## Beta

- Beta is due April 1, at noon
  That's 1 week from today!
- Beta includes presentations
  - 15 minutes per group
  - at least 2 students per group
  - practice practice practice

## Team Assessment

- Due **today**, March 25, by midnight

https://moodle.umass.edu/mod/questionnaire/view.php?id=636216

- will take less than 5 minutes

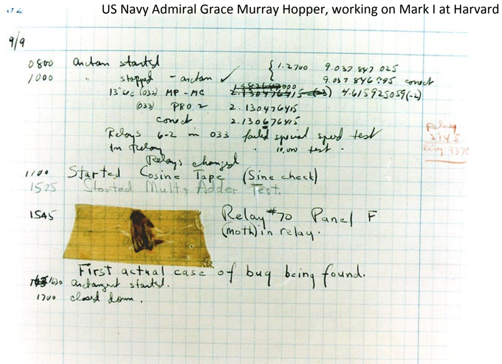
## Debugging

## 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

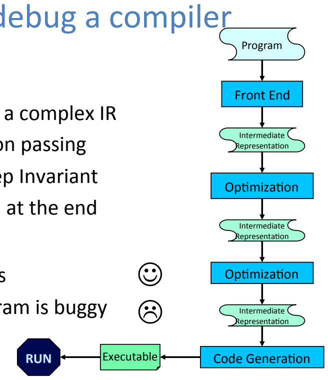
- If we can't prevent bugs, we can try to localize them to a small part of the program
  – Assertions: catch bugs early, before failure has a chance to contaminate (and be obscured by) further computation
  – Unit testing: when you test a module in isolation, you can be confident that any bug you find 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 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 guaranteed 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…