Conduite de Projet
Cours 7 — Building with make

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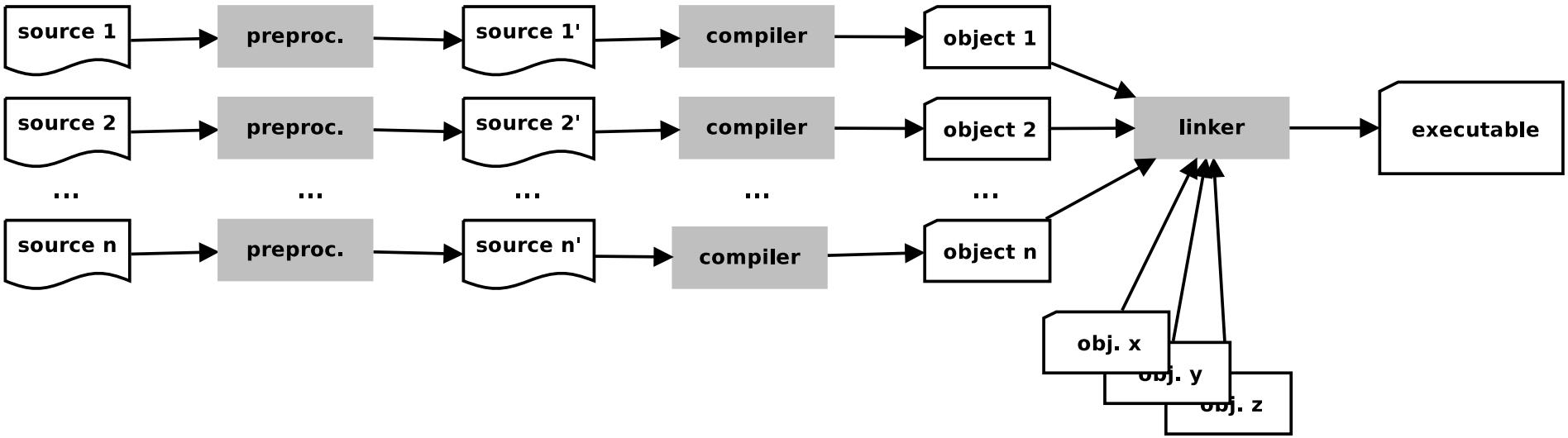
The build process (reminder)



Monolitic solution

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

void swap(int* x, int* y)
{
  ...
}

int gcd(int m, int n)
{
  ...
}

int main(int argc, char* argv[])
{
  ...
}
```

```
$ gcc main.c
$
```

Modularization

Let's split main program into 3 modules:

1. main program (`main.c`)
2. GCD (Greatest Common Divisor) computation (`gcd.c`)
3. value exchange (`swap.c`)

Either:

```
$ gcc -c main.c
$ gcc -c gcd.c
$ gcc -c swap.c
$ gcc main.o gcd.o swap.o
```

or

```
$ gcc -c main.c gcd.c swap.c
$ gcc main.o gcd.o swap.o
```

or even

```
$ gcc *.c
$
```

Inter-module code consistency

```c
void swap(int* x, int* y)
{
  int t = *x;
  *x = *y;
  *y = t;
}
```

```c
int gcd(int m, int n)
{
  while (m > 0) {
    if (m < n) swap(m, n);
    m -= n;
  }
  return n;
}
```

```
$ gcc -o gcd *.c
./gcd 5 6
```

Inter-module code consistency

```c
void swap(int* x, int* y)
{
  int t = *x;
  *x = *y;
  *y = t;
}
```

```c
int gcd(int m, int n)
{
  while (m > 0) {
    if (m < n) swap(m, n);
    m -= n;
  }
  return n;
}
```

```
$ gcc -o gcd *.c
./gcd 5 6
Segmentation fault
$
```

Headers

```c
#ifndef __SWAP_H__
#define __SWAP_H__

void swap(int*, int*);

#endif /* __SWAP_H__ */
```

```c
#include "swap.h"

int gcd(int m, int n)
{
  while (m > 0) {
    if (m < n) swap(m, n); /* error! */
    m -= n;
  }
  return n;
}
```

```
$ gcc -c gcd_wrong.c
gcd_wrong.c: In function ‘gcd’:
gcd_wrong.c:7: warning: passing argument 1 of ‘swap’ makes
pointer from integer without a cast
gcd_wrong.c:7: warning: passing argument 2 of ‘swap’ makes
pointer from integer without a cast
```

Correct version

```c
#ifndef __GCD_H__
#define __GCD_H__

int gcd(int, int);

#endif /* __GCD_H__ */
```

```c
#include "gcd.h" /* important! */
#include "swap.h"

int gcd(int m, int n)
{
  while (m > 0) {
    if (m < n) swap(&m, &n);
    m -= n;
  }

  return n;
}
```

Planning build with make

make allows to plan and describe once and for all the build process in a Makefile

```
gcd: main.c gcd.c swap.c
	gcc -o gcd main.c gcd.c swap.c
clean:
	rm -f gcd
```

- gcd and clean are targets of specified rules
- after ":" you have the target's prerequisites
- in subsequent line(s), prefixed by a *tabulation character*, you have the commands that allow to build a target

make behavior

If a `Makefile` (or a `makefile`) exists, executing `make` will try to produce the first target in the `Makefile`.

An alternative `Makefile` can be specified using `make -f FILENAME`.

The variant `make` *`target`* will try to produce the given *target* (instead of the first one).

With `make -n` we can examine the command sequence that `make` *would execute*, without actually executing them (dry run mode).

```
make -n
gcc -o gcd main.c gcd.c swap.c
```

Makefile variables

It often comes handy to make rules parametric, based on the value of variables.

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
        gcc -o gcd $(SOURCES)
clean:
        rm -f gcd
```

The reference `$(SOURCES)` expands to the string "`main.c gcd.c swap.c`"

Warning: make $() vs shell $()

In spite of having the same syntax, Make's `$(SOURCES)` has nothing to do with Shell's command substitution `$(code...)`. One is expanded by make, the other by the shell, and the semantics is radically different.

How make works

When you invoke `make` *`target`*, `make` computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

How make works

When you invoke `make` *`target`*, `make` computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

1. to obtain `gcd` we need `main.c gcd.c swap.c`

How make works

When you invoke `make` *`target`*, `make` computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

1. to obtain `gcd` we need `main.c gcd.c swap.c`
2. to obtain `main.c` we don't need anything, as the file is already available (on the filesystem)

How make works

When you invoke `make` *`target`*, make computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

1. to obtain gcd we need `main.c gcd.c swap.c`
2. to obtain `main.c` we don't need anything, as the file is already available (on the filesystem)
3. ditto for `gcd.c`

How make works

When you invoke `make` *`target`*, make computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

1. to obtain gcd we need `main.c gcd.c swap.c`
2. to obtain `main.c` we don't need anything, as the file is already available (on the filesystem)
3. ditto for `gcd.c`
4. ditto for `swap.c`

How make works

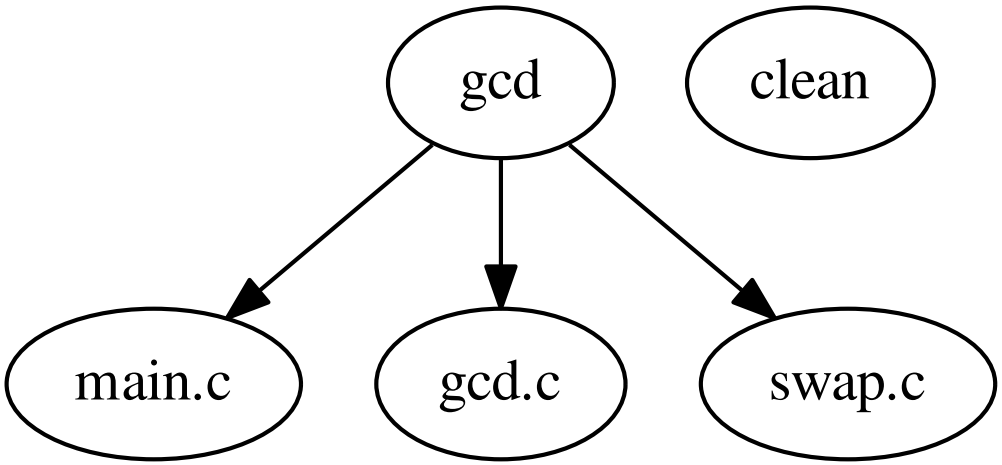
When you invoke `make` *target*, make computes the (acyclic!) graph of dependencies that are needed to produce *target*

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```

1. to obtain gcd we need `main.c gcd.c swap.c`
2. to obtain `main.c` we don't need anything, as the file is already available (on the filesystem)
3. ditto for `gcd.c`
4. ditto for `swap.c`
5. the prerequisites for gcd (i.e., its dependencies) are now satisfied, so we run the command(s) associated to the target gcd

How make works — dependency graph

```
SOURCES = main.c gcd.c swap.c

gcd: $(SOURCES)
	gcc -o gcd $(SOURCES)
clean:
	rm -f gcd
```



How make works: unsatisfied prerequisites

```
SOURCES = main.c gcd.c swop.c

gcd: $(SOURCES)
        gcc -o gcd $(SOURCES)
clean:
        rm -f gcd
```

make does not know that the Makefile is "wrong"

```
$ make -f Makefile.err
make: *** No rule to make target 'swop.c', needed by 'gcd'. Stop.
```

How make works: timestamps

make is lazy, and that's good

Before running the command(s) needed to build t, make checks:

1. the time T_t of last modifications of target t
   - assumption: targets are files
2. the *most recent* time T_d of modifications of t dependencies

- If $T_t > T_d$, the target is newer than *all* of its dependencies
  - therefore, no need to rebuild t, and the associated command(s) will be ignored
- else (i.e., $T_t \leq T_d$), the target is older than at least one of its dependencies
  - therefore, t needs to be rebuilt $\Rightarrow$ run the command(s)

How make works: timestamps — example

```
$ ls -l
total 32
-rwxr-xr-x 1 zack zack 7412 mar  6 19:23 gcd
-rw-r--r-- 1 zack zack  155 mar  6 19:23 gcd.c
-rw-r--r-- 1 zack zack   81 mar  6 19:23 gcd.h
-rw-r--r-- 1 zack zack  327 mar  6 19:24 main.c
-rw-r--r-- 1 zack zack   75 mar  6 19:28 Makefile
-rw-r--r-- 1 zack zack   65 mar  6 19:27 swap.c
-rw-r--r-- 1 zack zack   88 mar  6 19:23 swap.h
$ make
gcc -o gcd main.c gcd.c swap.c

$ ls -l
total 32
-rwxr-xr-x 1 zack zack 7412 mar  6 19:30 gcd
-rw-r--r-- 1 zack zack  155 mar  6 19:23 gcd.c
-rw-r--r-- 1 zack zack   81 mar  6 19:23 gcd.h
-rw-r--r-- 1 zack zack  327 mar  6 19:24 main.c
-rw-r--r-- 1 zack zack   75 mar  6 19:28 Makefile
-rw-r--r-- 1 zack zack   65 mar  6 19:27 swap.c
-rw-r--r-- 1 zack zack   88 mar  6 19:23 swap.h
$ make
make: 'gcd' is up to date.
```

Towards separate compilation

```
$ make
make: ‘gcd’ is up to date.

$ touch gcd.c
$ ls -l
-rwxr-xr-x 1 zack zack 7412 mar  6 19:30 gcd
-rw-r--r-- 1 zack zack  155 mar  6 19:31 gcd.c
-rw-r--r-- 1 zack zack   81 mar  6 19:23 gcd.h
-rw-r--r-- 1 zack zack  327 mar  6 19:24 main.c
-rw-r--r-- 1 zack zack   75 mar  6 19:28 Makefile
-rw-r--r-- 1 zack zack   65 mar  6 19:27 swap.c
-rw-r--r-- 1 zack zack   88 mar  6 19:23 swap.h

$ make
gcc -o gcd main.c gcd.c swap.c
```

- all `.c` files get recompiled even if only one has changed!

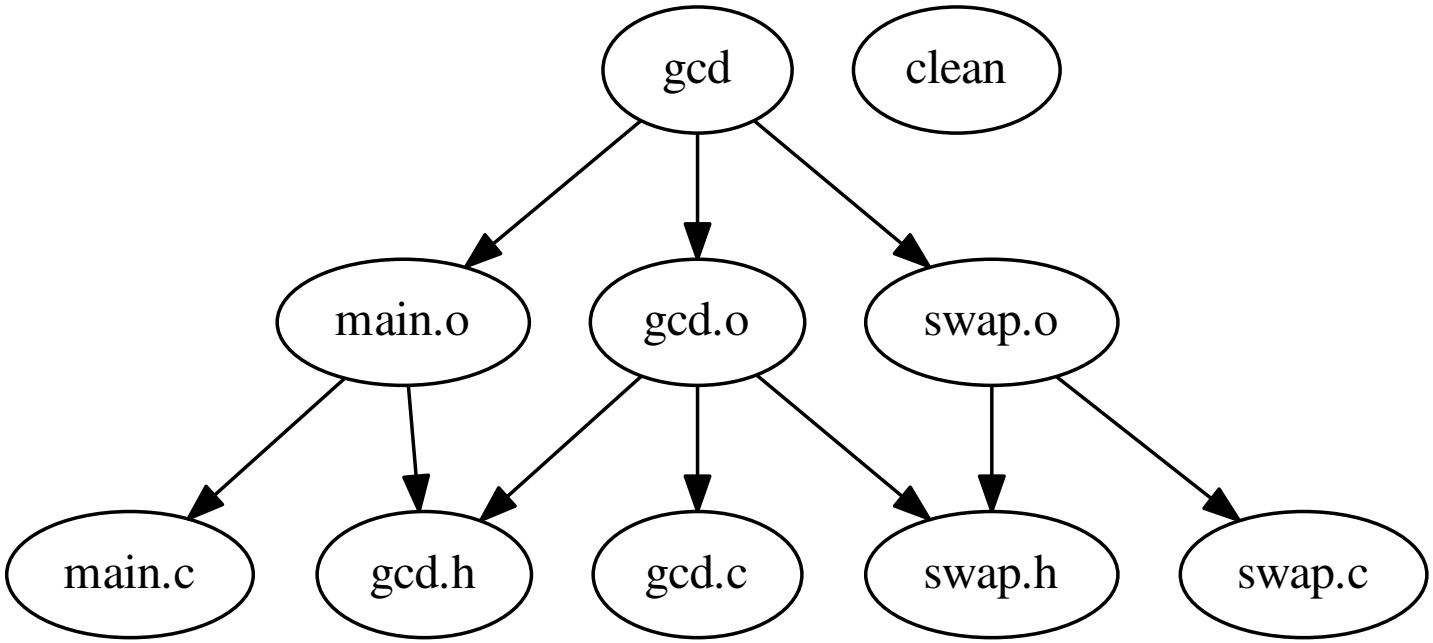
Separate compilation

```
SOURCES = main.c gcd.c swap.c
OBJS = main.o gcd.o swap.o

gcd: $(OBJS)
        gcc -o gcd $(OBJS)
main.o: main.c gcd.h
        gcc -c main.c
gcd.o: gcd.c gcd.h swap.h
        gcc -c gcd.c
swap.o: swap.c swap.h
        gcc -c swap.c

clean:
        rm -f gcd $(OBJS)
```

- dependencies are now more precisely associated to each target
  - and we also take into account `.h` files now

Separate compilation — dependency graph

```
OBJS = main.o gcd.o swap.o

gcd: $(OBJS)
	gcc -o gcd $(OBJS)
main.o: main.c gcd.h
	gcc -c main.c
gcd.o: gcd.c gcd.h swap.h
	gcc -c gcd.c
swap.o: swap.c swap.h
	gcc -c swap.c
```



Separate compilation — example

```
$ make
gcc -c main.c
gcc -c gcd.c
gcc -c swap.c
gcc -o gcd main.o gcd.o swap.o

$ touch gcd.c
$ ls -l
total 40
-rw-r--r--    1 zack     zack          231 Dec 12 13:12 Makefile
-rw-r--r--    1 zack     zack          322 Dec 12 13:08 main.c
-rw-r--r--    1 zack     zack          836 Dec 12 13:13 main.o
-rwxr-xr-x    1 zack     zack        12668 Dec 12 13:13 gcd
-rw-r--r--    1 zack     zack          156 Dec 12 13:13 gcd.c
-rw-r--r--    1 zack     zack           81 Dec 12 13:08 gcd.h
-rw-r--r--    1 zack     zack          436 Dec 12 13:13 gcd.o
-rw-r--r--    1 zack     zack           65 Dec 12 13:08 swap.c
-rw-r--r--    1 zack     zack           88 Dec 12 13:08 swap.h
-rw-r--r--    1 zack     zack          312 Dec 12 13:13 swap.o

$ make
gcc -c gcd.c
gcc -o gcd main.o gcd.o swap.o
```

Towards a nicer Makefile

```
SOURCES = main.c gcd.c swap.c
OBJS = $(SOURCES:%.c=%.o)

gcd: $(OBJS)
        gcc -o gcd $(OBJS)
main.o: main.c gcd.h
        gcc -c main.c
gcd.o: gcd.c gcd.h swap.h
        gcc -c gcd.c
swap.o: swap.c swap.h
        gcc -c swap.c

clean:
        rm -f gcd $(OBJS)
```

Other useful transformation

```
$(basename src/foo.c src-1.0/bar hacks) => src/foo src-1.0/bar hacks
$(addprefix src/,foo bar) => src/foo src/bar
$(wildcard *.c) => gcd.c main.c swap.c
```

See make manual, *Functions for transforming text*

Automatic variables

Automatic variables are predefined (and context-dependent) variables that you can use in Makefile-s.
Using automatic variables simplifies writing rules.

```
SOURCES = main.c gcd.c swap.c
OBJS = $(SOURCES:%.c=%.o)

gcd: $(OBJS)
	gcc -o $@ $(OBJS)
main.o: main.c gcd.h
	gcc -c $<
gcd.o: gcd.c gcd.h swap.h
	gcc -c $<
swap.o: swap.c swap.h
	gcc -c $<

clean:
	rm -f gcd $(OBJS)
```

Some (not so) frequently used automatic variables

- `$@` full target name
- `$<` name of the first dependency
- `$?` names of the dependencies that are more recent than target
- `$^` names of all dependencies (merging duplicates)
- `$+` names of all dependencies (not merging duplicates)

- `$(@D)` target's directory (`dir/foo.o` ⇒ `dir`)
- `$(@F)` target's base name (`dir/foo.o` ⇒ `foo.o`)
- `$(<D)` directory of the first dependency
- `$(<F)` base name of the first dependency
- ...

See `make` manual, *Automatic Variables*

Implicit rules

```
main.o: main.c gcd.h
        gcc -c $<              # same command
gcd.o: gcd.c gcd.h swap.h
        gcc -c $<              # same command
swap.o: swap.c swap.h
        gcc -c $<              # same command
```

Implicit rules

```
main.o: main.c gcd.h
        gcc -c $<              # same command
gcd.o: gcd.c gcd.h swap.h
        gcc -c $<              # same command
swap.o: swap.c swap.h
        gcc -c $<              # same command
```

An implicit rules defines a rule pattern

```
SOURCES = main.c gcd.c swap.c
OBJS = $(SOURCES:%.c=%.o)

gcd: $(OBJS)
        gcc -o $@ $(OBJS)
%.o: %.c
        @echo "building $(@:%.o=%) ..."
        @gcc -c $<
main.o: main.c gcd.h
gcd.o: gcd.c gcd.h swap.h
swap.o: swap.c swap.h

clean:
        rm -f gcd $(OBJS)
```

Larger project, more directories

```
$ ls -lR
.:
total 12
-rw-r--r--    1 zack     zack          394 Dec 12 14:03 Makefile
-rw-r--r--    1 zack     zack          137 Dec 12 13:42 common.h
drwxr-xr-x    7 zack     zack          238 Dec 12 14:09 io
-rw-r--r--    1 zack     zack          386 Dec 12 13:42 main.c
drwxr-xr-x    5 zack     zack          170 Dec 12 14:09 sorting

./io:
total 20
-rw-r--r--    1 zack     zack          260 Dec 12 14:08 Makefile
-rw-r--r--    1 zack     zack          367 Dec 12 14:05 reader.c
-rw-r--r--    1 zack     zack          121 Dec 12 13:59 reader.h
-rw-r--r--    1 zack     zack          159 Dec 12 13:45 writer.c
-rw-r--r--    1 zack     zack          124 Dec 12 13:45 writer.h

./sorting:
total 12
-rw-r--r--    1 zack     zack          221 Dec 12 14:08 Makefile
-rw-r--r--    1 zack     zack          499 Dec 12 14:02 sort.c
-rw-r--r--    1 zack     zack          113 Dec 12 14:01 sort.h
```

main.c

```c
#include <stdio.h>
#include "common.h"
#include "reader.h"
#include "writer.h"
#include "sort.h"

string lines[MAXLINES];

int main() {
  int n_lines = read_lines(lines, MAXLINES);

  if (n_lines > 0) {
    sort(lines, 0, n_lines - 1);
    write_lines(lines, n_lines);
    return 0;
  } else if (n_lines < 0) {
    fprintf(stderr, "error: too many input lines\n");
    return 1;
  }
}
```

common.h

```
#ifndef __COMMON_H__
#define __COMMON_H__

#define MAXLINES 5000
#define MAXLEN   1000

typedef char* string;

#endif /* __COMMON_H__ */
```

io/reader.h

```
#ifndef __READER_H__
#define __READER_H__

#include "common.h"
int read_lines(string[], int);

#endif /* __READER_H__ */
```

io/reader.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include "reader.h"

int read_lines(string line[], int max_lines) {
  int len;
  int n_lines = 0;
  char buffer[MAXLEN + 1];
  while (fgets(buffer, MAXLEN, stdin)) {
    line[n_lines] = (string) malloc(sizeof(char)
                                    * strlen(buffer));
    strcpy(line[n_lines], buffer);
    n_lines++;
  }
  return n_lines;
}
```

io/writer.h

```
#ifndef __WRITER_H__
#define __WRITER_H__

#include "common.h"

void write_lines(string[], int);

#endif /* __WRITER_H__ */
```

io/writer.c

```c
#include <stdio.h>

#include "writer.h"

void write_lines(string line[], int n_lines) {
  int i;
  for (i = 0; i < n_lines; i++)
    fputs(line[i], stdout);
}
```

sorting/sort.c

```c
#include <string.h>
#include "sort.h"

void swap(string line[], int i, int j) {
  string temp = line[i];
  line[i] = line[j];
  line[j] = temp;
}

void sort(string line[], int left, int right) {
  if (left < right) {
    int i, last;
    swap(line, left, (left + right) / 2);
    last = left;
    for (i = left + 1; i <= right; i++)
      if (strcmp(line[i], line[left]) < 0)
        swap(line, ++last, i);
    swap(line, left, last);
    sort(line, left, last - 1);
    sort(line, last + 1, right);
  }
}
```

Makefile

```
NAME = sort
SOURCES = main.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I. -Iio -Isorting
IOLIB = io/libio.a
SORTINGLIB = sorting/libsorting.a

all:
        make -C io
        make -C sorting
        make $(NAME)

$(NAME) : $(OBJS) $(IOLIB) $(SORTINGLIB)
        gcc -o $@ $^

%.o : %.c
        gcc -c $(INCLUDES) $<

main.o : io/reader.h io/writer.h common.h

clean:
        make -C io clean
        make -C sorting clean
        rm -f $(NAME) $(OBJS)
```

io/Makefile

```
SOURCES = reader.c writer.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I../

all : libio.a

libio.a : $(OBJS)
	ar cru $@ $^
	ranlib $@

%.o : %.c
	gcc -c $(INCLUDES) $<

reader.o : reader.h ../common.h
writer.o : writer.h ../common.h

clean:
	rm -f libio.a $(OBJS)
```

sort/Makefile

```
SOURCES = sort.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I../

all : libsorting.a

libsorting.a : $(OBJS)
	ar cru $@ $^
	ranlib $@

%.o : %.c
	gcc -c $(INCLUDES) $<

sort.o : ../common.h

clean:
	rm -f libsorting.a $(OBJS)
```

Building the project — example

```
$ make
make -C io
make[1]: Entering directory ‘io’
gcc -c -I../ reader.c
gcc -c -I../ writer.c
ar cru libio.a reader.o writer.o
ranlib libio.a
make[1]: Leaving directory ‘io’
make -C sorting
make[1]: Entering directory ‘sorting’
gcc -c -I../ sort.c
ar cru libsorting.a sort.o
ranlib libsorting.a
make[1]: Leaving directory ‘sorting’
make sort
make[1]: Entering directory ‘.’
gcc -c -I. -Iio -Isorting main.c
gcc -o sort main.o io/libio.a sorting/libsorting.a
make[1]: Leaving directory ‘.’
$
```

Dependencies on external libraries

Most programs rely on functionalities offered by external libraries, i.e., libraries other than the C standard library (that comes with the compiler).

To the end of building an executable that uses external libraries, we need to take care of:

1. ensure that external library header files (`.h`) are available at compile time
2. ensure that libraries (static `.a` and/or dynamic `.so`) are available at link time

common.h

```
#ifndef __COMMON_H__
#define __COMMON_H__

typedef char* string;

#endif /* __COMMON_H__ */
```

main.c

```c
#include <stdio.h>
#include <glib.h>
#include "reader.h"
#include "writer.h"
#include "sort.h"

int main() {
  GPtrArray* lines = read_lines();
  g_assert(lines);

  if (lines->len > 0) {
    sort(lines);
    write_lines(lines);
    return 0;
  } else
    return 1;
}
```

io/reader.c

(#include-s omitted)

```
#define MAXLEN 1000

GString* read_line() {
  gint len;
  GString* buffer = g_string_new("");
  gchar chunk[MAXLEN];
  do {
    if (fgets(chunk, MAXLEN, stdin))
      g_string_append(buffer, chunk);
    else
      return NULL;
  } while (!strchr(chunk, '\n'));
  return buffer;
}

GPtrArray* read_lines() {
  GPtrArray* lines = g_ptr_array_new();
  GString* line;
  while ((line = read_line()))
    g_ptr_array_add(lines, line);
  return lines;
}
```

io/writer.h

```
#ifndef __WRITER_H__
#define __WRITER_H__

#include <glib.h>

void write_lines(GPtrArray*);

#endif /* __WRITER_H__ */
```

io/writer.c

```c
#include <stdio.h>
#include "writer.h"

void write_line(GString* line, gpointer user_data) {
  g_return_if_fail(line != NULL);
  fputs(line->str, stdout);
}

void write_lines(GPtrArray* lines) {
  g_return_if_fail(lines != NULL);
  g_ptr_array_foreach(lines, (GFunc) write_line, NULL);
}
```

io/sort.h

```
#ifndef __SORT_H__
#define __SORT_H__

#include <glib.h>

void sort(GPtrArray*);

#endif /* __SORT_H__ */
```

io/sort.c

```c
#include <string.h>
#include "sort.h"

gint compare_lines(const GString** s1, const GString** s2) {
  g_return_val_if_fail(s1 != NULL, 0);
  g_return_val_if_fail(s2 != NULL, 0);
  return strcmp((*s1)->str, (*s2)->str);
}

void sort(GPtrArray* lines) {
  g_return_if_fail(lines != NULL);
  g_ptr_array_sort(lines, (GCompareFunc) compare_lines);
}
```

Makefile

```
NAME = sort
SOURCES = main.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I. -Iio -Isorting `pkg-config glib-2.0 --cflags`
LIBS = `pkg-config glib-2.0 --libs`
IOLIB = io/libio.a
SORTINGLIB = sorting/libsorting.a

all:
        make -C io
        make -C sorting
        make $(NAME)

$(NAME) : $(OBJS) $(IOLIB) $(SORTINGLIB)
        gcc -o $@ $^ $(LIBS)

%.o : %.c
        gcc -c $(INCLUDES) $<
main.o : io/reader.h io/writer.h common.h

clean:
        make -C io clean
        make -C sorting clean
        rm -f $(NAME) $(OBJS)
```

io/Makefile

```
SOURCES = reader.c writer.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I../ `pkg-config glib-2.0 --cflags`

all : libio.a

libio.a : $(OBJS)
	ar cru $@ $^
	ranlib $@

%.o : %.c
	gcc -c $(INCLUDES) $<

reader.o : reader.h ../common.h
writer.o : writer.h ../common.h

clean:
	rm -f libio.a $(OBJS)
```

sorting/Makefile

```
SOURCES = sort.c
OBJS = $(SOURCES:%.c=%.o)
INCLUDES = -I../ `pkg-config glib-2.0 --cflags`

all : libsorting.a

libsorting.a : $(OBJS)
	ar cru $@ $^
	ranlib $@

%.o : %.c
	gcc -c $(INCLUDES) $<

sort.o : ../common.h

clean:
	rm -f libsorting.a $(OBJS)
```

Building the project — example

```
$ make
make -C io
make[1]: Entering directory 'io'
gcc -c -I../ `pkg-config glib-2.0 --cflags` reader.c
gcc -c -I../ `pkg-config glib-2.0 --cflags` writer.c
ar cru libio.a reader.o writer.o
ranlib libio.a
make[1]: Leaving directory 'io'
make -C sorting
make[1]: Entering directory 'sorting'
gcc -c -I../ `pkg-config glib-2.0 --cflags` sort.c
ar cru libsorting.a sort.o
ranlib libsorting.a
make[1]: Leaving directory 'sorting'
make sort
make[1]: Entering directory 'sort-glib'
gcc -c -I. -lio -lsorting `pkg-config glib-2.0 --cflags` main.c
gcc -o sort main.o io/libio.a sorting/libsorting.a `pkg-config \
  glib-2.0 --libs`
make[1]: Leaving directory 'sort-glib'
$
```

- `ldd sort`

State of the project — discussion

- tool names (`gcc`, `ar`, `make`, ...) and their invocation syntax are hard-coded in `Makefile`-s
- building *needs* the existence of specific libraries and fails abruptly if the corresponding prerequisites are not available
- maintaining the project across several directories is clumsy and error-prone
- `Makefile`-s do not implement targets to package, install, and uninstall the software

All those aspects are tolerable for small projects. They become too constraining for large and complex projects.

⇒ GNU Autotools [1]

1. https://www.gnu.org/software/automake/manual/html_node/Autotools-Introduction.html

References

- GNU Make homepage: `http://www.gnu.org/software/make/`
- GNU Make manual
  - `$ info make`
  - `M-x info` in Emacs
  - `http://www.gnu.org/software/make/manual/`
- book: *Managing Projects with GNU Make*, Robert Mecklenburg, 3rd ed. O'Reilly, 2004.
  - available online at `http://oreilly.com/catalog/make3/book/index.csp` under the terms of the GNU Free Documentation License