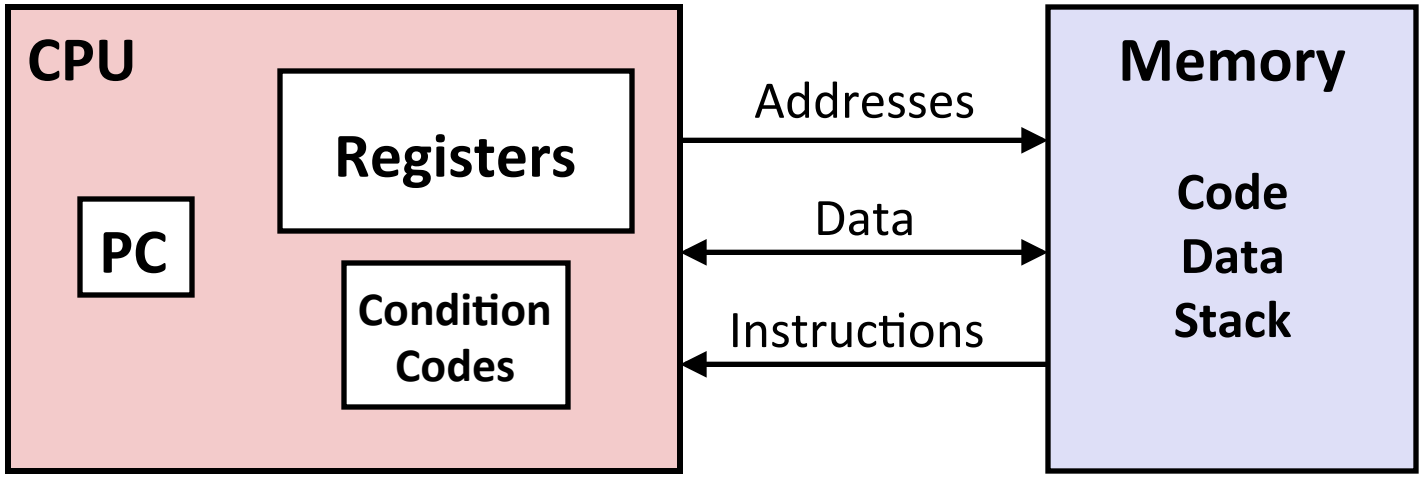
Today: Machine Programming I: Basics

- History of Intel processors and architectures
- **C, assembly, machine code**
- Assembly Basics: Registers, operands, move
- Arithmetic & logical operations

Definitions

- **Architecture: (also ISA: instruction set architecture) The parts of a processor design that one needs to understand or write assembly/machine code.**
  - Examples: instruction set specification, registers.
- **Microarchitecture: Implementation of the architecture.**
  - Examples: cache sizes and core frequency.
- **Code Forms:**
  - Machine Code: The byte-level programs that a processor executes
  - Assembly Code: A text representation of machine code
- **Example ISAs:**
  - Intel: x86, IA32, Itanium, x86-64
  - ARM: Used in almost all mobile phones

Assembly/Machine Code View

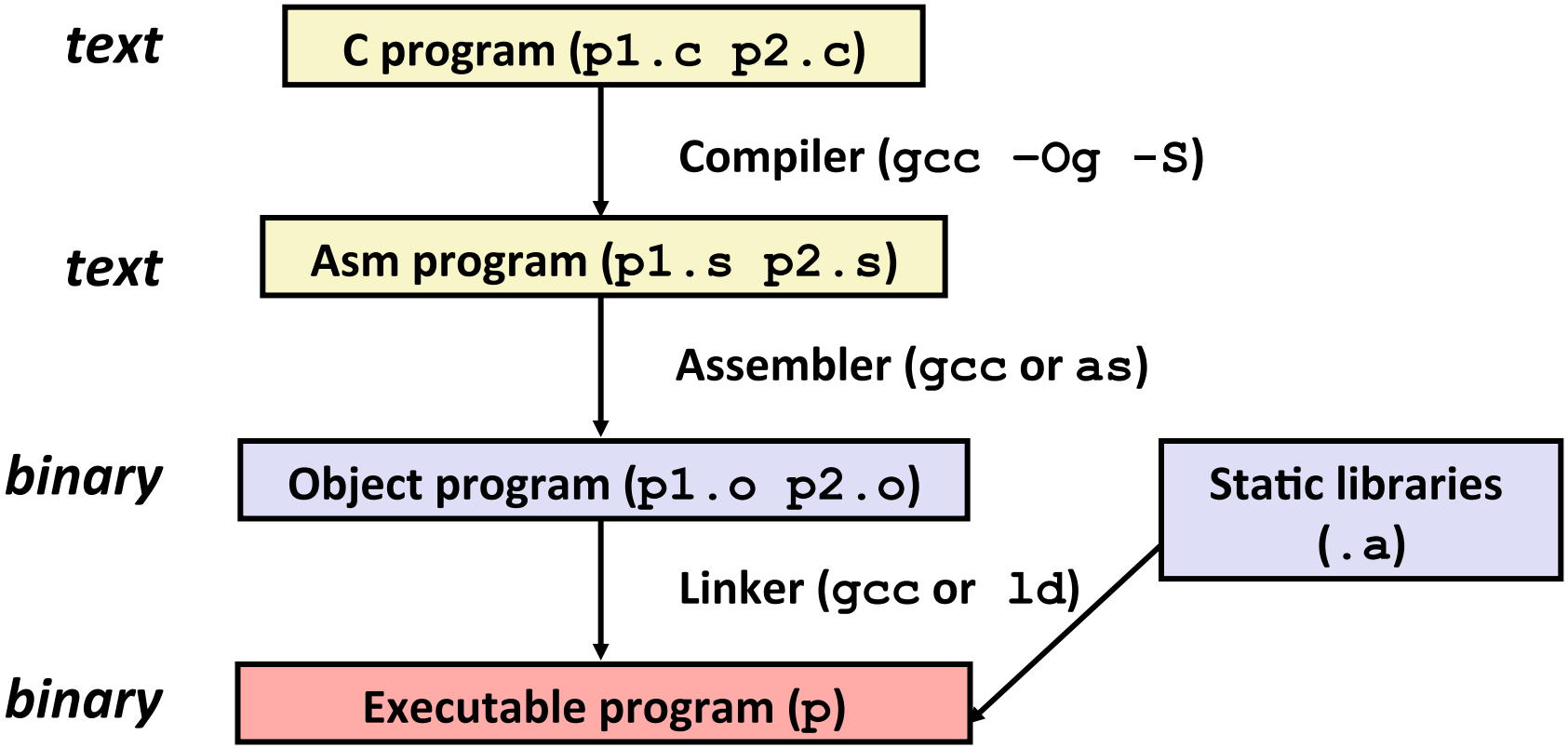


Programmer-Visible State

- **PC: Program counter**
  - Address of next instruction
  - Called "RIP" (x86-64)
- **Register file**
  - Heavily used program data
- **Condition codes**
  - Store status information about most recent arithmetic or logical operation
  - Used for conditional branching
- **Memory**
  - Byte addressable array
  - Code and user data
  - Stack to support procedures

Turning C into Object Code

- Code in files `p1.c p2.c`
- Compile with command: `gcc –Og p1.c p2.c -o p`
  - Use basic optimizations (`–Og`) [New to recent versions of GCC]
  - Put resulting binary in file `p`



Compiling Into Assembly

C Code (sum.c)

```
long plus(long x, long y);

void sumstore(long x, long y,
              long *dest)
{
    long t = plus(x, y);
    *dest = t;
}
```

Generated x86-64 Assembly

```
sumstore:
    pushq   %rbx
    movq    %rdx, %rbx
    call    plus
    movq    %rax, (%rbx)
    popq    %rbx
    ret
```

Obtain (on shark machine) with command

```
gcc –Og –S sum.c
```

Produces file `sum.s`

Warning: Will get very different results on non-Shark machines (Andrew Linux, Mac OS-X, …) due to different versions of gcc and different compiler settings.

Assembly Characteristics: Data Types

- **"Integer" data of 1, 2, 4, or 8 bytes**
  - Data values
  - Addresses (untyped pointers)
- **Floating point data of 4, 8, or 10 bytes**
- **Code: Byte sequences encoding series of instructions**
- **No aggregate types such as arrays or structures**
  - Just contiguously allocated bytes in memory

Assembly Characteristics: Operations

- **Perform arithmetic function on register or memory data**
- **Transfer data between memory and register**
  - Load data from memory into register
  - Store register data into memory
- **Transfer control**
  - Unconditional jumps to/from procedures
  - Conditional branches

Object Code

Code for `sumstore`

```
0x0400595:
    0x53
    0x48
    0x89
    0xd3
    0xe8
    0xf2
    0xff
    0xff
    0xff
    0x48
    0x89
    0x03
    0x5b
    0xc3
```

- **Total of 14 bytes**
- **Each instruction 1, 3, or 5 bytes**
- **Starts at address `0x0400595`**

- **Assembler**
  - Translates `.s` into `.o`
  - Binary encoding of each instruction
  - Nearly-complete image of executable code
  - Missing linkages between code in different files
- **Linker**
  - Resolves references between files
  - Combines with static run-time libraries
    - E.g., code for **`malloc`**, **`printf`**
  - Some libraries are *dynamically linked*
    - Linking occurs when program begins execution

Machine Instruction Example

```
*dest = t;
```

```
movq %rax, (%rbx)
```

```
0x40059e:  48 89 03
```

- **C Code**
  - Store value **t** where designated by **dest**
- **Assembly**
  - Move 8-byte value to memory
    - Quad words in x86-64 parlance
  - Operands:
    - **t:** Register **%rax**
    - **dest:** Register **%rbx**
    - ***dest:** Memory **M[%rbx]**
- **Object Code**
  - 3-byte instruction
  - Stored at address **0x40059e**

Disassembling Object Code

Disassembled

```
0000000000400595 <sumstore>:
  400595:  53                   push   %rbx
  400596:  48 89 d3             mov    %rdx,%rbx
  400599:  e8 f2 ff ff ff       callq  400590 <plus>
  40059e:  48 89 03             mov    %rax,(%rbx)
  4005a1:  5b                   pop    %rbx
  4005a2:  c3                   retq
```

- **Disassembler**

  `objdump -d sum`

  - Useful tool for examining object code
  - Analyzes bit pattern of series of instructions
  - Produces approximate rendition of assembly code
  - Can be run on either `a.out` (complete executable) or `.o` file

Alternate Disassembly

Object

```
0x0400595:
    0x53
    0x48
    0x89
    0xd3
    0xe8
    0xf2
    0xff
    0xff
    0xff
    0xff
    0x48
    0x89
    0x03
    0x5b
    0xc3
```

Disassembled

```
Dump of assembler code for function sumstore:
 0x0000000000400595 <+0>: push   %rbx
 0x0000000000400596 <+1>: mov    %rdx,%rbx
 0x0000000000400599 <+4>: callq  0x400590 <plus>
 0x000000000040059e <+9>: mov    %rax,(%rbx)
 0x00000000004005a1 <+12>:pop    %rbx
 0x00000000004005a2 <+13>:retq
```

- **Within gdb Debugger**

  `gdb sum`

  `disassemble sumstore`

  - Disassemble procedure

  `x/14xb sumstore`

  - Examine the 14 bytes starting at `sumstore`

What Can be Disassembled?

```
% objdump -d WINWORD.EXE

WINWORD.EXE:     file format pei-i386

No symbols in "WINWORD.EXE".
Disassembly of section .text:

30001000 <.text>:
30001000:
30001001:
30001003:
30001005:
3000100a:
```

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- Anything that can be interpreted as executable code
- Disassembler examines bytes and reconstructs assembly source