CS 45, Lecture 12
Debugging and Profiling

Spring 2023

Akshay Srivatsan, Ayelet Drazen, Jonathan Kula

Administrivia

- Assignment 4 is due tonight! It covers all things Git. Reach out if you need more time.
- Assignment 5 will come out sometime tonight or tomorrow!
- Thank you for the feedback 💘

What we will cover today

In today's lecture, we will learn about :

- Basic debugging techniques such as printing and logging
- Debugging tools
- Profiling your code for memory leaks, resource management, timing

This lecture may feel like a bunch of tools and demos. You don't need to become an expert in these now, but it's worth knowing they are out there!

Installations

Throughout this lecture, we will be looking at a number of different tools.

Some of these won't be installed on your machine but feel free to install as we go. For Python tools, use:

```
pip3 install <name-of-tool>
```

Introduction to Debugging

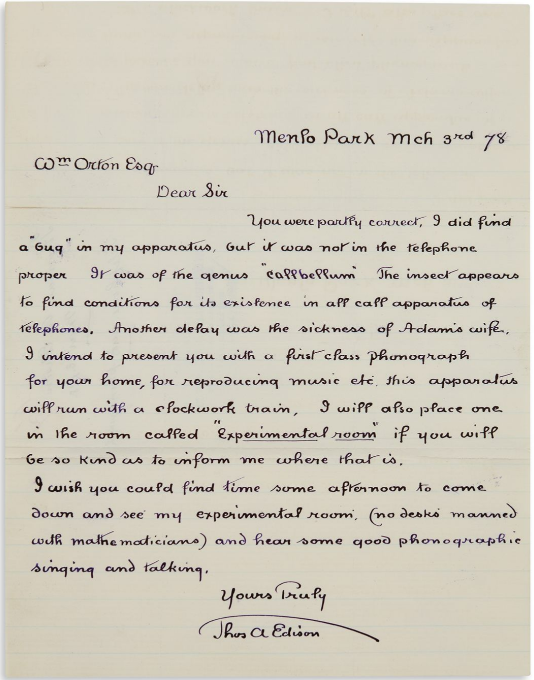
What’s the #1 issue I saw student having when working as a CA?

Not knowing how to debug.

Debugging
/ˌdiːˈbʌg -ing/
verb.
1. Being the detective in a crime movie where you are also the murderer.
See also: Developer and Genius

History of Debugging

The terminology of the term debugging has a fun history to it.



Menlo Park Mch 3rd 78

Wm Orton Esqr

Dear Sir

You were partly correct, I did find a "Bug" in my apparatus, but it was not in the telephone proper. It was of the genus "callbellum" The insect appears to find conditions for its existence in all call apparatus of telephones. Another delay was the sickness of Adams wife, I intend to present you with a first class phonograph for your home, for reproducing music etc. this apparatus will run with a clockwork train, I will also place one in the room called "Experimental room" if you will be so kind as to inform me where that is.

I wish you could find time some afternoon to come down and see my experimental room, (no desks manned with mathematicians) and hear some good phonographic singing and talking.

Yours Truly

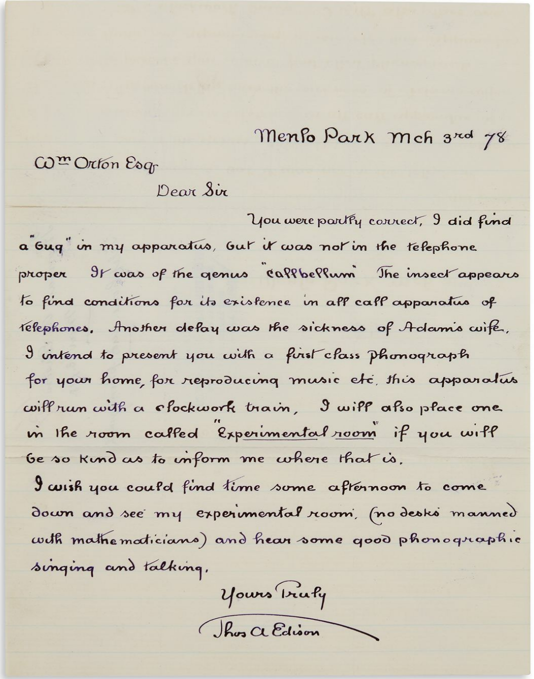
Thos A Edison

Note by Thomas Edison where he used the term bug to describe a technical error.

History of Debugging

The terminology of the term debugging has a fun history to it.

In 1878, Thomas Edison was the first to use the term “bug” to describe a technical error.



Menlo Park Mch 3rd 78

Wm Orton Esqr

Dear Sir

You were partly correct, I did find a "Bug" in my apparatus, but it was not in the telephone proper It was of the genus "callbellum" The insect appears to find conditions for its existence in all call apparatus of telephones. Another delay was the sickness of Adam's wife. I intend to present you with a first class Phonograph for your home, for reproducing music etc. this apparatus will run with a clockwork train, I will also place one in the room called "Experimental room" if you will be so kind as to inform me where that is.

I wish you could find time some afternoon to come down and see my experimental room, (no desks manned with mathematicians) and hear some good phonographic singing and talking.

Yours Truly

Thos A Edison

Note by Thomas Edison where he used the term bug to describe a technical error.

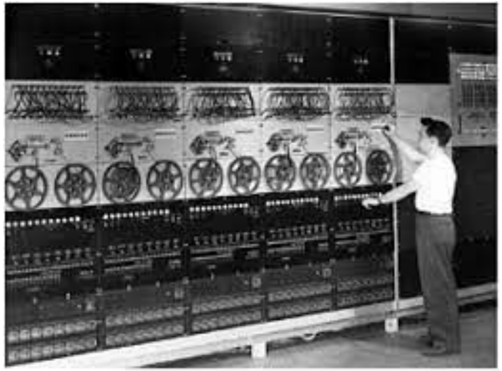
History of Debugging

In 1945, the first computers were being built.

History of Debugging

In 1945, the first computers were being built.

Mark III was one of these computers that was being built at Harvard. Grace Hopper was developing Mark III when she encountered a problem with its functionality.



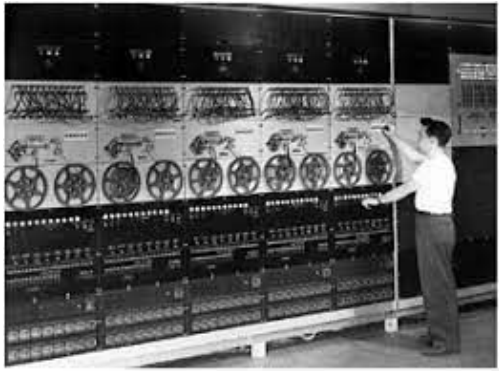
Mark III

History of Debugging

In 1945, the first computers were being built.

Mark III was one of these computers that was being built at Harvard. Grace Hopper was developing Mark III when she encountered a problem with its functionality.

After running some tests, she decided to look inside and found an actual moth, which lead to the usage of the word debugging in programming.



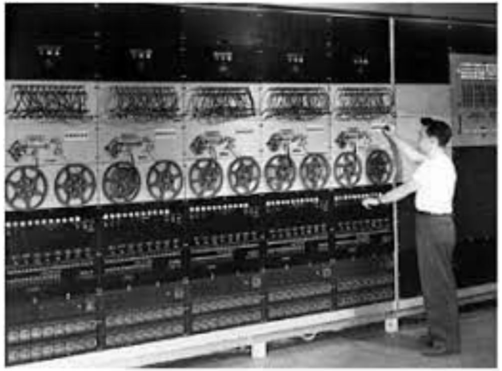
Mark III

History of Debugging

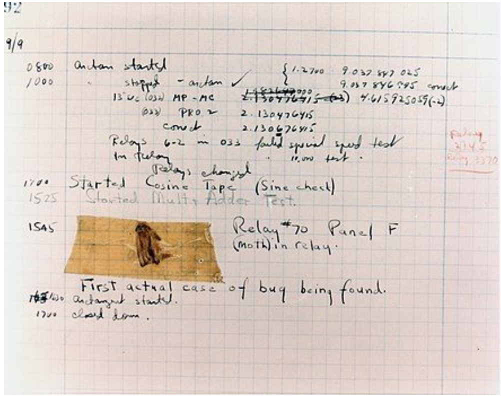
In 1945, the first computers were being built.

Mark III was one of these computers that was being built at Harvard. Grace Hopper was developing Mark III when she encountered a problem with its functionality.

After running some tests, she decided to look inside and found an actual moth, which lead to the usage of the word debugging in programming.



Mark III



92

9/9

0800 Anctan started
1000 " stopped - anctan ✓ {1.2700 9.037 847 025
9.037 846 995 correct
13" uc (032) MP-MC ~~1.982147000~~ ~~2.130476415~~ (-3) 4.615925059(-2)
(033) PRO 2 2.130476415
correct 2.130676415
Relays 6-2 in 033 failed special speed test
In relay " 10,000 test.
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Mult+ Adder Test.
1545 Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1630 Antangent started.
1700 closed down.

Relay 2145
Relay 3370

Note by Grace Hopper with moth attached.

Print Debugging

The simplest approach to debugging is to add print statements to figure out where your issue is.

Print Debugging

The simplest approach to debugging is to add print statements to figure out where your issue is.

This approach is known as `printf()` debugging (so called after the C function by the same name).

Print Debugging

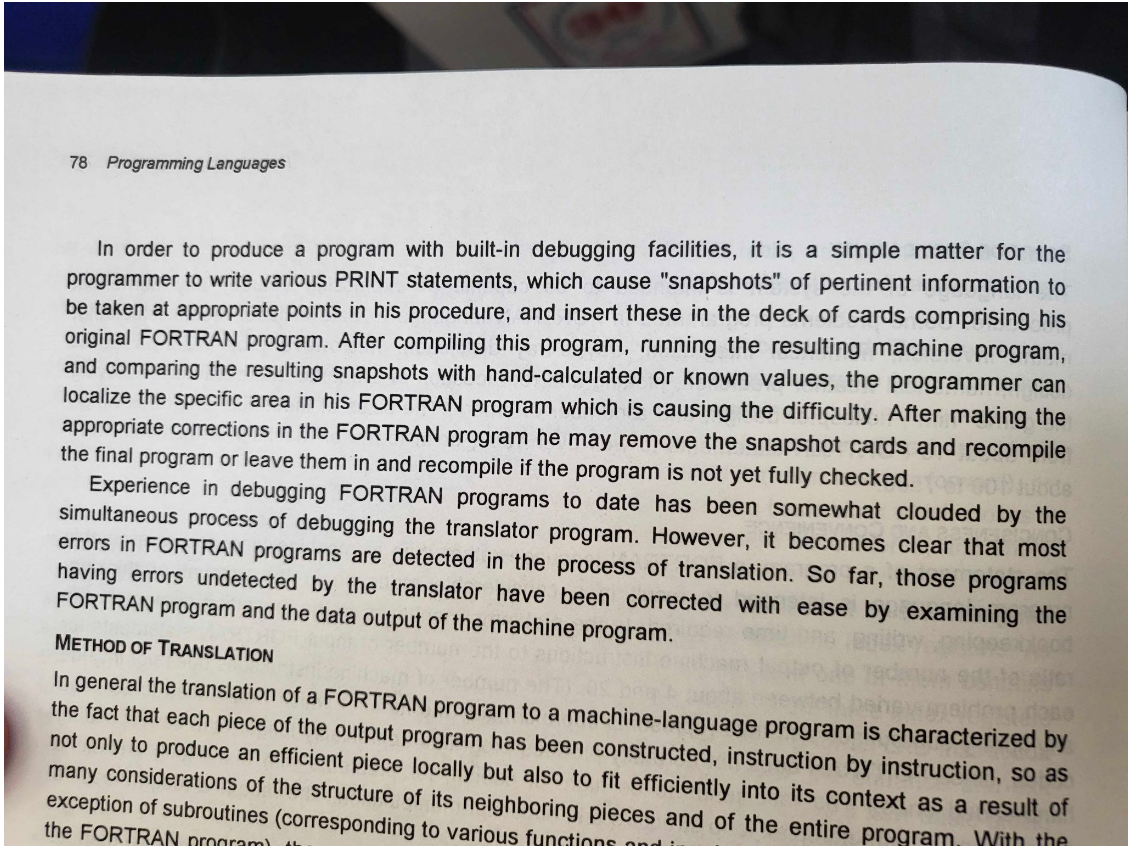
The simplest approach to debugging is to add print statements to figure out where your issue is.

This approach is known as `printf()` debugging (so called after the C function by the same name).

"The most effective debugging tool is careful thought, coupled with judiciously placed print statements."

– Brian Kernighan, *Unix for Beginners*

Print Debugging



In order to produce a program with built-in debugging facilities, it is a simple matter for the programmer to write various PRINT statements, which cause "snapshots" of pertinent information to be taken at appropriate points in his procedure, and insert these in the deck of cards comprising his original FORTRAN program. After compiling this program, running the resulting machine program, and comparing the resulting snapshots with hand-calculated or known values, the programmer can localize the specific area in his FORTRAN program which is causing the difficulty. After making the appropriate corrections in the FORTRAN program he may remove the snapshot cards and recompile the final program or leave them in and recompile if the program is not yet fully checked.

Experience in debugging FORTRAN programs to date has been somewhat clouded by the simultaneous process of debugging the translator program. However, it becomes clear that most errors in FORTRAN programs are detected in the process of translation. So far, those programs having errors undetected by the translator have been corrected with ease by examining the FORTRAN program and the data output of the machine program.

METHOD OF TRANSLATION

In general the translation of a FORTRAN program to a machine-language program is characterized by the fact that each piece of the output program has been constructed, instruction by instruction, so as not only to produce an efficient piece locally but also to fit efficiently into its context as a result of many considerations of the structure of its neighboring pieces and of the entire program. With the exception of subroutines (corresponding to various functions
the FORTRAN program)

Print Debugging

Each language has a standard printing function that can be used to print to standard output or standard error:

Python

Standard Output

```
print("Inside if-statement")
```

Standard Error

```
print("Inside if-statement", file=sys.stderr)
```

C++

Standard Output

```
std::cout << "Inside if-statement" << std::endl;
```

Standard Error

```
std::cerr << "Inside if-statement" << std::endl;
```

Print Debugging

The placement and structure of your print statements is important.

Print Debugging

The placement and structure of your print statements is important.

1. Wording matters: `“MADE IT HEEEEEERRRRREEE”` is less helpful than `“Inside else case to check if getData succeeded”`

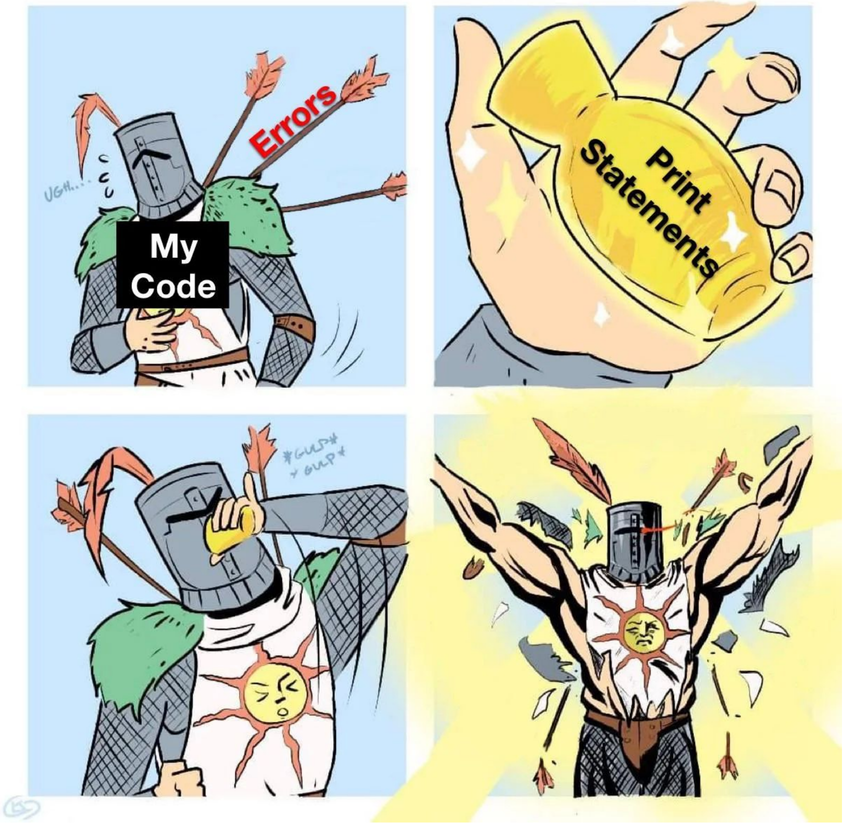
Print Debugging

The placement and structure of your print statements is important.

1. Wording matters: `“MADE IT HEEEEEERRRRREEE”` is less helpful than `“Inside else case to check if getData succeeded”`

2. Print statements are useful inside of if-else statements to see which branch of code execution is taken. They are also useful after a loop or a function call to see that the loop / function exits.

Print Debugging



Logging

A more complex version of print debugging is ***logging***. Logging is used to capture information about a system run. You can think of logging as a more structured and systematic framework to add print statements.

Logging

A more complex version of print debugging is ***logging***. Logging is used to capture information about a system run. You can think of logging as a more structured and systematic framework to add print statements.

It is used as part of industry standard for implementation of larger systems.

Logging

A more complex version of print debugging is ***logging***. Logging is used to capture information about a system run. You can think of logging as a more structured and systematic framework to add print statements.

It is used as part of industry standard for implementation of larger systems.

At a bare minimum, logging should allow you to do everything that print statements do: print messages to standard output and standard error.

Logging

Logging is normally done by designating different “levels” for each log message.

Different log levels have different levels of importance. A log message of type `ERROR` requires immediate attention while a log message of type `TRACE` might just be a “nice to have” confirmation that a given piece of code is executing.

Logging

`ERROR`	Extremely high severity, application will abort
`WARNING`	High severity, requires immediate attention
`INFO`	Moderate severity, reporting important information
`DEBUG`	Used for debugging purposes
`TRACE`	Used for tracing execution of code

Logging

Log levels allow a developer to toggle between different levels and filter based on these levels.

- A developer might only be interested in `WARNING` or `ERROR` messages for a certain run

In general, the default level of logging for production level code is `INFO`

Logging

Some languages have a built-in logging library such a Python. Others, such as C++, require you to implement a logging library.

Here is logging in Python:

```
import logging

logging.debug(“We’re debugging. Something happened!”)
logging.info(“For your info, something happened.")
logging.warning(“A warning occurred. Beware!”)
logging.error(“Something is in error. Go fix it.”)
logging.critical(“Critical condition. Go seek shelter. NOW.”)
```

Logging: Python

`CRITICAL`	Extremely high severity, application will abort
`ERROR`	High severity, requires immediate attention
`WARNING`	Moderate severity, detected an unexpected problem
`INFO`	Moderate severity, reporting important information
`DEBUG`	Used for debugging purposes

Logging: Python

By default, the logging level is set to `WARNING` which means only the last three lines will get printed:

```
import logging

logging.debug(“We’re debugging. Something happened!”)
logging.info(“For your info, something happened.)
logging.warning(“A warning occurred. Beware!”)
logging.error(“Something is in error. Go fix it.”)
logging.critical(“Critical condition. Go seek shelter. NOW.”)
```

Logging: Python

We can change the logging level to increase or decrease the number of logging messages we see:

```
import logging

logging.basicConfig(level = logging.DEBUG)

logging.debug(“We’re debugging. Something happened!”)
logging.info(“For your info, something happened.")
logging.warning(“A warning occurred. Beware!”)
logging.error(“Something is in error. Go fix it.”)
logging.critical(“Critical condition. Go seek shelter. NOW.”)
```

Logging: Python

Logging allows you to send the output to a variety of different places, not just standard output and standard error.

You can send your log messages to a file, a remote log server, a window event log, or a database.

```
import logging

logging.basicConfig(filename=‘example.log’, level=logging.DEBUG)

logging.debug(“We’re debugging. Something happened!”)
logging.info(“For your info, something happened.)
```

Advanced Logging

Let's take a look at how to implement logging in Python, including some fancy features with formatting and customization!

[Python Logging Demo]

Logging

Third party logs are useful when you use external libraries or dependencies.

- In UNIX, most programs write their logs in `/var/log`
- Example: if you have an issue where all of your apps freeze, you might find the `/var/log/system.log` file (on a Mac), the `/var/log/journal` file (on Linux), or the Event Viewer (on Windows) which will give you more information about why your apps are crashing

Debuggers

When print debugging and logging is not enough, you should use a ***debugger***. A debugger is a program that allows you to examine another program in order to detect errors in that other program.

With a debugger, you can:

- Halt execution of the program when it reaches a certain line
- Step through the program one line at a time
- Inspect values of variables after the program crashes

Debuggers

Many programming languages come with some sort of default debugger:

Python → `pdb` debugger

C/C++ → `gdb` and `lldb` are both C/C++ debuggers

Go → Delve is a GoLang debugger

Java → `jdb` is a Java debugger

In general, when choosing a debugger, you simply want to find one that is compatible with the language you are coding in.

Debuggers: pdb

Some common debugging commands:

`list` - displays some (around 11) lines of the program

`step` - execute a single line, and step into called function (if necessary)

`next` - execute a single line, do not step into called function

`print` - prints a variable or symbol

`break` - set a breakpoint

Debuggers: pdb

Let's deep dive into the `pdb` debugger!

To load a program with pdb:

```
python3 -m pdb bmi.py
```

Debuggers: pdb

Let's deep dive into the `pdb` debugger!

To load a program with pdb:

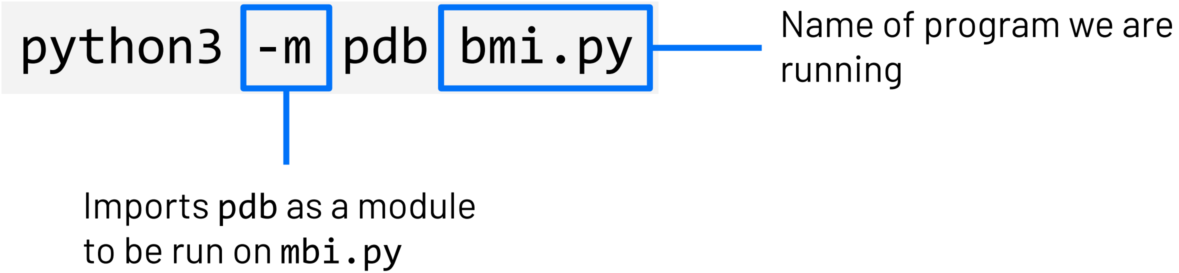
```
python3 -m pdb bmi.py
```

Imports `pdb` as a module
to be run on `mbi.py`

Debuggers: pdb

Let's deep dive into the `pdb` debugger!

To load a program with pdb:



```
python3 -m pdb bmi.py
```

Name of program we are running

Imports `pdb` as a module to be run on `mbi.py`

Let's practice!

I've uploaded a buggy program called `area_of_rectangle.py`.

```
curl -Lo area_of_rectangle.py
http://stanford-cs45.github.io/res/lec11/area_of_rectangle.py
```

Let's try to use pdb to debug it!

```
python3 -m pdb area_of_rectangle.py
```

Try adding logging statements using the `logging` library.

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

We need to compile our code:

```
g++ -std=c++11 -g -o weather_report weather_report.cc
```

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

We need to compile our code:

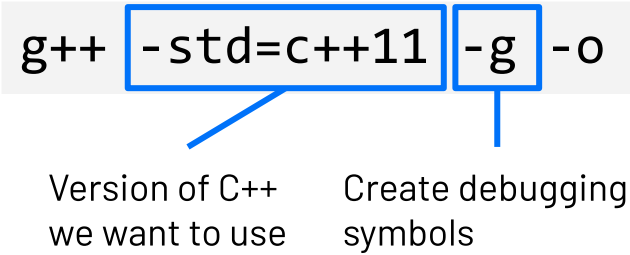
```
g++ -std=c++11 -g -o weather_report weather_report.cc
```

Version of C++
we want to use

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

We need to compile our code:



```
g++ -std=c++11 -g -o weather_report weather_report.cc
```

Version of C++
we want to use

Create debugging
symbols

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

We need to compile our code:

```
g++ -std=c++11 -g -o weather_report weather_report.cc
```

To run the program, we can use:

```
./weather_report
```

Debuggers: Life Hack (for C/C++)

Using `gdb` or `lldb` to find where your program is crashing!

We need to compile our code:

```
g++ -std=c++11 -g -o weather_report weather_report.cc
```

To run the program, we can use:

```
./weather_report
```

To run the program under lldb, we can use:

```
lldb weather_report
```

Debuggers: Life Hack (for C/C++)

Once your program is in `gdb` or `lldb`, you need to run it:

Debuggers: Life Hack (for C/C++)

Once your program is in `gdb` or `lldb`, you need to run it:

We need to compile our code:

```
(lldb) run
```

Debuggers: Life Hack (for C/C++)

Once your program is in `gdb` or `lldb`, you need to run it:

We need to compile our code:

```
(lldb) run
```

Once it crashes, you can run backtrace (or `bt`) to find where it crashed:

```
(lldb) bt
```

Web Debugging

Most modern browsers support built-in debugging tools.

> You can enter developer mode by pressing `F12` or hitting `Cmd + Option + I`
>
> You can navigate and examine the files, add breakpoints, trace execution, and add logging statements.

Compiler Errors

Compiler errors are your friends 😁

Always look at the line number and where the error occurred.

Look up compiler errors online on sites like StackOverflow. If you're running into an error, it's most likely someone else has run into that same error before.

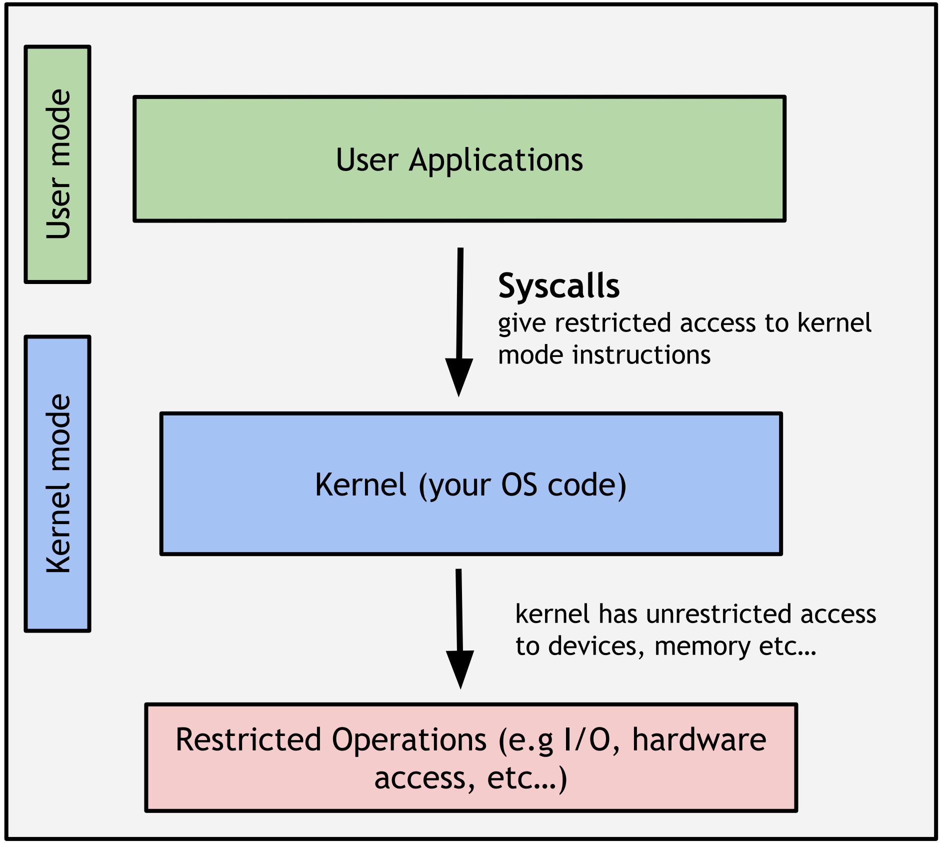
Specialized Tools

We can debug code even if we don’t have the source code. One example is debugging **system calls**

System calls are functions that are executed by the kernel (which is the computer program at the core of a computer’s operating system and generally has complete control over everything in the system).

We don’t have access to the internal implementations of system calls which means we can’t look inside to see what’s going on in the code.

Specialized Tools



Syscalls
give restricted access to kernel mode instructions

kernel has unrestricted access to devices, memory etc...

Specialized Tools

We can use a tool called **`strace`** in order to trace system calls.

> `strace` allows us to observe the execution of a system call.
>
> We don't have access to the internal implementations of system calls which means we can't look inside to see what's going on in the code.

Testing Your Code

A key part of debugging is testing your code :)

You can choose a testing framework to use in order to implement your tests.

There are also tools that will report the test coverage for your tests (check out `coverage` for Python). This is part of being a good programmer: ensuring that you commit code in small chunks and test each chunk.

Code Profiling

Profilers are good for when your code runs as expected (yay!) but is inefficient...

Profilers help you understand which parts of your program take up the most time and resources so you can focus on optimizing those parts.

"Premature optimization is the root of all evil." - Donald Knuth

Code Profiling

Profilers come in two flavors:

Tracing Profilers: keep a record of every function call your program makes.

Advantages: more accurate analysis

Disadvantages: add a lot of overhead to the program

Examples: `gprof`, VTune,

Sampling Profilers: periodically probe program to record the program's stack.

Advantages: does not disturb application at run time

Disadvantages: provides approximations

Examples: OProfile, `perf`, AMD uProf

Code Profiling

Python has a built in code profiler called `cProfile` that will allow us to identify bottlenecks.

```
python3 -m cProfile -s tottime site_scraper.py
```

Code Profiling

Sometimes we want to do line by line analysis of a specific function. Is there a single line in this function that is taking the most time?

```
kernprof -l -v site_scraper.py
```

Let's practice!

Try using `cProfile` and `line_profiler` on your `area_of_rectangle.py`

```
python3 -m cProfile area_of_rectangle.py
```

```
kernprof -l -v area_of_rectangle.py
```

Timing Your Code

If your code takes a really long time to run, this could be an indication of an issue.

Ideally, you need to figure out how much time the specific program took to run. (There are other things running on your computer that may be running in the background and slowing things down.)

Timing Your Code

`time` is a command that is used to execute a program and print a real time analysis of how long the program took to execute.

> In a zsh shell, there is a time keyword. If you want to use the time command, type: `command time <name-of-program>`

Example:

```
time ./memory_leak
```

or

```
time python3 site_scraper.py
```

Timing Your Code

The `time` command will report statistics on three different "types" of times: `real`, `user`, and `sys`:

```
adrazen$: time ./program
real    0m0.193s
user    0m0.012s
sys     0m0.056s
```

`real` is wall clock time (from start to finish)

`user` is time spent is user mode (for this program)

`sys` is time spent in kernel mode (for this program)

To get the actual CPU time your program used, add `user` + `sys`

Note that `real` will include time waiting for I/O, or time used by other processes.

Memory Access Tools

Memory access tools allow us to identify memory leaks and inefficient memory usage.

`valgrind` is a memory access and memory leak detection tool for GNU/Linux systems.

`leaks` is a similar tool for macOS systems.

Memory Access Tools

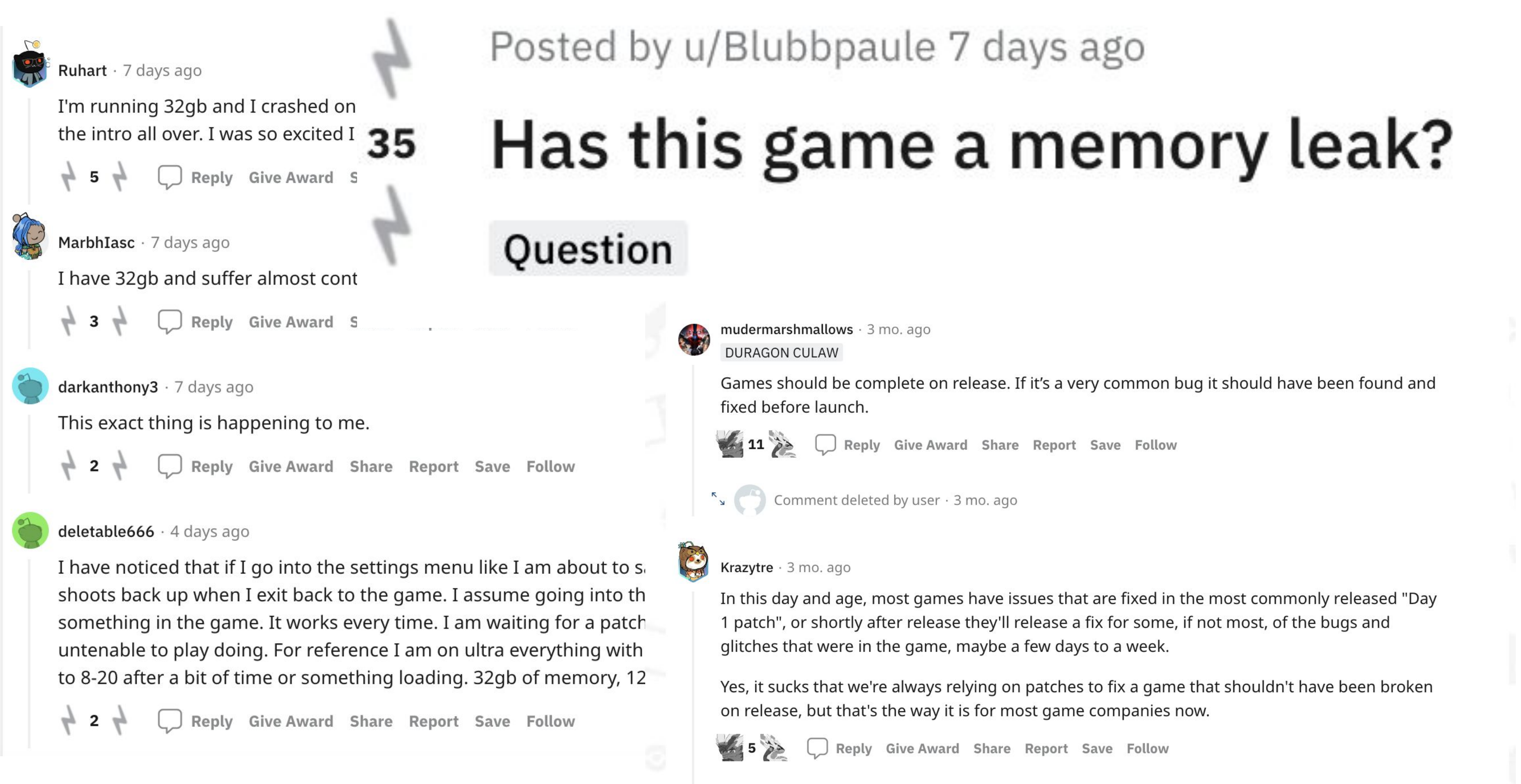
Memory access tools allow us to identify memory leaks and inefficient memory usage.

```
leaks --atExit -- ./YOUR_PROGRAM_NAME
```

```
valgrind --leak-check=yes YOUR_PROGRAM_NAME
```

Memory Access Tools

Memory Access Tools



35

Posted by u/Blubbpaule 7 days ago

Has this game a memory leak?

Question

Ruhart · 7 days ago

I'm running 32gb and I crashed on the intro all over. I was so excited I

MarbhIasc · 7 days ago

I have 32gb and suffer almost cont

darkanthony3 · 7 days ago

This exact thing is happening to me.

deletable666 · 4 days ago

I have noticed that if I go into the settings menu like I am about to s shoots back up when I exit back to the game. I assume going into th something in the game. It works every time. I am waiting for a patch untenable to play doing. For reference I am on ultra everything with to 8-20 after a bit of time or something loading. 32gb of memory, 12

mudermarshmallows · 3 mo. ago

DURAGON CULAW

Games should be complete on release. If it’s a very common bug it should have been found and fixed before launch.

Comment deleted by user · 3 mo. ago

Krazytre · 3 mo. ago

In this day and age, most games have issues that are fixed in the most commonly released "Day 1 patch", or shortly after release they'll release a fix for some, if not most, of the bugs and glitches that were in the game, maybe a few days to a week.

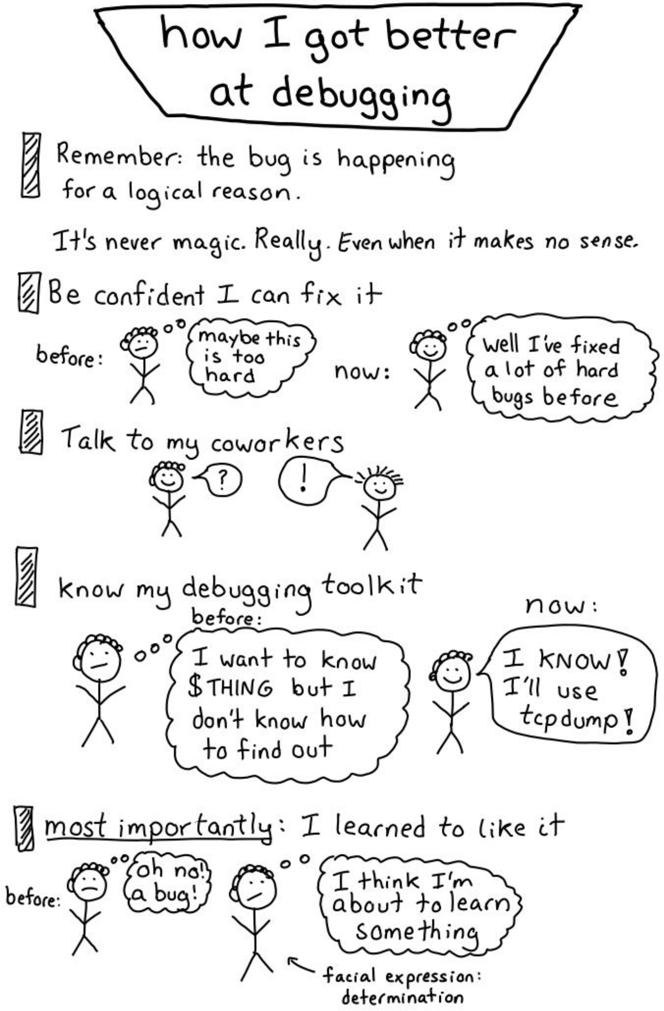
Yes, it sucks that we're always relying on patches to fix a game that shouldn't have been broken on release, but that's the way it is for most game companies now.

Linters, Static Analyzers and More

There are many, **many, *MANY*** more tools you can use to analyze and clean up your code!

There are even ones to correct your spelling (`writegood`).

Reach out to us if you are interested in learning more about any of these.



how I got better at debugging

- Remember: the bug is happening for a logical reason.

It's never magic. Really. Even when it makes no sense.

- Be confident I can fix it

before:
maybe this is too hard
now:
Well I've fixed a lot of hard bugs before

- Talk to my coworkers

- know my debugging toolkit

before:
I want to know $THING but I don't know how to find out
now:
I KNOW! I'll use tcpdump!

- most importantly: I learned to like it

before:
oh no! a bug!
I think I'm about to learn something
facial expression: determination

Credits: Julia Evans