Assembly & BombLab Introduction

15-213 (18-213): Introduction to Computer Systems
Recitation 4, Feb 4 2013

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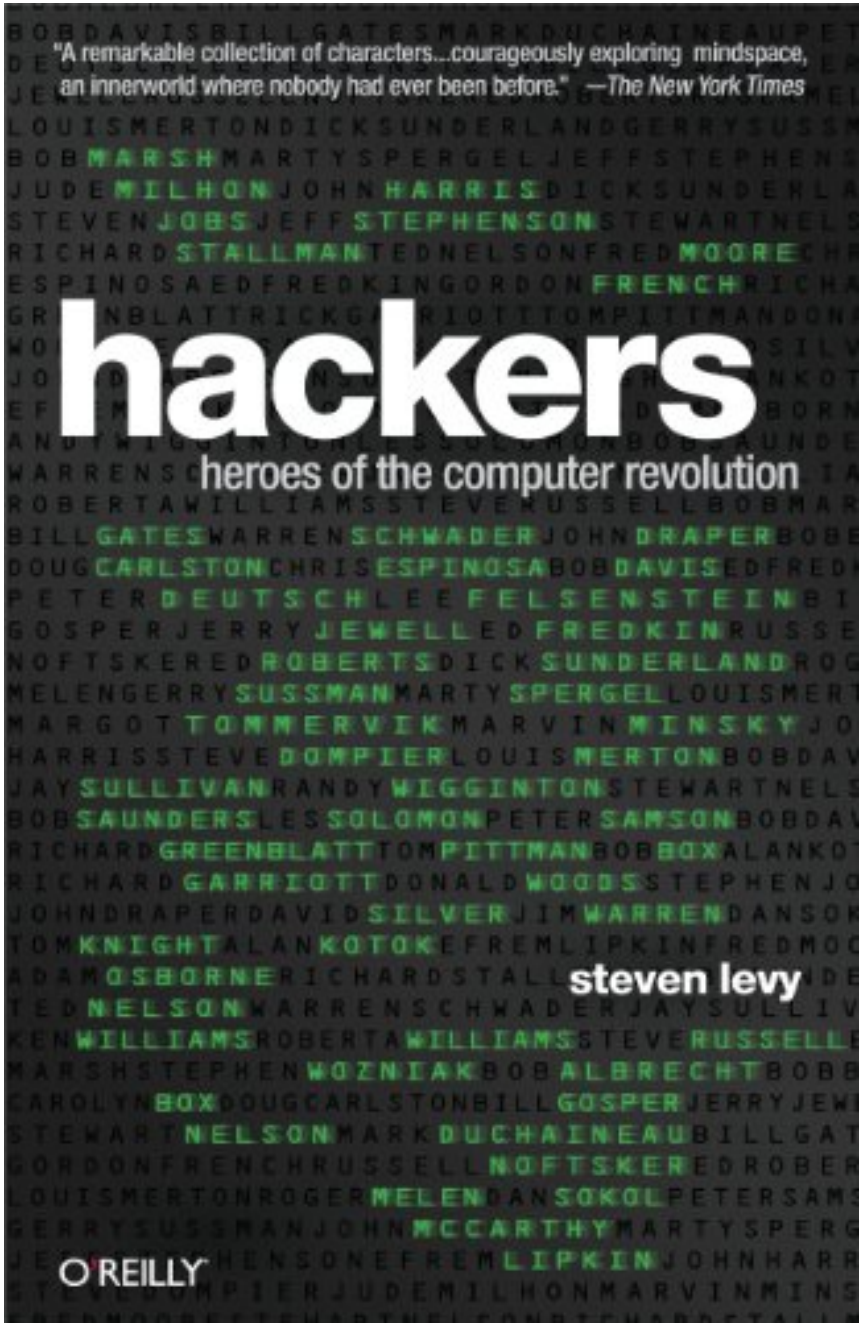
Section C, Monday 11:30 – 12:20, WeH 5302

Outline

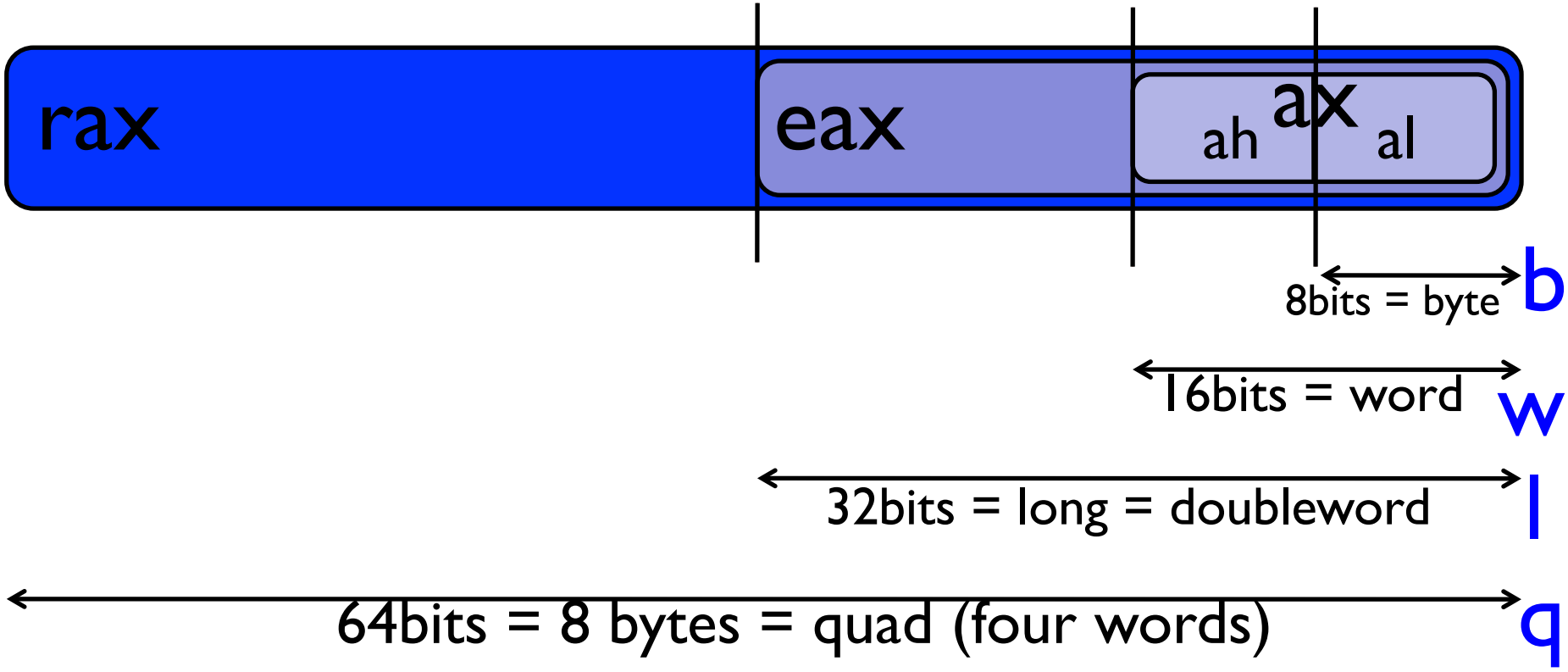
- Introduction to Assembly
  - register overview
  - assembly instructions
  - assembly instruction operands
  - managing control flow
- Introduction to Bomblab
  - lab overview
  - auxiliary tools
    - GNU debugger (gdb)



Administrativia

- FAQ: http://www.cs.cmu.edu/~213/faq.html
  - E.g. Why do I get "permission denied" error?
  - Read through before you ask questions
  - Check back for any future updates
- Style guide: http://www.cs.cmu.edu/~213/codeStyle.html
  - consistent indentation
  - reasonable variable names
  - document important parts of the code
  - fit within 80 character line width
  - ~/.vimrc or ~/.emacs
- TA Feedback form: https://www.ugrad.cs.cmu.edu/ta/feedback
  - open until Feb 17

Registers (32 & 64 bit)



Registers

- General purpose registers:
  - eax (accumulator), ebx (base), ecx (counter), edx
  - esi, edi (used for string manipulation by convention)
  - rax, rbx, rcx, rdx, rsi, rdi, r8 - r15, rbp (x86_64)
- Special purpose registers:
  - EIP – instruction pointer register
  - EBP – branch pointer register
  - ESP – stack pointer register
  - eflags (carry, parity, zero, sign, overflow)
- x86 → x86_64
  - ebp/rbp is no longer special
  - 8 new registers
  - 64 bit registers, subsuming 32 bit registers
  - full-width instructions : L → Q (e.g., movl → movq)

Assembly Instructions: Arithmetic + Logic

- Binary operators: *OP* SRC, DST ⇔ DST = *OP*(DST, SRC)
  - addl, subl, imull, sarl, sall, shrl, shll, xorl, andl, orl
  - operand order matters:
    - e.g., SARL %eax, %ebx → ebx = ebx >> eax

- Unary operators: *OP* DST ⇔ DST = *OP*(DST)
  - incl, decl, negl, notl

Assembly Operands

- Immediate
  - $0xff , $5 , $-1
  - decimal, octal, or hexadecimal (as in C)
  - size: byte, word, long, or quad
- Register
  - %rax, %r14
  - e.g., XORL %ebx, %ebx (Q: what does this do?)
  - e.g., MOVL %ecx, %eax : eax ← ecx
- Memory
  - D(Rb, Ri, S)
  - 8(%ebx), 12(%ebx, %ecx, 4)
  - e.g., MOVL 8(%ebx), %eax : move 1st arg from stack to %eax

Special Operations

- CLTQ (*may* see it in bomblab):
  - convert long to quad : %rax = SignExtend(%eax)
  - eax = 0x05→ rax = 0x05 ; eax = 0x80000000→ rax=0xffffffff 80000000
- LEAL: load effective address
  - does not dereference memory
  - used as an arithmetic operator to perform memory address calculations
    - commonly used for calculating offsets into an array in a loop
  - example: LEAL (%eax, %eax, 4): eax = eax * 5
- MOVZBL
  - move byte to long with zero fill

Memory Addressing Modes

- Most general form: Offset(Base, Index, Scale)
  - D(Rb, Ri, S) → Mem[Rb + Ri*S + D]
  - Offset (D) can be any signed integer
  - Scale is 1,2,4,8 (for byte, word, long, quad strides)
    - if omitted, assume 1
  - Base: if omitted, assume 0x0
- Special forms:
  - (%eax) → contents of memory at address stored in %eax
  - (%ebx, %ecx) → Mem[Reg[%ebx] + Reg[%ecx]]
  - (%ebx, %ecx, 8) → Mem[Reg[%ebx] + 8*Reg[%ecx]]

Memory Addressing: Example

Address	Value
0x100	0xFF
0x104	0xAB
0x108	0x13
0x10C	0x11

Register	Value
%eax	0x100
%ecx	0x1
%edx	0x3

Operand	Value
%eax	
0x104	
$0x108	
4(%eax)	
9(%eax,%edx)	
0xfc(, %ecx, 4)	
(%eax, %edx, 4)	

Memory Addressing: Example

Address	Value
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Register	Value
%eax	0x100
%ecx	0x1
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note the difference

Operand	Value	Why?
%eax	0x100	register contents
0x104	0xAB	absolute addr
$0x108	0x108	immediate operand
4(%eax)	0xAB	contents of 0x104
9(%eax,%edx)	0x11	contents of 0x10c
0xfc(, %ecx, 4)	0xff	contents of 0xfc+4
(%eax, %edx, 4)	0x11	contents of 0x10c

Control: Compare, Flags, and Jumps

- Explicit flag setting instructions:
  - cmpl b, a → execute a – b and set **eflags**
  - testl b, a → execute a&b and set **eflags**

- Flags: OF, SF, ZF, CF
  - **OF**: overflow (a<0 && b>0 && diff > 0) || (a>0 && b<0 && diff<0)
  - **SF**: sign bit set (a-b < 0)
  - **ZF**: a==b
  - **CF**: previous operation resulted in a carry out from MSB
- Conditional jumps:
  - je/jne (ZF), js/jns (SF),
  - jg/jge/jl/jle (SF, OF, ZF): **if** a >, >= , <, <= b **then** jump
    - e.g., JLE: jumps iff (SF^OF) | ZF (why?)
    - cmpl $5, $6 ; JLE .Lexit (Q: will this jump to .Lexit?)

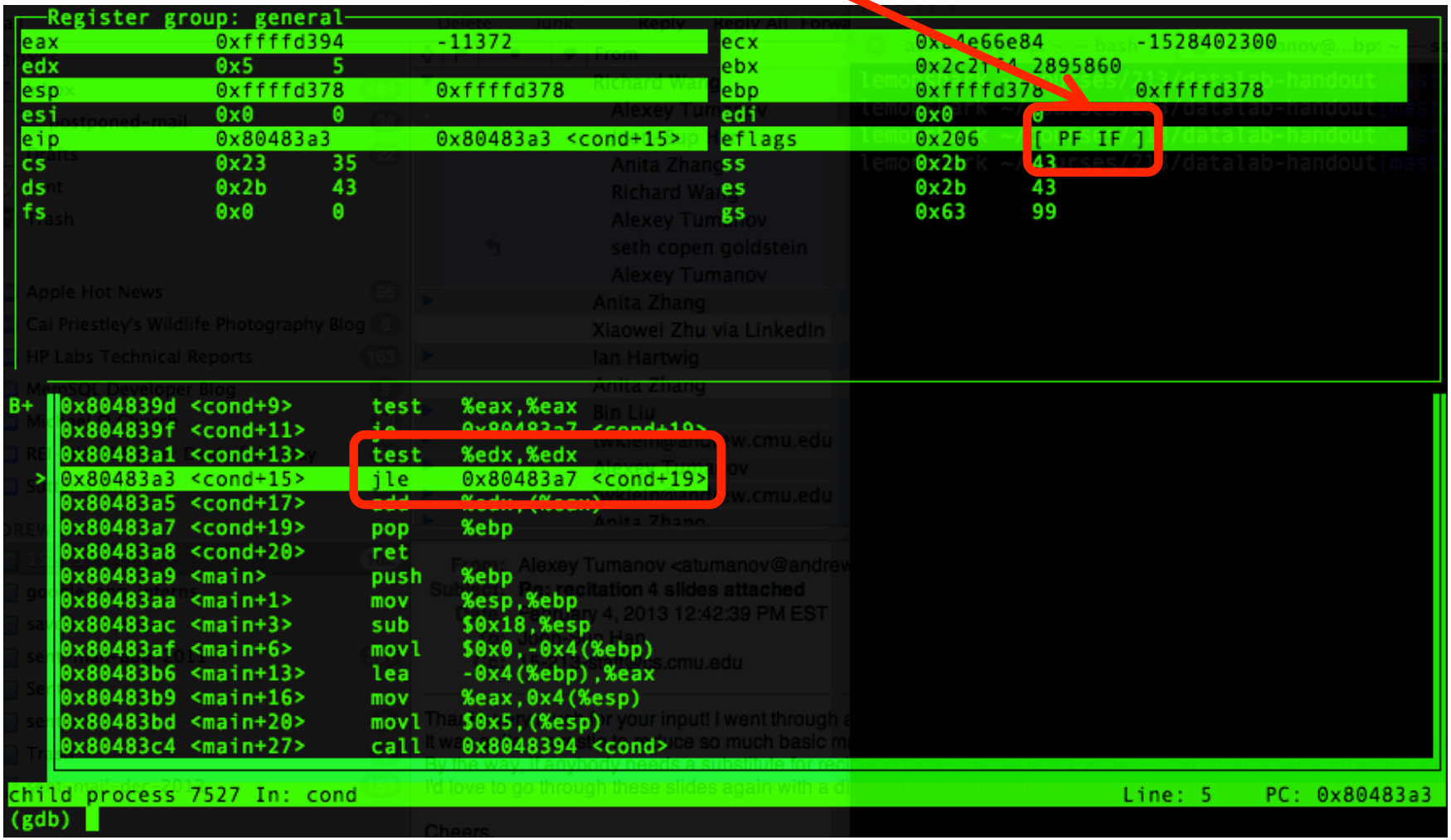
Control Flow Example

```
void cond(int a, int *p) {
  if (p && a > 0)
    *p += a;
}
```

```
  MOVL  8(%ebp), %edx
  MOVL  12(%ebp), %eax
  TESTL %eax, %eax
  JE    .LEXIT
  TESTL %edx, %edx
  JLE   .LEXIT
  ADDL  %edx, (%eax)
.LEXIT
```

Control Flow Example: Test & JLE

OF, SF, ZF not set => JLE won't jump



Control Flow Example

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    JLE   .LEXIT
    ADDL  %edx, (%eax)
.LEXIT
```

```
void goto_cond(int a, int *p)
{
    if (p == 0) goto LEXIT;
    if (a<=0) goto LEXIT;
    *p += a;
LEXIT:
    return;
}
```

jX	Condition	Description
JE	ZF	Equal/Zero
JLE	(SF^OF) | ZF	Less or Equal/Signed

Bomblab Overview

- Series of stages asking for an input string
  - input string can be anything: e.g., an array of chars or a number
  - ./bomb < mysolutions # one input string per line
- An incorrect input string causes the bomb to "explode"
  - ½ point deducted for each explosion – they cannot be "undone"
  - it is possible to try multiple incorrect answers without explosion (carefully)
- What's provided: ./bomb , bomb.c (partial source)
  - full C source is NOT provided
- What to do:
  - figure out the expected input string for each phase
- This must be done on shark machines
- Exercise great care
  - e.g., don't just enter garbage and see what happens

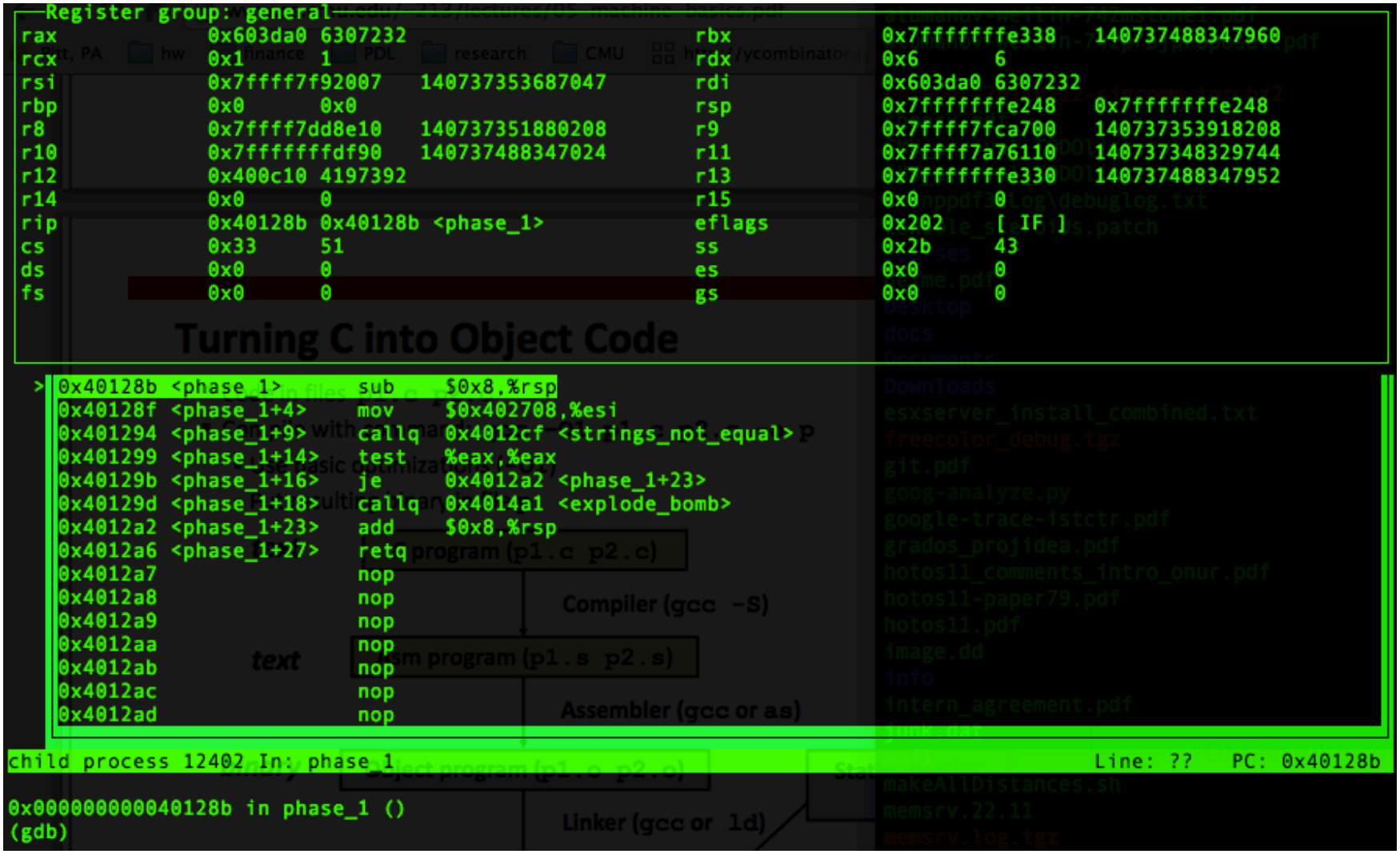
Toolz: GDB

- gdb <binary>
- Ultra useful gdb cheatsheet
  - http://csapp.cs.cmu.edu/public/docs/gdbnotes-ia32.txt
- Useful commands:
  - advance EIP: **s** , **n** , **si** , **ni** , **c** , **run**
  - print things out:
    - print <expression> : e.g., print variable_name
    - x [/format] <address> : print contents of memory
      - how much to print and how to print is dictated by format
  - disassemble: **disas** address
  - layout :
    - layout split , layout regs, layout src, layout asm
    - focus next (fs n)

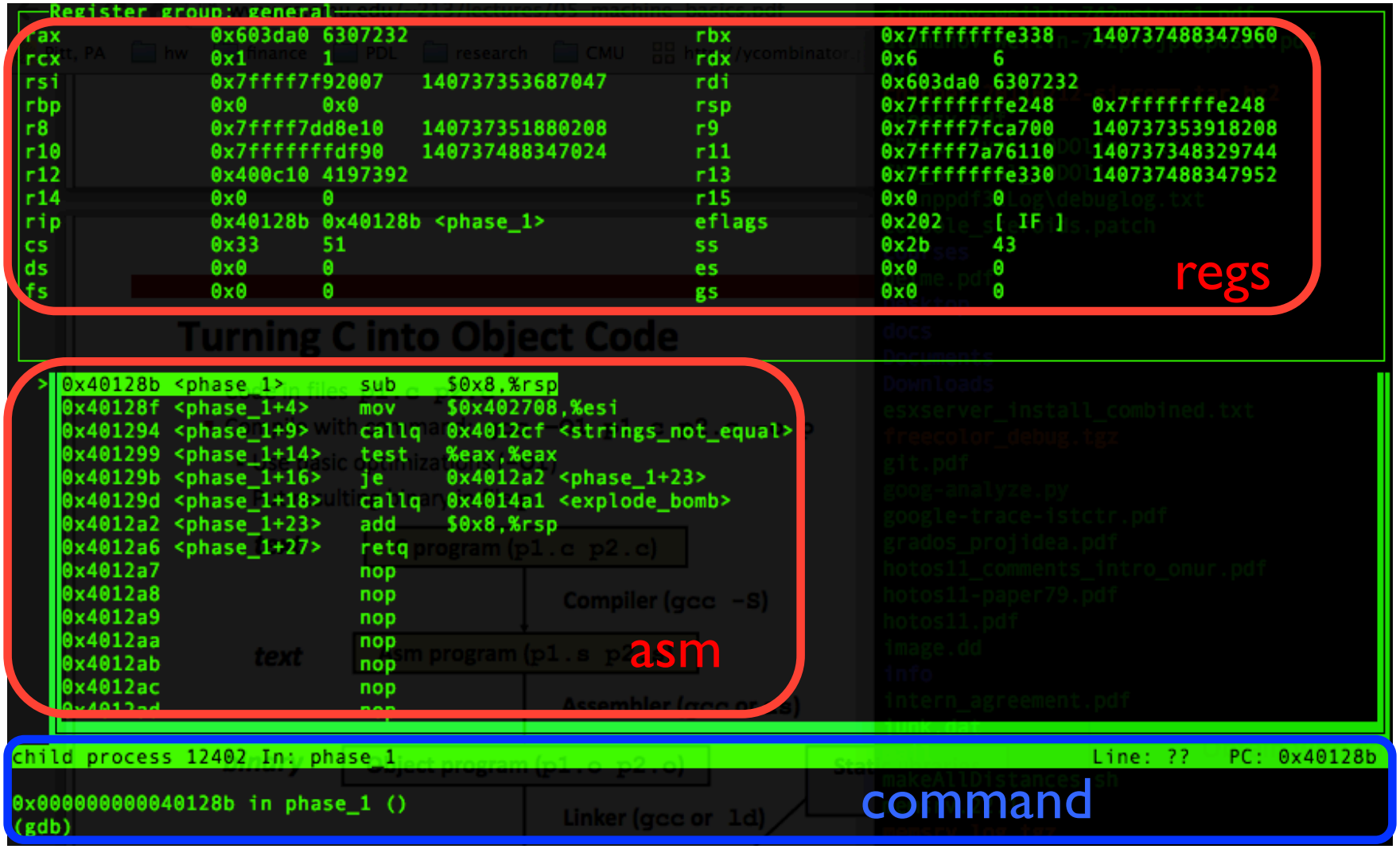
Toolz: GDB (continued)

- querying state:
  - info break
  - info frame (highly useful summary of the current activation record)
  - info program
  - info registers
- working with breakpoints:
  - break <address> ; break <function_name>
  - enable <breakpoint_number>
  - disable <breakpoint_number>
  - delete <breakpoint_number>
- start/stop execution:
  - run [command line args]: e.g., **run** *partial_answer_file*
  - quit (and confirm, if quitting a running executable)

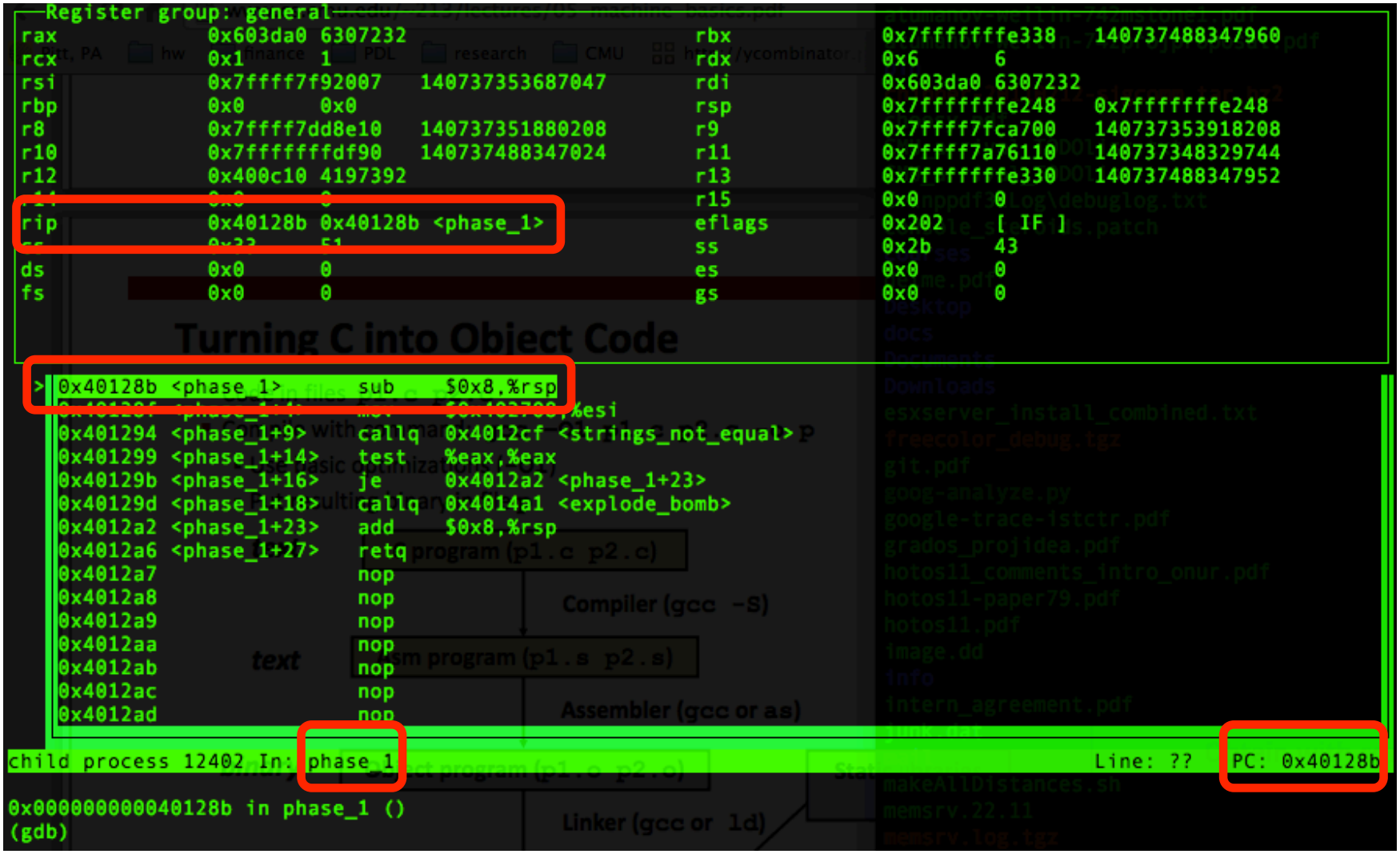
GNU Debugger



GNU Debugger



GNU Debugger



Toolz: objdump, strings

- objdump –d <binary>
  - disassembles the <binary>, dumps assembly output
  - redirect stdout to an output file: objdump –d ./bomb > bomb.S
  - redirect stdout to a pipe : objdump –d ./bomb | less
  - objdump –M intel # if you want intel syntax
    - hint: stick with default
- strings <binary>
  - dumps collections of printable characters from <binary>
  - may include:
    - function names, string literals
    - password hashes? <grin>

Bomb Walkthrough

- How to get started with defusing the bomb
- How to blow up the bomb