git status

- Homework 1 submitted
- Homework 2 will be posted October 26
  - due November 16, 9AM
- Projects underway
  - project status check-in meetings November 9

Steps for project success

System-building project

- Formulate what you're going to do
- Design the system you will build
- Develop a plan
  (assign team members jobs)
- Specify your system
- Create a testing plan
- Implement (prototype)
- Test
- Document

Research-centered project

- Formulate what you're going to do
- Design the experiment you will perform
- Identify the necessary artifacts to perform the experiment
- Develop a plan
  (assign team members jobs)
- Learn state-of-the-art
- Prototype the experiment
- Build necessary infrastructure

Milestones

- November 9:
  10-min meeting with an instructor:
  - Describe your plan / proposal for the project
  - Tell us what you will do
  - Show early design documents
  - Describe team member roles

Deliverables

- git repository
  - code
  - tests
  - documentation
- final poster presentation with 10-minute demo
- final report, if appropriate
- optional: continuous integration testing

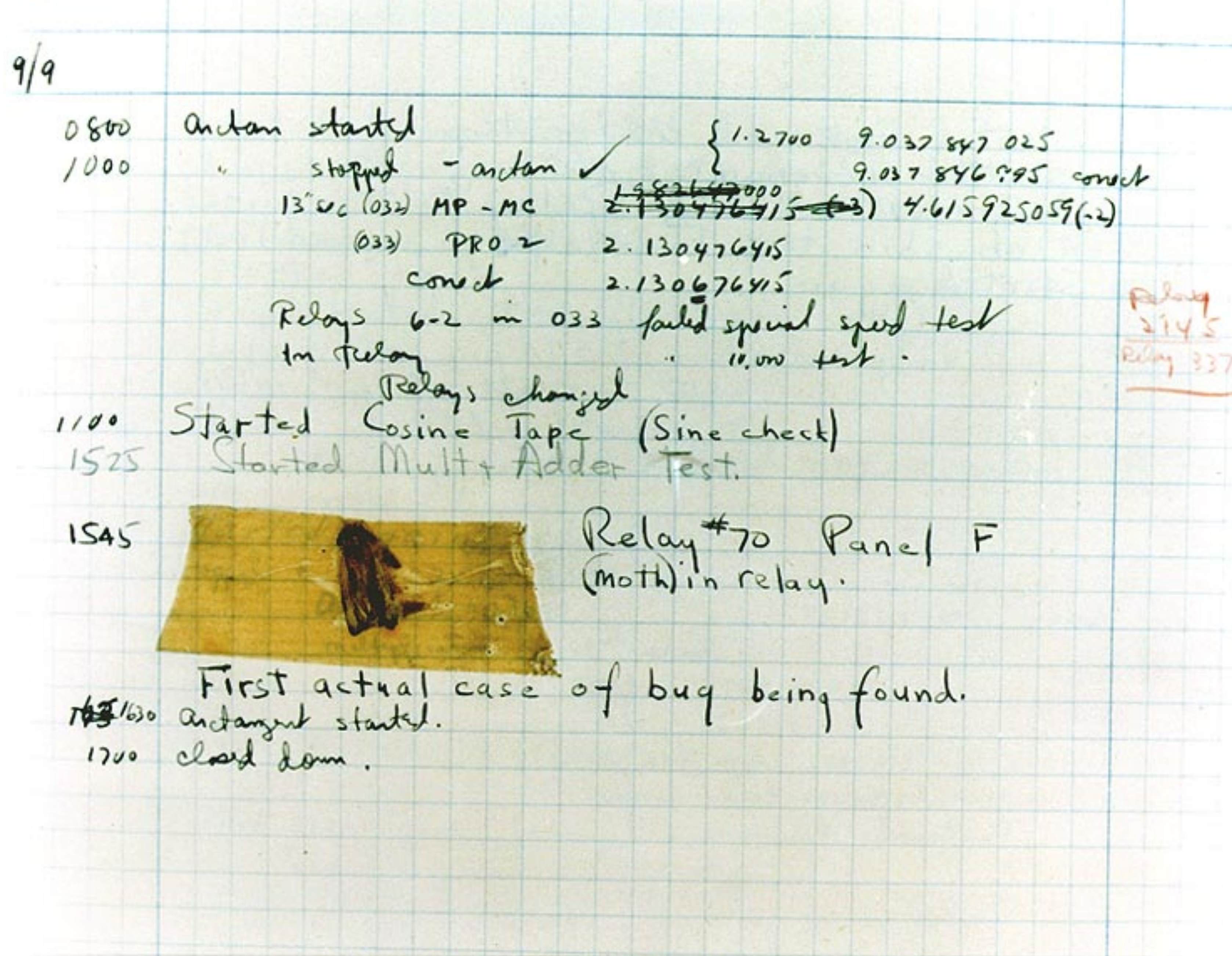
Debugging

Ways to get your code right

- Validation
  - Purpose is to uncover problems and increase confidence
  - Combination of reasoning and test
- Debugging
  - Finding out why a program is not functioning as intended
- Defensive programming
  - Programming with validation and debugging in mind
- Testing ≠ debugging
  - test: reveals existence of problem
  - debug: pinpoint location + cause of problem

A bug – September 9, 1947

US Navy Admiral Grace Murray Hopper, working on Mark I at Harvard



A Bug's Life

- Defect – mistake committed by a human
- Error – incorrect computation
- Failure – visible error: program violates its specification
- Debugging starts when a failure is observed
  - Unit testing
  - Integration testing
  - In the field

Defense in depth

1. Make errors impossible
   - Java makes memory overwrite bugs impossible
2. Don't introduce defects
   - Correctness: get things right the first time
3. Make errors immediately visible
   - Local visibility of errors: best to fail immediately
   - Example: checkRep() routine to check representation invariants
4. Last resort is debugging
   - Needed when effect of bug is distant from cause
   - Design experiments to gain information about bug
     - Fairly easy in a program with good modularity, representation hiding, specs, unit tests etc.
     - Much harder and more painstaking with a poor design, e.g., with rampant rep exposure

First defense: Impossible by design

- In the language
  - Java makes memory overwrite bugs impossible
- In the protocols/libraries/modules
  - TCP/IP will guarantee that data is not reordered
  - BigInteger will guarantee that there will be no overflow
- In self-imposed conventions
  - Hierarchical locking makes deadlock bugs impossible
  - Banning the use of recursion will make infinite recursion/insufficient stack bugs go away
  - Immutable data structures will guarantee behavioral equality
  - Caution: You must maintain the discipline

Second defense: correctness

- Get things right the first time
  - Don’t code before you think! Think before you code.
  - If you're making lots of easy-to-find bugs, you're also making hard-to-find bugs
  - don't use compiler as crutch
- Especially true, when debugging is going to be hard
  - Concurrency
  - Difficult test and instrument environments
  - Program must meet timing deadlines
- Simplicity is key
  - Modularity
    - Divide program into chunks that are easy to understand
    - Use abstract data types with well-defined interfaces
    - Use defensive programming; avoid rep exposure
  - Specification
    - Write specs for all modules, so that an explicit, well-defined contract exists between each module and its clients

Third defense: immediate visibility

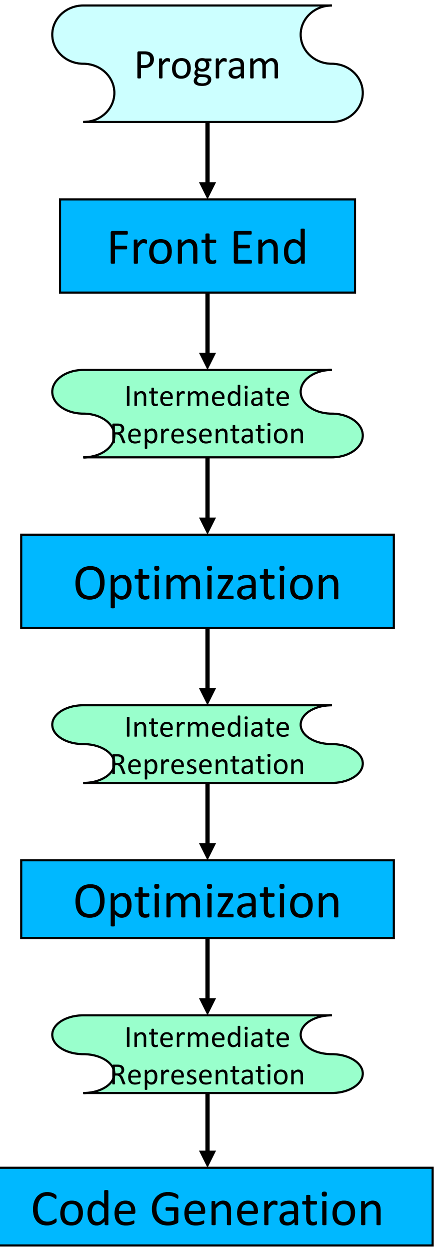
- If we can't prevent bugs, we can try to localize them to a small part of the program
  - Assertions: catch bugs early, before failure has a chance to contaminate (and be obscured by) further computation
  - Unit testing: when you test a module in isolation, you can be confident that any bug you find is in that unit (unless it's in the test driver)
  - Regression testing: run tests as often as possible when changing code. If there is a failure, chances are there's a mistake in the code you just changed
- When localized to a single method or small module, bugs can be found simply by studying the program text

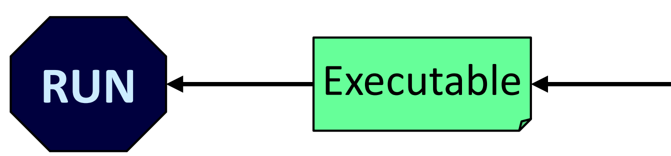
Benefits of immediate visibility

- Key difficulty of debugging is to find the code fragment responsible for an observed problem
  - A method may return an erroneous result, but be itself error free, if there is prior corruption of representation
- The earlier a problem is observed, the easier it is to fix
  - For example, frequently checking the rep invariant helps the above problem
- General approach: fail-fast
  - Check invariants, don't just assume them
  - Don't try to recover from bugs – this just obscures them

How to debug a compiler

- Multiple passes
  - Each operate on a complex IR
  - Lot of information passing
  - Very complex Rep Invariant
  - Code generation at the end
- Bug types:
  - Compiler crashes ☺
  - Generated program is buggy ☹





Don't hide bugs

```
// k is guaranteed to be present in array a
int i = 0;
while (true) {
    if (a[i]==k) break;
    i++;
}
```

- This code fragment searches an array a for a value k.
- Value is guaranteed to be in the array
- If that guarantee is broken (by a bug), the code throws an exception and dies.
- Temptation: make code more “robust” by not failing

Don't hide bugs

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
```

- Now at least the loop will always terminate
  - But no longer guarantees that `a[i]==k`
  - If rest of code relies on this, then problems arise later
  - *All we've done is obscure the link between the bug's origin and the eventual erroneous behavior it causes.*

Don't hide bugs

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
assert (i<a.length) : "key not found";
```

- Assertions let us document and check invariants

  Abort program as soon as problem is detected

Inserting Checks

- Insert checks galore with an intelligent checking strategy
  - Precondition checks
  - Consistency checks
  - Bug-specific checks
- Goal: stop the program as close to bug as possible

  Use debugger to see where you are, explore program a bit

Checking For Preconditions

```
// k is guaranteed to be present in a
        int i = 0;
        while (i<a.length) {
            if (a[i]==k) break;
            i++;
        }
        assert (i<a.length) : "key not found";
```

Precondition violated? Get an assertion!

Downside of Assertions

```
static int sum(Integer a[], List<Integer> index) {
    int s = 0;
    for (e:index) {
            assert(e < a.length, “Precondition violated”);
            s = s + a[e];
    }
    return s;
}
```

Assertion not checked until we use the data

Fault occurs when bad index inserted into list

May be a long distance between fault activation and error detection

checkRep: Data Structure Consistency Checks

```
static void checkRep(Integer a[], List<Integer> index) {
    for (e:index) {
        assert(e < a.length, "Inconsistent Data Structure");
    }
}
```

- Perform check after all updates to minimize distance between bug occurrence and bug detection
- Can also write a single procedure to check ALL data structures, then scatter calls to this procedure throughout code

Bug-Specific Checks

```
static void check(Integer a[], List<Integer> index) {
    for (e:index) {
        assert(e != 1234, "Inconsistent Data Structure");
    }
}
```

Bug shows up as 1234 in list

Check for that specific condition

Checks In Production Code

- Should you include assertions and checks in production code?
  - Yes: stop program if check fails – don't want to take chance program will do something wrong
  - No: may need program to keep going, maybe bug does not have such bad consequences
  - Correct answer depends on context!
- Ariane 5 – program halted because of overflow in unused value, exception thrown but not handled until top level, rocket crashes…

Ariane 5 rocket (1996)