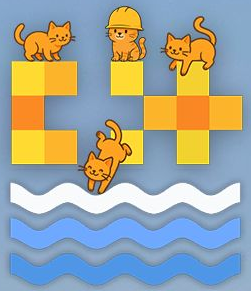
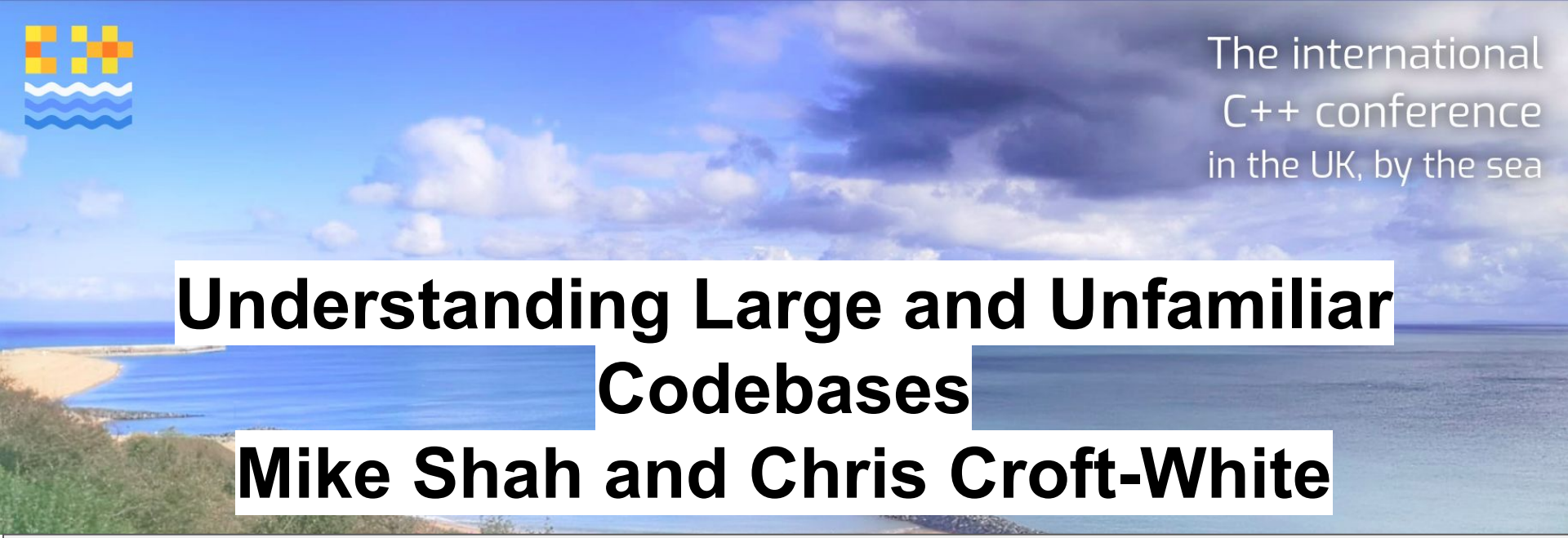


Understanding Large and Unfamiliar Codebases

Mike Shah &
Chris Croft-White

2025



Understanding Large and Unfamiliar Codebases

Mike Shah and Chris Croft-White

Chris Croft-White
Staff Solutions Architect
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Web: mshah.io
YouTube www.youtube.com/c/MikeShah
Social: mikeshah.bsky.social
Courses: courses.mshah.io
Talks: http://tinyurl.com/mike-talks

60 minutes | Intermediate Audience
09:15 - 10:15 Tuesday, June 24, 2025

Abstract (Which you already read :))

Talk Abstract: It's your first day on the job as a new employee. You set up your workstation and then download a repository of over 1,000,000 lines of code. Even more intimidating, the code has been around for 20 years and has parts of it in legacy C++ and also using tentative C++ 26 features from various libraries. You feel overwhelmed! Don't fret however! In this talk, I provide you a collection of tools to help software engineers of all levels understand what is going on in large unfamiliar codebases. The audience will leave this talk with a few simple and advanced tricks for navigating large and complicated codebases.

https://cpponsea.uk/2025/session/understanding-large-and-unfamiliar-codebases

Your Tour Guide(s) for Today

Chris Croft-White

- **Current Role:** Staff Solutions Architect at Undo.io (5 years)
  - Supporting new customers and creating content to help people debug software
  - Background: ~20 years a pre-sales engineer
- **Available for:**
  - **Time Travel Debugging,** happy to explain the technology, its uses, and get you started
  - **Sleep,** it's dreadfully lacking and top of the list if I ever get any of this spare time I keep hearing about
- **Fun:**
  - Computer games, travelling, food & drink, learning cool new technologies, meeting new people.

Your Tour Guide(s) for Today

Mike Shah

- **Current Role:** Teaching Faculty at **Yale University** (Previously Teaching Faculty at Northeastern University)
  - **Teach/Research**: computer systems, graphics, geometry, game engine development, and software engineering.
- **Available for:**
  - **Contract work** in Gaming/Graphics Domains
    - e.g. tool building, plugins, code review
  - **Technical training** (virtual or onsite) in Modern C++, D, and topics in Performance or Graphics APIs
- **Fun**:
  - Guitar, running/weights, traveling, video games, and cooking are fun to talk to me about!

Web
www.mshah.io
YouTube
https://www.youtube.com/c/MikeShah
Non-Academic Courses
courses.mshah.io
Conference Talks
http://tinyurl.com/mike-talks

Question to the Audience:

What's the biggest codebase you have ever worked on?

(i.e. the approximate lines of code)

M

What's the biggest codebase you have every worked on? (2/3)

Follow-up question(s):

1. Did that codebase ever get smaller?
2. Did that codebase become less complex over time?
3. How well was that codebase documented?
    a. i.e. Could I go find tutorials, internal wiki pages, or internal/external videos explaining the code or architecture?
4. Did anyone say "Scrap the project -- let's rebuild it from scratch"?

What's the biggest codebase you have every worked on? (3/3)

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    a. i.e. Could I go find tutorials, internal wiki pages, or internal/external videos explaining the code or architecture?
4. Did anyone say "Scrap the project -- let's rebuild it from scratch"?
    a. ^Sometimes we feel this way -- but it can be hard to convince a business to throw away thousands/millions of lines of code :)

How Big are Codebases (1/2)

- Today we are talking about **large** and **unfamiliar** codebases
- I think we have an idea of what this means, but the scale I'm interested in is anything from tens of thousands of lines, to billions of lines of code (e.g. monorepo)
  - i.e. Big enough you cannot keep the whole design in your head
- Note:
  - The figure on the right gives a very *rough* approximation of various codebases.

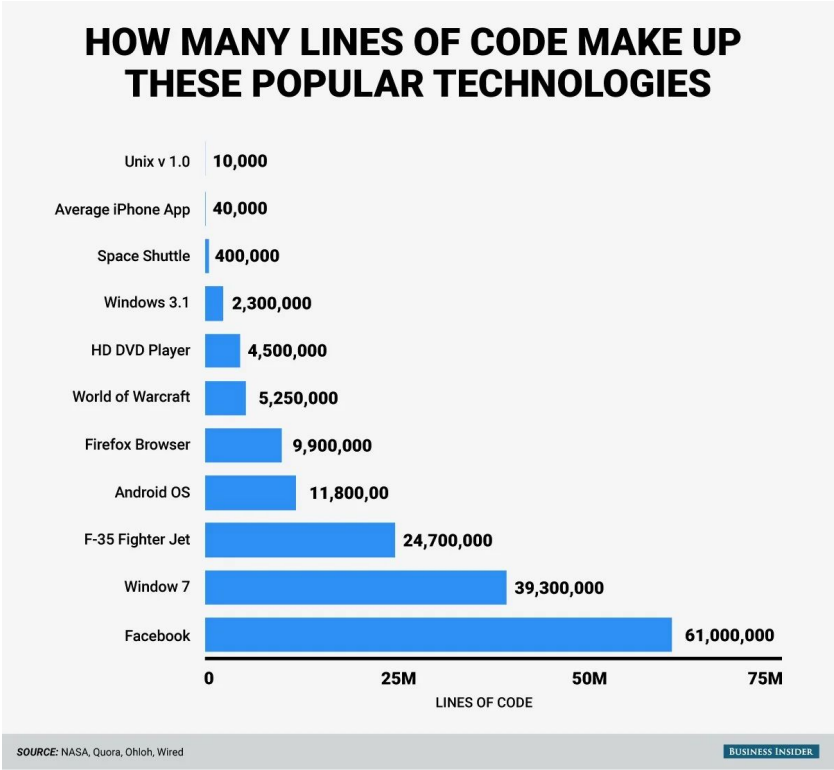


Figure source:
https://external-preview.redd.it/RP36x-Dy-3iZn_CEMh_mEfs7GlqvhjKlasyWAQk2v_M.jpg?auto=webp&s=b6177113412f10a5c9a2672738736d4e8647883d
Wired Article for more on code sizes: https://www.wired.com/2015/09/google-2-billion-lines-codeand-one-place/

How Big are Codebases (2/2)

- For a reference of scale --
  - “***A million lines of code***, *if printed, would be* ***about 18,000 pages of text***. *That’s* ***14x the length of War and Peace.***”
    - https://www.visualcapitalist.com/millions-lines-of-code/
- That’s a lot of ‘text’, architecture, subsystems, etc. to keep in our head!

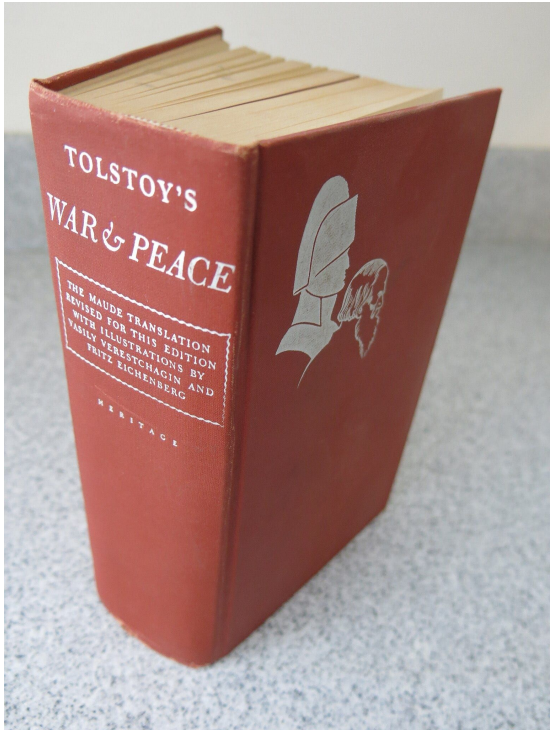


Figure source: https://substackcdn.com/image/fetch/f_auto,q_auto:good,fl_progressive:steep/https%3A%2F%2Fsubstack-post-media.s3.amazonaws.com%2Fpublic%2Fimages%2Fd6b32b94-f99e-498f-840b-4cf789c6503c_1536x2048.jpeg

Question to the Audience:

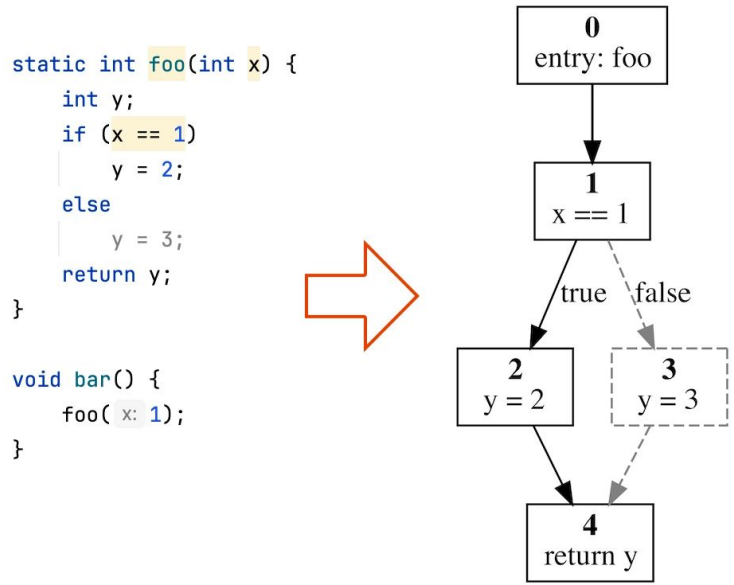
What makes a codebase hard to understand?

C

What makes a codebase hard to understand? (1/3)

- **Understanding the logical control flow** (and/or data flow)
  - Where are the entry points?
  - Are there threads / fibers / coroutines
  - What are the ‘hot spots’ and important subsystems
  - Where does ‘state’ change in the program
  - What is a specific function doing?
    - Is the name of the function reflective of what it does?
    - Are the parameters named well and consistent?

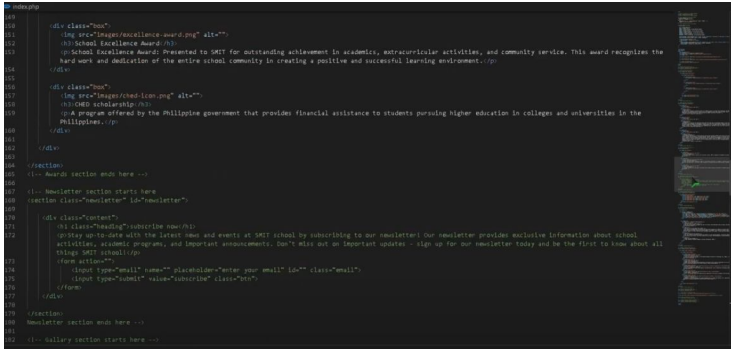
```
static int foo(int x) {
    int y;
    if (x == 1)
        y = 2;
    else
        y = 3;
    return y;
}

void bar() {
    foo( x: 1);
}
```

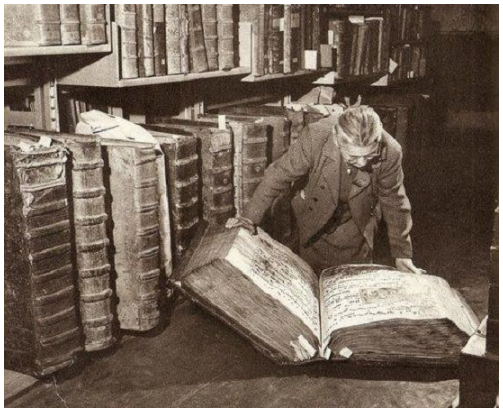


To the right is a visualization of a ‘Data Flow Analysis’. This is useful once you know the isolated fragment(s) of code you want to look at (but this visualization technique otherwise does not work on the entire codebase). https://blog.jetbrains.com/clion/2023/11/striving-for-better-cpp-code-part-i-data-flow-analysis-basics/

What makes a codebase hard to understand? (2/3)

- The **pure scale** of software and its relation to complexity
  - i.e. The number of lines of source code
- Different variations of code
  - e.g. Legacy C++ mixed with C++26
  - Different ‘design patterns’ or architecture design within the source code

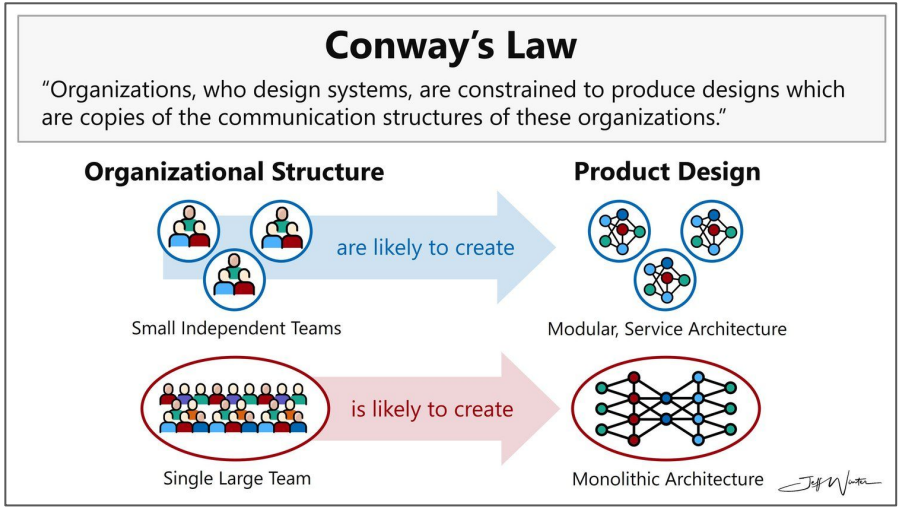




‘source code’ we visualize as text -- printing out the code will look something like the bottom-right image.

What makes a codebase hard to understand? (3/3)

- **Human factors** can additionally contribute to making your life harder
  - Team size / structure
  - Accessibility to code that you may not own.
    - (Is all the code in the same repo, or do you need permission to view other libraries?)
  - No version history or documentation of the ‘why’ something evolved
  - Undocumented code that only a ‘senior engineer’ understands, and everyone is afraid to touch.



Every heard of Conway’s law? Organizational structure can potentially impact the very structure of code itself!

https://www.jeffwinterinsights.com/insights/conways-law-enterprise-architecture

Question to the Audience:

Why do folks think I’m talking about this topic?

M

Why do folks think I'm talking about this topic? (2/3)

- **Answer:** It was an honest difficulty of mine when I started out as a software engineer!

- (more on next slide)

Ah, I have found memories of TortoiseSVN -- it's still active as far as I know!

https://preview.redd.it/whatdididone-v0-tv7l0uo8hdyc1.jpeg?width=320&crop=smart&auto=webp&s=5d56747737e31e0cf8ba5caa6cebfbfebb9f173e

Why do folks think I'm talking about this topic? (3/3)

- **Answer:** It was an honest difficulty of mine when I started out as a software engineer!

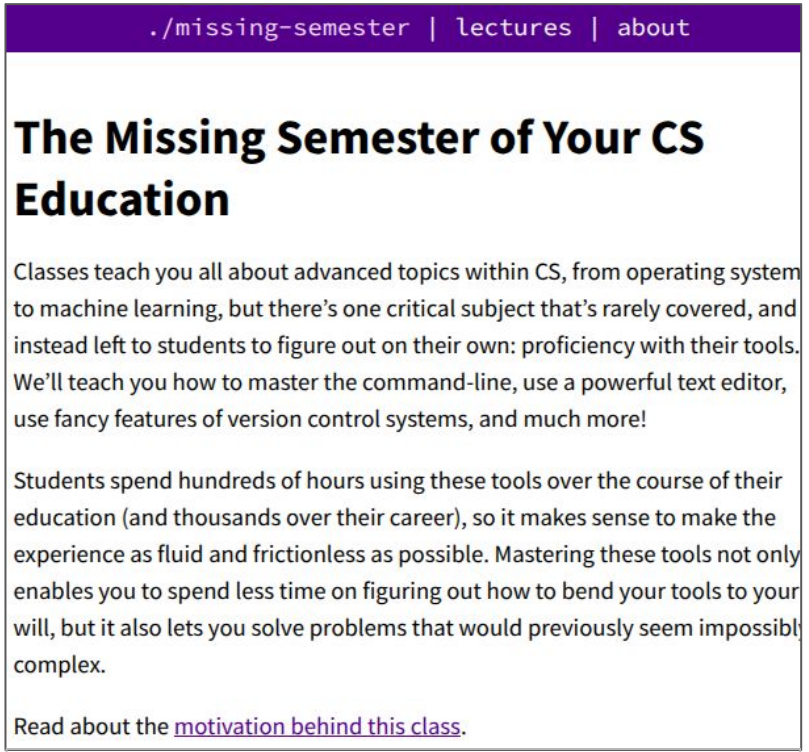
- I remember the difficulty and overwhelming feeling as an intern learning new tools & code!
  - (On occasion I consult on short contracts -- so this is still relevant today!)
  - I suspect there are others in the audience who remember this daunting feeling too
- It probably feels a bit embarrassing to admit that feeling on the first day of work!
  - We should not be afraid to ask questions however!

Ah, I have found memories of TortoiseSVN -- it's still active as far as I know!

https://preview.redd.it/whatdididone-v0-tv7l0uo8hdyc1.jpeg?width=320&crop=smart&auto=webp&s=5d56747737e31e0cf8ba5caa6cebfbfebb9f173e

Where do we learn to read code?

- The other reason is that we are are not always taught many tools or how to read large codebases in school or our workplace
  - **Let me be clear -- I'm not necessarily blaming schools** -- there is a lot of computer science to cover.
    - Some large projects in school are maybe 2-5k lines of code -- but again not quite the scale we are talking about for millions of lines of code
  - **Note:** I (and many other professors) do often expose students to large codebases at various points -- probably some professors out their doing an excellent job as well!



MIT, Tufts, Yale, UMich, etc. have various courses in this spirit for helping students learn tools that I know of.
https://missing.csail.mit.edu/

Understanding Large and Unfamiliar Codebases

- Now from this talks title, the word ‘understanding’ is important
- We might also mean:
  - The **performance** of some aspect
  - The **memory safety** or **security** of a system
  - Or really any other metric about a piece of software.
- That said -- today we are going to focus more on understanding **-- what our code is *logically* doing -- and what tools can help!**

Today we'll focus on these 3 categories

1. **Understanding the control flow**
2. The **pure scale** of software and its relation to complexity
3. **Human factors** can additionally contribute to making your life harder

Given:

An unknown (open-source) codebase

C

Real World Example: Transport Tycoon (1/2)

- Today I'll give be giving some tips on understanding larger source code projects.
- We will look at the **video game -- Transport Tycoon**
  - Some of you may be familiar with it, and it is perhaps better if you are not!
  - (Although, I will say it's a wonderfully charming game...)

Real World Example: Transport Tycoon (2/2)

- If you are following along at home, you can follow along by picking Transport Tycoon (https://www.openttd.org/) or a similar project.
- A good candidate project to practice with is:
  - Open Source
  - Many collaborators, perhaps of different levels of seniority/experience
  - Long-lived, and lots of lines of code!
  - Ideally with some ‘git’ history, but not strictly necessary (i.e. may be fun to practice applying patches, fixing bugs, etc.)
  - And again -- perhaps even better if you’re not 100% familiar with the project
    - (but perhaps have some domain experience or interest in the domain)

Project Scale

- The **‘cloc’** tool will count the lines of code in a project
  - This may give some insights as well if there are multiple languages used
- Our stats for the Open Transport Tycoon game for example are:
  - 188,428 C++
  - 123,108 C/C++ headers
  - 670 lines of C
  - etc.
- Let’s agree this is a large size codebase to investigate!

```
mike@mike-MS-7B17:openttd-14.1$ cloc .
    3138 text files.
    2402 unique files.
    1371 files ignored.

github.com/AlDanial/cloc v 1.98  T=1.86 s (1293.4 files/s, 534526.5 lines/s)
-------------------------------------------------------------------------------
Language                     files          blank        comment           code
-------------------------------------------------------------------------------
Text                            86          53266              0         308781
C++                            499          40695          47958         188428
C/C++ Header                   768          23071          41636         123108
D                              477              0              0          93912
make                            59           6122           4985          16050
CMake                          304           1380           1520          11791
INI                             21            614            149           5023
JSON                             5              1              0           3140
HTML                             5            278              1           3106
Squirrel                        33            364            238           3050
Markdown                        26            966             32           3011
YAML                            25            480            117           2819
Objective-C++                    4            499            432           1742
SVG                              2              1              2           1353
C                                1            149             61            670
awk                              1             41             32            217
XML                              4              3             12            199
diff                             2              3             31            174
Python                           2             68             55            168
TypeScript                      61              0              0            122
PowerShell                       5             34             27            113
JavaScript                       1             16             24             86
Tcl/Tk                           1             22             32             52
Bourne Shell                     3             17             32             41
reStructuredText                 1              5              0             22
DOS Batch                        5              4              0             18
Dockerfile                       1              1              0              3
-------------------------------------------------------------------------------
SUM:                          2402         128100          97376         767199
-------------------------------------------------------------------------------
mike@mike-MS-7B17:openttd-14.1$
```

1. **Understanding the control flow**
2. The **pure scale** of software and its relation to complexity
3. **Human factors** can additionally contribute to making your life harder

M

Understanding Control Flow: **Run our program!**

- The **very first thing to do**, is run whatever game/application/service/system/etc you are building
  - This sounds silly and is obvious, but you should have a high level understanding of what your program actually does is key.
- **I will assume** that you can build the software using whatever build system you are provided.
  - And I fully acknowledge, this it is not often trivial to build!

Understanding Control Flow: Entry Points (1/3)

- One of the first things I like to do -- is to anchor around the ‘`main()`’ function
- From the `main()` function, you will often get hints as to the overall software architecture
  - (i.e. are there plugins loaded, is there an event loop, etc.)
  - Some things you can actively log are:
    - What happens before main (any initialization code)
    - What happens after (cleanup code)

```
21 int CDECL main(int argc, char *argv[])
22 {
23   /* Make sure our arguments contain only valid UTF-8 characters. */
24   for (int i = 0; i < argc; i++) StrMakeValidInPlace(argv[i]);
25
26   CrashLog::InitialiseCrashLog();
27
28   SetRandomSeed(time(nullptr));
29
30   signal(SIGPIPE, SIG_IGN);
31
32   return openttd_main(argc, argv);
33 }
```

In my opinion, a good software engineering practice is to keep your ‘main’ relatively clean. Observe here, the main entry point returns to the ‘real main (openttd_main)’

In this particular software, you’ll observe there are also different ‘main’ functions per operating system.

Understanding Control Flow: Entry Points (2/3)

- Here's an example of finding '`main()`' with **grep**
- grep is a tool for searching for patterns within files
  - e.g.
    - `grep -irn "main"`
    - This does a case insensitive(i) search, recursively through the directory (r), and provides line numbers (n) with the filenames
  - This gives us around **37 places to look**

```
mike@mike-MS-7B17:openttd-14.1$ grep -irn "main()" .
grep: ./build/openttd: binary file matches
grep: ./build/openttd_test: binary file matches
./build/CMakeFiles/_CMakeLTOTest-CXX/src/main.cpp:3:int main()
./build/CMakeFiles/3.28.3/CompilerIdC/CMakeCCompilerId.c:848:void main() {}
grep: ./build/CMakeFiles/openttd_lib.dir/src/video/opengl.cpp.o: binary file matches
./os/emscripten/cmake/FindLibLZMA.cmake:8:    int main() { return 0; }"
./.github/unused-strings.py:184:def main():
./.github/unused-strings.py:220:    main()
./.github/script-missing-mode-enforcement.py:53:def main():
./.github/script-missing-mode-enforcement.py:71:    main()
./src/table/opengl_shader.h:17: "void main() {",
./src/table/opengl_shader.h:32: "void main() {",
./src/table/opengl_shader.h:45: "void main() {",
./src/table/opengl_shader.h:56: "void main() {",
./src/table/opengl_shader.h:67: "void main() {",
./src/table/opengl_shader.h:80: "void main() {",
./src/table/opengl_shader.h:115:        "void main() {",
./src/table/opengl_shader.h:138:        "void main() {",
./src/table/opengl_shader.h:164:        "void main() {",
./src/table/opengl_shader.h:191:        "void main() {",
./src/os/macosx/macos.mm:211: * These are called from main() to prevent a _NSAutoreleaseNoPool error when
./src/openttd.cpp:123:   * openttd_main() is never executed. */
```

Understanding Control Flow: Entry Points (3/3)

- **grep** is quite powerful, so you will want to spend some time playing with it
- Here's a more specific search that gives us around 7 **places to look**
  - `grep -irn -I --include=*.cpp "main()" .`
    - `-I` tells us to ignore binary files
    - `--include=*.cpp` tells us to look at .cpp files

```
mike@mike-MS-7B17:openttd-14.1$ grep -irn -I --include=*.cpp "main()" .
./build/CMakeFiles/_CMakeLTOTest-CXX/src/main.cpp:3:int main()
./src/openttd.cpp:123:    * openttd_main() is never executed. */
./src/landscape.cpp:1322:        finder.Main();
./src/video/sdl2_v.cpp:623:                * openttd_main() is never executed. */
./src/3rdparty/md5/md5.cpp:46:  2002-03-11 lpd Corrected argument list for main(), and added int return
./src/pathfinder/npf/aystar.cpp:245:int AyStar::Main()
./src/pathfinder/npf/npf.cpp:1044:      [[maybe_unused]] int r = _npf_aystar.Main();
```

Pro Tip: Debug Symbols (1/2)

- grep is going to be quite useful, but it can sometimes be a ‘treasure hunt’ if we do not know what we’re looking for
- **Remember -- we can simply run our program**
  - **And you did compile with debug symbols** (i.e. ‘-g’) **right?**

A nice write up on Debug information is here:

- https://developers.redhat.com/articles/2022/01/10/gdb-developers-gnu-debugger-tutorial-part-2-all-about-debuginfo
- https://undo.io/resources/guide-to-symbols-debug-info/

Note: If you’re in a live system, you can ‘gdb -ex 'attach $PID' app.debug’ add debug info as well -- but let’s assume we have our debugging symbols in order!

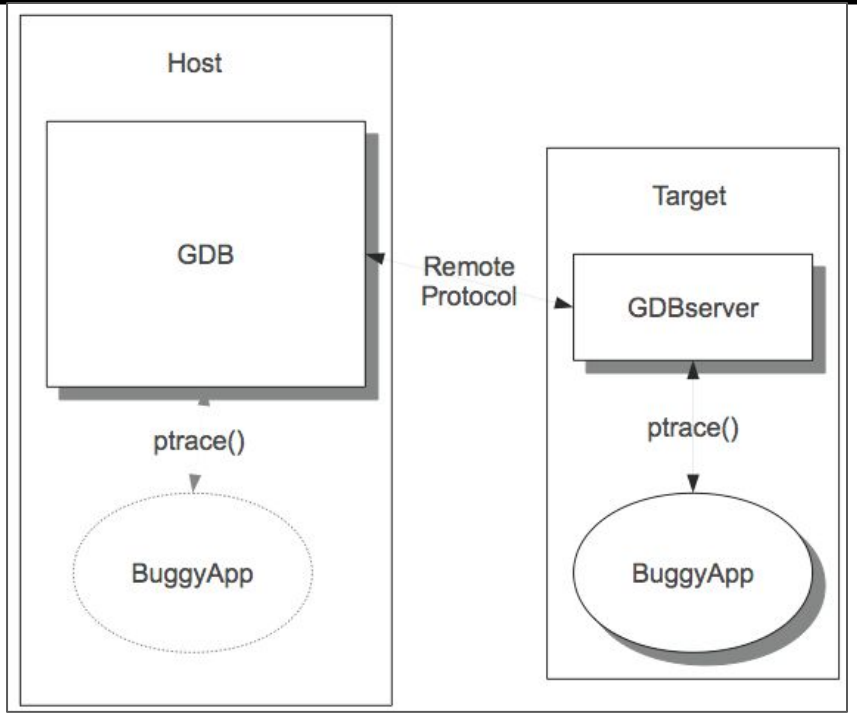
Pro Tip: Debug Symbols (2/2)

- **Note:** A **key** that will make your life easier
  - **Build/Compile with debug information!**
    - `cmake -DCMAKE_BUILD_TYPE=Debug ..`
  - In some instances, this may also include making sure to build 3rd party libraries in debug as well
- **Debug information** is useful for helping you inspect and gather more information about your programs execution with the tools we will use

A nice write up on Debug information is here: https://developers.redhat.com/articles/2022/01/10/gdb-developers-gnu-debugger-tutorial-part-2-all-about-debuginfo
Note: If you're in a live system, you can 'gdb -ex 'attach $PID' app.debug' add debug info as well -- but let's assume we have our debugging symbols in order!

Step-by-Step debugging (1/3)

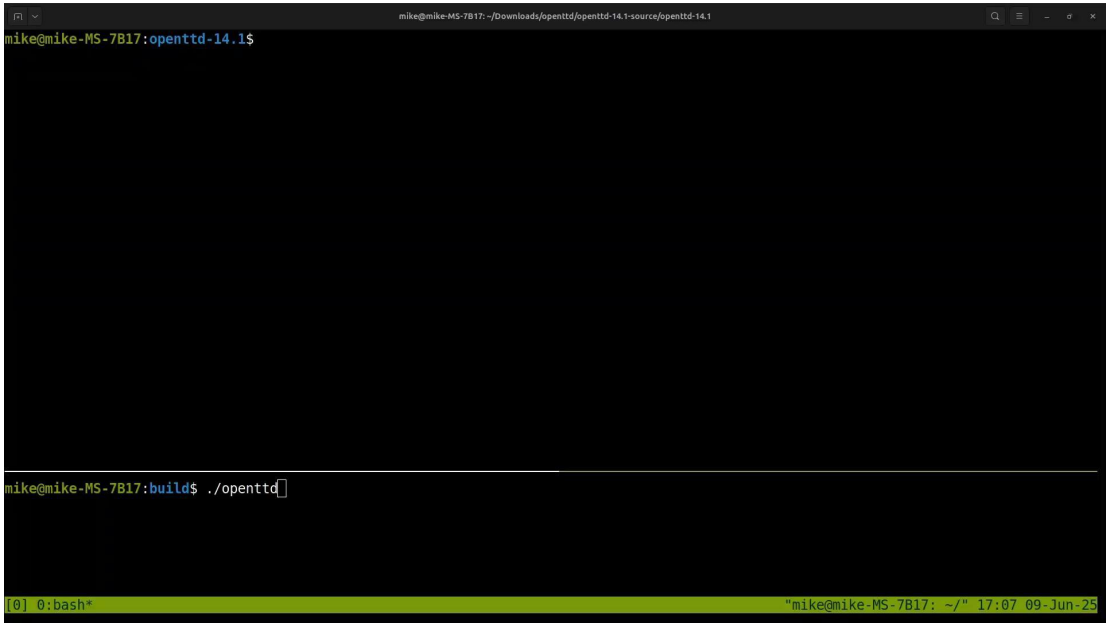
- So now we have a ‘large unfamiliar codebase’ that we have compiled in ‘debug’
- So we can use a ‘debugger’ to step through the execution
  - **And of course** use a ‘debug build’ of the source.
- **Let’s repeat our first task of finding `main()` that we did with ‘grep’, but this time with a debugger**



You can learn more about how debuggers work here: https://aosabook.org/en/v2/gdb.html

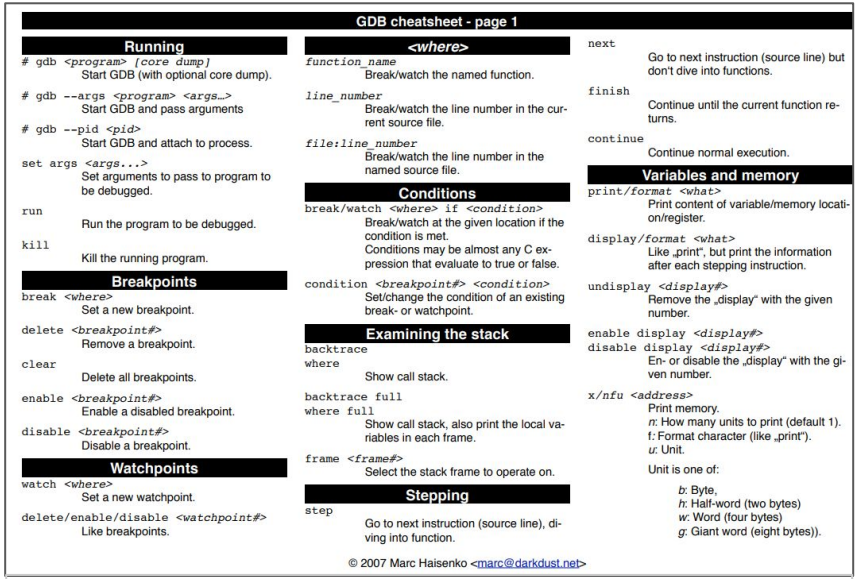
Step-by-Step debugging (2/3)

- GDB is a good free debugger to start with
- In this video, I attach a debugger to a running process
  - ps aux | grep ‘openttd’
    - This gives me the name
  - Then I attach to the running process
    - sudo gdb -p *pid*
- **next slide for more!**



Step-by-Step debugging (3/3)

- Once you have the ‘`main()`’ function, you can start stepping through the code.
- Some important commands in GDB
  - **Ctrl+C** // Pause running program
  - **br** *main()* // breakpoint in main
  - **c** // continue
  - **s** // to step into a function
  - **n** // next line
  - **f** // finish the stack frame
    - Useful if you’re in library code you do not own
  - **bt** // print out the backtrace
  - **kill** // to exit the process, but stay in GDB



GDB cheatsheet - page 1

Running

`# gdb <program> [core dump]`
Start GDB (with optional core dump).

`# gdb --args <program> <args…>`
Start GDB and pass arguments

`# gdb --pid <pid>`
Start GDB and attach to process.

`set args <args...>`
Set arguments to pass to program to be debugged.

`run`
Run the program to be debugged.

`kill`
Kill the running program.

Breakpoints

`break <where>`
Set a new breakpoint.

`delete <breakpoint#>`
Remove a breakpoint.

`clear`
Delete all breakpoints.

`enable <breakpoint#>`
Enable a disabled breakpoint.

`disable <breakpoint#>`
Disable a breakpoint.

Watchpoints

`watch <where>`
Set a new watchpoint.

`delete/enable/disable <watchpoint#>`
Like breakpoints.

<where>

function_name
Break/watch the named function.

line_number
Break/watch the line number in the current source file.

file:line_number
Break/watch the line number in the named source file.

Conditions

`break/watch <where> if <condition>`
Break/watch at the given location if the condition is met.
Conditions may be almost any C expression that evaluate to true or false.

`condition <breakpoint#> <condition>`
Set/change the condition of an existing break- or watchpoint.

Examining the stack

`backtrace`
`where`
Show call stack.

`backtrace full`
`where full`
Show call stack, also print the local variables in each frame.

`frame <frame#>`
Select the stack frame to operate on.

Stepping

`step`
Go to next instruction (source line), diving into function.

`next`
Go to next instruction (source line) but don't dive into functions.

`finish`
Continue until the current function returns.

`continue`
Continue normal execution.

Variables and memory

`print/format <what>`
Print content of variable/memory location/register.

`display/format <what>`
Like „print“, but print the information after each stepping instruction.

`undisplay <display#>`
Remove the „display“ with the given number.

`enable display <display#>`
`disable display <display#>`
En- or disable the „display“ with the given number.

`x/nfu <address>`
Print memory.
n: How many units to print (default 1).
f: Format character (like „print“).
u: Unit.

Unit is one of:

b: Byte,
h: Half-word (two bytes)
w: Word (four bytes)
g: Giant word (eight bytes)).

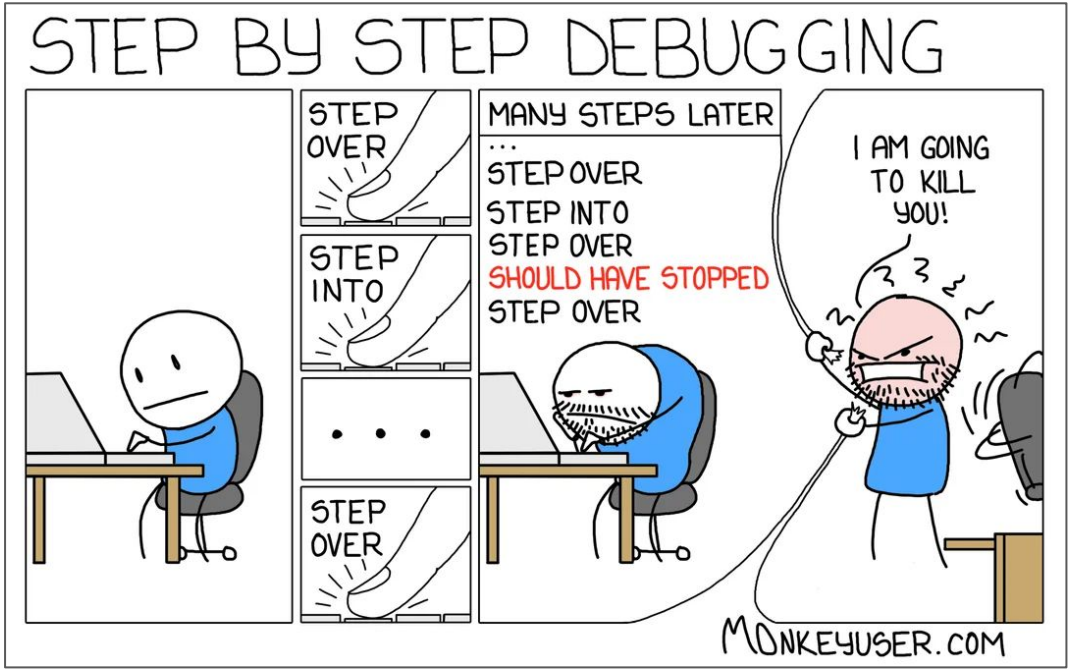
GDB Cheat sheet (page 1 of 2)
https://darkdust.net/files/GDB%20Cheat%20Sheet.pdf

Step-by-Step: Backwards (i.e. Time Travel)

C

Reverse debugging (1/5)

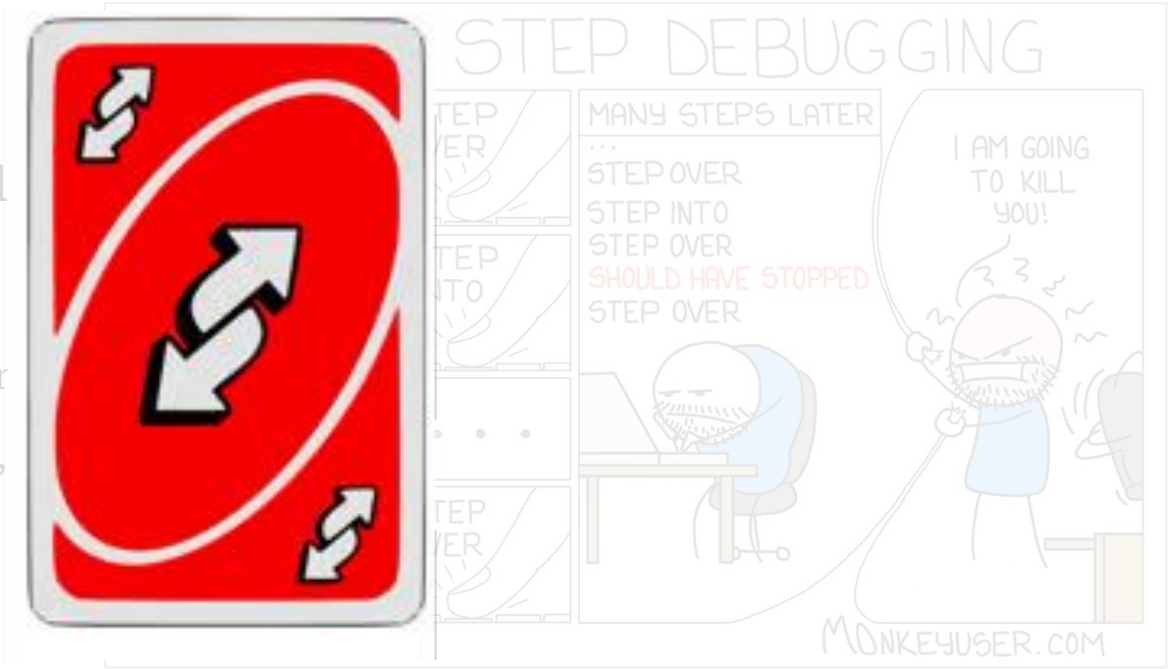
- Just a brief aside on debuggers
- At some point you will probably have this experience.
  - So it's worth mentioning 'reverse-debuggers' or 'time travel debuggers' to you :)



https://preview.redd.it/e4b0jejmlxxz.png?width=1080&crop=smart&auto=webp&s=5b03b0d54dbe429bace5820da37a2345682eaada

Reverse debugging (2/5)

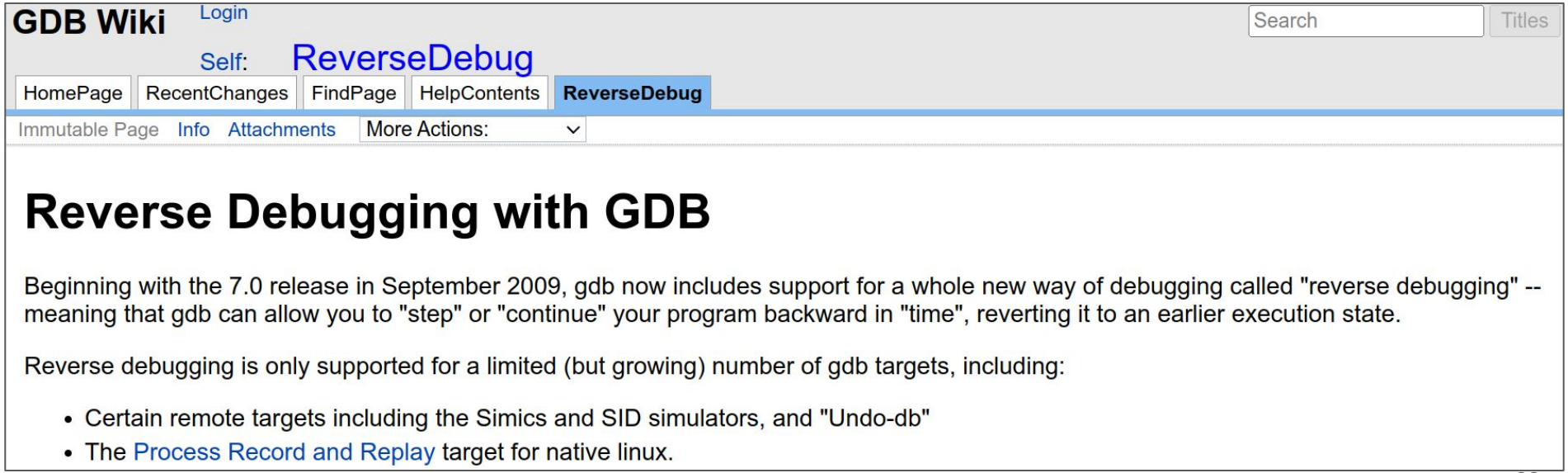
- Just a brief aside on debuggers
- At some point you wil probably have this experience.
  - So it's worth mentionir 'reverse-debuggers' or 'time travel debuggers' you :)



https://preview.redd.it/e4b0jejmlxxz.png?width=1080&crop=smart&auto=webp&s=5b03b0d54dbe429bace5820da37a2345682eaada

Reverse debugging (3/5)

- Reverse debuggers (since GDB 7.0) allow you to ‘reverse-step’ or ‘reverse-next’ where you are.
- This is very useful during your code exploration!

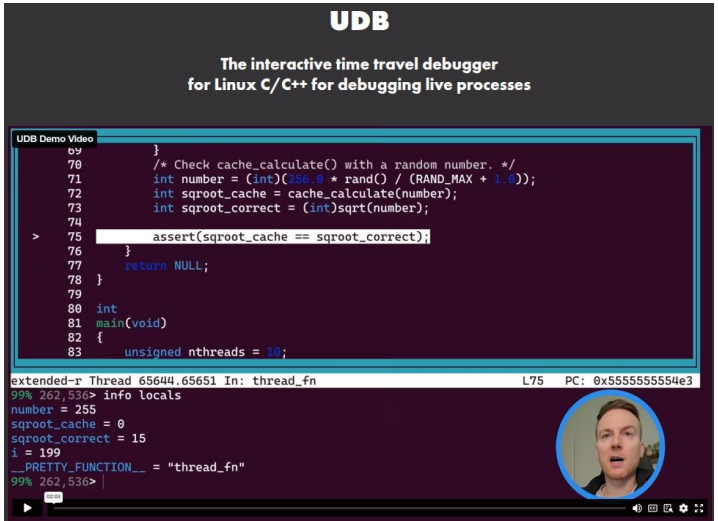


https://sourceware.org/gdb/wiki/ReverseDebug

Reverse debugging (4/5

QR code to UDB trial

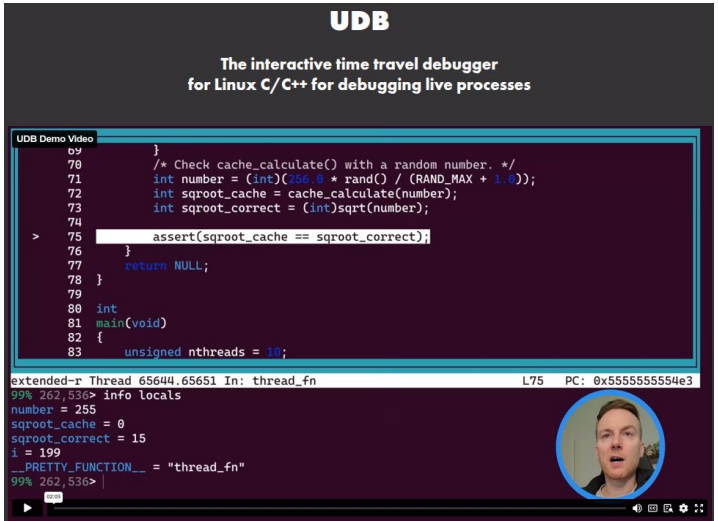
- UDB from Undo is another invaluable tool I'll demonstrate shortly.
- UDB effectively uses the same GDB commands -- so if you know one, you know both!
- More information
  - Performance Differences between UDB and GDB [link]
  - If you can't use a reversible debugger? , then click this link for the GDB equivalents to try



Reverse debugging (5/5

QR code to UDB trial

- I'll give you a minute to scan the QR code, or otherwise you may consider visiting this link
  - https://undo.io/udb-free-trial/
- Okay -- so let's see how reverse debugging can help us

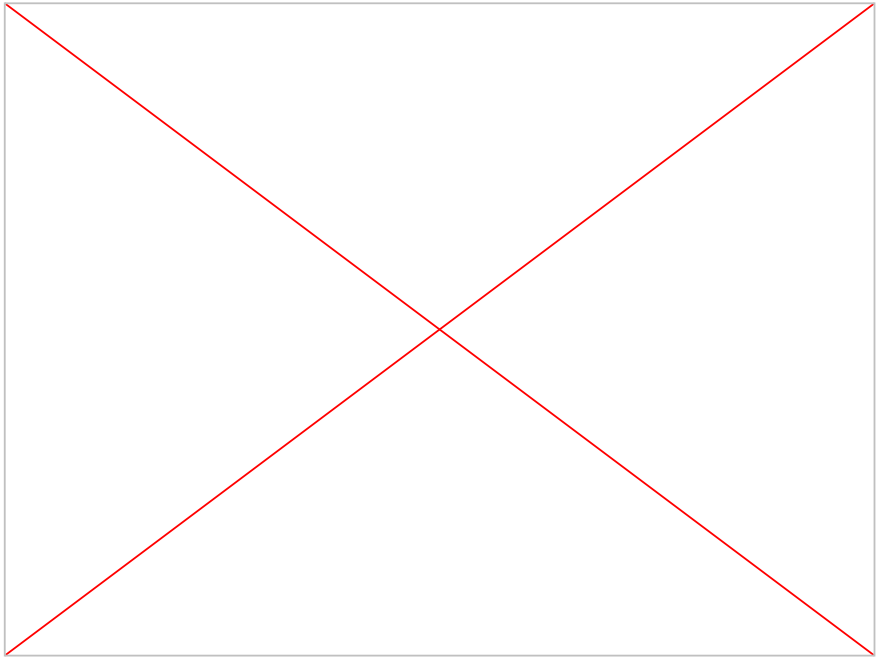


Reverse debugging (UDB) (1/3)

- The UDB Suite of tools is quite powerful -- so I will show a sample of ‘recording’ and then traversing that recording
- **First- capture the recording**
  - `~/Downloads/Undo-Suite-x86-8.3.0/live-record --record-on symbol:_Z12PostMainLoopv ./build/openttd`
  - A few neat things
    - You can trigger the recording to start on a particular symbol
    - Tools like ‘nm’ can be helpful here to find such symbols
      - `nm build/openttd | grep MainLoop`
- **Then- replay the recording**
  - `~/Downloads/Undo-Suite-x86-8.3.0/udb openttd-466718-2025-06-10T19-18-20.511.undo`

Reverse debugging (UDB) (2/3)

- Here’s an example of loading up a recording and stepping forward and backward
- Pretty neat!



Reverse debugging (UDB) (3/3)

- One more demo worth showing -- this one uses **watchpoints**
- **So instead of hopping around with ‘next’** -- we can **pause** on data that changes
- You can find interesting data (e.g. a ‘train data structure that might get modified’) as shown in this example
  - *hint* ‘ptype’ can help here in GDB once you find an object and want to look at the struct.

Time Travel Debugging - Greg Law - Meeting C++ 2023
https://www.youtube.com/watch?v=gyGdk6QMpMY

Pro Tip: Keep a Journal

- Now that you have done a few investigations -- take some notes!
  - Making lists about what you learned or need to revisit will be useful!
- I recommend using whatever journaling tool is the lowest friction thing for you
  - e.g. physical notebook perhaps, but a ‘Google Doc’ or text file that is ‘greppable’ may be best
  - More on note taking systems (e.g. .plan files):
    - https://www.youtube.com/watch?v=SW1fzrB-UEg

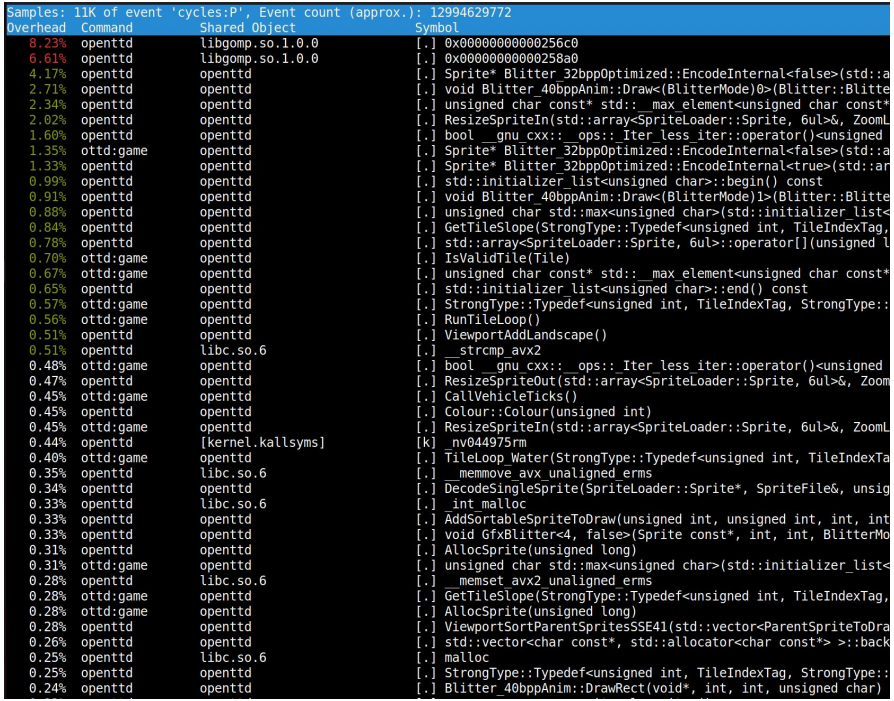
```
[idsoftware.com]
Login name: johnc In real life: John Carmack
Directory: /raid/nardo/johnc Shell: /bin/csh
Never logged in.
Plan:

This is my daily work ...

When I accomplish something, I write a * line that day.

Whenever a bug / missing feature is mentioned during the day and
I don't fix it, I make a note of it. Some things get noted many times
before they get fixed.

Occasionally I go back through the old notes and mark with a +
the things I have since fixed.

--- John Carmack

= feb 18 ==================================
* page flip crap
* stretch console
* faster swimming speed
* damage direction protocol
* armor color flash
* gib death
* grenade tweaking
* brightened alias models
* nail gun lag
* dedicated server quit at game end
+ scoreboard
+ optional full size
+ view centering key
+ vid mode 15 crap
+ change ammo box on sbar
+ allow "restart" after a program error
+ respawn blood trail?
+ -1 ammo value on rockets
+ light up characters
```

M //garbagecollected.org/2017/10/24/the-carmack-plan/

How else can we find what's important?

- Sampling profilers can be another good tool to see 'what is going on'
- A profiler like perf will show you what may be interesting.
  - i.e. the 'hot paths' in a codebase

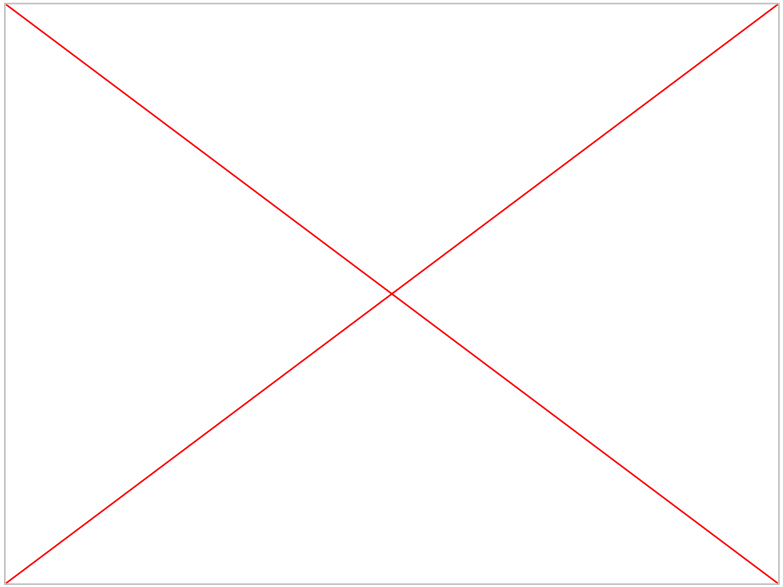
```
sudo perf record ./openttd
sudo perf report
```



Attaching to a Running Process

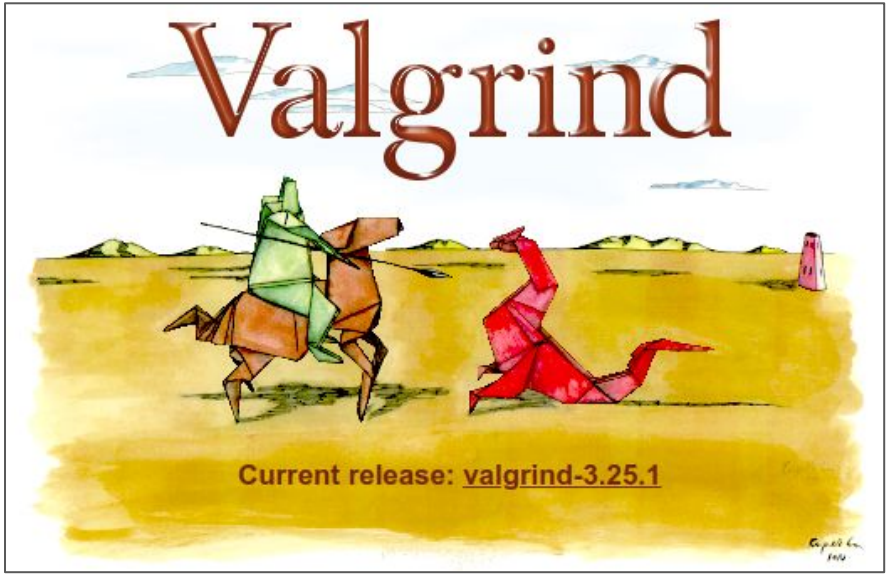
- Note: With most of the tools I'm showing you today (GDB, UDB, etc.) it's possible to 'attach to a running process'
  - This allows us to collect information from a specific point and time.

```
sudo perf record -p <pid> -g
sudo perf report
```



Visualization: callgrind and kcachegrind (1/2)

- There's a good number of tools as well that can help you visualize the profile -
- The 'Valgrind' toolsuite (pronounced: val-grinn) is another dynamic analysis tool

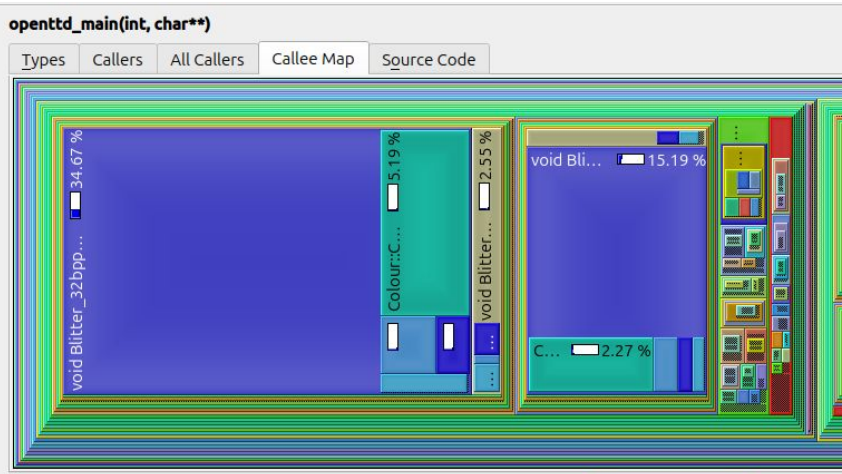


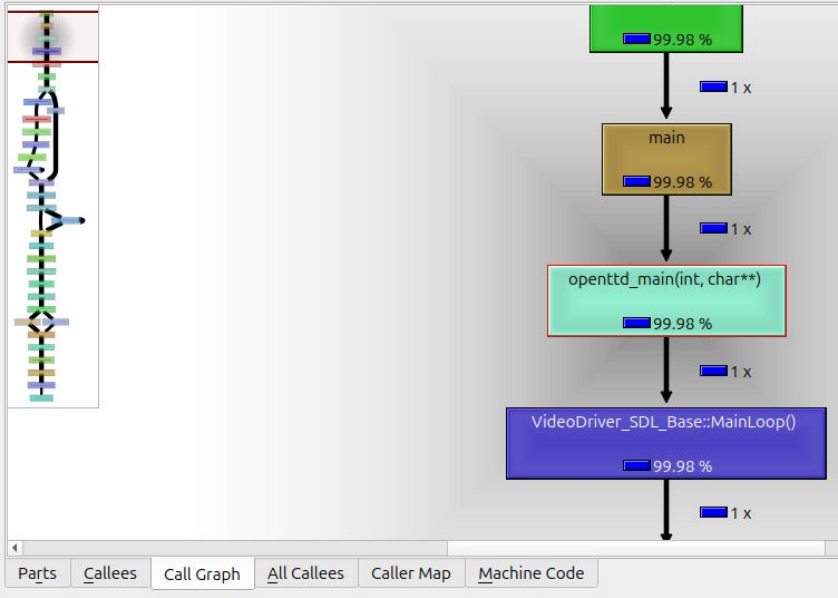
Visualization: callgrind and kcachegrind (2/2)

- The goal here is to again ‘sample’ where we execute code
  - (The call graphs will look pretty in your journal too)
- **Run:**
  - `valgrind --tool=callgrind -v --dump-every-bb=10000000 ./openttd`
    - This grabs a sample every 10000000 basic blocks executed
    - Note again: There are some mechanisms to turn on/off sampling if things are too slow
      - e.g. `callgrind_control --instr=on`
  - Documentation for usage:
    - https://kcachegrind.sourceforge.net/html/Usage.html

Visualization: callgrind and kcachegrind (1/3)

- Here's an example of the output from 'callgrind' visualized in 'kcachgrind'
- Simply run:
  - kcachegrind
  - (from the directory where the output of callgrind is dumped)





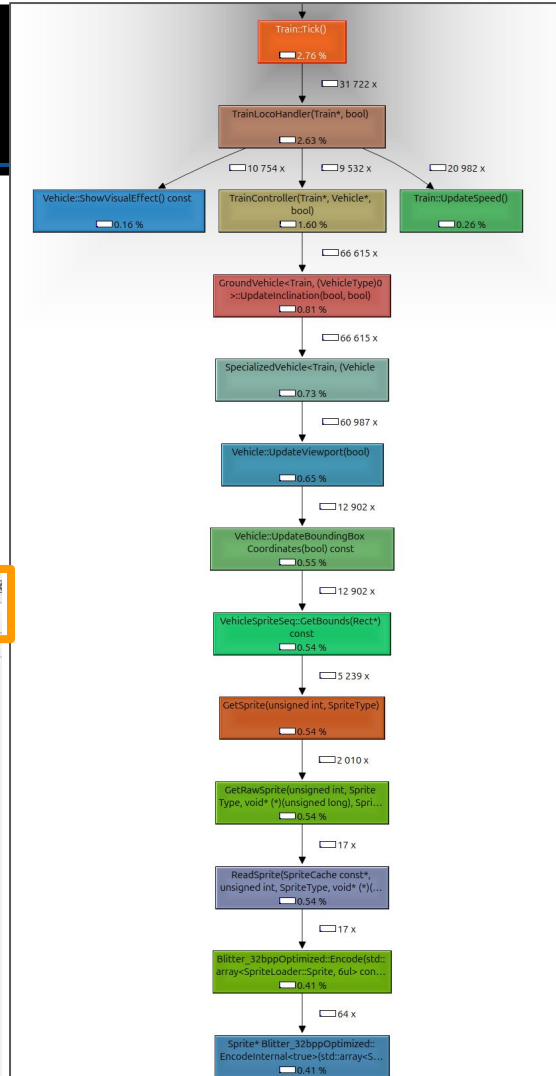
Visualization: callgrind and kcachegrind (2/3)

- Again, as you find things interesting, you can explore the call graph
- kcachegrind has a way to ‘search’ for functions
  - Using the ‘called’ column, you can find what may be important

F&lat Profile

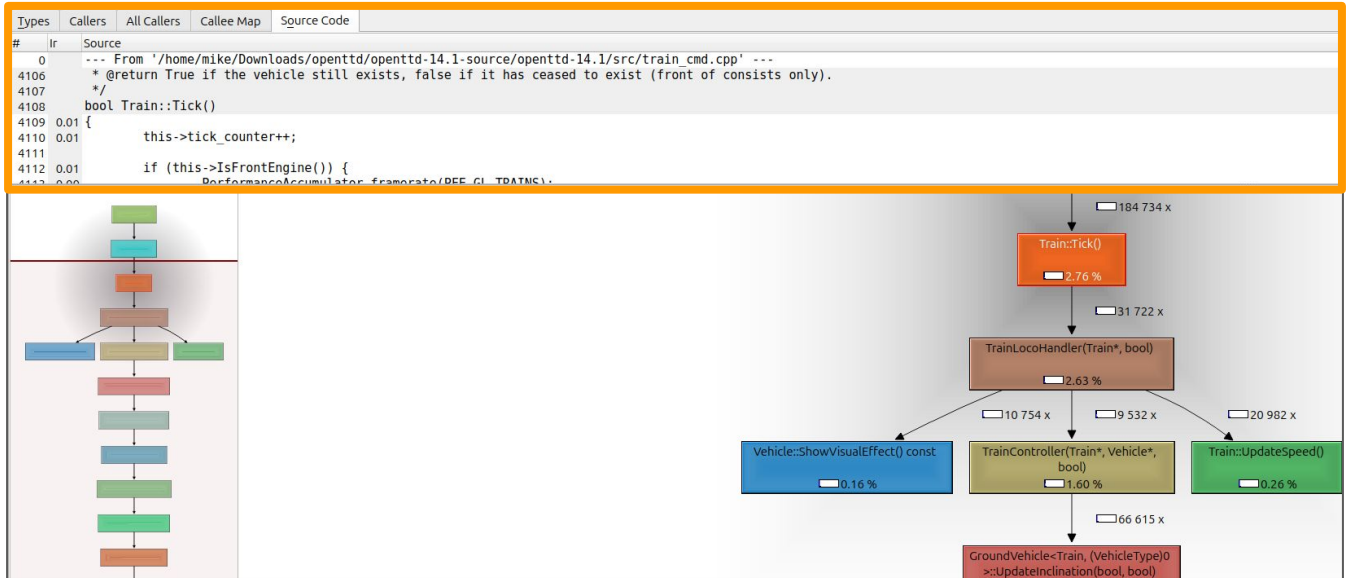
Search: tick (No Grouping)

Incl.	Self	Called	Function	Location
49.59	0.00	25	VideoDriver::Tick()	openttd: video_driver.cpp
31.92	0.00	18	CallWindowRealtimeTic…	openttd: window.cpp
31.92	0.00	18	SelectGameWindow::On…	openttd: intro_gui.cpp
8.78	0.18	311	CallVehicleTicks()	openttd: vehicle.cpp, vehicle_base.h, bitmath_…
2.92	0.00	5 598	Ship::Tick()	openttd: ship_cmd.cpp
2.76	0.07	184 734	Train::Tick()	openttd: train_cmd.cpp, vehicle_base.h, bitma…
1.89	0.02	49 138	RoadVehicle::Tick()	openttd: roadveh_cmd.cpp, vehicle_base.h, bi…
0.36	0.00	5 598	Aircraft::Tick()	openttd: aircraft_cmd.cpp
0.23	0.00	311	CallLandscapeTick()	openttd: landscape.cpp
0.19	0.01	311	OnTick_Station()	openttd: station_cmd.cpp
0.11	0.00	23 243	EffectVehicle::Tick()	openttd: effectvehicle.cpp
0.10	0.00	22 112	DieselSmokeTick(Effect…	openttd: effectvehicle.cpp
0.09	0.00	20 837	StationHandleSmallTick…	openttd: station_cmd.cpp
0.07	0.00	67	StationHandleBigTick(B…	openttd: station_cmd.cpp
0.03	0.00	311	OnTick_Industry()	openttd: industry_cmd.cpp
0.01	0.00	1 131	SmokeTick(EffectVehicl…	openttd: effectvehicle.cpp
0.00	0.00	311	OnTick_Town()	openttd: town_cmd.cpp



Visualization: callgrind and kcachegrind (3/3)

- Note: You can directly view the source from this tool as well
- **However** -- I'd recommend doing a debug session with **udb or gdb** and setting a breakpoint at these points of interest



1. **Understanding the control flow**
2. The **pure scale** of software and its relation to complexity
3. **Human factors** can additionally contribute to making your life harder

C

Note: By ***pure scale*** that is an expression to mean: “The vast size” of the number of files and lines of code in a project.

Dealing with Pure Scale of Software

- Once you have some idea of the project flow, it may be time to ‘dive into’ the project into more specifics
- But since we cannot again look at all of the source, we’ll focus on **reducing scale** to the things you care about
  - i.e. You don’t necessarily have to understand about all of the codebase at once -- often just smaller subsystems

```
mike@mike-MS-7B17:openttd-14.1$ cloc .
    3138 text files.
    2402 unique files.
    1371 files ignored.

github.com/AlDanial/cloc v 1.98  T=1.86 s (1293.4 files/s, 534526.5 lines/s)
-------------------------------------------------------------------------------
Language                     files          blank        comment           code
-------------------------------------------------------------------------------
Text                            86          53266              0         308781
C++                            499          40695          47958         188428
C/C++ Header                   768          23071          41636         123108
D                              477              0              0          93912
make                            59           6122           4985          16050
CMake                          304           1380           1520          11791
INI                             21            614            149           5023
JSON                             5              1              0           3140
HTML                             5            278              1           3106
Squirrel                        33            364            238           3050
Markdown                        26            966             32           3011
YAML                            25            480            117           2819
Objective-C++                    4            499            432           1742
SVG                              2              1              2           1353
C                                1            149             61            670
awk                              1             41             32            217
XML                              4              3             12            199
diff                             2              3             31            174
Python                           2             68             55            168
TypeScript                      61              0              0            122
PowerShell                       5             34             27            113
JavaScript                       1             16             24             86
Tcl/Tk                           1             22             32             52
Bourne Shell                     3             17             32             41
reStructuredText                 1              5              0             22
DOS Batch                        5              4              0             18
Dockerfile                       1              1              0              3
-------------------------------------------------------------------------------
SUM:                          2402         128100          97376         767199
-------------------------------------------------------------------------------
mike@mike-MS-7B17:openttd-14.1$
```

Remember, 300,000+ lines of code -- wow

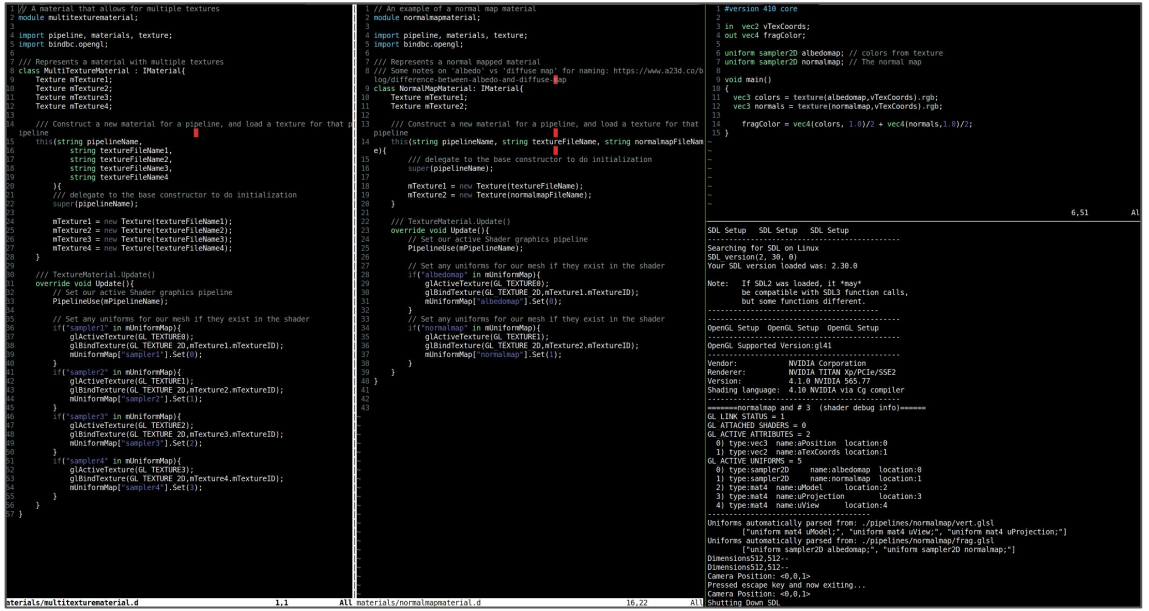
Source code uses ‘text’ as a visualization

- The **pure scale** (i.e. the size) of codebases is a challenge, and since we’ll be looking at a lot of text...
  - If at all possible beg / borrow / steal a large 4K+ screen, or two screens...
  - This is one of the few real hardware advantages these days for developers as build / test is often remote.
  - Dell's 27" 4K screen start £270 - £300 (inc. 20% VAT)

https://i.pcmag.com/imagery/roundups/01Y9bqNdRmGOzHcetHQG2FW-36.fit_lim.size_1050x.webp

Windows/Screen Management

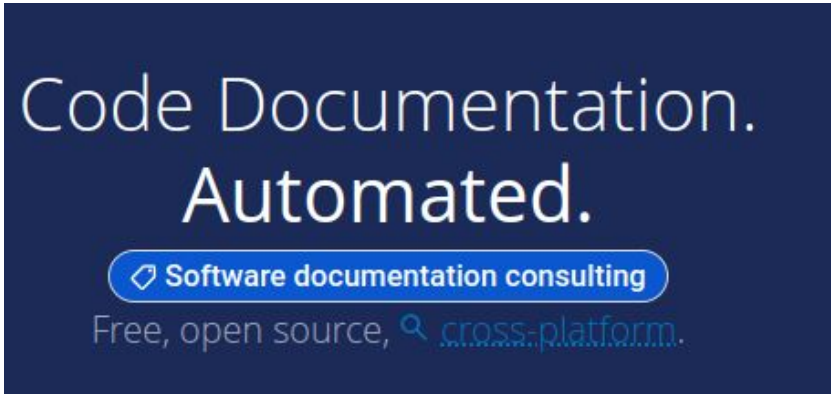
- Another less technical (but important) suggestion
- Find a good window manager
  - Either for your operating system, or a multiplexer (e.g. tmux) if you're working in terminal.
- The number of times I've needed to compare code side-by-side can be very helpful to see 'what have I missed'



Tools like tmux and VIM can split and manage all your code windows. Find some tools you are otherwise comfortable with

Generate your Documentation (1/3)

- By now hopefully you've found a few useful functions
  - Perhaps using **udb**, **kcachegrind,** etc.
- But how to keep notes of what was important?
- No docs in your project?
- No problem -- generate them yourself
  - Doxygen, Doxypress, or other documentation generates can be helpful here



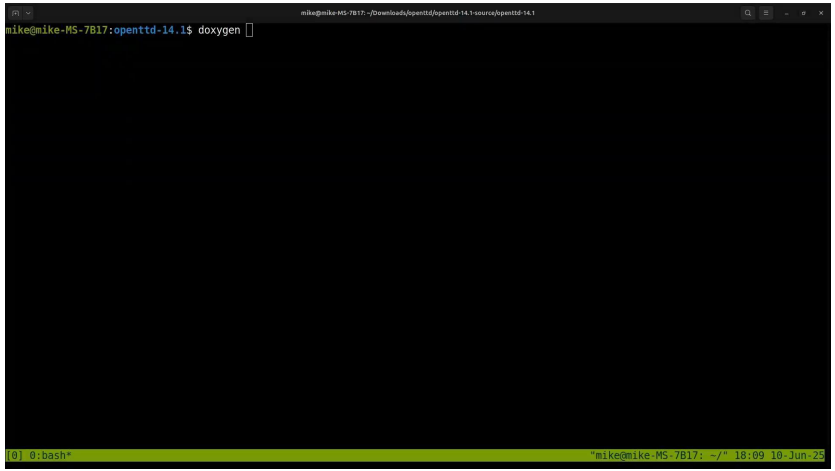
https://www.doxygen.nl/

M

Generate your Documentation (2/3)

- *Example Video* in 1-minute
- For more configuration options check:
  - https://www.youtube.com/watch?v=tLPHQMosF9M

```
doxygen -g
doxygen Doxyfile
```



Generate your Documentation (3/3)

- Some more examples of what is generated
  - left: documentation extracted from functions and members of types
  - right: inheritance diagrams

Classes

struct **AcceptedCargo**
struct **ProducedCargo**
struct **ProducedHistory**

Public Types

using **ProducedCargoArray** = std::array< ProducedCargo, INDUSTRY_NUM_OUTPUTS >
using **AcceptedCargoArray** = std::array< AcceptedCargo, INDUSTRY_NUM_INPUTS >

Public Types inherited from **Pool< Titem, Tindex, Tgrowth_step, Tmax_size, Tpool_type, Tcache, Tzero >::PoolItem<&_industry_pool >**

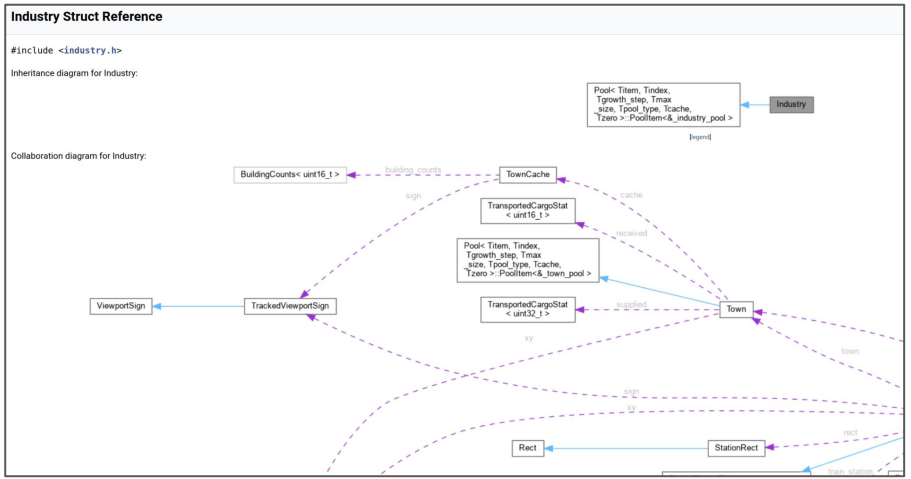
Public Member Functions

Industry (TileIndex tile=INVALID_TILE)
void **RecomputeProductionMultipliers** ()
bool **TileBelongsToIndustry** (TileIndex tile) const
ProducedCargoArray::iterator **GetCargoProduced** (CargoID cargo)
ProducedCargoArray::const_iterator **GetCargoProduced** (CargoID cargo) const
AcceptedCargoArray::iterator **GetCargoAccepted** (CargoID cargo)
bool **IsCargoAccepted** () const
bool **IsCargoProduced** () const
bool **IsCargoAccepted** (CargoID cargo) const
bool **IsCargoProduced** (CargoID cargo) const
const std::string & **GetCachedName** () const

Public Member Functions inherited from **Pool< Titem, Tindex, Tgrowth_step, Tmax_size, Tpool_type, Tcache, Tzero >::PoolItem<&_industry_pool >**

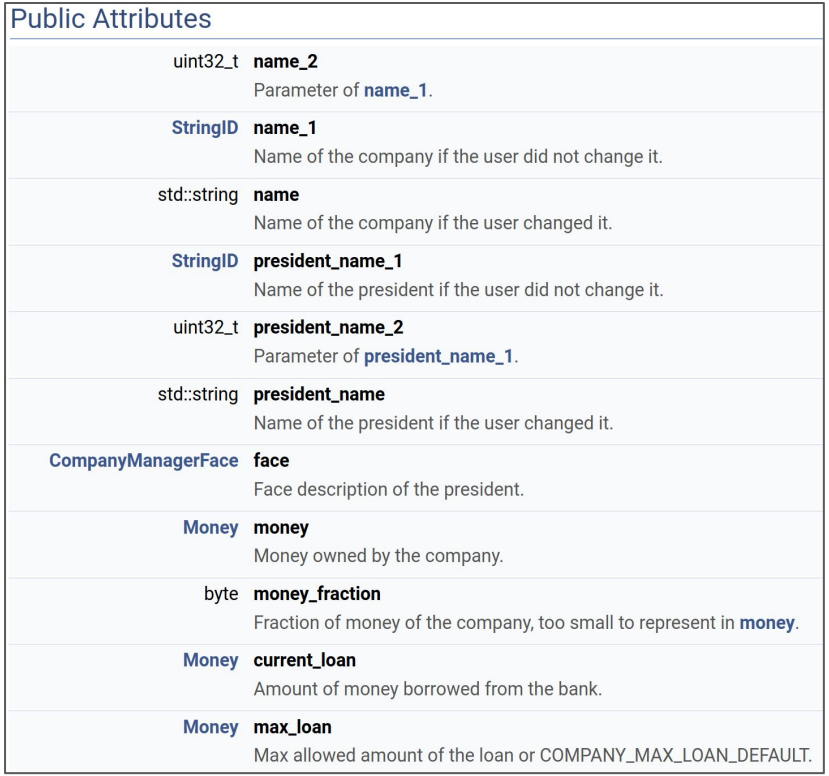
Static Public Member Functions

static Industry * **GetByTile** (TileIndex tile)



Recap and Some Observations

- No documentation -- no problem
  - Generate your own using Doxygen, Doxypress, or other tools to extract information out.
  - Can often use your compiler to see the dependencies at the least
- Viewing the ‘doxygen’ files (or any documentation) gives you hints as a developer to a few things
  - How are things named?
    - i.e. the naming convention
  - How are ‘errors’ propagated (return codes or exceptions?)
- Take a few notes of this -- it will help you when it does become time to submit for code review!



Public Attributes

uint32_t	**name_2** Parameter of **name_1**.
StringID	**name_1** Name of the company if the user did not change it.
std::string	**name** Name of the company if the user changed it.
StringID	**president_name_1** Name of the president if the user did not change it.
uint32_t	**president_name_2** Parameter of **president_name_1**.
std::string	**president_name** Name of the president if the user changed it.
CompanyManagerFace	**face** Face description of the president.
Money	**money** Money owned by the company.
byte	**money_fraction** Fraction of money of the company, too small to represent in **money**.
Money	**current_loan** Amount of money borrowed from the bank.
Money	**max_loan** Max allowed amount of the loan or COMPANY_MAX_LOAN_DEFAULT.

Local file from Doxygen generated documentation: file:///home/mike/Downloads/openttd/openttd-14.1-source/openttd-14.1/html/structCompanyProperties.html

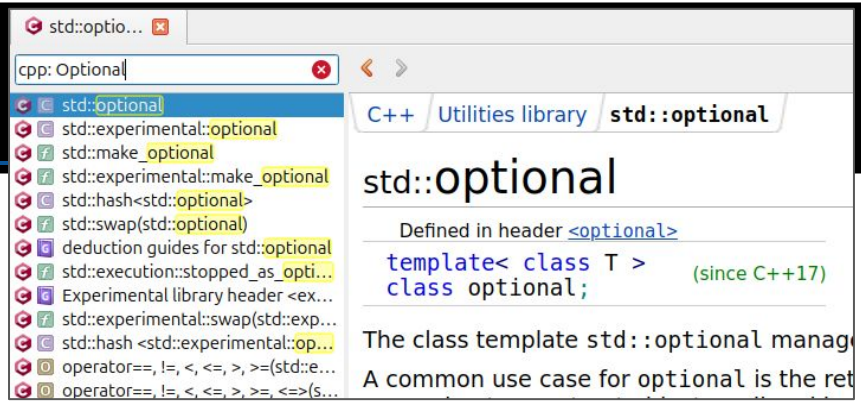
Code you do not own

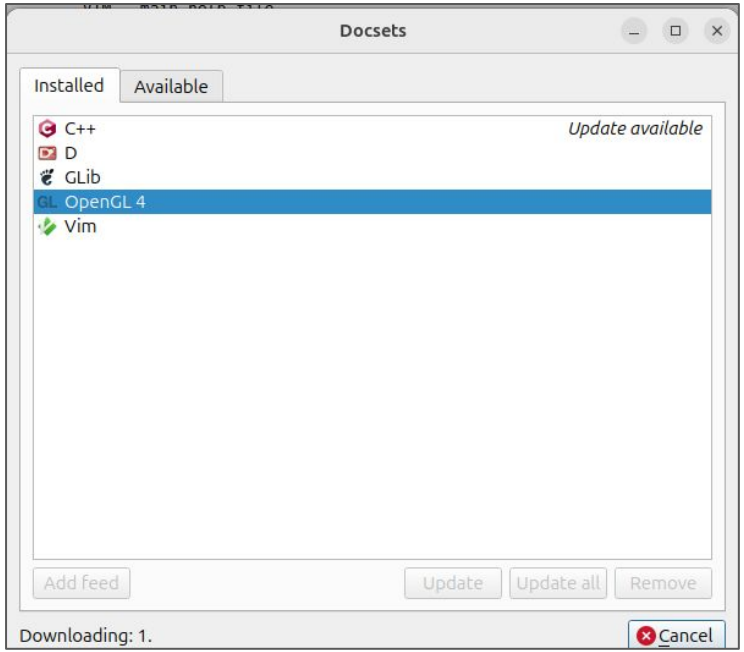
- In any big project, there will also be code that you **do not own**
- For example, shared libraries
- Finding shared libraries is easy
  - Just run a tool like ldd (Dependency Walker on Windows is also quite nice)
- You'll often get some hints of what 'graphics libraries' to otherwise pay attention to.

```
mike@mike-MS-7B17:build$ ldd openttd
        linux-vdso.so.1 (0x00007ffcc2dec000)
        libpng16.so.16 => /lib/x86_64-linux-gnu/libpng16.so.16 (0x0000705b9a3b1000)
        libz.so.1 => /lib/x86_64-linux-gnu/libz.so.1 (0x0000705b9a395000)
        liblzma.so.5 => /lib/x86_64-linux-gnu/liblzma.so.5 (0x0000705b9a363000)
        libfluidsynth.so.3 => /lib/x86_64-linux-gnu/libfluidsynth.so.3 (0x0000705b9a27c000)
        libSDL2-2.0.so.0 => /lib/x86_64-linux-gnu/libSDL2-2.0.so.0 (0x0000705b97824000)
        libfreetype.so.6 => /lib/x86_64-linux-gnu/libfreetype.so.6 (0x0000705b97758000)
        libfontconfig.so.1 => /lib/x86_64-linux-gnu/libfontconfig.so.1 (0x0000705b97707000)
        libharfbuzz.so.0 => /lib/x86_64-linux-gnu/libharfbuzz.so.0 (0x0000705b975fa000)
        libicui18n.so.74 => /lib/x86_64-linux-gnu/libicui18n.so.74 (0x0000705b97200000)
```

Zeal Docs (or Dash)

- For these function calls, I recommend finding fast offline documentation
  - no latency, and usually easier to organize and keep tabs
  - Sometimes more powerful search options as well
    - e.g. fuzzy search
- Note:
  - These tools in combination with code you own can also be useful





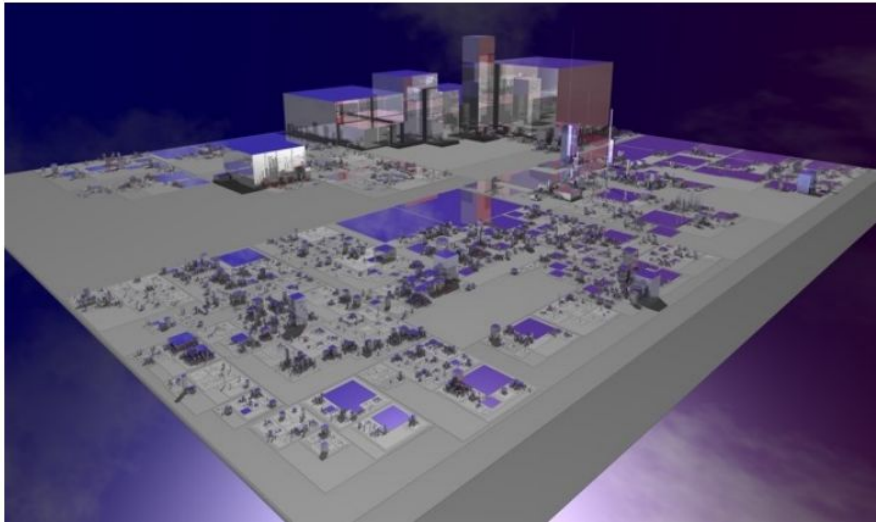
Still too much? Try Running Examples/tests

- Try to reducing the scale of the project further
- If you're working in a framework, then running some of the smaller samples
  - e.g. a graphics library likely has tutorials out there
- If you're lucky, there may also be some 'tests' that mock or showcase behavior.

```
mike@mike-MS-7B17:openttd-14.1$ tree src/tests/
src/tests/
├── bitmath_func.cpp
├── CMakeLists.txt
├── landscape_partial_pixel_z.cpp
├── math_func.cpp
├── mock_environment.h
├── mock_fontcache.h
├── mock_spritecache.cpp
├── mock_spritecache.h
├── string_func.cpp
├── strings_func.cpp
├── test_main.cpp
├── test_script_admin.cpp
└── test_window_desc.cpp
```

Some Other Tips (1/3)

- Some of you have the fortune of working on nicely formatted codebases
  - If your codebase is ‘ugly’ -- consider running clang-tidy, indent, or similar formatting tools to reformat and unify the code.
- There’s a world coming soon where we’ll need different abstractions to visualize our code -- perhaps you’ll come up with other neat abstractions (e.g. “software cities”)
  - https://ieeexplore.ieee.org/document/4290706
  - https://www.cs.nmt.edu/~jeffery/city-surv.pdf



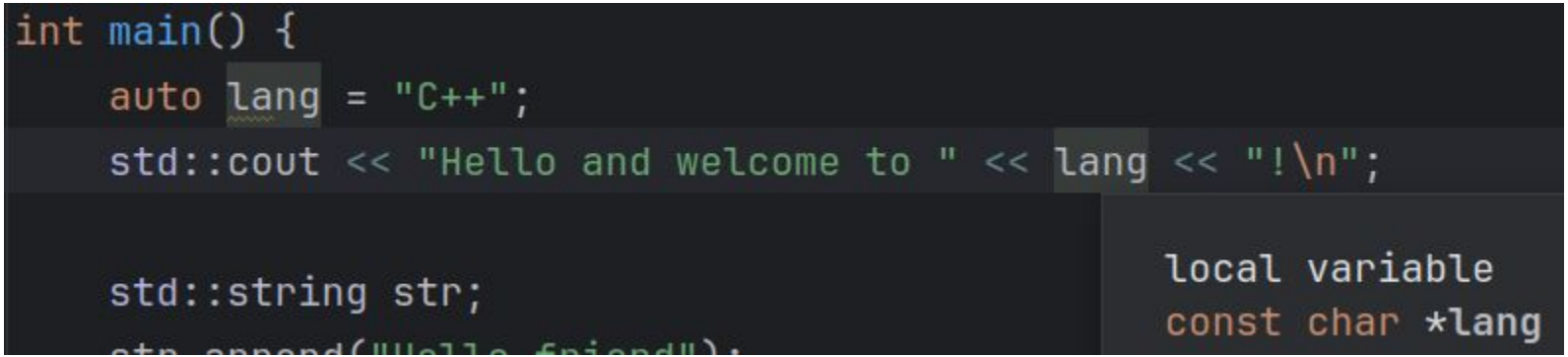
A ‘software city’ is a metaphor for the source code. Blocks may represent ‘namespaces’ or ‘directories’ and buildings ‘files’ for instance.

Some Other Tips (2/3)

- Study Design Patterns
  - Yes, they're not perfect, but traditional patterns like 'observer', 'visitor', etc. tend to show up.
    - These are found in the 'Design Patterns' or 'Gang of Four' book
  - Other sorts of software design things (e.g. 'event-loop', 'component-pattern', 'plugin-system') are also good to search for examples.
  - Often times writing a toy version of these patterns can help you understand the context in a larger system.
- In some cases, you can try to find an application that may be similar to what you're developing, and learn about how that system is documented.
  - There may be some hints within software case studies otherwise if your software has absolutely no documentation on its architecture by looking at related software.
  - See: https://aosabook.org/en/

Some Other Tips (3/3)

- Text editor and IDE Support continues to improve.
  - i.e. inference of types and other information often available as needed.

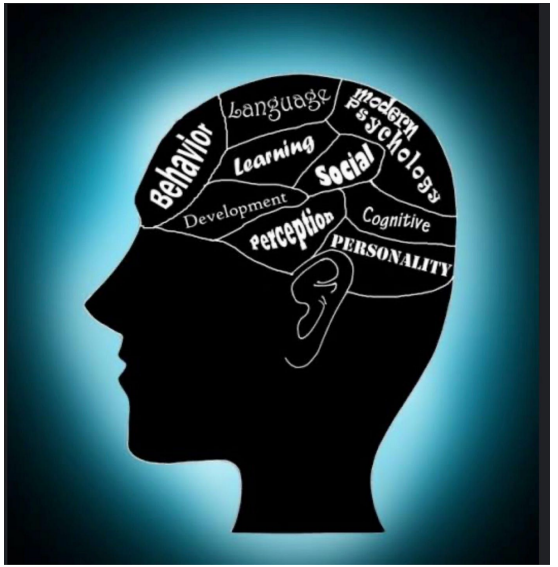


1. **Understanding the control flow**
2. The **pure scale** of software and its relation to complexity
3. **Human factors** can additionally contribute to making your life harder

M

Human Factors

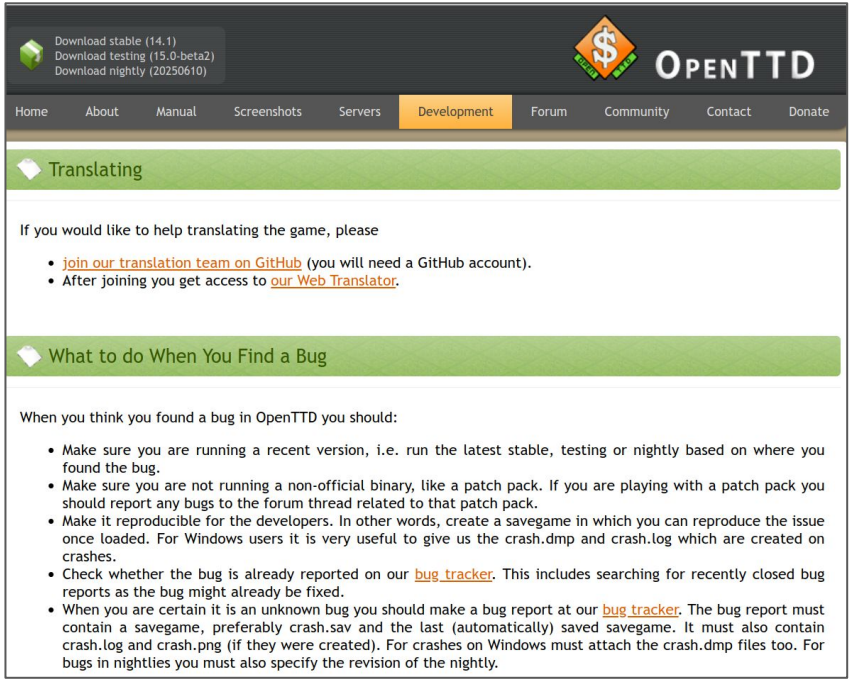
- We have some tools now to help us **understand the control flow** and **working at scale**.
- But sometimes the hardest problems in software are sometimes -- i.e. **human factors**
- What I mean by this is -- how do I get motivated or focused to actually learn a codebase?
    - **My best answer** is to put a real problem in front of you that you will learn from!



https://miro.medium.com/v2/resize:fit:1400/1*nOZxRBAQwq8FZ-lINA630w@2x.jpeg

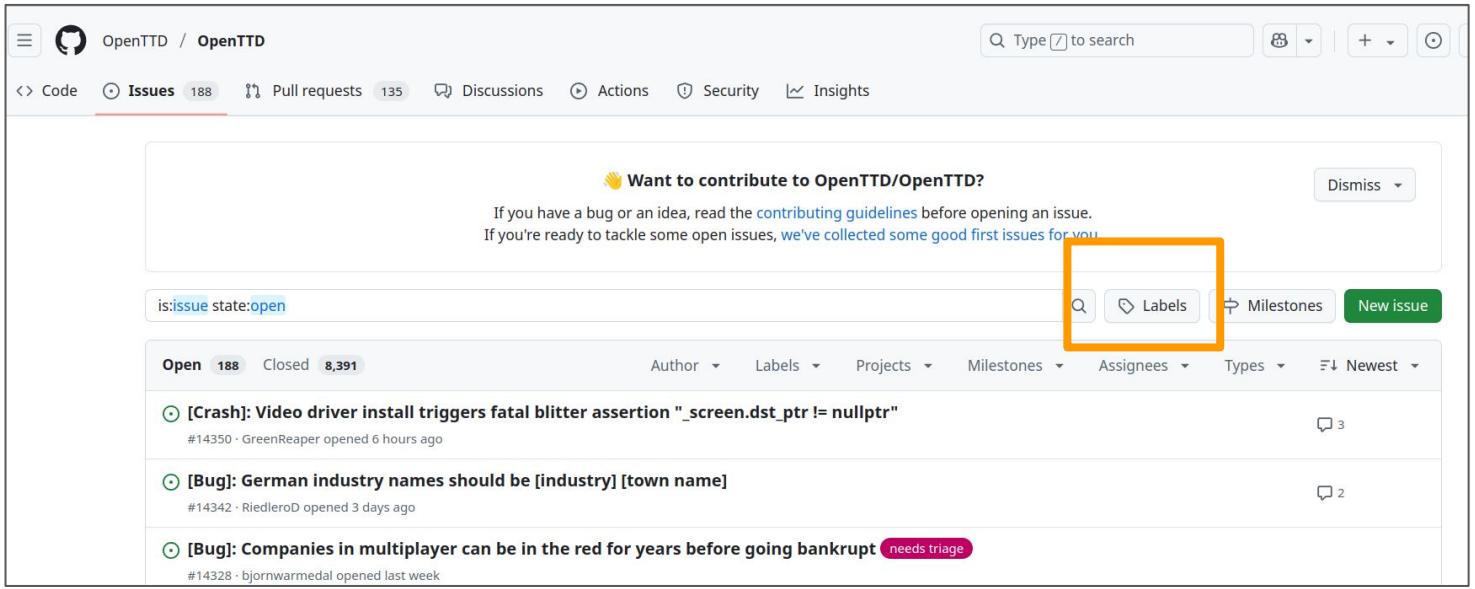
Find a first good task (1/3)

- With a large codebase, we might get some direction by literally just solving a problem.
  - If you're lucky, your code base will be labeled with 'good first tasks'
  - Good first tasks are 'byte sized' -- i.e. small, and picked out by engineers on your team
- For our project today -- observe there is a **Development** tab on the website.
  - https://www.openttd.org/development



Find a first good task (2/3)

- Searching for ‘bugs’ or ‘issues’ are a great place to start
- Often time these issues will be labeled



https://github.com/OpenTTD/OpenTTD/issues

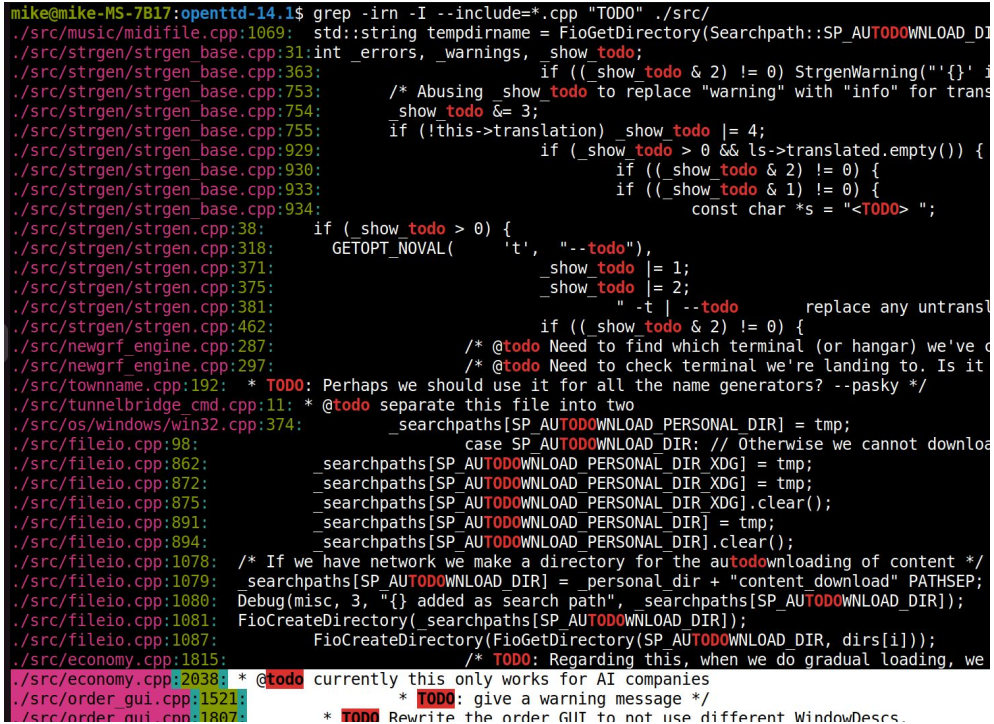
Find a first good task (3/3)

- Of the labels for this particular project, I found two that are probably good ‘starting places’
  - i.e. they imply a small amount of work

https://github.com/OpenTTD/OpenTTD/issues

If you are not assigned a good ‘first task’:

- Don’t forget about our tool ‘grep’
  - Try searching for ‘TODO’, ‘FIXME’ or ‘Later’ as ‘keywords’
  - If you’re lucky, you may find notes something like:
    - *“This is 'hard-coded' and should be fixed later”*
    - “FIXME, this is a ‘magic constant’ that should be loaded from a config file…”
    - etc.
- `grep -irn -I --include=*.cpp "TODO" ./src/`
  - TODO Show an example of how to query for small ‘git diff’ messages in the git log.
  - Ideally can do this in a ‘subsystem’ you’re working in or interested in.
  - Thegithub messages should give some hints about what is going on, or at the least the code change.



More ideas for ‘first’ tasks

- Another idea is to try fixing some 'warnings' in the code.
  - Not glorious, but at the least can give you some practice.
- Probably more exciting is to try to ‘add’ something
  - This might be adding another item to a ‘listbox’ user interface widget
    - That will teach you if this data is hard-coded, comes from a configuration file, is downloaded, etc.
    - Again, it will probably give you an idea of how some system works.
- **Exercise**: Try using udb or gdb to ‘track’ what function is called when you click on something.
  - udb has live recorder for tracking changes, and otherwise we can use our grep skills to search the codebase

Human Factors: Asking for Help (on a team)

- Don't be arrogant, and be always be nice to your teammates.
  - Empathy matters **a lot** when working on teams, and it helps when you want to ask each other questions!
- "If you don't know, just ask"
  - If you're a junior engineer, then bring what you have tried/learned for the problem you have solved
  - If you're a senior engineer, make a note of where reoccurring questions may be coming from in the project.
    - Generally, don't put juniors in uncomfortable positions either -- sit down with them when they first join your team to help them get acquainted!
    - Screen record your session if appropriate, or let junior engineers take a picture of the whiteboard

1. **Understanding the control flow**
2. The **pure scale** of software is often one factor.
3. **Human factors** can additionally contribute to making your life harder

Bonus Round: **AI**

C

Does AI Solve this problem?

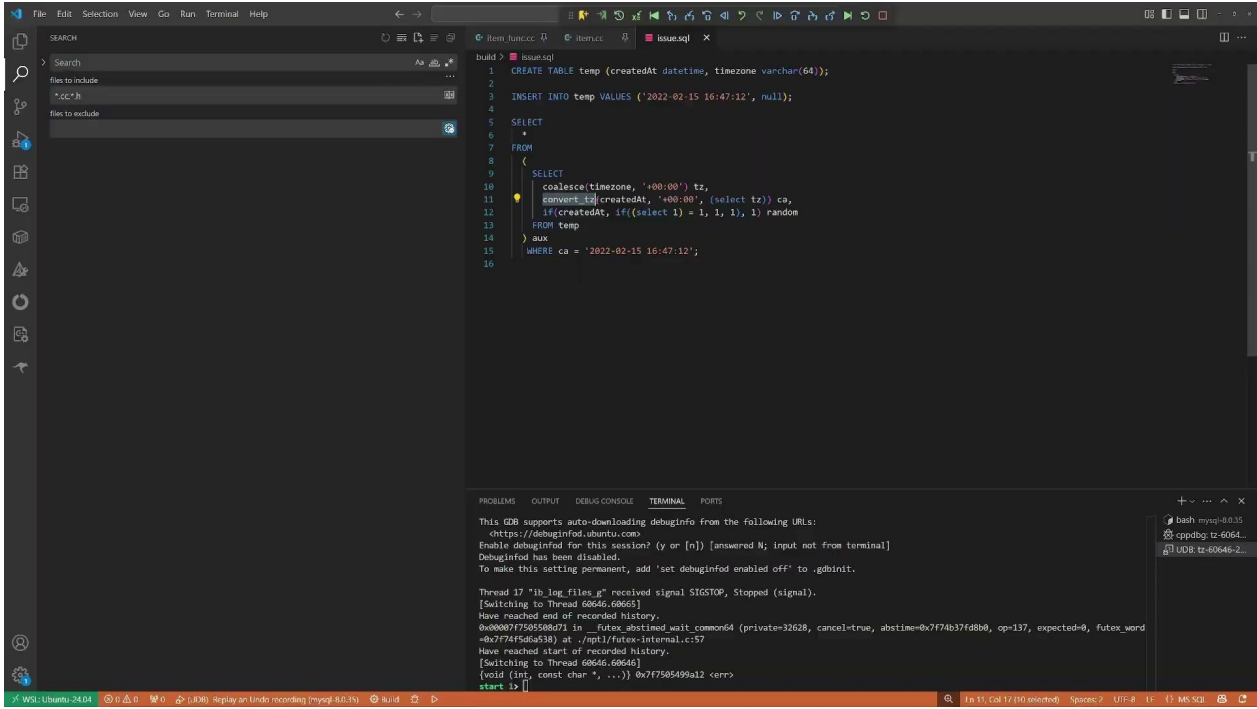
- I’m not sure -- yet (sorry!)
  - But if you have access to enterprise AI tools (i.e. where it’s safe to paste some code in if you’re working at a company) -- they may help summarize what code is doing.
- Some spaces to watch out for
  - Code/context summarizers (e.g. https://sourcegraph.com/)
  - Debugging assistants chatDBG
  - All of these tools will likely continue to improve, so keep an eye on this space!

Does AI Solve this problem?

- It's getting there, but there's a way to go
  - But if you have access to enterprise AI tools (i.e. where it's safe to paste some code in if you're working at a company) -- they can help summarize what code is doing, answer your questions about the codebase, help with basic tasks.
- Some spaces to watch out for
  - Code/context summarizers (e.g. https://sourcegraph.com/)
  - Debugging assistants chatDBG
  - Claude Code terminal based collaborative coder
  - Undo's AI integration coming soon (see the lightning talk by Rashmi *time TBC*)
- Things to watch out for
  - AIs get distracted if something looks like something it have seen before
  - They can be very convincing, especially when you don't know the codebase either
  - They rarely challenge you or defend their positions with evidence
  - "Trust but verify" is the safest approach today

Time Travel debugging & AI Vs A MySQL Issue (1/2)

- I recently started looking at an open issue with MySQL
- I've no knowledge of the codebase, so I had to get started somewhere
- Again, searching code and setting breakpoints is the way to start



Time Travel debugging & AI Vs A MySQL Issue (2/2)

- AI isn't really the topic today
- AI (Claude and ChatGPT) was hallucinating at first and running off after any vaguely plausible root cause with intense conviction
- Time Travel debugging allowed me to constrain the AI by making it confirm with evidence every hypothesis

```
chris@hyperion:~/tmp/mysql-8.0.35$ cloc .
   35707 text files.
   12819 unique files.
   21827 files ignored.

github.com/AlDanial/cloc v 1.98  T=9.82 s (1305.6 files/s, 650515.5 lines/s)
-------------------------------------------------------------------------------
Language                     files          blank        comment           code
-------------------------------------------------------------------------------
C++                           4467         437653         561364        2384569
C/C++ Header                  5211         200309         511638         895020
C                              635          59973          75534         341537
Text                           186          10159              0         164174
JSON                            70              3              0         115239
Pascal                         260          17800          35508         103489
Bourne Shell                   122          15026          17801          94354
Java                           534          12915          21441          55213
m4                              20           3950            962          36727
CMake                          451           6030          14147          36434
SQL                            203           2307           6319          26634
Perl                           122           7794           5270          25205
                          ---- Snip -----
-------------------------------------------------------------------------------
SUM:                         12819         781666        1261752        4343511
-------------------------------------------------------------------------------
```

Article documenting my experience analysing this issue:
https://undo.io/resources/time-travel-debugging-tames-complex-codebases-and-overconfident-ai/

More Resources

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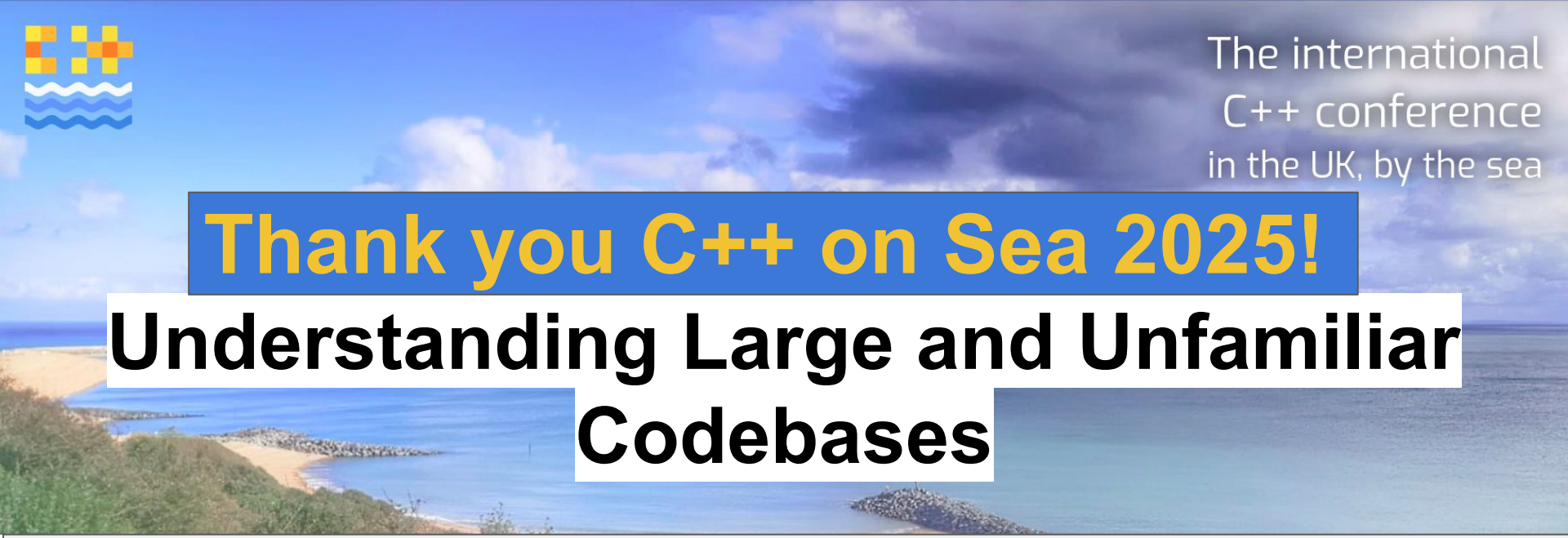
Talks on Tools / Debuggers (Linux Focus)

- Debugging and Tools
  - Time Travel Debugging - Greg Law - Meeting C++ 2023
    - https://www.youtube.com/watch?v=qyGdk6QMpMY
      - Note: Example of following ‘data’
  - Back to Basics: Debugging in Cpp - Greg Law - CppCon 2023
    - https://www.youtube.com/watch?v=qgszy9GquRs
  - Back to Basics: Debugging in C++ - Mike Shah - CppCon 2022
    - https://www.youtube.com/watch?v=YzIBwqWC6EM
  - Cool New Stuff in Gdb 9 and Gdb 10 - Greg Law - CppCon 2021
    - https://www.youtube.com/watch?v=xSnetY3eoIk
  - CppCon 2018: Greg Law “Debugging Linux C++”
    - https://www.youtube.com/watch?v=V1t6faOKjuQ
  - CppCon 2016: Greg Law “GDB - A Lot More Than You Knew"
    - https://www.youtube.com/watch?v=-n9Fkq1e6sg
- Time Travel Case Studies
  - Quake 2 https://www.jwhitham.org/2015/05/review-undodb-reversible-debugger.html
  - Doom - Reviving a zombie: https://www.youtube.com/watch?v=tjJLZ1da6xs

Summary

We have many tools to help us!

- For Understanding the control flow
  - Use debuggers and profilers to find what is important and ‘slow down’
    - ‘attaching’ to live running processes is incredibly helpful
- The pure scale of software is often one factor.
  - Try to reduce the scale
    - Use documentation tools and visualizations
      - docs are also easy to ‘bookmark’ and recall over time as you understand software
    - Take your own notes as you learn!
- Human factors can additionally contribute to making your life harder
  - Find ‘small’ problems to understand first
  - Don’t be afraid to ask for help



Thank you C++ on Sea 2025!

Understanding Large and Unfamiliar Codebases

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60 minutes | Intermediate Audience
09:15 - 10:15 Tuesday, June 24, 2025