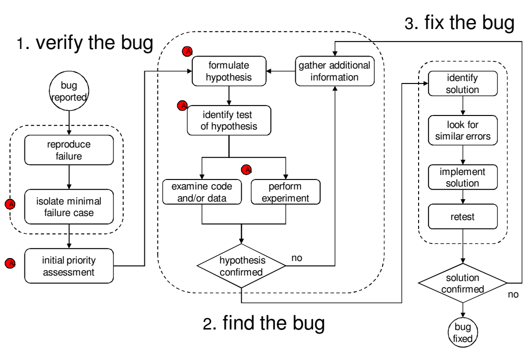
Debugging

- finding problems
  - the scientific method
  - verification, assessment, triage
  - confident problem identification
  - debugging tools
- fixing problems
  - root cause analysis
- psychological issues in debugging
  - how to become a better debugger
- bug reports and tracking

What makes debugging hard?

- programs are not as simple as theorems
  - much larger, nowhere nearly as well designed
- complex causes
  - faults may have very complex preconditions
    - interactions between components & people
    - relative timing of complex events
  - some causal elements may seem unrelated
- complex cause/symptom relationships
  - symptoms result from a cascade of events
  - symptoms may occur long after cause
  - symptoms may appear in unrelated areas

the scientific debugging process



when it doesn't make sense ...

- get more information
  - identify more failure (and non-failure) cases
  - use tracers or debuggers
  - instrumentation to catch errors sooner
  - try everything on McConnell's brute force list
- write down all the facts you know
  - spread them out on the wall or a white board
- ask for help
  - more eyes and brains in the analysis
  - suggestions for additional instrumentation

information - program output

- programs often produce progress output
  - files processed, actions, events received
  - may have to be enabled w/verbose options
- many programs have diagnostic options
  - enable more detailed activity traces
  - request dumps of internal tables
- this can help us understand the problem
  - what is happening when the problem occurs
  - interesting state associated with the event

debugger stack traces

simple gdb stack trace

```
#0 0x080483cb in function_2 ()
#1 0x080483b4 in function_1 ()
#2 0x08048385 in main ()
#3 0x4003ddc6 in __libc_start_main () from /lib/libc.so.6
```

gdb backtrace with parameters and source info

```
#0  0x080ca21b in _efree (ptr=0xbfffdb9b)                at zend_alloc.c:240
#1  0x080d691a in _zval_dtor (zvalue=0x8186b94)           at zend_variables.c:44
#2  0x080cfab3 in _zval_ptr_dtor (zval_ptr=0xbfffdbfc)    at zend_execute_API.c:274
#3  0x080f1cc4 in execute (op_array=0x816c670)            at zend_execute.c:1605
```

(information - back-traces)

- history of all active sub-routine calls
  - an interpreted trace back through stack
    - list of all currently stacked subroutine calls
    - often includes values of parameters
    - may include values of all automatic variables
- tells us, in general, what program is doing
- can generate from core dump after fault
  - e.g. invalid address, zero-divide
- can also be obtained from a debugger

system call tracing

Sample system call trace (strace) output

```
open("/opt/gnome2/lib/libc.so.6", O_RDONLY) = -1 ENOENT (No such file or directory)
stat64("/opt/gnome2/lib", {st_mode=S_IFDIR|0755, st_size=20480, ...}) = 0
open("/etc/ld.so.cache", O_RDONLY)      = 3
fstat64(3, {st_mode=S_IFREG|0644, st_size=65928, ...}) = 0
old_mmap(NULL, 65928, PROT_READ, MAP_PRIVATE, 3, 0) = 0xbf596000
close(3)                                = 0
open("/lib/tls/libc.so.6", O_RDONLY)    = 3
read(3, "\177ELF\1\1\1\0\0\0\0\0\0\0\0\0\3\0\3\0\1\0\0\0`ht\000"..., 512) = 512
```


(information - execution traces)

- run program under an execution tracer
  - normal instructions execute normally
  - tracer intercepts all system calls
    - logs the system call and its parameters
    - allows OS to execute the system call
    - logs the returned values
    - allows program to continue executing
- fast and simple trace of program activities
  - generates a huge amount of information
  - good idea of what program was doing

information - run in debugger

- debuggers have many valuable features
  - source level (vs machine language)
  - code break points (stop when it gets here)
  - single-stepping (line or instruction at a time)
  - data watch points (stop when it touches this)
  - view and change variables at any time
- invaluable for <u>brute force debugging</u>
  - when you aren't sure what you're looking for
  - run to an interesting point, stop, look around

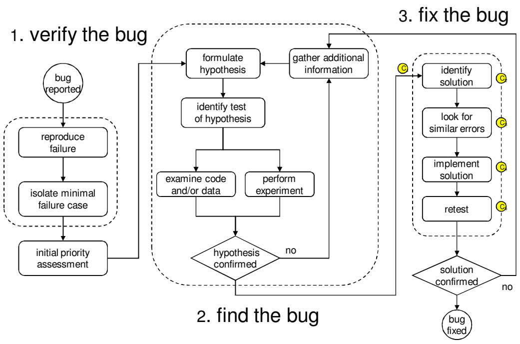
information – instrumentation

- there isn't always enough information
  - program produces little diagnostic output
  - stack/execution traces are useless
    - detected failure occurs long after the actual error
  - execution in debugger is not practical
    - don't know what code to look at
    - suspect code is called very frequently
- add new instrumentation to program
  - log all conceivably interesting events
  - attempt to reproduce failures w/new version
  - may change symptoms of the failure

information - forensic analysis

- some problems can be hard to recreate
  - distributed apps often have timing problems
  - pointer errors can have indeterminate results
- some problems have leave little evidence
  - failure may occur long after the original error
  - most of the evidence is long since gone
- we must infer cause from remaining clues
  - often requires CSI-like detective-work
  - such systems often include diagnostic logs
  - the ultimate fall-back: complete core dump

the scientific debugging process



reviewing fixes

- original code clearly needed more review
  - original developer did not get it right
  - original reviewers did not find the error
  - original test cases did not find the error
- bug fixes almost always require review
  - correctness of code is clearly not obvious
  - bug fixers are often not original developer
  - they often have less familiarity with the code
  - they often have less programming experience
- how did this get past us before?

Root Cause Analysis

- some bugs may be essentially random
  - software is complex, people are fallible
- many bugs turn out not to be random
  - people keep repeating the same mistakes
  - inadequate training, tools & methodology
- after a problem has been found and fixed
  - identify the <u>root cause</u> of the defect
    - understand how we made and failed to find it
- do statistical studies of root causes
  - identify clusters, find ways to eliminate them

Psychological Issues

- We assume what we think we know
  - we do not see our work as it actually is
  - rather, we see it as we intended it to be
- We assume we are better than we are
  - we believe in our abilities and methodology
  - we don't like to believe ourselves error-prone
  - we suspect problems come from elsewhere
- These blind us to many hypotheses
  - this blindness impairs our debugging ability

Inconceivability

- It is <u>possible</u> that the bug isn't your fault
  - operating systems are not perfect
    - they do contain bugs, especially new releases
  - compilers sometimes generate incorrect code
    - I've personally tracked down a few of these
  - computers can even mis-execute instructions
    - in 35 years, I have encountered <u>one</u> instance
- these <u>may</u> be conclusions you come to
  - they should <u>never</u> be assumptions you make

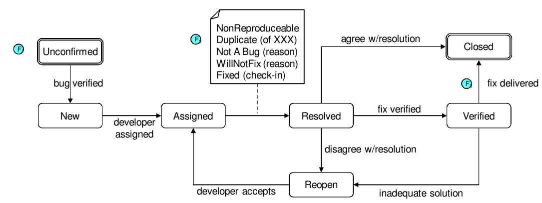
Becoming a Better Debugger

- Keep an open mind
  - there are none so blind as those who will not see
- Learn from your programming mistakes
  - what did you do wrong?
  - why didn't you notice it sooner?
- Learn from your debugging mistakes
  - what clues were there, but you missed them?
  - what dead-ends did you wind up following?
- Learn from others
  - questions they ask, details they notice
  - tools and techniques do they use

Key Attributes of a Bug Report

- ID (assigned automatically)
- Title (one line description of bug)
- Status
  - current state, severity, priority, owner
- Description
  - suspected component at fault
  - platform, symptoms, how to cause
  - diagnosis, work-arounds, and fix location
- History
  - log of all associated operations & comments

Bug Report Life Cycle
(simplified typical model)



Good Bug Reports

- Clearly describe the problem
  - what should have happened, what did happen
- Clearly describe the impact
  - consequences to the affected users
- Clearly describe the affected systems
  - what platforms, what versions of what software
- Clearly describe how to cause the problem
  - ideally with a relatively simple test case
  - developing minimal failure cases is work
- Dispassionate, separate facts from opinions

Bug Tracking Systems

- List of open tasks for developers
  - what work needs to be done
  - communication between developers & users
- Current status of product/development
  - what known problems are there (#, severity)
  - what is the status of each
- Support database
  - known problems and work arounds
- Project management database
  - defect detection rates, fix rates
  - number of problems discovered
  - regression and not-a-bug rates

bug triage and priority

- in emergency, sort patients into 3 groups
  - those who can wait a few hours
  - those who will die no matter what
  - those who need immediate attention
- bugs are prioritized in a similar fashion
  - disastrous bugs, must fix ASAP
    - they render the product unacceptable
  - serious bugs, should fix before shipment
    - they significantly compromise value of the product
  - minor bugs, fixes can be deferred to later

For Next Lecture

- McConnell, chapter 29
  - overview of basic integration strategies
- Kampe, Integration Strategy
  - integration, architecture, testing, and schedule
- Kampe, Solaris Train Model
  - incremental integration for existing products
- Fowler, Continuous Integration
  - good advice for a more rational process
- Wikipedia, Test Driven Development
  - introduction to a useful agile development practice
- Kampe, Test Harnesses
  - introduction to a general class of testing tools
- Sourceforge: CUnit (just skim)
  - an instance of a noble family of testing harnesses

Supplementary Slides

bug verification

- reproduce the reported error
  - find a test case that reliably causes error
    - it is difficult to fix a problem one cannot observe
  - confirm that we observe reported behavior
    - we may have misunderstood the report
  - enable a preliminary assessment
    - does this, indeed, appear to be an error
- verify that program behavior is wrong
  - problem may be user-error or documentation
  - user may have unreasonable expectations

minimal failure cases

- some failures are complex or subtle
  - failure occurs after millions of operations
  - failure depends on environmental factors
  - failure isn't always in the same place
- find a simple case that fails solidly
  - isolate the contributing factors
  - find minimal combination that fails reliably
- this makes problem easier to reproduce, and easier to debug