Cornell University
Computing and Information Science

CS 5150 Software Engineering

Verification, Testing, and Bugs

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Building Reliable Systems: Two Principles

For a software system to be reliable:

- Each stage of development must be done well, with incremental verification and testing.
- Testing and correction do not ensure quality, but reliable systems are not possible without thorough testing.

Static and Dynamic Verification

Static verification:

Techniques of verification that do not include execution of the software.

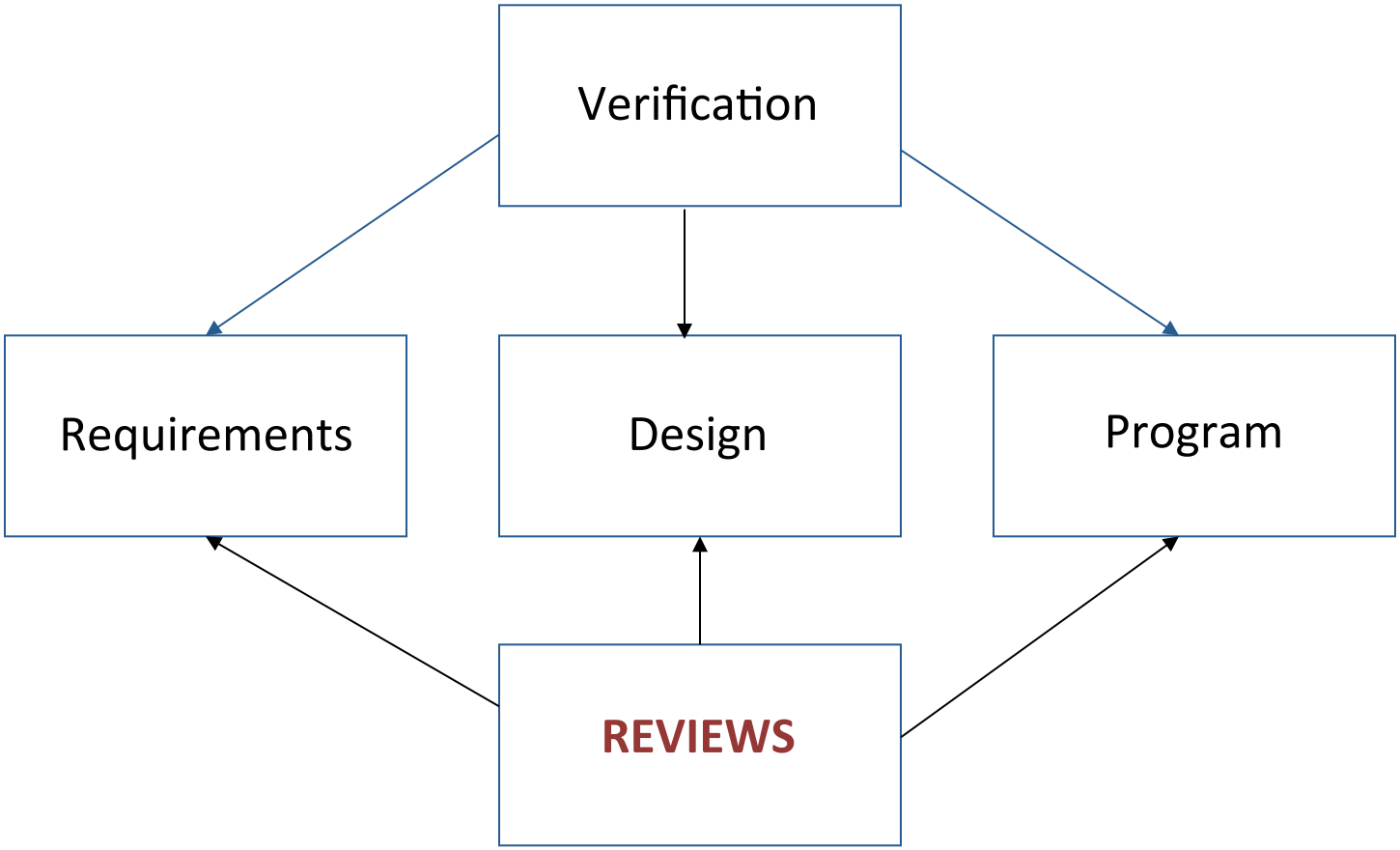
- May be manual or use computer tools.

Dynamic verification:

- Testing the software with trial data.
- Debugging to remove errors.

Static Verification: Reviews

Reviews are a form of static verification that is carried out throughout the software development process.



Reviews

Reviews are a fundamental part of good software development

Concept

Colleagues review each other's work:

- can be applied to any stage of software development, but particularly valuable to review program design or code
- can be formal or informal

Preparation

The developer(s) provides colleagues with documentation (e.g., models, specifications, or design), or code listing.

Participants study the materials in advance.

Meeting

The developer leads the reviewers through the materials, describing what each section does and encouraging questions.

The Review Meeting

A review is a structured meeting

Participants and their roles:

Developer(s): person(s) whose work is being reviewed

Moderator: ensures that the meeting moves ahead steadily

Scribe: records discussion in a constructive manner

Interested parties: other developers on the same project

Outside experts: knowledgeable people who are not working on this project

Client: representatives of the client who are knowledgeable about this part of the process

Benefits of Reviews

Benefits:

- Extra eyes spot mistakes, suggest improvements
- Colleagues share expertise; helps with training
- Incompatibilities between components can be identified
- Gives developers an incentive to tidy loose ends
- Helps scheduling and management control

Successful Reviews

To make a review a success:

- Senior team members must show leadership
- Good reviews require good preparation by everybody
- Everybody must be helpful, not threatening

Allow plenty of time and be prepared to continue on another day.

Static Verification: Pair Design and Pair Programming

Concept: achieve benefits of review by shared development

Two people work together as a team:

- design and/or coding
- testing and system integration
- documentation and hand-over

Benefits include:

- two people create better software with fewer mistakes
- cross training

Many software houses report excellent productivity

Static Verification: Program Inspections

Formal program reviews whose objective is to detect faults

- Code is read or reviewed line by line.
- 150 to 250 lines of code in 2 hour meeting.
- Use checklist of common errors.
- Requires team commitment, e.g., trained leaders

So effective that it is claimed that it can replace unit testing

Program Inspections: Common Errors

Check list of common errors

Data faults: Initialization, constants, array bounds, character strings

Control faults: Conditions, loop termination, compound statements, case statements

Input/output faults**:** All inputs used; all outputs assigned a value

Interface faults: Parameter numbers, types, and order; structures and shared memory

Storage management faults: Modification of links, allocation and de-allocation of memory

Exceptions: Possible errors, error handlers

Static Verification: Analysis Tools

Program analyzers scan the source of a program for **possible** errors and anomalies.

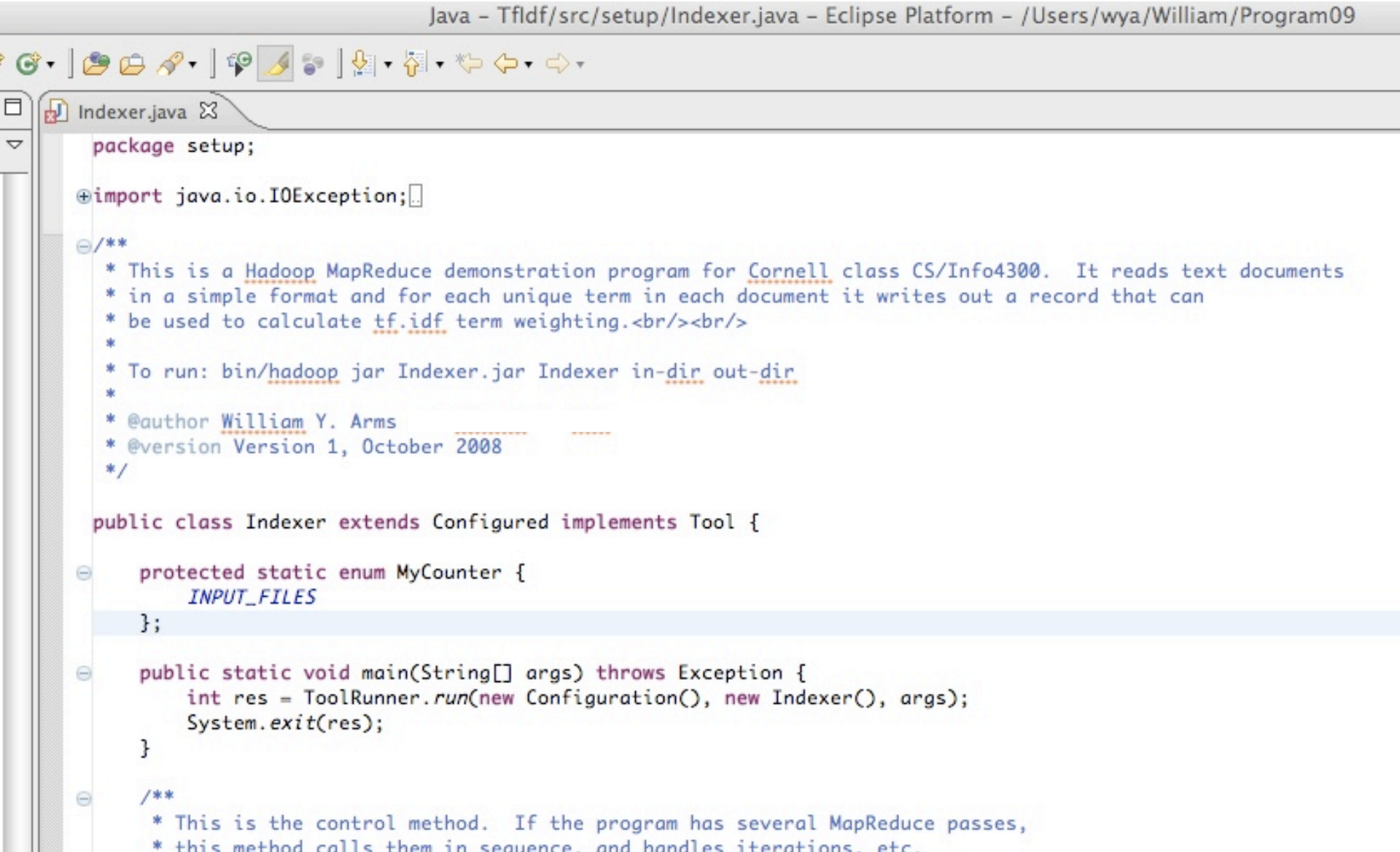
- Control flow: Loops with multiple exit or entry points
- Data use: Undeclared or uninitialized variables, unused variables, multiple assignments, array bounds
- Interface faults: Parameter mismatches, non-use of functions results, uncalled procedures
- Storage management: Unassigned pointers, pointer arithmetic

Static Analysis Tools (continued)

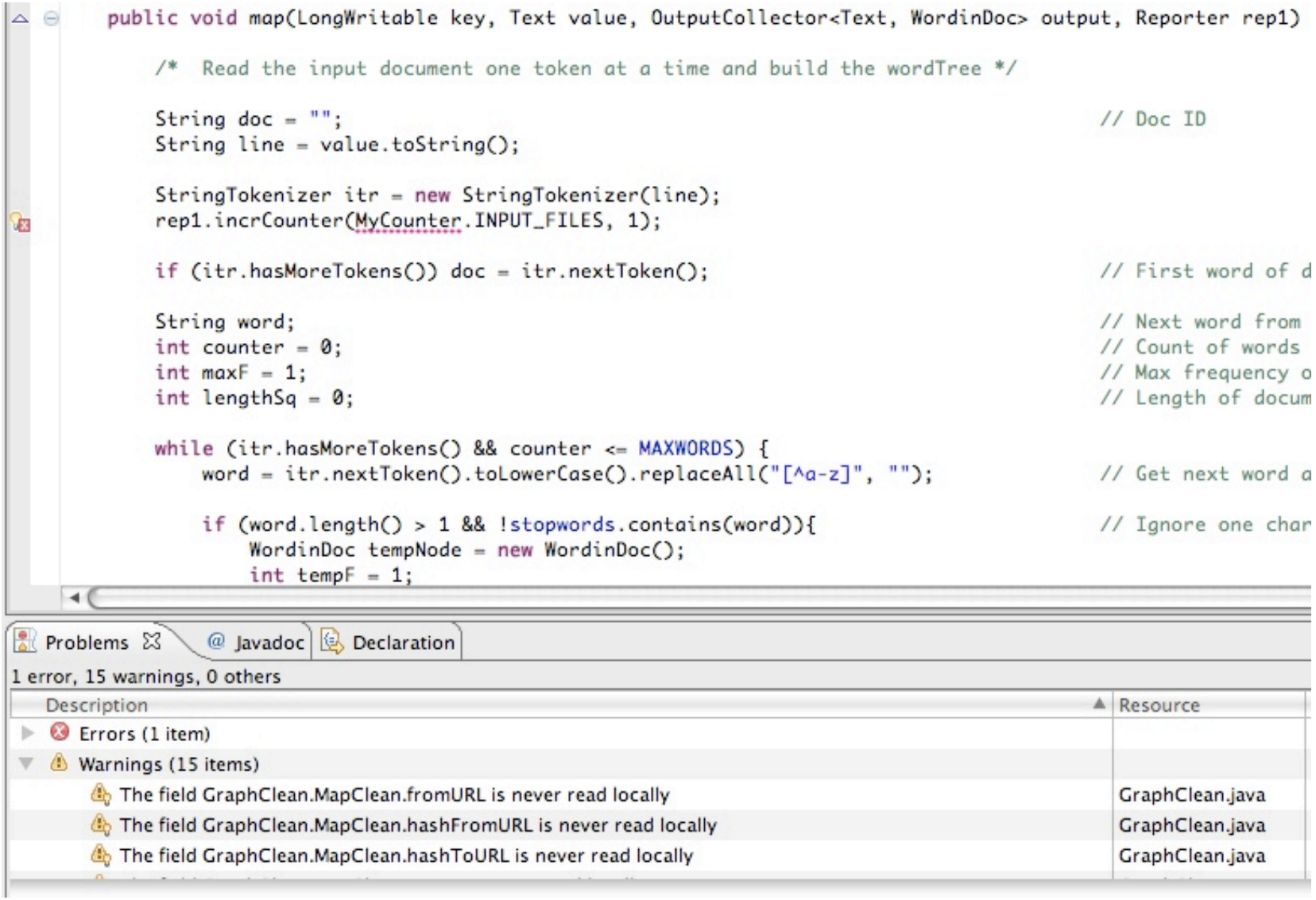
Static analysis tools

- Cross-reference table: Shows every use of a variable, procedure, object, etc.
- Information flow analysis: Identifies input variables on which an output depends.
- Path analysis: Identifies all possible paths through the program.

Static Analysis Tools in Programming Toolkits



Static Analysis Tools in Programming Toolkits



Defensive Programming

Murphy's Law:

If anything can go wrong, it will.

Defensive Programming:

- Write simple code.
- Avoid risky programming constructs.
- If code is difficult to read, rewrite it.
- Incorporate redundant code to check system state after modifications.
- Test implicit assumptions explicitly, e.g., check all parameters received from other routines.

Good programming practice eliminates all warnings from source code.

Dynamic Verification: Stages of Testing

Testing is most effective if divided into stages

User interface testing (carried out separately)

Unit testing

unit test

System testing

integration test

function test

performance test

installation test

Acceptance testing (carried out separately)

Testing Strategies

Bottom-up testing

Each unit is tested with its own test environment. Used for all systems.

Top-down testing

Large components are tested with dummy stubs. Particularly useful for:

user interfaces
work-flow
client and management demonstrations

Stress testing

Tests the system at and beyond its limits. Particularly useful for:

real-time systems
transaction processing

Most systems require a combination of all three strategies.

Methods of Testing

Open box testing

Testing is carried out by people who know the internals of what they are testing.

Example: Tick marks in a graphing package

Closed box testing

Testing is carried out by people who do not know the internals of what they are testing.

Example: Educational demonstration that was not foolproof

Testing: Unit Testing

- Tests on small sections of a system, e.g., a single class
- Emphasis is on accuracy of actual code against specification
- Test data is usually chosen by developer(s) based on their understanding of specification and knowledge of the unit
- Can be at various levels of granularity
- **Can be open box or closed box:** by the developer(s) of the unit or by special testers

If unit testing is not thorough, system testing becomes almost impossible. If your are working on a project that is behind schedule, do not rush the unit testing.

Testing: System and Sub-System Testing

- Tests on components or complete system, combining units that have already been thoroughly tested
- Emphasis on integration and interfaces
- Trial data that is typical of the actual data, and/or stresses the boundaries of the system, e.g., failures, restart
- Carried out systematically, adding components until the entire system is assembled
- **Can be open or closed box:** by development team or by special testers

System testing is finished fastest if each component is completely debugged before assembling the next

Dynamic Verification: Test Design

Testing can never prove that a system is correct.

It can only show that either (a) a system is correct in a special case, or (b) that it has an error.

- The objective of testing is to find errors or demonstrate that program is correct in specific instances.
- Testing is never comprehensive.
- Testing is expensive.

Test Cases

Test cases are specific tests that are chosen because they **are likely to find specific problems**.

Test cases are chosen to balance expense against chance of finding serious errors.

- Cases chosen by the development team are effective in testing known vulnerable areas.
- Cases chosen by experienced outsiders and clients will be effective in finding gaps left by the developers.
- Cases chosen by inexperienced users will find other errors.

Variations in Test Sets

A **test suite** is the set of all test cases that apply to a system or component of a system.

When running tests, there are some errors that occur only under certain circumstances, e.g., when certain other software is running on the same machine, when tasks are scheduled in specific sequences, with unusual data sets, etc.

Therefore it is customary for each test to vary some of the test cases systematically, and to change the order in which the tests are made, etc.

Incremental Testing (e.g., Daily Testing)

- Create a first iteration that has the structure of the final system and some basic functionality.
- Create an initial set of test cases.
- Check-in changes to the system on a daily basis, rebuild entire system daily.
- Run a comprehensive set of test cases daily, identify and deal with any new errors.
- Add new test cases continually.

Many large software houses, e.g., Microsoft, follow this procedure with a daily build of the entire system and comprehensive sets of test cases. For a really big system this may require hundreds or even thousands of test computers and a very large staff of testers.

Dynamic Verification: Regression Testing

When software is modified, **regression testing** is used to check that modifications behave as intended and do not adversely affect the behavior of unmodified code.

- After **every change**, however small, rerun the **entire testing suite.**

Regression Testing: Program Testing

1. Collect a **suite of test cases**, each with its expected behavior.
2. Create scripts to run all test cases and compare with expected behavior. (Scripts may be automatic or have human interaction.)
3. When a change is made to the system, however small (e.g., a bug is fixed), add a new test case that illustrates the change (e.g., a test case that revealed the bug).
4. Before releasing the changed code, **rerun the entire test suite.**

Incremental Testing: a Small Example

Example

A graphics package consisting of a pre-processor, a runtime package (set of classes), and several device drivers.

Starting point

A prototype with a good overall structure, and most of the functionality, but hastily coded and not robust.

Approach

On a daily cycle:

- Design and code one small part of the package (e.g., an interface, a class, a dummy stub, an algorithm within a class.)
- Integrate into prototype.
- Create additional test cases if needed.
- Regression test.

Documentation of Testing

Every project needs a **test plan** that documents the testing procedures for thoroughness, visibility, and for **future maintenance**. It should include:

- Description of testing approach.
- List of test cases and related bugs.
- Procedures for running the tests.
- Test analysis report

Fixing Bugs

Isolate the bug

- Intermittent --> repeatable
- Complex example --> simple example

Understand the bug and its context

- Root cause
- Dependencies
- Structural interactions

Fix the bug

- Design changes
- Documentation changes
- Code changes
- Create new test case

Moving the Bugs Around

Fixing bugs is an error-prone process

- When you fix a bug, fix its environment
- Bug fixes need static and dynamic testing
- Repeat all tests that have the slightest relevance (regression testing)

Bugs have a habit of returning

- When a bug is fixed, add the failure case to the test suite for future regression testing.

Persistence

- Most people work around a problem. The best people track down the root cause and fix it for ever!

Difficult Bugs

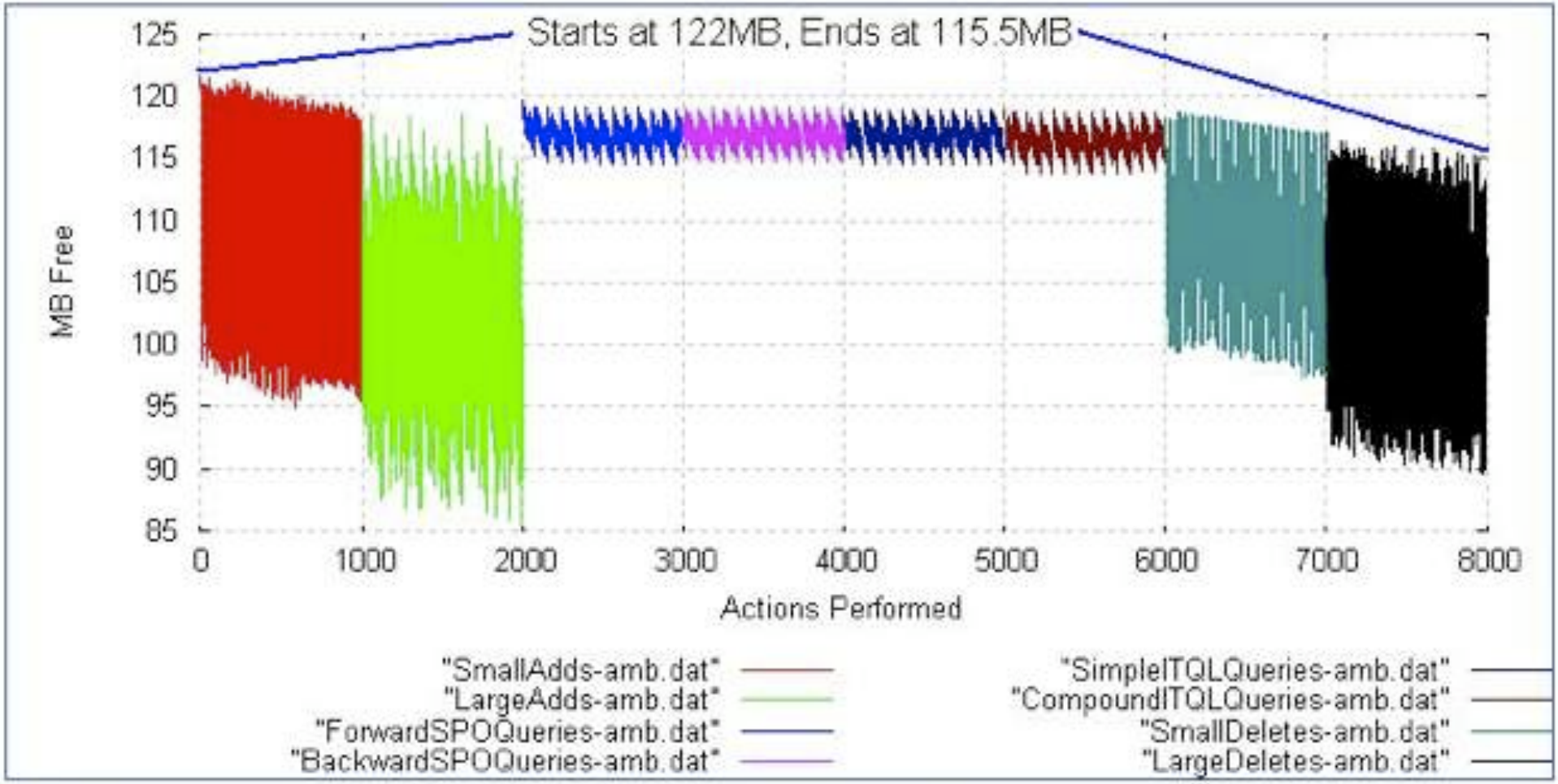
Some bugs may be extremely difficult to track down and isolate. This is particularly true of intermittent failures.

- A large central computer stops a few times every month with no dump or other diagnostic.
- A database load dies after running for several days with no diagnostics.
- An image processing system runs correctly, but uses huge amounts of memory.

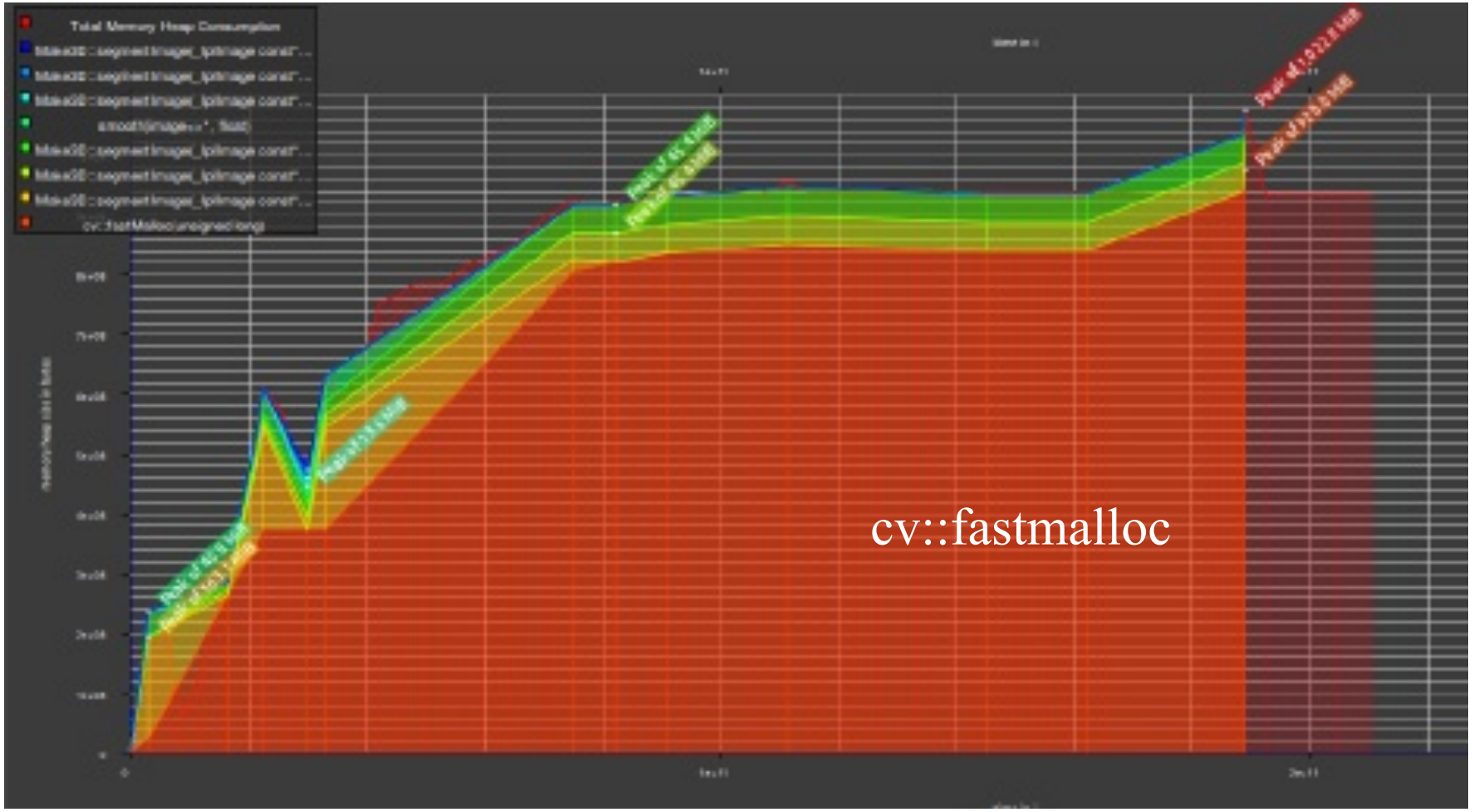
Such problems may require months of effort to track down.

For a fictional example, see: Ellen Ullman, *The Bug: a Novel*, (Doubleday 2003).

Tracking Down a Difficult Bugs: The Heisenbug



Tracking Down a Difficult Bug: Make3D



Memory usage by function

Bugs in System Software

Even system software from good manufacturers may contain bugs:

- Built-in function in Fortran run-time environment ($e^0 = 0$)
- The string-to-number function that was very slow with integers
- The preload system with the memory leak

Bugs in Hardware

Three times in my career I have encountered hardware bugs:

- The film plotter with the missing byte (1:1023)
- Microcode for virtual memory management
- The Sun page fault

Each problem was actually a bug in embedded software/firmware

When Fixing a Bug Creates a Problem for Customers

Sometimes customers will build applications that rely upon a bug. Fixing the bug will break the applications.

- The graphics package with rotation about the Z-axis in the wrong direction.
- An application crashes with an emulator, even though the emulator is bug free. (Compensating bug problem.)
- The 3-pixel rendering problem with Internet Explorer.

With each of these bugs the code was easy to fix, but releasing it would have caused problems for existing programs.

A Note on User Interface Testing

User interfaces need several categories of testing.

- During the **design phase**, user interface testing is carried out with trial users to ensure that the design is usable. Design testing is also used to develop graphical elements and to validate the requirements.
- During the **implementation phase**, the user interface goes through the standard steps of unit and system testing to check the reliability of the implementation.
- Finally, **acceptance testing** is carried out with users, on the complete system.