Debugging as engineering

- Much of your time in this course will be spent debugging
  - In industry, 50% of software dev is debugging
  - Even more for kernel development
- How do you reduce time spent debugging?
  - Produce working code with smallest effort
- Optimize a process involving you, code, computer
Debugging as science

- Understanding -> design -> code
  - not the opposite
- Form a hypothesis that explains the bug
  - Which tests work, which don’t. Why?
  - Add tests to narrow possible outcomes
- Use best practices
  - Always walk through your code line by line
  - Module tests - narrow scope of where problem is
  - Develop code in stages, with dummy replacements for later functionality

x86 abstract model

- I/O: Communicating data to and from devices
- CPU: Logic for performing computation
- Memory: Storage
x86 CPU/memory interaction

- Memory stores instruction and data
- CPU interprets instructions

x86 implementation

- EIP points to next instruction
- Incremented after each instruction
- x86 instructions are not fixed length
- EIP modified by CALL, RET, JMP, and conditional JMP
### x86 general purpose registers (GPR)

<table>
<thead>
<tr>
<th>Register</th>
<th>EAX</th>
<th>EBX</th>
<th>ECX</th>
<th>EDX</th>
<th>EDI</th>
<th>ESI</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-bits</td>
<td>AX</td>
<td>BX</td>
<td>CX</td>
<td>DX</td>
<td>8-bits</td>
<td>8-bits</td>
</tr>
<tr>
<td>8-bits</td>
<td>AH</td>
<td>BH</td>
<td>CH</td>
<td>DH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-bits</td>
<td>AL</td>
<td>BL</td>
<td>CL</td>
<td>DL</td>
<td>32-bits</td>
<td></td>
</tr>
</tbody>
</table>

- Temporary registers
- Contents may be changed by instructions
- Contents not changed by interrupts / exceptions / traps
- EDI/ESI used by string ops but also as GPR

### x86 memory models

- **Real mode** with segmentation (16-bit mode)
  - Used by early OSes
  - All x86 still boots in Real Mode for “compatibility” reasons
  - You can only use 1MB memory (4-bit segment + 16-bit address)
    \[
    \text{PhysicalAddress} = \text{segment} \times 16 + \text{offset}
    \]

- **Protected mode** w. segmentation & paging (32-bit)
  - 4GB memory
  - Segmentation done via GDT (Global Descriptor Table)
    - A code segment descriptor holding a base address
    - A data segment descriptor holding a base address
    - A TSS segment descriptor …
x86 segmentation registers

- 8086 registers 16-bit w/20-bit bus addresses

- Solution: segment registers
  - CS: code segment, EIP
  - SS: stack segment, ESP and EBP
  - DS: data segment, register mem ops
  - ES: string segment, string ops

- Linear address computation:
  - EIP => CS:EIP = 0x8000:0x1000 = 0x81000
  - ESP => SS:ESP = 0xF800:0x1000 = 0xF9000
  - (EAX) => DS:EAX = 0xC123:0x1000 = 0xC2230

x86 real mode

- 8086 16-bit with 20-bit address bus
- Stored in segment registers CS, DS, ES, FS

- Logical address: segment:offset
- Physical address: segment*0x10 + offset
x86: the runtime stack

- Additional (temporary) storage
- Stack registers --- 32-bits long
- ESP - stack pointer
- EBP - base pointer

x86 EFLAGS register

![EFLAGS Register Diagram]
Using EFLAGS register

- Lots of conditional jumps
  
  en.wikibooks.org/wiki/X86_Assembly/Control_Flow

```assembly
mov $5, %ecx
mov $5, %edx
cmp %ecx, %edx # ZF = 1
je equal
...
equal:
...
```

x86 assembly

We will use AT&T syntax

```assembly
int main(void)
{
    return f(3) + 1;
}

int f(int x)
{
    return x + 4;
}

_main:
opushl %ebp  # prologue
movl %esp, %ebp
pushl $3  # body
call f
addl $1, %eax
movl %ebp, %esp
popl %ebp
ret

_f:
opushl %ebp  # don't clobber registers
movl %esp, %ebp
pushl %ebx
movl $(%ebp), %ebx  # access argument
addl $4, %ebx
movl %ebx, %eax
popl %ebx  # restore
movl %ebp, %esp  # epilogue
popl %ebp
ret
```
x86 memory layout

CS422/522 Lab 1: Bootloader & Physical Memory Management (due 9/17/2020)

- Learn how to use git
- Part 1: PC Bootstrap
  - x86 assembly & QEMU & BIOS
- Part 2: Bootloader
  - Learn how to use QEMU & GDB & read ELF file
- Part 3: Physical Memory Management
  - The MATIntro Layer
  - The MATInit Layer
  - The MATOp Layer
- Enrichment (optional)