# C AND ASSEMBLY

BLG413E – System Programming, Practice Session 1

# Compiling, linking and running hello.asm

- By convention, NASM (The Netwide Assembler) source files have the **.asm** extension.
- hello.asm:

```
segment .data                ;initialized data definitions
msg db "Hello, world!",10 ;initialized data bytes (10 is ASCII code for newline)
len equ $ - msg              ;length of msg

segment .text                ;the start of a group of instructions to be assembled
global _start                ;entry label for the program

_start:
    mov eax,4                ;write system call
    mov ebx,1                ;output descriptor (standart output)
    mov ecx,msg              ;start of output buffer
    mov edx,len              ;length of output
    int 80h                  ;software interrupt 80h to implement the system call

    mov eax,1                ;exit system call
    mov ebx,0                ;return status: success
    int 80h                  ;software interrupt 80h to implement the system call
```

starting a comment

# Compiling, linking and running hello.asm

- **Compilation using NASM:**

  nasm -f elf32 hello.asm -o hello.o

  Executable and Linkable Format (32 bit)

- **Linking:**

  ld hello.o -o hello

  - **Note:** If the entry label of is not _START, then it must be specified using the –e flag:

    ld hello.o -o hello –e label

- **Running:**

  ./hello

# Creating and interpreting a listing file

- A listing file (containing both the source listing of the assembly program and the hexadecimal machine code for each operation) can be created by using the -l option:

  nasm -f elf32 hello.asm -l hello.lis -o hello.o

- hello.lis:

```
 1                                          segment .data
 2 00000000 48656C6C6F2C20776F-             msg db "Hello, world!",10
 3 00000009 726C64210A
 4                                          len equ $ - msg
 5
 6                                          segment .text
 7                                          global _start
 8
 9                                          _start:
10 00000000 B804000000                          mov eax,4
11 00000005 BB01000000                          mov ebx,1
12 0000000A B9[00000000]                        mov ecx,msg
13 0000000F BA0E000000                          mov edx,len
14 00000014 CD80                                int 80h
15
16 00000016 B801000000                          mov eax,1
17 0000001B BB00000000                          mov ebx,0
18 00000020 CD80                                int 80h
```

relative address

opcode for mov eax

immediate argument 4 (representation: 32-bit little endian)

# Russian peasant method of multiplication

- Write the numbers on top of two columns.
- At each step:
  - divide the number on the 1st column by 2 (ignoring the remainder),
  - multiply the number on the 2nd column by 2,
  - stop when the number on the 1st column becomes 0.
- The result is the sum of corresponding numbers on the 2nd column with odd numbers on the 1st column.

| | |
|---|---|
| 19 | **22** |
| 9 | **44** |
| 4 | 88 |
| 2 | 176 |
| 1 | **352** |
| 0 | |
| **19x22 = 22+44+352 = 418** | |

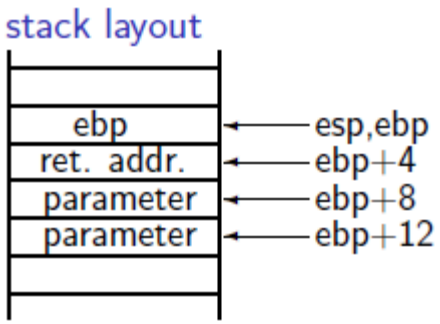
# ASM code (russian.asm) conforming to the C language calling conventions

```
segment .text
global russian

russian:
    push ebp            ;save the old base pointer value
    mov  ebp,esp        ;base pointer <- stack pointer

    mov  ecx,[ebp+8]    ;first argument
    mov  edx,[ebp+12]   ;second argument
    xor  eax,eax        ;clear eax (used for returning the result)
next:
    shr  ecx,1          ;divide the number on the 1st column by 2
    jnc  even           ;even number (no carry) on the 1st column
    add  eax,edx        ;odd number: add the 2nd column to the result
even:
    shl  edx,1          ;multiply the number on the 2nd column by 2
    cmp  ecx,0          ;stop when the number on the 1st column becomes 0
    jne  next           ;continue if it is not 0

    pop  ebp            ;restore base pointer
    ret                 ;jump to return address
```



# Usage of assemby function in a C program (rusmain.c)

- A simple C program using the russian() assembly function for multiplying two numbers.

```c
#include <stdio.h>

int russian(int x, int y);

int main(void)
{
    int x, y, z;

    printf("Enter numbers: ");
    scanf("%d %d", &x, &y);
    z = russian(x, y);
    printf("The product is: %d\n", z);
    return 0;
}

```

# Building the executable from russian.asm and rusmain.c

- Compile the assembly program (NASM):

  nasm -f elf32 russian.asm -o russian.o

- Compile the C program (gcc):

  gcc -c rusmain.c -o rusmain.o

- Link them into an executable using gcc:

  gcc russian.o rusmain.o -o russian

# Disassembling instructions in an object file

- Displays the machine instructions from an object file.
- Disassembly is done only on the sections containing instructions.

# Disassembling russian.o

nasm -f elf32 russian.asm -o russian.o

objdump -d russian.o

```
russian.o:     file format elf32-i386

Disassembly of section .text:

00000000 <russian>:
   0:   55                      push   %ebp
   1:   89 e5                   mov    %esp,%ebp
   3:   8b 4d 08                mov    0x8(%ebp),%ecx
   6:   8b 55 0c                mov    0xc(%ebp),%edx
   9:   31 c0                   xor    %eax,%eax

0000000b <next>:
   b:   d1 e9                   shr    %ecx
   d:   73 02                   jae    11 <even>
   f:   01 d0                   add    %edx,%eax

00000011 <even>:
  11:   d1 e2                   shl    %edx
  13:   83 f9 00                cmp    $0x0,%ecx
  16:   75 f3                   jne    b <next>
  18:   5d                      pop    %ebp
  19:   c3                      ret
```

relative branching address

# Disassembling rusmain.o

gcc -c rusmain.c -o rusmain.o

objdump -d rusmain.o

```
rusmain.o:     file format elf32-i386

Disassembly of section .text:

00000000 <main>:
   0:   55                      push   %ebp
   1:   89 e5                   mov    %esp,%ebp
   3:   83 e4 f0                and    $0xfffffff0,%esp
   6:   83 ec 20                sub    $0x20,%esp
   9:   b8 00 00 00 00          mov    $0x0,%eax
   e:   89 04 24                mov    %eax,(%esp)
  11:   e8 fc ff ff ff    printf call   12 <main+0x12>
  16:   b8 10 00 00 00          mov    $0x10,%eax
  1b:   8d 54 24 18             lea    0x18(%esp),%edx
  1f:   89 54 24 08             mov    %edx,0x8(%esp)
  23:   8d 54 24 14             lea    0x14(%esp),%edx
  27:   89 54 24 04             mov    %edx,0x4(%esp)
  2b:   89 04 24                mov    %eax,(%esp)
  2e:   e8 fc ff ff ff    scanf call   2f <main+0x2f>
  33:   8b 54 24 18             mov    0x18(%esp),%edx
  37:   8b 44 24 14             mov    0x14(%esp),%eax
  3b:   89 54 24 04             mov    %edx,0x4(%esp)
  3f:   89 04 24                mov    %eax,(%esp)
  42:   e8 fc ff ff ff   russian call   43 <main+0x43>
  47:   89 44 24 1c             mov    %eax,0x1c(%esp)
  4b:   b8 16 00 00 00          mov    $0x16,%eax
  50:   8b 54 24 1c             mov    0x1c(%esp),%edx
  54:   89 54 24 04             mov    %edx,0x4(%esp)
  58:   89 04 24                mov    %eax,(%esp)
  5b:   e8 fc ff ff ff    printf call   5c <main+0x5c>
  60:   b8 00 00 00 00          mov    $0x0,%eax
  65:   c9                      leave
  66:   c3                      ret
```

As linking is not done, addresses for printf, scanf and russian functions are not available.

# Dynamic linking of shared libraries

gcc russian.o rusmain.o -o russian.dynamic

objdump -d russian.dynamic

```
08048440 <russian>:
 8048440:       55                      push   %ebp
 8048441:       89 e5                   mov    %esp,%ebp
 8048443:       8b 4d 08                mov    0x8(%ebp),%ecx
 8048446:       8b 55 0c                mov    0xc(%ebp),%edx
 8048449:       31 c0                   xor    %eax,%eax

0804844b <next>:
 804844b:       d1 e9                   shr    %ecx
 804844d:       73 02                   jae    8048451 <even>
 804844f:       01 d0                   add    %edx,%eax

08048451 <even>:
 8048451:       d1 e2                   shl    %edx
 8048453:       83 f9 00                cmp    $0x0,%ecx
 8048456:       75 f3                   jne    804844b <next>
 8048458:       5d                      pop    %ebp
 8048459:       c3                      ret
```

```
0804845c <main>:
 804845c:       55                      push   %ebp
 804845d:       89 e5                   mov    %esp,%ebp
 804845f:       83 e4 f0                and    $0xfffffff0,%esp
 8048462:       83 ec 20                sub    $0x20,%esp
 8048465:       b8 a0 85 04 08          mov    $0x80485a0,%eax
 804846a:       89 04 24                mov    %eax,(%esp)
 804846d:       e8 ce fe ff ff          call   8048340 <printf@plt>
 8048472:       b8 b0 85 04 08          mov    $0x80485b0,%eax
 8048477:       8d 54 24 18             lea    0x18(%esp),%edx
 804847b:       89 54 24 08             mov    %edx,0x8(%esp)
 804847f:       8d 54 24 14             lea    0x14(%esp),%edx
 8048483:       89 54 24 04             mov    %edx,0x4(%esp)
 8048487:       89 04 24                mov    %eax,(%esp)
 804848a:       e8 e1 fe ff ff          call   8048370 <__isoc99_scanf@plt>
 804848f:       8b 54 24 18             mov    0x18(%esp),%edx
 8048493:       8b 44 24 14             mov    0x14(%esp),%eax
 8048497:       89 54 24 04             mov    %edx,0x4(%esp)
 804849b:       89 04 24                mov    %eax,(%esp)
 804849e:       e8 9d ff ff ff          call   8048440 <russian>
 80484a3:       89 44 24 1c             mov    %eax,0x1c(%esp)
 80484a7:       b8 b6 85 04 08          mov    $0x80485b6,%eax
 80484ac:       8b 54 24 1c             mov    0x1c(%esp),%edx
 80484b0:       89 54 24 04             mov    %edx,0x4(%esp)
 80484b4:       89 04 24                mov    %eax,(%esp)
 80484b7:       e8 84 fe ff ff          call   8048340 <printf@plt>
 80484bc:       b8 00 00 00 00          mov    $0x0,%eax
 80484c1:       c9                      leave
 80484c2:       c3                      ret
```

- Addresses for printf, scanf and russian functions are available.
- russian function is available, but printf and scanf functions are not.

# Static linking of shared libraries

- gcc -static russian.o rusmain.o -o russian.static
- objdump -d russian.static
- russian, printf and scanf functions are available.
- File sizes of executables:
  - russian.static (725.5 KB) is much bigger than russian.dynamic (7.1 KB)
- List of shared libraries required by the program:

  ldd ./russian.dynamic → libc.so.6

  ldd ./russian.static → not a dynamic executable (shared libraries are bound during linking)

# Monitoring the runtime system calls

- strace ./russian.static

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ strace ./
russian.static
execve("./russian.static", ["./russian.static"], [/* 39 vars */]) = 0
uname({sys="Linux", node="musty-VirtualBox", ...}) = 0
brk(0)                                  = 0x8217000
brk(0x8217d40)                          = 0x8217d40
set_thread_area({entry_number:-1 -> 6, base_addr:0x8217840, limit:1048575, seg_3
2bit:1, contents:0, read_exec_only:0, limit_in_pages:1, seg_not_present:0, useab
le:1}) = 0
brk(0x8238d40)                          = 0x8238d40
brk(0x8239000)                          = 0x8239000
fstat64(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 2), ...}) = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x3f
5000
fstat64(0, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 2), ...}) = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x5d
3000
write(1, "Enter numbers: ", 15Enter numbers: )         = 15
read(0, 34 15 → values are entered via keyboard
"34 15\n", 1024)                = 6
write(1, "The product is: 510\n", 20The product is: 510
)   = 20
exit_group(0)                           = ?
```

# Monitoring the runtime system calls

- strace ./russian.dynamic

open libc.so.6 → shared libraries are bound at runtime

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ strace ./
russian.dynamic
execve("./russian.dynamic", ["./russian.dynamic"], [/* 39 vars */]) = 0
brk(0)                                  = 0x84a8000
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
mmap2(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x14
a000
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat64(3, {st_mode=S_IFREG|0644, st_size=67261, ...}) = 0
mmap2(NULL, 67261, PROT_READ, MAP_PRIVATE, 3, 0) = 0x307000
close(3)                                = 0
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
open("/lib/i386-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\1\1\1\0\0\0\0\0\0\0\0\0\3\0\3\0\1\0\0\0000\226\1\0004\0\0\0"...
, 512) = 512
fstat64(3, {st_mode=S_IFREG|0755, st_size=1713640, ...}) = 0
mmap2(NULL, 1723100, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x3
8b000
mmap2(0x52a000, 12288, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE
, 3, 0x19f) = 0x52a000
mmap2(0x52d000, 10972, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS
, -1, 0) = 0x52d000
close(3)                                = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x76
0000
set_thread_area({entry_number:-1 -> 6, base_addr:0x760900, limit:1048575, seg_32
bit:1, contents:0, read_exec_only:0, limit_in_pages:1, seg_not_present:0, useabl
e:1}) = 0
mprotect(0x52a000, 8192, PROT_READ)     = 0
mprotect(0x8049000, 4096, PROT_READ)    = 0
mprotect(0x63a000, 4096, PROT_READ)     = 0
munmap(0x307000, 67261)                 = 0
fstat64(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 2), ...}) = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0xbb
0000
fstat64(0, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 2), ...}) = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x11
0000
write(1, "Enter numbers: ", 15Enter numbers: )         = 15
read(0, 34 51
"34 51\n", 1024)                = 6
brk(0)                                  = 0x84a8000
brk(0x84c9000)                          = 0x84c9000
write(1, "The product is: 1734\n", 21The product is: 1734
)  = 21
exit_group(0)                           = ?
```

# Monitoring the library calls

ltrace ./russian.static

ltrace ./russian.dynamic

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ ltrace ./
russian.static
ltrace: Couldn't find .dynsym or .dynstr in "./russian.static"
```

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ ltrace ./
russian.dynamic
__libc_start_main(0x804845c, 1, 0xbfa7bd34, 0x80484d0, 0x8048540 <unfinished ...
>
printf("Enter numbers: ")                          = 15
__isoc99_scanf(0x80485b0, 0xbfa7bc84, 0xbfa7bc88, 0x143235, 0x9d0270Enter number
s: 34 15
) = 2
printf("The product is: %d\n", 510The product is: 510
)              = 20
+++ exited (status 0) +++
```

# Listing symbols in an object file

nm russian.o

nm rusmain.o

- t: text, T: text (global), U: undefined (imported)

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ nm russian.o
00000011 t even
0000000b t next
00000000 T russian
```

```
musty@musty-VirtualBox:/media/sf_virtualbox_shared_folder/ps1/russian$ nm rusmain.o
         U __isoc99_scanf
00000000 T main
         U printf
         U russian
```

nm /lib/libc.so.6 → nm -D /lib/i386-linux-gnu/libc.so.6

dynamic

- printf etc…

# Debugging

- **Compiling and linking:**

  nasm -f elf32 -g russian.asm

  gcc -c -g rusmain.c

  gcc -g russian.o rusmain.o -o russian

- **Running the debugger:**

  gdb ./russian

- **Getting help:**

  help (all) → get list of classes of commands

  help breakpoints → breakpoints

  help running → running the program

  help data → examining data

  help info → list of info subcommands

# Debugging: Breakpoints

- Setting a breakpoint:

  break *function_name*

  break *line_number*

- Removing a breakpoint:

  clear *function_name*

  clear *line_number*

# Debugging: Breakpoints

```
(gdb) break russian
Breakpoint 1 at 0x8048443
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian
Enter numbers: 12 20

Breakpoint 1, 0x08048443 in russian ()
(gdb) continue
Continuing.
The product is: 240
[Inferior 1 (process 2294) exited normally]
```

skipping some instructions !

```
08048440 <russian>:
 8048440:       55              push   %ebp
 8048441:       89 e5           mov    %esp,%ebp
 8048443:       8b 4d 08        mov    0x8(%ebp),%ecx
 8048446:       8b 55 0c        mov    0xc(%ebp),%edx
 8048449:       31 c0           xor    %eax,%eax

0804844b <next>:
 804844b:       d1 e9           shr    %ecx
 804844d:       73 02           jae    8048451 <even>
 804844f:       01 d0           add    %edx,%eax

08048451 <even>:
 8048451:       d1 e2           shl    %edx
 8048453:       83 f9 00        cmp    $0x0,%ecx
 8048456:       75 f3           jne    804844b <next>
 8048458:       5d              pop    %ebp
 8048459:       c3              ret
```

# Debugging: Breakpoints

```
(gdb) clear russian
Deleted breakpoint 1
(gdb) break main
Breakpoint 2 at 0x8048465: file rusmain.c, line 9.
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian

Breakpoint 2, main () at rusmain.c:9
9           printf("Enter numbers: ");
(gdb) continue
Continuing.
Enter numbers: 10 23
The product is: 230
[Inferior 1 (process 2297) exited normally]
```

the first executable command in main (int x, y, z; is skipped)

# Debugging: Breakpoints

```
(gdb) clear main
Deleted breakpoint 2
(gdb) break 9
Breakpoint 3 at 0x8048465: file rusmain.c, line 9.
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian

Breakpoint 3, main () at rusmain.c:9
9           printf("Enter numbers: ");
(gdb) continue
Continuing.
Enter numbers: 15 22
The product is: 330
[Inferior 1 (process 2299) exited normally]
```

# Debugging: Running

- start : run the debugged program until the beginning of the main procedure
- run : start debugged program
- continue : continue program being debugged
- next : causes the debugger to execute the current command, stepping over function calls
- nexti : shows the next machine instruction, rather than source line (stepping over function calls)
- step : causes the debugger to execute the current command, stepping into function calls
- stepi : step by machine instructions, rather than source lines (stepping into function calls)

- *Note: "next 5", "step 5", "nexti 5" and "stepi 5" repeat same 5 times*

# Debugging: Scenarios

- <u>Scenario1:</u>

  break russian

  run

  //see effects of next, nexti, step and stepi

  continue

- <u>What you will observe:</u>
  - next and step have the same effect inside assembly code. They both cause the debugger to go to the next label.
  - nexti and stepi have the same effect inside the assembly code. They both cause the debugger to go to the next instruction.

# Debugging: Scenarios

- <u>Scenario2:</u>

  clear russian

  start // stops at beginning of main function

  //see effects of next, nexti, step and stepi

- <u>What you will observe:</u>
  - The debugger does not step into shared library functions using next.
  - step causes the debugger to step into shared library functions.

# Debugging: Scenarios

- Compile and link sum.c (producing debug information using –g flag):
  - gcc –g sum.c –o sum

- Scenario3:

  start

  //see effects of next, nexti, step and stepi

- What you will observe:
  - step can be used here to step into user defined C function sum().

```c
#include <stdio.h>

int sum(int x, int y){
    int result;
    result = x+y;
    return result;
};

int main(void)
{
    int x, y, z;

    printf("Enter numbers: ");
    scanf("%d %d", &x, &y);
    z = sum(x, y);
    printf("The sum is: %d\n", z);
    return 0;
}
```

# Debugging: info

- <u>info breakpoints:</u>

```
(gdb) break russian
Breakpoint 1 at 0x8048443
(gdb) break 12
Breakpoint 2 at 0x80484a7: file rusmain.c, line 12.
(gdb) info breakpoints
Num     Type           Disp Enb Address    What
1       breakpoint     keep y   0x08048443 <russian+3>
2       breakpoint     keep y   0x080484a7 in main at rusmain.c:12
(gdb) clear russian
Deleted breakpoint 1
(gdb) clear 12
Deleted breakpoint 2
```

# Debugging: info

- info address:

```
(gdb) info address russian
Symbol "russian" is at 0x8048440 in a file compiled without debugging.
(gdb) info address main
Symbol "main" is a function at address 0x804845c.
(gdb) info address even
Symbol "even" is at 0x8048451 in a file compiled without debugging.
(gdb) info address y
No symbol "y" in current context.
```

remember that y is not a symbol with a fixed location

# Debugging: info

- <u>info frame, backtrace and frame:</u>

```
(gdb) break russian
Breakpoint 1 at 0x8048443
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian
Enter numbers: 10 15

Breakpoint 1, 0x08048443 in russian ()
(gdb) info frame
Stack level 0, frame at 0xbffff2d0:
 eip = 0x8048443 in russian; saved eip 0x80484a3
 called by frame at 0xbffff300
 Arglist at 0xbffff2c8, args:
 Locals at 0xbffff2c8, Previous frame's sp is 0xbffff2d0
 Saved registers:
  ebp at 0xbffff2c8, eip at 0xbffff2cc
(gdb) backtrace
#0  0x08048443 in russian ()
#1  0x080484a3 in main () at rusmain.c:11
(gdb) frame
#0  0x08048443 in russian ()
```

# Debugging: Examining registers

- info registers : list of integer registers and their contents

```
(gdb) break russian
Breakpoint 1 at 0x8048443
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian
Enter numbers: 12 15

Breakpoint 1, 0x08048443 in russian ()
(gdb) info registers
eax            0xc      12
ecx            0x2      2
edx            0xf      15
ebx            0x2e6ff4 3043316
esp            0xbffff2c8       0xbffff2c8
ebp            0xbffff2c8       0xbffff2c8
esi            0x0      0
edi            0x0      0
eip            0x8048443        0x8048443 <russian+3>
eflags         0x286    [ PF SF IF ]
cs             0x73     115
ss             0x7b     123
ds             0x7b     123
es             0x7b     123
fs             0x0      0
gs             0x33     51
(gdb) info registers edx
edx            0xf      15
```

- see how the register contents change after each operation

# Debugging: Examining data

- Examine memory: x/FMT ADDRESS
  - FMT is: a repeat count followed by a format letter and a size letter.
  - Format letters: o(octal), x(hex), d(decimal), u(unsigned decimal), t(binary), f(float), a(address), i(instruction), c(char) and s(string).
  - Size letters: b(byte), h(halfword), w(word), g(giant, 8 bytes).

# Debugging: Examining data

- <u>Scenario:</u>

```
info breakpoints
// clear all previous breakpoints
break russian
run
info registers
// look at ebp and eip
// calculate ebp+8 and ebp+12
x/d [ebp+8]
x/d [ebp+12]
x/2d [ebp+8]
x/i [eip]
x/2i [eip]
```

# Debugging: Examining data

```
(gdb) break russian
Breakpoint 1 at 0x8048443
(gdb) run
Starting program: /media/sf_virtualbox_shared_folder/ps1/russian/russian
Enter numbers: 12 20
Breakpoint 1, 0x08048443 in russian ()
(gdb) info registers
eax            0xc      12
ecx            0x2      2
edx            0x14     20
ebx            0x2e6ff4 3043316
esp            0xbffff2c8       0xbffff2c8
ebp            0xbffff2c8       0xbffff2c8
esi            0x0      0
edi            0x0      0
eip            0x8048443        0x8048443 <russian+3>
eflags         0x286    [ PF SF IF ]
cs             0x73     115
ss             0x7b     123
ds             0x7b     123
es             0x7b     123
fs             0x0      0
gs             0x33     51
(gdb) x/d 0xbffff2d0
0xbffff2d0:      12
(gdb) x/d 0xbffff2d4
0xbffff2d4:      20
(gdb) x/2d 0xbffff2d0
0xbffff2d0:      12      20
(gdb) x/i 0x8048443
=> 0x8048443 <russian+3>:       mov    0x8(%ebp),%ecx
(gdb) x/2i 0x8048443
=> 0x8048443 <russian+3>:       mov    0x8(%ebp),%ecx
   0x8048446 <russian+6>:       mov    0xc(%ebp),%edx
```

x/d [ebp+8]

x/d [ebp+12]

x/2d [ebp+8]

x/i [eip]

x/2i [eip]

```
08048440 <russian>:
 8048440:       55              push   %ebp
 8048441:       89 e5           mov    %esp,%ebp
 8048443:       8b 4d 08        mov    0x8(%ebp),%ecx
 8048446:       8b 55 0c        mov    0xc(%ebp),%edx
 8048449:       31 c0           xor    %eax,%eax

0804844b <next>:
 804844b:       d1 e9           shr    %ecx
 804844d:       73 02           jae    8048451 <even>
 804844f:       01 d0           add    %edx,%eax

08048451 <even>:
 8048451:       d1 e2           shl    %edx
 8048453:       83 f9 00        cmp    $0x0,%ecx
 8048456:       75 f3           jne    804844b <next>
 8048458:       5d              pop    %ebp
 8048459:       c3              ret
```