Automated Oracle Comparators for Testing Web Applications

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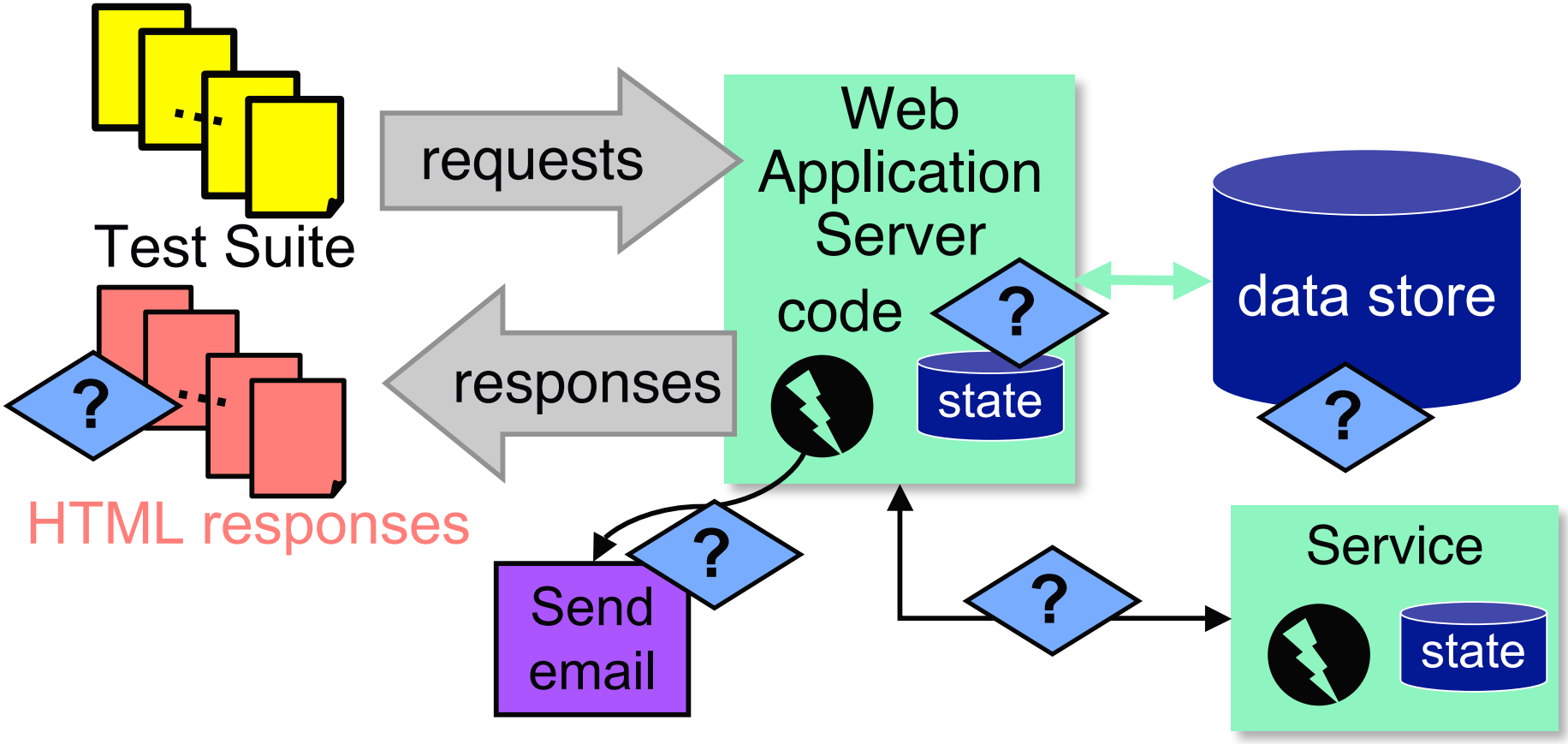
Testing Web Applications

- 772 million people online in May 2007*
- Amazon.com had 142K *unique* visitors, on average visit 3.1 times, in May 2007*
  - Earned $10.7 billion in revenue in 2006
- Need reliable web applications
  - Errors are seen by many, quickly
  - Frequent maintenance/update cycles
  - Need fast, effective oracles

* Source: comScore

Oracles for Web Applications

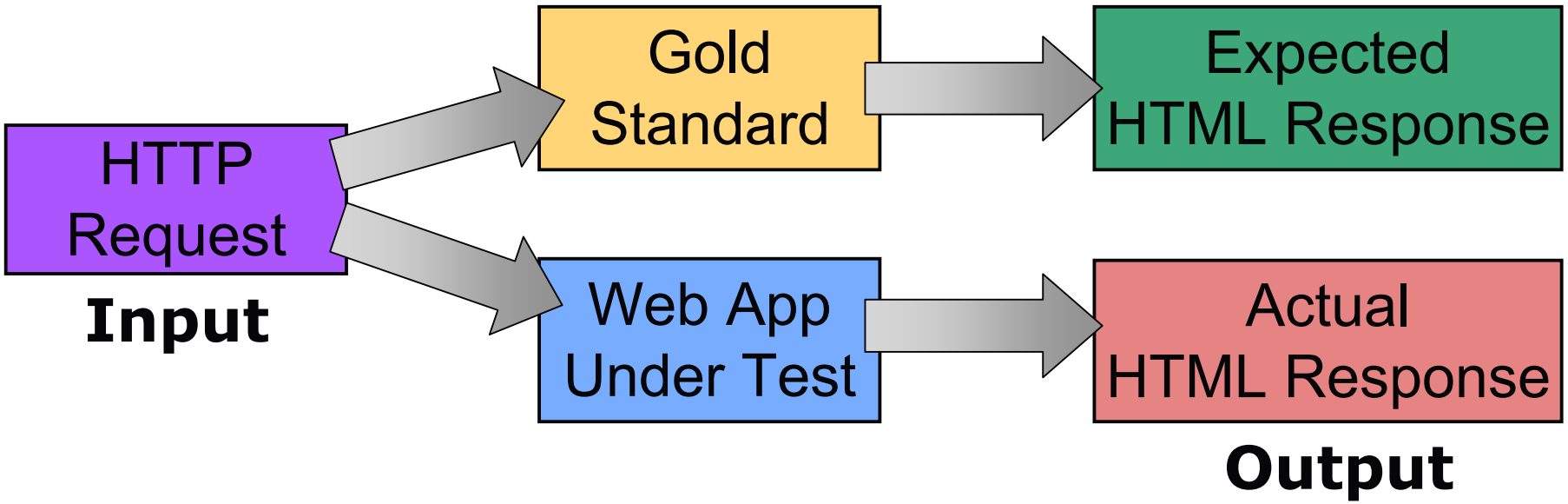


- Challenge: Low observability of outputs
- Solution: Use “pseudo-oracle” [Weyuker 82] on HTML
  - HTML: Common output for web applications

Overview of Contributions

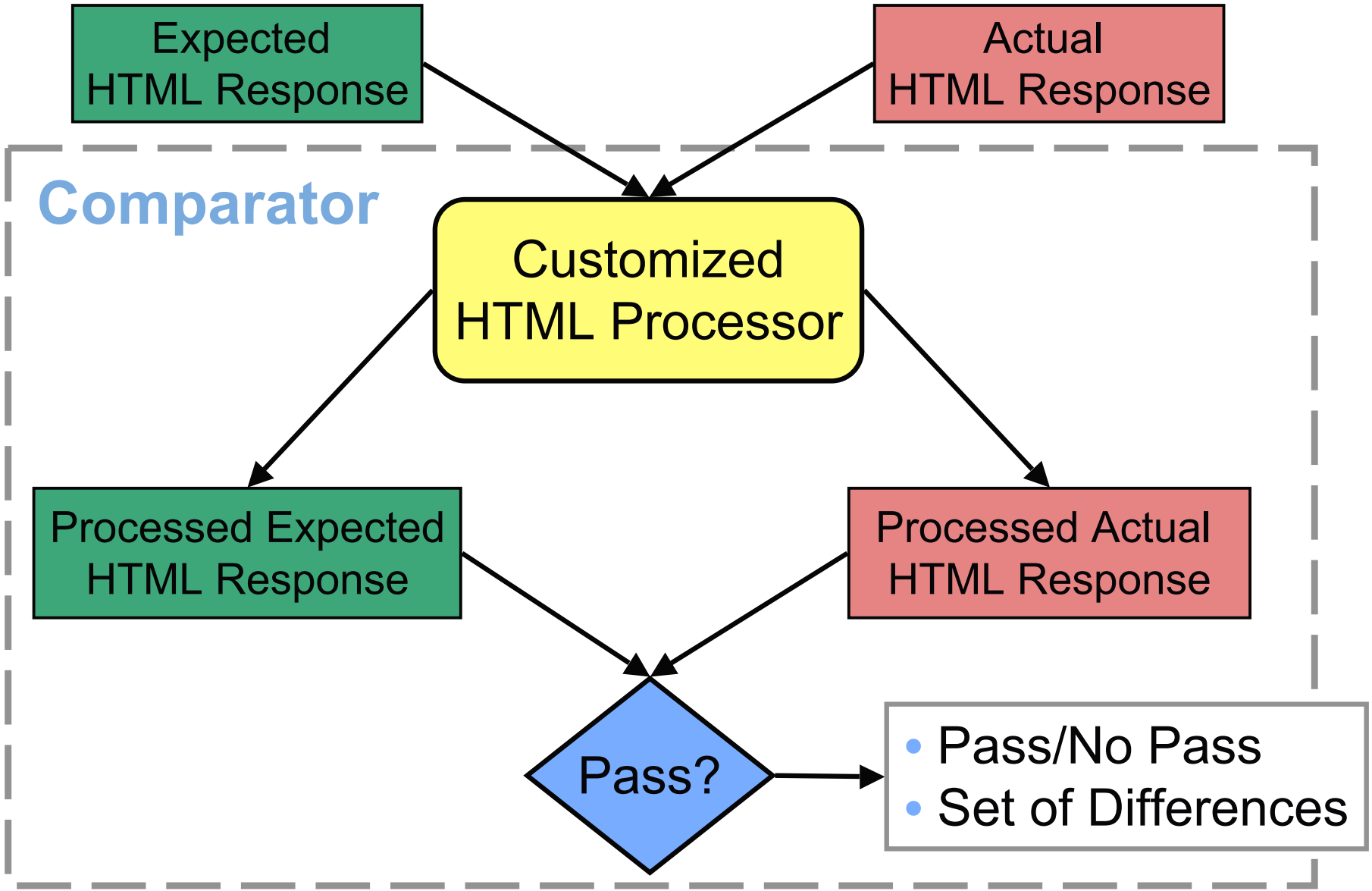
- Developed 22 automated HTML comparison algorithms
  - Why HTML? Common web application output, users *see* output, side effects of failures may show up in HTML
- Evaluated comparators on 4 deployed subject applications
  - False positives, false negatives
- Made recommendations to testers about selecting effective oracles

Our Oracle Process



- Expected results: use original version of application (assumed to be correct)
  - Gold Standard

Our Oracle Process



Importance of Accurate Oracle

- Oracle is quality inspector
- Need oracle to be accurate
  - Allow only the applications that behave as expected to be deployed
- Consequences of inaccurate oracle
  - Buggy application is deployed
    - Customers may see errors
  - Correct application is not deployed
    - Not taking advantage of improvements

Evaluating Oracles

		Application Under Test	
		Faulty Application	Correct Application
Oracle Result (Is there a fault?)	Positive (fault)	True Positive	False Positive Look for a non-existent fault!
	Negative (no fault)	False Negative Missed a fault!	True Negative

- False positive
  - Oracle says “fault” but application does not have a fault
- False negative
  - Oracle says “no fault” but application contains a fault

Evaluating Oracles

		Application Under Test	
		Faulty Application	Correct Application
Oracle Result (Is there a fault?)	Positive (fault)	True Positive	False Positive Look for a non-existent fault!
	Negative (no fault)	False Negative Missed a fault!	True Negative

- HTML comparator algorithms
  - False negatives: for faults that do not show up in the HTML

Example of an HTML Response

```
<html>
<head>
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-1">
<title>hiperspace lab</title>
<style>a:hover{color:#952C2C; text-decoration:none}… </style>
<script language="Javascript"> … </script>
</head>
<body>
<table border=0 cellspacing=0 width="580">
<tr> <td rowspace=2>
<img src="books.gif" width=310></td></tr>
…</table>
<!-- Sidebar Links -->
<ul>…
<li><a href="alumni.html">Alumni</a>
</ul>
</body>
</html>
```

Start tag

Content

Style

Layout

Comment

Content

Attribute

Close tag

- Browser collapses white space

Comparing the HTML Output

Expected

```
<html>
<head><title>My Page</title>
</head>
<body>
<h1>Intro</h1>
<p> Text…
<p> Today is January 10.
<a href="link.html">link</a>
<h2>Subsection</h2>
<form method=post …>…</form>
</body>
```

Actual

```
<html>
<head><title>My Page</title>
</head>
<body>
<h1>Intro</h1>
<p> Text…
<br> Today is January 11.
<a href="link2.html">link</a>
<h2>Subsection</h2>
<form method=post …>…</form>
</body>
```

Comparison Algorithm: Document

- Diff entire document
  - Cheap, thorough

```
<html>
<head><title>My Page</title>
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```

Not a fault

Appearance fault

Link fault

Comparison Algorithm: Document

- Diff entire document
  - Cheap, thorough

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</head>
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</head>
<body>
<h1>Intro</h1>
<p> Text…
<br> Today is January 11.
<a href="link2.html">link</a>
<h2>Subsection</h2>
<form method=post …>…</form>
</body>
```

- **Options**: ignore comments, some tags; collapse white space

Comparison Algorithm: Content

- Diff document's text

My Page Intro Text… Today is January 10. Subsection	My Page Intro Text… Today is January 11. Subsection

- Misses link fault
- **Options**: collapse white space, ignore dates

Comparison Algorithm: Structure

- Diff document's tags

```
<html>
<head><title></title>
</head>
<body>
<h1></h1>
<p>
<p>
<a href="link.html">
<h2></h2>
<form method=post …>…</form>
</body>
```

```
<html>
<head><title></title>
</head>
<body>
<h1></h1>
<p>
<br>
<a href="link2.html">
<h2></h2>
<form method=post …>…</form>
</body>
```

- Miss errors in content
- **Options**: ignore closing tags, style, layout, unimportant attributes, all attributes, form options, order of links/imgs

HTML Comparison Algorithms

False negatives: faults not manifested in HTML

Comparison Algorithm	False Positives	False Negatives
Document	Dynamic, real-time changes	————
Content	Dynamic, real-time changes	Errors in structure, e.g. forms
Structure	Display changes that do not affect app behavior	Errors in content

Partial Ordering of Implemented Comparison Algorithms

Document-based oracles:

Document (D)
DocumentBase (DB)
DocumentBase-CollapsedWS (DB-W)

Content-based oracles:

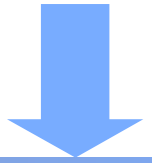
Content (C)
Content-CollapsedWS (C-W)
Content-CollapsedWS-Dates (C-WD)

Structure-based classes:

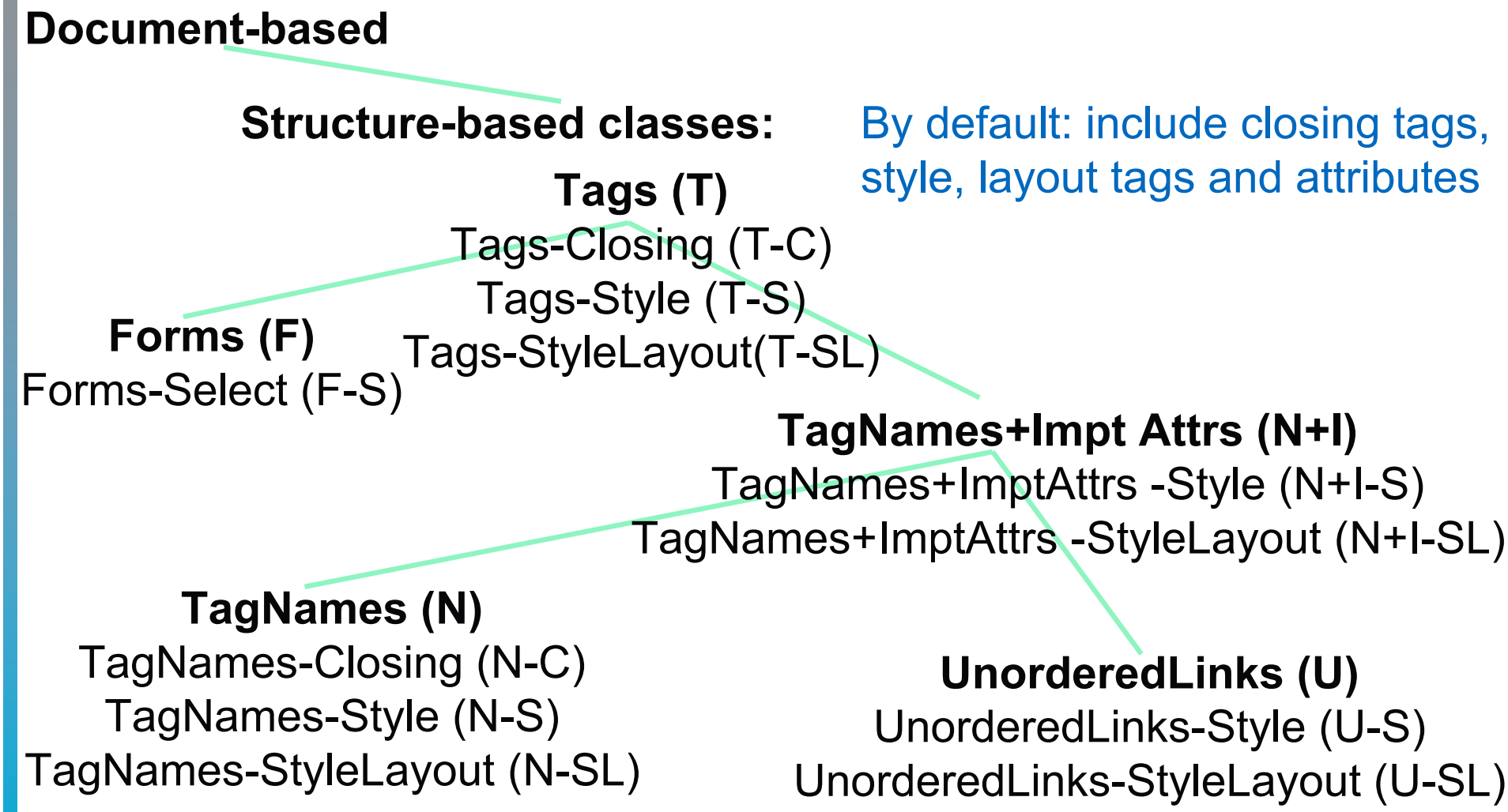
Tags (T)
- Forms (F)
- TagNames+Impt Attrs (N+I)
  - TagNames (N)
  - UnorderedLinks (U)


More information


Fewer False Negatives


Fewer False Positives

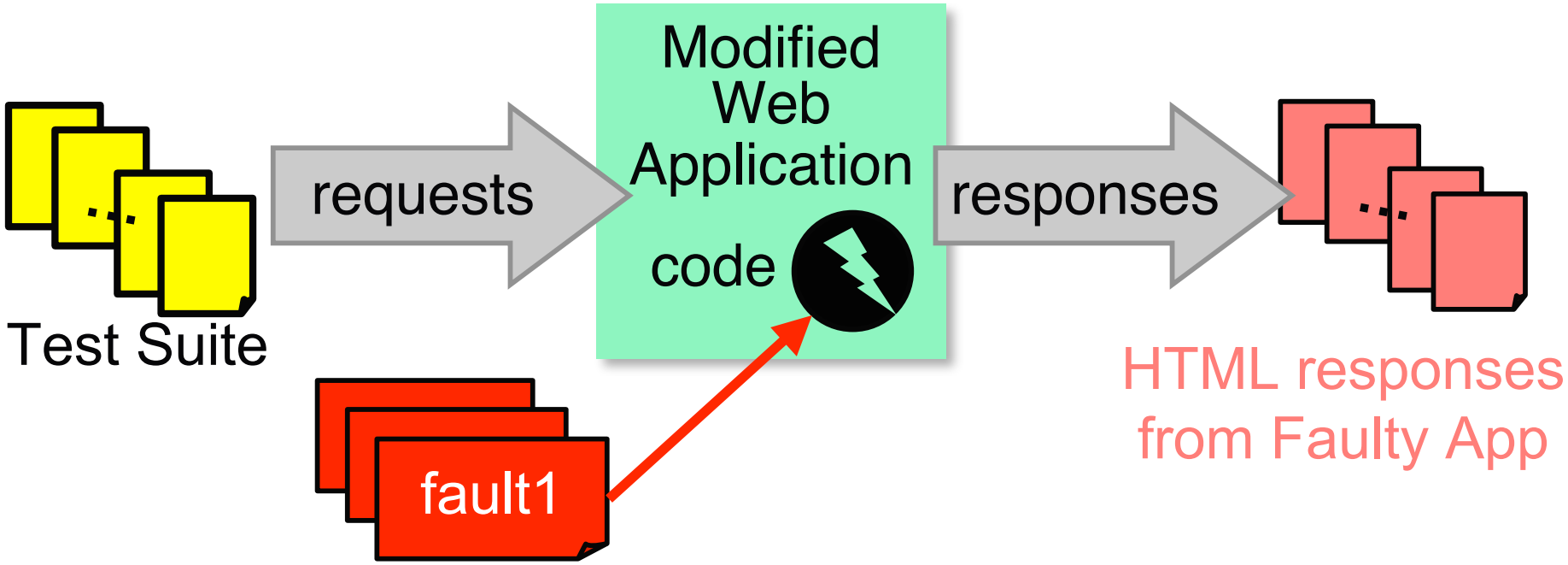
Partial Ordering of Implemented Comparison Algorithms



Experimental Study

- **Goal**: oracle evaluation and recommendations to testers, researchers
- Exp 1: Effect of nondeterministic, real-time behavior
  - False positives
- Exp 2: Failure detection
  - Number & types of detected faults
  - Precision: $\frac{\text{\# failures correct}}{\text{Total failures reported}}$ (higher means few false +)
  - Recall: $\frac{\text{\# failures correct}}{\text{Expected \# of failures}}$ (higher means few false -)

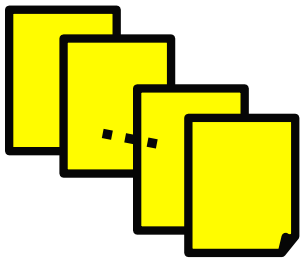
Methodology: Failure Detection Study



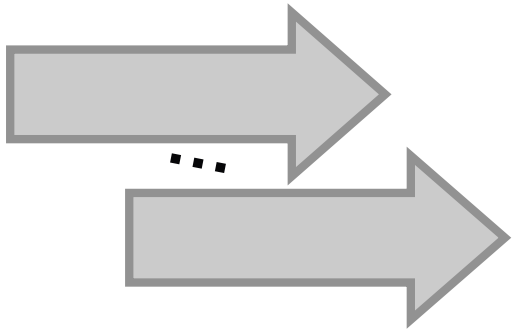
- Faults seeded manually into application code
- Various *categories* of seeded faults
  - data, logic, form, appearance, link

Methodology: Evaluating Oracles

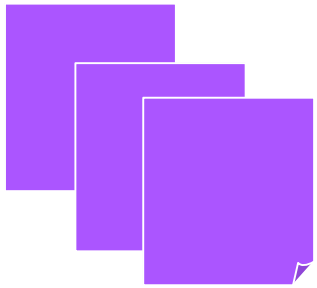
For the test suite of each subject application:



Test Suite



Replay suite on clean and fault-seeded version(s) of code



Generate failure detection reports for each **fault class** using each **oracle**

Comparator's Failure Detection Report:

Request/Response	Failure? (Yes/No)

Subject Applications

- Four deployed subject applications

Application	Test Cases	Requests	NCLOC*	Faults Exposed
Masplas	169	1103	999	22
E-Commerce Bookstore (Book)	125	3564	7791	36
Course Project Manager (CPM)	890	12352	9300	96
DSpace	75	3183 (3023 HTML pages)	49513	20

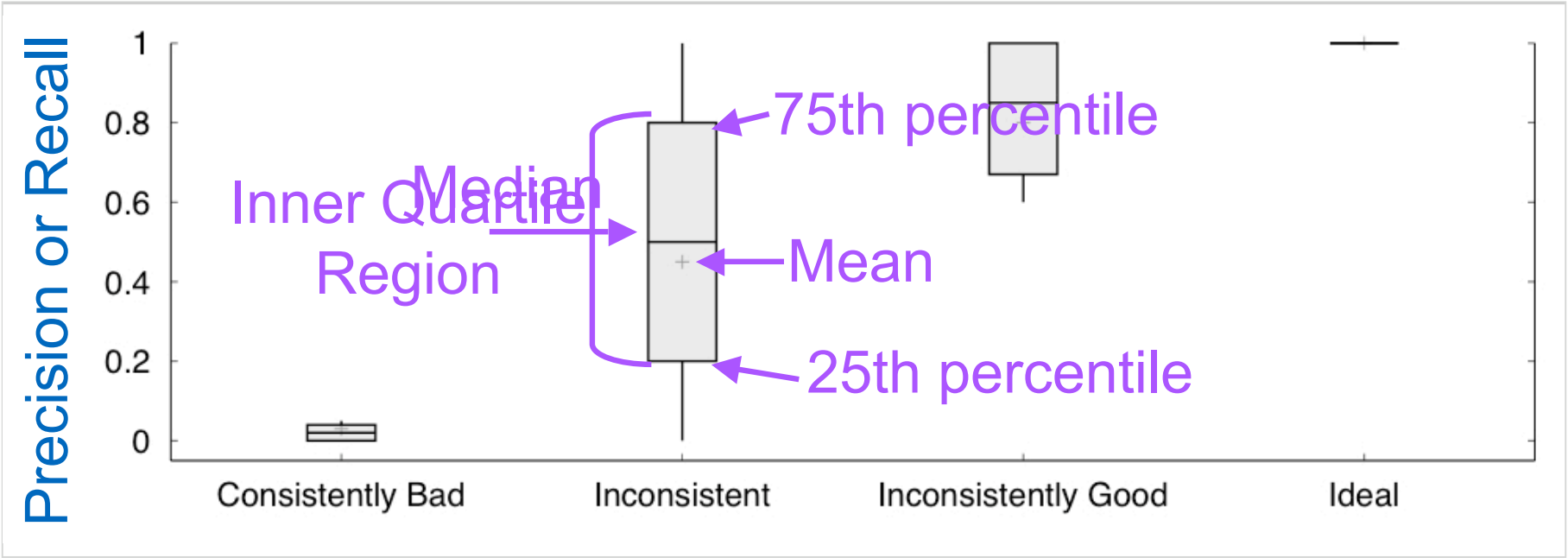
Deterministic behavior

Nondeterministic, real-time behavior

*NCLOC: Non-comment Lines of Code

Total: 174 Faults

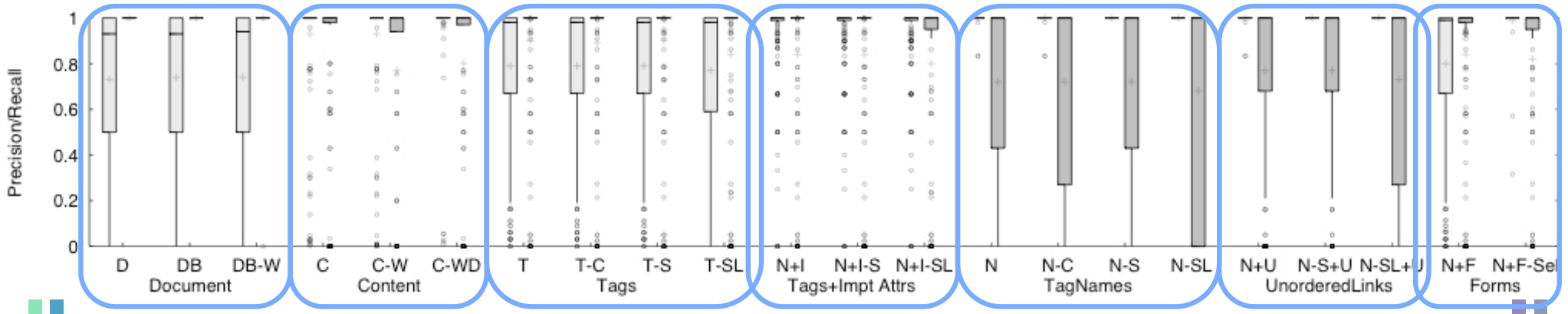
How to Interpret Results



- Legend:
  - Horizontal Bar: Median
  - + : Mean
  - Box: Inner quartile region (IQR) -- inner 50% of data
  - Vertical line: 1.5 * IQR
- Point in distribution: comparator's precision or recall for 1 fault

Failure Detection Results

- Precision: light gray, left
- Recall: dark gray, right
- Across all applications, all fault types
  - Individual graphs in Sprenkle thesis



- Tradeoff between precision and recall
- Trends follow hierarchy
  - Top of hierarchy: higher recall, lower precision
  - Leaves of hierarchy: lower recall, higher precision

Combinations of Oracles

- **Key Insight**: combine best oracles that focus on disparate parts of the HTML document to improve effectiveness over individual comparators
  - Union: improves recall, may affect precision
  - Intersection: improves precision, decreases recall
- Empirically best combination, across all apps: **C-WD ∪ N+I**

Guidance to Testers

- Execute test suite several times
  - Identify responses with nondeterministic, real-time behavior
  - Identify comparators with fewest false positives
- Vary comparator by response's behavior
  - Deterministic: use Document
  - Nondeterministic: use C-WD ∪ N+I
- Use more precise oracle in early testing stages
  - Don't overwhelm testers with failure reports
  - Flesh out bugs w/o sifting through false positives
- **Document** family for fewest false negatives
- **Forms-Select** for fewest false positives w/ highest recall

Related Work

- Model-based testing of web applications
  - Ricca01, Liu00, Deng04
  - Andrews05: suggests partial oracles
- HttpUnit
  - Testers create oracles manually
- HTML-based comparators
  - Elbaum05, DiLucca02 -- few details of implementation, no evaluation of false positives, negatives

Conclusions and Future Work

- Proposed, evaluated a suite of customized, HTML-based oracle comparators
- Recommendations to testers for selecting oracle
  - Most effective oracle in general: Content-CollapsedWS-Dates ∪ TagNames+ImptAttrs
- Learning effective oracle comparator combinations: STEV2007
  - Train on faults from bug reports
- Future work
  - Fully customizable comparator
  - Evaluate with more applications, faults