Functions and Header/Source files in C++

Based on materials by Dianna Xu and
Bjarne Stroustrup (www.stroustrup.com/Programming)

Declarations

- A declaration introduces a name into a scope.
- A declaration also specifies a type for the named object.
- Sometimes a declaration includes an initializer.
- A name must be declared before it can be used in a C++ program.
- Examples:
  - **int a = 7;** *// an int variable named 'a' is declared*
  - **const double cd = 8.7;** *// a double-precision floating-point constant*
  - **double sqrt(double);** *// a function taking a double argument and*
// returning a double result
  - **vector<Token> v;** *// a vector variable of* ***Token****s (variable)*

Declarations

- Declarations are frequently introduced into a program through “headers”
  - A header is a file containing declarations providing an interface to other parts of a program
- This allows for abstraction – you don’t have to know the details of a function like **cout** in order to use it. When you add

```
#include "../../std_lib_facilities.h"
```

to your code, the declarations in the file **std_lib_facilities.h** become available (including **cout** etc.).

Definitions

A declaration that (also) fully specifies the entity declared is called a definition

- Examples

```
  int a = 7;
  int b;                          // an int with the default value (0)
  vector<double> v;               // an empty vector of doubles
  double sqrt(double) { … };      // i.e. a function with a body
  struct Point { int x; int y; };
```

- Examples of declarations that are not definitions

```
double sqrt(double);              // function body missing
struct Point;                     // class members specified elsewhere
extern int a;                     // extern means "not definition"
                                  // "extern" is archaic; we will hardly use it
```

Declarations and definitions

- You can’t *define* something twice
  - A definition says what something is
  - Examples

```
int a;                           // definition
int a;                           // error: double definition
double sqrt(double d) { … }      // definition
double sqrt(double d) { … }      // error: double definition
```

- You can *declare* something twice
  - A declaration says how something can be used

```
int a = 7;                       // definition (also a declaration)
extern int a;                    // declaration
double sqrt(double);             // declaration
double sqrt(double d) { … }      // definition (also a declaration)
```

Why both declarations and definitions?

- To refer to something, we need (only) its declaration
- Often we want the definition "elsewhere"
  - Later in a file
  - In another file
    - preferably written by someone else
- Declarations are used to specify interfaces
  - To your own code
  - To libraries
    - Libraries are key: we can' t write all ourselves, and wouldn' t want to
- In larger programs
  - Place all declarations in header files to ease sharing

Functions

- Function: Unit of operation
  - A series of statements grouped together
- Must have the **`main`** function
- Write *small* functions!
- Most programs contain multiple function definitions

Functions

- General form:
  - **return_type** ***name*** **(*formal arguments*);** *// a declaration*
  - **return_type** ***name*** **(*formal arguments*)** ***body*** *// a definition*
  - For example

    double f(int a, double d) { return a*d; }
- Formal arguments are often called parameters
- If you don' t want to return a value give **void** as the return type

  void increase_power(int level);
  - Here, **void** means "don' t return a value"
- A body is a block or a try block
  - For example

    { */* code */* **}** *// a block*

    try { */* code */* **} catch(exception& e) {** */* code */* **}** *// a try block*
- Functions represent/implement computations/calculations

Identify Repeated Code

```
int main() {
  int choice;

  printf("=== Expert System ===\n");
  printf("Question1: ...\n");
  printf(
    "1. Yes\n"
    "0. No\n"
    "Enter the number corresponding to your choice: ");
  scanf("%d", &choice);

  if (choice == 1) { /* yes */
    printf("Question 2: ...\n");
    printf(
      "1. Yes\n"
      "0. No\n"
      "Enter the number corresponding to your choice: ");
    scanf("%d", &choice);
  /* skipped */
```

Identify Repeated Code

```
int menuChoice() {
  int choice;
  printf(
    "1. Yes\n"
    "0. No\n"
    "Enter the number corresponding to your choice: ");
  scanf("%d", &choice);
  return choice;
}

int main() {
  int choice;

  printf("=== Expert System ===\n");
  printf("Question1: ...\n");
  choice = menuChoice();

  if (choice == 1) { /* yes */
    printf("Question 2: ...\n");
  choice = menuChoice();
  /* skipped */
```

Identify Similar Code

```
int main() {
  int choice;  double km, mile;
  scanf("%d", &choice);

  switch (choice) {
  case 1:
    printf("Enter a mile value: ");
    scanf("%lf", &mile);
    km = mile * 1.6;
    printf("%f mile(s) = %f km\n", mile, km);
    break;

  caes 2:
    printf("Enter a km value: ");
    scanf("%lf", &km);
    mile = km / 1.6;
    printf("%f km = %f mile(s)\n", km, mile);
    break;

  default:
    printf("\n*** error: invalid choice ***\n");
  }
}
```

Similar unit

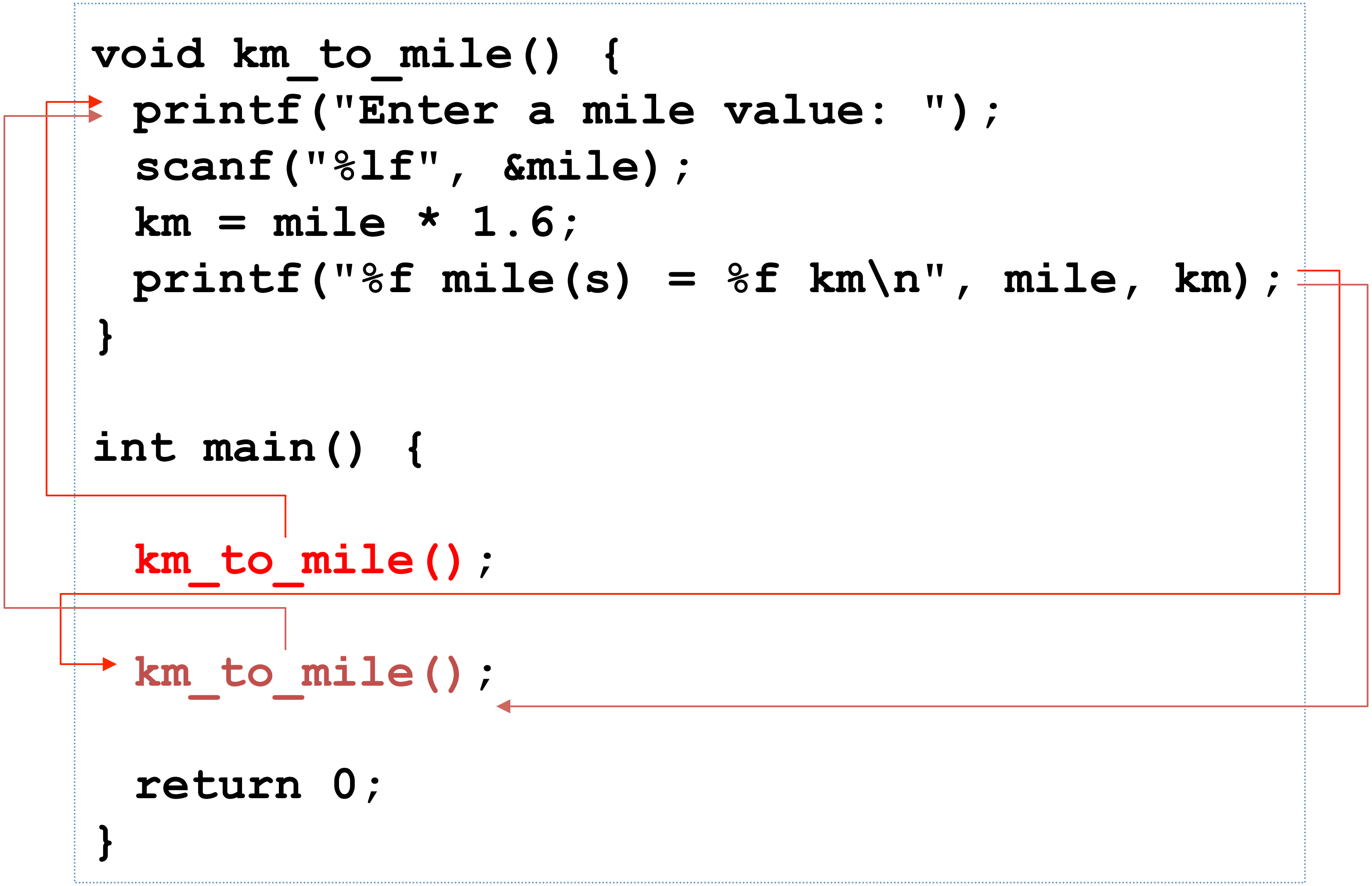
Similar unit

Use Parameters to Customize

```
void km_mile_conv(int choice) {
   int input;
   printf("Enter a %s value: ", choice==1?"mile":"km");
   scanf("%lf", &input);
   if (choice == 1)
      printf("%f mile(s) = %f km(s)\n", input, input*1.6);
   else
      printf("%f km(s) = %f mile(s)\n", input, input/1.6);
}
int main() {
   int choice;
   scanf("%d", &choice);
   switch (choice) {
   case 1:
      km_mile_conv(choice);
      break;
   case 2:
      km_mile_conv(choice);
      break;
   /* more cases */
   }
}
```

More readable `main`

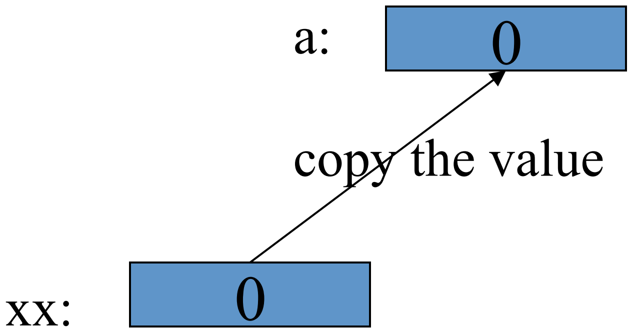
Function Call

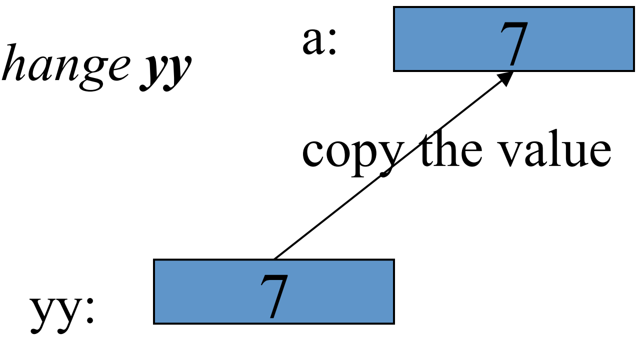


```
void km_to_mile() {
  printf("Enter a mile value: ");
  scanf("%lf", &mile);
  km = mile * 1.6;
  printf("%f mile(s) = %f km\n", mile, km);
}

int main() {

  km_to_mile();

  km_to_mile();

  return 0;
}
```

Functions: Pass by Value

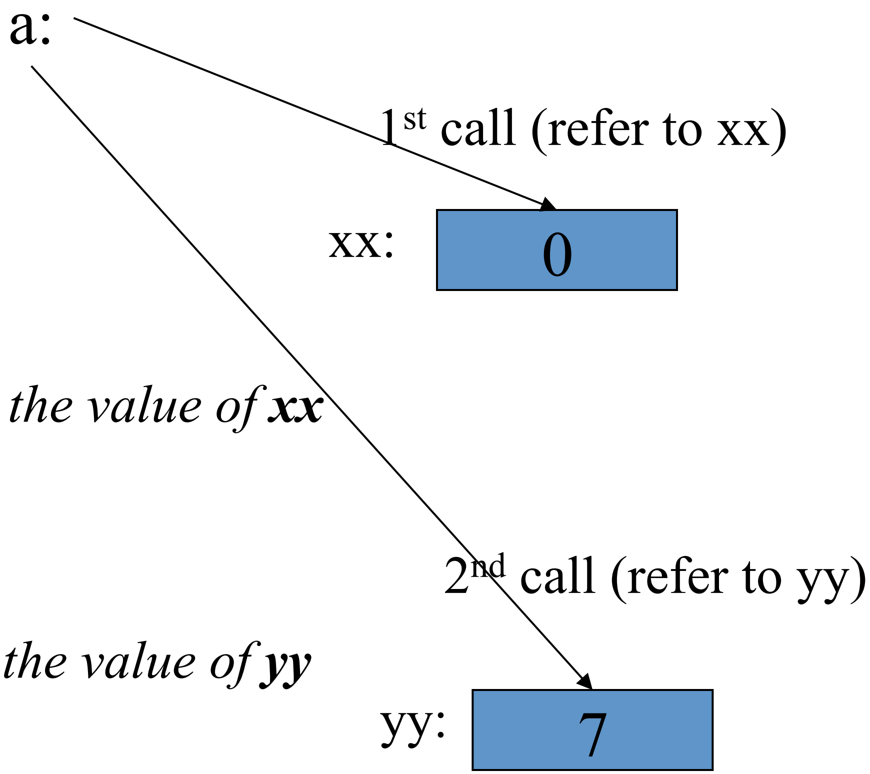
```
// pass-by-value (send the function a copy of the argument’s value)
int f(int a) { a = a+1; return a; }


int main()
{
    int xx = 0;
    cout << f(xx) << endl; // writes 1
    cout << xx << endl;    // writes 0; f() doesn’t change xx
    int yy = 7;
    cout << f(yy) << endl; // writes 8;  f() doesn’t change yy
    cout << yy << endl;    // writes 7
}
```





Functions: Pass by Reference

```
// pass-by-reference (pass a reference to the argument)
int f(int& a) { a = a+1; return a; }


int main()
{
    int xx = 0;
    cout << f(xx) << endl; // writes 1
                           // f() changed the value of xx
    cout << xx << endl;    // writes 1
    int yy = 7;
    cout << f(yy) << endl; // writes 8
                           // f() changes the value of yy
    cout << yy << endl;    // writes 8

}
```



a:

1st call (refer to xx)

xx: 0

2nd call (refer to yy)

yy: 7

Functions

- Avoid (non-const) reference arguments when you can
  - They can lead to obscure bugs when you forget which arguments can be changed

```
int incr1(int a) { return a+1; }
void incr2(int& a) { ++a; }
int x = 7;
x = incr1(x);// pretty obvious
incr2(x);      // pretty obscure
```

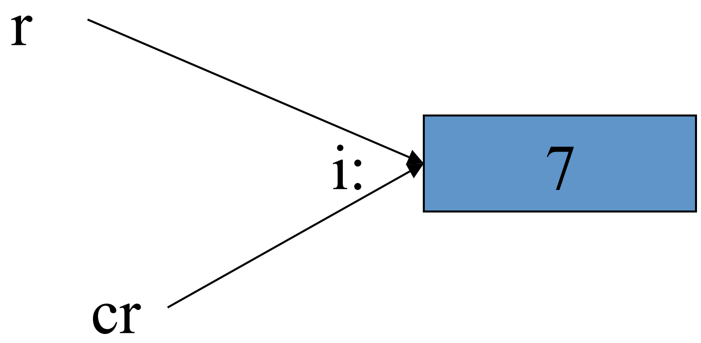
- So why have reference arguments?
  - Occasionally, they are essential
    - *E.g.,* for changing several values
    - For manipulating containers (*e.g.,* vector)
  - **const** reference arguments are very often useful
- Really, it's best just to learn to use pointers correctly and avoid references altogether

Pass by value/by reference/ by const-reference

```
void f(int a, int& r, const int& cr) { ++a; ++r; ++cr; } // error: cr is const
void g(int a, int& r, const int& cr) { ++a; ++r; int x = cr; ++x; } // ok

int main()
{
    int x = 0;
    int y = 0;
    int z = 0;
    g(x,y,z);   // x==0; y==1; z==0
    g(1,2,3);   // error: reference argument r needs a variable to refer to
    g(1,y,3);   // ok: since cr is const we can pass "a temporary"
}
// const references are very useful for passing large objects
```

References

- “reference” is a general concept
  - Not just for pass-by-reference



```
int i = 7;
int& r = i;
r = 9;                  // i becomes 9
const int& cr = i;
// cr = 7;              // error: cr refers to const
i = 8;
cout << cr << endl;    // write out the value of i (that’s 8)
```

- You can
  - think of a reference as an alternative name for an object
- You can’t
  - modify an object through a **const** reference
  - make a reference refer to another object after initialization

Guidance for Passing Variables

- Use pass-by-value for very small objects
- Use pass-by-const-reference for large objects
- Return a result rather than modify an object through a reference argument
- Use pass-by-reference only when you have to

- For example

```
class Image { /* objects are potentially huge */ };
void f(Image i);  … f(my_image);   // oops: this could be s-l-o-o-o-w
void f(Image& i); … f(my_image); // no copy, but f() can modify my_image
void f(const Image&); … f(my_image);  // f() won’t mess with my_image
```

Function Return and Parameters

- The syntax for C++ functions is the same as Java methods
- **`void`** keyword can be omitted

```
void km_to_mile(void) {

}

mile_to_km() {

}

int main() {
   int choice;
}
```

Use of `return` in `void` Functions

- Exit from the function

```
void getinput() {
  int choice;

  while (1) {
    scanf("%d", &choice);

    switch (choice) {
    case 1:
      /* some action */
      break;
    case 0:
      return; /* exit from getinput */
    }
  }
}
```

Function Prototype

- A prototype is a function declaration which includes the return type and a list of parameters
- A way to move function definitions after **`main`**
- Need not name formal parameters

```
/*  function prototypes  */
double km2mile(double);
double mile2km(double);
int main() {
}
/*  actual function definitions  */
double km2mile(double k) {

}
double mile2km(double m) {

}
```

Documenting Functions

- A comment for each function
- Use descriptive function name, parameter names

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

/* truncate a value to specific precision */
double truncate(double val, int precision) {
  double adj = pow(10, precision);
  int tmp;

  tmp = (int) (val * adj);
  return tmp / adj;
}

int main() {
}
```

Keep **`main`** Uncluttered

- Your **`main`** function should consist mainly of function calls
- One main input loop or conditional is okay
- Write your **`main`** and choose your function name in such a way so that
  - the main algorithm and program structure is clearly represented
  - the reader can get an idea how your program works simply by glancing at your **`main`**

Scope

- A scope is a region of program text
  - Examples
    - Global scope (outside any language construct)
    - Class scope (within a class)
    - Local scope (between { … } braces)
    - Statement scope (e.g. in a for-statement)
- A name in a scope can be seen from within its scope and within scopes nested within that scope
    - After the declaration of the name ("can't look ahead" rule)
- A scope keeps "things" local
    - Prevents my variables, functions, etc., from interfering with yours
    - Remember: real programs have **many** thousands of entities
    - Locality is good!
      - Keep names as local as possible

Scope

```
#include "std_lib_facilities.h"          // get max and abs from here
                                          // no r, i, or v here
class My_vector {
    vector<int> v;                        // v is in class scope
public:
    int largest()                         // largest is in class scope
    {
     int r = 0;                           // r is local
     for (int i = 0; i<v.size(); ++i)         // i is in statement scope
          r = max(r,abs(v[i]));
                                          // no i here
     return r;
    }
                                          // no r here
};
                                          // no v here
```

Scopes nest

```
int x;     // global variable – avoid those where you can
int y;     // another global variable

int f()
{
    int x;           // local variable (Note – now there are two x’s)
    x = 7;           // local x, not the global x
    {
     int x = y;      // another local x, initialized by the global y
                     // (Now there are three x’s)
     x++;            // increment the local x in this scope
    }
}

// avoid such complicated nesting and hiding: keep it simple!
```

Local/Global Variables

- Variables declared *inside* a function are local
- Function arguments are local to the function passed to
- A global variable is a variable declared *outside* of any function.
- In a name conflict, the local variable takes precedence
- When local variable shadows function parameter?

```
int x = 0;
int f(int x) {
   int x = 1;
   return x;
}

int main() {
   int x;
   x = f(2);
}
```

Scope of Global Variables

- The scope of a global variable starts at the point of its definition.
- Globals should be used with caution
  - Avoid changing a global inside a function
  - Change a global by setting it the return value of a function
  - If using globals at all, declare them at the top.

```
int x;
int f() {
}

int y;
int g(){
}

int main() {

}
```

Storage Classes

- `auto`
  - The default – life time is the defining function
  - De-allocated once function exits
- `static` (w.r.t. local variables)
  - Life time is the entire program – defined and initialized the first time function is called only
  - Scope remains the same

```
void f() {
   static int counter = 0;
   counter++;
}
```

`static`: globals and functions

- Using the keyword **`static`** in front of a global or a function changes the linkage, that is, the scope across multiple files.
- **`static`** changes the linkage of an identifier to *internal*, which means shared within a single (the current) file
- We will discuss more of linkage and related keywords, as well as header files when we discuss multiple source files

Namespaces

- Consider this code from two programmers Jack and Jill

```
class Glob { /*…*/ };           // in Jack's header file jack.h
class Widget { /*…*/ };         // also in jack.h

class Blob { /*…*/ };           // in Jill's header file  jill.h
class Widget { /*…*/ };         // also in jill.h


#include "jack.h";              // this is in your code
#include "jill.h";              // so is this

void my_func(Widget p)          // oops! – error: multiple definitions of Widget
{
  // …
}
```

Namespaces

- The compiler will not compile multiple definitions; such clashes can occur from multiple headers.
- One way to prevent this problem is with namespaces:

```
namespace Jack {                        //  in Jack’s header file
    class Glob{ /*…*/ };
    class Widget{ /*…*/ };
}

#include "jack.h";                      // this is in your code
#include "jill.h";                      // so is this

void my_func(Jack::Widget p)            // OK, Jack’s Widget class will not
{                                       // clash with a different Widget
  // …
}
```

Namespaces

- A namespace is a named scope
- The :: syntax is used to specify which namespace you are using and which (of many possible) objects of the same name you are referring to
- For example, **cout** is in namespace **std**, you could write:

```
std::cout << "Please enter stuff… \n";
```

using Declarations and Directives

- To avoid the tedium of
  - **std::cout << "Please enter stuff… \n";**

  you could write a "using declaration"
  - **using std::cout;** // *when I say* ***cout****, I mean* ***std::cout***"
  - **cout << "Please enter stuff… \n";** // *ok: std::cout*
  - **cin >> x;** // *error: cin not in scope*

- or you could write a "using directive"
  - **using namespace std;** // *"make all names from* ***std*** *available"*
  - **cout << "Please enter stuff… \n";** // *ok: std::cout*
  - **cin >> x;** // *ok: std::cin*

- More about header files later

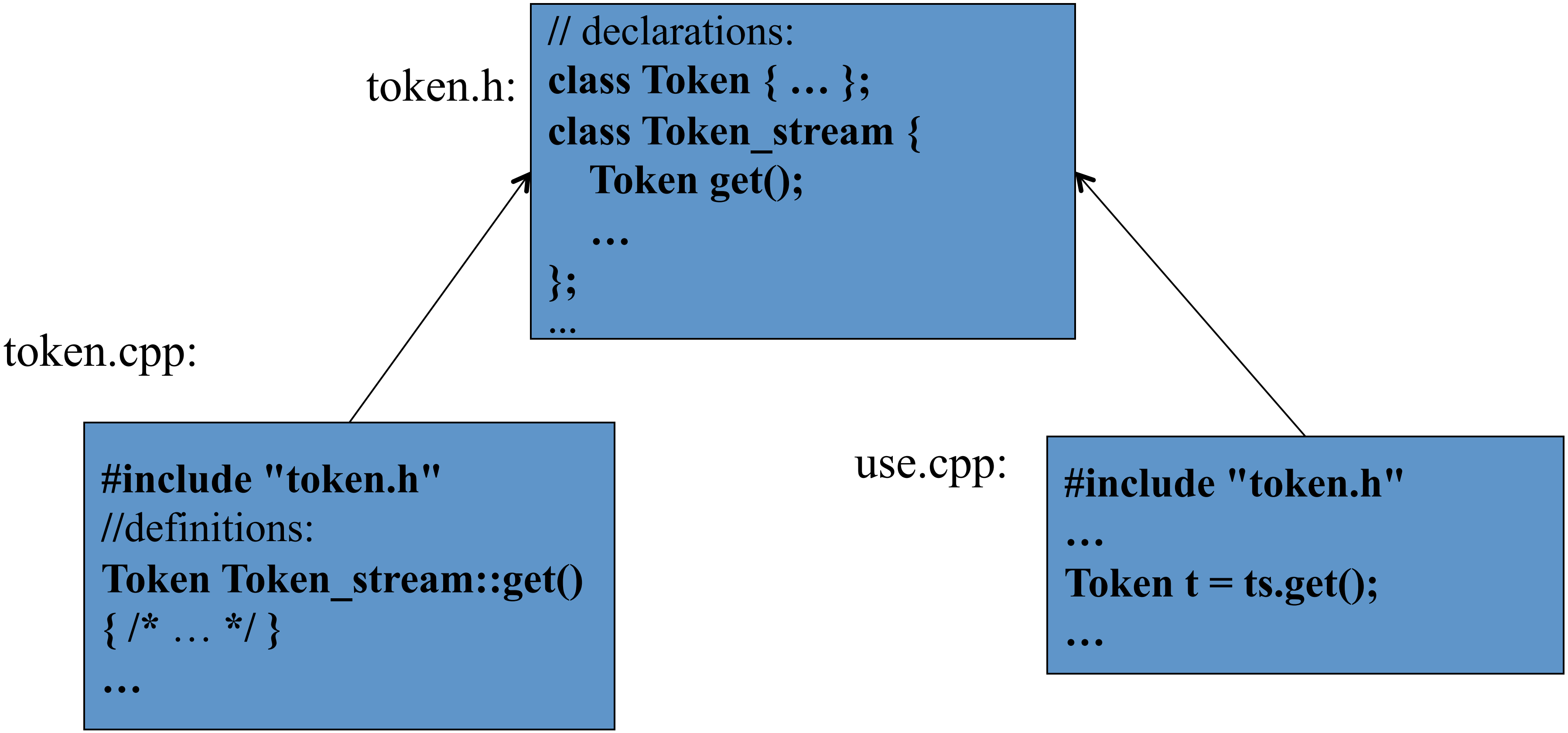
Header Files and the Preprocessor

- A header is a file that holds declarations of functions, types, constants, and other program components.
- The construct

  #include "../../std_lib_facilities.h"

  is a “preprocessor directive” that adds declarations to your program
  - Typically, the header file is simply a text (source code) file
- A header gives you access to functions, types, etc. that you want to use in your programs.
  - Usually, you don’t really care about how they are written.
  - The actual functions, types, etc. are defined in other source code files
    - Often as part of libraries

Source files



token.h:

```
// declarations:
class Token { … };
class Token_stream {
    Token get();
    …
};
…
```

token.cpp:

```
#include "token.h"
//definitions:
Token Token_stream::get()
{ /* … */ }
…
```

use.cpp:

```
#include "token.h"
…
Token t = ts.get();
…
```

- A header file (here, **token.h**) defines an interface between user code and implementation code (usually in a library)
- The same **#include** declarations in both **.cpp** files (definitions and uses) ease consistency checking

Header Files

- Contains a collection of function prototypes, constant and preprocessor definitions
- Named with extension **`.h`**
- By convention carries the same name as the associated **`.cpp`** file
  - **`hw1.h`** → **`hw1.cpp`**
- Included in the source file with **`#include`**
  - **`#include <stdio.h>`**
  - **`#include "hw1.h"`**
- A way to use functions defined in other source files

The Preprocessor

- A piece of software that processes C/C++ programs before compilation
- Preprocessor commands begin with a **`#`**
  - **`#include`** – includes a named file
  - **`#define`** – defines a (text replacement) *macro*
  - **`#ifdef/#else/#endif -`** conditional compilation

```
#ifdef MACRONAME
 part 1
#else
 part 2
#endif
```

`#define`

- Often used to define constants
  - `#define TRUE 1 #define FALSE 0`
  - `#define PI 3.14159`
  - `#define SIZE 20`
- Offers easy one-touch change of scale/size
- **`#define`** vs constants
  - The preprocessor directive uses no memory
  - **`#define`** may not be local

`#define` makes it more readable

```
#include<stdio.h>
#define MILE 1
#define KM   2

void km_mile_conv(int choice) {
  // …
  if (choice == MILE)
  // …
}
int main() {
  // …
  switch (choice) {
  case MILE:
    km_mile_conv(choice);
    break;
  caea KM:
    km_mile_conv(choice);
    break;
  /* more cases */
  }
}
```

Longer Macros

- Use the comma operator to create longer and more sophisticated macros

-
  ```
  #define ECHO(c)
  (c=getchar(), putchar(c))
  ```
- Use in program

```
 char c;
 while(1)
   ECHO(c);
```

Conditional Compiling

- Debugging (so that you don't have to remove all your **`printf`** debugging!)

```
#ifdef DEBUG
  // lots and lots of printfs
#else
  // nothing often omitted
#endif
```

- Portability

```
#ifdef  WINDOWS
// code that only works on windows
#endif
```

Defining a Macro for **#ifdef**

- **#define DEBUG**
- **#define DEBUG 0**
- **#define DEBUG 1**
- The **–Dmacro[=def]** flag of **g++**
  - **g++ -DDEBUG hw1.cpp -o hw1**
  - **g++ -DDEBUG=1 hw1.cpp -o hw1**
  - **g++ -DDEBUG=0 hw1.cpp -o hw1**

#ifndef, **#if**, **#elif**, **#else**

- **#ifndef** is the opposite of **#ifdef**
- **#if DEBUG**
  - Test to see if **DEBUG** is non-zero
  - If using **#if**, must use **#define DEBUG 1**
  - Undefined macros are considered to be **0**.
- **#elif MACRONAME**

```
#if WINDOWS
 //included if WINDOWS is non-zero
#elif LINUX
 //included if WINDOWS is 0 but LINUX is non-zero
#else
 //if both are 0
#endif
```

Predefined Macros

- Useful macros that primarily provide information about the current compilation
  - **`__LINE__`** Line number of file compiled
  - **`__FILE__`** Name of file being compiled
  - **`__DATE__`** Date of compilation
  - **`__TIME__`** Time of compilation
- **`printf("Comipiled on %s at %s.\n", __DATE__, __TIME__);`**

#error

- **#error message**
  - prints **message** to screen
  - often used in conjunction with **#ifdef**, **#else**

```
#if WINDOWS
//...
#elif LINUX
//...
#else
#error OS not specified
#endif
```

Program Organization

- **`#include`** and **`#define`** first
- Globals if any
- Function prototypes, unless included with header file already
- **`int main()`** – putting your **`main`** before all other functions makes it easier to read
- The rest of your function definitions

Math Library Functions

- Requires an additional header file

  ```
  #include <math.h>
  ```

- Must compile with additional flag **`-lm`**
- Prototypes in math.h
  - `double sqrt(double x);`
  - `double pow(double x, double p);` x^p
  - `double log(double x);` (natural log, base e)
  - `double sin(double x)`
  - `double cos(double x)`