# Coding Examples

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Lecture 09

B3B36PRG – Programming in C



## Overview of the Lecture







Part I

## Part 1 – Undefined behaviour and inspecting implementation





## Arguments of the main() Function

- During the program execution, the OS passes to the program the number of arguments (argc) and the arguments (argv).

  *In the case we are using OS.*
  - The first argument is the name of the program.

```
int main(int argc, char *argv[])
{
   int v;
   v = 10;
   v = v + 1;
   return argc;
}
```

lec09/var.c

- The program is terminated by the return in the main() function.
- The returned value is passed back to the OS, and it can be further used, e.g., to control the program execution.

Reminder





## Example of Compilation and Program Execution

- Building the program by the clang compiler – it automatically joins the compilation and linking of the program to the file a.out.

  **clang var.c**
- The output file can be specified, e.g., program file var.

  **clang var.c -o var**
- Then, the program can be executed as follows.

  **./var**
- The compilation and execution can be joined to a single command.

  **clang var.c -o var; ./var**
- The execution can be conditioned to successful compilation.

  **clang var.c -o var && ./var**

*Programs return value — 0 means OK.*

*Logical operator && depends on the command interpret, e.g., sh, bash, zsh.*

Reminder





## Example – Program Execution under Shell

- The return value of the program is stored in the variable $?.

  *sh, bash, zsh*
- Example of the program execution with a different number of arguments.

```
./var
./var; echo $?
1
./var 1 2 3; echo $?
4
./var a; echo $?
2
```

Reminder





## Example – Processing the Source Code by Preprocessor

- Using the -E flag, we can perform only the preprocessor step.

  gcc -E var.c

  *Alternatively* clang -E var.c

```
# 1 "var.c"
# 1 "<built-in>"
# 1 "<command-line>"
# 1 "var.c"
int main(int argc, char **argv) {
   int v;
   v = 10;
   v = v + 1;
   return argc;
}
```

lec09/var.c

Reminder





## Example – Compilation of the Source Code to Assembler

- Using the -S flag, the source code can be compiled to Assembler.

  clang -S var.c -o var.s

```
  .file "var.c"
  .text
  .globl  main
  .align  16, 0x90
  .type main,@function
main:                          # @main
  .cfi_startproc
# BB#0:
  pushq %rbp
.Ltmp2:
  .cfi_def_cfa_offset 16
.Ltmp3:
  .cfi_offset %rbp, -16
  movq  %rsp, %rbp
.Ltmp4:
  .cfi_def_cfa_register %rbp
  movl  $0, -4(%rbp)
  movl  %edi, -8(%rbp)
  movq  %rsi, -16(%rbp)
  movl  $10, -20(%rbp)
  movl  -20(%rbp), %edi
  addl  $1, %edi
  movl  %edi, -20(%rbp)
  movl  -8(%rbp), %eax
  popq  %rbp
  ret
.Ltmp5:
  .size main, .Ltmp5-main
  .cfi_endproc

  .ident  "FreeBSD clang version 3.4.1 (tags
     /RELEASE_34/dot1-final 208032) 20140512"
  .section  ".note.GNU-stack","",@progbits
```





## Undefined Behaviour

- Some statements can cause **undefined behavior** according to the C standard.
  - c = (b = a + 2) - (b - 1);
  - j = i * i++;
- The program may behave differently according to the used compiler but may also not compile or may not run, or it may even crash and behave erratically or produce meaningless results.
- It may also happen if variables are used without initialization.
- Avoid statements that may produce undefined behavior!

## Example of Undefined Behaviour

- C standard does not define the behavior for the overflow of the integer value (`signed`)
  - E.g., for the complement representation, the expression can be `127 + 1` of the `char` equal to `-128` (see `lec09/demo-loop_byte.c`).
  - Representation of integer values may depend on the architecture and can be different, e.g., when binary or inverse code is used.
- Implementation of the defined behavior can be computationally expensive, and thus, the behavior is not defined by the standard.
- Behaviour is not defined and depends on the compiler, e.g. `clang` and `gcc` without/with the optimization `-O2`.
  - ```
    for (int i = 2147483640; i >= 0; ++i) {
       printf("%i %x\n", i, i);
    }
    ```
    lec09/int_overflow-1.c

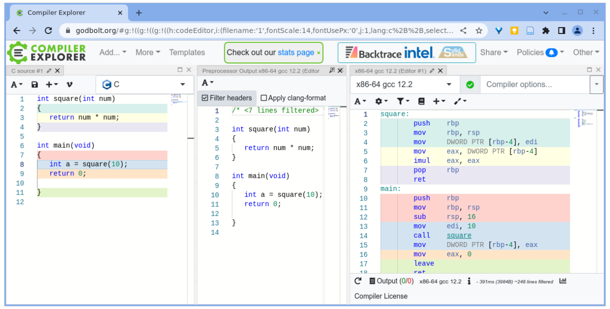
    Without the optimization, the program prints 8 lines, for `-O2`, the program compiled by `clang` prints 9 lines, and `gcc` produces an infinite loop.
  - ```
    for (int i = 2147483640; i >= 0; i += 4) {
       printf("%i %x\n", i, i);
    }
    ```
    lec09/int_overflow-2.c

    Program compiled by `gcc` and `-O2` crashed. *Take a look at the assembler code using the compiler parameter `-S`.*





## Compiler Explorer



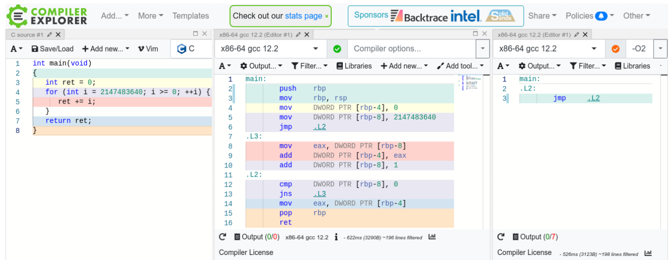
https://godbolt.org/z/K9r1eWqcd





## Compiler Explorer – Analysis of the Optimized Code

- Effect of the code optimization `-O2` on the resulting code that contains undefined behavior (integer overflow).

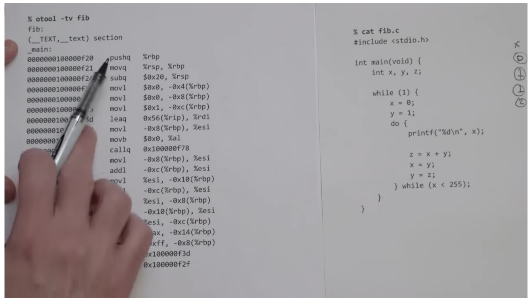


https://godbolt.org/z/G3GEz4vbv





## Comparing C to Machine Code



https://www.youtube.com/watch?v=yOyaJXpAYZQ





# Part II

# Part 2 – Debugging





## Debugging the Code

- Principally there are two ways of debugging: **stepping** (program animation) and **logging**.
- **Stepping** is interactive debugging that might be suitable for relatively small, less complex codes and non-real-time applications.
  - In stepping, we use **breakpoints**, **watches** to stop the program execution at certain conditions and then inspect variables and stepping next instructions.
  - In C, most of the visual interfaces use **gdb**.
  - It might be suitable to compile the program with **debugging information**, e.g., using `-g` flag.

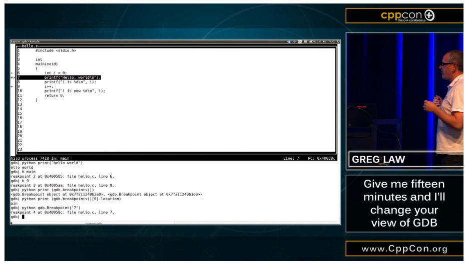
    `clang -g main.c -o main`
- **Logging** can range from simple print messages to `stderr` to sophisticated **loggers**, such as `log4c`.
- We can further enjoy tools such as **valgrind** for dynamic analysis, specifically for bugs in memory access. *For more than 20 years, see https://valgrind.org/.*





## Debugging using gdb (or VS Code)

- Interactive examples of debugging or watch the available examples and tutorials.




- *CppCon 2015: Greg Law " Give me 15 minutes & I'll change your view of GDB."*

https://www.youtube.com/watch?v=PorfLSr3DDI





## Example of using `valgrind`

```
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
   int *a = malloc(2 * sizeof *a);

   for (int i = 0; i < 3; ++i) {
      a[i] = i;
   }
   for (int i = 0; i < 3; ++i) {
      printf("%d\n", a[i]);
   }
   //free(a);
   return 0;
}
```

```
$ clang -g mem_val.c -o mem_val
$ valgrind ./mem_val
....
==87826== Invalid write of size 4
==87826==    at 0x201999: main (mem_val.c:9)
==87826==  Address 0x5400048 is 0 bytes after
     a block of size 8 alloc'd
==87826==    at 0x4853B74: malloc (in /usr/
     local/libexec/valgrind/vgpreload_memcheck-
     amd64-freebsd.so)
==87826==    by 0x201978: main (mem_val.c:6)
==87826==
....
0
```

lec09/mem_val.c

- Try to compile the program with and w/o `-g`.
- See the **valgrind** output with and w/o calling `free()`.





## Example of `malloc` failure

```
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
   const size_t size = 20 * 1024 * 1024;
     // 20 MB
   size_t *a = malloc(size * sizeof *a);
     // 20 MB * sizeof(long)
   if (!a) {
      fprintf(stderr, "ERROR: malloc
       failed!\n");
      return -1;
   }
   for (size_t i = 0; i < size; ++i) {
      a[i] = i;
   }
   fprintf(stderr, "INFO: array of %lu
    size_t values initialized.\n", size)
```

```
$ clang mem_fail.c -o mem_fail
$ bash
$ ulimit -d 10 -m 10 -v 1000000  -w 0
$ ./mem_fail
INFO: array of 20971520 size_t values
     initialized.
$ exit
exit
$ bash
$ ulimit -d 10 -m 10 -v 10000  -w 0
$ ./mem_fail
ERROR: malloc failed!
```

lec09/mem_fail.c

- See `ulimit -help` and set the memory limits.
- Run it in the separate shell to recover from too restrictive settings.

# Part III

## Part 3 – Examples





## Communication using Named Pipes

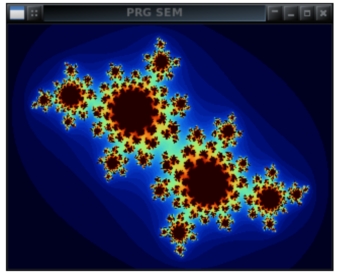
- Implement two applications **main** and **module** that communicates through named **pipes**. `lec09/pipes/create_pipes.sh`
  `lec09/pipes/prg_lec09_main.c`, `lec09/pipes/prg-lec09-module.c`
- **module** opens pipe `/tmp/prg-lec09.pipe` for reading.
- **main** opens pipe `/tmp/prg-lec09.pipe` for writting.
- The applications communicate using a simple character oriented protocol.
  - `'s'` – stop.
  - `'e'` – enable (start).
  - `'b'` – bye.
  - `'1'`–`'5'` – set sleep period to 50 ms, 100 ms, 200 ms, 500 ms, 1000 ms.
- The pipe can be opened using functions from the `prg_io_nonblock` library.
  `lec09/pipes/prg_io_nonblock.h`, `lec09/pipes/prg_io_nonblock.c`
- Examine the provided code and test it. *The example is without threads.*





## Remote Control of Computational Application (Module) – Semetral Project

- Implement multi-thread application with separate threads for sources of asynchronous events.
  - User input from `stdin` (**keyboard**).
  - Pipe reading from the computational module.
- Use simple visualization using `sdl`.
- Implement the main program logic in the main (boss) thread using `event queue`.
  - The main thread reads from the queue.
  - The secondary threads (keyboard and pipe) write to the queue.
- The main thread manages output resources (**visualization**, **write to pipe**).
  Eventually also `stdout` or even `stderr`, which is, however, not required.
- Use the example of a multi-thread application from Lecture 8. `https://cw.fel.cvut.cz/wiki/courses/b3b36prg/semestral-project/start`








## Summary of the Lecture





## Topics Discussed

- Program compilation.
- Undefined behaviour.
- Comments on debugging.
- Named pipes.
- Semetral project.