣' OR 'a'='♣a`
- But user input could include anything
- Solution:
  - Generate unique, fixed-length, random (unpredictable), private key for each query
  - Prefix each query with its key
  - Our prototype uses 64-bit keys (8 char)


```
w8#pER7}SELECT * FROM scenarios
        WHERE username='w8#pER7}gregw8#pER7}'
        AND password='w8#pER7}secretw8#pER7}';
```

```
u3Gd(lcASELECT * FROM scenarios
        WHERE username='u3Gd(lcAgregu3Gd(lca'
        AND password='u3Gd(lcAsecretu3Gd(lca';
```

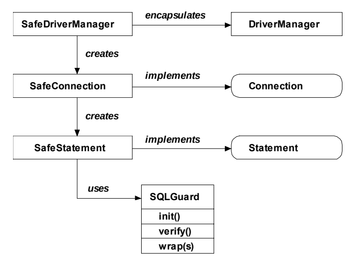
```
w;hX@K--SELECT * FROM scenarios
        WHERE username='w;hX@K--gregw;hX@K--'
        AND password='w;hX@K--secretw;hX@K--';
```

```
WHERE usSELECT * FROM scenarios
        WHERE username='WHERE usgregWHERE us'
        AND password='WHERE ussecretWHERE us';
```


Ease of Use

```
Connection conn = SafeDriverManager.getConnection(DB);
. . .
Statement s = conn.createStatement();
String q = SQLGuard.init() + "SELECT * from scenarios "
        + "WHERE username='" + SQLGuard.wrap(user)
        + "' AND password='" + SQLGuard.wrap(pass)
        + "';";
ResultSet RS = s.execute(q);
. . .
RS.close();
conn.close()
```

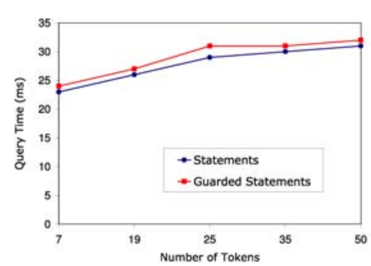

Architecture



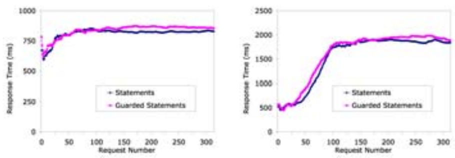
Multithreading

- For scalability to many users, web applications are highly concurrent and multithreaded
  - SQLGuard must generate and keep track of multiple keys simultaneously
- Concurrent calls to SQLGuard must be serialized
- Calls to wrap() must be associated with correct (matching) call to init()
  - Thread id used to distinguish instances

Performance Considerations



Performance Considerations



Conclusions

- All known forms of SQL injection involve modification of the intended parse tree
  - Our approach guarantees that dynamically provided parameters are leaf nodes *only*
  - Modification of intended parse tree is not possible
- Limitations:
  - Unguessability of demarcation key
  - Quality of error message available for client
  - SQL tutorial web application
- Implementation available at
  - http://www.cse.ohio-state.edu/~paolo/software

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Discussion Points

- Tension between weak & strong typing
  - weak typing: flexibility, rapid development, prototyping
  - strong typing: correctness, confidence, security
  - trend: weaker typing
    - e.g., scripting languages, HTTP