

# C++ For C Coders 8

## Build Process

Data Structures  
C++ for C Coders

한동대학교 김영섭 교수  
idebtor@gmail.com

build process  
compile & link  
static library  
make & makefile

# Build Process

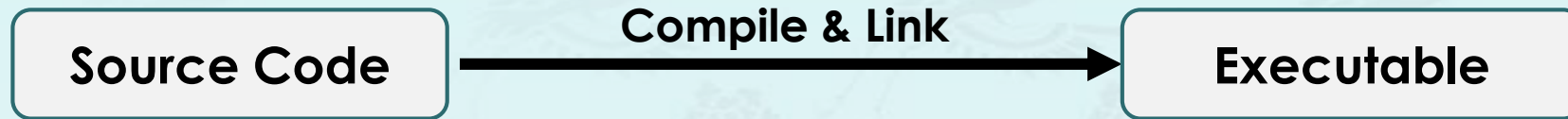
---

1. Compile & Link
2. Build Process
3. Make and makefile
4. Build a static library

# Build Process

The term build process here refers to the steps starting with source code (**a set of .cpp and .h files**) ending with an executable file representing your program.

- A simplistic view of the build process

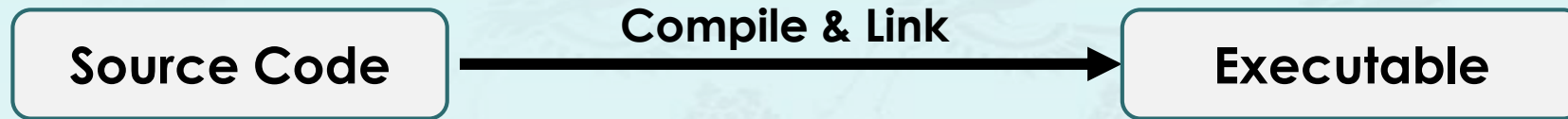


```
$ g++ quick.cpp comparator.cpp printlist.cpp -I../include -o sort
```

# Build Process

The term build process here refers to the steps starting with source code (**a set of .cpp and .h files**) ending with an executable file representing your program.

- A simplistic view of the build process



> g++ quick.cpp comparator.cpp printlist.cpp -I../include -o qsort

- A simple but realistic view of the build process



> g++ -c quick.cpp comparator.cpp printlist.cpp -I../include

> g++ quick.o comparator.o printlist.o -L../lib -lsort -o qsort

Compile

Link

The two command lines can be combined into one line shown below:

> g++ quick.cpp comparator.cpp printlist.cpp -I../include -L../lib -lsort -o qsort  
(Assume that **../lib/libsort.a** exists.)

# Compile & Link

---

Building an executable for a program consists of two major stages:

- **Compile stage (.cpp, .h → .o)**
  - **Syntax** checked for correctness.
  - Variables and function calls checked to insure that correct declarations were made and that they match.
  - It **doesn't match function definitions** to their calls at this point.
  - Translation into **object code**. It is not an executable.

# Compile & Link

---

Building an executable for a program consists of two major stages:

- **Compile stage (.cpp, .h → .o)**
  - **Syntax** checked for correctness.
  - Variables and function calls checked to insure that correct declarations were made and that they match.
  - It **doesn't match function definitions** to their calls at this point.
  - Translation into **object code**. It is not an executable.
- **Linking stage (.o, .a → .exe)**
  - Links the object code into an executable.
  - May involve one or more object code files.
  - **Function calls** are matched up with their definitions, and the compiler checks to make sure it has one, and only one, definition for every function.
  - The end result of linking is usually an executable.



# Compiling options

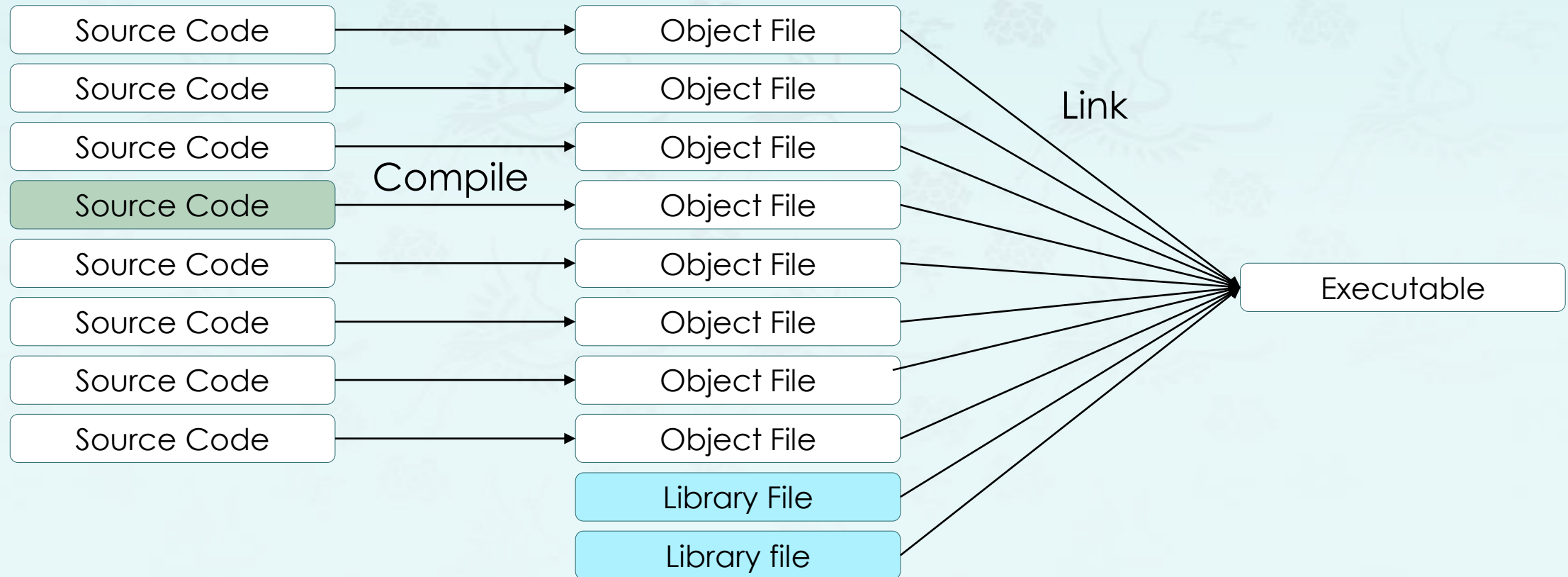
---

- **-g** - turn on debugging (so GDB gives more friendly output)
  - **-Wall** - turns on most warnings
  - **-O** or **-O2** - turn on optimizations
  - **-o <name>** - name of the output file
  - **-c** - output an object file (**.o**)
  - **-I<include path>** - specify an **include** directory
  - **-L<library path>** - specify a **lib** directory
  - **-l<library>** - link with library **lib<library>.a**
- 
- Use **-Ldir** option such that linker looks for library files in in **dir** folder.  
Use **-llibrary** such that linker searches the library named **library**.

# Build Process

Addressing the build process efficiency:

- In this case we highlight the situation where ONE of those files has changed since the previous build. In building the naive brute-force way, ALL source code is recompiled, even those source code files that have not changed.

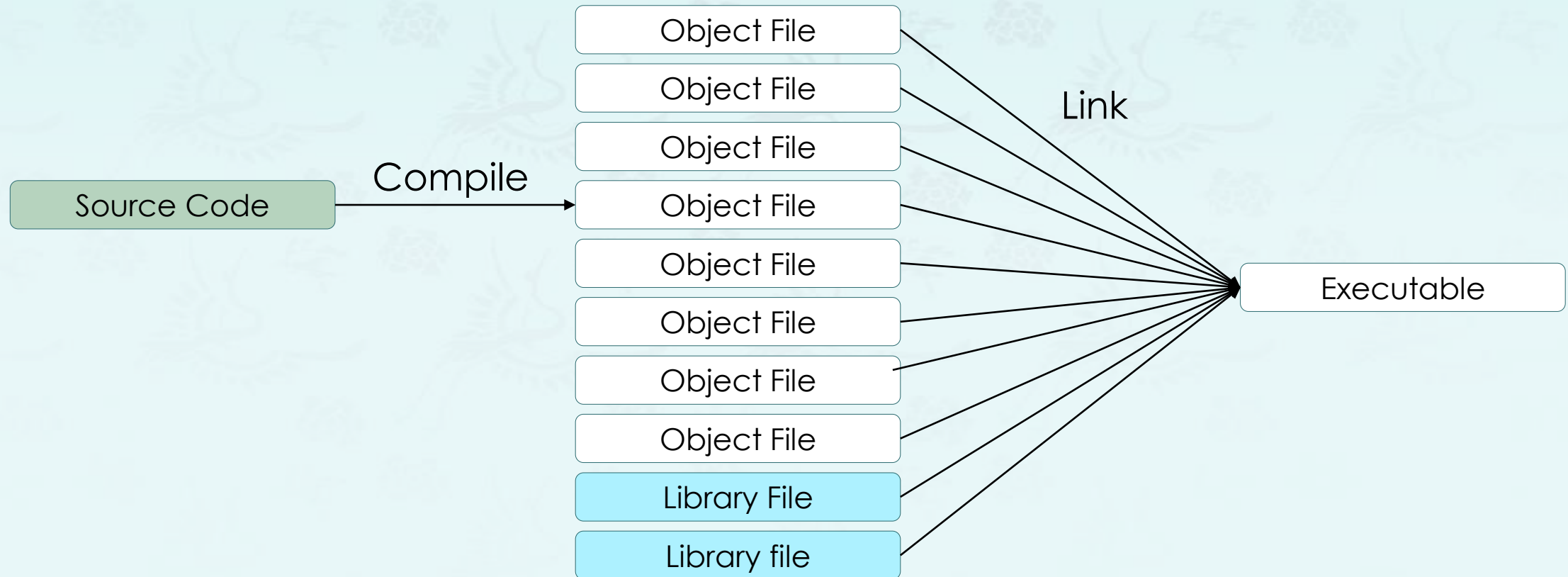




# Build Process

Addressing the build process efficiency:

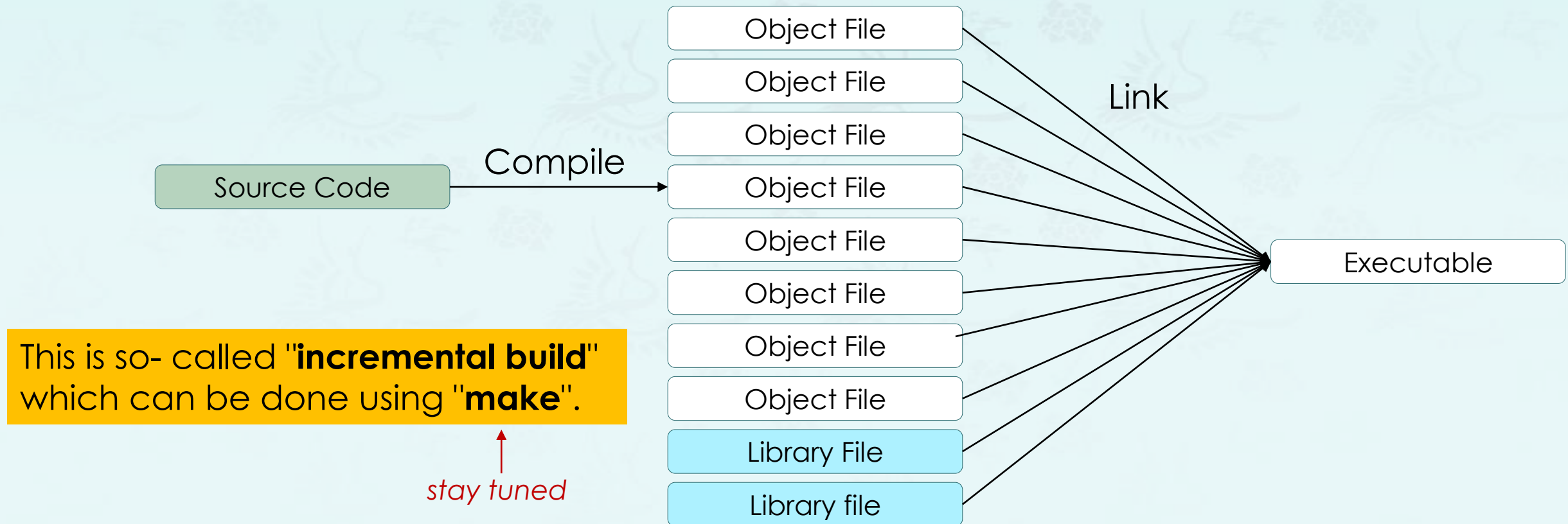
- Only one source file has changed since the last build. This is the only file re-compiled on the following build. The build otherwise uses the unchanged object files from the previous build, shortening the overall build time.



# Build Process

Addressing the build process efficiency:

- Only one source file has changed since the last build. This is the only file re-compiled on the following build. The build otherwise uses the unchanged object files from the previous build, shortening the overall build time.



# Creating a Library Archive

---

An archive in C/C++ is a file that bundles a set of object files into a single file.

- This file always follows the naming convention of starting with **lib** and ending with **.a**, e.g., `libsort.a` and `libnowic.a` in our library examples.
- An archive file can be build from object files using the **ar** command:  

```
> ar crs libsort.a bubble.o insertion.o quick.o selection.o
```
- **ar** Options
  - c: Create an archive file
  - r: Insert the files member... into archive (with replacement).
  - s: Write an object-file index into the archive, change is made to the archive
  - t: Display contents of archive (show the list of .o files, use `nm ~.o` to see functions in ~.o)

# Creating a Library Archive

---

- **ar** Examples:
  - `g++ -c nowic.cpp -I../include` // produces `nowic.o`
  - `ar crs libnowic.a nowic.o` // produces `libnowic.a` that includes `nowic.o`
  - `ar` // list all the options available
  - `ar t libnowic.a` // list `~.o` files archived
  - `ar x libnowic.a` // extract `~.o` files archived
  - `nm nowic.o` // list the actual function names in `.o` file
- You may refer to **`/nowic/UsingStaticLib.md`**.

# The make utility

---

- Building a program from its source files can be a complicated and time-consuming operation. The commands are too long to be typed in manually every time. However, a straightforward shell script is seldom used for compiling a program, because it's too time-consuming to recompile all modules when only one of them has changed.
- However, it's too error-prone to allow a human to tell the computer which files need to be recompiled. Forgetting to recompile a file can mean hours of frustrating debugging. A reliable automatic tool is necessary for determining exactly which modules need recompilation.
- A standard tool for solving exactly this problem is called **make**. It relies either on its own built-in knowledge, or on a file called a **makefile (or Makefile)** that contains a detailed recipe for building the program.

## References:

- <http://nuclear.mutantstargoat.com/articles/make/>
- <https://skandhurkat.com/post/makefile-dependencies/>
- <https://www.tuwlabs.com/ece/27193> ← one of the best, must-read



# The make utility

---

- You may need to install some packages.  
(Install it as **admin privilege**. 관리자모드로 설치하십시오)
  - > `pacman -S base-devel` #install the build toolchain
  - > `pacman -Syu` #update msys2Alternatively,
  - > `pacman -S --needed base-devel mingw-w64-i686-toolchain mingw-w64-x86_64-toolchain`
- For macOS, use 'Homebrew' to install these kinds of packages in general.
  - <https://osxdaily.com/2018/03/07/how-install-homebrew-mac-os/>
  - <https://whitepaek.tistory.com/3>
- For Linux,
  - > `./configure`
  - > `make`
  - > `sudo make install`



# The make utility – a simple example of makefile

---

- **Basic syntax for makefile:**

```
target: dependencies  
<tab>system command(s)
```

- **Example:**

Source files: quick.cpp, comparator.cpp, printlist.cpp  
Executable: qsort.exe

- **makefile:**

# The make utility – a simple example of makefile

- **Basic syntax for makefile:**

```
target: dependencies
<tab>system command(s)
```

- **Example:**

Source files: quick.cpp, comparator.cpp, printlist.cpp  
Executable: qsort.exe

- **makefile:**

```
qsort: quick.o comparator.o printlist.o
    g++ quick.o comparator.o printlist.o -o qsort
quick.o: quick.cpp
    g++ -c quick.cpp ../../include
comparator.o: comparator.cpp
    g++ -c comparator.cpp
printlist.o: printlist.cpp
    g++ -c printlist.cpp
clean:
<tab>rm -f *.o qsort.exe qsort
```

```
makefile:14: ***분리기호가 빠졌음. 멈춤.
```

```
PS C:\GitHub\nowicx\labs\labmake> make
makefile:14: *** missing separator. Stop.
PS C:\GitHub\nowicx\labs\labmake>
```

# The make utility – a simple example of makefile

- **Basic syntax for makefile:**

```
target: dependencies  
<tab>system command(s)
```

- **Example:**

Source files: quick.cpp, comparator.cpp, printlist.cpp  
Executable: qsort.exe

- **makefile:**

```
qsort: quick.o comparator.o printlist.o  
    g++ quick.o comparator.o printlist.o -o qsort  
quick.o: quick.cpp  
    g++ -c quick.cpp ../../include  
comparator.o: comparator.cpp  
    g++ -c comparator.cpp  
printlist.o: printlist.cpp  
    g++ -c printlist.cpp  
clean:  
<tab>rm -f *.o qsort.exe qsort
```

```
> make  
> make clean
```

# The make utility – a simple example of makefile

- **Basic syntax for makefile:**

```
target: dependencies
<tab>system command(s)
```

- **Example:**

Source files: quick.cpp, comparator.cpp, printlist.cpp  
Executable: qsort.exe

- **makefile:**

```
qsort: quick.o comparator.o printlist.o
    g++ quick.o comparator.o printlist.o -o qsort
quick.o: quick.cpp
    g++ -c quick.cpp ../../include
comparator.o: comparator.cpp
    g++ -c comparator.cpp
printlist.o: printlist.cpp
    g++ -c printlist.cpp
clean:
    <tab>rm -f *.o qsort.exe qsort
```

```
PS C:\GitHub\nowicx\labs\labmake> make
g++ -c quick.cpp -I../../include
g++ -c comparator.cpp
g++ -c printlist.cpp
g++ quick.o comparator.o printlist.o -o qsort
PS C:\GitHub\nowicx\labs\labmake> 
```

```
> make
> make clean
```

# The make utility – a simple example of makefile

## ■ Basic syntax for makefile:

```
target: dependencies
<tab>system command(s)
```

## ■ Example:

Source files: quick.cpp, comparator.cpp, printlist.cpp  
Executable: qsort.exe

## ■ makefile:

```
qsort: quick.o comparator.o printlist.o
    g++ quick.o comparator.o printlist.o -o qsort
quick.o: quick.cpp
    g++ -c quick.cpp ../../include
comparator.o: comparator.cpp
    g++ -c comparator.cpp
printlist.o: printlist.cpp
    g++ -c printlist.cpp
clean:
    <tab>rm -f *.o qsort.exe qsort
```

- Turn on main() in quick.cpp since it is the only one in the source files. Otherwise, you may get the following error message.

```
C:/msys64/mingw64/bin/./lib/gcc/x86_64-w64-mingw32/10.2.0/./././././x86_64-w64-mingw32/
bin/ld.exe: C:/msys64/mingw64/bin/./lib/gcc/x86_64-w64-mingw32/10.2.0/./././././x86_64-
w64-mingw32/lib/./lib/libmingw32.a(lib64_libmingw32_a-crt0_c.o): in function `main':
D:/mingwbuild/mingw-w64-crt-git/src/mingw-w64/mingw-w64-crt/crt/crt0_c.c:18: undefined ref
erence to `WinMain'
collect2.exe: error: ld returned 1 exit status
make: *** [makefile:14: qsort] 오류 1
```

```
> make
> make clean
```

# The make utility – sort example

---

- Source files and their dependencies are listed:
  - **sortDriver.cpp**: printlist.cpp, nowic.h, sort.h, libnowic.a
  - comparator.cpp
  - printlist.cpp
  - bubble.cpp: comparator.cpp, sort.h
  - quick.cpp: comparator.cpp, sort.h
- Build an executable file: sortDriver.exe
  - Using a command line:

```
> g++ -std=c++11 -Wall sortDriver.cpp comparator.cpp printlist.cpp bubble.cpp \
    quick.cpp -I../..../include -L../..../lib -lnowic -o sortDriver
```
  - Using a makefile



# The make utility – make.1

```
sortDriver: sortDriver.o comparator.o printlist.o bubble.o quick.o
```

```
<tab> g++ sortDriver.o comparator.o printlist.o bubble.o quick.o \  
      -I../../include -L../../lib -lnowic -o sortDriver
```

```
sortDriver.o: sortDriver.cpp
```

```
g++ -c -std=c++11 -Wall sortDriver.cpp -I../../include
```

```
comparator.o: comparator.cpp
```

```
g++ -c -std=c++11 -Wall comparator.cpp
```

```
printlist.o: printlist.cpp
```

```
g++ -c -std=c++11 -Wall printlist.cpp
```

```
bubble.o: bubble.cpp
```

```
g++ -c -std=c++11 -Wall bubble.cpp -I../../include
```

```
quick.o: quick.cpp
```

```
g++ -c -std=c++11 -Wall quick.cpp -I../../include
```

```
clean:
```

```
<tab> rm -f *.o sortDriver.exe sortDriver
```

- Turn off main() in all other files, if any, since main() in sortDriver.cpp will be used.

```
> make -f make.1  
> make clean
```

# The make utility – make.1

```
sortDriver: sortDriver.o comparator.o printlist.o bubble.o quick.o
```

```
<tab> g++ sortDriver.o comparator.o printlist.o bubble.o quick.o \  
      -I../../include -L../../lib -lnowic -o sortDriver
```

```
sortDriver.o: sortDriver.cpp
```

```
      g++ -c -std=c++11 -Wall sortDriver.cpp -I../../include
```

```
comparator.o: comparator.cpp
```

```
      g++ -c -std=c++11 -Wall comparator.cpp
```

```
printlist.o: printlist.cpp
```

```
      g++ -c -std=c++11 -Wall printlist.cpp
```

```
bubble.o: bubble.cpp
```

```
      g++ -c -std=c++11 -Wall bubble.cpp -I../../include
```

```
quick.o: quick.cpp
```

```
      g++ -c -std=c++11 -Wall quick.cpp -I../../include
```

```
clean:
```

```
<tab> rm -f *.o sortDriver.exe sortDriver
```

```
# Using Rules
```

```
INCDIR = ../../include
```

```
SRCS = sortDriver.cpp comparator.cpp bubble.cpp ...
```

```
OBJS = $(SRCS:.cpp=.o)
```

```
TARGET = sortDriver
```

```
$(TARGET): $(OBJS)
```

```
      g++ -I$(INCDIR) $(SRCS) -o $(TARGET)
```

```
> make -f make.1
```

```
> make clean
```

# The make utility – make.1

```
sortDriver: sortDriver.o comparator.o printlist.o bubble.o quick.o
```

```
<tab> g++ sortDriver.o comparator.o printlist.o bubble.o quick.o \  
      -I../../include -L../../lib -lnowic -o sortDriver
```

```
sortDriver.o: sortDriver.cpp
```

```
g++ -c -std=c++11 -Wall sortDriver.cpp -I../../include
```

```
comparator.o: comparator.cpp
```

```
g++ -c -std=c++11 -Wall comparator.cpp
```

```
printlist.o: printlist.cpp
```

```
g++ -c -std=c++11 -Wall printlist.cpp
```

```
bubble.o: bubble.cpp
```

```
g++ -c -std=c++11 -Wall
```

```
quick.o: quick.cpp
```

```
g++ -c -std=c++11 -Wall
```

```
clean:
```

```
<tab> rm -f *.o sortDriver.
```

```
# Using Rules
```

```
INCDIR = ../../include
```

```
SRCS = sortDriver.cpp comparator.cpp bubble.cpp ...
```

```
OBJS = $(SRCS:.cpp=.o)
```

```
TARGET = sortDriver
```

```
PS C:\GitHub\nowicx\labs\lab7build> make -f make.1
```

```
g++ -c -std=c++11 -Wall sortDriver.cpp -I../../include
```

```
g++ -c -std=c++11 -Wall comparator.cpp
```

```
g++ -c -std=c++11 -Wall printlist.cpp
```

```
g++ -c -std=c++11 -Wall bubble.cpp -I../../include
```

```
g++ -c -std=c++11 -Wall quick.cpp -I../../include
```

```
g++ sortDriver.o comparator.o printlist.o bubble.o quick.o -I../../include -L../../lib -lnowic -o sortDriver
```

```
PS C:\GitHub\nowicx\labs\lab7build> █
```

```
> make -f make.1
```

```
> make clean
```



# The make utility – make.2

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR) -lnowic

SRCS = sortDriver.cpp comparator.cpp printlist.cpp bubble.cpp quick.cpp
OBS = $(SRCS:.cpp=.o)
EXE1 = sortDriver

$(EXE1): $(OBS)
    $(CC) -o $@ $^ $(LDFLAGS)
%.o: %.cpp
    $(CC) -c $(CCFLAGS) -I$(INCDIR) $<

.PHONY: all clean
all: $(EXE1)
clean:
    rm -f $(OBS) $(EXE1)
```

make automatic variables

`$@` the filename of the target  
`$^` the filenames of all the prerequisites  
`$<` the filenames of the first prerequisites  
`$*` the stem of the target filename  
`$(*)` Same as `$^` except that `$(*)` includes duplicates

# The make utility – make.2

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR) -lnowic

SRCS = sortDriver.cpp comparator.cpp printlist.cpp bubble.cpp quick.cpp
OBJS = $(SRCS:.cpp=.o)
EXE1 = sortDriver

$(EXE1): $(OBJS)
    $(CC) -o $@ $^ $(LDFLAGS)

%.o: %.cpp
    $(CC) -c $(CCFLAGS) -I$(INCDIR) $<

.PHONY: all clean
all: $(EXE1)
clean:
    rm -f $(OBJS) $(EXE1)
```

```
> make -f make.2
> make clean
```

```
$(EXE1): $(OBJS)
    $(CC) $(CCFLAGS) -I$(INCDIR) -o $@ $^ $(LDFLAGS)
```

make automatic variables

- \$@ the filename of the target
- \$^ the filenames of all the prerequisites
- \$< the filenames of the first prerequisites
- \$\* the stem of the target filename
- \$+ Same as \$^ except that \$+ includes duplicates

# The make utility – make.2

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR) -lnowic

SRCS = sortDriver.cpp comparator.cpp printlist.cpp bubble.cpp quick.cpp
OBJS = $(SRCS:.cpp=.o)
EXE1 = sortDriver
```

```
$(EXE1): $(OBJS)
    $(CC) -o $@ $^ $(LDFLAGS)

%.o: %.cpp
    $(CC) -c $(CCFLAGS) -I$

.PHONY: all clean
all: $(EXE1)
clean:
    rm -f $(OBJS) $(EXE1)
```

```
> make -f make.2
> make clean
```

```
PS C:\Github\nowicx\labs\labmake> make -f make.2
g++ -c -Wall -std=c++11 -g -I../../include -o sortDriver.o sortDriver.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o comparator.o comparator.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o printlist.o printlist.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o bubble.o bubble.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o quick.o quick.cpp
g++ -o sortDriver sortDriver.o comparator.o printlist.o bubble.o quick.o -L../../lib -lnowic
PS C:\Github\nowicx\labs\labmake>
```



# Build a static library(libsort.a)

- Using a command line
  - Build `libsort.a`, and place its copy to `../..lib` folder.
  - Assume that we have all source files at the current folder and `../..include/sort.h`.

```
> g++ -c -std=c++11 -Wall comparator.cpp
> g++ -c -std=c++11 -Wall printlist.cpp
> g++ -c -std=c++11 -Wall bubble.cpp -I../..include
> g++ -c -std=c++11 -Wall quick.cpp -I../..include
>
> ar cru libsort.a comparator.o printlist.o bubble.o quick.o
> ar t libsort.a
> cp libsort.a ../..lib
```

- Using a makefile

# Build a static library(libsort.a) – make.libsort

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR)

SRCS = comparator.cpp printlist.cpp bubble.cpp quick.cpp
OBJS = $(SRCS:.cpp=.o)
ARCH = libsort.a

$(ARCH): $(OBJS)
    ar cru $@ $+
    ranlib $@

%.o: %.cpp
    $(CC) -c $(CCFLAGS) $<

.PHONY: all install clean
all: $(ARCH)
clean:
    rm -f $(OBJS)
install:
    cp -v $(ARCH) ../../nowic/lib
```

```
> make -f make.libsort
> ar t libsort.a
> make -f make.libsort install
```

make automatic variables

- \$@ the filename of the target
- ^ the filenames of all the prerequisites
- < the filenames of the first prerequisites
- \* the stem of the target filename
- + Same as ^ except that + includes duplicates

# Build a static library(libsort.a) – make.libsort

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR)

SRCS = comparator.cpp printlist.cpp bubble.cpp quick.cpp
OBJS = $(SRCS:.cpp=.o)
ARCH = libsort.a

$(ARCH): $(OBJS)
    ar cru $@ $+
    ranlib $@

%.o: %.cpp
    $(CC) -c $(CCFLAGS) $<

.PHONY: all install clean
all: $(ARCH)
clean:
    rm -f $(OBJS)
install:
    cp -v $(ARCH) ../../nowic/lib
```

```
> make -f make.libsort
> ar t libsort.a
> make -f make.libsort install
```

```
PS C:\GitHub\nowicx\labs\labmake> make -f make.libsort
g++ -c -Wall -std=c++11 -g bubble.cpp
ar cru libsort.a comparator.o printlist.o bubble.o quick.o
ranlib libsort.a
PS C:\GitHub\nowicx\labs\labmake> █
```

# Build an executable using a static lib

- Source files and their dependencies are listed:
  - `sortDriver.cpp`: `nowic.h`, `sort.h`, `libnowic.a`, `libsort.a`
- Build an executable file: `sortDriver.exe`
  - `g++ -Wall -std=c++11 sortDriver.cpp -I.././include -L.././lib -lsort -lnowic -o sortDriver`

# Build an executable(sortDriver) using a static lib – make.3

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR) -lnowic -lsort

SRC1 = sortDriver.cpp
OBJ1 = $(SRC1:.cpp=.o)
EXE1 = sortDriver

$(EXE1): $(OBJ1)
    $(CC) -o $@ $^ $(LDFLAGS)

%.o: %.cpp
    $(CC) $(CCFLAGS) -c $< -I$(INCDIR)

.PHONY: all clean
all: $(EXE1)
clean:
<tab> rm -f $(OBJ1) $(EXE1)
```

```
> make -f make.3
```

```
$(EXE1): $(OBJS)
    $(CC) $(CCFLAGS) -I$(INCDIR) -o $@ $^ $(LDFLAGS)
```

make automatic variables

\$@ the filename of the target  
\$^ the filenames of all the prerequisites  
\$< the filenames of the first prerequisites  
\$\* the stem of the target filename  
\$+ Same as \$^ except that \$+ includes duplicates



# Build an executable(sortDriver) using a static lib – make.3

```
CC = g++
LIBDIR = ../../lib
INCDIR = ../../include
CCFLAGS = -Wall -std=c++11 -g
LDFLAGS = -L$(LIBDIR) -lnowic -lsort
```

```
SRC1 = sortDriver.cpp
OBJ1 = $(SRC1:.cpp=.o)
EXE1 = sortDriver
```

```
$(EXE1): $(OBJ1)
    $(CC) -o $@ $^ $(LDFLAGS)
%.o: %.cpp
    $(CC) $(CCFLAGS) -c $< -I$(INCDIR)

.PHONY: all clean
all: $(EXE1)
clean:
```

```
<tab> rm -f $(OBJ1) $(EXE1)
```

- Make sure that you have only one main() turned on in sortDriver.cpp.

```
> make -f make.3
```

```
PS C:\Github\nowicx\labs\labmake> make -f make.3
g++ -c -Wall -std=c++11 -g -I../../include -o sortDriver.o sortDriver.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o comparator.o comparator.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o printlist.o printlist.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o bubble.o bubble.cpp
g++ -c -Wall -std=c++11 -g -I../../include -o quick.o quick.cpp
g++ -o sortDriver sortDriver.o comparator.o printlist.o bubble.o quick.o -L../../lib -lnowic
PS C:\Github\nowicx\labs\labmake>
```



# C++ For C Coders 8

## Build Process

Data Structures  
C++ for C Coders

한동대학교 김영섭 교수  
idebtor@gmail.com

build process  
compile & link  
static library  
make & makefile