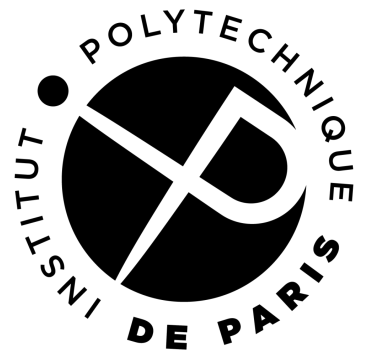

Modular programming

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Key concepts

- Compilation versus linking
  - Compilation: generate an object file from a source file
  - Linking: generate an executable from object files

- Header file
  - Gather the data structures and function definitions used in multiple source files
  - Guarded with `#ifndef`/`#define`/`#endif`

- Libraries: brings a set of object files together
  - Static (.a): included in each executable
  - Shared (.so): shared between multiple processes

Modular programming

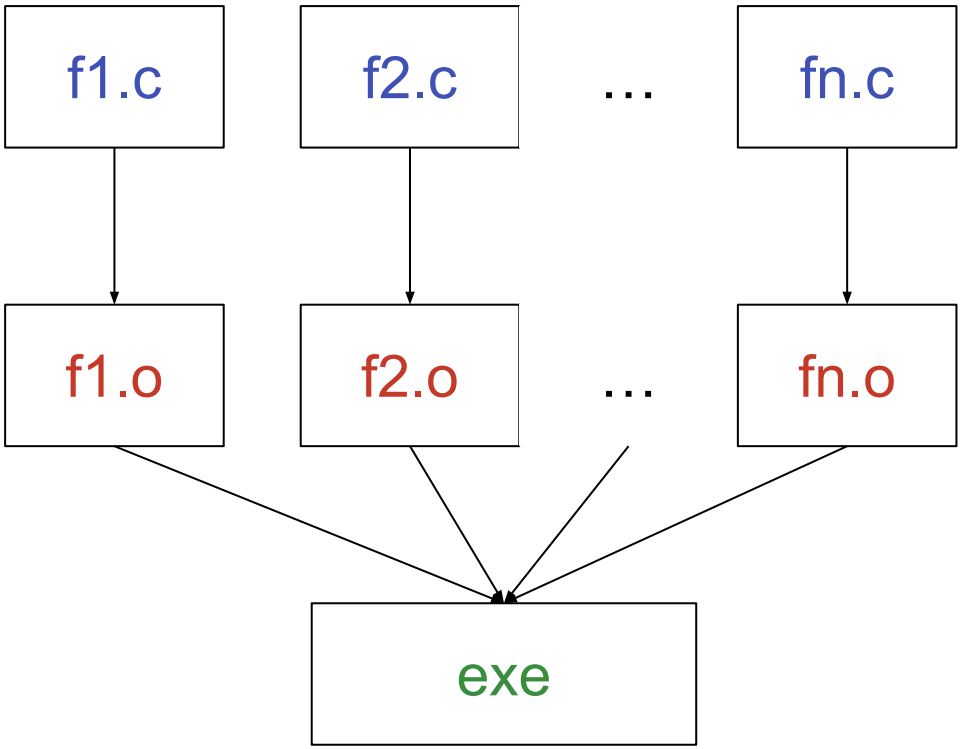
- Putting all the code in a single file is sometime unrealistic
  - For example, Linux is 25 millions lines of code
- Sometime, we have to aggregate codes from different entities
  - Reuse the code written in another program
- Solution: put the code in different files
  - Generate a binary from several source files

Multiple source files in a binary

- (Bad) solution:
  - Call `gcc -o binary file1.c file2.c`
- Bad solution because we have to recompile all the source files whenever a single file is modified
  - Very inefficient
- (Good) solution: split compilation in two phases
  - Compilation: translates from source to binary objects
  - Linking: aggregates several binary objects into an executable

Compilation versus linking

- Two different commands
  - **`gcc -c f.c -o f.o`**: compile f.c in f.o
  - **`gcc f.o g.o -o exe`**: linke f.o and g.o into exe



Problems

- What about the data structures?
  - Replicating the definition of a data structure in each source file is not maintainable
- What about the function declarations?
  - How a source g.c can call a function implemented in f.c
- Solution: define a **header file**
  - Suffix: `.h`
  - Contains data structures and function declarations (not the function implementations)
  - A function declaration has to be prefixed by `extern`

Header file

`#include` means
“copy-paste”

```c
struct point {
  int x;
  int y;
};

extern struct point* create();
```

point.h

```c
#include "point.h"

int main(...) {
  struct point* p = create();
  ...
}
```

main.c

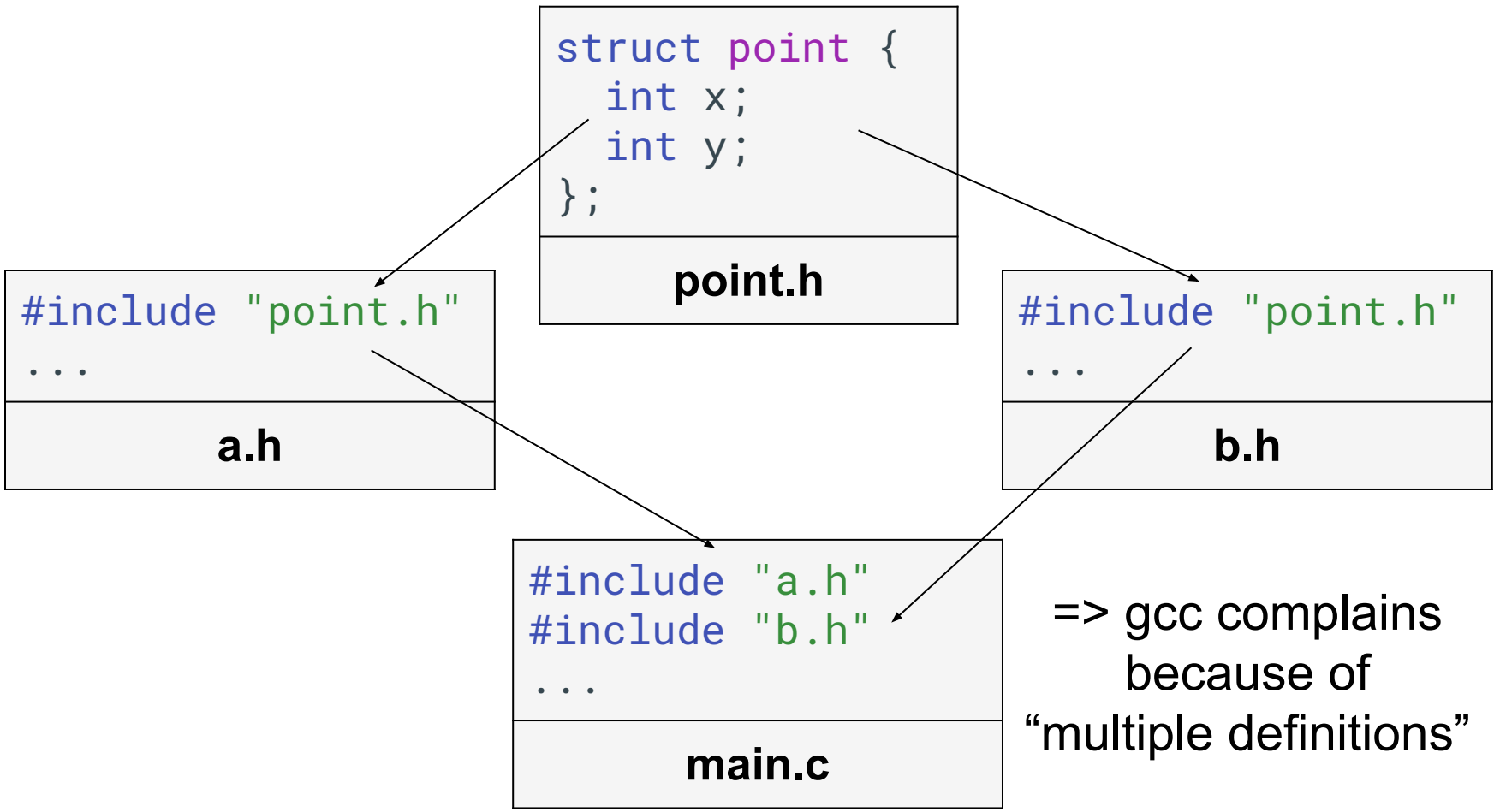
```c
#include "point.h"
#include <stdlib.h>

struct point* create() {
  struct point* p =
    malloc(sizeof(*p));
  p->x = 0;
  p->y = 0;
  return p;
}
```

point.c

Include once (1/2)

- We can end up with multiple definitions of a structure



Include once (2/2)

- Avoid multiple definitions with `#ifndef`/`#define`/`#endif`

```
#ifndef _POINT_H_
#define _POINT_H_

struct point {
  int x;
  int y;
};

#endif
```

point.h

- First include
  - `_POINT_H_` is not defined
  - copy the content
    - define `_POINT_H_`
    - we have the definition
- Second include
  - `_POINT_H_` is already defined
  - ignore the content
  - => a single definition

Static libraries

- Static libraries: used to reuse multiple object files at once
  - Aggregate several object files in an archive
  - `ar rcs libengine.a f1.o f2.o …`

- Two solutions to link a binary with a static library
  - `gcc -o exe f3.o ../other_project/libengine.a`
  - `gcc -o exe f3.o -lengine -L../other_project/`

Shared library (1/2)

- With a static library, the code is replicated in each process
  - Uselessly consumes memory
- Shared library: share the code between different processes
  - `gcc -shared -o libengine.so f1.c f2.c`
- Link an executable with a shared library
  - `gcc -o exe f3.c -L../other_project -lengine`
- At runtime:
  - The operating system loads the library if it is not loaded yet
  - Share the code from another process if the library is loaded

Shared library (2/2)

- When the operating system loads a binary
  - It searches the shared library in the file system
  - By default in /lib and /usr/lib

- Sometimes, a shared library is located elsewhere
  - Use the shell variable LD_LIBRARY_PATH

- Usage

```
$ LD_LIBRARY_PATH=../other_project
$ ./my_great_program

# => search libengine in ../other_project
```

terminal

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