

Bugs in Large Software Systems

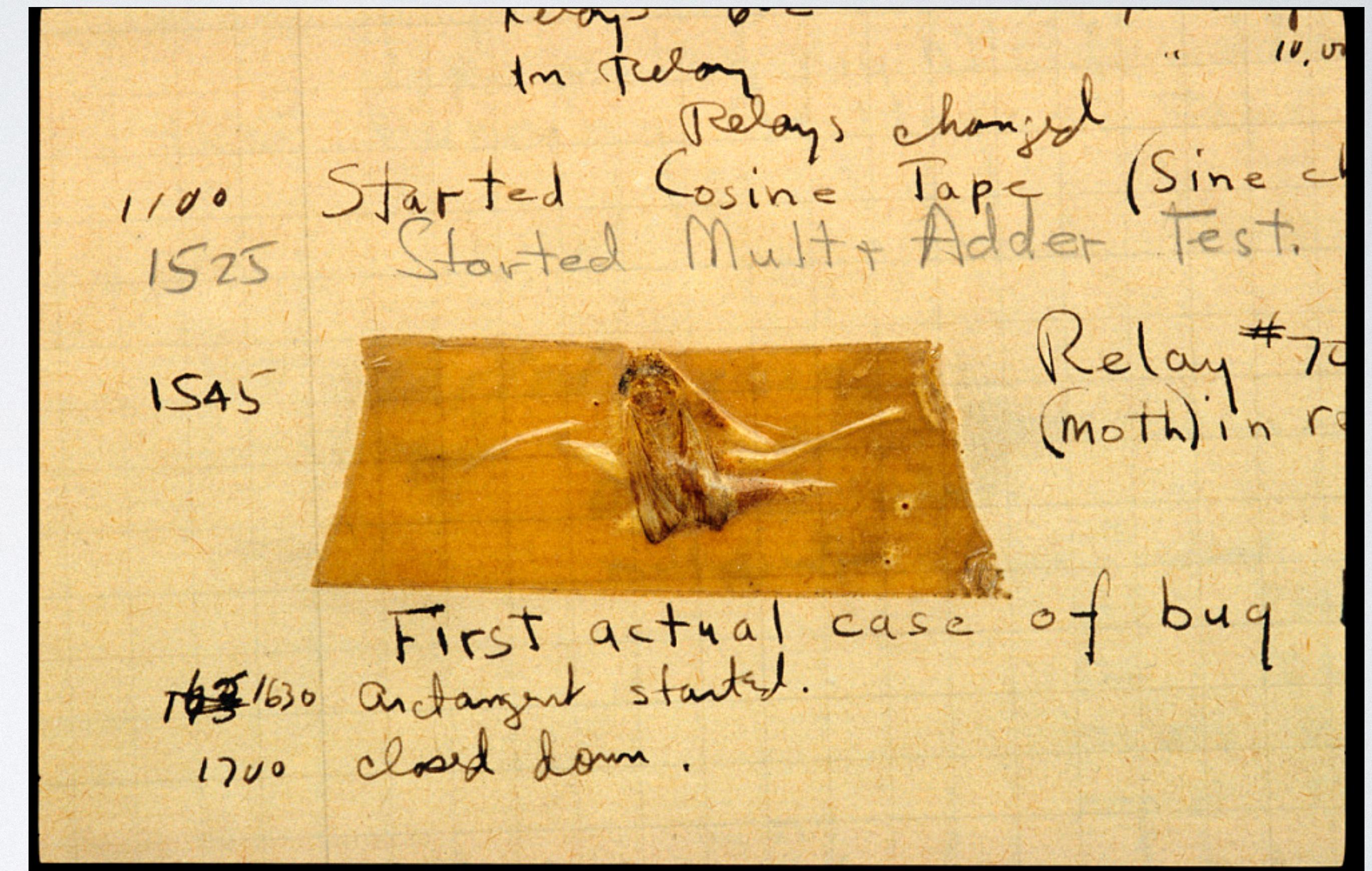
Practice and Research

Debugging Strategies

- Goal today: debugging strategies for large systems
- Large means "too big to fit in your head all at once"
- If you are using a framework, your system is large!

Origin of "Bug"

- Wikipedia: Middle English word *bugge* is the basis for the terms "bugbear" and "bugaboo" as terms used for a monster.
- The term "bug" to describe defects has been a part of engineering jargon since the 1870s
- Thomas Edison wrote in a letter to an associate in 1878:
 - "... difficulties arise—this thing gives out and [it is] then that "Bugs"—as such little faults and difficulties are called—show themselves"



Bug found in Mark II computer in 1947 (Harvard University)

Plan A: Avoid Fixing It (at Least, for Now)

Unfortunately

- You (usually) can't fix every bug.
- There are too many
 - Lots of bugs don't really matter
- But you'd better fix the important ones!

It's a Feature, Not a Bug?

- Bugs represent *discrepancies* between expectations and the implementation
 - Some (but in most systems, not all!) expectations are encoded in specifications
- Two ways to fix bugs
 - Change code
 - Change the specification

Priorities

- Manager: "Please fix this performance bug. It's super important."
- You: "No problem. I'll re-architect module X."
- Manager: "How long will that take?"
- You: "Two weeks."
- Manager: "If we do that, we won't have time to fix ten other bugs. Actually, that bug wasn't so important after all."

Risk

- Manager: "Please fix this performance bug. It's super important."
- You: "No problem. I'll re-architect module X."
- Manager: "What might break if you do that?"
- You: "Modules Y and Z depend on X, so we'd have to re-test them."
- Manager: "Ugh. Let's fix it in the next release."

In Contrast: Severity

- You: "We need to fix this bug."
- Manager: "How long will it take?"
- You: "Two weeks."
- Manager: "No way."
- You: "But otherwise we might leak private customer data to the Internet."
- Manager: "Ugh, okay, go ahead."

Moral

- Consider *cost, risk, and severity* before fixing a bug.

On Culture

- "Whose fault is this bug?"
- Leads to a culture of blame.
- Incentivizes bad behavior. Instead, want all bugs to all get reported/logged
- Report and prioritize all bugs
 - Your "very serious" bug may be low priority or actually a feature!

A Bug Report

- Should say:
 - How to reproduce bug
 - (otherwise you won't know whether you've fixed it!)
 - What the observed behavior is
 - What the expected behavior is
- Don't assume the expected behavior is the correct behavior, either! (recall plan A)

Fixing Bugs

- Two phases
 - Fault localization ("which code is buggy?")
 - Fault repair ("what do I do about it?")
- Most of the work (in my experience) is usually in fault localization

Fault Localization

- Traditional approach: you're supposed to come up with hypotheses
 - And then test them (order according to likelihood and ease of elimination)
- But sometimes you just don't know!
- I'm going to show you some tricks
- Goal: fix the bug while understanding no more than necessary
 - Assumption: reading all the code is impossible.

Test Case Minimization

- Remove all elements of the test case that are unnecessary.
- Maybe your QA staff can help you with this.

Narrowing Down the Responsible Code

- Replace modules with mock modules that do the right thing
- Try to show the bug is in a framework you're using: build a minimal broken example
 - Either you file a bug report against the framework, or you learn a key ingredient in the bug and a possible workaround
- Descend a layer of abstraction (debug into the framework)

Regressions

- Did this use case previously work, but now it's broken?
 - Then you have a *regression*
 - Try: find out which specific change broke it
 - *git bisect*
 - Now you know at least some of the relevant code.

Bad State

- Bug: after doing X, some state is wrong.
- Doing X involves running a lot of code.
- Plan: Sprinkle assertions throughout code for X.
- Drill down.

```
assert(state correct);  
foo();  
assert(state correct);  
bar();
```

(OK)



(assertion failed. Bug must be in **foo()**.)

Next step: sprinkle assertions inside **foo()**. Avoid reading **bar()**.

"I Have No Idea Where to Start."

- Search code for relevant-sounding words
- Add breakpoints, trace through relevant code
- Anything hit?
 - If so, you may have found something relevant

Ask an Expert

- "Can you give me a pointer to where I might start looking?"
- Not asking someone else to do your job
- You will get up to speed faster and be more helpful if you take a little advice

Which Expert?

- If you can find remotely-related code: git blame

```
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 81) def removeThisFieldType(fieldName: String): Context =  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 82)     Context(contractTable,  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 83)         underlyingVariableMap,  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 84)         isThrown,  
ff40088b2 (Michael Coblenz 2019-11-25 14:00:30 -0500 85)         transitionFieldsDefinitelyInitialized,  
ff40088b2 (Michael Coblenz 2019-11-25 14:00:30 -0500 86)         transitionFieldsMaybeInitialized,  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 87)         localFieldsInitialized,  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 88)         thisFieldTypes - fieldName,  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 89)         valVariables)  
c3264e536 (Michael Coblenz 2019-09-06 15:41:37 -0400 90)  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 91) def updatedMakingVariableVal(variableName: String): Context =  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 92)     Context(contractTable,  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 93)         underlyingVariableMap,  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 94)         isThrown,  
ff40088b2 (Michael Coblenz 2019-11-25 14:00:30 -0500 95)         transitionFieldsDefinitelyInitialized,  
ff40088b2 (Michael Coblenz 2019-11-25 14:00:30 -0500 96)         transitionFieldsMaybeInitialized,  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 97)         localFieldsInitialized,  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 98)         thisFieldTypes,  
c8f738622 (Michael Coblenz 2019-04-02 11:10:28 -0400 99)         valVariables + variableName)
```

Print Statements

- Both for logging data and for monitoring control flow
 - Did this code run?
- Especially useful for debugging race conditions

Narrowing Down the Problem

- Compare how you think it *should* work to how it *does* work
- Plan A: read the code (like reading English)
- Plan B: trace through the code very carefully

Unusual Situations

- "Heisenbugs": bugs that disappear when you try to debug them
- Usual suspects:
 - Race conditions (try using print statements or lightweight logging)
 - Compiler optimizations (either due to performance changes or due to compiler bugs)
 - Hardware failures, configuration errors (does it reproduce on another machine?)

When the Going Gets Tough

- Get out a notebook.
- Record:
 - Each hypothesis
 - Test inputs and results (every test) and what you conclude
 - Change only one thing at a time

Fault Repair

- Complaint:
NullPointerException raised
on last line of **foo()**
- Add null check in **foo()**?
- Avoid passing null in **cause()**?
- Usually, you want to fix the root cause.
Which is it?

```
void cause() {  
    String x = foo(null);  
}  
  
int foo(String s) {  
    List<String> l = new List<>();  
    l.add(s);  
    Map<Integer, List<String>> m = new Map<>();  
    m.put(42, l);  
    // a bunch more computation  
    String p = m.get(42).get(0);  
    return p.length();  
}
```

Fix Both?

- Wearing both belt and suspenders prevents disaster...



Best Fix Depends on Risk Tolerance



<https://pxhere.com/en/photo/895059>



https://commons.wikimedia.org/wiki/File:Tweezers_2019.jpg

Git Blame, Again

c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	81)	def removeThisFieldType(fieldName: String): Context =
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	82)	Context(contractTable,
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	83)	underlyingVariableMap,
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	84)	isThrown,
ff40088b2 (Michael Coblenz	2019-11-25	14:00:30 -0500	85)	transitionFieldsDefinitelyInitialized,
ff40088b2 (Michael Coblenz	2019-11-25	14:00:30 -0500	86)	transitionFieldsMaybeInitialized,
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	87)	localFieldsInitialized,
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	88)	thisFieldTypes - fieldName,
c3264e536 (Michael Coblenz	2019-09-06	15:41:37 -0400	89)	valVariables)
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c8f738622 (Michael Coblenz	2019-04-02	11:10:28 -0400	93)	underlyingVariableMap,
c8f738622 (Michael Coblenz	2019-04-02	11:10:28 -0400	94)	isThrown,
ff40088b2 (Michael Coblenz	2019-11-25	14:00:30 -0500	95)	transitionFieldsDefinitelyInitialized,
ff40088b2 (Michael Coblenz	2019-11-25	14:00:30 -0500	96)	transitionFieldsMaybeInitialized,
c8f738622 (Michael Coblenz	2019-04-02	11:10:28 -0400	97)	localFieldsInitialized,
c8f738622 (Michael Coblenz	2019-04-02	11:10:28 -0400	98)	thisFieldTypes,
c8f738622 (Michael Coblenz	2019-04-02	11:10:28 -0400	99)	valVariables + variableName)

- Maybe change ff40088b2 is suspicious.

Git Show

```
commit ff40088b2466d724295a4c7e1d6f8385644d8de2
Author: Michael Coblenz <mcoblenz@cs.cmu.edu>
Date:   Mon Nov 25 14:00:30 2019 -0500
```

Track state field assignments properly so we can give the right errors when one branch assigns but fails to transition.

```
diff --git a/src/main/scala/edu/cmu/cs/obsidian/typecheck/Checker.scala b/src/main/scala/
edu/cmu/cs/obsidian/typecheck/Checker.scala
index 8c93fe4b..627376a6 100644
--- a/src/main/scala/edu/cmu/cs/obsidian/typecheck/Checker.scala
+++ b/src/main/scala/edu/cmu/cs/obsidian/typecheck/Checker.scala
@@ -18,7 +18,8 @@ import scala.collection.immutable.TreeMap
 case class Context(table: DeclarationTable,
                     underlyingVariableMap: Map[String, ObsidianType],
                     isThrown: Boolean,
-                    transitionFieldsInitialized: Set[(String, String, AST)],
+                    transitionFieldsDefinitelyInitialized: Set[(String, String, AST)],
+                    transitionFieldsMaybeInitialized: Set[(String, String, AST)],
                     localFieldsInitialized: Set[String],
                     thisFieldTypes: Map[String, ObsidianType],
                     valVariables : Set[String]) {
@@ -28,7 +29,8 @@ case class Context(table: DeclarationTable,
                     Context(contractTable,
                             underlyingVariableMap.updated(s, t),
                             isThrown,
-                            transitionFieldsInitialized,
+                            transitionFieldsDefinitelyInitialized,
+                            transitionFieldsMaybeInitialized,
                             localFieldsInitialized,
                             thisFieldTypes,
                             valVariables)
```

Fixing the Bug

- Write a test case for the bug (which initially fails)
- Fix the bug
- Search for additional instances of the bug
- Run all the tests
- Get your change reviewed

A Classic Job Interview Question

- Tell me about a tough bug you fixed.

Conclusion

- Narrowing down the test case and the possibly-relevant code can help you identify the root cause
 - Even in unfamiliar code!
- Asking experts is often a good plan.