CS1010 Programming Methodology

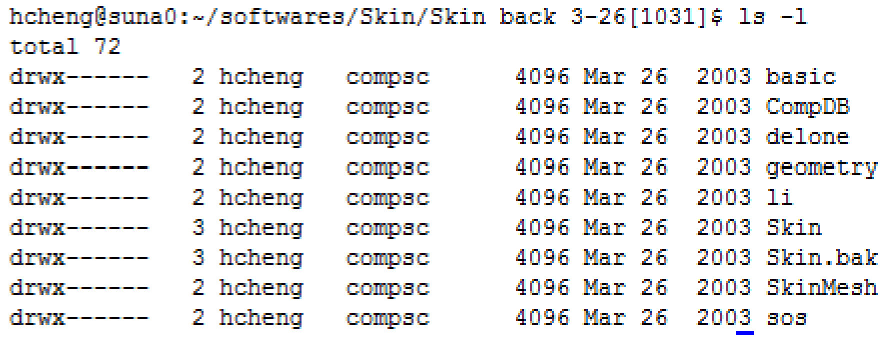
http://www.comp.nus.edu.sg/~cs1010/

UNIT 13

Separate Compilation

NUS National University of Singapore | School of Computing

My Ph.D Code



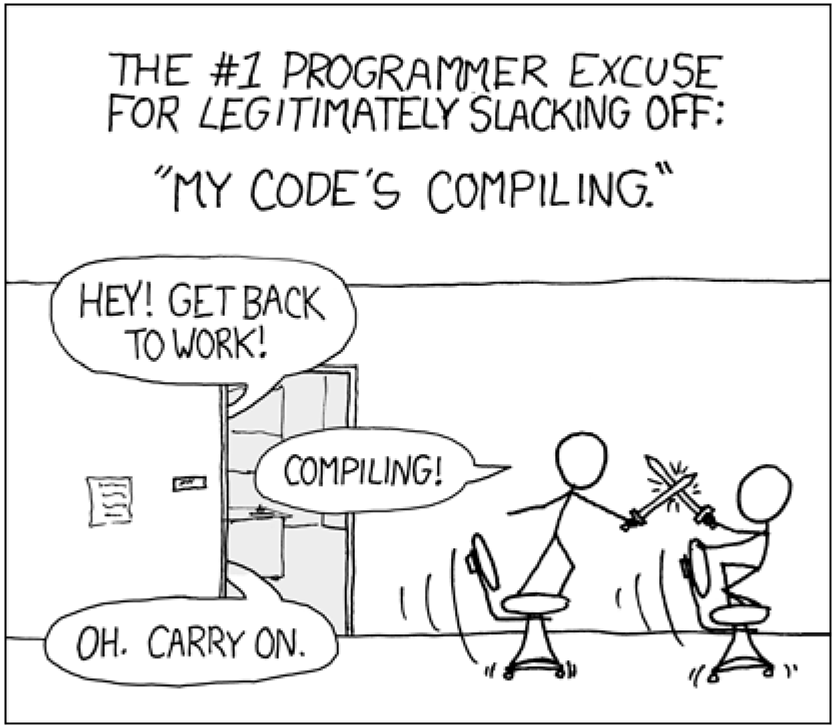
```
hcheng@suna0:~/softwares/Skin/Skin back 3-26[1031]$ ls -l
total 72
drwx------   2 hcheng   compsc      4096 Mar 26  2003 basic
drwx------   2 hcheng   compsc      4096 Mar 26  2003 CompDB
drwx------   2 hcheng   compsc      4096 Mar 26  2003 delone
drwx------   2 hcheng   compsc      4096 Mar 26  2003 geometry
drwx------   2 hcheng   compsc      4096 Mar 26  2003 li
drwx------   3 hcheng   compsc      4096 Mar 26  2003 Skin
drwx------   3 hcheng   compsc      4096 Mar 26  2003 Skin.bak
drwx------   2 hcheng   compsc      4096 Mar 26  2003 SkinMesh
drwx------   2 hcheng   compsc      4096 Mar 26  2003 sos
```

```
basic:
arg.c                 cmdlookup.cpp         farray.hpp            license.cpp           nurbsdata.cpp         rarray.h              rgitypes.h            versions.h
basic.c               cmdlookup.h           files.c               license.h             nurbsdata.h           rarray.hpp            rgivector.cpp         vertexarray.cpp
basic.dsp             command.cpp           flexlm.cpp            list.h                orindex.h             rectsel.cpp           rgivector.h           vertexarray.h
basic.h               command.h             flexlm.h              list.hpp              orindex.hpp           rectsel.h             rgivector.hpp         vltdata.cpp
basic.plg             comment.cpp           freearray.h           lm_attr.h             ortri.h               rgicstring.cpp        spectrum.cpp          vltdata.h
binio.cpp             comment.h             freearray.hpp         lm_code.h             ortri.hpp             rgicstring.h          spectrum.h            wfshortestpather.cpp
binio.h               console.cpp           genmatrix.cpp         lmclient.h            perftimer.cpp         rgicstring.hpp        stackbv.cpp           wfshortestpather.h
binio.hpp             console.h             genmatrix.h           lmpolicy.h            perftimer.h           rgimatrix.cpp         stackbv.h             win_basic.h
bitvector.cpp         convert.cpp           getarg.c              logfile.cpp           points.cpp            rgimatrix.h           stringtable.cpp       wireframe.cpp
bitvector.h           convert.h             history.cpp           logfile.h             points.h              rgimatrix.hpp         stringtable.h         wireframe.h
bitvector.hpp         convert.hpp           history.h             malloc.c              points.hpp            rgimessage.cpp        time.c                wireframe.hpp
build.h               data.cpp              iit.c                 map.h                 pqueue.h              rgimessage.h          tokenize.c            xdr.c
callbacklist.cpp      data.h                index.h               map.hpp               pqueue.hpp            rgimessagestack.cpp   tritype.h             xdr.h
callbacklist.h        dumpable.cpp          isort.c               math2.c               prime.c               rgimessagestack.h     uf.c
callbackobject.cpp    dumpable.h            iterstack.h           miscmath.cpp          qsort.c               rgistring.cpp         unix_basic.h
callbackobject.h      dumpable.hpp          iterstack.hpp         miscmath.h            queue.h               rgistring.h           util.h
cb_doprnt.c           facepoint.h           kdtree.cpp            multitree.h           queue.hpp             rgitranslator.cpp     vectmat.cpp
cb.c                  farray.h              kdtree.h              multitree.hpp         raindrop.c            rgitranslator.h       vectmat.h

CompDB:
compDB.cpp  CompDB.dsp  compDB.h    CompDB.plg

delone:
boundary.cpp   dcbuilder.cpp  dcofaces.cpp   dcomp.cpp      dcompiter.cpp  delone.dsp     faces.cpp      ksimpsize.h    simpsize.h
boundary.h     dcbuilder.h    dcofaces.h     dcomp.h        dcompiter.h    delone.plg     ksimpsize.cpp  simpsize.cpp

geometry:
animate.cpp         comp.cpp            edgeset.h           ihandler.cpp        modtrinfo.hpp       segmenttree.cpp     simplex.h           trist.cpp           vertarray.h
animate.h           comp.h              fliphandler.cpp     ihandler.h          orienter.cpp        segmenttree.h       simplexset.cpp      trist.h             vertex.cpp
boxes.cpp           computil.cpp        fliphandler.h       ksimplex.cpp        orienter.h          shortestpather.cpp  simplexset.h        trist.hpp           vertex.h
boxes.h             computil.h          geometry.dsp        ksimplex.h          ortribv.cpp         shortestpather.h    testint.cpp         tristconnector.cpp  vertset.cpp
bvtag.cpp           edgecycleset.cpp    geometry.plg        locate.cpp          ortribv.h           simph.cpp           testint.h           tristconnector.h    vertset.h
bvtag.h             edgecycleset.h      geomutil.cpp        locate.h            packedihandler.cpp  simph.h             tolerancer.cpp      tristmodifier.h
cofaces.h           edgeset.cpp         geomutil.h          modtrinfo.h         packedihandler.h    simplex.cpp         tolerancer.h        vertarray.cpp

li:
base.h        det.c         li.dsp        li.hpp        lia.c         liaux.c       lidet.cpp     liminor.cpp   lipoints.cpp  listack.cpp   pool.c
chars.c       li.cpp        li.h          li.plg        lia.h         liaux.c.old   lidet.h       liminor.h     lipoints.h    listack.h     stack.c

Skin:
a.h                   ChildFrm.cpp          FormCommandView.cpp   MainFrm.h             resource.h            Skin.dsw              Skin.plg              SkinView.cpp
AlphaDlg.cpp          ChildFrm.h            FormCommandView.h     ReadMe.txt            Skin.aps              Skin.h                Skin.rc               SkinView.h
AlphaDlg.h            dump.stl              InputCQ.cpp           RenderView.cpp        Skin.clw              skin.log              Skin.reg              StdAfx.cpp
beforeRefinement.sav  FileOpenOption.cpp    InputCQ.h             RenderView.h          Skin.cpp              Skin.ncb              SkinDoc.cpp           StdAfx.h
beforeRefinement.stl  FileOpenOption.h      MainFrm.cpp           res                   Skin.dsp              Skin.opt              SkinDoc.h
```

Unit 13: Separate Compilation

Objective:

- Learn how to use separate compilation for program development

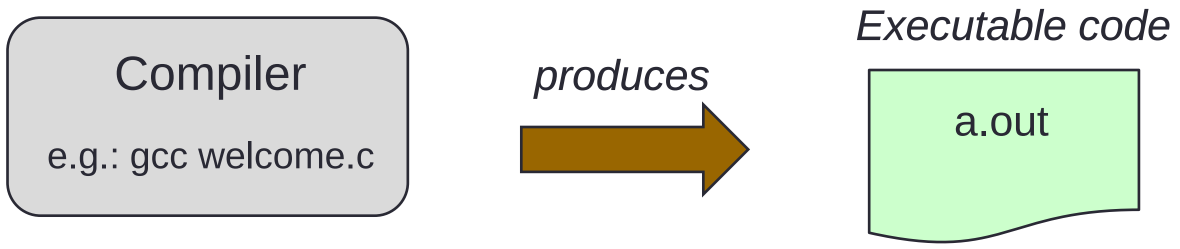


Unit 13: Separate Compilation

1. Introduction
2. Separate Compilation
3. Notes

1. Introduction (1/4)

- So far we have compiled our programs directly from the source into an executable:



- For the development of large programs with teams of programmers the following is practised
  - "Break" the program into multiple modules (files)
  - Compile the modules separately into object files (in C)
  - Link all object files into an executable file

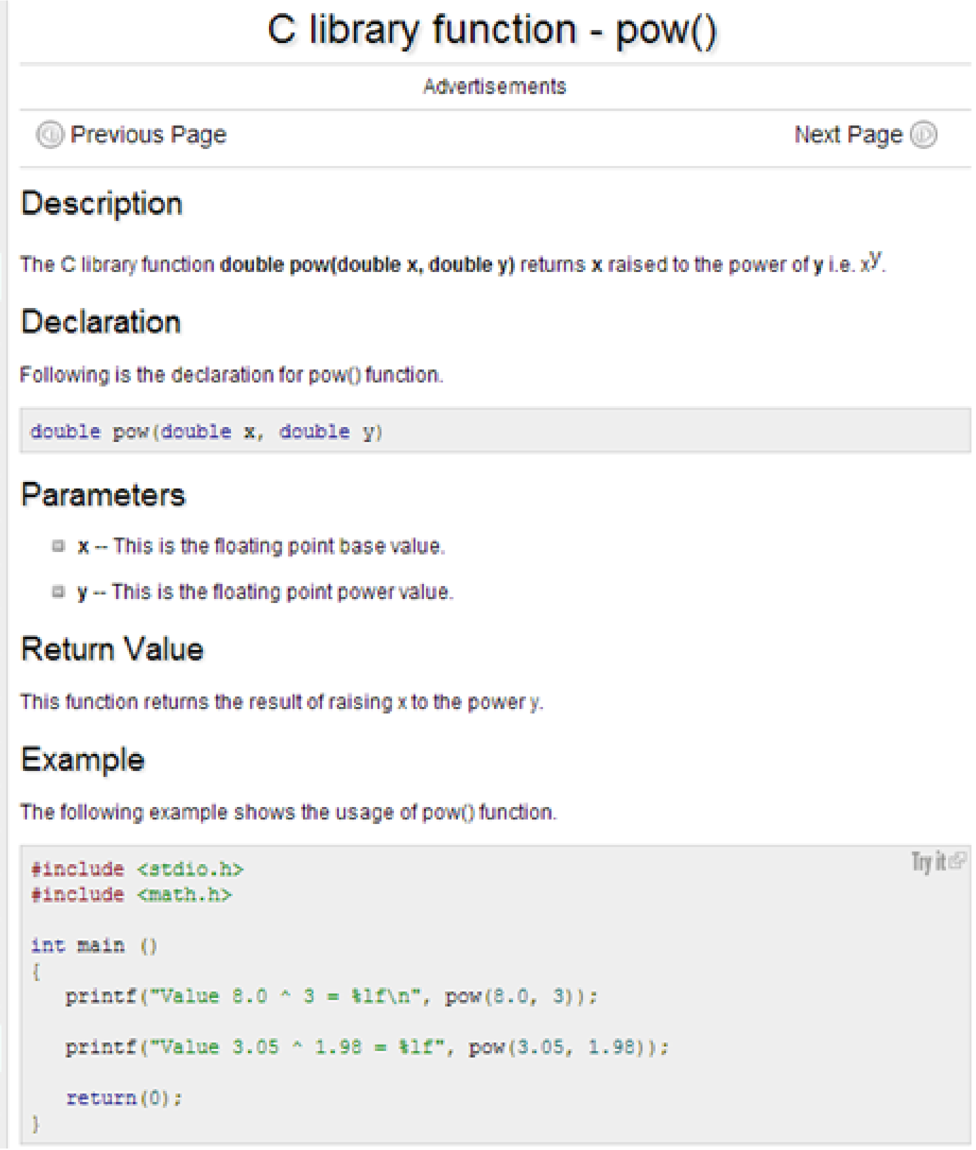
1. Introduction (2/4)

- Header Files and Separate Compilation
  - Problem is broken into sub-problems and each sub-problem is tackled separately – divide-and-conquer
  - Such a process is called modularization
  - The modules are possibly implemented by different programmers, hence the need for well-defined interfaces
  - The function prototype constitutes the interface (header file). The function body (implementation) is hidden – abstraction
  - Good documentation (example: comment to describe what the method does) aids in understanding

1. Introduction (3/4)

- Example of documentation
  - The function header is given
  - A description of what the function does is given
  - How the function is implemented is not shown

```
double pow(double x, double y);
// Returns the result of raising
// x to the power of y.
```



C library function - pow()

Advertisements

Previous Page Next Page

Description

The C library function **double pow(double x, double y)** returns **x** raised to the power of **y** i.e. x^y.

Declaration

Following is the declaration for pow() function.

```
double pow(double x, double y)
```

Parameters

- **x** -- This is the floating point base value.
- **y** -- This is the floating point power value.

Return Value

This function returns the result of raising x to the power y.

Example

The following example shows the usage of pow() function.

```
#include <stdio.h>
#include <math.h>

int main ()
{
   printf("Value 8.0 ^ 3 = %lf\n", pow(8.0, 3));

   printf("Value 3.05 ^ 1.98 = %lf", pow(3.05, 1.98));

   return(0);
}
```

Try it

1. Introduction (4/4)

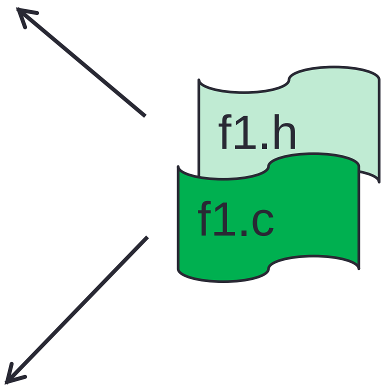
- Reason for Modular Programming
  - Divide problems into manageable parts
  - Reduce compilation time
    - Unchanges modules do not eed to be re-compiled
  - Facilitate debugging
    - The modules can be debugged separately
    - Small test programs can be written to test the functions in a module
  - Build libraries of useful functions
    - Faster development
    - Do not need to know how some functionality is implemented, e.g., image processing routines
    - Example: OpenCV – a computer vision library.

2. Separate Compilation (1/2)

- From http://encyclopedia2.thefreedictionary.com/
- Separate Compilation:
  - A feature of most modern programming languages that allows each program module to be compiled on its own to produce an object file which the linker can later combine with other object files and libraries to produce the final executable file.
- Advantages
  - Separate compilation avoids processing all the source code every time the program is built, thus saving development time. The object files are designed to require minimal processing at link time. The can also be collected together into libraries and distributed commercially without giving away source code (through they can be disassembled).
- Examples of output of separate compilation:
  - C object files (.o files) and Java .class files.

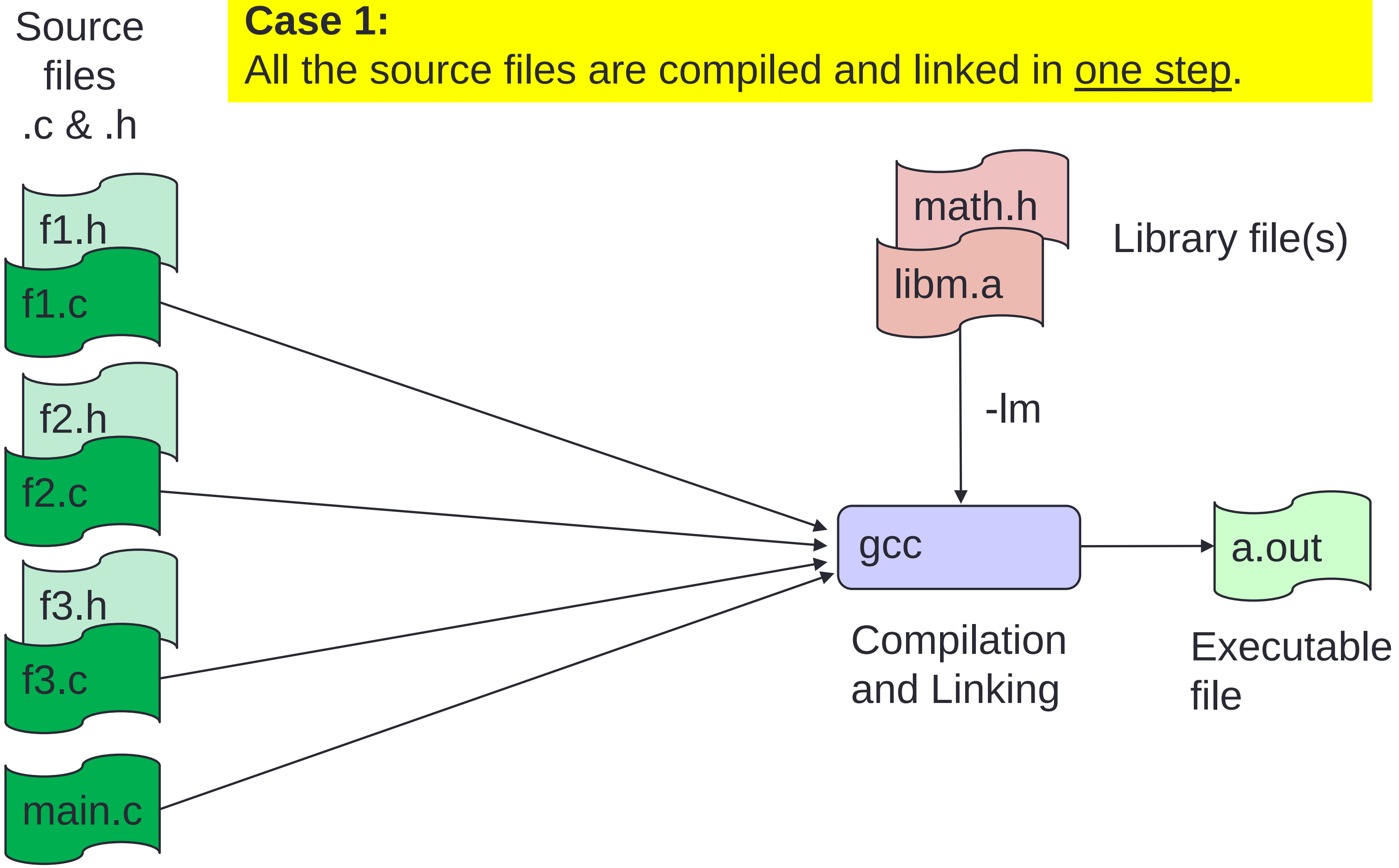
2. Separate Compilation (2/2)

- In most cases, a module contains functions that are related, e.g., math functions.
- A module consists of
  - A header file (e.g. f1.h) which contains:
    - Constant definitions, e.g.:
      - `#define   MAX  100`
    - Function prototypes, e.g.:
      - `double mean(double, double);`
  - A source file (e.g. f1.c) which contains:
    - The functions that implement the function prototypes in the header file (e.g., the code for the function `mean(…)`).
    - Other functions, variables, and constants that are only used within the module (i.e., they are module-local).



2.1 Separate Compilation: Case 1

Case 1:
All the source files are compiled and linked in <u>one step</u>.



2.1 Case 1 Demo

- Let's re-visit the Freezer version 2 program in Unit 4 Exercise 6. We will create a module that contains a function to calculate the freezer temperature:
  - Module header file:

Unit13_FreezerTemp.h

```
// Compute new temperature in freezer
float calc_temperature(float);
```

  - Module source file:

Unit13_FreezerTemp.c

```
#include <math.h>

// Compute new temperature in freezer
float calc_temperature(float hr) {
   return ((4.0 * pow(hr, 10.0))/(pow(hr, 9.0) + 2.0)) - 20.0;
}
```

2.1 Case 1 Demo: Main Module

Unit13_FreezerMain.c

```
#include <stdio.h>
#include "Unit13_FreezerTemp.h"

int main(void) {
    int hours, minutes;
    float hours_float;  // Convert hours and minutes into hours_float
    float temperature;  // Temperature in freezer

    // Get the hours and minutes
    printf("Enter hours and minutes since power failure: ");
    scanf("%d %d", &hours, &minutes);

    // Convert hours and minutes into hours_float
    hours_float = hours + minutes/60.0;

    // Compute new temperature in freezer
    temperature = calc_temperature(hours_float);

    // Print new temperature
    printf("Temperature in freezer = %.2f\n", temperature);

    return 0;
}
```

Include the header file (Note "..." instead of <…>).
Header file should be in the same directory as this program.

Now we can write a program which uses the new external function

2.1 Case 1 Demo: Compile and Link

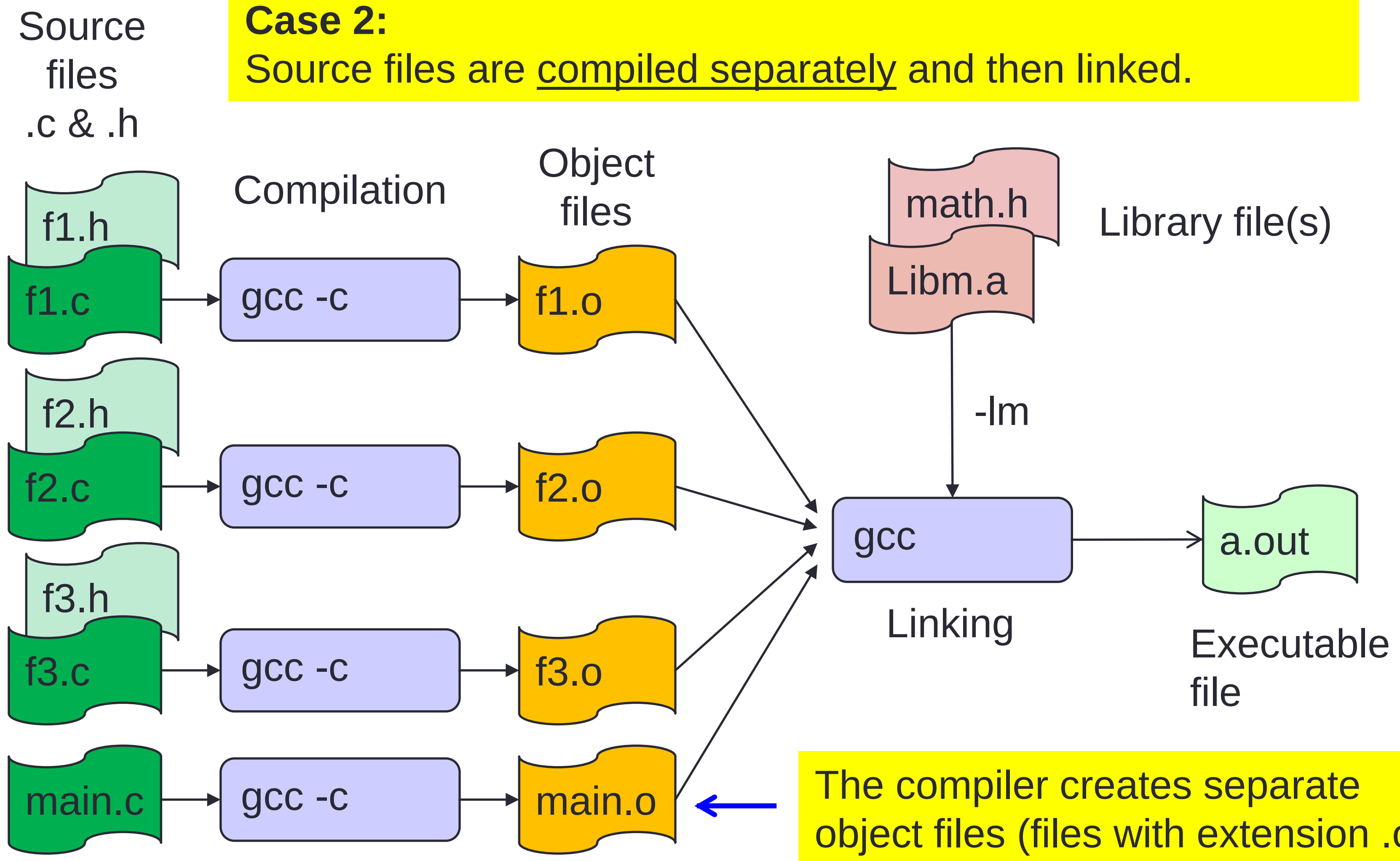
- How do we run Unit13_FreezerMain.c, since it doesn't contain the function definition of calc_temperature()?
- Need to compile and link the programs

```
$ gcc Unit13_FreezerMain.c Unit13_FreezerTemp.c -lm
```

- Here, the compiler creates temporary object files (which are immediately removed after linking) and directly creates a.out
- Hence, you don't get the chance to see the object files (files with extension .o)
- (Note: The option –Wall is omitted above due to space constraint. Please add the option yourself.)

2.2 Separate Compilation: Case 2

Case 2:
Source files are compiled separately and then linked.



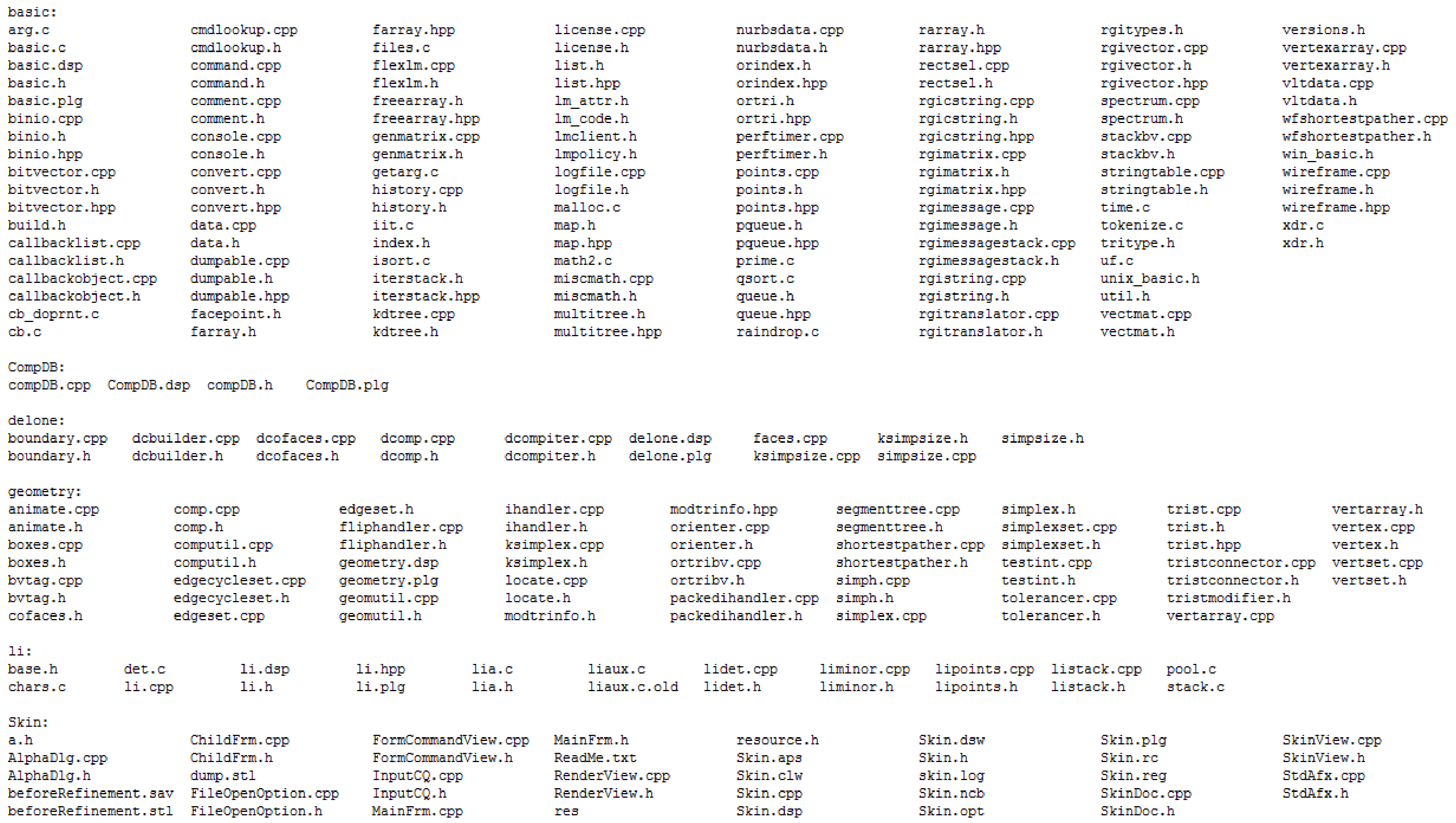
The compiler creates separate object files (files with extension .o)

2.2 Case 2 Demo: Compile and Link

- For our Freezer program:

```
$ gcc –c Unit13_FreezerMain.c
$ gcc –c Unit13_FreezerTemp.c
$ gcc Unit13_FreezerMain.o Unit13_FreezerTemp.o  -lm
```

- Here, we first create the Unit13_FreezerMain.o and Unit13_FreezerTemp.o object files, using the –c option in gcc.
- Then, we link both object files into the a.out executable
- (Note: The option –Wall is omitted above due to space constraint. Please add the option yourself.)



```
basic:
arg.c                 cmdlookup.cpp         farray.hpp            license.cpp           nurbsdata.cpp         rarray.h              rgitypes.h            versions.h
basic.c               cmdlookup.h           files.c               license.h             nurbsdata.h           rarray.hpp            rgivector.cpp         vertexarray.cpp
basic.dsp             command.cpp           flexlm.cpp            list.h                orindex.h             rectsel.cpp           rgivector.h           vertexarray.h
basic.h               command.h             flexlm.h              list.hpp              orindex.hpp           rectsel.h             rgivector.hpp         vltdata.cpp
basic.plg             comment.cpp           freearray.h           lm_attr.h             ortri.h               rgicstring.cpp        spectrum.cpp          vltdata.h
binio.cpp             comment.h             freearray.hpp         lm_code.h             ortri.hpp             rgicstring.h          spectrum.h            wfshortestpather.cpp
binio.h               console.cpp           genmatrix.cpp         lmclient.h            perftimer.cpp         rgicstring.hpp        stackbv.cpp           wfshortestpather.h
binio.hpp             console.h             genmatrix.h           lmpolicy.h            perftimer.h           rgimatrix.cpp         stackbv.h             win_basic.h
bitvector.cpp         convert.cpp           getarg.c              logfile.cpp           points.cpp            rgimatrix.h           stringtable.cpp       wireframe.cpp
bitvector.h           convert.h             history.cpp           logfile.h             points.h              rgimatrix.hpp         stringtable.h         wireframe.h
bitvector.hpp         convert.hpp           history.h             malloc.c              points.hpp            rgimessage.cpp        time.c                wireframe.hpp
build.h               data.cpp              iit.c                 map.h                 pqueue.h              rgimessage.h          tokenize.c            xdr.c
callbacklist.cpp      data.h                index.h               map.hpp               pqueue.hpp            rgimessagestack.cpp   tritype.h             xdr.h
callbacklist.h        dumpable.cpp          isort.c               math2.c               prime.c               rgimessagestack.h     uf.c
callbackobject.cpp    dumpable.h            iterstack.h           miscmath.cpp          qsort.c               rgistring.cpp         unix_basic.h
callbackobject.h      dumpable.hpp          iterstack.hpp         miscmath.h            queue.h               rgistring.h           util.h
cb_doprnt.c           facepoint.h           kdtree.cpp            multitree.h           queue.hpp             rgitranslator.cpp     vectmat.cpp
cb.c                  farray.h              kdtree.h              multitree.hpp         raindrop.c            rgitranslator.h       vectmat.h

CompDB:
compDB.cpp  CompDB.dsp  compDB.h    CompDB.plg

delone:
boundary.cpp   dcbuilder.cpp  dcofaces.cpp   dcomp.cpp      dcompiter.cpp  delone.dsp     faces.cpp      ksimpsize.h    simpsize.h
boundary.h     dcbuilder.h    dcofaces.h     dcomp.h        dcompiter.h    delone.plg     ksimpsize.cpp  simpsize.cpp

geometry:
animate.cpp         comp.cpp            edgeset.h           ihandler.cpp        modtrinfo.hpp       segmenttree.cpp     simplex.h           trist.cpp           vertarray.h
animate.h           comp.h              fliphandler.cpp     ihandler.h          orienter.cpp        segmenttree.h       simplexset.cpp      trist.h             vertex.cpp
boxes.cpp           computil.cpp        fliphandler.h       ksimplex.cpp        orienter.h          shortestpather.cpp  simplexset.h        trist.hpp           vertex.h
boxes.h             computil.h          geometry.dsp        ksimplex.h          ortribv.cpp         shortestpather.h    testint.cpp         tristconnector.cpp  vertset.cpp
bvtag.cpp           edgecycleset.cpp    geometry.plg        locate.cpp          ortribv.h           simph.cpp           testint.h           tristconnector.h    vertset.h
bvtag.h             edgecycleset.h      geomutil.cpp        locate.h            packedihandler.cpp  simph.h             tolerancer.cpp      tristmodifier.h
cofaces.h           edgeset.cpp         geomutil.h          modtrinfo.h         packedihandler.h    simplex.cpp         tolerancer.h        vertarray.cpp

li:
base.h        det.c         li.dsp        li.hpp        lia.c         liaux.c       lidet.cpp     liminor.cpp   lipoints.cpp  listack.cpp   pool.c
chars.c       li.cpp        li.h          li.plg        lia.h         liaux.c.old   lidet.h       liminor.h     lipoints.h    listack.h     stack.c

Skin:
a.h                   ChildFrm.cpp          FormCommandView.cpp   MainFrm.h             resource.h            Skin.dsw              Skin.plg              SkinView.cpp
AlphaDlg.cpp          ChildFrm.h            FormCommandView.h     ReadMe.txt            Skin.aps              Skin.h                Skin.rc               SkinView.h
AlphaDlg.h            dump.stl              InputCQ.cpp           RenderView.cpp        Skin.clw              skin.log              Skin.reg              StdAfx.cpp
beforeRefinement.sav  FileOpenOption.cpp    InputCQ.h             RenderView.h          Skin.cpp              Skin.ncb              SkinDoc.cpp           StdAfx.h
beforeRefinement.stl  FileOpenOption.h      MainFrm.cpp           res                   Skin.dsp              Skin.opt              SkinDoc.h
```

2.2 Case 2 Demo: Compile and Link

- For our Freezer program:

```
$ gcc –c Unit13_FreezerMain.c
$ gcc –c Unit13_FreezerTemp.c
$ gcc Unit13_FreezerMain.o Unit13_FreezerTemp.o  -lm
```

- Let’s say if you only modified Unit13_FreezerTemp.c but NOT Unit13_FreezerMain.c, you can skip the first compilation

~~$ gcc –c Unit13_FreezerMain.c~~

```
$ gcc –c Unit13_FreezerTemp.c
$ gcc Unit13_FreezerMain.o Unit13_FreezerTemp.o  -lm
```

- Speed of a lot if you have tons of files

3. Notes (1/2)

- Difference between
  - #include < … > and #include " … "
  - Use " … " to include your own header files and < … > to include system header files. The compiler uses different directory paths to find < … > files.
- Inclusion of header files
  - Include *.h files only in *.c files, otherwise duplicate inclusions may happen and later may create problems:
    - Example: Unit13_FreezerTemp.h includes <math.h>
      Unit13_FreezerMain.c includes <math.h> and “Unit13_FreezerTemp.h”
      Therefore, Unit13_FreezerMain.c includes <math.h> twice.

3. Notes (2/2)

- ‘Undefined symbol’ error
  - ld: fatal: Symbol referencing errors.
  - The linker was not able to find a certain function, etc., and could not create a complete executable file.
    - Note: A library can have missing functions → it is not a complete executable.
  - Usually this means you forgot to link with a certain library or object file. This also happens if you mistyped a function name.

Summary

- In this unit, you have learned about
  - How to split a program into separate modules, each module containing some functions
  - How to separately compile these modules
  - How to link the object files of the modules to obtain the single executable file

End of File