

## Coding Examples

Jan Faigl

Department of Computer Science  
Faculty of Electrical Engineering  
Czech Technical University in Prague

Lecture 09

PRG – Programming in C

## Overview of the Lecture

- Part 1 – Undefined behaviour and inspecting implementation
  - Program Compilation
  - Undefined Behaviour
  - Comparing C to Machine Code
- Part 2 – Debugging
  - Debugging
- Part 3 – Examples
  - Named pipes
  - Multi-thread Applications – Semestral Project

Program Compilation

Undefined Behaviour

Comparing C to Machine Code

## Part I

## Part 1 – Undefined behaviour and inspecting implementation

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## Arguments of the main() Function

- During the program execution, the OS passes to the program the number of arguments (`argc`) and the arguments (`argv`).
  - The first argument is the name of the program.
    - `1 int main(int argc, char *argv[])`
    - `2 {`
    - `3 int v;`
    - `4 v = 10;`
    - `5 v = v + 1;`
    - `6 return argc;`
    - `7 }`
- 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 use, e.g., to control the program execution.

*In the case we are using OS.*

`lec09/var.c`

*Reminder*

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## 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 # 1 "var.c"
2 # 1 "<built-in>"
3 # 1 "<command-line>"
4 # 1 "var.c"
5 int main(int argc, char **argv) {
6     int v;
7     v = 10;
8     v = v + 1;
9     return argc;
10 }
```

`lec09/var.c`

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## 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*

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## 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`

```
1 .file "var.c"
2 .text
3 .globl main
4 .align 16,0x90
5 .type main,@function
6 main:
7     # @main
8     # BB#0:
9     pushq %rbp
10    .Ltmp2:
11    .cfi_def_cfa_offset 16
12    .Ltmp3:
13    .cfi_offset %rbp, -16
14    movq %rsp, %rbp
15    .Ltmp4:
16    .cfi_def_cfa_register %rbp
17    movl $0, -4(%rbp)
18    movl %edi, -8(%rbp)
19    movq %rsi, -16(%rbp)
20    movl $10, -20(%rbp)
21    movl -20(%rbp), %edi
22    addl $1, %edi
23    movl %edi, -20(%rbp)
24    movl -8(%rbp), %eax
25    popq %rbp
26    ret
27    .Ltmp5:
28    .size main, .Ltmp5-main
29    .cfi_endproc
30
31
32    .ident "FreeBSD clang version 3.4.1 (
33    tags/RELEASE_34/dot1-final 208032)
34    20140512"
35    .section ".note.GNU-stack","",
36    @progbits
```

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## 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 different number of arguments.
  - `./var`
  - `./var; echo $?`
  - `1`
  - `./var 1 2 3; echo $?`
  - `4`
  - `./var a; echo $?`
  - `2`

*Reminder*

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Program Compilation Undefined Behaviour Comparing C to Machine Code

## Undefined Behaviour

- There are some statements that can cause **undefined behavior** according to the C standard.
  - `c = (b = a + 2) - (b - 1);`
  - `j = i * i++;`
- The program may behaves 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 happened if variables are used without initialization.
- Avoid statements that may produce undefined behavior!**

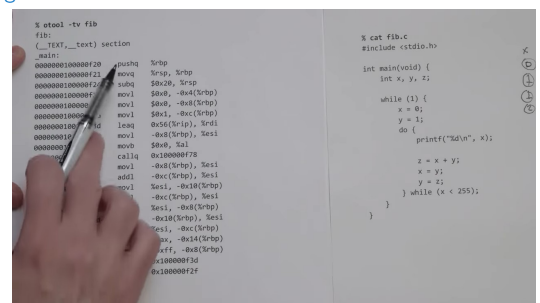
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### Example of Undefined Behaviour

- C standard does not define the behaviour 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 behaviour can be computationally expensive, and thus the behaviour 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 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 to the asm code using the compiler parameter -S.](#)

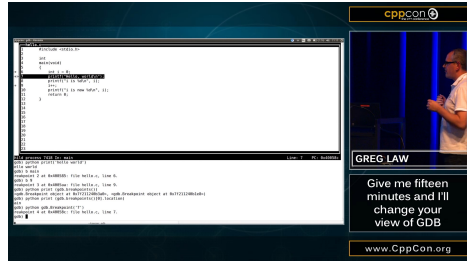
### Comparing C to Machine Code



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

### Debugging using gdb (or VS Code)

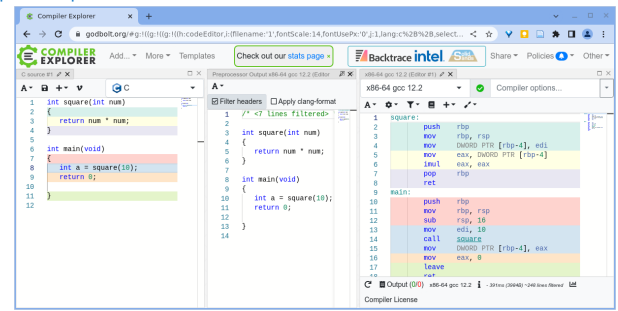
- Interactive example of debugging or watch the available examples and tutorials.



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

<https://www.youtube.com/watch?v=PorFLS3r3DDI>

### Compiler Explorer

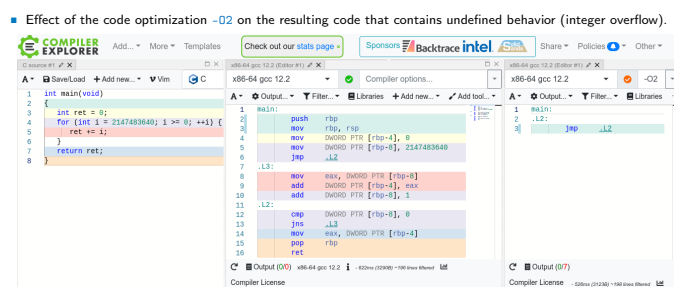


<https://godbolt.org/z/K9rieWqcd>

### Part II

### Part 2 – Debugging

### Compiler Explorer – Analysis of the Optimized Code



<https://godbolt.org/z/G3GEz4vrv>

### 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 uses **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/>.*

### 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 0x540048 is 0 bytes after
a block of size 8 allocated
==87826== at 0x4853B74: malloc (in /usr/
local/libexec/valgrind/vgpreload_memcheck-
amd64-freebsd.so)
==87826== by 0x201978: main (mem_val.c:6)
==87826==
.....
0
```

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

### Part III

### Part 3 – Examples

## Communication using Named Pipes

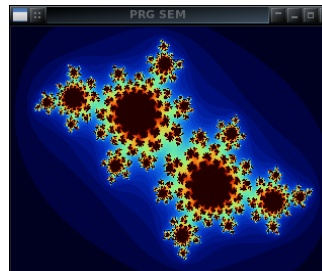
- Implement two applications `main` and `module` that communicates through named pipes.
  - `lec09/pipes/create_pipes.sh`
  - `lec09/pipes/prg-lec09-main.c`, `lec09/pipes/prg-lec09-module.c`
- `module` opens pipe `/tmp/prg-lec09.pipe` for reading.
- `main` opens pipe `/tmp/prg-lec09.pipe` for writing.
- The applications communicate using simple character orienter 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 provide code and test it. *The example is without threads.*

## Topics Discussed

- Program compilation.
- Undefined behaviour.
- Comments on debugging.
- Named pipes.
- Semetral project.
- Next: ANSI C, C99, C11 – differences and extensions

## 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 multi-thread application from Lecture 8. <https://cw.fel.cvut.cz/wiki/courses/b3b36prg/semestral-project/start>



## Summary of the Lecture