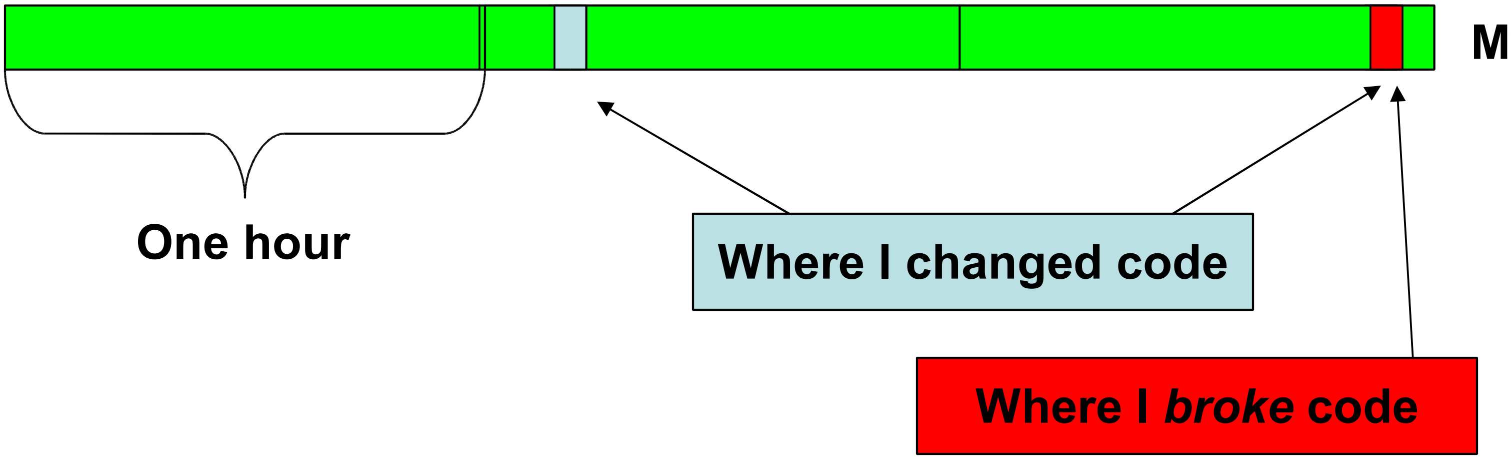
Test Factoring: Focusing test suites on the task at hand

David Saff, MIT

ASE 2005

The problem:
large, general system tests



My test suite

One hour

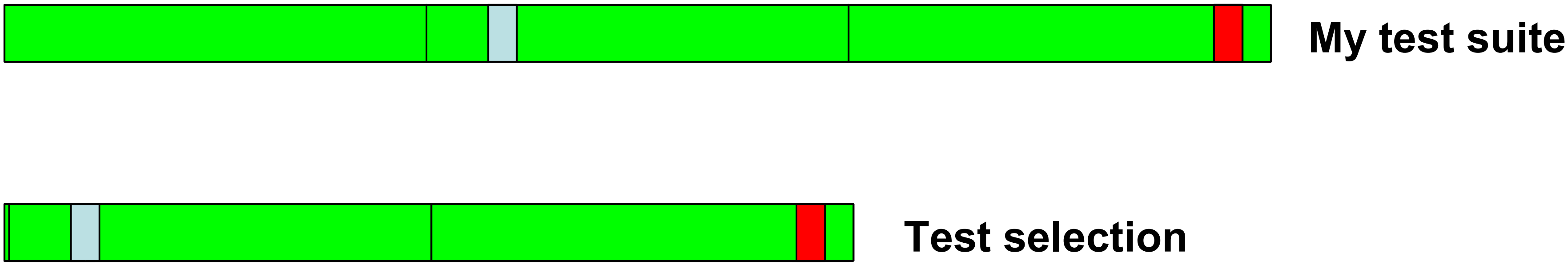
Where I changed code

Where I *broke* code

How can I get:
Quicker feedback?
Less wasted time?

[Saff, Ernst, ISSRE 2003]

The problem:
large, general system tests



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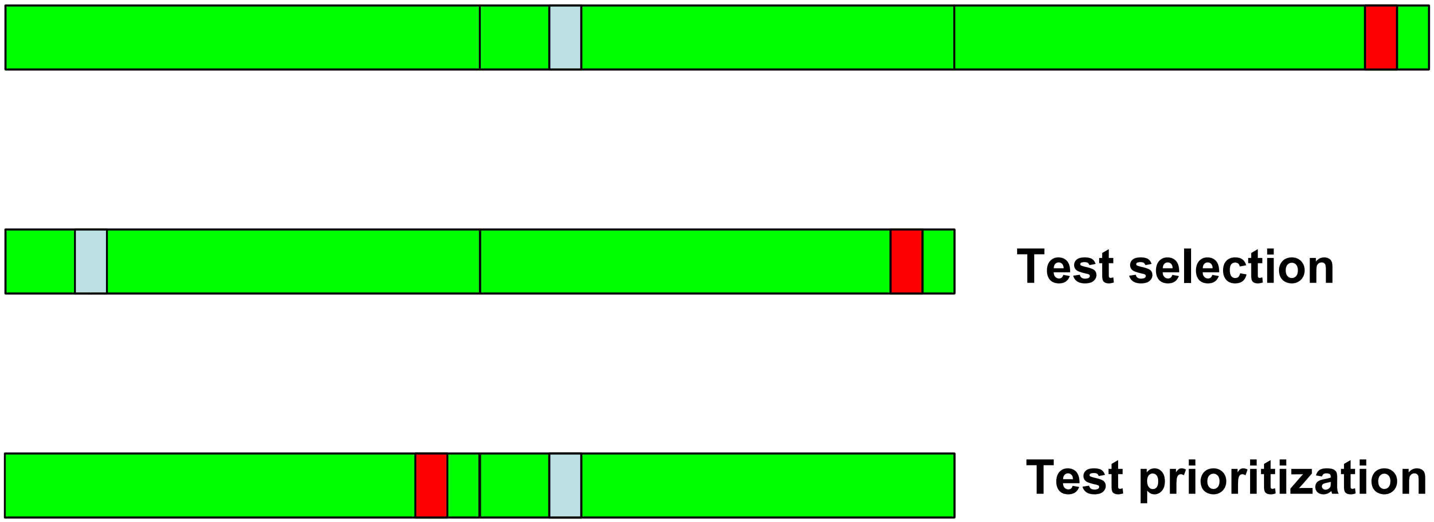
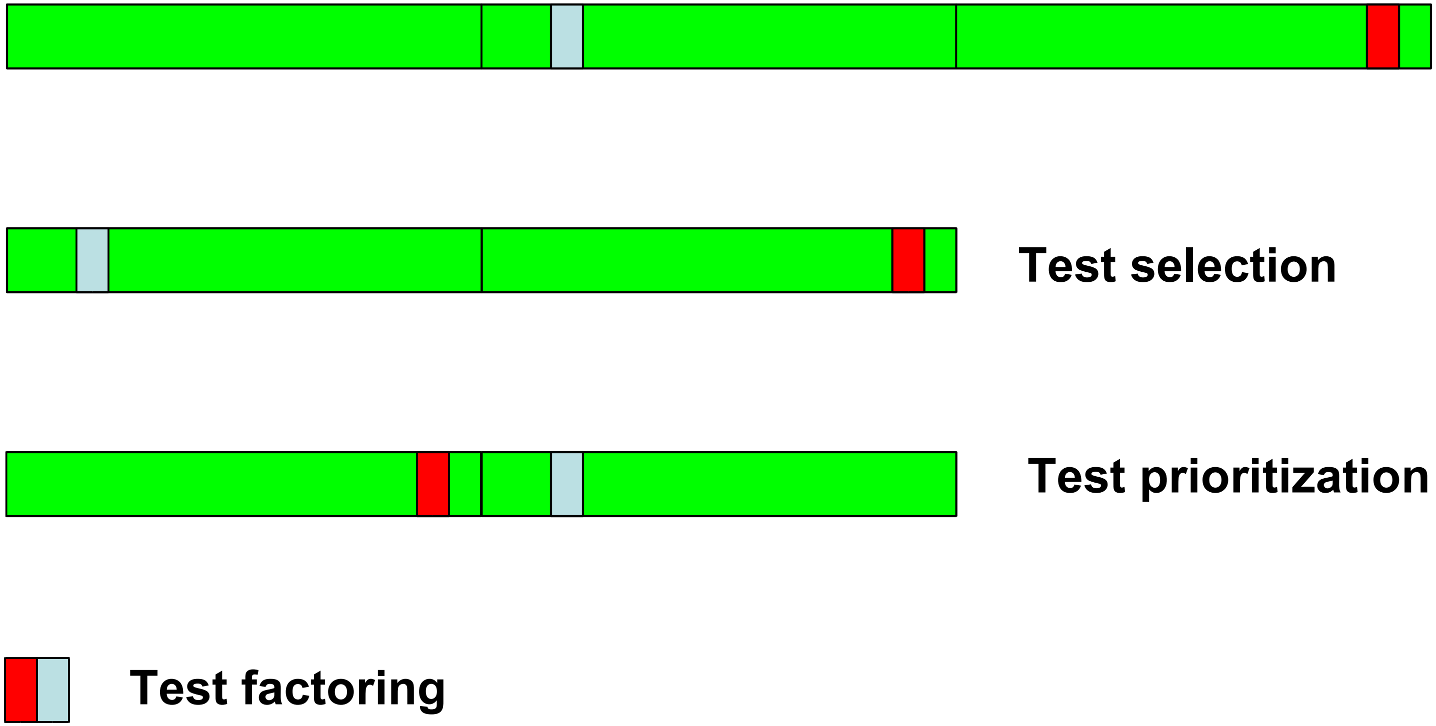


My test suite

Test selection

Test prioritization

The problem:
large, general system tests



My test suite

Test selection

Test prioritization

Test factoring

Test factoring

- Input: large, general system tests
- Output: small, focused unit tests

- Work with Shay Artzi, Jeff Perkins, and Michael D. Ernst

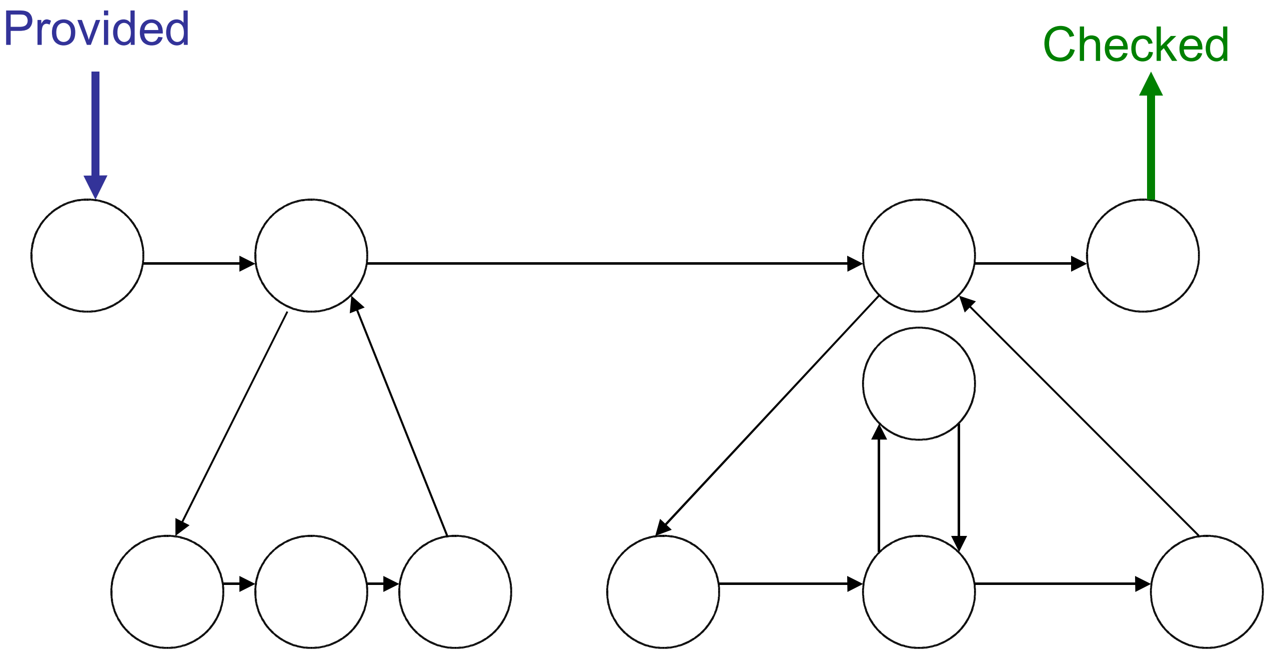
A factored test…

- exercises less code than system test
- should be faster if a system test is slow
- can eliminate dependence on expensive resources or human interaction
- isolates bugs in subsystems
- provides new opportunities for prioritization and selection

Test Factoring

- What?
  - – Breaking up a system test
- How?
  - – Automatically creating mock objects
- When?
  - – Integrating test factoring into development
- What next?
  - – Results, evaluation, and challenges

System Test

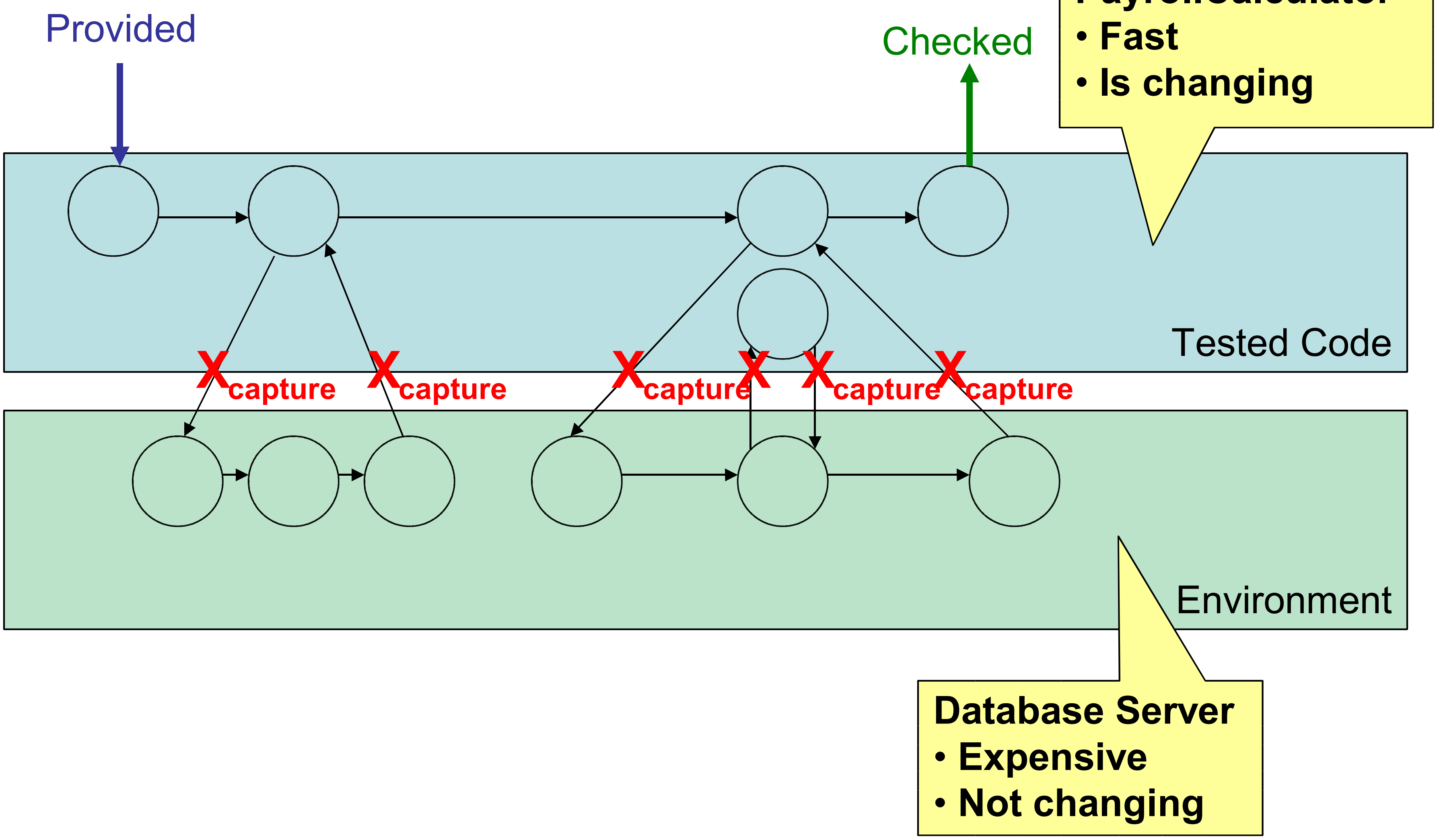


There’s more than one way to factor a test!

Basic strategy:

- *Capture* a subset of behavior beforehand.
- *Replay* that behavior at test time.

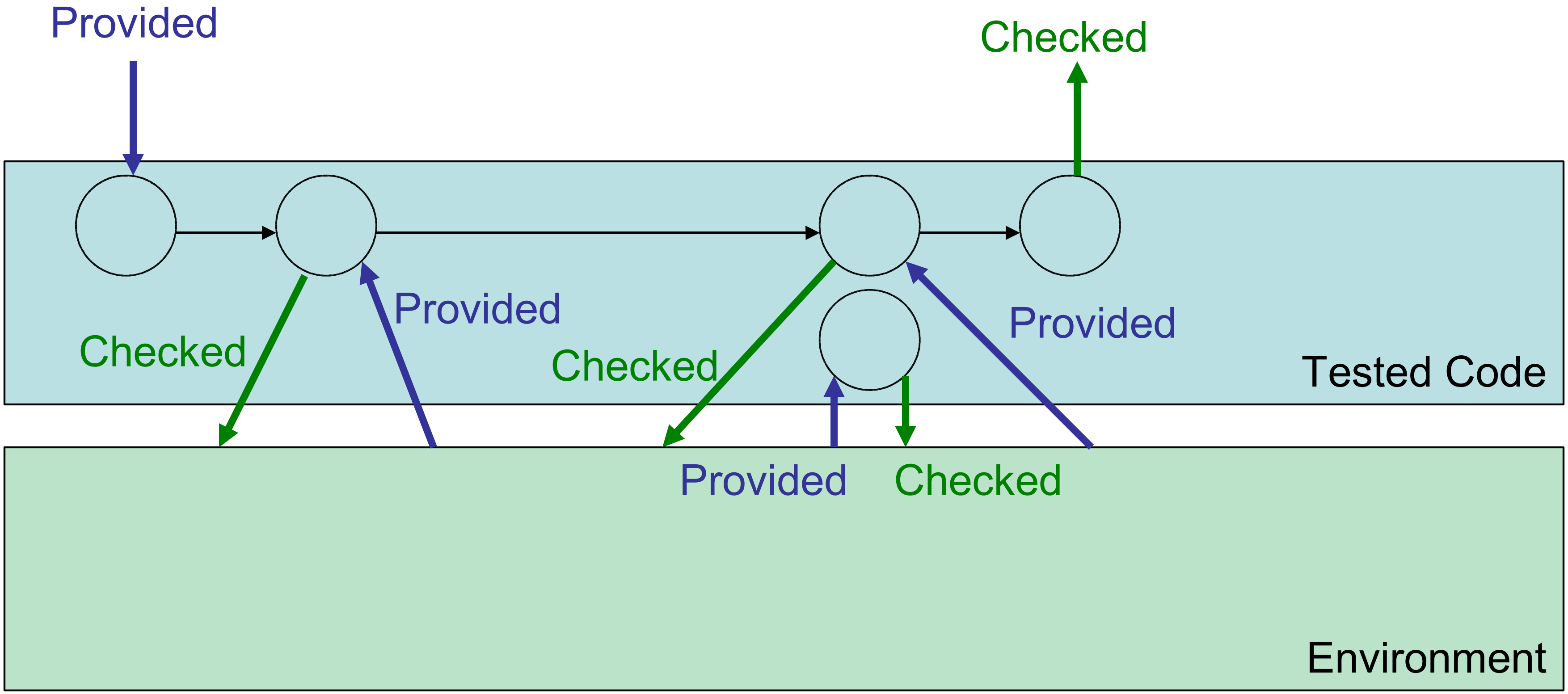
System Test



PayrollCalculator
- **Fast**
- **Is changing**

Database Server
- **Expensive**
- **Not changing**

Introduce Mock



Introduce Mock:

- simulate *part* of the functionality of the original environment
- validate the unit's interaction with the environment

[Saff, Ernst, PASTE 2004]

Test Factoring

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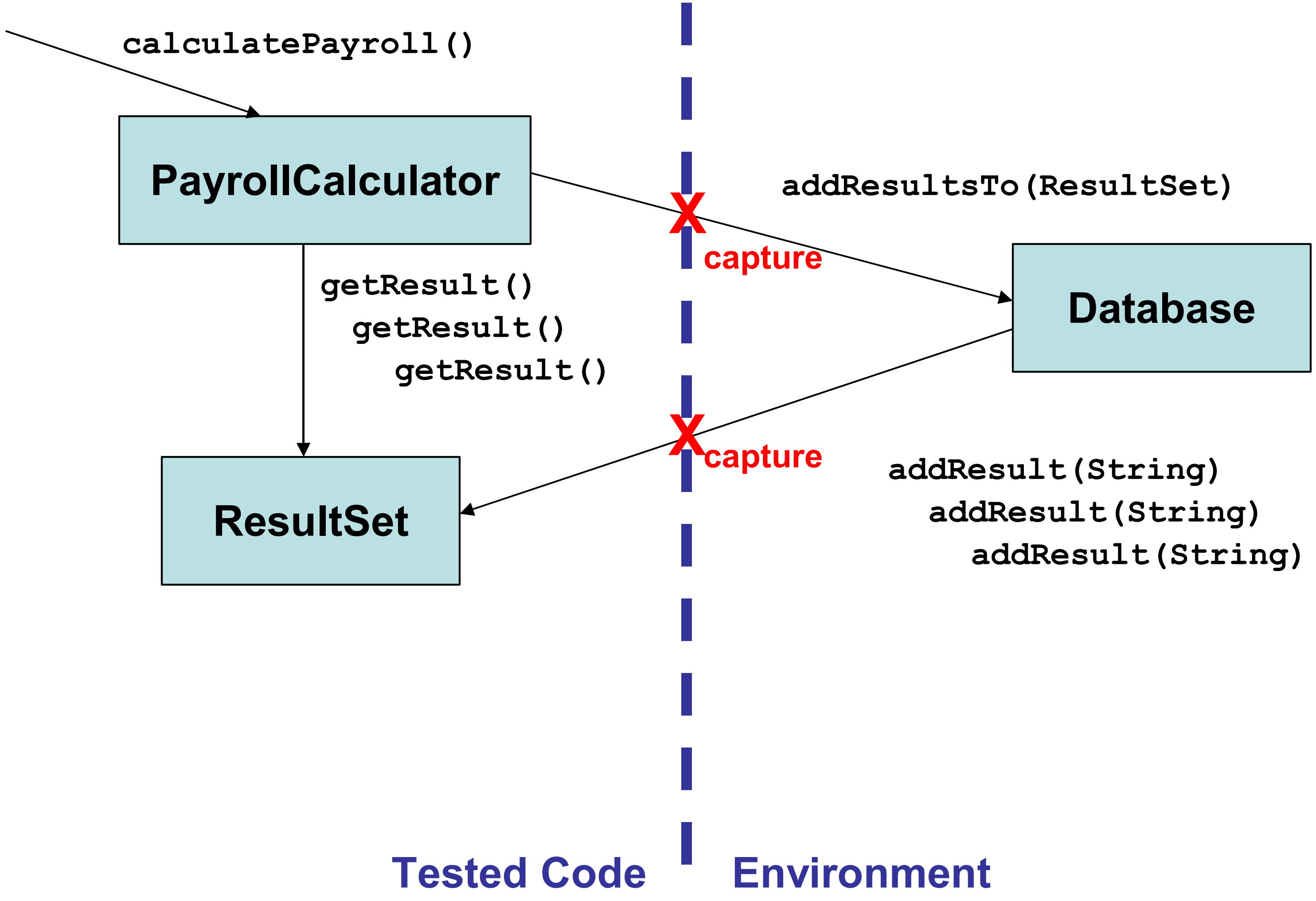
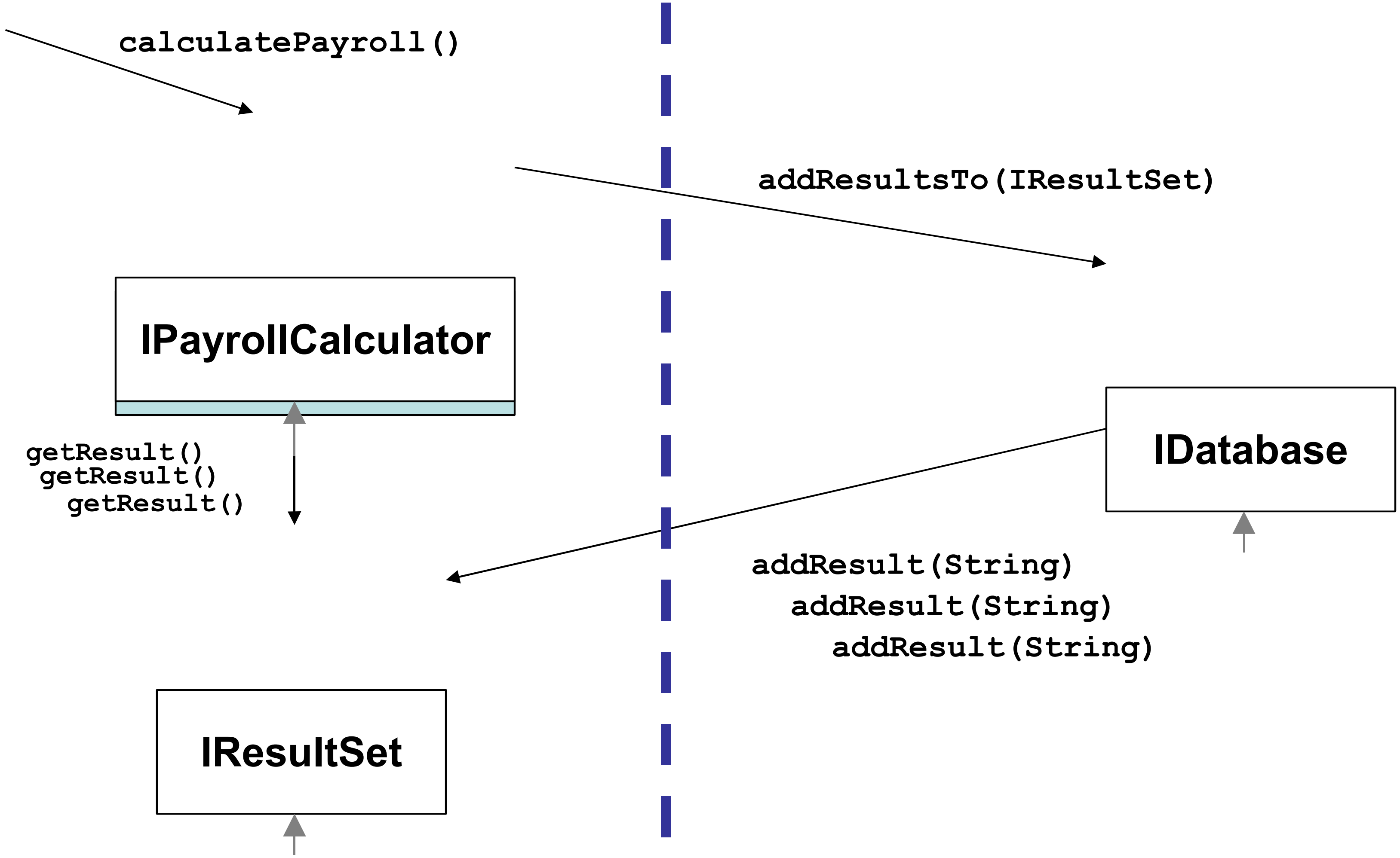
How? Automating *Introduce Mock*



Interfacing: separate type hierarchy from inheritance hierarchy



`calculatePayroll()`

`addResultsTo(IResultSet)`

IPayrollCalculator

IDatabase

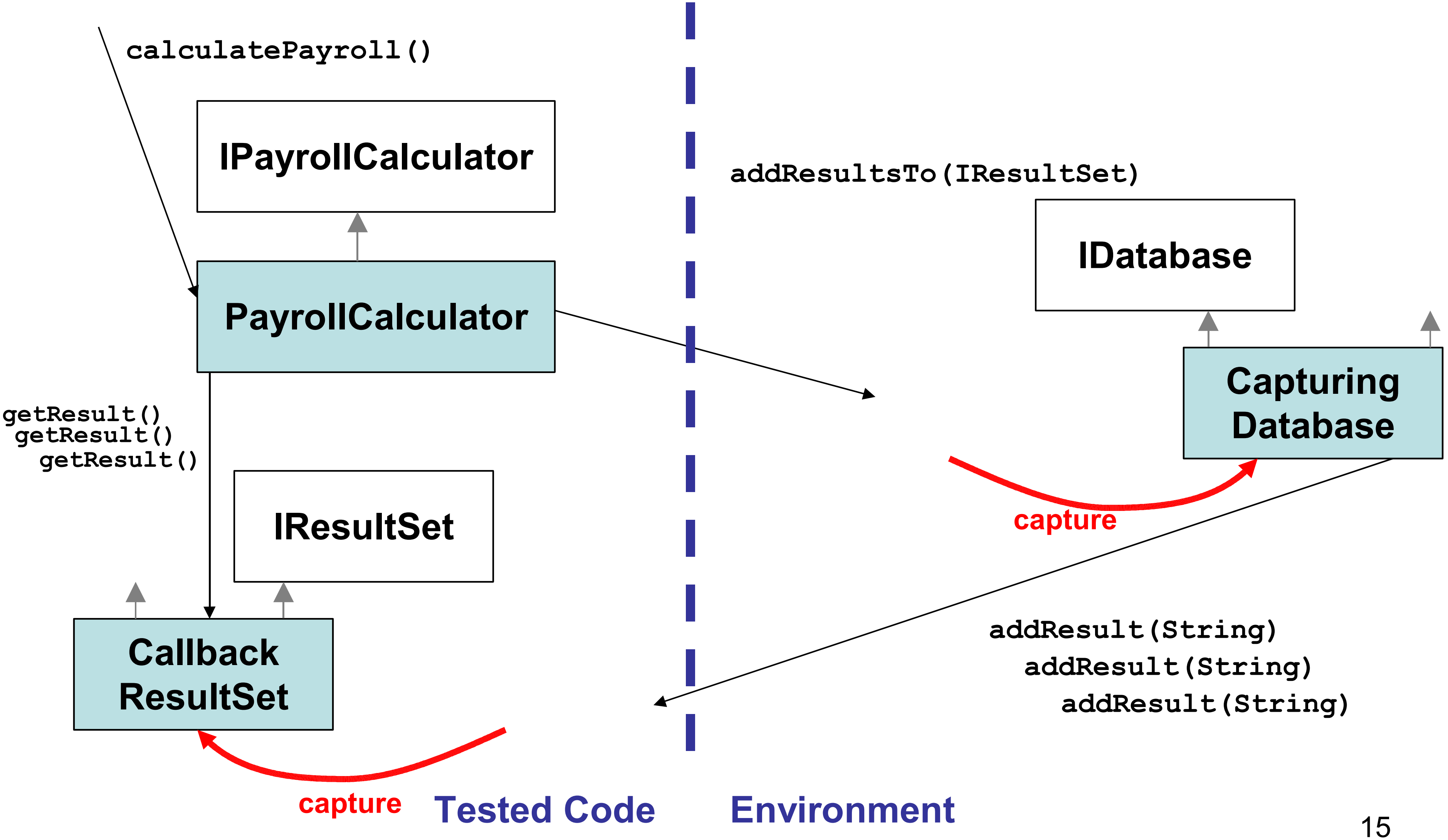
`getResult()`
`getResult()`
`getResult()`

`addResult(String)`
`addResult(String)`
`addResult(String)`

IResultSet

Tested Code **Environment**

Capturing: insert recording decorators where capturing must happen



`calculatePayroll()`

IPayrollCalculator

PayrollCalculator

`getResult()`
`getResult()`
`getResult()`

IResultSet

Callback ResultSet

capture

`addResultsTo(IResultSet)`

IDatabase

Capturing Database

capture

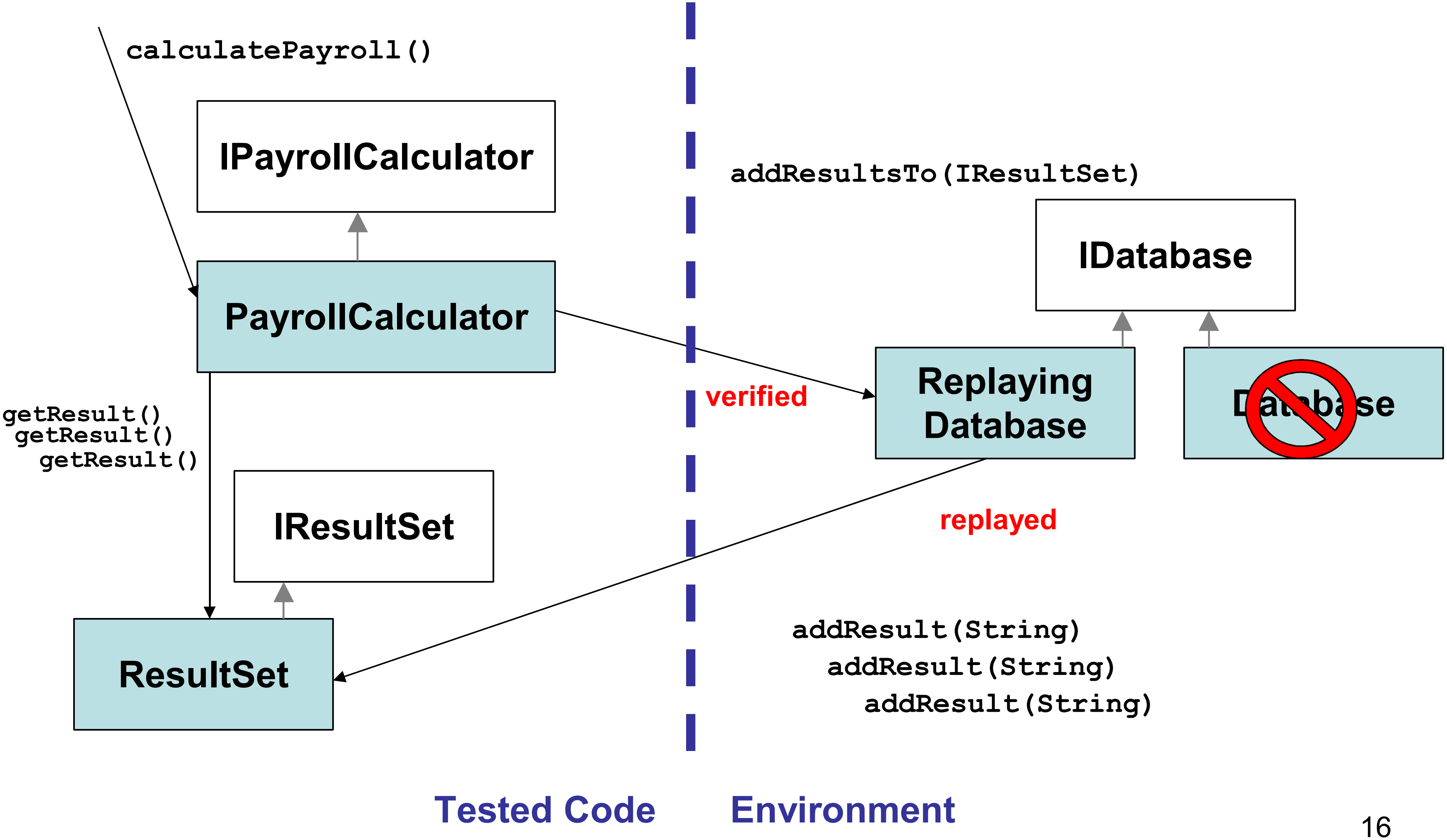
`addResult(String)`
`addResult(String)`
`addResult(String)`

Tested Code

Environment

David Saff

Replay: simulate environment's behavior



`calculatePayroll()`

IPayrollCalculator

PayrollCalculator

`getResult()`
`getResult()`
`getResult()`

IResultSet

ResultSet

`addResultsTo(IResultSet)`

IDatabase

verified

Replaying Database

Database

replayed

`addResult(String)`
`addResult(String)`
`addResult(String)`

Tested Code

Environment

Test Factoring

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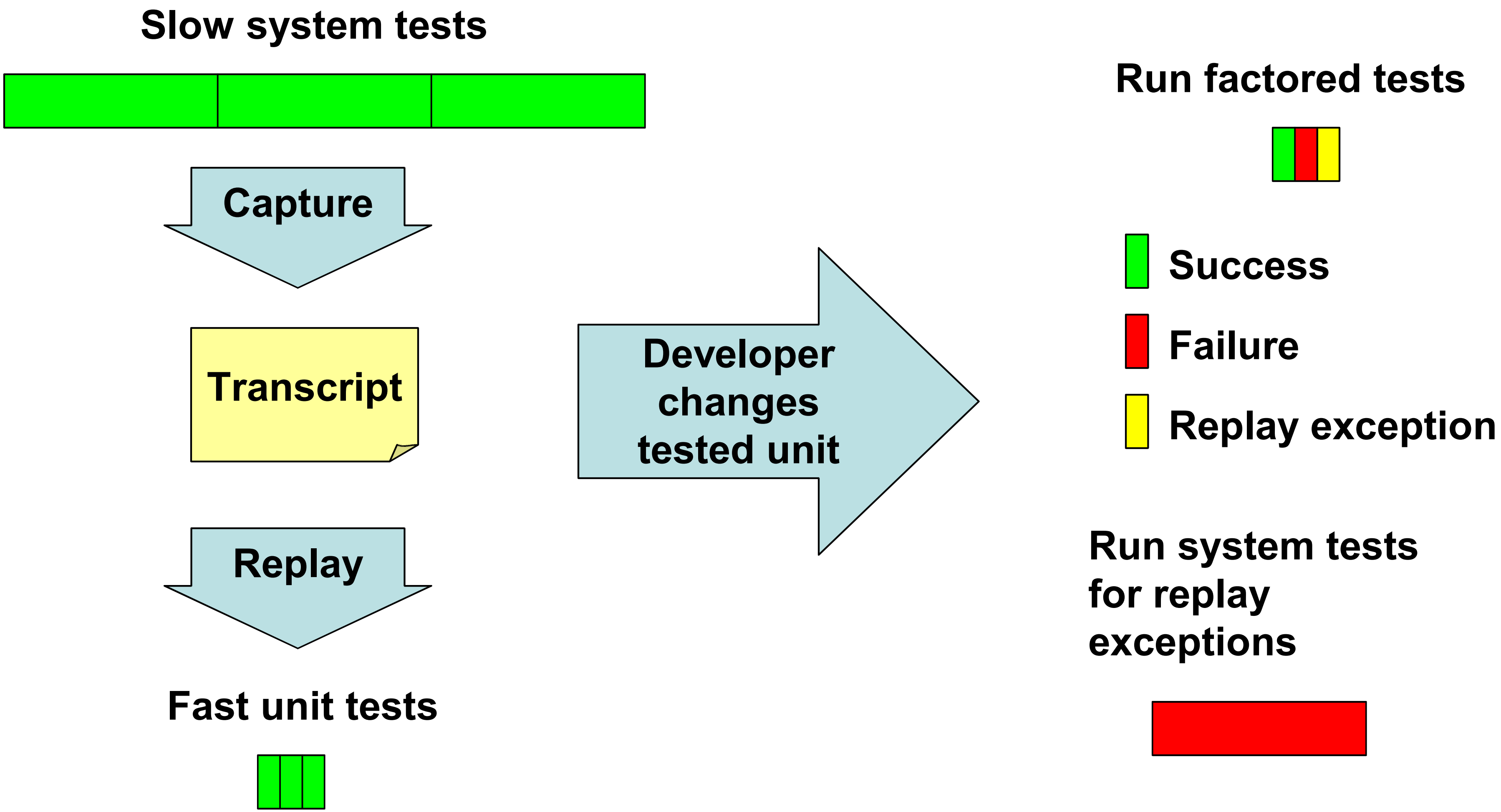
When? Test factoring life cycle:



Slow system tests

Capture

Transcript

Replay

Fast unit tests

Developer changes tested unit

Run factored tests

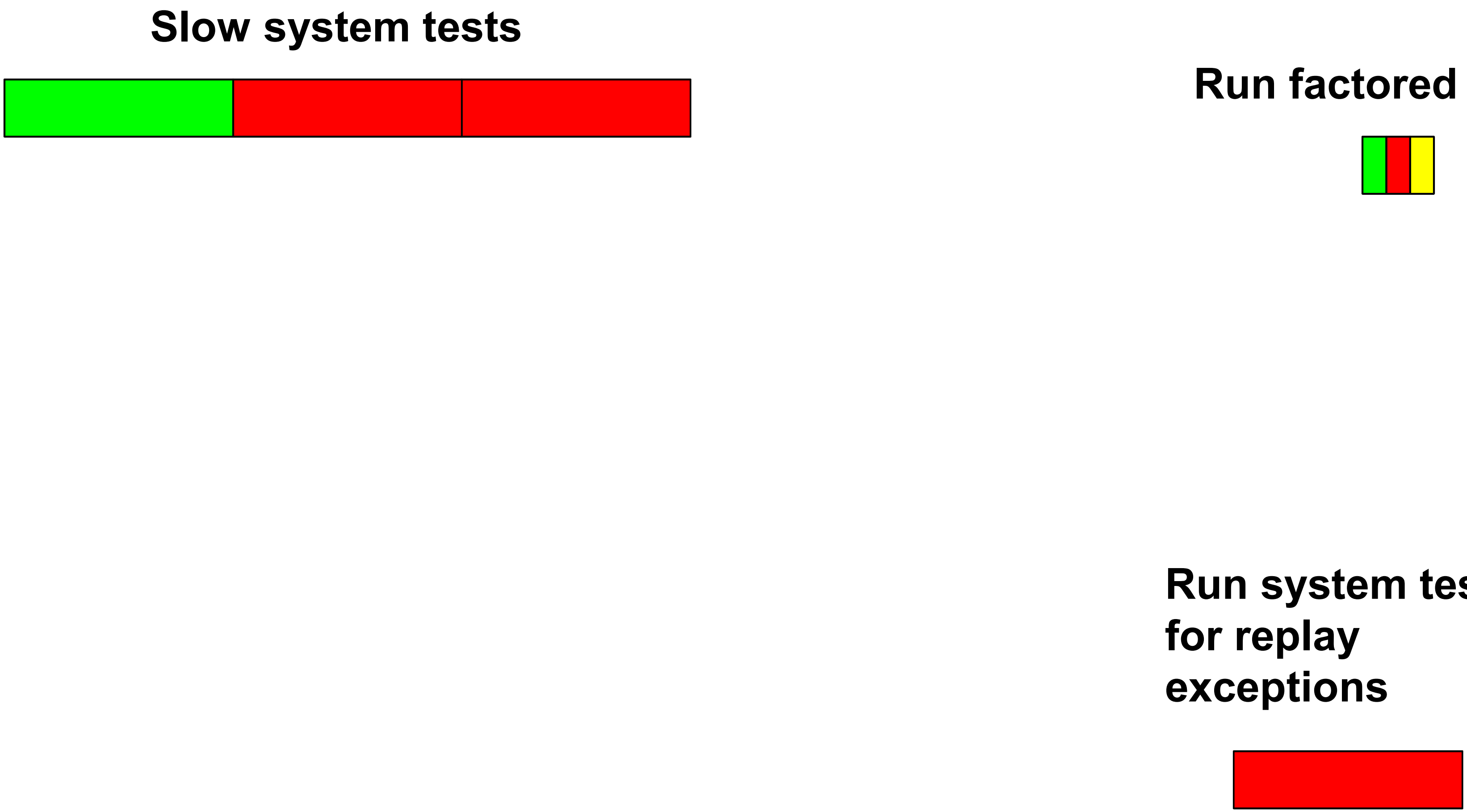
🟩 Success

🟥 Failure

🟨 Replay exception

Run system tests for replay exceptions

Time saved:

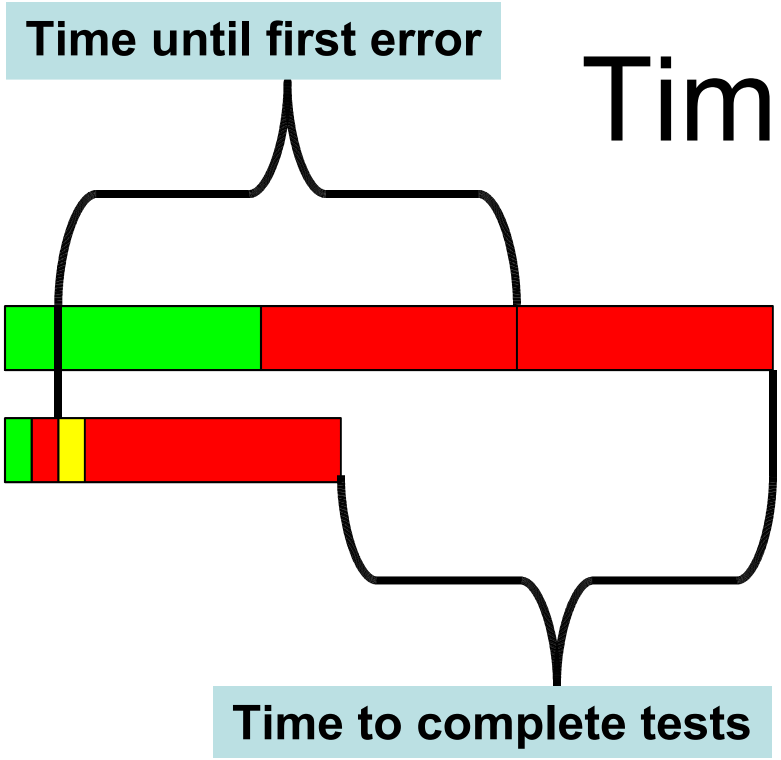


Slow system tests

Run factored tests

Run system tests for replay exceptions

Time saved:



Time until first error

Slow system tests

Factored tests

Time to complete tests

Test Factoring

- What?
  - Breaking up a system test
- How?
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- When?
  - Integrating test factoring into development
- What next?
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Implementation for Java

- Captures and replays
  - Static calls
  - Constructor calls
  - Calls via reflection
  - Explicit class loading
- Allows for shared libraries
  - i.e., tested code and environment are free to use disjoint ArrayLists without verification.
- Preserves behavior on Java programs up to 100KLOC

Case study

- Daikon: 347 KLOC
  - Uses most of Java: reflection, native methods, JDK callbacks, communication through side effects
- Tests found real developer errors
- Two developers
  - Fine-grained compilable changes over two months: 2505
  - CVS check-ins over six months (all developers): 104

Evaluation method

- Retrospective reconstruction of test factoring's results during real development
  - Test on every change, or every check-in.
- Assume capture happens every night
- If transcript is too large, don't capture
  - just run original test
- If factored test throws a ReplayException, run original test.

Measured Quantities

- *Test time*: total time to find out test results
- *Time to failure*: If tests fail, how long until first failure?
- *Time to success*: If tests pass, how long until all tests run?

- ReplayExceptions are treated as giving the developer no information

Results

	How often?	Test time	Time to failure	Time to success
Dev. 1	Every change	.79 (7.4 / 9.4 min)	1.56 (14 / 9 s)	.59 (5.5 / 9.4 s)
Dev. 2	Every change	.99 (14.1 / 14.3 min)	1.28 (64 / 50 s)	.77 (11.0 / 14.3 s)
All devs.	Every check-in	.09 (0.8 / 8.8 min)	n/a	.09 (0.8 / 8.8 min)

Discussion

- Test factoring dramatically reduced testing time for checked-in code (by 90%)
- Testing on every developer change catches too many meaningless versions
- Are ReplayExceptions really not helpful?
  - When they are surprising, perhaps they are

Future work: improving the tool

- Generating automated tests from UI bugs
  - Factor out the user
- Smaller factored tests
  - Use static analysis to distill transcripts to bare essentials

Future work: Helping users

- How do I partition my program?
  - Should ResultSet be tested or mocked?
- How do I use replay exceptions?
  - Is it OK to return null when “” was expected?
- Can I change my program to make it more factorable?
  - Can the tool suggest refactorings?

Conclusion

- Test factoring uses large, general system tests to create small, focused unit tests
- Test factoring works now
- How can it work better, and help users more?
- saff@mit.edu

Challenge: Better factored tests

- Allow more code changes
  - It’s OK to call toString an additional time.
- Eliminate redundant tests
  - Not all 2,000 calls to calculatePayroll are needed.

Evaluation strategy

1) *Observe*: minute-by-minute code changes from real development projects.
2) *Simulate:* running the real test factoring code on the changing code base.
3) *Measure:*
   - Are errors found faster?
   - Do tests finish faster?
   - Do factored tests remain valid?
4) *Distribute:* developer case studies

Conclusion

- Rapid feedback from test execution has measurable impact on task completion.
- Continuous testing is publicly available.
- Test factoring is working, and will be available by year’s end.
- To read papers and download:
  - Google “continuous testing”

Case Study

- Four development projects monitored
- Shown here: Perl implementation of `delta` tools.
- Developed by me using test-first development methodology. Tests were run often.
- Small code base with small test suite.

lines of code	5714
total time worked (hours)	59
total test runs	266
average time between tests (mins)	5

We want to reduce *wasted time*

Test-wait time.

If developers test often, they spend a lot of time waiting for tests to complete.

Regret time:

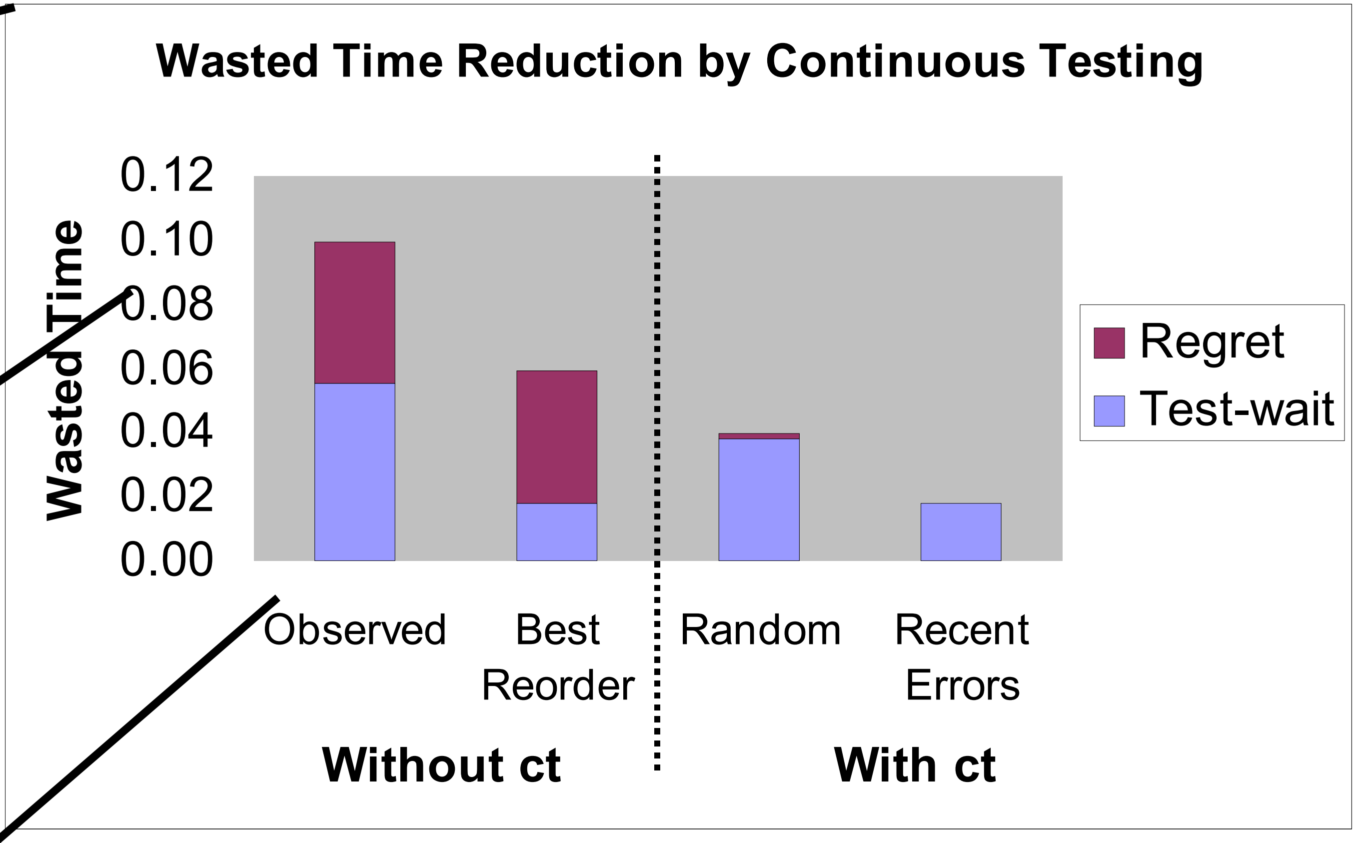
If developers test rarely, regression errors are not found quickly. Extra time is spent remembering and fixing old changes.

Results predict: continuous testing reduces wasted time

Best we can do by changing frequency

Best we can do by changing order

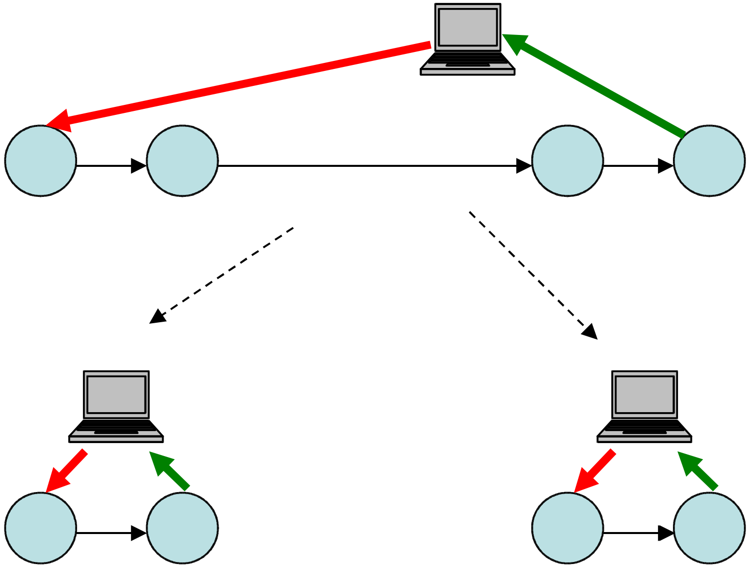
Continuous testing drastically cuts regret time.



A small catalog of test factorings

- Like refactorings, test factorings can be catalogued, reasoned about, and automated

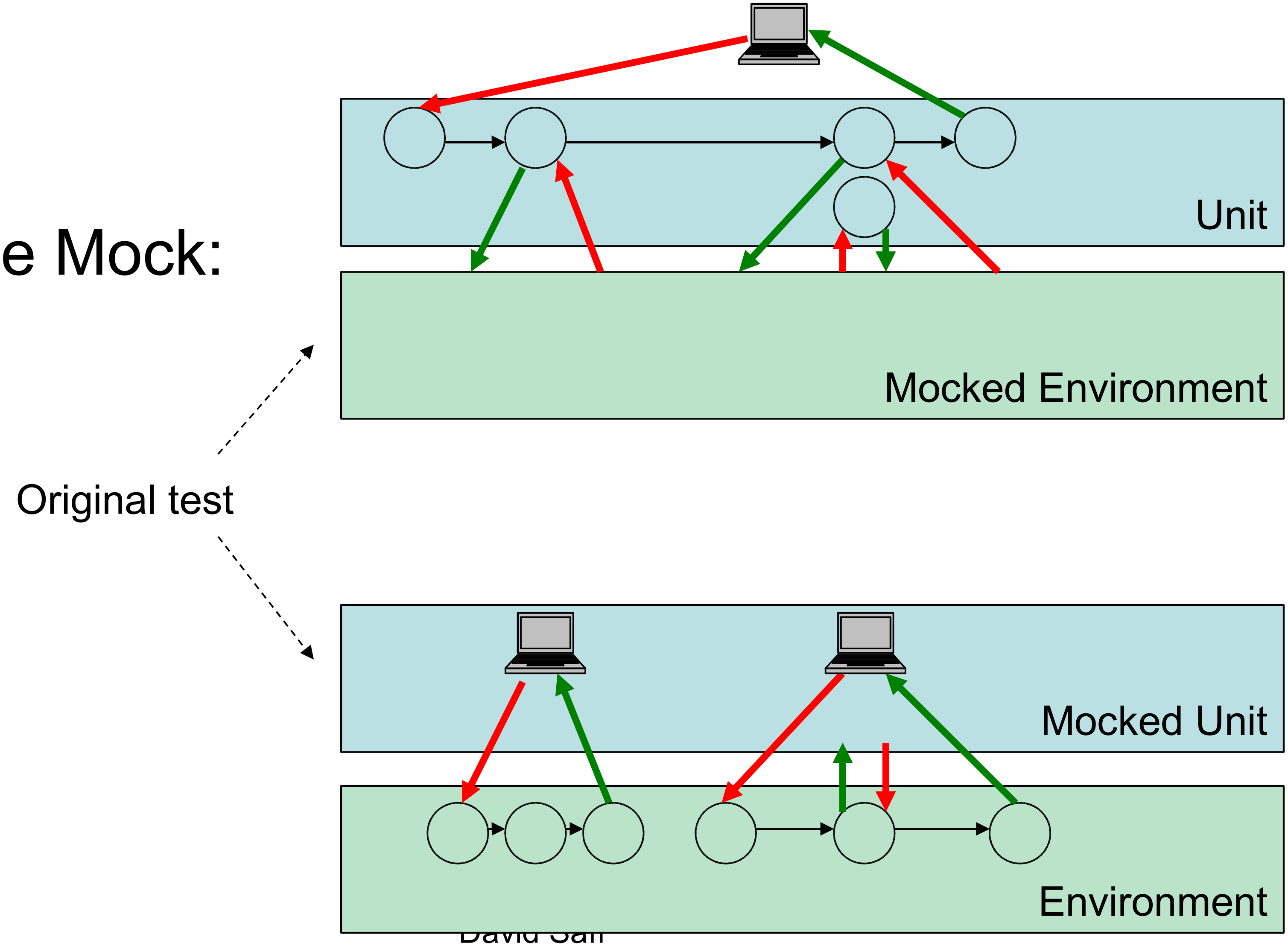
Separate Sequential Code:



Also “Unroll Loop”, “Inline Method”, etc. to produce sequential code

A small catalog of test factorings

Introduce Mock:



Original test

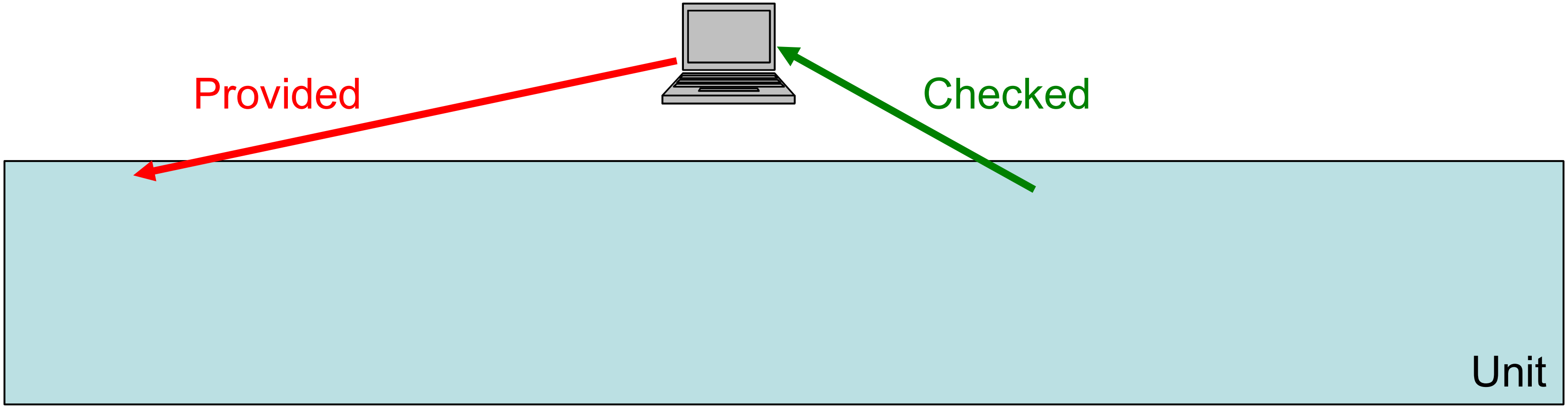
Unit

Mocked Environment

Mocked Unit

Environment

Unit test



Always tested: Continuous Testing and Test Factoring

David Saff

MIT CSAIL

IBM T J Watson, April 2005

Overview

- **Part I: Continuous testing**

  Continuous testing runs tests in the background to provide feedback as developers code.

- **Part II: Test factoring**

  Test factoring creates small, focused unit tests from large, general system tests

Part I: Continuous testing

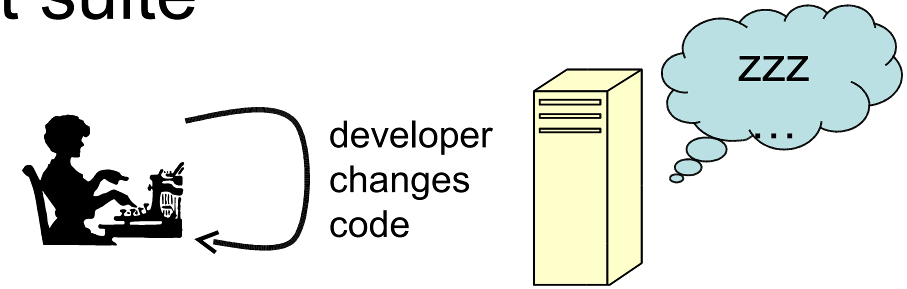
- **Continuous testing** runs tests in the background to provide feedback as developers code.
- Work with Kevin Chevalier, Michael Bridge, Michael D. Ernst

Part I: Continuous testing

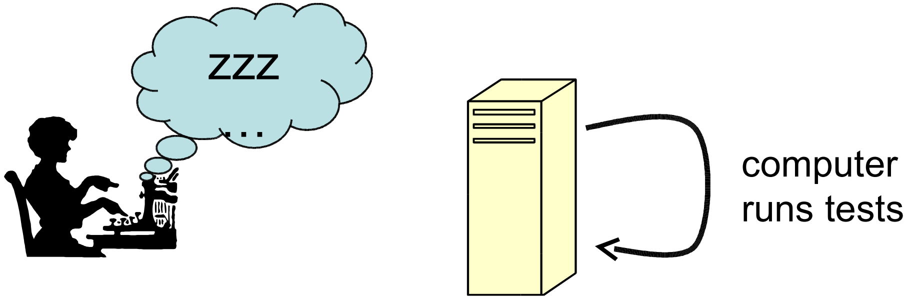
- Motivation
- Students with continuous testing:
  - Were more likely to complete an assignment
  - Took no longer to finish
- A continuous testing plug-in for Eclipse is publicly available.
- Demo!

“Traditional” testing during software maintenance (v2.0 → v2.1)

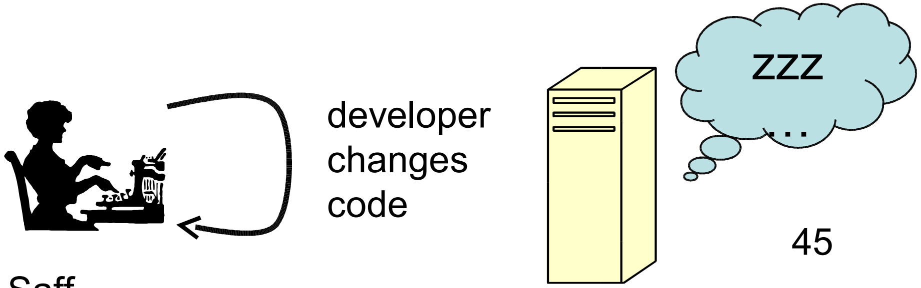
- Developer has v2.0 test suite
  - Changes the code



  - Runs the tests
  - Waits for completion

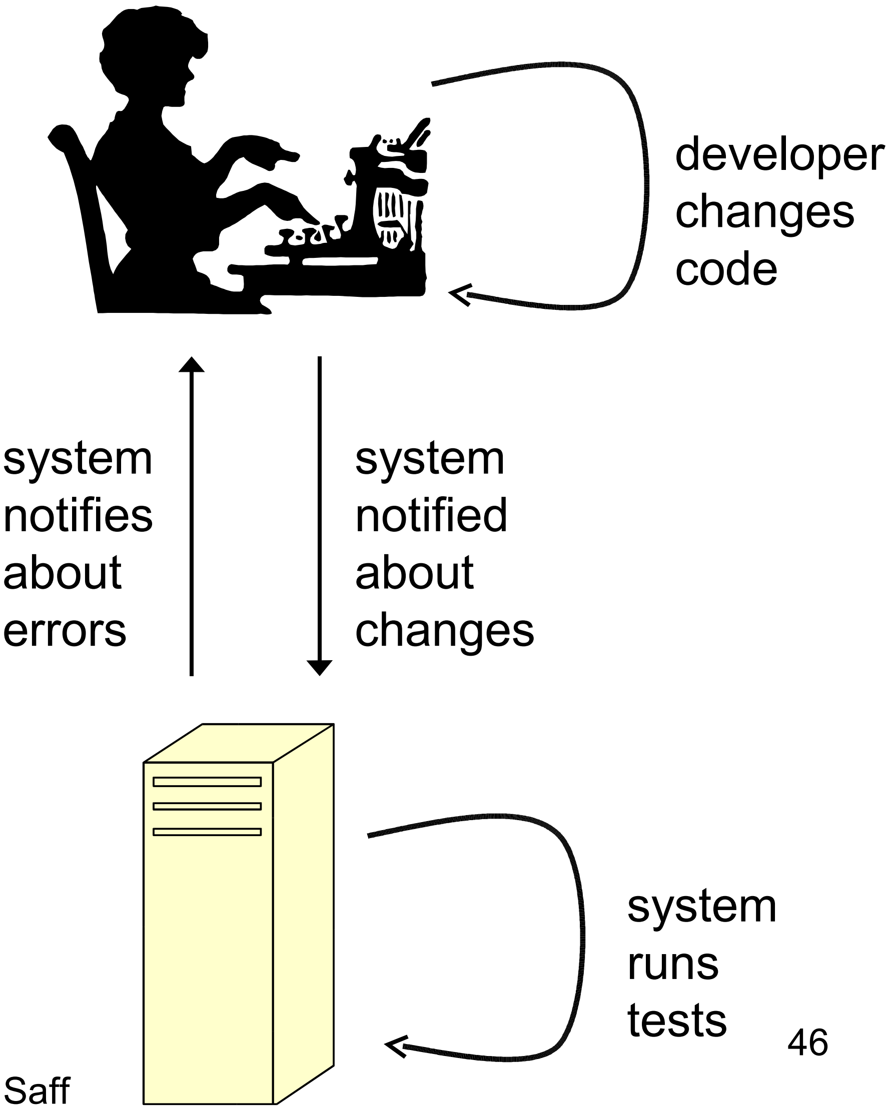


  - Repeats…



Continuous Testing

- Continuous testing uses excess cycles on a nearby workstation to continuously run regression tests in the background as the developer edits code.
- Developer no longer thinks about what to test when.



developer changes code

system notifies about errors

system notified about changes

system runs tests

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Continuous testing: inspired by continuous compilation

- Continuous compilation, as in Eclipse, notifies the developer quickly when a *syntactic error* is introduced:

	✓	!	Description
X			Syntax error on token "a", "]" expected

- Continuous testing notifies the developer quickly when a *semantic error* is introduced:

	✓	!	Description
T			Test failure: testArithmetic(ct.test.MainTestSuite)

Case study

- Single-developer case study [ISSRE 03]
- Maintenance of *existing software* with regression test suites
- Test suites took *minutes*: test prioritization needed for best results
- Focus: *quick discovery of regression errors* to reduce development time (10-15%)

Controlled human experiment

- 22 undergraduate students developing Java in Emacs
- Each subject performed two 1-week class programming assignments
  - Test suites provided in advance
- *Initial development*: regressions less important
- Test suites took *seconds*: prioritization unnecessary
- Focus: "*What happens when the computer thinks about testing for us?*"

Experimental Questions

1. Does continuous testing improve productivity?	Yes
2. Does continuous compilation improve productivity?	Yes
3. Can productivity benefits be attributed to other factors?	No
4. Does asynchronous feedback distract users?	No

Productivity measures

- *time worked*: Time spent editing source files.
- *grade*: On each individual problem set.
- *correct program*: True if the student solution passed *all* tests.
- *failed tests*: Number of tests that the student submission failed.

Treatment predicts correctness (Questions 1 and 2)

Treatment	N	Correct programs
No tool	11	27%
Continuous compilation	10	50%
Continuous testing	18	78%

$p < .03$

Can other factors explain this? (Question 3)

- Frequent testing: no
  - – Frequent manual testing: 33% success
- Easy testing: no
  - – All students could test with a keystroke
- Demographics: no
  - – No significant differences between groups

Treatment	correct
No tool	27%
Cont. comp.	50%
Cont. testing	78%

No significant effect on other productivity measures

Treatment	N	Time worked	Failed tests	Grade
No tool	11	10.1 hrs	7.6	79%
Cont. comp.	10	10.6 hrs	4.1	83%
Cont. testing	18	10.7 hrs	2.9	85%

Did continuous testing win over users? (Question 4)

I would use the tool…	Yes
…for the rest of the class	94%
…for my own programming	80%
I would recommend the tool to others	90%

Eclipse plug-in for continuous testing

- Upgrades current Eclipse JUnit integration:
  - Remember and display results from several test suites
  - Pluggable test prioritization and selection strategies.
  - Remote test execution
  - Associate test suites with projects

Eclipse plug-in for continuous testing

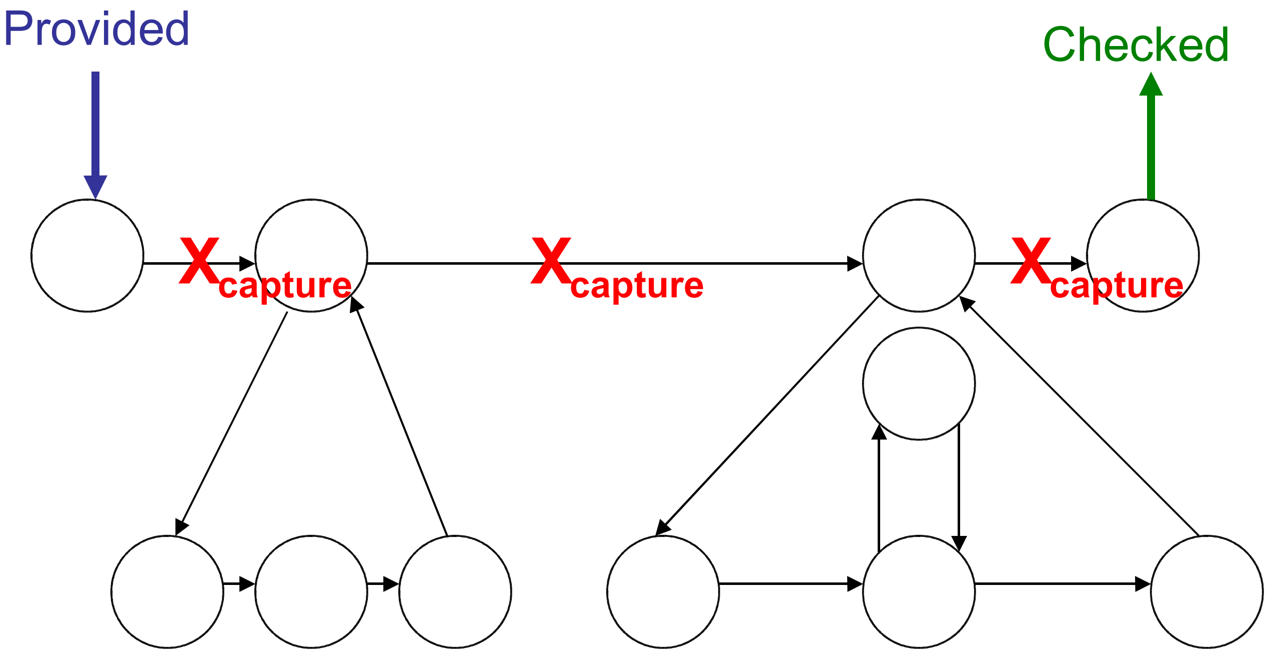
- Adds continuous testing:
  - Tests run with every compile
  - Can run as low-priority process
  - Can take advantage of hotswapping JVMs
  - Works with plug-in tests, too.

- Demo!

Future Work: Continuous testing

- Incorporate JUnit and continuous testing features from plug-in directly into Eclipse
- Encourage test prioritization researchers to implement JUnit plug-ins
- Industrial case studies

System Test



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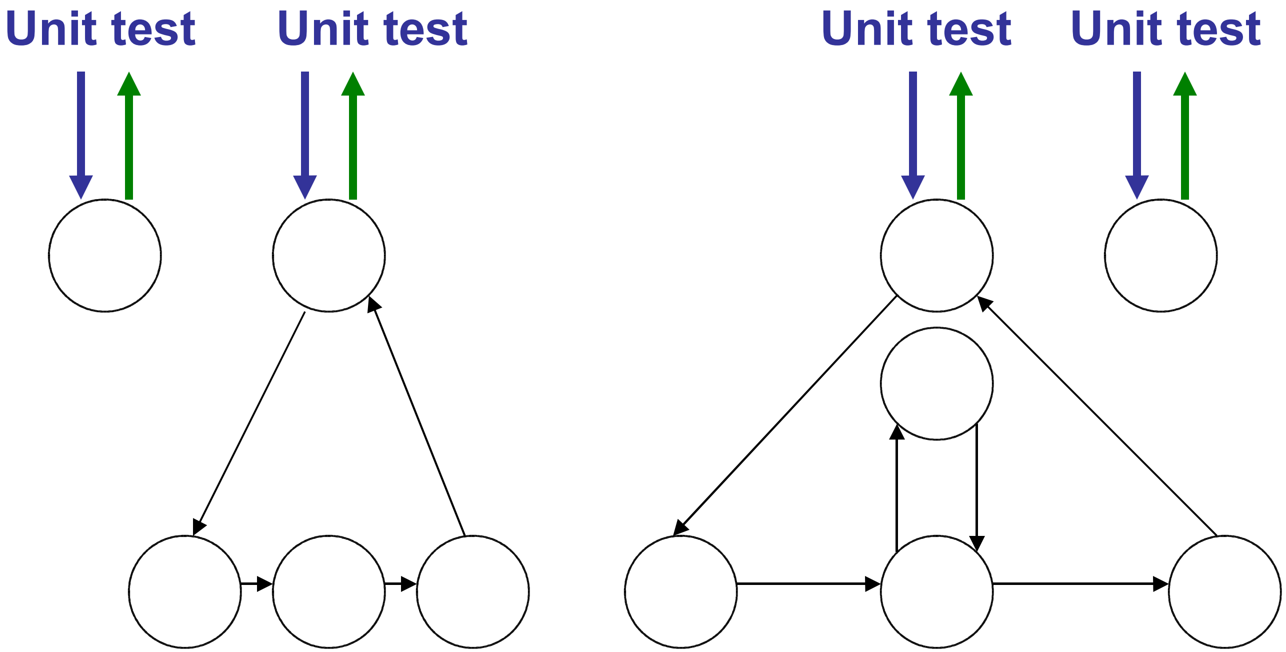

Separate Sequential:

- Before each stage, recreate state
- After each stage, confirm state is correct