# Object-Oriented Programming and Data Structures

# COMP2012: Data Abstraction & Classes

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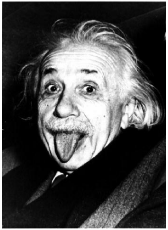
# Part I

## What is Data Abstraction?



$\Longrightarrow$

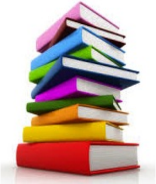
# Data Abstraction: What is a Chair?





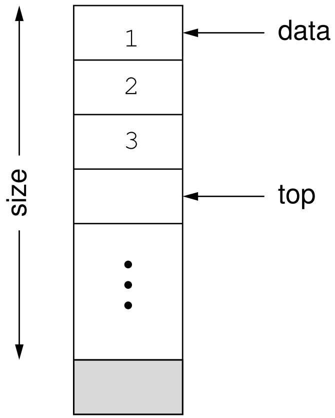



# Data Abstraction: What is a Stack?

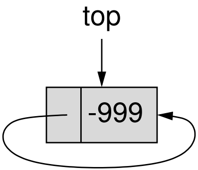



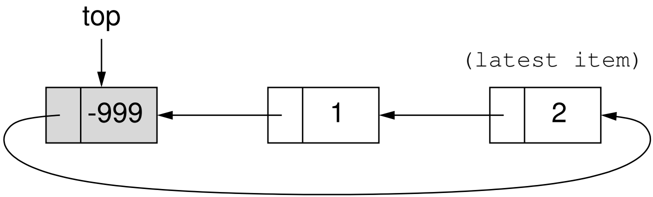
- A data abstraction is a simplified view of an object that includes only features one is interested in while hides away the unnecessary details.
- In programming languages, a data abstraction becomes an abstract data type or a user-defined type.
- In OOP, it is implemented as a class.

# Example: Implement a Stack with an Array



# Example: Implement a Stack with a Linked List



# Information Hiding

- An abstract specification tells us the behavior of an object independent of its implementation.
- It tells us what an object does independent of how it works.
- Information hiding is also known as data encapsulation, or representation independence.

**The Principle of Information Hiding**

Design a program so that the implementation of an object can be changed without affecting the rest of the program.

- E.g., changing the implementation of a stack from an array to a linked list has no effect on users' programs.

# Example: stack.h

```
#include <iostream>                                      /* File: stack.h */
#include <cstdlib>
using namespace std;
const int BUFFER_SIZE = 5;

class Stack
{
  private:
    int data[BUFFER_SIZE];                        // Use an array to store data
    int top_index;                            // Starts from 0; -1 when empty

  public:
    // CONSTRUCTOR member functions
    Stack( );                                            // Default constructor
    // ACCESSOR member functions: const => won't modify data members
    bool empty( ) const;                            // Check if the stack is empty
    bool full( ) const;                              // Check if the stack is full
    int size( ) const;                 // Give the number of data currently stored
    int top( ) const;                       // Retrieve the value of the top item
    // MUTATOR member functions
    void push(int);                         // Add a new item to the top of the stack
    void pop( );                               // Remove the top item from the stack
};
```

# Structure vs. Class

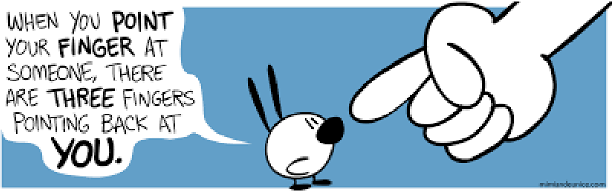
```
const int BUFFER_SIZE = 5;                          /* File: stack-struct.h */

struct Stack
{
    int data[BUFFER_SIZE];                      // Use an array to store data
    int top_index;                           // Starts from 0; -1 when empty

    Stack( );                                         // Default constructor
    bool empty( ) const;                         // Check if the stack is empty
    bool full( ) const;                           // Check if the stack is full
    int size( ) const;               // Give the number of data currently stored
    int top( ) const;                      // Retrieve the value of the top item
    void push(int);                       // Add a new item to the top of the stack
    void pop( );                          // Remove the top item from the stack
};
```

- In C++, structures are special classes and they can have member functions.
- By default,

$$\text{struct } \{ \ldots \}; \equiv \text{class } \{ \text{ public: } \ldots \};$$
$$\text{class } \{ \ldots \}; \equiv \text{struct } \{ \text{ private: } \ldots \};$$

Part II

# C++ Class Basics & this Pointer



# Class Name: Name Equivalence

- A class definition introduces a new abstract data type.
- C++ relies on name equivalence (and not structure equivalence) for class types.

```
class X { int a; };
class Y { int a; };
class W { int a; };
class W { int a; };                    // Error, double definition

X x;
Y y;

x = y;                                 // Error: type mismatch
```

# Class Data Members

Data members can be any basic type, or any user-defined types if they are already declared.

Below are special cases:

- A class name can be used in its own definition for its pointers:

  ```
  class Cell { int info; Cell *next; ... };
  ```

- A forward declaration for class pointers:

  ```
  class Cell;                                    // Forward declaration
  class Stack
  {
      int size;
      Cell* data;   // Points to an object with forward declaration
      Cell x;                           // Error: Cell not defined yet!
  };
  ```

# Data Members Cannot be Initialized In Class Definition

```
class Stack
{
    ...
    // Error: data member cannot be initialized
    // inside class definition
    int top_index = 0;
};
```

Initialization should be done with appropriate

- constructors, or
- member functions

of the class.

# Class Member Functions

- These are the functions declared inside the body of a class.
- They can be defined in two ways:

1. Within the class body, then they are inline functions. The keyword inline is optional in this case.

```
class Stack
{
    ...
    void push(int x) { if (!full( )) data[++top_index] = x; }
    void pop( ) { if (!empty( )) --top_index; }
};
```

Or,

```
class Stack
{
    ...
    inline void push(int x) { if (!full( )) data[++top_index] = x; }
    inline void pop( ) { if (!empty( )) --top_index; }
};
```

2. Outside the class body, then add the prefix consisting of the class name and the class scope operator ::
(Any benefits of doing this?)

```
/* File: stack.h */
class Stack
{
    ...
    void push(int x);
    void pop( );
};

/* File: stack.cpp */
void Stack::push(int x) { if (!full( )) data[++top_index] = x; }
void Stack::pop( ) { if (!empty( )) --top_index; }
```

Question: Can we add data and function declarations to a class after the end of the class definition?

# Class Scope and Scope Operator ::

- C++ uses lexical (static) scope rules: the binding of name occurrences to declarations are done statically at compile-time.
- Identifiers declared inside a class definition are under its scope.
- To access the public members (data or functions) explicitly, prefix the identifier with the class scope operator ::
- e.g., std::cin, Stack::push

```
int height;
class Weird
{
    short height;
    Weird( ) { height = 0; }
};
```

Q1: Which "height" is used in Weird::Weird()?

Q2: Can we access the global height inside the Weird class body?

# Inline Functions

- Function calls are expensive because when a function is called, the operating system has to do a lot of things behind the scene to make that happens.

```
int f(int x) { return 4*x*x + 9*x + 1; }
int main( ) { int y = f(5); }
```

- For small functions that are called frequently, it is actually more efficient to unfold the function codes at the expense of program size (both source file and executable).

```
int main( ) { int y = 4*5*5 + 9*5 + 1; }
```

- But functions has the benefit of easy reading, easy maintenance, and type checking by the compiler.
- You have the benefits of both by declaring the function inline.

```
inline int f(int x) { return 4*x*x + 9*x + 1; }
int main( ) { int y = f(5); }
```

- When you define a member function inside a class, it is treated as an inline function.
- *However*, C++ compilers may not honor your inline declaration.
- The inline declaration is just a hint to the compiler which still has the freedom to choose whether to inline your function or not, especially when it is large!

# Inline Class Member Functions

- Class member functions can be defined inside the class body and are automatically treated as inline functions.
- To enhance readability, one may also define them outside the class definition but in the same header file.

```
/* File: stack1.h */
class Stack
{
    ...
    inline void pop( )
    {
        if (!empty( ))
            --top_index;
    }
};
```

```
/* File: stack2.h */
class Stack
{
    ...
    inline void push( );
};

inline void Stack::pop( )
{
    if (!empty( )) --top_index;
}
```

# Member Access Control

A member of a class can be:

1. public: accessible to anybody (class developer and application programmers)
2. private: accessible only to
   - member functions and
   - friends of the class

   $\Rightarrow$ class developer enforces information hiding
3. protected: accessible to
   - member functions and friends of the class, as well as
   - member functions and friends of its derived classes (subclasses)

   $\Rightarrow$ class developer restricts what subclasses may directly use (more about this when we talk about inheritance)

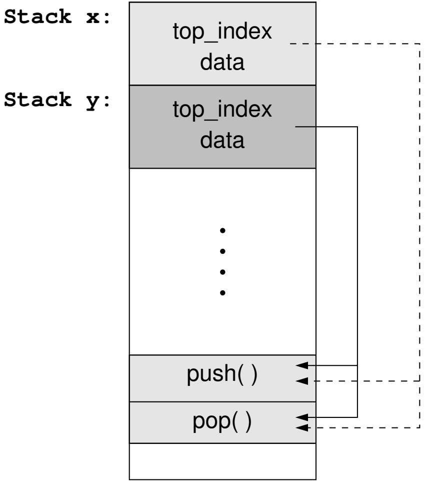
# Example: Member Access Control

```
class Stack
{
  private:
    int data[BUFFER_SIZE];
    int top_index;
  public:
    void push(int);
    ...
};

int main( )
{
    Stack x;
    x.push(2);                          // OK: push( ) is public
    cout << x.top_index;                // Error: cannot access top_index
    return 0;
}
```

# How Are Objects Implemented?

- Each class object gets its own copy of the class data members.
- All objects of the same class share one copy of the member functions.

```
int main( )
{
    Stack x(2), y(3);

    x.push(1);
    y.push(2);
    y.pop( );
}
```



# This Pointer

- Each class member function implicitly contains a pointer of its class type named "this".
- When an object calls the function, this pointer is set to point to the object.
- For example, after compilation, the Stack::push(int x) function in the Stack class will be translated to a unique global function by adding a new argument:

```
void Stack::push(Stack* this, int x)
{
    if (!this->full( ))
        this->data[++(this->top_index)] = x;
}
```

- a.push(x) becomes push(&a, x).

# Example: Return an Object by (*this)

```
class Complex                                          /* File: complex.cpp */
{
  private:
    float real; float imag;
  public:
    Complex(float r, float i) { real = r; imag = i; }
    Complex add(const Complex& x)         // Addition of complex numbers
    {
        real += x.real;
        imag += x.imag;
        return *this;
    }
};

int main( )
{
    Complex x(1, 2);
    Complex y(3, 4);
    Complex z = x.add(y);
    return 0;
}
```

# File Organization and Separate Compilation

- Suppose you want to write an application using a class called Picture.
- The class developer usually give you 2 files
  - class header file, "picture.h": the class interface
  - class library, "libpicture.a": a binary file consisting of the compiled code of the Picture class' implementation (of constructors, destructor, and other member functions)
- You, the application programmer need to
  - include the Picture class header file in your application programs.
  - link your object files with the Picture class library to produce the final executable.
- In this course, for simplicity, usually we assume that you will be both the class developer and the application programer, and you have the class implementation source files (e.g., picture.cpp).

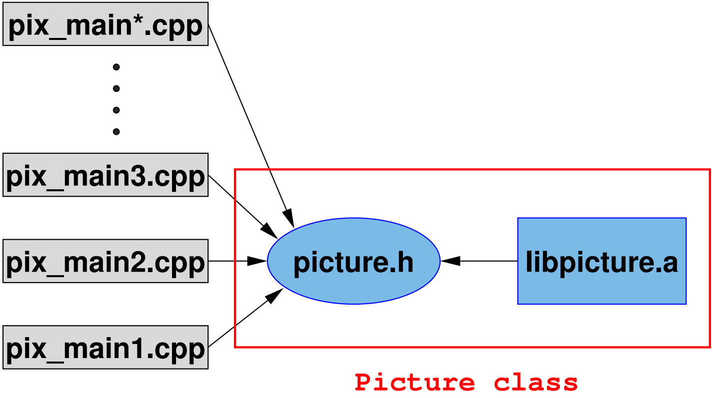
# File Organization and Separate Compilation ..

```
/* picture.h */
class Picture
{
    // ...
    Picture* frame(const Picture&);
}
```

```
/* picture.cpp */
#include "picture.h"

Picture* frame(const Picture& x)
{
    ABC_Picture* p
        = new Frame_Picture(x);
    return new Picture(p);
}
// ...
```

```
/* program.cpp */
#include "picture.h"

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

# Separate Compilation



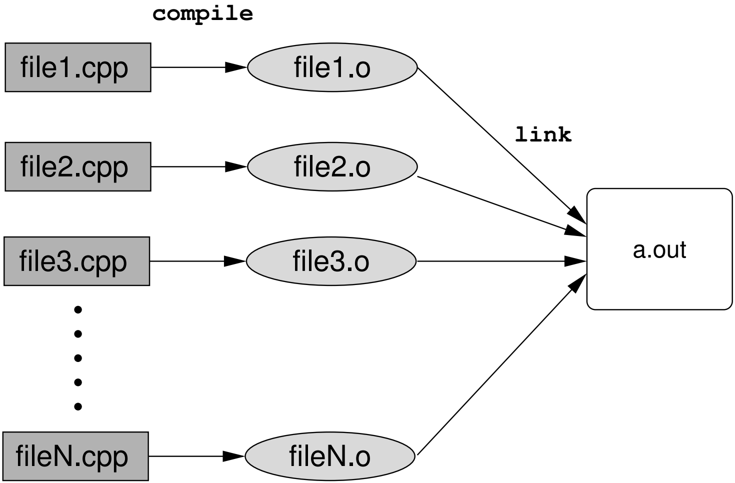
# Example: Separate Compilation

- In Linux, compile the program with the GNU C++ compiler as follows:

  ```
  g++ -c program.cpp
  g++ -c picture.cpp
  g++ -o program program.o picture.o
  ```

- g++ has many options; man g++ for details.
- The first two lines with "-c" option create the object files "program.o" and "picture.o". They can't run on their own.
- The last line creates the executable program called "program" (with the "-o" option) by linking the object files together.
- Linker: is a program that binds together separately compiled codes.

# Linking Object Files



- If "program.cpp" is changed but "picture.cpp" is not, then the second line is not necessary and you just need:

```
g++ -c program.cpp
g++ -o program program.o picture.o
```

- The separate compilation process can be simplified using "make" on a "Makefile".
- If you don't want the ".o" files, you may compile as follows:

```
g++ -o program program.cpp picture.cpp
```

  But then you don't get the object files, "program.o" and "picture.o", but only the executable "program".

# Libraries

- If you use any functions declared in the standard C++ header files (iostream, string, etc.), to produce a working executable, the linker needs to include their codes, which can be found in the standard C++ libraries.
- A library is a collection of object files.
- The linker selects object codes from the libraries that contain the definitions for functions used in the program files, and includes them in the executable.
- Some libraries, such as the standard C++ library, are searched automatically by the C++ linker.
- Other libraries have to be specified by the user during the linking process with the '-l" option.

  e.g., To link with the standard math library "libm.a",

  ```
  g++ -o myprog myprog.o -lm
  ```

# Preprocessor Directives: #include

- Besides statements allowed in a programming language, some useful program development features are added via directives.
- Directives are handled by a program called preprocessor before the source code is compiled.
- In C++, preprocessor directives begin with the # sign in the very first column.
- The #include directive reads in the contents of the named file.

```
#include <iostream>
#include "myfile.h"
```

- < > are used to include standard header files which are searched at the standard library directories.
- " " are used to include user-defined header files which are searched first at the current directory.
- "g++ -I" may be used to change the search path.

# #ifndef, #define, #endif

```
/* program.h */      /* b.h */          /* c.h */
#include "b.h"       #include "a.h"     #include "a.h"
#include "c.h"       #include "d.h"     #include "e.h"
...                  ...                ...
```

Since #include directives may be nested, the same header file may be included twice!

- multiple processing ⇒ waste of time
- re-definition of #define constants/macros

Thus, the need of conditional directives

```
#ifndef PICTURE_H
#define PICTURE_H
// object declarations, class definitions, functions
#endif                                        // PICTURE_H
```