# Debugging & Profiling

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# Outline

Profiling

Debugging

# Profiling **outline**

Mapping

Profiling Tools

Profiling Behaviour

Profiling Efficiency

# Map the workflow

A call tree (more precisely, a **call graph)** is a control flow graph that exhibits the calling relationships among routines in a program.
A *node* in the graph represent a routine, while an *edge* represents a calling relationship.

We'll concentrate on ***dynamic* call graphs** – i.e. the **records of program executions.**

The most complete graph is context-sensitive, which means that every call stack of a procedure is recorded as a separate node (the resulting graph is called *calling context tree* instead of *call tree*).

However, that requires a larger amount of memory for large program, it is useful in case of code reuse (the same code being executed at different points by differentcall paths).

# Basic profiling concepts

## INSTRUMENTATION

Inserts extra code at compile time wrapping function calls to count how many times it calls / is called and how much time it takes to execute.

## SAMPLING

The profiler ask for interrupts $\mathtt{N}_{\mathtt{samples}}$ per sec + interrupts at function calls + interrupts at selected events, and records on a histogram the number of occurrences in every part of the program. The call graph is inferred from these data.

## DEBUGGING

The profiler ask for interrupts at every line code and function call (more correct: enters the by-step execution mode)

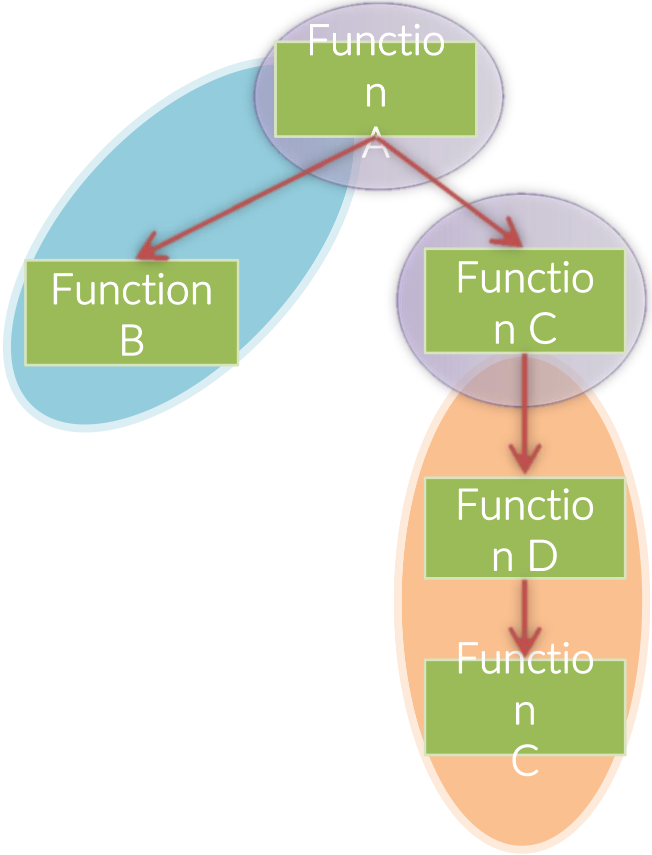
# Basic profiling concepts

## Collect **program events**

- Hardware interrupts
- Code instrumentation
- Instruction set simulation
- tracing

## **Periodic sampling**

- Top of the stack (exclusive)
- All stack (children inclusive)



# How to obtain the call tree

There are several way to obtain a dynamic call tree.
The main open source alternatives are:

1. Using gcc and **gprof**
2. Using **valgrind**
3. Using **perf**
4. Some others, mostly non-free (among significant free: CodeXL by AMD

Many IDE uses the aforementioned tools or their own plug-ins (eclipse, netbeans, code::block, codelite, …)

# The call-tree

## Using `gcc + gprof`

Just compile your source using **-pg** option.
You should also profile turning on the optimizations you're interested in.

```
gcc -[my.optimizations] -pg -o myprogram.x myprogram.c
```

*Note: don't use the option –p. It provides less information than –pg.*

After that, run your program normally. Profiling infos will be written in the file `gmon.out`.

- You can read (options and details in the man page) the informations by **`gprof myprogram.x`**

- You can visualize the call graph by (read the man pages…)

```
gprof myprogram.x | gprof2dot.py | dot -T png -o callgraph.png
```

# The call-tree

Well, now that you just met, say goodbye to the glorious **`gprof`**

He’s a dinosaur from the past decades..

- lacks real multithread support
- lacks real line-by-line capability
- does not profile shared libraries
- need recompilation
- may lie easier than other tools (see later..)

*You may still consider it for some call counts business*

# How to induce you profiler to lie

**gprof** (gcc -pg) does not record the call stack

```
#include <stdlib.h>
void loop(int n)
{
  int volatile i; // does not optimize out
  i = 0;
  while(i++ < n);
}

void light(int n) { loop(n); }void heavy(int n)
{ loop(n); }

int main(void)
{
  light(100000);
  heavy(100000000);
  return 0;
}
```

# How to induce you profiler to lie

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  ms/call  ms/call  name
101.30      0.20     0.20        2   101.30   101.30  loop
  0.00      0.20     0.00        1     0.00   101.30  heavy
  0.00      0.20     0.00        1     0.00   101.30  light
```

# How to induce you profiler to lie

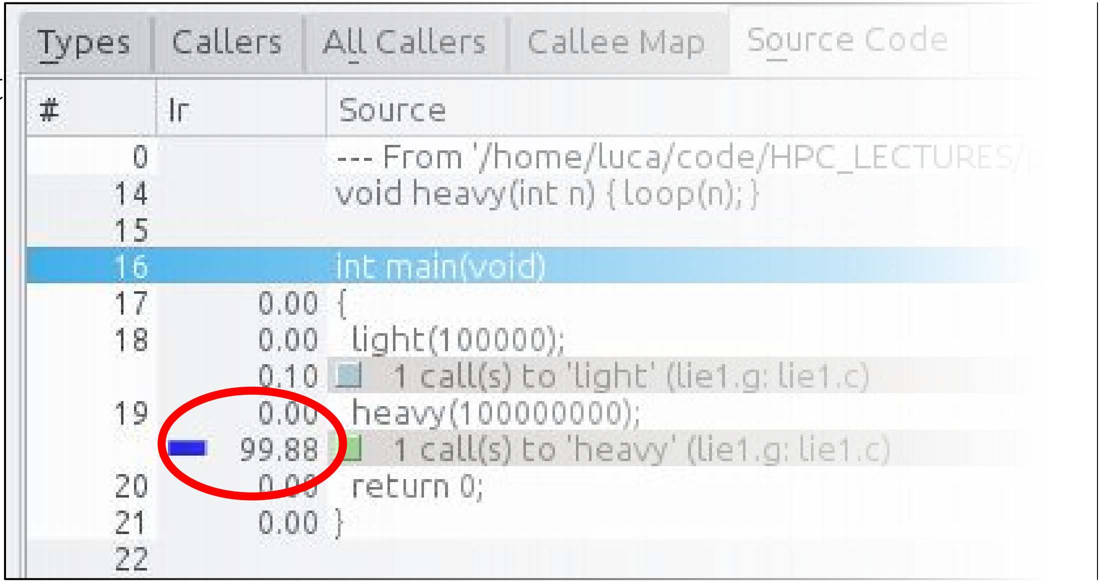
How could it happen?
The man page is clear:

```
We assume that the time for each execution of a function can
be expressed by the total time for the function divided by
the number of times the function is called.

Thus the time propagated along the call graph arcs to the
function's parents is directly proportional to the number of
times that arc is traversed.
```

# How to induce you profiler to lie

**VALGRIND** seems to better understand the situation, because it doesn't record only  the number of calls to a function but also the time spent in a function given a call path (which, at odds, gprof infers backwardly).
That's way the valgrind measure of time spent in a function plus its callees is reliable.

However, it may as well end up to a misleading picture if we stick in and additional layer of complexity, *unless* you explicit tells it to track separately different call stacks with the command-line option `--separate-callers = N`



# The call-tree

## Using **perf**

[1] COMPILING

```
gcc -g -fno-omit-frame-pointer my_prog.c -o my_prog
```

[2] RUNNING

```
perf record -F ffff -call-graph <fp|lbr|dwarf> \
my_prog.c <args>
```

[3] ANALYZING

```
perf report --call-graph=graph < --stdio >
```

# The call-tree

## Using **valgrind**

[1] COMPILING

```
gcc -g -fno-omit-frame-pointer my_prog.c -o my_prog
```

[2] RUNNING

```
Valgrind -tool=callgrind -callgrind-out-file= $CALLGRIND_OUT -dump-
instr=yes -coolect-jumps=yes -cache-sim=yes -branch-sim=yes < --I1=… >
< --D1=…>  my_prog <args>
```

[3] ANALYZING

```
kcachegrind $CALLGRIND_OUT
```

# Tools

- **BASIC / SYSTEM tools**
  - gprof / gdb / perf / gperftools
  - Valgrind – cachegrind, callgrind, ..
- **HARDWARE COUNTER / PMU interface**
  - perf
  - PAPI
  - Intel PMI
  - Likwid
  - …
- **HPC Tools**
  - HPCtoolkit
  - OpenISpeedShop
  - TAU
  - SCOREP +
- **VENDOR tools**
  - ARM-Allinea
  - CodeXL (AMD)
  - Intel tools
  - …

# Tools : valgrind

An instrumentation framework for building dynamic analysis tools.
Valgrind basically runs your code in a virtual “sandobx” where a synthetic CPU (the same you have) is simulated and executes an instrumented code.

There are various Valgrind based tools for debugging and profiling purposes.

- **Memcheck** is a memory error detector → correctness
- **Cachegrind** is a cache and branch-prediction profiler → velocity
- **Callgrind** is a call-graph generating cache profiler. It has some overlap with Cachegrind
- **Helgrind** is a thread error detector → correctness
- **DRD** is also a thread error detector.
  Different analysis technique than Helgrind
- **Massif** is a heap profiler → memory efficiency using less memory
- **DHAT** is a different kind of heap profiler → memory layout inefficiencies
- **SGcheck** (experimental tool) that can detect overruns of stack and global arrays

**KCacheGrind is a very useful GUI**

# Tools : valgrind

## Memcheck : highlighting memory errors

- Unvalid memory access: overrunning/underrunning of heap blocks or top of stack, addressing freed blocks, …
- Use of variables with undefined values
- Incorrect freeing of heap memory
- Errors in moving memory (unwanted src/dst overlaps, …)
- Memory leaks

## Cachegrind: simulating the cache

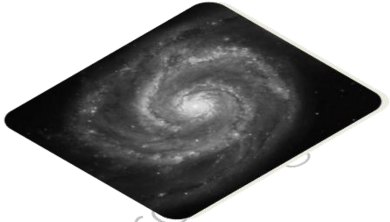
It can report how many hits (L1, L2 and L3, I- and D-) and how many misses.
It can analyze CPU's branch prediction.

`Ir, I1mr, LLmr, Dr, D1mr, DLmr, Bc, Bcm, Bi, Bim, …`

## Callgrind: profiling the CPU

It collects the number of instructions executed, links them to source lines, records the caller/callee relationship between functions, and the numbers of such calls. It can collect data on cache simulation and/or branches.

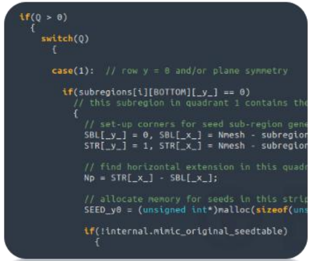
# Outline



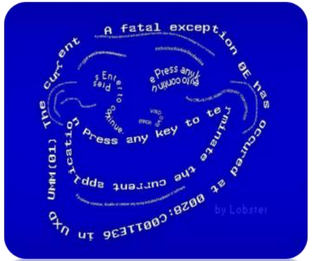
Debugging

# Debugging **outline**

Introduction




Debugging a code




Inspecting a code crash

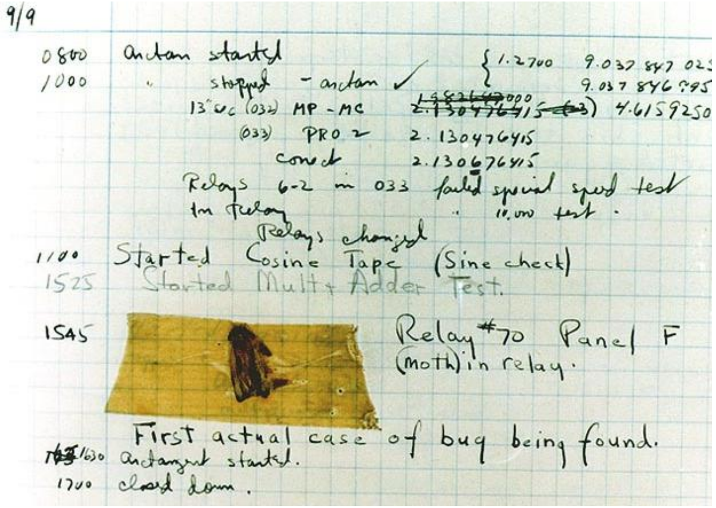
Debugging running process(es)

# Introducing debugging

Smithsonian

It has long been recognized and documented that insects are the most diverse group of organisms, meaning that the numbers of species of insects are more than any other group. In the world, some 900 thousand different kinds of living insects are known. This representation approximates 80 percent of the world's species. The true figure of living species of insects can only be estimated from present and past studies. Most authorities agree that there are more insect species that have not been described (named by science) than there are insect species that have been previously named. Conservative estimates suggest that this figure is 2 million, but estimates extend to 30 million. In the last decade, much attention has been given to the entomofauna that exists in the canopies of tropical forests of the world. From studies conducted by Terry Erwin of the Smithsonian Institution's Department of Entomology in Latin American forest canopies, the number of living species of insects has been estimated to be 30 million. Insects also probably have the largest biomass of the terrestrial animals. At any time, it is estimated that there are some 10 quintillion (10,000,000,000,000,000,000) individual insects alive.

# Introducing debugging




The usage of ***bug*** and, hence, of ***de-bugging*** referred to programming is a long-standing tradition, whose origin is difficult to trace back.

An often-told story is about Mark-II calculator located at Harvard: On Sept. 9th, 1945, a technician found a moth in a relay that caused a flaw in a “program” execution.

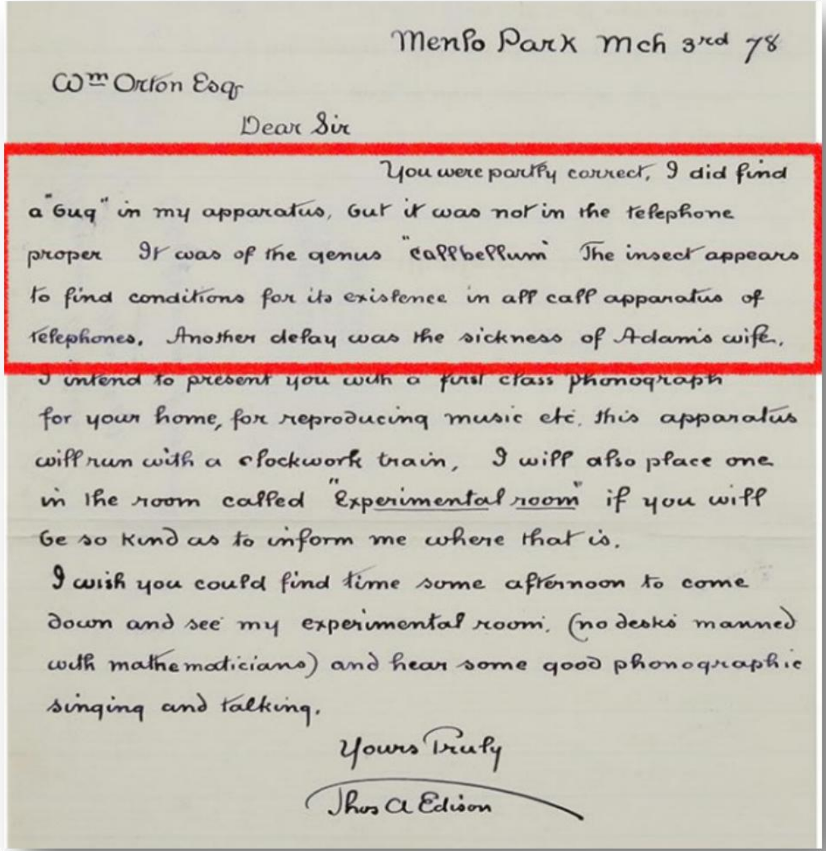
Adm. Grace Hopper is reported to have written in its diary about that as “first *actual* case of bug being found”.

# Introducing debugging

However, **Thomas Edison** found another *actual* bug in one of his phones, as he reports in a letter to an associate.

He later writes:

*"It has been just so in all of my inventions. The **first step** is an intuition and comes with a burst, **then difficulties arise**—this thing gives out and [it is] then that "**bugs**"—as such little faults and difficulties are called—show themselves and **months of intense watching, study and labor are requisite** before commercial success or failure is certainly reached."*



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

# Introducing debugging

It is difficult to trace back how this term has been poured into computer programming jargon. However, already in the early 60s it was appearing in technical papers without need of explanation.

The immortal I. Asimov used it in a 1944 short robot story “Catch that rabbit”, and his enormous influence contributed much to make the term popular.

More funny infos:
[IEEE Annals of the History of Computing](#)
( Volume: 20 , Issue: 4 , Oct-Dec 1998 )

*ask for the PDF if you’re interested and do not have access*

## Stalking the Elusive Computer Bug

PEGGY ALDRICH KIDWELL

*From at least the time of Thomas Edison, U.S. engineers have used the word “bug” to refer to flaws in the systems they developed. This short word conveniently covered a multitude of possible problems. It also suggested that difficulties were small and could be easily corrected. IBM engineers who installed the ASSC Mark I at Harvard University in 1944 taught the phrase to the staff there. Grace Murray Hopper used the word with particular enthusiasm in documents relating to her work. In 1947, when technicians building the Mark II computer at Harvard discovered a moth in one of the relays, they saved it as the first actual case of a bug being found. In the early 1950s, the terms “bug” and “debug,” as applied to computers and computer programs, began to appear not only in computer documentation but even in the popular press.*

### Introduction

Stalking computer bugs—that is to say, finding errors in computer hardware and software—occupies and has occupied much of the time and ingenuity of the people who design, build, program, and use computers.[1] Early programmers realized this with some distress. Maurice Wilkes recalls that in about June of 1949:

> I was trying to get working my first non-trivial program, which was one for the numerical integration of Airy’s dif-

published in the *Annals* in 1981. Here the time is given as the summer of 1945, but the computer is the Mark II, not the Mark I. A photograph shows the moth taped in the logbook, labeled “first actual case of bug being found.” Small problems with computers have been called bugs ever since.[5]

# Introducing debugging

That maybe is too dramatic and emphatic, but the point to get from Edison is that the *de-bugging activity* is an inherent and intrinsic one in software development

*"It has been just so in all of my inventions. The **first step** is an intuition and comes with a burst, **then difficulties arise**—this thing gives out and [it is] then that "**bugs**"—as such little faults and difficulties are called—show themselves and **months of intense watching, study and labor are requisite** before commercial success or failure is certainly reached."*

T. Edison

# Introducing debugging

Provided that

- you’ll have close encounters with bugs in your life;
- de-bugging is a fundamental and unavoidable part of your work;

what is the best way to proceed ?

# Introducing debugging

1. **Do not insert bugs**
   *Highly encouraged, but rarely works*

# Introducing debugging

1. **Do not insert bugs**
   *Highly encouraged, but rarely works*

2. **Add `printf` statements everywhere**
   *Highly discouraged, but sometimes it works.*
   *In case of memory problems – tipically due to pointers chaos – you may see that the problem "disappear", or changes its appearance, when you insert a new printf*

# Introducing debugging

1. **Do not insert bugs**
   *Highly encouraged, but rarely works*

2. **Add `printf` statements everywhere**
   *Highly discouraged, but sometimes works.*
   *In case of memory problems – tipically due toaos*

3. **Use a DEBUGGER**
   *That is definitely the best choice and, fortunately, the subject of this lecture.*

# Introducing debugging

**gdb** is almost certainly the best free, extremely feature-rich command-line debugger ubiquitously available on *niX systems.

There are 3 basic usages(*) of GDB:

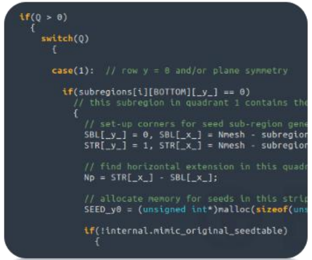
1. Debugging a code
   *quite mandatory to compile with −g*

2. Inspecting a code crash through a core file

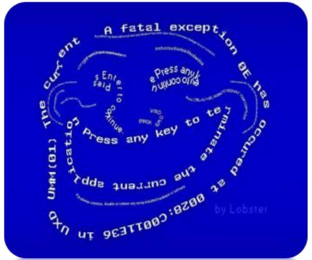
3. Debugging / inspecting a running code

(*) Higly advised: learn keyboard commands. Although many gui exist (we'll see some later), keyboard is still the best productivity tool.

# Debugging **outline**


Debugging a code




Inspecting a code crash

Debugging a running process(es)

# Compiling with dbg infos

In order to include debugging information in your code, you need to compile it with –g family options (read the gcc manual for complete info):

| | |
|---|---|
| **-g** | produce dbg info in O.S. native format |
| **-ggdb** | produce gdb specific extended info, as much as possible |
| **-g*level*** | default level is 2. 0 amounts to no info, 1 is minimal, 3 includes extra information (for instance, macros expansion) – this allows macro expansion; add **-gdwarf-*n*** in case, where possibile, where $n$ is the maximum allowed (4) |
| **-ggdb*level*** | you can combine the two to maximize the amount of useful info generated |
| | remember: **-fno-omit-frame-pointer**, especially if you are using –Ox |

# Debugging: start

You just start your code under `gdb` control:

```
%> gdb program
```

You can define the arguments needed by your program already at invocation:

▶ live demo with `gdb_try_args.c`

```
%> gdb --args program arg1 arg2 … argN
```

Or you can define the arguments from within the gdb session:

```
%> gdb program
Reading symbols from program...done.
(gdb) set args arg1 arg2 … argN
(gdb) run
```

# Debugging: run & stop

You may just want the code to run, for instance to reach the point of a seg fault:

```
%> (gdb) run
```

Or, you may want to stop it from the beginning to have full control of each step:

```
%> (gdb) break main
%> (gdb) run
```

Or you may already know what is the problematic point to stop at:

```
%> (gdb) break location
%> (gdb) run
```

# Debugging: run & stop

**Breakpoints** are a key concept in debugging. They are stopping point at which the execution interrupts and the control is given back to you, so that you can inspect the memory contents (variables values, registers values, … ) or follow the subsequent execution step by step.

You can define a breakpoint in several way

| | |
|---|---|
| `(gdb) break` | insert a break at the current pos |
| `(gdb) break ± offset` | insert a break *offset* lines after/before the current line |
| `(gdb) break filename:linenum` | insert a break at *linenum* of file *filename* |
| `(gdb) break functionname` | insert a break at the entry point of function *functionname* |

There are more options, just check the manual

# Debugging: run & stop

A breakpoint may be defined as dependent on a given condition:

```
(gdb) break my_function if (arg1 > 3 )
```

This sets a breakpoint at function *my_function* : the condition will be evaluated each time the point is reached, and the execution is stopped only if it is true.

Condition can be any valid expression.

```
(gdb) info break
```

gives you informations on active breakpoints.

```
(gdb) delete [n]
      clear [location]
      <disable | enable>  see the manual
```

# Debugging: run & stop

You can define a list of commands to be executed when a given breakpoint is reached:

```
(gdb) break my_function if (arg1 > 3 )
Breakpoint 1 at 0x..............: file blabla.c, line 42
(gdb) command 1
Type commands for when breakpoint 1 is hit, one per
line.
End with a line saying just "end".
> print arg1
> print another_useful_variable
> x/10wd a_global_integer_array
```

# Debugging: run & stop

When you have the control of the program execution, you can decide how to proceed:

| | |
|---|---|
| `(gdb) cont [c]` | continue until the end / next stop |
| `(gdb) cont` *`count-ignore`* | continue ignoring the next *count-ignore* stops (for instance, a bp) |
| `(gdb) next [n]` \| *`count`*<br>`nexti` | continue to the next src line *in the current stack frame* |
| `(gdb) step [s]` \| *`count`*<br>`stepi` | continue to the next src line |
| `(gdb) until [u]` \| *`count`* | continue until a src line past the current one is reached in the current stack fr. |
| `(gdb) advance` *`location`* | continue until the specified location is reached |

# Debugging: run & stop

You can also rewind your execution step-by-step

```
(gdb) reverse-continue [rc]

(gdb) reverse-step [count]
      reverse-stepi

(gdb) reverse-next [count]
      reverse-nexti

(gdb) set exec-direction <verse | forward >
```

# Debugging: source list

Often, when you are debugging, you may have the need of looking at either the source lines or at the generated assembler:

| | |
|---|---|
| `(gdb) list` *`linenum`* | print src lines around line *linenum* of the current source file |
| `(gdb) list` *`function`* | print the source lines of *function* |
| `(gdb) list` *`location`* | print src lines around *location* |
| `(gdb) set listsize` *`count`* | control the number of src lines printed |
| `(gdb) disass` *`[/m][function][location]`* | show the assembler |



# Debugging: stack examination

Examining the stack is often of vital importance. With GDB you can have a quick and detailed inspection of all the stack frames.

| | |
|---|---|
| `backtrace[`*args*`]` | print the backtrace of the whole stack |
| *n* | print only the *n* innermost frames |
| -*n* | print only the *n* outermost frames |
| *full* | print local variables value, also |
| `where, info stack` | additional aliases |

# Debugging: memory examination

Accessing to the content of memory is a fundamental ability of a debugger. You have several different ways to do that:

| | |
|---|---|
| `(gdb) print` *`variable`* | print the value of *variable* |
| `p/F` *`variable`* | print *variable* in a different format (`x,d,u,o,t,a,c,f,s`)<br>*see then manual for advanced location* |
| `(gdb) x/FMT` *`address`* | Explore memory starting at address *address*<br>-> see at live demo how to use this |
| `(gdb) display` *`expr`* | Add *expr* to the list of expressions to display each time your program stops |
| `display/`*`fmt expr`*<br>`display/`*`fmt addr`* | |

# Debugging: memory examination

Memory can be searched to find a particular value, of a given size

```
(gdb) find [/sn] start, end, val1 [,val2, …]

      find [/sn] start, +len, val1 [,val2, …]
```

Search memory for a particular sequence of bytes.
*s* is the size of type to be searched
*n* is the max number of occurrences

# Debugging: registers examination

Examining registers may be also useful (although it's something that only quite advanced users can conceive)

| | |
|---|---|
| `(gdb) info registers` | print the value of all registers |
| `(gdb) info vector` | print the content of vector registers |
| `(gdb) print $rsp` | print value of the stack pointer |
| `(gdb) x/10wd $rsp` | print values of the first 10 4-bytes integers on the stack |
| `(gdb) x/10i $rip` | print the next 10 asm instructions |

# Debugging: macro expansion

If there are macros in your code, they can be expanded, provided that you compiled the code with the appropriate option:

*-g3 [gdb3][-dwarf-4]*

| | |
|---|---|
| `(gdb) macro expand` *macro* | shows the expansion of macro *macro*; *expression* can be any string of tokens |
| `(gdb) info macro [`*-a*`|`*-all*`]` *macro* | shows the current (or all) definition(s) of *macro* |
| `(gdb) info macros` *location* | shows all macro definitions effective at *location* |

# Debugging: watch points

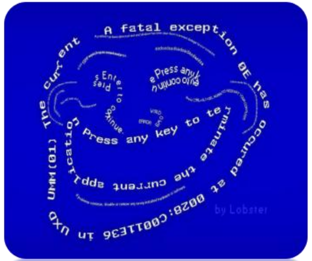
You can set *watchpoints* (aka “keep an eye on this and that”) instead of breakpoints, to stop the execution whenever a value of an expression / variable / memory region changes

| | |
|---|---|
| `(gdb) watch` *`variable`* | keep an eye onto *variable* |
| `(gdb) watch` *`expression`* | stops when the value of expression changes (the scope of variables is respected) |
| `(gdb) watch -l` *`expression`* | Interpret *expression* as a memory location to be watched |
| `(gdb) watch -l` *`expression`* `[mask` *`maskvalue`*`]` | a mask for memory watching: specifies what bits of an address should be ignored (to match more addressese) |
| `(gdb) rwatch [-`*`l`*`]` *`expr`* `[mask` *`mvalue`*`]` | stops when the value of *expr* is read |

# Debugging **outline**

Introduction

Debugging
a code




Inspecting
a code crash

Debugging
a running
process(es)

# After a crash : having the core file

It happens that you have code crashes in conditions not easily reproducible when you debug the code itself, for a number of reasons.

However, the O.S. can dump the entire “program status” on a file, called the *core file*:

```
luca@GGG:~/code/tricks% ./gdb_try_watch
no arguments were given, using default: 100

something wrong at point 2
[1]    8435 segmentation fault (core dumped)  ./gdb_try_watch
luca@GGG:~/code/tricks% ls -l core
-rw------- 1 luca luca 413696 nov  8 15:45 core
luca@GGG:~/code/tricks% 
```

In order to allow it to dump the core, you have to check / set the core file size limit:

%> `ulimit -c [`*size limit in KB*`]`

# After a crash : inspect the core file

Once you have a core, you can inspect it with GDB

```
%> gdb executable_name core_file_name
```

Or

```
%> gdb executable_name
  (gdb)core core_file_name
```

The first thing to do, normally, is to unwind the stack frame to understand where the program crashed:

```
  (gdb) bt full
```

# Debugging **outline**

Introduction

Debugging
a code

Inspecting
a code crash

Debugging
a running
process

# Attach to a process

In order to debug a running process, you can simply attach gdb to it:

```
%> gdb
(gdb) attach process-id
```

and start searching it to understand what is going on

# Debugging **outline**

Debugging parallel processes



# Debugging in parallel

The problem is much more complex: the fundamental additional challenge is the simultaneous execution.

## **Shared memory paradigm:** OpenMP, pthreads, …

- Multiple threads running
- Shared vs private memory regions
- Race conditions

## **Message-passing paradigm:** MPI

- Multiple independent processes (+ possible multithread)
- Communication
- Deadlocks

# Multi-threads capability of gdb

Let's have a try:

```
:~$ gcc -g -o my_threadprog  my_threadprog.c -lpthread

:~$ gdb ./my_threadprog
```

# Multi-threads capability of gdb

```
:~$ gdb ./my_threadprog
Reading symbols from my_threadprog...done.

(gdb) r

(gdb) Starting program: my_threadprog

[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
Creating thread 0
[New Thread 0x7ffff77ef700 (LWP 24144)]
Thread #0 says: " Hello World! "
Creating thread 1
[New Thread 0x7ffff6fee700 (LWP 24145)]
Thread #1 says: " Hello World! "
Creating thread 2
[New Thread 0x7fffeffff700 (LWP 24146)]
Thread #2 says: " Hello World! "
Creating thread 3
[New Thread 0x7ffff65d6700 (LWP 24147)]
Thread #3 says: " Hello World! "
[Thread 0x7fffeffff700 (LWP 24146) exited]
[Thread 0x7ffff6fee700 (LWP 24145) exited]
[Thread 0x7ffff77ef700 (LWP 24144) exited]
[Thread 0x7ffff7fac700 (LWP 24140) exited]
[Inferior 1 (process 24140) exited normally]
(gdb) Quit
(gdb)
```

# Multi-threads capability of gdb

It is necessary to explicitly set up **gdb** for multi-thread debugging

```
(gdb) set pagination off
(gdb) set target-async on
(gdb) set non-stop on
```

# Multi-threads capability of **gdb**

In **`all-stop`** mode, whenever the execution stops, *all* the threads stop (wherever they are).
Whenever you restart the execution, *all* the threads re-start: however, **`gdb`** can not single-step all the threads in the steplock. Some threads may execute several instructions even if you single-stepped the thread under focus with *step* or *next* commands.

**`non-stop`** mode means that when you stop a thread, all the other ones continue running until they finish or they reach some breakpoint that you pre-defined

**→ live demo**

# Multi-threads capability of **gdb**

Change focus to *threas_no*

Shows info on active threads.
* tags the active thread

```
(gdb) thread thread_no
(gdb) info threads
(gdb) thread apply [thread_no] [all] args
(gdb) break <…> thread thread_no
```

Insert a break into a list of threads

Apply a command to a list of threads

# Some hint on the workflow

- If possible, write a code natively parallel but able to run in serial, which means with 1 MPI task or 1 thread
- Profile, debug and optimize that code in serial first
- If multi-threaded, deal with thread sync / races with 1 MPI task

# Some hint on the workflow

- Deal with communications, synchronization and race/deadlock conditions on a *small* number of MPI tasks
- Profile, debug and optimize communications on a *small* number of MPI tasks
- Get to the full-size run
  *unfortunately, some times bugs or improper design issues arise only with large number of processes or threads*

# gdb and MPI

It is still possible to use **gdb** directly, called from mpirun:

```
:~$ mpirun -np <NP> -e gdb ./program
```

However, depending on your system that may not work properly.



# gdb and MPI

The simplest way to use **gdb** with a parallel program is :

```
:~$ mpirun -np <NP> xterm -hold -e gdb ./program
```

Which launches <NP> xterm windows with running gdb processes in which you can run each parallel process

```
(gdb) run <arg_1> <arg_2> … <arg_n>
```

or

```
… xterm -hold -e gdb -args ./program <arg_1> …
```

# gdb and MPI

```
:~$ mpirun -np <NP> xterm –hold -e gdb --args ./program <arg_1> … <arg_2>
```

On a HPC facility, normally you do that while running an *interactive session*..
..and in several occasion *this* will not work, because HPC environments are hostile to X for several reasons (remember to connect with –X or –Y switch of ssh).

# gdb and MPI

Another not so handy possibility is to open as many connections as processes on different terminals on your local machine, and *attach* **`gdb`** to the already running MPI processes

```
:~$ mpirun -np <NP> ./program
```

Followed by:

```
:~$ gdb -p <PID_of_MPI_task_n>
```

For each MPI task you want to follow.

# gdb and MPI

There are still 2 issues

1. *Where* to run **`gdb`**, if **`xterm`** is not available and you do not want to use it in multi-thread mode ?

   You may consider using **`screen`** (practical example in few minutes)

2. *How* the MPI tasks should be convinced to wait for **`gdb`** to step in ?

   → *Next slides*



# gdb and MPI

## Note

A possible issue for **attacching gdb** to a running process is that you **may not have the capability to do that** on a Linux system.

Look in the file:
`/proc/sys/kernel/yama/ptrace_scope`

```
0 ("classic ptrace permissions")
       No additional restrictions on operations that perform
       PTRACE_MODE_ATTACH checks (beyond those imposed by the
       commoncap and other LSMs).

       The use of PTRACE_TRACEME is unchanged.

1 ("restricted ptrace") [default value]
       When performing an operation that requires a
       PTRACE_MODE_ATTACH check, the calling process must either have
       the CAP_SYS_PTRACE capability in the user namespace of the
       target process or it must have a predefined relationship with
       the target process.  By default, the predefined relationship
       is that the target process must be a descendant of the caller.

       A target process can employ the prctl(2) PR_SET_PTRACER
       operation to declare an additional PID that is allowed to
       perform PTRACE_MODE_ATTACH operations on the target.  See the
       kernel source file Documentation/admin-guide/LSM/Yama.rst (or
       Documentation/security/Yama.txt before Linux 4.13) for further
       details.

       The use of PTRACE_TRACEME is unchanged.

2 ("admin-only attach")
       Only processes with the CAP_SYS_PTRACE capability in the user
       namespace of the target process may perform PTRACE_MODE_ATTACH
       operations or trace children that employ PTRACE_TRACEME.

3 ("no attach")
       No process may perform PTRACE_MODE_ATTACH operations or trace
       children that employ PTRACE_TRACEME.
```

# gdb and MPI

We are left with the problem of *attaching* the **gdb** to a running process (or several running processes).

There is a classical trick, that requires to insert some small additional code in your program

```
int wait = 1

while(wait)
   sleep(1);
```

The MPI processes will wait indefinitely until the value of wait does not change..
*which you can do from inside **gdb** attached to each process.*

# gdb and MPI

## Note

Solutions:

1. Get the capability
2. As root type:
   **`echo 0 > /proc/sys/kernel/yama/ptrace_scope`**
3. Set the **`kernel.yama.ptrace_scope`** variable in the file **`/etc/sysctl.d/10-ptrace.conf`** to 0

The last solution turns off the security measure permanently, it is not a good idea (at least on a facility)

```
0 ("classic ptrace permissions")
       No additional restrictions on operations that perform
       PTRACE_MODE_ATTACH checks (beyond those imposed by the
       commoncap and other LSMs).

       The use of PTRACE_TRACEME is unchanged.

1 ("restricted ptrace") [default value]
       When performing an operation that requires a
       PTRACE_MODE_ATTACH check, the calling process must either have
       the CAP_SYS_PTRACE capability in the user namespace of the
       target process or it must have a predefined relationship with
       the target process.  By default, the predefined relationship
       is that the target process must be a descendant of the caller.

       A target process can employ the prctl(2) PR_SET_PTRACER
       operation to declare an additional PID that is allowed to
       perform PTRACE_MODE_ATTACH operations on the target.  See the
       kernel source file Documentation/admin-guide/LSM/Yama.rst (or
       Documentation/security/Yama.txt before Linux 4.13) for further
       details.

       The use of PTRACE_TRACEME is unchanged.

2 ("admin-only attach")
       Only processes with the CAP_SYS_PTRACE capability in the user
       namespace of the target process may perform PTRACE_MODE_ATTACH
       operations or trace children that employ PTRACE_TRACEME.

3 ("no attach")
       No process may perform PTRACE_MODE_ATTACH operations or trace
       children that employ PTRACE_TRACEME.
```

# gdb and MPI

Let’s say that you MPI program start with:

```
int main(int argc, char **argv)
{
  int Me, Size;

  MPI_Init(&argc, &argv);

  MPI_Comm_rank(MPI_COMM_WORLD, &Me);
  MPI_Comm_size(MPI_COMM_WORLD, &Size);

   ...
```

and that you insert the following code snippets right after it →

# gdb and MPI

compiled only if DEBUGGER is defined

```
#ifdef DEBUGGER
  int    wait = 1;
  pid_t my_pid;
  char   my_host_name[200];

  gethostname(my_host_name, 200);
  my_pid = getpid();

  for(int i = 0; i < Size; i++)
    {
      if(i == Me)
        printf("task with PID %d on host %s is waiting\n",
                  my_pid, my_host_name);
      MPI_Barrier(MPI_COMM_WORLD);
    }

  while ( wait )
    sleep(1);

  MPI_Barrier(MPI_COMM_WORLD);
#endif
```

Each process print the message, forced to follow rank-order

`wait` is 1, so each process is just spinning

Once MPI procs exit the previous while they are not rushing away

A little bit more of flexibility:

```
char *env_ptr;
if( ( (env_ptr = getenv("DEBUG_THIS")) != NULL) &&
    ( strncasecmp(env_ptr, "YES", 3) == 0) )
    {
       int   wait = 1;
       pid_t my_pid;
       char  my_host_name[200];

       gethostname(my_host_name, 200);
       my_pid = getpid();

       < … >

       while ( wait )
       sleep(1);

       MPI_Barrier(MPI_COMM_WORLD);
    }
```

Now this code is always there.
It becomes active only when you define the environment variable “DEBUG_THIS” as being “YES”, which you can do at the shell prompt right before calling mpirun.

# gdb and MPI

Even more flexibility:

```
char *env_ptr;
if( ( (env_ptr = getenv("DEBUG_THIS")) != NULL) &&
    ( strncasecmp(env_ptr, "YES", 3) == 0) )
    {
       int   get_through = Me;
       pid_t my_pid;
       char  my_host_name[200];

       gethostname(my_host_name, 200);
       my_pid = getpid();

       < … >

       while ( get_through )
       sleep(1);

       MPI_Barrier(MPI_COMM_WORLD);
    }
```

**`get_through`** is is set to the MPI rank of the process, i.e. it is > 0 for all the procs but for the 0 one.
In other words, all the MPI tasks but the 0th will wait at the subsequent barrier.
This way, you can avoid to manually change **`get_through`** for *all* the tasks and unlock only the 0th

A handy alternative to  is to use **`screen`** on a single term.
**`screen`** is a utility you may have to install by yourself (or ask the sys admin to do that):
check your preferred packaging system or whatever you use to install apps ( on HPC facilities you shall compile and install in your home, however ).
Basic commands:

| | | |
|---|---|---|
| `screen` | | start the screen |
| `Ctrl+a` | `?` | get help on commands |
| | `“` | get the list of active windows |
| | `c` | create a new window |
| | `A` | rename the current window |

# Debugging **outline**

## GUI
### for GDB

1. GDB text-user-interface
2. GDB DASHBOARD
3. GDBGUI
4. EMACS
5. DDD
6. NEMIVER, ECLIPSE, NETBEANS, CODEBLOCKS, many others..

# GDB built-in tui

You can start gdb with a text-user-interface:

```
%> gdb -tui
```

Or you can activate/deactivate it from gdb itself:

| | |
|---|---|
| `(gdb)ctrl-x a` | |
| `(gdb)ctrl-x o` | change focus |
| `(gdb)ctrl-x 2` | shows assembly windows |
| `(gdb)layout src` | display src and commands |
| `asm` | display assembly and commands |
| `split` | display src, asm and commands |
| `regs` | display registers window |

# GDB built-in `tui`

```
gdb_try_breaks.c
     372       {
     373
B+>  374         if ( argc > 1)
     375           // arg 0 is the name of the program itself
     376           {
     377             printf( "\nexploring my %d argument%c:\n", argc-1, (argc>2)?'s':' ' );
     378               for ( int i = 1; i < argc; i++ )
     379                 {
     380                   printf( "\targument %d is : %s\n", i, *(argv+i) );
     381                 }
     382               printf( "\n" );
     383           }
     384
     385         else
     386
     387           printf ( "no arguments were given, using default: %d\n\n", DEFAULT_ARG1 );
     388
     389
     390         int arg1;
     391
     392         if ( argc > 1 )
     393           arg1 = atoi( *(argv+1) );
     394
     395         else
     396           arg1 = DEFAULT_ARG1;
     397
     398         int ret;
     399
     400         ret = function_1( arg1 );
native process 8943 In: main                                         L374   PC: 0x555555554d38
(gdb) l
360       in /home/luca/code/tricks/gdb_try_breaks.c
(gdb) break main
Breakpoint 1 at 0xd38: file gdb_try_breaks.c, line 374.
(gdb) r
Starting program: /home/luca/code/tricks/gdb_try_breaks

Breakpoint 1, main (argc=1, argv=0x7fffffffdaa8) at gdb_try_breaks.c:374
(gdb) 
```

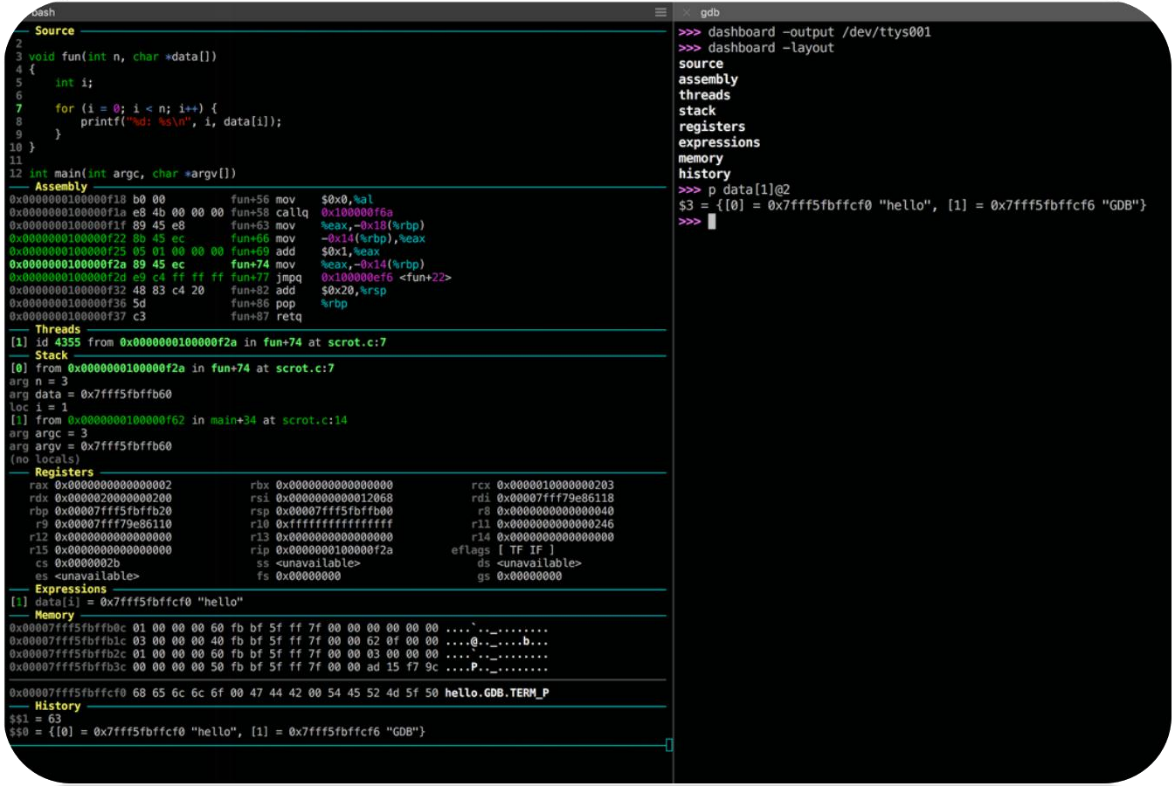
GUI for GDB

# GDB built-in `tui`

```
  ┌─gdb_try_breaks.c─────────────────────────────────────────────────────────────────┐
B+>│374        if ( argc > 1)
   │375          // arg 0 is the name of the program itself
   │376          {
   │377            printf( "\nexploring my %d argument%c:\n", argc-1, (argc>2)?'s':' ' );
   │378              for ( int i = 1; i < argc; i++ )
   │379                {
   │380                  printf( "\targument %d is : %s\n", i, *(argv+i) );
   │381                }
   │382              printf( "\n" );
   │383          }
   │384
   │385        else
   │386
   │387          printf ( "no arguments were given, using default: %d\n\n", DEFAULT_ARG1 );

B+>│0x555555554d38 <main+15>        cmpl   $0x1,-0x14(%rbp)
   │0x555555554d3c <main+19>        jle    0x555555554db7 <main+142>
   │0x555555554d3e <main+21>        cmpl   $0x2,-0x14(%rbp)
   │0x555555554d42 <main+25>        jle    0x555555554d4b <main+34>
   │0x555555554d44 <main+27>        mov    $0x73,%edx
   │0x555555554d49 <main+32>        jmp    0x555555554d50 <main+39>
   │0x555555554d4b <main+34>        mov    $0x20,%edx
   │0x555555554d50 <main+39>        mov    -0x14(%rbp),%eax
   │0x555555554d53 <main+42>        sub    $0x1,%eax
   │0x555555554d56 <main+45>        mov    %eax,%esi
   │0x555555554d58 <main+47>        lea    0x2bf(%rip),%rdi        # 0x55555555501e
   │0x555555554d5f <main+54>        mov    $0x0,%eax
   │0x555555554d64 <main+59>        callq  0x555555554680 <printf@plt>
   │0x555555554d69 <main+64>        movl   $0x1,-0xc(%rbp)

native process 9102 In: main                                          L374   PC: 0x555555554d38
(gdb) break main
Breakpoint 1 at 0xd38: file gdb_try_breaks.c, line 374.
(gdb) r
Starting program: /home/luca/code/tricks/gdb_try_breaks

Breakpoint 1, main (argc=1, argv=0x7fffffffdaa8) at gdb_try_breaks.c:374
(gdb) layout split
```

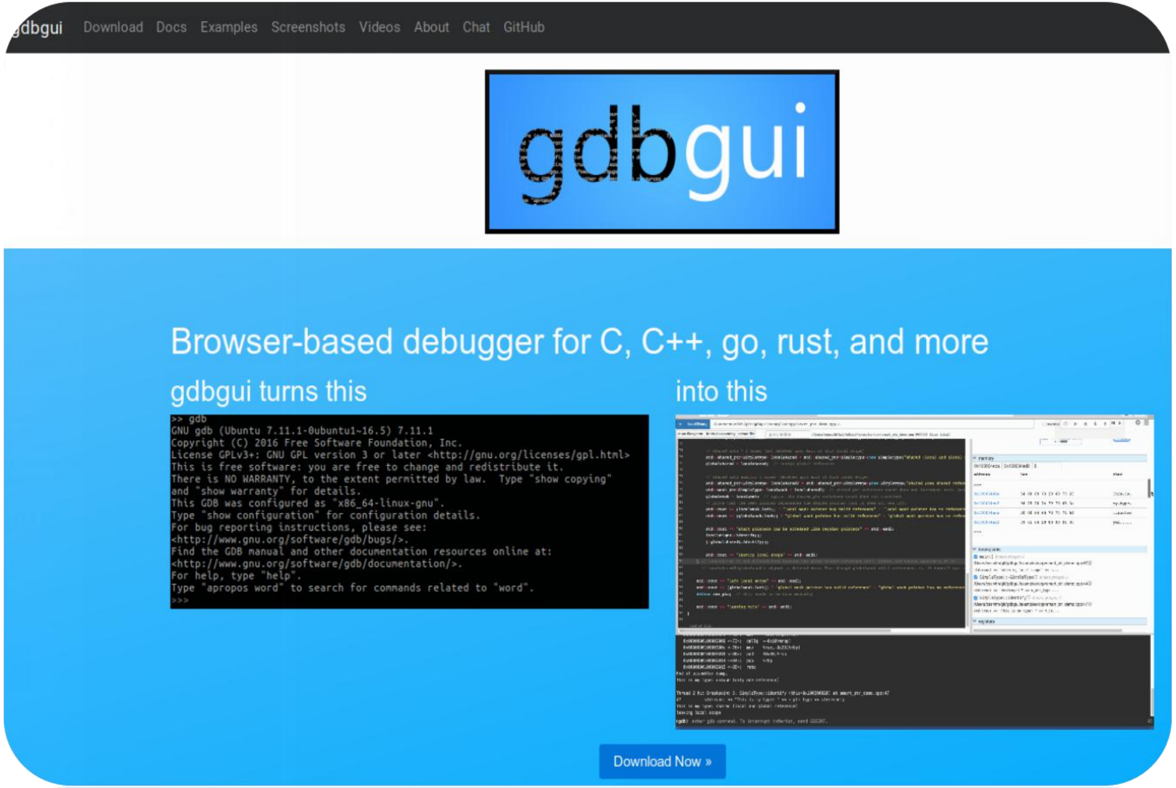
# GDB dashboard

https://github.com/cyrus-and/gdb-dashboard



# GDBgui

https://gdbgui.com/



# that’s all, have fun