C/C++ Compilation and Linkage

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C/C++ Build Stages

example.c

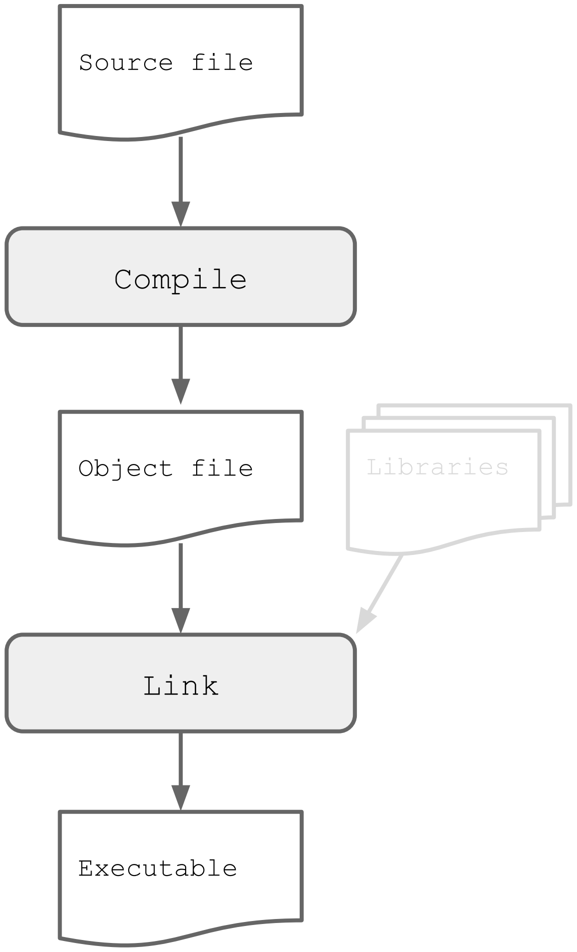
```
int FuncInt(int a, int b) {
  ...
}

int FuncDouble(double a, double b, double c) {
  ...
}

int main() { ... }
```

example.o

```
_FuncInt: ........
_FuncDouble: ........
_main: ........
```

example (example.exe)

```
........
```

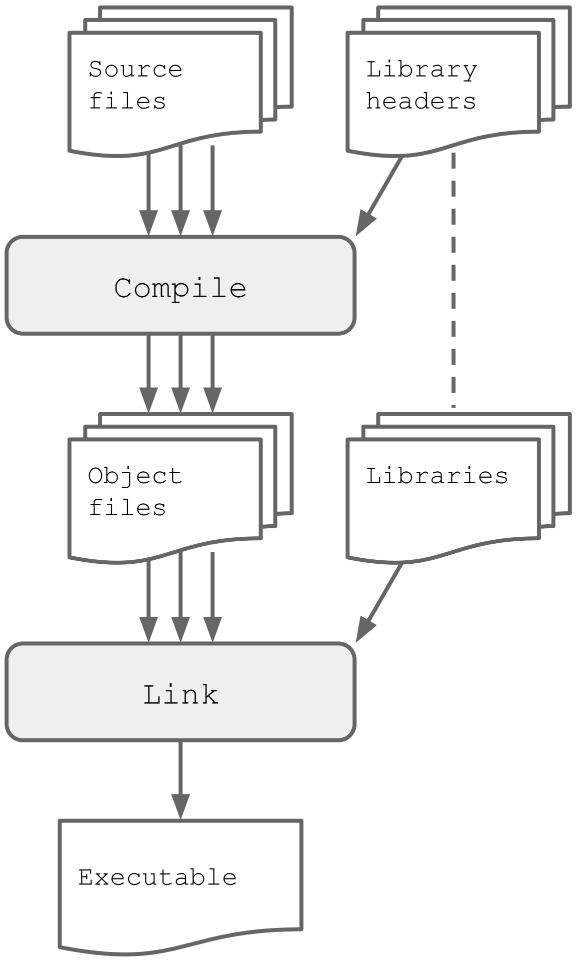


C/C++ Build Stages

example.c

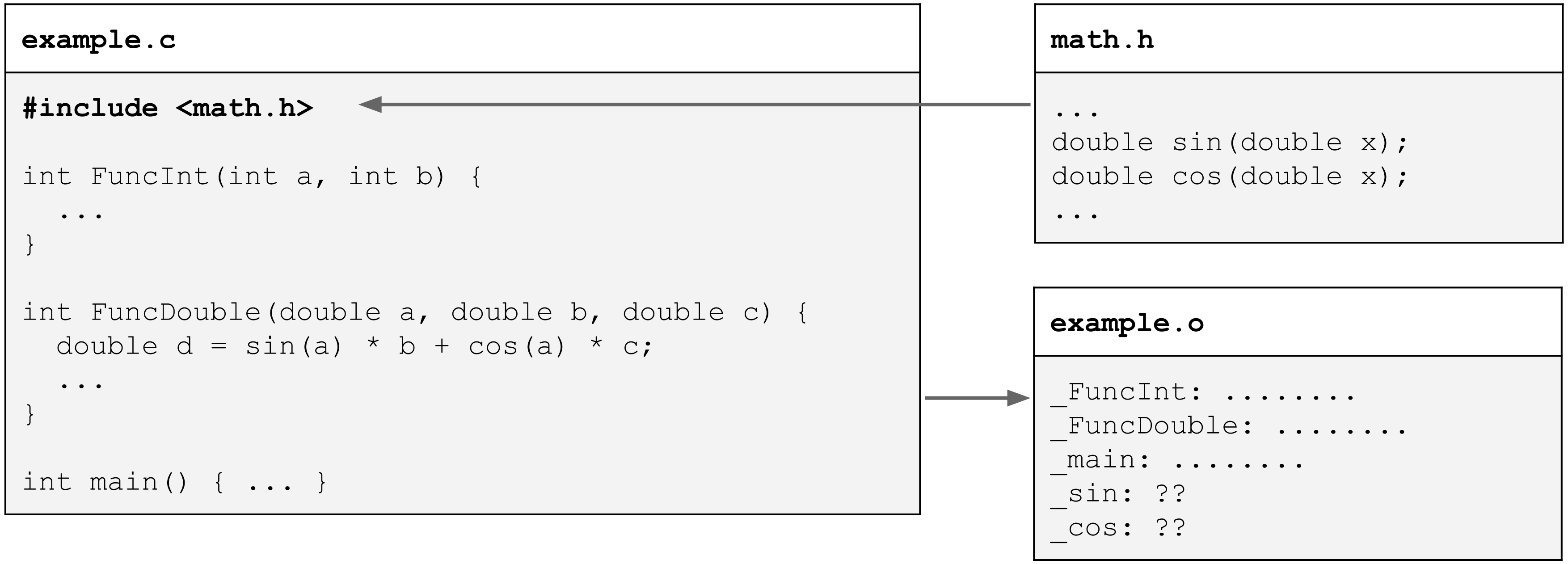
```
#include <math.h>

int FuncInt(int a, int b) {
  ...
}

int FuncDouble(double a, double b, double c) {
  double d = sin(a) * b + cos(a) * c;
  ...
}

int main() { ... }
```

How do we know the signature of the function `sin` and `cos`? E.g. how can the compiler find syntax errors?



C/C++ Compilation

- Compilers only need to know the declarations (signatures) of the functions or external variables.
- The preprocessor just replaces `#include` statements with their file content.



example.c

```
#include <math.h>

int FuncInt(int a, int b) {
  ...
}

int FuncDouble(double a, double b, double c) {
  double d = sin(a) * b + cos(a) * c;
  ...
}

int main() { ... }
```

math.h

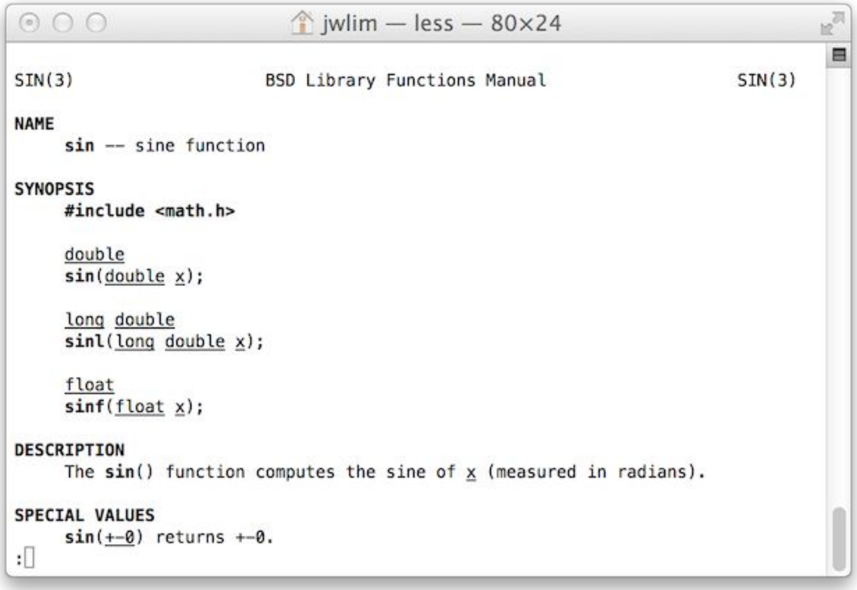
```
...
double sin(double x);
double cos(double x);
...
```

example.o

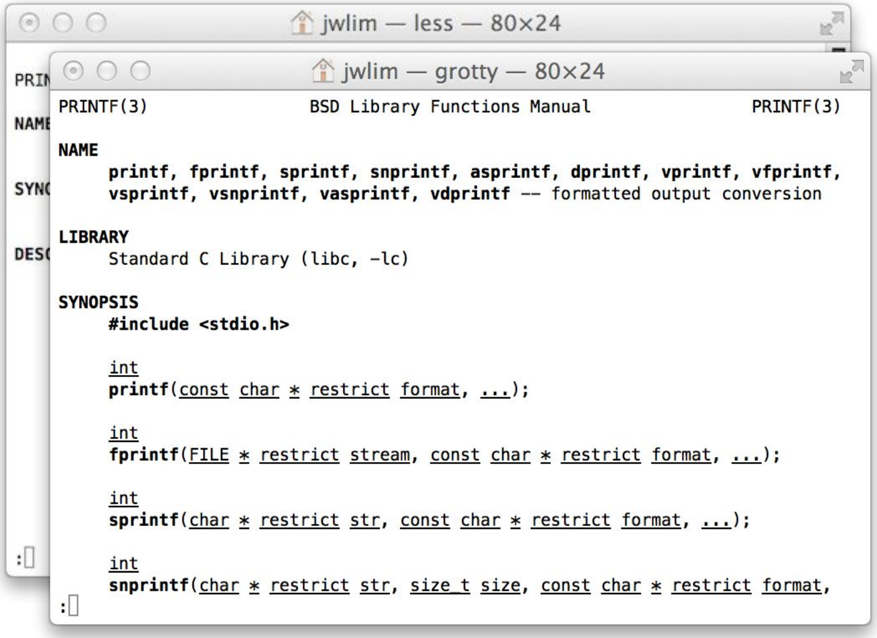
```
_FuncInt: ........
_FuncDouble: ........
_main: ........
_sin: ??
_cos: ??
```

C/C++ Standard Library Header

- You don't need to find the actual header file to check the function signatures while you are programming.
- There are man pages for all functions in C standard library.



```
SIN(3)                  BSD Library Functions Manual                  SIN(3)

NAME
     sin -- sine function

SYNOPSIS
     #include <math.h>

     double
     sin(double x);

     long double
     sinl(long double x);

     float
     sinf(float x);

DESCRIPTION
     The sin() function computes the sine of x (measured in radians).

SPECIAL VALUES
     sin(+-0) returns +-0.
:
```



```
PRINTF(3)               BSD Library Functions Manual               PRINTF(3)

NAME
     printf, fprintf, sprintf, snprintf, asprintf, dprintf, vprintf, vfprintf,
     vsprintf, vsnprintf, vasprintf, vdprintf -- formatted output conversion

LIBRARY
     Standard C Library (libc, -lc)

SYNOPSIS
     #include <stdio.h>

     int
     printf(const char * restrict format, ...);

     int
     fprintf(FILE * restrict stream, const char * restrict format, ...);

     int
     sprintf(char * restrict str, const char * restrict format, ...);

     int
     snprintf(char * restrict str, size_t size, const char * restrict format,
:
```

C/C++ Build Stages

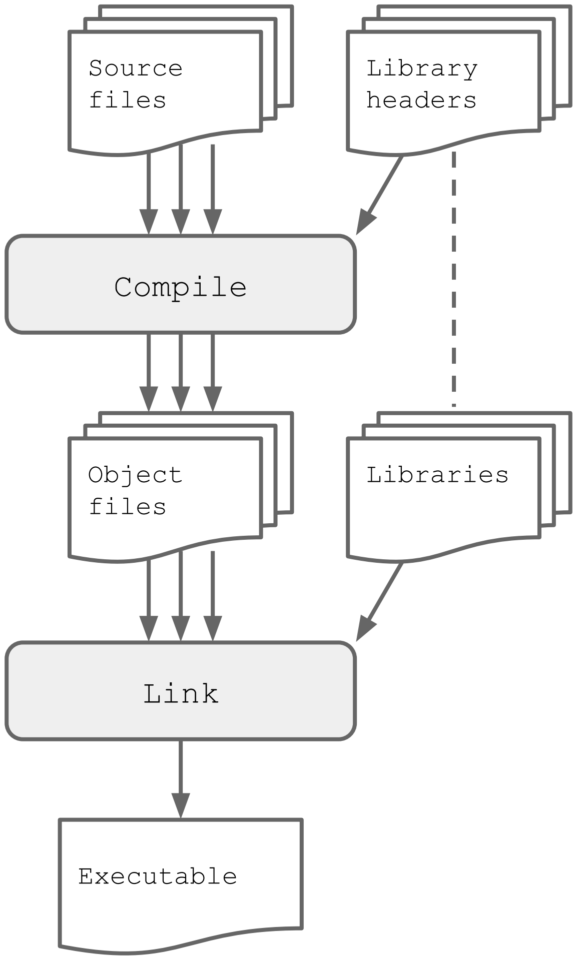
example.c

```
#include <math.h>

int FuncInt(int a, int b) {
  ...
}

int FuncDouble(double a, double b, double c) {
  double d = sin(a) * b + cos(a) * c;
  ...
}

int main() { ... }
```

example.o

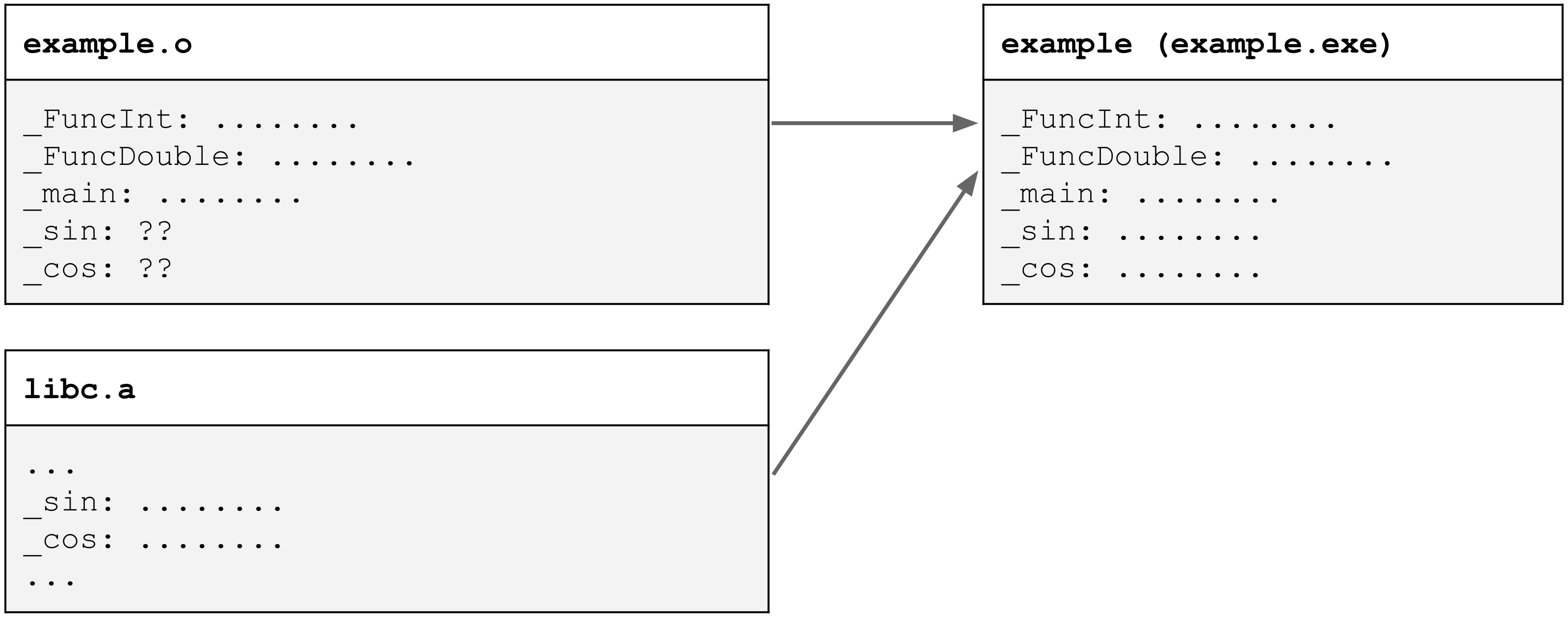
```
_FuncInt: ........
_FuncDouble: ........
_main: ........
_sin: ??
_cos: ??
```

Where can we find the definition of the function `sin` and `cos`?



C/C++ Linking

- Linker tries to find all unknown symbols in the object files and the libraries.
- A library is just a collection of object files.



```
example.o
_FuncInt: ........
_FuncDouble: ........
_main: ........
_sin: ??
_cos: ??
```

```
libc.a
...
_sin: ........
_cos: ........
...
```

```
example (example.exe)
_FuncInt: ........
_FuncDouble: ........
_main: ........
_sin: ........
_cos: ........
```

Header and Source Files

Header file's extension is '.h' and source file's is '.cc' or 'cpp'.

C/C++ header files contain

- function and external variable declarations.
- struct and class (type) declarations.
- enumeration definitions.
- macro definitions.
- inline function definitions (C++).
- ...

Headers show the interface of the entities in the source files.

Function Declaration and Definition

- Function declaration only specifies the function name, parameter profile, and the return type.
- Function definition provides the actual implementation of the function body.

```
#include <math.h>

int FuncInt(int a, int b);

double MyFunc(const int* array, int n, const char* command);

int FuncInt(int a, int b) {
  return a * 10 + b * b;
}

double Norm(const double* array, int n) {
  double sqsum = 0;
  for (int i = 0; i < n; ++i) sqsum += array[i] * array[i];
  return sqrt(sqsum);
}
```

C/C++ Preprocessor

- When compilation begins, the preprocessor replaces the # directives in the source.

```
#include <math.h>
#include <iostream>
#include "my_header.h"

#pragma once

#define PI 3.141592
#define PI_2 (PI/2)

#define MAX(a, b) ((a) > (b) ? (a) : (b))

int main() {
  const double angle = PI / 3;
  int n, min_iter = 10;
  std::cin >> n;
  const int num_iter = MAX(n, min_iter);
  // What happens if we use MAX(++n, min_iter);
  for (int i = 0; i < n; ++i) {
    ...
  }
  return 0;
}
```

Inline Function

- Function definitions should not be in header files, except inline functions.
- Inline expansion : an inline function works as if the function call is replaced with the function body.
- Use with care : often executes faster but bloats the code.

```
#include <iostream>

#define MAX(a, b) ((a) > (b) ? (a) : (b))

inline int max(int a, int b) {
  return a > b ? a : b;
}

int main() {
  const int size = 5;
  int array[size] = { 2 3 1 5 3 };
  for (int i = 1; i < size; ++i)
    std::cout << max(array[i - 1], array[i]) << std::endl;
  return 0;
}
```

Inline Function

- Function definitions in a class definition are inline functions.
- Otherwise specify with the keyword `inline`.

```
class SimpleIntSet {
 public:
  SimpleIntSet() : values_(NULL), size_(0) {}
  ~SimpleIntSet() { delete[] values; }

  inline void Set(const int* values, size_t size);
  const int* values() const { return values_; }
  size_t size() const { return size_; }

 private:
  int* values_;
  size_t size_;
};

void SimpleIntSet::Set(const int* values, size_t size) {
  ...
}

int main() {
  SimpleIntSet int_set;
  int_set.Set(...);
  return 0;
}
```

Building Multi-file Project

- Give all source files to the compiler.

```
$ g++ -o my_example my_example.cc main.cc
```

- Compile the source files first, then link the object files.

```
$ g++ -c my_example.cc main.cc
$ g++ -o my_example my_example.o main.o
```

- Make a library with the source files, then link the library.

```
$ g++ -c my_example.cc main.cc
$ ar rvs libmyex.a my_example.o
$ g++ -o my_example main.o libmyex.a    # OR -lmyex -L.
```

Example Header and Source

my_example.h

```
// my_example.h
// Author: jwlim

#ifndef MY_EXAMPLE_H_
#define MY_EXAMPLE_H_

#define MIN(a, b) ((a) < (b) ? (a) : (b))
extern int my_error_no;

enum {
  ERROR = 0, OK = 1, WARNING = 2
};

// Returns the squared sum of the array.
double SquaredSum(const double* array,
                  int n);
// Computes the norm of the vector.
double Norm(const double* array, int n);

#endif  // MY_EXAMPLE_H_
```

my_example.cc

```
// my_example.cc
// Author: jwlim

#include "my_example.h"
#include <math.h>

int my_error_no = 0;

double SquaredSum(const double* array,
                  int n) {
  int sqsum = 0;
  for (int i = 0; i < n; ++i) {
    sqsum += array[i] * array[i];
  }
  return sqsum;
}

double Norm(const double* array, int n) {
  return sqrt(SquaredSum(array, n));
}
```

Example Header and Source

my_example.h

```
// my_example.h
// Author: jwlim

#ifndef MY_EXAMPLE_H_
#define MY_EXAMPLE_H_

#define MIN(a, b) ((a) < (b) ? (a) : (b))
extern int my_error_no;

enum {
  ERROR = 0, OK = 1, WARNING = 2
};

// Returns the squared sum of the array.
double SquaredSum(const double* array,
                  int n);
// Computes the norm of the vector.
double Norm(const double* array, int n);

#endif  // MY_EXAMPLE_H_
```

my_example_main.cc

```
// main.cc
// Author: jwlim

#include <stdio.h>
#include <stdlib.h>
#include "my_example.h"

int main(int argc, const char** argv) {
  if (argc < 2) return 0;
  const int buflen = 10;

  // Q: will MIN(--argc, buflen) work?
  const int n = MIN(argc - 1, buflen);
  // Q: will 'double val[n];' compile?
  double val[buflen];
  for (int i = 0; i < n; ++i) {
    val[i] = atof(argv[i + 1]);
  }

  double norm = Norm(val, n);
  printf("norm = %.3f, error = %d\n",
         norm, my_error_no);
  return 0;
}
```

Command-line Arguments

- C/C++ main function may take additional input parameters.

```
int main();          // OR int main(void);
int main(int argc, char **argv);
int main(int argc, char *argv[]);
int main(int argc, char **argv, char **env); // UNIX
```

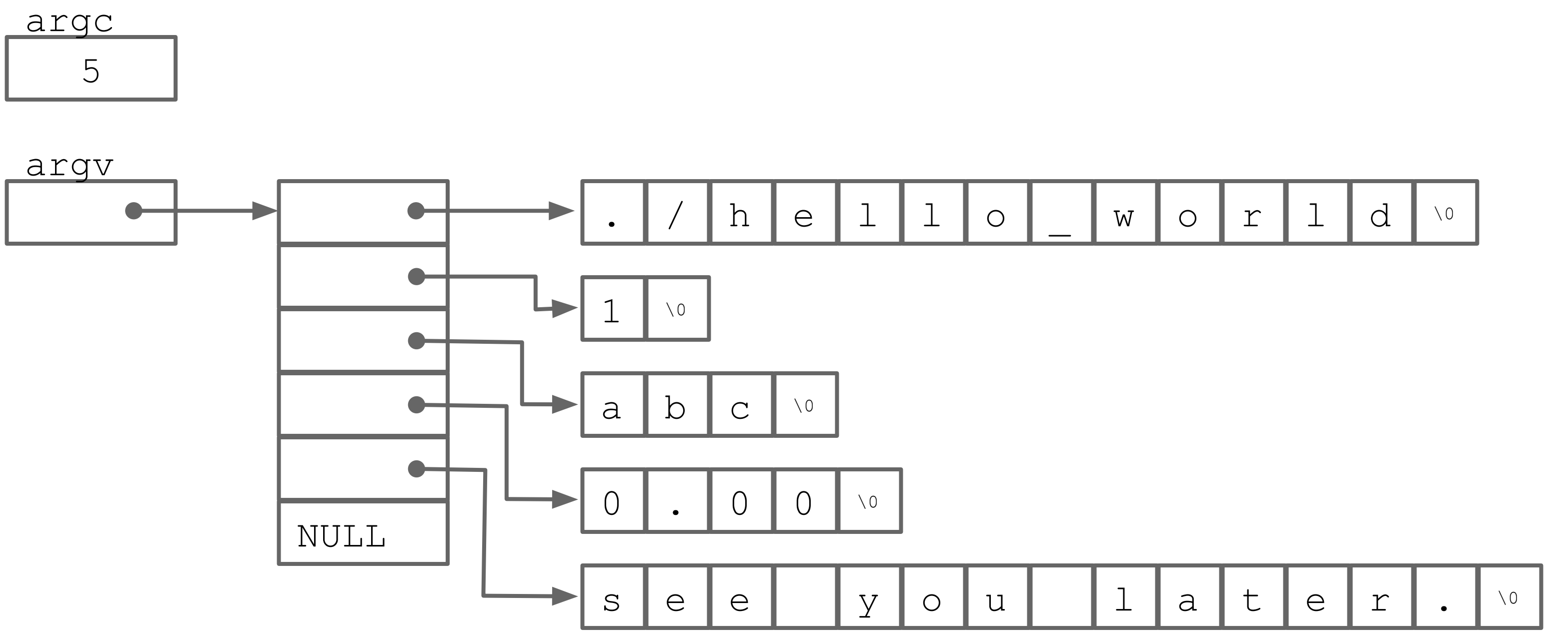
- When the program is executed the arguments are passed.

```
$ ./hello_world 1 abc 0.00 "see you later."

-> argc: 5
   argv[0]: "./hello_world"   argv[3] = "0.00"
   argv[1]: "1"                    argv[4] = "see you later."
   argv[2]: "abc"                  argv[5] = NULL
```

- The return value of the main function is the program's exit status.
  - EXIT_SUCCESS (typically 0) or EXIT_FAILURE.

Command-line Arguments

```
$ ./hello_world 1 abc 0.00 "see you later."

-> argc: 5
   argv[0]: "./hello_world"   argv[3] = "0.00"
   argv[1]: "1"                    argv[4] = "see you later."
   argv[2]: "abc"                  argv[5] = NULL
```



Command-line Arguments

- A simple program to print all command-line arguments.

```
#include <stdio.h>

int main(int argc, const char **argv) {
  for (int i = 0; i < argc; ++i) printf("%s\n", argv[i]);
  return 0;
}
```

- You may need string-to-number conversion.

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

int main(int argc, const char **argv) {
  for (int i = 1; i < argc; ++i) printf("%d\n", atoi(argv[i]));
  return 0;
}
```

Command-line Arguments

- The return value of the main function is the program's exit status.
    - EXIT_SUCCESS (typically 0) or EXIT_FAILURE.

- Where is this return value used?

```
$ command_a ; command_b       # Execute command_a then command_b.

$ command_a && command_b # Execute command_a AND IF IT IS SUCCESSFUL
                              # execute command_b.

$ command_a || command_b # Execute command_a AND IF IT FAILS
                              # execute command_b.
```

Summary

- Function declaration vs. definition
- Header files and source files
- Compiler, linker, preprocessor
- Command-line arguments