



bw|HPC – C5

bwHPC course – Tutorial: Compiling, Makefile

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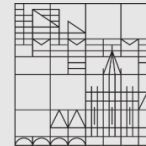
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Outline

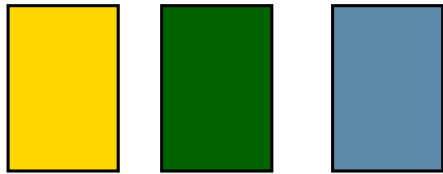
- Compiler + Numerical Libraries
 - Compiling
 - Linking
- Makefile
 - Intro, Syntax (Explicit + Implicit Rules ...)



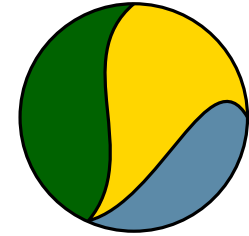
1. Compilation

Object files

source (.c)



executable (.x)

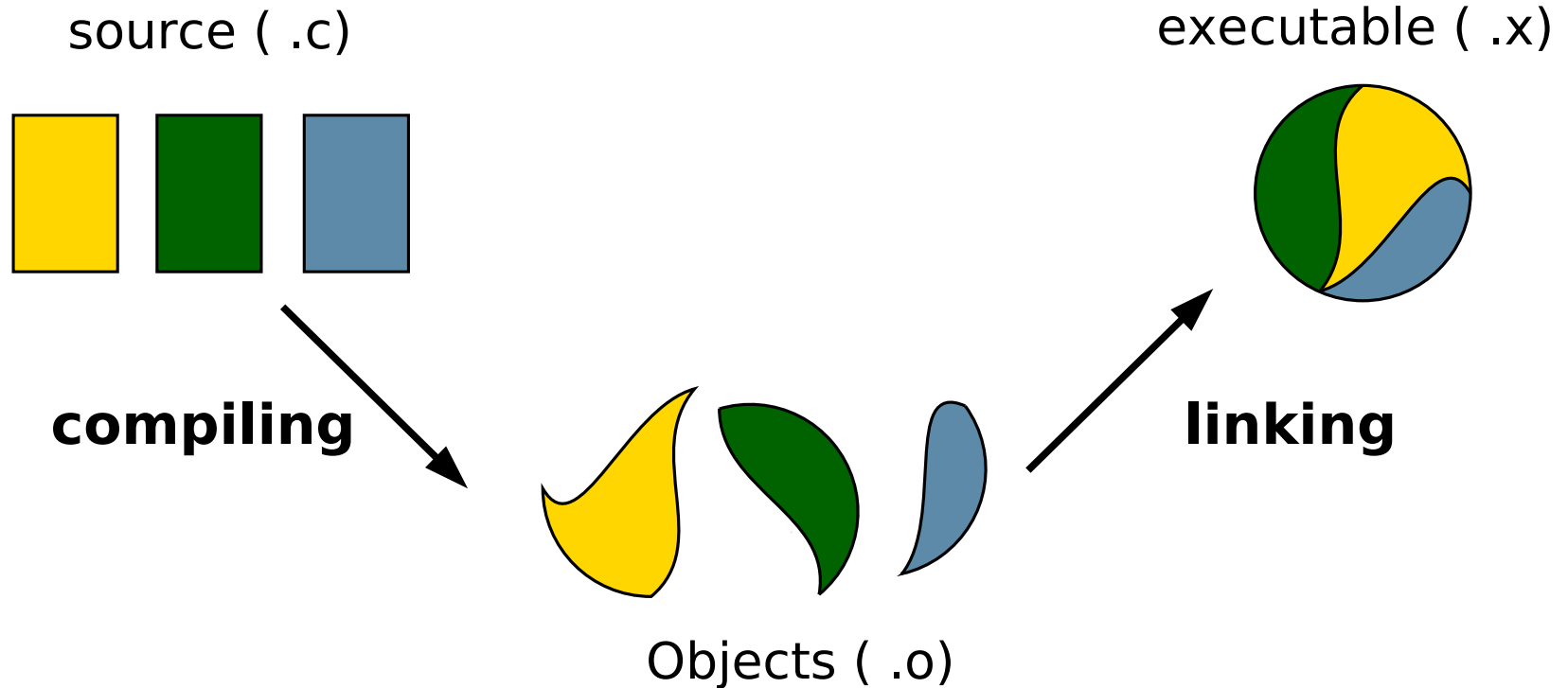


■ Example:

```
$ gcc -o exec.x src1.c src2.c src3.c
```

```
$ ./exec.x
```

Object files



```
$ gcc -c src1.c; gcc -c src2.c; gcc -c src3.c  
$ gcc -o exec.x src1.o src2.o src3.o
```

- Changes in a single file don't require the compilation of whole source code.

Include files

- Header files (.h)
 - Declaration of variables
 - Definition of static variables
 - Declaration of functions/subroutines
 - ..
- Example: include header file `/home/myincs/header.h`
 - Preprocessor directive in source code:

```
#include "header.h"  
...  
src1.c
```

'#' does **not** initiate command lines but preprocessor directives in C/C++ code!

- Add header directory `-I<include_directory>`

```
$ gcc -I/home/myincs -c src1.c; gcc -c src2.c
```

```
$ gcc -o exec.x src1.o src2.o
```

```
$ ./exec.x
```



Example: Hello

Main Program

```
#include "hello.h"

int main(void){
    print_hello();

    return 0;
}
```

hello.c

Header (Declarations)

```
#ifndef _HELLO_H_
#define _HELLO_H_

int print_hello(void);

#endif
```

hello.h

Functions (Definitions)

```
#include <stdio.h>

int print_hello(void){
    printf(„hello!\n“);

    return 0;
}
```

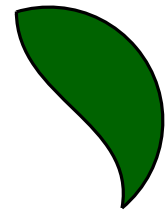
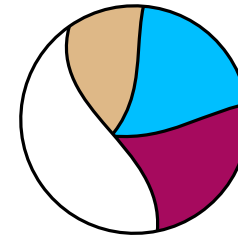
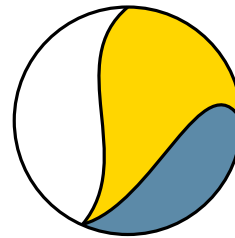
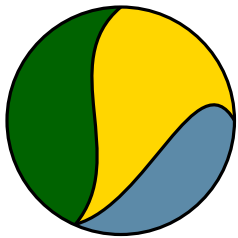
hello_fct.c

- Exercise: *hello*
 - Build objects *hello.o* *hello_fct.o*
 - Build executable by linking objects
 - **\$./hello**



Shared object files and Libraries

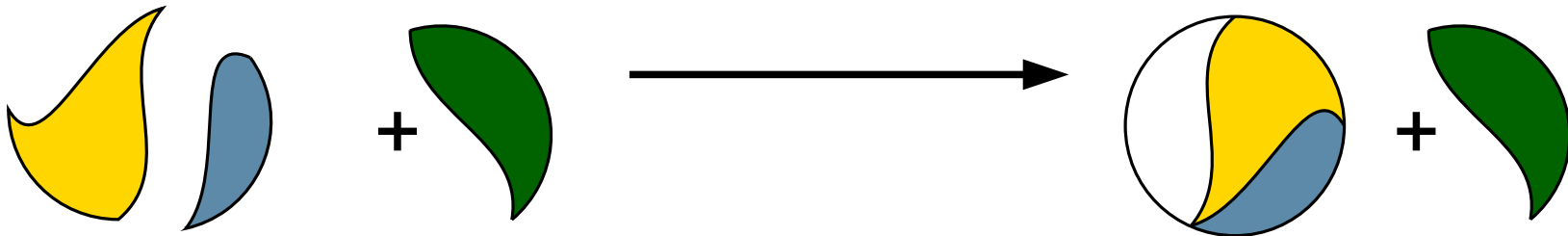
- Objects can be used by different executables.
- A **library** contains program parts (subroutines, classes, type definitions, ...) that can be used by different executables.
- Static library
 - Linked during building executable
- Shared library
 - Loaded during runtime



Shared Object files and Libraries

objects (.o) library (.so)

executable (.x) library (.so)



■ Example: link library `/home/mylibs/libexample.so`

■ Build executable:

■ Add library directory `-L<library_directory>`

■ load library `-l<library_name>` **after** referring source/object files

```
$ gcc -o exec.x src1.o src2.o -L/home/mylibs -lexample
```

■ Run executable:

■ Add `<library_directory>` to list of library directories
`${LD_LIBRARY_PATH}`

```
$ export LD_LIBRARY_PATH=${LD_LIBRARY_PATH}:/home/mylibs
```

```
$ ./exec.x
```

Module files

- Module files set/prepare following environment variables amongst others:
 - `*_LIB_DIR = <library_directory>`
 - `*_INC_DIR = <include_directory>`
 - `#{LD_LIBRARY_PATH}`
- Show module file setup with `$ module show <module_file>`
- Example: link NETCDF library
 - Build executable:

```
$ module load compiler/intel
$ module load lib/netcdf
$ icc -I#{NETCDF_INC_DIR} -c src1.c; gcc -c src2.c
$ icc -o exec.x src1.o src2.o -L#{NETCDF_LIB_DIR} -lnetcdf
```
 - Run executable:

```
$ module load lib/netcdf
$ ./exec.x
```



2. Makefile



Motivation

- Interactively

- `$ gcc -o hello -I./include hello.c hello_fct.c`
- Works as long as command history is active

- Shell script

- `$./compile.sh`
- Does always recompile the whole code

- Makefile

- `$ make`
- better organisation of code compilation
- recompiles only updated files,
`make: `hello' is up to date.`



Makefile

- `$ make [-f <Makefile_name>] [<target>]`
- executes script named *Makefile* or *makefile*
 - without argument first rule in *Makefile* is executed

- Rule definition (format):

`target: prerequisites`

`<TAB>command`

Rule has to be applied, if any of these files is changed

To apply the rule, command has to be executed.

Only works with beginning tab stop!

```
hello: hello.h hello.c hello_fct.c
      gcc -o hello -I./include hello.c hello_fct.c
```

Makefile.1

- Exercise: *Makefile.1*

- define a second rule named `clean` to remove the executable



Rules - Content

■ Explicit rules

■ `hello.o:` rule to build target *hello.o*

■ Wildcards

■ `hello: *.c` *hello* depends on all files with suffix `.c` in this directory

■ Pattern rules

■ `%.o:` rule for all files with suffix `.o`

■ `%.o: %.c` % in prerequisites substitutes the same as % in the target

■ Phony Targets

■ `.PHONY: clean` target *clean* is nothing to build
`clean:`



Variables

■ Variable assignment

- = recursively expanded (referenced by reference)
- := simply expanded (referenced by value)
- = only if variable is not defined yet (no overwrite)</li- += add item to variable array

```
CC      = gcc
CFLAGS = -I./include
INC     := include/hello.h
OBJ     := hello.o
OBJ     += hello_fct.o
EXE     := hello

${EXE}: ${OBJ}
        ${CC} -o ${EXE} ${OBJ}

.PHONY: clean
clean:
        rm -f ${OBJ} ${EXE}</pre
```

Makefile.2

- Exercise: run *Makefile.2*
 - Why does it work?



Automatic Variables

- Automatic variables change from rule to rule

`$$` = target

`$$` = first item of prerequisites

`$$^` = all items of prerequisites separated by ' '

- Exercise: *Makefile.3*
 - Use automatic variables in rule to build *hello*

```
CC      ?= gcc
CFLAGS  = -I./include
INC      := include/hello.h
OBJ      := hello.o
OBJ      += hello_fct.o
EXE      := hello

%.o: %.c ${INC}
        ${CC} ${CFLAGS} -c $$

${EXE}: ${INC} ${OBJ}
        ${CC} -o ${EXE} ${OBJ}

.PHONY: clean
clean:
        rm -f ${OBJ} ${EXE}
```

Makefile.3



Automatic Variables

- Automatic variables change from rule to rule

`$@` = target

`$<` = first item of prerequisites

`$$` = all items of prerequisites separated by ' '

```
CC      ?= gcc
CFLAGS  = -I./include
INC      := include/hello.h
OBJ      := hello.o
OBJ      += hello_fct.o
EXE      := hello

%.o: %.c ${INC}
        ${CC} ${CFLAGS} -c $<

${EXE}: ${OBJ}
        ${CC} -o $@ $$

.PHONY: clean
clean:
        rm -f ${OBJ} ${EXE}
```

Makefile.4



Directives

- Conditions can be expressed by directives

- if VAR is (not) defined

```
ifdef/ifndef VAR
```

```
..
```

```
else
```

```
..
```

```
endif
```

- if A and B are (not) equal

```
ifeq/ifneq (A,B)
```

```
..
```

```
else
```

```
..
```

```
endif
```

- Example:

- Conditional assignment: `CC ?= gcc` is equivalent to

```
ifndef CC
  CC = gcc
endif
```



Include

- Parts of *Makefile* can be outsourced
 - e.g. platform specific statements
- External makefile code, e.g. file *make.inc*, can be loaded in *Makefile* via

```
include make.inc
```

- Example: Use the INTEL compiler
 - *make.inc.gcc* and *make.inc.icc* contain compiler specific makefile statements

```
CC      = gcc
CFLAGS  = -I./include -O

make.inc.gcc
```

- *make.inc* is included depending on `${CC}`

```
CC      = icc
CFLAGS  = -I./include -O

make.inc.icc
```

- `$ module load compiler/gnu`
`$ make -f Makefile.5`
- `$ module load compiler/intel`
`$ make -f Makefile.5`

```
include make.inc.${CC}
...
%.o: %.c ${INC}
        ${CC} ${CFLAGS} -c $<
...

Makefile.5
```



3. MPI-Parallelization

(only 1 slide)



MPI-Course and -Informations

- MPI-course
 - 7/11/18 (one day) from 11.30 to 16.30 (SCC-building, CS)
- Informations on MPI
 - MPI tutorial from Livermore Computing Center (<https://computing.llnl.gov/tutorials/mpi/>)
 - MPI Standards on <http://www.mpi-forum.org>

