EECS 22: Advanced C Programming

Lecture 11

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Lecture 11: Overview

- Warm-up Quiz
- Shared Libraries
  - Static object file archives
  - Dynamically loaded shared objects
- Make and Makefile
  - Rules
  - Dependencies
  - Application example **`PhotoLab2`**
    - Modules **`FileIO`**, **`Age`**, **`Main`**
    - **`Makefile`**
  - Advanced features

Quiz: Question 1

- Which Linux command shows you the path to the current directory?
  a) `cd`
  b) `pwd`
  c) `dir`
  d) `ls`
  e) `list`

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  d) `ls`
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Quiz: Question 2

- Which of the following Linux commands renames file “homework1.c” into “text1.c”?

a) `rn text1.c homework1.c`
b) `rn homework1.c text1.c`
c) `rm text1.c homework1.c`
d) `mv homework1.c text1.c`
e) `mv text1.c homework1.c`

Quiz: Question 2

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Quiz: Question 3

- What is C *not*?
  a) a structured programming language
  b) a object-oriented programming language
  c) a compiled programming language
  d) a high-level programming language
  e) a portable programming language

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  b) a object-oriented programming language
  c) a compiled programming language
  d) a high-level programming language
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Quiz: Question 4

- What is the meaning of the following code fragment?

```
/* printf("C programming is great!\n") */
```

a) it prints “C programming is boring!”
b) it prints “C programming is great!”
c) it is a syntax error because a semicolon is missing after the `printf()` statement
d) it is the main function of the C program
e) it is a comment ignored by the compiler

Quiz: Question 4

- What is the meaning of the following code fragment?

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```

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b) it prints “C programming is great!”
c) it is a syntax error because a semicolon is missing after the `printf()` statement
d) it is the main function of the C program
e) it is a comment ignored by the compiler

Quiz: Question 5

- What is true about of the following compiler call? (Check all that apply!)

```
% gcc HelloWorld.c -Wall -ansi -o HelloWorld
```

a) the GNU C Compiler is called to generate an executable program called **`HelloWorld`**

b) the compiler will print warning and/or error messages about any non-ANSI compliance in the code

c) the compiler will ignore all warnings

d) the compiler will read the file **`HelloWorld.c`**

e) the compiler will overwrite the **`HelloWorld`** file if it already exists

Quiz: Question 5

- What is true about of the following compiler call? (Check all that apply!)

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% gcc HelloWorld.c -Wall -ansi -o HelloWorld
```

a) the GNU C Compiler is called to generate an executable program called **`HelloWorld`**

b) the compiler will print warning and/or error messages about any non-ANSI compliance in the code

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d) the compiler will read the file **`HelloWorld.c`**

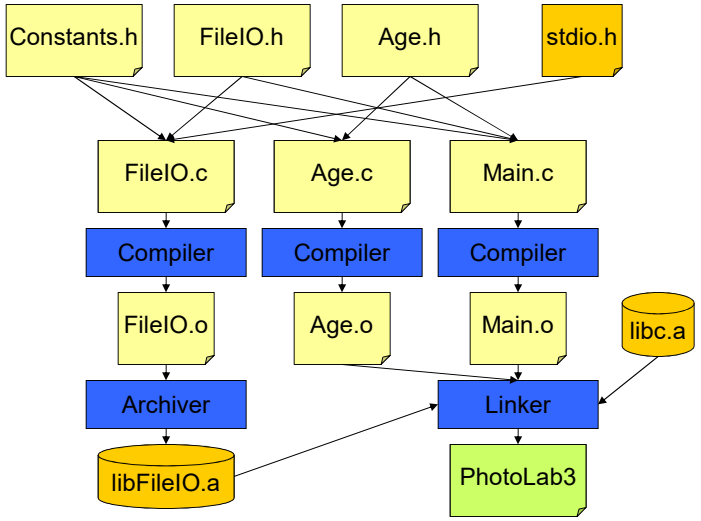
e) the compiler will overwrite the **`HelloWorld`** file if it already exists

Shared Libraries

- When a set of modules is useful for multiple applications, a *shared library* can be built for reusing the functionality provided by the modules
  1) *Static library*: Archive of object files (linked at compile-time)
     - Examples: **`libC.a`**, **`libM.a`**
     - Archive tools **`ar`** and **`ranlib`**
       - can combine multiple object files into linker archives
  2) *Dynamic library*: Shared object file (loaded at run-time)
     - Examples: **`libC.so`**, **`libM.so`**
     - Compiler **`gcc`**
       - can create position-independent code (**`-fPIC`**)
       - can create shared libraries (**`-shared`**)
       - can create executable files that load shared object files at run-time (**`-Lpath -Xlinker -R -Xlinker path`**)

Shared Libraries

- Example: Shared **`FileIO`** Library for **`PhotoLab3`**



Shared Libraries

- Example: Shared **`FileIO`** Library for **`PhotoLab3`**
- Option 1: Static shared library
  - Preparing the archive file:

```
% vi Constants.h
% vi FileIO.h
% vi FileIO.c
```

```
% gcc -c FileIO.c -o FileIO.o -Wall -ansi -std=c99
% ar rc libFileIO.a FileIO.o
% ranlib libFileIO.a
%
```

  - Building and compiling the application:

```
% vi Age.h
% vi Age.c
% vi Main.c
```

```
% gcc -c Age.c -o Age.o -Wall -ansi -std=c99
% gcc -c Main.c -o Main.o -Wall -ansi -std=c99
% gcc Main.o Age.o -lFileIO -L. -o PhotoLab3
% ./PhotoLab3
%
```


Shared Libraries

- Example: Shared **`FileIO`** Library for **`PhotoLab3`**
- Option 2: Dynamically loaded shared library
  - Preparing the shared object file:

```
% gcc -c -fPIC FileIO.c -o FileIO.o -Wall -ansi -std=c99
% gcc -shared -fPIC -o libFileIO.so FileIO.o
%
```

  - Building and compiling the application:

```
% gcc -c Age.c -o Age.o -Wall -ansi -std=c99
% gcc -c Main.c -o Main.o -Wall -ansi -std=c99
% gcc Main.o Age.o -lFileIO -L.
      -Xlinker -R -Xlinker . -o PhotoLab3
% ./PhotoLab3
% ldd PhotoLab3
        linux-vdso.so.1 =>  (0x00007fff07550000)
        libFileIO.so => ./libFileIO.so (0x00007f2ddf1ac000)
        libc.so.6 => /lib64/libc.so.6 (0x00000035f5000000)
        /lib64/ld-linux-x86-64.so.2 (0x00000035f4c00000)
%
```

Make and Makefile

- Building an application from multiple source files requires multiple compiler calls
  - Typing compiler calls manually is tedious and error-prone
  - ➢ Automation can help: build scripts!
- Linux tool **`make`**
  - reads compilation rules from a **`Makefile`** (script)
  - automatically executes necessary build commands
- **`Makefile`** consists of a set of rules
- Rules consist of
  - *Target* (usually a file)
  - *Dependencies* (typically source files)
  - *Command(s)* to generate the target from the sources

Make and Makefile

- Example Rule:

```
HelloWorld: HelloWorld.c
     gcc -Wall -ansi -std=c99 HelloWorld.c -o HelloWorld
```

  Target **`HelloWorld`**
  - depends on source file **`HelloWorld.c`**
  - can be built by executing the listed command
    - Note: Command line starts with a *horizontal tabulator* (TAB)!
- Compilation: Make!

```
% vi HelloWorld.c
% vi Makefile
% make
gcc -Wall -ansi -std=c99 HelloWorld.c -o HelloWorld
% ./HelloWorld
Hello World!
%
```

Make and Makefile

- **`Makefile`** with Multiple Rules
  - **`make`**
    - Builds the first target (executes first rule)
  - **`make target`**
    - Builds the specified target (executes specified rule)
- Rules and Dependencies
  - Rules are applied *if and only if* the target file…
    - … does not exist, or
    - … is out of date
      - Target file is older than any of its dependencies
      - Every file has a time stamp of its last modification time, so **`make`** can determine what needs to be re-built
  - Rules are applied *recursively*
    - If a dependency is missing or is not up-to-date, **`make`** builds it first!

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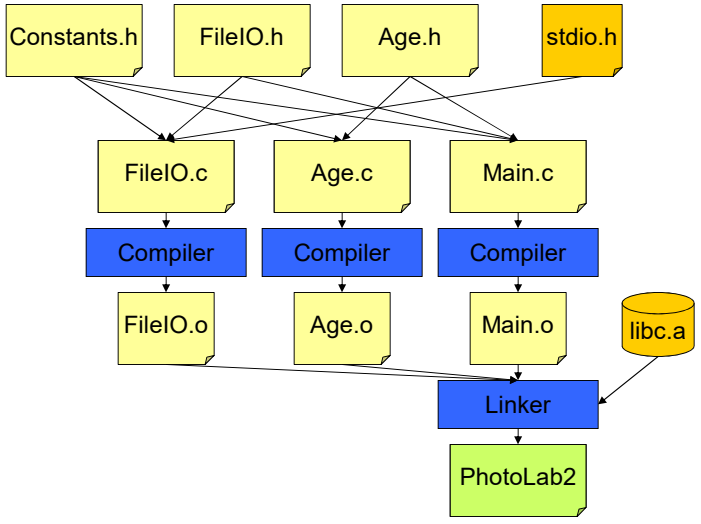
Make and Makefile

- Making **`PhotoLab2`**



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Make and Makefile

- Example: Basic **`Makefile`** for **`PhotoLab2`**

```
# Makefile: PhotoLab2

PhotoLab2: FileIO.o Age.o Main.o
     gcc -Wall -ansi -std=c99 FileIO.o Age.o Main.o -o PhotoLab2

FileIO.o: FileIO.c FileIO.h Constants.h
     gcc -Wall -ansi -std=c99 -c FileIO.c -o FileIO.o

Age.o: Age.c Age.h Constants.h
     gcc -Wall -ansi -std=c99 -c Age.c -o Age.o

Main.o: Main.c Constants.h FileIO.h Age.h
     gcc -Wall -ansi -std=c99 -c Main.c -o Main.o
```


Make and Makefile

- Example session: **`make PhotoLab2`**

```
% vi Constants.h
% vi FileIO.h
% vi FileIO.c
% vi Age.h
% vi Age.c
% vi Main.c
% vi Makefile
% make
gcc -Wall -ansi -std=c99 -c FileIO.c -o FileIO.o
gcc -Wall -ansi -std=c99 -c Age.c -o Age.o
gcc -Wall -ansi -std=c99 -c Main.c -o Main.o
gcc -Wall -ansi -std=c99 FileIO.o Age.o Main.o -o PhotoLab2
% ./PhotoLab2
% vi Age.c
% make
gcc -Wall -ansi -std=c99 -c Age.c -o Age.o
gcc -Wall -ansi -std=c99 FileIO.o Age.o Main.o -o PhotoLab2
% ./PhotoLab2
```

Advanced Makefile

- Commands issued by **`make`**
  - Command line must start with a (horizontal) TAB character
    - Spaces are not recognized!
  - Multiple commands are executed in order
    - Long command lines can be wrapped to the next line by a backslash (`\`) immediately followed by a newline
  - Commands are echoed to the standard output
    - Echo can be suppressed with a `@` prefix before the command
  - Commands are executed as shell commands
    - The **`sh`** shell is used (similar to **`bash`** in Linux)
  - Return value of command determines success
    - Return value 0 indicates success (no errors)
    - Return value not equal to 0 indicates error
  - Execution of commands stops with the first error
    - Errors can be ignored with a `-` prefix before the command

Advanced Makefile

- Advanced Features
  - Makefile variables

```
DEBUG = -g -DDEBUG
CFLAGS = -Wall -ansi -std=c99 $(DEBUG)
...
Program: Program.c Program.h
	gcc $(CFLAGS) Program.c -o Program
```

  - Dummy targets (aka. *pseudo* or *phony* targets)

```
# default target
all: PhotoLab2

clean:
	rm -f *.o
	rm -f PhotoLab2
```

  - Many more features are available…
    - **`man make`**

Advanced Makefile

- Advanced **`Makefile`** for **`PhotoLab2`** (part 1/2)

```
# Makefile: PhotoLab2
# 10/19/17 RD

# variable definitions
CC      = gcc
DEBUG   = -g -DDEBUG
#DEBUG  = -O2 -DNDEBUG
CFLAGS  = -Wall -ansi -std=c99 $(DEBUG) -c
LFLAGS  = -Wall $(DEBUG)

# convenience targets
all: PhotoLab2

clean:
        rm -f *.o
        rm -f PhotoLab2

test: PhotoLab2
        ./PhotoLab2
...
```


Advanced Makefile

- Advanced **`Makefile`** for **`PhotoLab2`** (part 2/2)

```
...

# compilation rules
FileIO.o: FileIO.c FileIO.h Constants.h
        $(CC) $(CFLAGS) FileIO.c -o FileIO.o

Age.o: Age.c Age.h Constants.h
        $(CC) $(CFLAGS) Age.c -o Age.o

Main.o: Main.c Constants.h FileIO.h Age.h
        $(CC) $(CFLAGS) Main.c -o Main.o

PhotoLab2: FileIO.o Age.o Main.o
        $(CC) $(LFLAGS) FileIO.o Age.o Main.o -o PhotoLab2
```

Advanced Makefile

- Example session: **`make PhotoLab2`**

```
...
% vi Makefile
% make clean
rm -f *.o
rm -f PhotoLab2
% make test
gcc -Wall -ansi -std=c99 -c FileIO.c -o FileIO.o
gcc -Wall -ansi -std=c99 -c Age.c -o Age.o
gcc -Wall -ansi -std=c99 -c Main.c -o Main.o
gcc -g FileIO.o Age.o Main.o -o PhotoLab2
./PhotoLab2
% vi Age.c
% make test
gcc -Wall -ansi -std=c99 -c Age.c -o Age.o
gcc -g FileIO.o Age.o Main.o -o PhotoLab2
./PhotoLab2
%
```