

HPC tools for programming

Victor Eijkhout

2024

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Justification

High Performance Computing requires, beyond simple use of a programming language, a number programming tools. These tutorials will introduce you to some of the more important ones.

Intro to file types

Compilation

Basic compilation

Basic compilation

Libraries

Intro to file types

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

File types

Text files

Source	Program text that you write
Header	also written by you, but not really program text.

Binary files

Object file	The compiled result of a single source file
Library	Multiple object files bundled together
Executable	Binary file that can be invoked as a command
Data files	Written and read by a program

Text files

- Source files and headers
- You write them: *make sure you master an editor*
- The computer has no idea what these mean.
- They get compiled into programs.

(Also ‘just text’ files: READMEs and such)

Binary files

- Programs. (Also: object and library files.)
- Produced by a compiler.
- Unreadable by you; executable by the computer.

Also binary data files; usually specific to a program.
(Why don't programs write out their data in readable form?)

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Compilation

Compilers

Compilers: a major CS success story.

- The first Fortran compiler (Backus, IBM, 1954):
multiple man-years.
- These days: semester project for graduate students.
Many tools available (lex, yacc, clang-tidy)
Standard textbooks ('Dragon book')
- Compilers are very clever!
You can be a little more clever in assembly – maybe
but compiled languages are 10× more productive.

Compilation vs interpreted

- Interpreted languages: lines of code are compiled ‘just-in-time’.
Very flexible, sometimes very slow.
- Compiled languages: code is compiled to machine language:
less flexible, very fast execution.
- Virtual machine: languages get compiled to an intermediate
language
(Pascal, Python, Java)
pro: portable; con: does not play nice with other languages.
- Scientific computing languages:
 - Fortran: pretty elegant, great at array manipulation
Note: Fortran20003 is modern; F77 and F90 are not so great.
 - C: low level, allows great control, tricky to use
 - C++: allows much control, more protection, more tools
(kinda sucks at arrays)

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Basic compilation

Simple compilation: files involved

- Use a text editor to create a program file: `myprogram.cpp`
- Use a compiler to translate that to an executable: `myprogram`
- ... and then run that file.

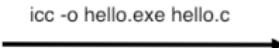
Simple compilation: the process

hello.c

```
int main() {  
    printf("Hello world\n");  
    return 0;  
}
```

hello.exe

icc -o hello.exe hello.c



- From source straight to program.
- Use this only for short programs.

```
%% icpx hello.cpp  
%% ./a.out  
hello world
```

```
%% icpx -o helloprog hello.cpp  
%% ./helloprog  
hello world
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Exercise 1, C++ version

Create a file with these contents, and make sure you can compile it:

```
#include <iostream>
using std::cout;

int main() {
    cout << "hello world\n";
    return 0;
}
```

Exercise 1, C version

Create a file with these contents, and make sure you can compile it:

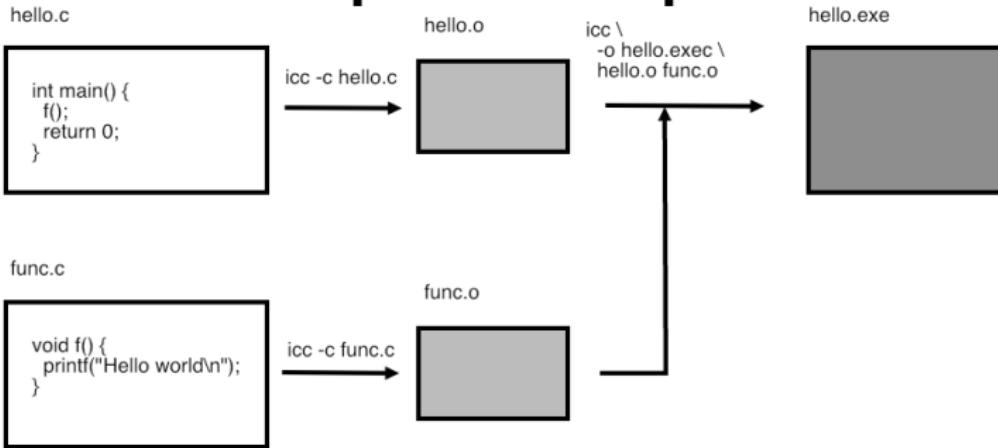
```
#include <stdlib.h>
#include <stdio.h>

int main() {
    printf("hello world\n");
    return 0;
}
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Basic compilation

Separate compilation



- Large programs best broken into small files,
- ... and compiled separately (can you guess why?)
- Then 'linked' into a program; linker is usually the same as the compiler.

Exercise 2, C++ version

Make the following files:

Main program: fooprog.cxx

```
#include <iostream>
using std::cout;
#include <string>
using std::string;
extern void bar(string);
int main() {
    bar("hello world\n");
    return 0;
}
```

Subprogram: foosub.cxx

```
#include <iostream>
using std::cout;
#include <string>
using std::string;
void bar( string s ) {
    cout << s;
}
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Exercise 2, C version

Make the following files:

Main program: fooprog.c

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

extern void bar(char*);

int main() {
    bar("hello world\n");
    return 0;
}
```

Subprogram: foosub.c

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

void bar(char *s) {
    printf("%s", s);
    return;
}
```

Exercise 2 continued, C++ version

- Compile in one:

```
icpc -o program fooprog.cxx foosub.cxx
```

- Compile in steps:

```
icpc -c fooprog.cxx
```

```
icpc -c foosub.cxx
```

```
icpc -o program fooprog.o foosub.o
```

What files are being produced each time?

Can you write a shell script to automate this?

Exercise 2 continued, C version

- Compile in one:

```
icc -o program fooprog.c foosub.c
```

- Compile in steps:

```
icc -c fooprog.c
```

```
icc -c foosub.c
```

```
icc -o program fooprog.o foosub.o
```

What files are being produced each time?

Can you write a shell script to automate this?

Header files

- `extern` is not the best way of dealing with ‘external references’
- Instead, make a header file `foo.h` that only contains

```
void bar(char *);
```

- Include it in both source files:

```
#include "foo.h"
```

- Do the separate compilation calls again.

Now is a good time to learn about makefiles ...

Compiler options 101

- You have just seen two compiler options.
- Commandlines look like

command [options] [argument]

where square brackets mean: ‘optional’

- Some options have an argument

icc -o myprogram mysource.c

- Some options do not.

icc -g -o myprogram mysource.c

- Question: does -c have an argument? How can you find out?

icc -g -c mysource.c

Object files

- Object files are unreadable. (Try it. How do you normally view files? Which tool sort of works?)
- But you can get some information about them.

```
#include <stdlib.h>           [c:264] nm foosub.o
#include <stdio.h>             0000000000000000 T _bar
void bar(char *s) {           U _printf
    printf("%s", s);
}
```

Where T: stuff defined in this file
U: stuff used in this file

Compiler options 102

- Optimization level: -00, -01, -02, -03
(‘I compiled my program with oh-two’)
Higher levels usually give faster code. Level 3 can be unsafe.
(Why?)
- `-g` is needed to run your code in a debugger. Always include this.
- The ultimate source is the ‘man page’ for your compiler.

Compiler optimizations

Common subexpression
elimination:

```
x1 = pow(5.2,3.4) * 1;  
x2 = pow(5.2,3.4) * 2;
```

becomes

```
t = pow(5.2,3.4);  
x1 = t * 1;  
x2 = t * 2;
```

Loop invariants lifting

```
for (int i=0; i<1000; i++)  
    s += 4*atan(1.0) / i;
```

becomes

```
t = 4*atan(1.0);  
for (int i=0; i<1000; i++)  
    s += t / i;
```

Example of optimization

Givens program

```
void rotate(double& x, double& y, double alpha) {  
    double x0 = x, y0 = y;  
    x = cos(alpha) * x0 - sin(alpha) * y0;  
    y = sin(alpha) * x0 + cos(alpha) * y0;  
    return;  
}
```

Run with optimization level 0,1,2,3 we get:

```
Done after 8.649492e-02  
Done after 2.650118e-02  
Done after 5.869865e-04  
Done after 6.787777e-04
```

Exercise 3

The file `rotate.cxx` (or `rotate.c`) can be speeded up by compiler transformations.

Compile this file with optimization levels `0, 1, 2, 3`

(try both the Intel and gcc compilers)

observe run time and conjecture what transformations can explain this.

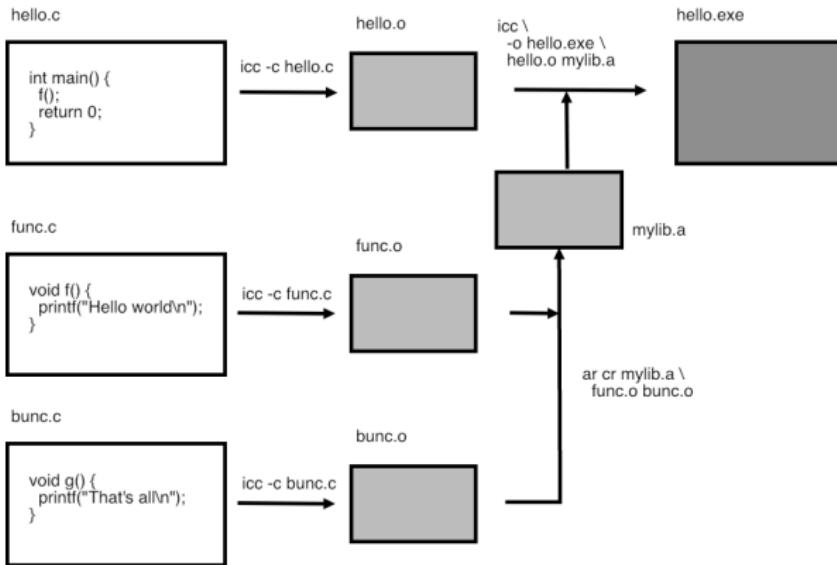
Apply these transformations by hand and see if they indeed lead to improvements.

Write a report of your investigations.

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Libraries

Libraries



- Sometimes you have many object files:
convenient to bundle them
- Easier to link to
- Easy to distribute as a product

Static / non-shared libraries

- Static libraries are created with `ar`
- Inspect them with `nm`
- Link as object file:

```
icc -o myprogram main.o ../lib/libfoo.a
```

- Or:

```
icc -o myprogram main.o -L../lib -lfoo.a
```

```
mkdir ..\lib          %% nm ..\lib/libfoo.a
ar cr ..\lib/libfoo.a foosub.o
                           ..\lib/libfoo.a(foosub.o):
                           00000000 T _bar
                           U _printf
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Static library example

Use ar to add object files to .a file.

```
icc -g -O2 -std=c99 -c foosub.c
for o in foosub.o ; do \
    ar cr libs/libfoo.a ${o} ; \
done
icc -o staticprogram fooprog.o -Llibs -lfoo
-rwx----- 1 eijkhout G-25072 38192 Sep 23 18:15 staticprogram
./staticprogram
hello world
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Dynamic/shared libraries

Created with the compiler,
-shared flag.

```
icc -O2 -std=c99 -fPIC -c foosub.c
icc -o libs/libfoo.so -shared foosub.o
icc -o dynamicprogram fooprog.o -Llibs -lfoo
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

Executable size

Static libraries are baked into the executable
shared libraries are linked at runtime.

```
# Making static library
icc -o staticprogram fooprog.o -Llibs -lfoo
-rwx----- 1 eijkhout G-25072 28232 Sep 23 14:25 staticprogram
# Using dynamic library
icc -o dynamicprogram fooprog.o -Llibs -lfoo
-rwx----- 1 eijkhout G-25072 28160 Sep 23 14:25 dynamicprogram
```

- Intro to file types
- Compilation
- Basic compilation
- Basic compilation
- Libraries

Needs something more

Program can not immediately be run.

Use `ldd` to see what libraries it needs:

```
./dynamicprogram: error while loading shared libraries:  
    libfoo.so: cannot open shared object file: No such file or directory
```

```
ldd dynamicprogram | grep libfoo  
    libfoo.so => not found
```

Intro to file types
Compilation
Basic compilation
Basic compilation
Libraries

The ell-dee library path

Libraries are found by updating the `LD_LIBRARY_PATH`:

```
export LD_LIBRARY_PATH=${LD_LIBRARY_PATH}:./libs
ldd dynamicprogram | grep libfoo
    libfoo.so => ./libs/libfoo.so (0x00002ad6604c1000)
./libs dynamicprogram
hello world
```

The rpath

You can also bake the path into the program:

```
icc -O2 -std=c99 -fPIC -c foosub.c
icc -o libs/libfoo.so -shared foosub.o
icc -o rpathprogram fooprog.o \
    -Wl,-rpath,./libs -Llibs -lfoo
-rwx----- 1 eijkhout G-25072 28160 Sep 23 13:41 rpathprogram
./rpathprogram
hello world
```

Note

- the bizarre combination of minuses and commas
- you may also come across the `rpath=` syntax, but that's a GNU extension.