CS 3110

Testing

Nate Foster
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Review

Previously in 3110:

- Modules
- Specification (functions, modules)

Today:

- Validation
- Testing
  - Black box
  - Glass box
  - Randomized

Validation

- **Validation:** does program behave as intended?
- **Testing:** a process for validation
- **Debugging:** determining cause of unintended behavior
- **Defensive programming:** implementation techniques for making validation and debugging easier

Approaches to validation

- Social
  - Code reviews
  - Extreme/Pair programming
- Methodological
  - Test-driven development
  - Version control
  - Bug tracking
- Technological
  - Static analysis
    (“lint” tools, FindBugs, ...)
  - Fuzzers
- Mathematical
  - Type systems
  - Formal verification

Less formal: Techniques may miss problems in programs

All of these methods should be used!

Even the most formal can still have holes:

- did you prove the right thing?
- do your assumptions match reality?

More formal: eliminate *with certainty* as many problems as possible.

Testing vs. Verification

Testing:

- Cost effective
- Guarantee that program is correct on tested inputs and in tested environments

Verification:

- Expensive
- Guarantee that program is correct on all inputs and in all environments

Edsger W. Dijkstra

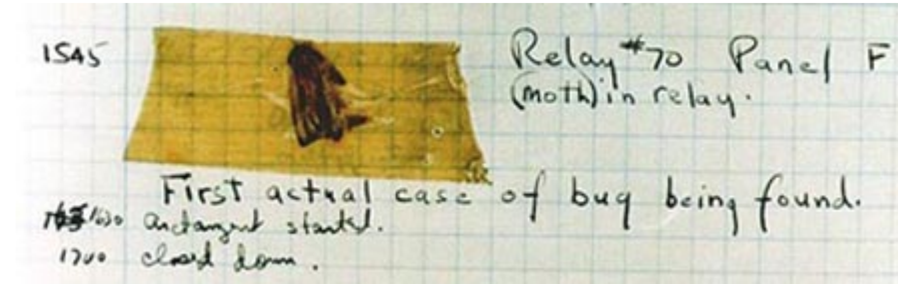
(1930-2002)

Turing Award Winner (1972)

For eloquent insistence and practical demonstration that programs should be composed correctly, not just debugged into correctness

"Program testing can at best show the presence of errors but never their absence."

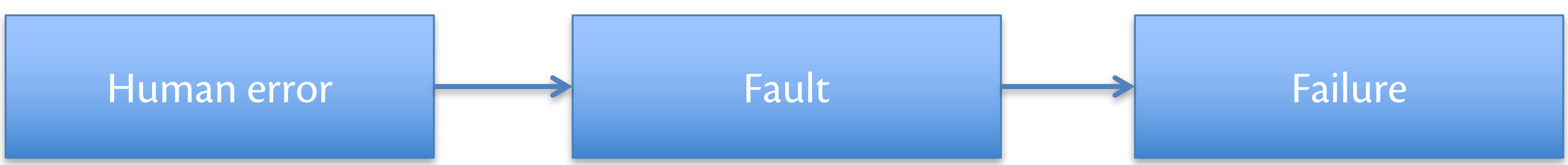
Bugs



"bug": suggests something just wandered in

[IEEE 729]

- Fault: result of human error in software system
  - E.g., implementation doesn't match design, or design doesn't match requirements
  - Might never appear to end user
- Failure: violation of requirement
  - Something goes wrong for end user



Testing

- Goal is to expose existence of faults, so that they can be fixed
- **Unit testing:** isolated components
- **Integration testing:** combined components
- **System testing:** functionality, performance, acceptance, installation

Regression testing

- **Regression:** a previously fixed fault is reintroduced into the code
- **Regression testing:** running tests against new version of software to ensure no regressions
- If you ever find and fix a fault…
  - Put a test case into your suite for it
  - Run suite frequently to detect regressions

Testing

When do you stop testing?

- **Bad answer:** when time is up
- **Bad answer:** what all tests pass

Fun fact

Pr[undetected faults]

increases

with *# detected faults*

[Myers 1979, 2004]

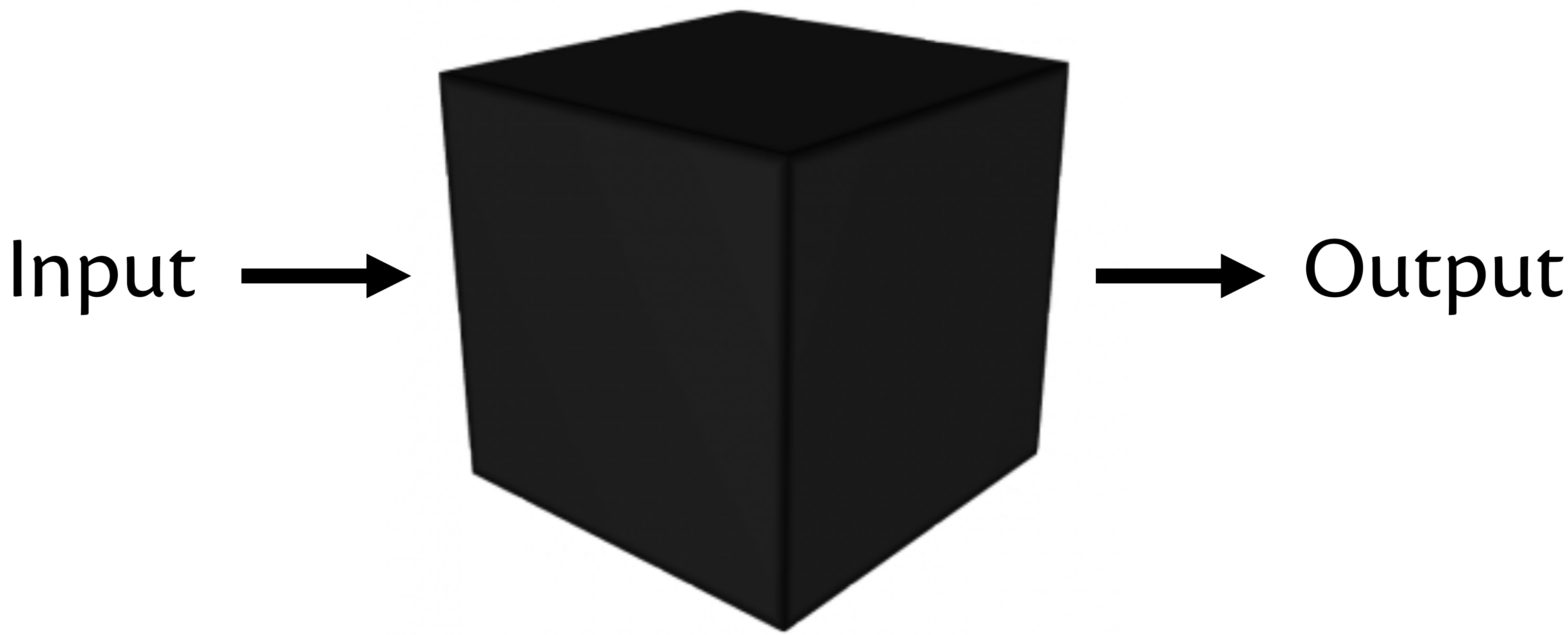
Testing

When do you stop testing?

- **Good answer:** when testing methodology is complete
- **Future answer:** statistical estimation says *Pr[undetected faults]* is low enough (active research)

TESTING

Black box testing



tester knows nothing about internals of functionality being tested

Glass box testing

Input →  → Output

tester knows internals of functionality being tested

Black box testing

Input →

→ Output

tester knows nothing about internals of functionality being tested

Glass box testing

Input →  → Output

tester knows internals of functionality being tested

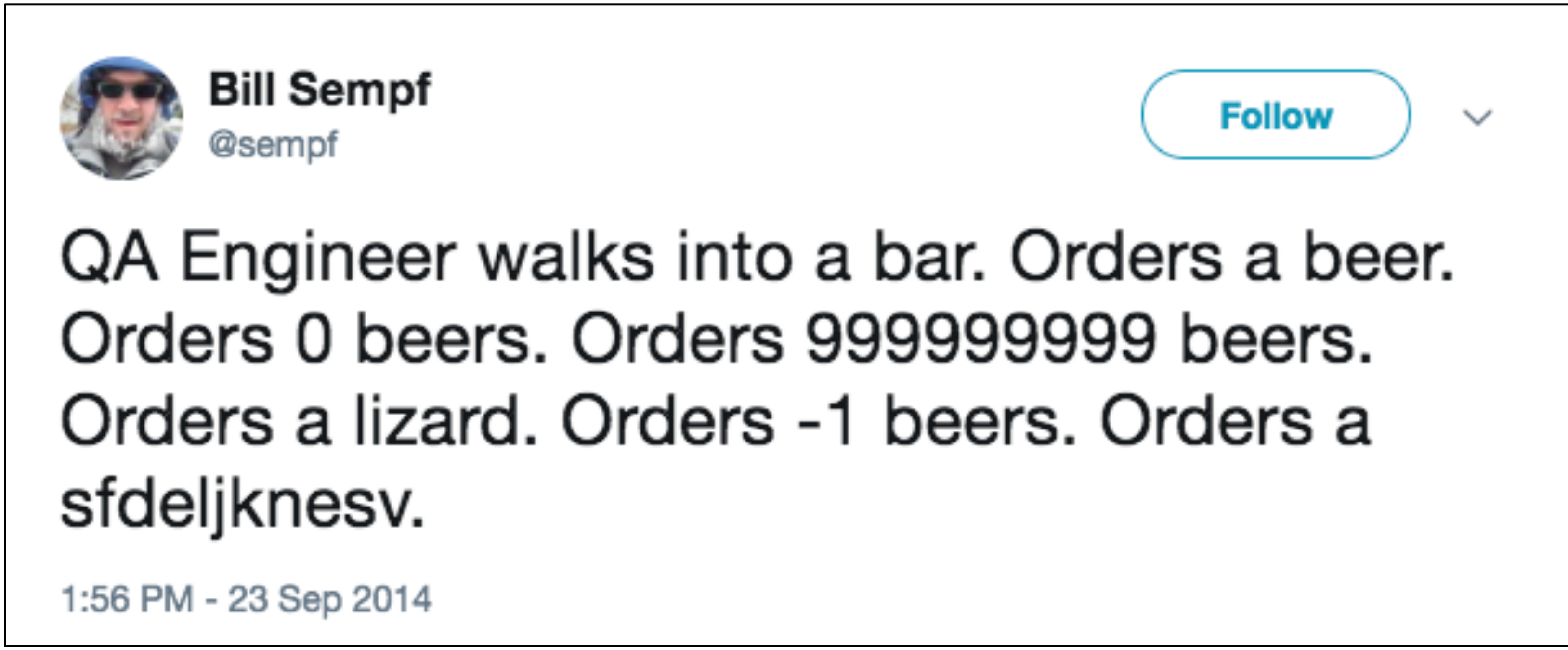
Black box testing

- Tests are based on the specification
- **Advantages:**
  - Tester is not biased by assumptions made in implementation
  - Tests are robust w.r.t. changes in implementation
  - Tests can be read and evaluated by reviewers who are not implementers
- Main kinds of black box tests:
  - Example inputs provided by spec
  - Typical inputs
  - Boundary cases
  - Paths through spec

Typical inputs

- Common, simple values of a type
  - `int`: small integers like 1 or 10
  - `char`: alphabetic letters, digits
  - `string`: whose length is a small integer and whose characters are typical
  - `'a list`: a small integer number of elements, each of which is a typical value of type `'a`
  - **records/tuples:** each field/component with a typical value
  - **variants:** typical constructors, if there is such a thing

Boundary cases


Bill Sempf
@sempf
Follow

QA Engineer walks into a bar. Orders a beer. Orders 0 beers. Orders 999999999 beers. Orders a lizard. Orders -1 beers. Orders a sfdeljknesv.

1:56 PM - 23 Sep 2014

Boundary cases

- aka *corner cases* or *edge cases*
- Atypical or extremal values of a type, and values nearby
  - **`int`**: **`0`**, **`1`**, **`-1`**, **`min_int`**, **`max_int`**
  - **`char`**: **`'\000'`**, **`'\255'`**, **`'\032'`** (space), **`'\127'`** (delete)
  - **`string`**: empty string, string with a single character, unreasonably long string
  - **`'a list`**: empty list, list with a single element, list with enough elements to trigger stack overflow on non-tail-recursive functions
  - **records/tuples:** combinations of atypical values
  - **variants:** all constructors

Paths through spec

Representative inputs for classes of outputs

```
(* [is_prime n] is true iff [n] is prime *)
val is_prime: int -> bool
```

two classes of output:

- true: representative input: n=13
- false: representative input: n=42

other examples:

- **`compare`** functions have three classes of output
- functions that return variants have several classes of output

Paths through spec

Representative inputs for each way of satisfying the precondition

```
(* [sqrt x n] is the square root of [x]
 * computed to an accuracy of [n]
 * significant digits
 * requires: x >= 0 and n >= 1 *)
val sqrt : float -> int -> float
```

(i) x=0.0, n=1,   (ii) x=1.0, n=1,
(iii) x=0.0, n=2,   (iv) x=1.0, n=2

Paths through spec

Representative inputs for each way of raising and not raising exception

```
(* [pos x lst] is the 0-based position of
 * the first element of [lst] that equals [x].
 * raises:  Not_found if [x] is not in [lst].
*)
val pos: 'a -> 'a list -> int
```

(i) x=1, lst=[1],   (ii) x=0, lst[1]

Glass box testing

- aka *white box testing*
- **Advantages:**
  - can determine whether a new test case really yields additional information about correctness of implementation
  - can address likely errors that are not apparent from specification
- **Supplements** black-box testing; does not **replace** examination of specification
- Main kind of glass box test cases:
  - *paths through implementation* aka *path coverage*

Paths through implementation

All execution paths through implementation are tested

```
let max3 x y z =
  if x>y then
    if x>z then x else z
  else
    if y>z then y else z
```

Testing according to black-box specification might lead to all kinds of inputs

But there are really only four paths through implementation!
Representatives: (i) 3 2 1, (ii) 3, 2, 4, (iii) 1, 2, 1, (iv) 1, 2, 3

Achieving path coverage

- Include test cases for:
  - each branch of each (nested) if expression
  - each branch of each (nested) pattern match
- Particularly watch out for:
  - base cases of recursive function
  - recursive calls in recursive function
  - every place where an exception might be raised

Testing data abstractions

- Some functions of a data abstraction *produce* a value of it
  - **`empty`** produces an empty set
  - **`union`** produces a set
- Other functions *consume* a value
  - **`size`** consumes a dictionary and produces an integer
  - **`bindings`** consumes a dictionary and produces a list
- For every possible path through spec and impl of producers... test how a consumer handles it
  - e.g. if producers of a set handle sets of size 0, 1, and >1 differently...
  - then test each such set with every consumer
- For every value returned by abstraction, check the RI

Randomized testing

- *"It was a dark and stormy night..."*
- Generate random inputs and feed them to programs:
  - Crash? hang? terminate normally?
  - Of ~90 utilities in '89, crashed about 25-33% in various Unixes
  - Crash => buffer overflow potential
- Since then, "fuzzing" has become a standard practice for security testing
- Results have been repeated for X-windows system, Windows NT, Mac OS X
  - Results keep getting **worse** in GUIs but better on command line

Upcoming events

- [Friday] A2 due
- [next Tuesday] Prelim I
- [Thursday, 7-9pm] Review Session, Gates G01
- [Sunday, 12-2pm] Review Session, Gates G01

Advice on

DEBUGGING

Debugging

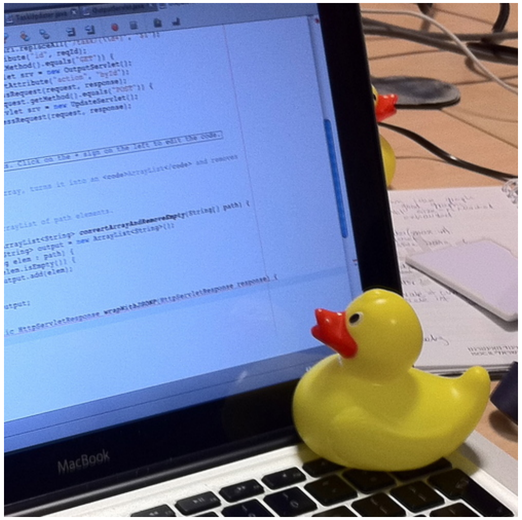
- *Testing* reveals a fault in program
- *Debugging* reveals the cause of that fault
- "Bug" is misleading
  - it didn't just crawl into program
  - **programmer put it there**
- Debugging takes more time than programming
  - get it right the first time!
  - understand exactly why you expect code to work before testing/debugging it

Debugging advice

- Follow the scientific method:
  - formulate a falsifiable hypothesis
  - create an experiment that can refute that hypothesis
  - run that experiment
  - keep a lab notebook
- Find the simplest possible input that causes fault
- Find the first manifestation of inappropriate behavior

Debugging advice

- Invest effort in writing code to help you understand intermediate results
- The bug is probably not where you think it is…ask yourself where it cannot be
- Get someone else to help you



Debugging advice

- If all else if failing, doubt your sanity: do you have the right compiler? the right source code
- Don't debug when angry or tired: give it a break; come back refreshed
- Think through the fix carefully: "fixing" a bug often leads to new bugs

Defensive programming

- *Proactive debugging:* make it easier to detect faults by writing fault-detection code during implementation
- Techniques:
  - Asserting preconditions
  - Asserting (rep) invariants
  - Exhaustive conditionals
    - check for all the possible values in an `if` or `match`
    - don't assume that `x<>a` means `x=b`

Defensive programming

Q: "Isn't this expensive?"

A: It only seems that way!

- For **implementer**: the defensive code you write tends to pay off in the faults it catches early
- For **performance**: the faults you catch in production might save more money than the run-time cost of the checks