Preventing Security Bugs Through Software Design

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The Same Bugs, Over and Over Again...

- SQL-injection, XSS, XSRF, etc -- OWASP Top 10
- Root cause
  - Inherently bug-prone APIs
  - Developers are humans and make mistakes
  - APIs often widely used
- Many *potential* bugs
  → Some *actual* bugs
- Inherently incomplete bug-finding approaches (testing, static analysis)
  → Once introduced, bugs are difficult to eliminate

Don't Blame the Developer, Blame the API

Inherently Safe APIs

- API design prevents introduction of security bugs in application code
- Approx. as convenient to use as original, vuln-prone API
- Soo… Is this practical?

Preventing SQL Injection

SQL Injection

```
String getAlbumsQuery = "SELECT … WHERE " +
    " album_owner = " + session.getUserId() +
    " AND album_id = " + servletReq.getParameter("album_id");
ResultSet res = db.executeQuery(getAlbumsQuery);
```

Existing Best Practices

- "Use Prepared Statements"
  - Developers forget → potential bug
  - ```
    dbConn.prepareStatement(
        "... WHERE foo = " + req.getParameter("foo"));
    ```
  - (yes, not making this up)
- "Use Structural Query Builder APIs"
  - Cumbersome for complex statements
    ```

A Simple, Safe Query API

```
public class QueryBuilder {
  private StringBuilder query;

  /** ... Only call with compile-time-constant arg!!! ... */
  public QueryBuilder append(
      @CompileTimeConstant String sqlFragment) {...}

  public String getQuery() { return query.build(); }
}
```

Static Check of API Contract

```
qb.append(
    "WHERE album_id = " + req.getParameter("album_id"));


-->
java/com/google/.../Queries.java:194: error: [CompileTimeConstant] Non-
compile-time constant expression passed to parameter with
@CompileTimeConstant type annotation.
    "WHERE album_id = " + req.getParameter("album_id"));
                          ^
```

[github.com/google/error-prone, Aftandilian et al, SCAM '12]

Application Code

```
// Unsafe API
String sql = "SELECT ... FROM ...";
sql += "WHERE A.sharee = :user_id";

if (req.getParam("rating")!=null) {
  sql += " AND A.rating >= " +
      req.getParam("rating");
}

Query q = sess.createQuery(sql);
q.setParameter("user_id", ...);
```

```
// Safe API
QueryBuilder qb = new QueryBuilder(
    "SELECT ... FROM ...");
qb.append("WHERE A.sharee = :user_id");
qb.setParameter("user_id", ...);

if (req.getParam("rating")!=null) {
  qb.append(" AND A.rating >= :rating");
  qb.setParameter("rating", ...);
}

Query q = qb.build(sess);
```

In Practice

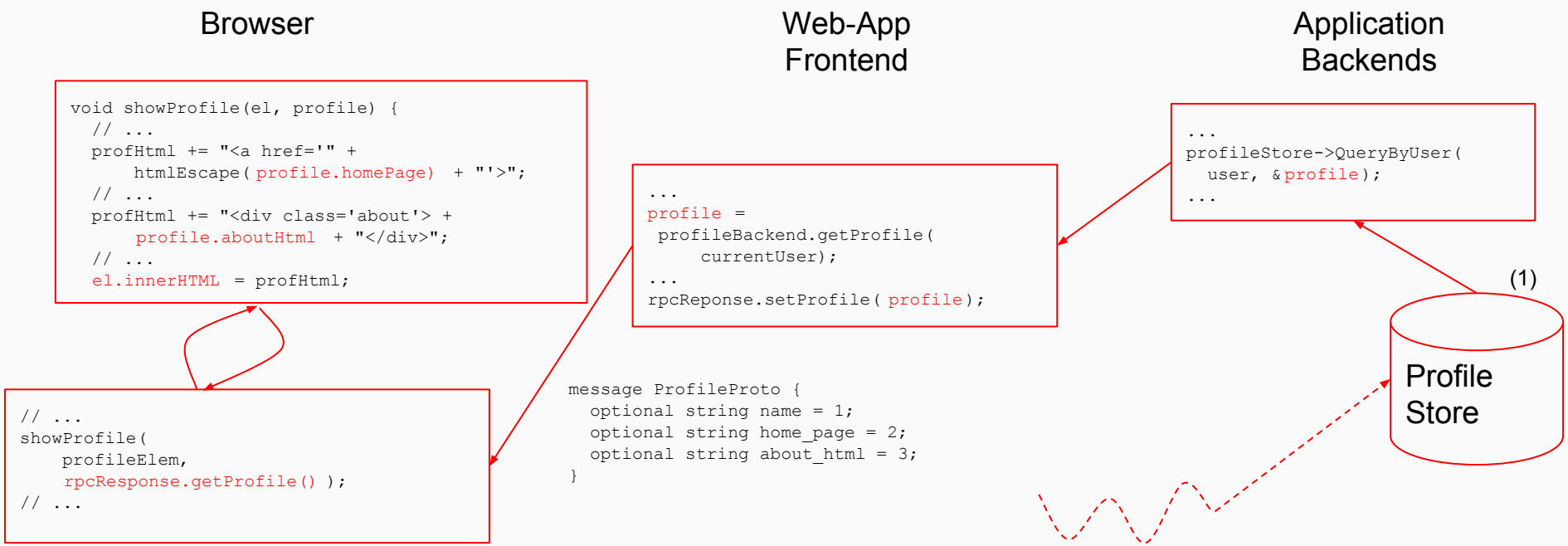
- Implemented inherently-safe Builder APIs for F1 [SIGMOD '12, VLDB '13] (C++, Java), Spanner [OSDI '12] (C++, Go, Java), and Hibernate.
- Refactored all existing call-sites across Google
  - Few person-quarters effort
- Removed (*) bug-prone `executeQuery(String)` methods
  ⇒ SQL Injection doesn't even compile
- Straightforward implementation

(*) Exceptional Use Cases

- E.g.: Command-line query tool
- Provide potentially-unsafe, unconstrained API
  - "Back door" for `executeQuery(String)`
  - Subject to security review
  - Enforced using visibility whitelists [bazel.io/docs/build-encyclopedia.html#common.visibility]
  - Needed rarely (1-2% of call sites)

Preventing XSS

Many Injection Sinks & Complex Data Flows



Safe HTML Rendering:
Strict Contextual Autoescaping

```
{template .profilePage autoescape="strict"}
  …
  <div class="name">{$profile.name}</div>
  <div class="homepage">
    <a href="{$profile.homePage}">...
  <div class="about">
    {$profile.aboutHtml}
  …
{/template}
```

Safe HTML Rendering:
Strict Contextual Autoescaping

```
{template .profilePage autoescape="strict"}
  …
  <div class="name">{$profile.name |escapeHtml}</div>
  <div class="homepage">
    <a href="{$profile.homePage |sanitizeUrl|escapeHtml}">...
  <div class="about">
    {$profile.aboutHtml |escapeHtml}
  …
{/template}
```

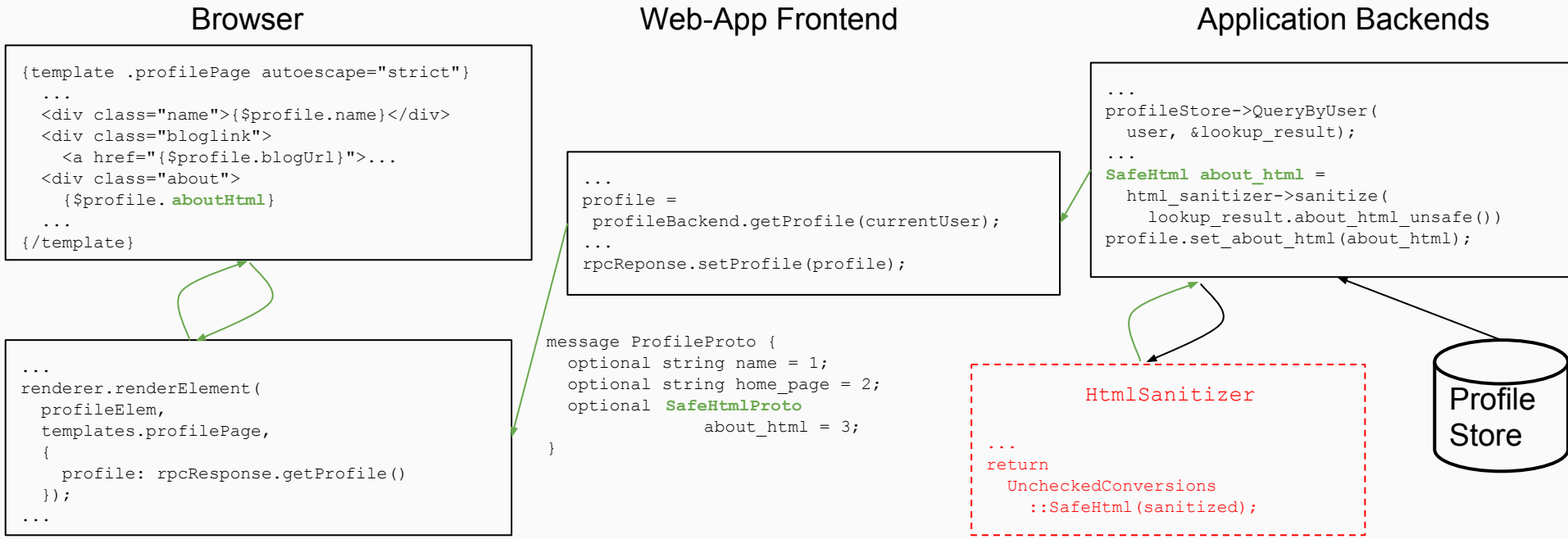
Types to Designate Safe Content

- Context-specific types
  - SafeHtml
  - SafeUrl
  - ...
- Security type contracts
  - "Safe to use (wrt XSS) in corresponding HTML context"
  - Contract ensured by types' public API (builders/factory-functions)
  - "Unchecked Conversions" -- mandatory security review

Coding Rules

- Use strict template for all HTML markup
- Bug-prone DOM-APIs (.innerHTML, location.href, etc) strictly forbidden in application code
- Enforced by compile-time check (Closure JS Conformance)
- Errors reference safe alternatives
  - .innerHTML -> strict template; goog.dom.safe.setInnerHtml(Element, SafeHtml)
  - location.href -> goog.dom.safe.setLocationHref(Location, string|SafeUrl)
  - etc

Safe-Coding-Conformant Application Code



Practical Application

- Strict contextual escaping in Closure Templates, AngularJS, et al.
- Adopted in several flagship Google applications
- Drastic reduction in bugs
  - One case: **~30 XSS** in 2011, **~0** (*) since Sep 2013
- More background: [Kern, CACM 9/'14]

Design Patterns

Inherently Safe APIs: Confining/Eliminating "Bug Potential"

- Inherently-safe API: By design, calling code can't have (certain types of) bugs
  - Potential for bugs (of specific class) *confined* in API's implementation
  - Potential for bugs *eliminated* from application code
- In practice: Reduction in *actual* bugs

API Design Principle:
No Unsupported Assumptions

- Values of basic types (esp String):
  (conservatively) assumed attacker-controlled
  - Unconditionally apply run-time escaping/validation
  - In practice, almost always functionally correct
- Dual of static/dynamic taint tracking
  - "Strings are evil, unless proven otherwise"
    vs. "Strings are harmless unless tainted"

Types & Type Contracts

- Type Contract "tele-ports" promise about a value from source to sink
  - *Irrespective* of complexity of intervening (whole-system) data flow
- Enable localized reasoning about whole-program correctness
- Modulo type integrity
  - Assumes reasonably rigorous type encapsulation

Usability & Practical Applicability

- Similarity to familiar APIs and coding patterns
  - Some refactoring OK, esp if automatable
- Lightweight approval process for exceptions
- Errors and findings: Compile time is best time
  - Before changelist is even sent for review
  - Clear-cut "deviation from safe coding practice" error vs. ambiguous "potential bug" finding
  - Familiar presentation (type error, straightforward static check)

Design for Reviewability

- "What percentage of source code do I have to read/analyze/understand to establish absence of a class of bugs?"
  - > yy% + large project → you'll almost certainly have some bugs
  - < 0.xx% → probably in good shape
- Inherently Safe APIs & confined bug potential

  ⇒ Drastically reduced review burden

  ⇒ Comprehensive reviews become practical

  ⇒ High-confidence assessments

Open Source

- Closure SafeHtml types & DOM wrappers
- Closure Templates Strict Contextual Escaping
- Closure Compiler Conformance
- AngularJS Strict Contextual Escaping
- @CompileTimeConstant checker (part of Error Prone)
- ~~Coming soon~~ Just released: Java Safe HTML types

Questions?