Programs

Part 3

1

Compilers, Assemblers & Linkers

Programs, Coding, and Nerds… oh my!

2

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

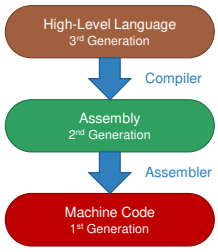
3

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

4

From Abstract to Machine



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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

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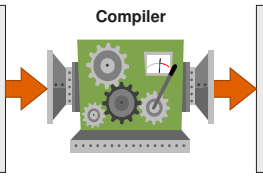
Compilers: 3rd → 2nd Generation

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




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

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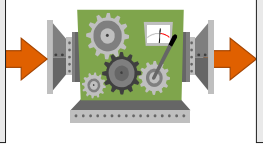
Assembler: 2nd → 1st Generation

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




```
01000100
01100101
01110110
01101001
01101110
```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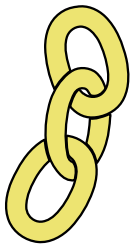
Linkers

- 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



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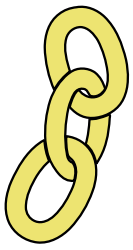
What a Linker Does

- 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



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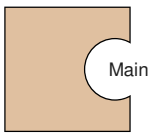
Linking your program

- 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*



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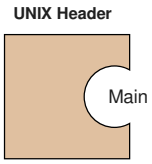
Linking your program

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



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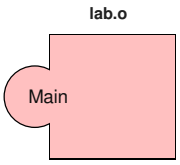
Linking your program

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



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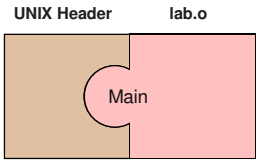
Linking to the UNIX Header



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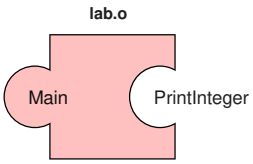
You will use my library

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



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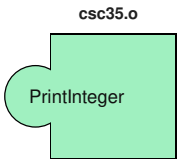
You will use my library

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



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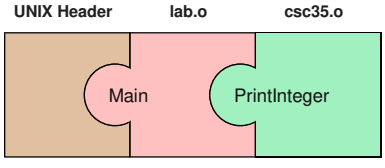
You will use my library



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Assembly Basics

The beautiful language of the computer

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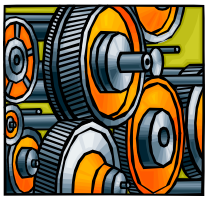
Assembly Language

- *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"



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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

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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

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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

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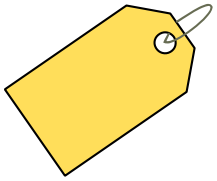
3. Labels & Addresses

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



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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)*

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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

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AT&T Example

```
# Just a simple add

mov $42, %rbx       #rbx = 42
mov value, %rdx     #rdx = value
add %rbx, %rax      #rax += rbx
```


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Intel Example

```
# Just a simple add

mov rbx, 42         #rbx = 42
mov rdx, value      #rdx = value
add rax, rbx        #rax += rbx
```


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Assembly Program Structure

How these little beasties are organized

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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

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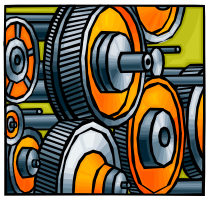
Directives

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



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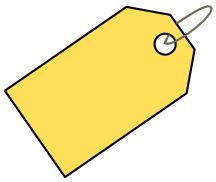
Labels

- 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



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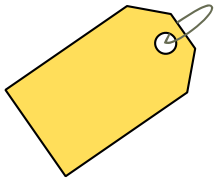
Labels

- 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



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Hello World – Using csc35.o

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

.text
.global Main

Main:
    lea   rdx, message
    call  PrintString

    call  EndProgram
```


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Hello World – Using csc35.o

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

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Main:
    lea   rdx, message
    call  PrintString

    call  EndProgram
```

Data Section

35

Data Section

Use Intel format

No prefix characters

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

Start data section

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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

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Hello World – x86, Linux

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

.text
.global Main

Main:
    lea   rdx, message
    call  PrintString

    call  EndProgram
```

Text / Code Section

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Text / Code Section

```
.text
.global Main

Main:
    lea   rdx, message
    call  PrintString

    call  EndProgram
```

Start text section

Make label visible to the linker. Header will call Main

Loads the Effective Address 'message' into rdx

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

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Basics of UNIX

Feel the pow-wah of the dark side

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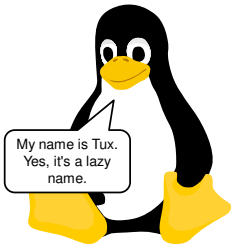
Basics UNIX

- 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



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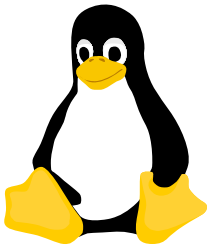
Basics UNIX



- 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

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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!
```


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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 …
```


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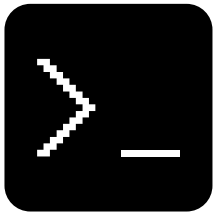
`ls` Command

- 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



45

`ls` Command

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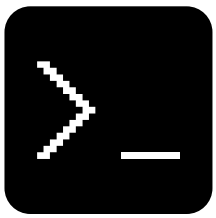
`ll` Command

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



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`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
```


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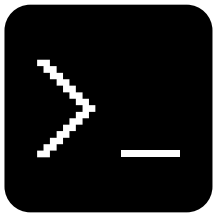
nano Application

- 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



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nano Application

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

```
nano filename
```


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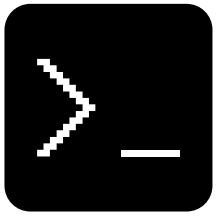
as Command

- 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)



51

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
```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as Command

- **Be very careful** – anything after –o will be destroyed
- There is no "undo" in UNIX!
- Check the two extensions for "o" then "asm"

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


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as Command

```
> ls
lab.asm

> as -o lab.o lab.asm

> ls
lab.asm  lab.o
```


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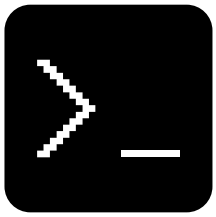
`ld` Command

- 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



55

`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
```


56

`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
```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`ld` Command

```
> ls
lab.o  csc35.o

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

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


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UNIX Directories

Feel the pow-wah of the dark side

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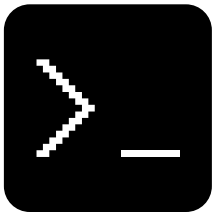
`cd` Command

- 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



60

`cd` Command

```
> cd csc35

> cd ..
```

Move into csc35 folder

Return to parent folder

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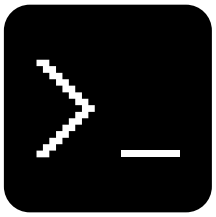
`pwd` Command

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



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`pwd` Command

```
> pwd

/gaia/class/student/cookd
```


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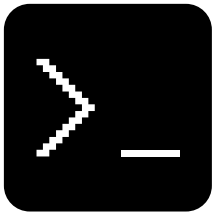
`mkdir` Command

- 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



64

`mkdir` Command

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

> mkdir csc35

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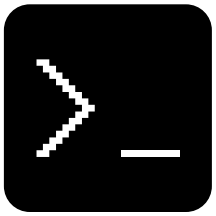
`rm` Command

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



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`rm` Command

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

> rm a.out

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


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