Programs

Part 3

1

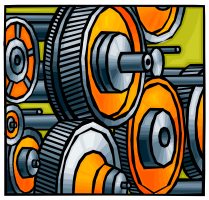
Machine Language

The raw bytes of your program

2

Machine Language

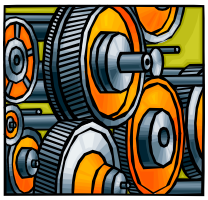
- The instructions, that are *actually* executed on the processor, are just bytes
- In this raw binary form, instructions are stored in *Machine Language (aka Machine Code)*



3

Machine Language

- Each instruction is *encoded* (stored) is in a compact binary form
- Easy for the processor to interpret and execute
- Some instructions may take more bytes than others – not all are equal in complexity



4

Instruction Encoding

- Each instruction must contain everything the processor needs to know to do something
- Think of them as functions in Java: they need a name and arguments to work

5

Instruction Encoding

- For example: if you want it to add 2 things…
- The instruction needs:
  - something to tell the processor to add
  - something to identify the two "things"
  - destination to save the result

6

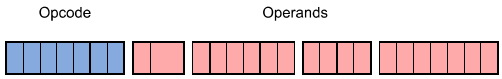
Operation Codes

- Each instruction has a unique *operation code (Opcode)*
- This is a value that specifies the exact operation to be performed by the processor
- Assemblers use friendly names called *mnemonics*

7

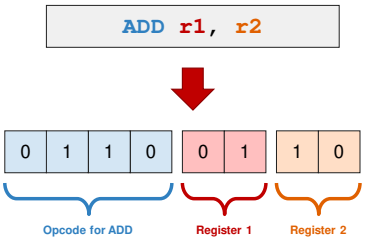
Typical Instruction Format

- The opcode is, typically, followed by various *operands* – what data is to be used
- These can be register codes, addressing data, literal values, etc…



8

Machine Code Example (not x86)



9

Compilers, Assemblers & Linkers

Programs, Coding, and Nerds… oh my!

10

Compilers & Assemblers

- When you hit "compile" or "run" (e.g. in your Java IDE), many actions take place *"behind the scenes"*
- You are usually only aware of the work that the parser does

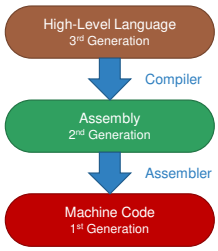
11

Development Process

1. Write program in high-level language
2. Compile program into assembly
3. Assemble program into objects
4. Link multiple objects programs into one executable
5. Load executable into memory
6. Execute it

12

From Abstract to Machine



13

Compiler

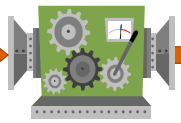
- Convert programs from high-level languages (such as C or C++) into assembly language
- Some create machine-code directly…
- *Interpreters*, however…
  - never compile code
  - Instead, they run parts of their own program

14

Compilers: 3rd → 2nd Generation

```
x = 1846;
x += 42;
n = 3;
a[n] = x;
```

Compiler



```
mov r8, 1846
add r8, 42
mov r9, 3
mov [a+r9*8], r8
```


15

Assembler

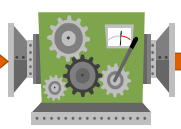
- Converts assembly into the binary representation used by the processor
- Often the result is an *object file*
  - usually not executable - yet
  - contains computer instructions and information on how to "link" into other executable units
  - file may include: relocation data, unresolved labels, debugging data

16

Assembler: 2nd → 1st Generation

```
mov r8, 1846
add r8, 42
mov r9, 3
mov [a+r9*8], r8
```

Assembler

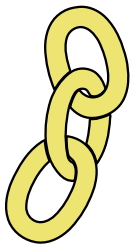


```
01000100
01100101
01110110
01101001
01101110
```


17

Linkers

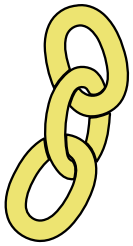
- Often, parts of a program are created separately
- Happens *more often than you think* – almost always
- Different parts of a program are called *objects*
- A *linker* joins them into a single file



18

What a Linker Does

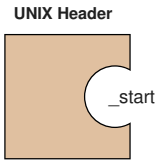
- Connects labels (identifiers) - used in one object - to the object that defines it
- So, one object can call another object
- A linker will show an error if there are label conflicts or missing labels



19

Linking your program

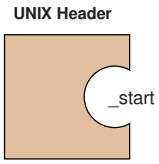
- UNIX header is defined by crt1.o and crti.o
- They are supplied behind the scenes, *so you don't need to worry about them*



20

Linking your program

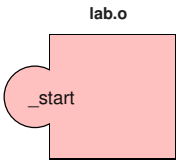
- It references a subroutine called _start
- But… it is not defined in the header
- It is used to start your program (main in Java)



21

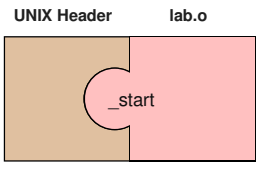
Linking your program

- Your program supplies this subroutine
- The linker connects the two, so the header calls your subroutine



22

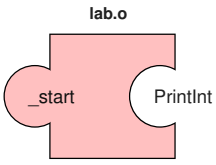
Linking to the UNIX Header



23

You will use my library

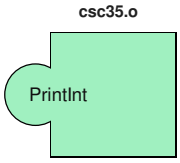
- To make labs easier, you will use my library
- Your program will reference its subroutines



24

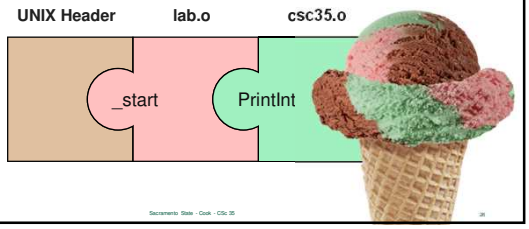
You will use my library

- Once the object file "csc35.o" is linked, the program is complete



25

You will use my library



26

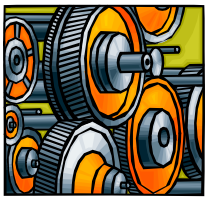
Assembly Basics

The beautiful language of the computer

27

Assembly Language

- *Assembly* allows you to write machine language programs using easy-to-read text
- Assembly programs is based on a specific processor architecture
- So, it won't "port"



28

Assembly Benefits

1. Consistent way of writing instructions
2. Automatically counts bytes and allocates buffers
3. *Labels* are used to keep track of **addresses** which prevents common machine-language mistakes

29

1. Consistent Instructions

- Assembly combines related machine instructions into a single notation *(and name)* called a *mnemonic*
- For example, the following machine-language actions are different, but related:
  - register → memory
  - register → register
  - constant → register

30

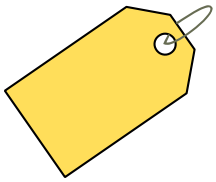
2. Count and Allocate Buffers

- Assembly automatically counts bytes and allocates buffers
- Miscounts (when done by hand) can be very problematic – and can lead to hard to find errors

31

3. Labels & Addresses

- Assembly uses *labels* to store **addresses**
- Used to keep track of locations in your programs
  - data
  - subroutines (functions)
  - …and much more



32

Battle of the Syntax

- The basic concept of assembly's notation and syntax hasn't changed
- However, there are two major competing notations
- They are *just* different enough to make it confusing for students and programmers *(who are used to the other notation)*

33

Battle of the Syntax

- AT&T Syntax
  - dominate on UNIX / Linux systems
  - registers prefixed by %, values with $
  - receiving register is last
- Intel Syntax
  - *actually created by Microsoft*
  - dominate on DOS / Windows systems
  - neither registers or values have a prefix
  - receiving register is first

34

AT&T Example (not x86)

```
# Just a simple add

mov $42, %b       #b = 42
mov value, %a     #a = value
add %b, %a        #a += b
```


35

Intel Example (not x86)

```
# Just a simple add

mov b, 42         #b = 42
mov a, value      #a = value
add a, b          #a += b
```


36

Assembly Program Structure

How these little beasties are organized

37

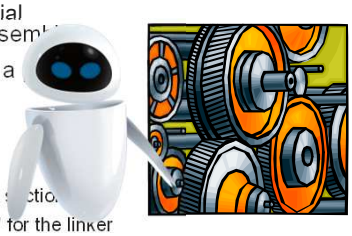
Assembly Programs

- Assembly programs are divided into two sections
- *data section* allocate the bytes to store your constants, variables, etc…
- *text section* contains the instructions that will make up your program

38

Directives

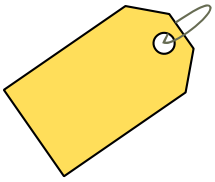
- A *directive* is a special command for the assembler
- Notation: starts with a .
- What they do:
  - allocate space
  - define constants
  - start the text or data section
  - make labels "global" for the linker



39

Labels

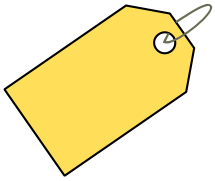
- You can define *labels* by following an identifier with a colon
- As the assembler is reading your program, it is generating machine code instructions and storage



40

Labels

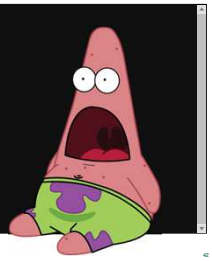
- When the assembler sees a label declaration, it will save the current address (at that point) into a table
- Anytime you use a label, it is replaced by that address
- Labels are addresses



41

Hello World – Using csc35.o

```
.intel_syntax noprefix
.data
message:
   .ascii "Hello World!\n\0"

.text
.global _start

_start:
    lea   rdx, message
    call  PrintZString

    call  Exit
```



42

Hello World – Using csc35.o

```
.intel_syntax noprefix
.data
message:
    .ascii "Hello World!\n\0"

.text
.global _start

_start:
    lea   rdx, message
    call  PrintZString

    call  Exit
```

Data Section

43

Data Section

```
.intel_syntax noprefix
.data
message:
    .ascii "Hello World!\n\0"
```

Use Intel format

No prefix characters

Start data section

44

Data Section

```
.intel_syntax noprefix
.data
message:
    .ascii "Hello World!\n\0"
```

Create a label called 'message'. It will store an address.

Allocate the bytes required to store text

45

Hello World – x86, Linux

```
.intel_syntax noprefix
.data
message:
    .ascii "Hello World!\n\0"

.text
.global _start

_start:
    lea   rdx, message
    call  PrintZString

    call  Exit
```

Text / Code Section

46

Text / Code Section

```
.text
.global _start

_start:
    lea   rdx, message
    call  PrintZString

    call  Exit
```

Start text section

Make label visible to the linker. Header will call _start

Loads the Effective Address 'message' into rdx

Call the library subroutine (it needs an address in rdx)

47

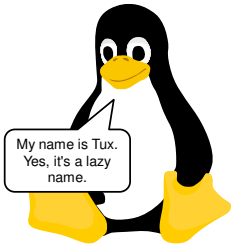
Basics of UNIX

Feel the pow-wah of the dark side

48

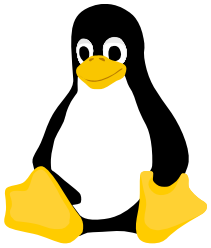
Basics UNIX

- UNIX was developed at AT&T's Bell Labs in 1969
- Design goals:
  - operating system for mainframes
  - stable and powerful
  - but not exactly easy to use – GUI hadn't been invented yet



49

Basics UNIX



- There are versions of UNIX with a nice graphical user interface
- A good example is all the various versions of Linux
- However, all you need is a command line interface

50

Command Line Interface

- Command line interface is text-only
- But, you can perform all the same functions you can with a graphical user interface
- This is how computer scientists have traditionally used computers

```
>gcc hello.c
>ls
a.out hello.c

>a.out
Hello world!
```


51

Command Line Interface

- Each command starts with a name followed by zero or more arguments
- Using these, you have the same abilities that you do in Windows/Mac

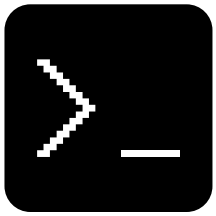
Spaces separate name & arguments

```
name argument1 argument2 …
```


52

`ls` Command

- Short for *List*
- Lists all the files in the current directory
- It has arguments that control how the list will look
- Notation:
  - directory names have a slash suffix
  - programs have an asterisk suffix



53

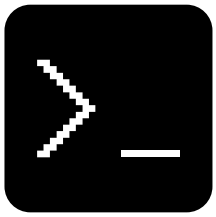
`ls` Command

```
> ls
a.out*  csc35/  html/  mail/
test.asm
```


54

`ll` Command

- Short for *List Long*
- This command is a shortcut notation for **`ls -l`**
- Besides the filename, its size, access rights, etc… are displayed



55

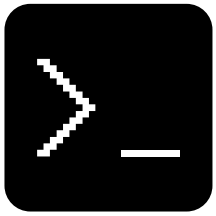
`ll` Command

```
> ll

-rwx------  1 cookd othcsc  4650 Sep 10 17:44 a.out*
drwx------  2 cookd othcsc  4096 Sep  5 17:49 csc35/
drwxrwxrwx 10 cookd othcsc  4096 Sep  6 11:04 html/
drwxrwxrwx  2 cookd othcsc  4096 Jun 20 17:58 mail/
-rw-------  1 cookd othcsc    74 Sep 10 17:44 test.asm
```


56

`rm` Command

- Short for *Remove*
- It essentially deletes a file
- Be careful…
  - files don't move into a "recycle bin'
  - they are gone forever!
- It can also delete multiple files using patterns



57

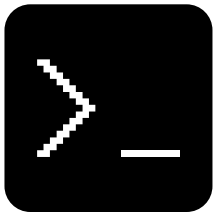
`rm` Command

```
> ls
a.out*  html/  mail/  test.asm

> rm a.out

> ls
html/  mail/  test.asm
```


58

`nano` Application

- Nano is the UNIX text editor (well, the best one – that is)
- It is very similar to Windows Notepad – but can be used on a terminal
- You will use this to write your programs



59

`nano` Application

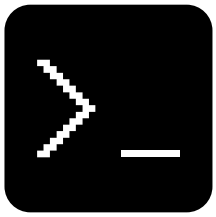
- Nano will open and edit the filename provided
- If the file doesn't exist, it will create it

```
nano filename
```


60

as Command

- This is the GNU assembler
- It will take an assembly program and convert it into an object
- You will be alerted of any syntax errors or unrecognized mnemonics (typos)



61

as Command

- The **-o** specifies the next name listed is the output file
- So, the second is the output file (object)
- The third is your input (assembly)

```
as -o lab.o lab.asm
```


62

as Command

- **Be very careful** – if you list your input file first, it will be destroyed
- There is no "undo" in UNIX!
- Check the two extensions for "o" then "asm"

```
as -o lab.o lab.asm
```


63

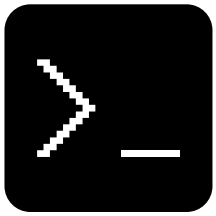
as Command

```
> ls
lab.asm

> as -o lab.o lab.asm

> ls
lab.asm  lab.o
```


64

ld Command

- This is the GNU linker
- It will take one (or more) objects and link them into an executable
- You will be alerted of any unresolved labels



65

ld Command

- The **-o** specifies the next name is the output
- The second is the output file (executable)
- The third is your input objects (1 or more)

```
ld -o a.out csc35.o lab.o
```


66

`ld` Command

- Be very careful – if you list your input file (an object) first, it will be destroyed
- I will provide the "csc35.o" file

```
ld -o a.out csc35.o lab.o
```


67

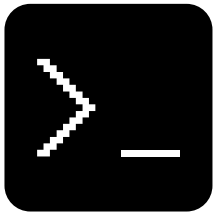
`ld` Command

```
> ls
lab.o  csc35.o

> ld -o a.out lab.o csc35.o

> ls
lab.o  csc35.o  a.out*
```


68

`alpine` Application

- Alpine is an e-mail application
- Has an easy-to-use interface similar to Nano
- You will use this software to submit your work



69

`alpine` Application

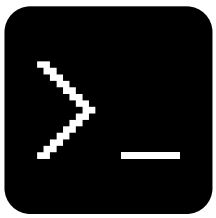
- To run Alpine, just type its name at the command line
- There are no arguments
- You will have to login (again)

```
alpine
```


70

`pwd` Command

- Short for *Print Working Directory*
- It displays the path your current directory (the one you are looking at).
- Slashes separate the directory names



71

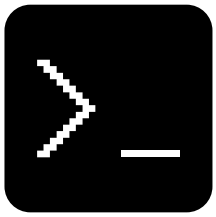
`pwd` Command

```
> pwd

/gaia/class/student/cookd
```


72

`cd` Command

- Short for *Change Directory*
- Allows you to change your current working directory
- If you specify a folder name, you will move into it
- If you use .. (two dots), you will go to the parent folder



73

`cd` Command

```
> cd csc35

> cd ..
```

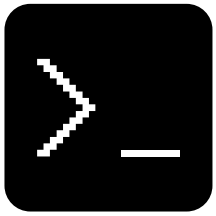
Move into csc35 folder

Return to parent folder

74

`mkdir` Command

- Short for *Make Directory*
- Essentially the same as making a new subfolder in Windows or Mac-OS
- You may want to create one to store your CSc 35 work



75

`mkdir` Command

```
> ls
a.out*  html/  mail/  test.asm

> mkdir csc35

> ls
a.out*  csc35/  html/  mail/  test.asm
```


76