Separate Compilation

EECS 211

Winter 2019
Initial code setup

$ cd eecs211
$ wget $URL211/lec/03separate.tgz
...
$ tar zxf 03separate.tgz
$ cd 03separate
The general problem

It would be really nice if we could:

1. Write some functions in one place.
2. Call those functions from multiple programs.
A more specific problem for today

We need to:

1. Write some functions in one place.
2. Write a program that uses those functions.
3. Write tests that ensure those functions are correct.
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We need to:

1. Write some functions in one place.
2. Write a program that uses those functions.
3. Write tests that ensure those functions are correct.

But: C has no facilities for testing. Your tests are just an ordinary program that calls the functions and checks the results.

So the goal is the same: one library with two (or more) clients.
Making it concrete

1. The posn library: provides the `struct` `posn` type and three functions, `read_posn()`, `make_posn()`, and `manhattan_dist()`.

2. Client 1, the interact program: uses the posn library to read positions from the standard input, calculate distances, and print the distances to the standard output.

3. Client 2, the posn_test test program: checks that the posn library’s `manhattan_dist()` function gives the answers we expect.
The posn library (highlights)

// A 2-D point.
struct posn
{
    double x;
    double y;
};

// Computes the Manhattan distance between two posns.
double manhattan_dist(struct posn p, struct posn q)
{
    return fabs(p.x - q.x) + fabs(p.y - q.y);
}
The interact program

// import posn library somehow?
#include <stdio.h>

int main()
{
    struct posn target = read_posn();

    for (;;) {
        struct posn each = read_posn();
        double dist = manhattan_dist(target, each);
        printf("%f\n", dist);
    }
}
The posn_test test program

// import posn library somehow?
#include <assert.h>

int main()
{
    struct posn p = make_posn(0, 0);
    struct posn q = make_posn(3, 4);

    assert( manhattan_dist(p, p) == 0 );
    assert( manhattan_dist(q, p) == 7 );
}

(The assert() function crashes the program if its argument is false, or does nothing if its argument is true. We’ll have nicer ways to write tests in the future, but right now we’ll stick with assert.)
The solution, generally

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The solution, generally

1. Put implementations of functions in .c files.
2. Describe the interface to each .c file (type definitions, function *signatures*) in a corresponding .h (header) file.
3. Each .c file that wants to call code from another .c file must *include* the corresponding .h file.
4. Each .c file is its own *compilation unit*, which means it is translated by the compiler in isolation, with no direct knowledge of the other .c files, into a .o (object) file containing machine code. All dependencies are via .h files that the .c file *includes.*
The solution, generally

1. Put implementations of functions in `.c` files.
2. Describe the interface to each `.c` file (type definitions, function *signatures*) in a corresponding `.h` (header) file.
3. Each `.c` file that wants to call code from another `.c` file must `#include` the corresponding `.h` file.
4. Each `.c` file is its own *compilation unit*, which means it is translated by the compiler in isolation, with no direct knowledge of the other `.c` files, into a `.o` (object) file containing machine code. All dependencies are via `.h` files that the `.c` file `#includes`.
5. Once all the `.c` files for a program have been translated into `.o` files, the *linker* combines them into a single executable, resolving the references between them.
(And the fiddly details)

- When translating individual source files, pass `cc` the `-c` switch to suppress linking.
- Every `.h` file should start with a *guard*,
  
  ```
  #pragma once
  ```
  
  to prevent processing it more than once per compilation unit.
- Never `#include` a `.c` file. Ever.
Why this works

The C compiler is pretty stupid:

- Remembers nothing from one `.c` file to the next
- Reads strictly downward (so it doesn’t know about things at the bottom of a file when it’s processing the top of that file)
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- Reads strictly downward (so it doesn’t know about things at the bottom of a file when it’s processing the top of that file)

But:

- To compile a function call, it only needs to know the signature (type) of the function, not its whole definition.
- A function declaration specifies a function signature without the definition, like so:

  ```c
  double manhattan_dist(struct posn, struct posn);
  ```

  (The parameter names are optional, so it makes sense to omit them from signatures when they aren’t informative.)
Example of C scope

C compiler is happy:

double min2(double x, double y)
{
    return x < y ? x : y;
}

double min3(double x, double y, double z)
{
    return min2(x, min2(y, z));
}
Example of C scope

C compiler is unhappy, says that min2 isn't defined:

```c
double min3(double x, double y, double z)
{
    return min2(x, min2(y, z));
}

double min2(double x, double y)
{
    return x < y ? x : y;
}
```
Example of C scope

C compiler is happy once again:

```c
double min2(double, double);

double min3(double x, double y, double z)
{
    return min2(x, min2(y, z));
}

double min2(double x, double y)
{
    return x < y ? x : y;
}
```
The solution, applied

- `src/posn.h` contains
  - Definition of `struct posn` type
  - Signatures for shared functions (`read_posn()`, `make_posn()`, and `manhattan_dist()`)

- `src/posn.c` includes `src/posn.h` and contains definitions of the same shared functions

- `src/interact.c` includes `src/posn.h` and contains the main function for the `interact` program

- `test/posn_test.c` includes `src/posn.h` and contains a main function that tests the functions defined in `src/posn.c`. 
The solution, applied

- `src/posn.h` contains
  - Definition of `struct posn` type
  - Signatures for shared functions (`read_posn()`, `make_posn()`, and `manhattan_dist()`)
- `src/posn.c` includes `src/posn.h` and contains definitions of the same shared functions
- `src/interact.c` includes `src/posn.h` and contains the main function for the interact program
- `test/posn_test.c` includes `src/posn.h` and contains a main function that tests the functions defined in `src/posn.c`.

Important C rule: You cannot have more than one definition of the same symbol (variable, constant, or function) in the same program. This means that attempting to link `interact.o` and `posn_test.o` together will result in an error.
Build dependencies

header files:

source files:

object files:

executable files:

cc -c
cc -c
cc -c
cc
cc
cc
cc
cc
cc
cc
cc
cc
cc
To implement the previous slide in Make, we define *pattern rules* for particular types of files. Here’s the rule for translating any `.c` file into a `.o` file:

```
build/%.o: src/%.c | build/
    cc -c -o $@ $< $(CFLAGS)
```
A bit more Make

To implement the previous slide in Make, we define *pattern rules* for particular types of files. Here’s the rule for translating any `.c` file into a `.o` file:

```
build/%.o: src/%.c  |  build/
    cc  -c  -o  $@  $<  $(CFLAGS)
```

We also need to let Make know which object files depend on which header files. These dependency specifications say that if `src/posn.h` changes then each of the three object files dependent on it needs to be rebuilt:

```
build/interact.o:  src/posn.h
build/posn.o:  src/posn.h
build/posn_test.o:  src/posn.h
```
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

$
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Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

$ make clean
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

```
$ make clean
rm -Rf build
$
```

```
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

$ make clean
rm -Rf build
$ make build/interact
$ make build/posn_test
$ make build/posn_test
make: `build/posn_test' is up to date.
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

$ make clean
rm -Rf build
$ make build/interact
mkdir -p build
cc -c -o build/interact.o src/interact.c -std=c11…
cc -c -o build/posn.o src/posn.c -std=c11 -pedant…
cc -o build/interact build/interact.o build/posn.…
$
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

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$ make clean
rm -Rf build
$ make build/interact
mkdir -p build
cc -c -o build/interact.o src/interact.c -std=c11...
cc -c -o build/posn.o src/posn.c -std=c11 -pedant...
cc -o build/interact build/interact.o build/posn....
$ make build/posn_test
```
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Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

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c -o build/interact build/interact.o build/posn....
$ make build/posn_test
cc -c -o build/posn_test.o test/posn_test.c -std=... cc -o build/posn_test build/posn_test.o build/posn_test.o $
Make understands dependencies

Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

```
$ make clean
rm -Rf build
$ make build/interact
mkdir -p build
cc -c -o build/interact.o src/interact.c -std=c11...
c -c -o build/posn.o src/posn.c -std=c11 -pedant...
c -o build/interact build/interact.o build/posn....
$ make build/posn_test
cc -c -o build/posn_test.o test/posn_test.c -std=...
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$ make build/posn_test
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Notice that when we build build/posn_test, Make does not recompile src/posn.c to build/posn.o, because it already did that to build build/interact.

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c -o build/interact build/interact.o build/posn....
$ make build/posn_test
cc -c -o build/posn_test.o test/posn_test.c -std=...
c -o build/posn_test build/posn_test.o build/posn...
$ make build/posn_test
make: `build/posn_test' is up to date.
Make performs minimal rebuilds

The touch command updates a file’s modification time. This lets us see how make deals with files changing:

$
Make performs minimal rebuilds

The `touch` command updates a file’s modification time. This lets us see how `make` deals with files changing:

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$ make
```

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$ make
make: Nothing to be done for `all'.
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make: Nothing to be done for `all'.
$ touch src/interact.c
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Make performs minimal rebuilds

The touch command updates a file’s modification time. This lets us see how make deals with files changing:

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$ make
make: Nothing to be done for `all'.
$ touch src/interact.c
$ make
cc -c -o build/interact.o src/interact.c -std=c11...
c...  
```

```bash
  cc -c -o build/posn.o src/posn.c -std=c11 -pedant...
cc -o build/interact build/interact.o build/posn.o...
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$ touch src/interact.c
$ make
cc -c -o build/interact.o src/interact.c -std=c11...
cc -c -o build/posn.o src/posn.c -std=c11 -pedant...
cc -o build/interact build/interact.o build/posn....
$ touch src/posn.h
```
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$ make
make: Nothing to be done for `all'.
$ touch src/interact.c
$ make
$ touch src/posn.h
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make: Nothing to be done for `all'.  
$ touch src/interact.c  
$ make  
cc -c -o build/interact.o src/interact.c -std=c11...  
cc -o build/interact build/interact.o build/posn....  
$ touch src/posn.h  
$ make
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$ touch src/posn.h
$ make
cc -c -o build/interact.o src/interact.c -std=c11...
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cc -o build/posn_test build/posn_test.o build/posn_test....
```