C++ Overview (1)

COS320

Heejin Ahn
(heejin@cs.princeton.edu)

Introduction

- Created by Bjarne Stroustrup
- Standards
  - C++98, C++03, C++07, C++11, and C++14
- Features
  - Classes and objects
  - Operator overloading
  - Templates
  - STL (Standard Template Library)
  - …
- Still widely used in performance-critical programs
- This overview assumes that you know C and Java

C++ is a Federation of Languages

from [3]

- C
  - Mostly backward compatible with C
  - Blocks, statements, preprocessor, built-in data types, arrays, pointers, …
- Object-Oriented C++
  - Classes, encapsulation, inheritance, polymorphism, virtual functions, …
- Template C++
  - Paradigm for generic programming
- STL (Standard Template Library)
  - Generic library using templates
  - Containers, iterators, algorithms, function objects …

Topics

- Today
  - Heap memory allocation
  - References
  - Classes
  - Inheritance
- Next time
  - Operator overloading
  - I/O streams
  - Templates
  - STL
  - C++11

Heap allocation: new and delete

from [1]

- new/delete is a type-safe alternative to malloc/free
- new T allocates an object of type T on heap, returns pointer to it
  - `Stack *sp = new Stack();`
- new T[n] allocates array of T's on heap, returns pointer to first
  - `int *stk = new int[100];`
  - By default, throws exception if no memory
- delete p frees the single item pointed to by p
  - `delete sp;`
- delete[] p frees the array beginning at p
  - `delete[] stk;`
- new uses T's constructor for objects of type T
  - need a default constructor for array allocation
- delete uses T's destructor ~T()
- use new/delete instead of malloc/free and never mix new/delete and malloc/free

References

- Controlled pointers
- When you need a way to access an object, not a copy of it
- In C, we used pointers
  - `int var = 3;`
  - `int *pvar = &var;`
  - `*pvar = 5; // now var == 5`
- In C++, references attach a name to an object
  - `int var  = 3;`
  - `int &rvar  = var;`
  - `rvar = 5; // now var == 5`
- Unlike pointers, you can't define a reference without an object it refers to
  - `int &x;` (X)

Call-by-Reference

- Call-by-reference allows you to modify arguments
  - Now you can implement swap() function using call-by-reference

```
void swap(int *x, int *y) {
  int temp;
  temp = *x;
  *x = *y;
  *y = temp;
}

swap (&a, &b);
```

```
void swap(int &x, int &y) {
  int temp;
  temp = x;
  x = y;
  y = temp;
}

// pointers are implicit
swap(a, b);
```

Call-by-Value / Call-by-Reference

- Call-by-value
  - By default, C/C++'s uses call-by-value
  - If you pass an object using call-by-value, it causes the object to copy, which is inefficient if it is large
- Call-by-reference
  - In effect, you just pass the address of an object
  - Call-by-const-reference additionally guarantees that the object will not be modified during the call
  - Java function call is similar to call-by-reference
    - Java actually passes pointers internally

```
// call-by-reference
void foo(Stack &s) {
  …
}

Stack s;
foo(s); // s can be modified in foo
```

```
// call-by-const-reference
void foo(const Stack &s) {
  …
}

Stack s;
foo(s); // s is guaranteed to stay the same
```

Constness

- Way to say something is not modifiable

from [3]

```
char greeting[] = "Hello";
char *p = greeting; // non-const pointer, non-const data
const char *p = greeting; // non-const pointer, const data
char * const p = greeting; // const pointer, non-const data
const char * const p = greeting; // const pointer, const data
```

```
// Objects ‘a’ references or ‘b’ points to cannot be modified in this function
void foo(const Stack &a, const Stack *b);

// For class member member method
// This does not modify any status of ‘this’ object
void Stack::size() const;
```

C++ Classes

from [1]

Don’t miss ‘;’

```
class Thing {
public:
  methods and variables accessible from all classes
protected:
  methods and variables accessible from this class and child classes
private:
  methods and variables only visible to this class
};
```

- defines a data type 'Thing’
  - can declare variables and arrays of this type, create pointers to them, pass them to functions, return them, etc.
- Object: an instance of a class variable
- Method: a function defined within the class

Stack Class in C++

from [1]

```
// simple-minded stack class
class Stack {
public:
  Stack(); // constructor decl
  int push(int);
  int pop();
private: // default visibility
  int stk[100];
  int *sp;
};

Stack::Stack() { // constructor implementation
  sp = stk;
}
int stack::push(int n) {
  return *sp++ = n;
}
int stack::pop() {
  return *--sp;
}

Stack s1, s2; // calls constructors
s1.push(1); // method calls
s2.push(s1.pop());
```

Constructors

```
class Student {
public:
  Student(const string &n, double gpa) {
     name = n;
     this->gpa = gpa; // when a member variable name and a parameter name are the same
  }
private:
  string name;
  double gpa;
};
```

- Creates a new object
- Construction includes initialization, so in may be parameterized like other methods
  - You can have multiple constructors with different parameters
- If you don’t define any constructors, a default constructor will be generated
  - `Student() {}`
- ‘this’ is a pointer – so you need ‘->’ to refer to it

Constructors

```
class MyClass {
public:
  MyClass(int arg) { … }
  MyClass(int arg1, arg2) { … }
  …
};

// These call constructor and create objects on the stack
MyClass m1(100);
MyClass m2 = 100;
MyClass m3(100, 300);

// These call constructor and create objects on the heap
MyClass *m4 = new MyClass(100);
MyClass *m5 = new MyClass(100, 300);

// You can omit () when you call the default constructor (if there is one)
MyClass m6; // equivalent to 'MyClass m6();'
MyClass *m7 = new MyClass; // equivalent to 'MyClass *m7 = new MyClass();'
```

'explicit' Keyword

- Compiler does automatic type-conversion for one-argument constructors
  - When this is a constructor:
    - `MyClass(int arg);`
  - This creates a temporary object and assigns it to m
    - `MyClass m = 5;`
- It is sometimes not what we want; to prevent this, use 'explicit' keyword
  - `explicit MyClass(int arg);`

```
// When this can be desirable
class string {
public:
  string(const char *s);
};

string str = "Hello world"; // Good!
```

```
// When this is not desirable
class vector {
public:
  vector(int size);
};

vector v = 5; // Oh no! Use 'explicit'
```

Inline Functions

- Inlined functions are copied into callers' body when compiled
  - Can prevent function call overhead
  - Can increase code size
- 'inline' directive suggests the function is to be inlined
  - So inline functions should be available at compile time (not link time) – they should exist in the same source file or any other header files included
  - But the final inlining decision is on compiler
- Member functions defined within a class have the same effect

```
class Student {
public:
  void setGPA(double gpa) {
    this->gpa = gpa;
  }
  …
};
```

```
class Student {
public:
  void setGPA(double gpa);
  …
};
inline void setGPA(double gpa) {
  this->gpa = gpa;
}
```

Two are Same!

Accessors vs. Mutators

- Mutators can alter the state (= non-static member variables) of an object, while accessors cannot
- Accessors have 'const' at the end of the signature

```
class Student {
public:
  …
  void setGPA(double gpa) { this->gpa = gpa; } // mutator
  double getGPA() const { return gpa; } // accessor
  …
};
```

Initializer Lists

```
class Student {
public:
  // This calls default constructor for string
  // first and then assigns new string 'n' to
  // it again
  Student(const string &n, double gpa) {
    name = n;
    this->gpa = gpa;
  }
private:
  string name;
  double gpa;
};
```

```
class Student {
public:
  // This calls constructor for string only
  // once
  Student(const string &n, double gpa)
    : name(n), gpa(gpa) {}

private:
  string name;
  double gpa;
};
```

- Initialization lists are more efficient
  - Only call constructors once
  - Difference is small for primitive data types
- You have to use initializer lists for some variables
  - Class objects that do not have default (= no argument) constructors
  - Reference variables
    - They cannot be created without the target they refer to

Default Parameters

- Specifies default values for function parameters
- Included in the function declaration

from [2]

```
void printInt(int n, int base=10);

printInt(50); // equivalent to 'printInt(5, 10);', outputs 50
printInt(50, 8); // outputs 62 (50 in octal)
```

from [2]

The Big Three

- Copy Constructor
  - `MyClass(const MyClass &rhs)`
  - Special constructor to construct a new object as a copy of the same type of object
- operator=
  - `operator=(const MyClass &rhs)`
  - Copy assignment operator
  - Applied to two already constructed objects
- Destructor
  - `~MyClass()`
  - Destroys an existing object
  - If you have some member variables that are 'new'ed, you should delete them here
  - Called when
    - An object on the stack goes out of scope ({})
    - An object on the heap is deleted using 'delete'
- If you don't write these by yourself, default ones will be generated by compiler
  - Write these only if you want to do some additional tasks

The Big Three

```
class Student {
public:
  // Normal constructor
  Student(const string &name, double gpa) : name(name), gpa(gpa) {
    someObj = new MyClass();
  }

  // Copy constructor
  Student(const Student &rhs) : name(rhs.name), gpa(rhs.gpa) {
    someObj = new MyClass();
  }

  // Destructor
  ~Student() { delete someObj; }

  // operator=
  operator=(const Student &rhs) {
    name = rhs.name;
    gpa = rhs.gpa;
    someObj = MyClass(rhs.someObj); // Calls copy constructor of MyClass
  }

private:
  string name;
  double gpa;
  MyClass *someObj;
};
```

The Big Three

```
void someFunction() {

// Calls the normal constructor
Student jane("Jane", 3.0); // stack
Student *pJane = new Student("Jane", 3.0); // heap

// Calls the copy constructor
Student tom(jane); // stack
student *pTom = new Student(jane); // heap

// Calls the operator=()
tom = jane;
*pTom = *pJane;

// Calls the destructor for heap objects
delete pJane;
delete pTom;

} // At this point the destructor for stack objects (jane and tom) are called
```

Friends

- Way to grant private member access to specific classes/functions

from [2]

```
class ListNode {
private:
  int element;
  ListNode *next;
  ListNode(int element, ListNode *next=NULL) : element(element), next(next) {}

  friend class List; // friend class
  friend int someFunction(); // friend methods
};

class List {
public:
  List() {
    head = new ListNode(); // can call ListNode's private constructor
  }
private:
  ListNode *head;
};

int someFunction() { … }
```

The `struct` Type

- A class in which the members default to public
  - In a class, the members default to private
- Unlike C, you don't need a 'struct' keyword to refer to a struct type, because it is now a 'class'

```
struct MyClass {
  MyClass(int arg) { … }
  …
};

MyClass m(100);
```

Namespaces

- C++ equivalent of Java packages

```
namespace myspace {
class Student { … };
class Professor { … };
}

// Refers to student class with the namespace name
myspace::Student s;
myspace::Professor p;

// This allows you to use 'Student' without the namespace name
using myspace::Student;
Student s;
myspace::Professor p;

// This allows you to use everything in myspace without the namespace name
using myspace;
Student s;
Professor p;
```

Incomplete Class Declaration

- Unlike Java, the order of class declaration matters
  - If class B is declared after class A, class A does not know about class B
  - But sometimes class A needs to know (at least) the existence of class B
    - ex) A has B's pointer as a member and B has A's pointer too
- Solution: incomplete class declaration
  - We can incompletely declare class B before class A
  - The only thing class A knows about B is its existence; A does not know about B's members or B's object size because B's full declaration is below A

Incomplete Class Declaration

```
class B; // incomplete class declaration

class A { // Now A knows B's existence
public:
  void foo1(B *b); // OK
  void foo2(B &b); // OK
  void foo3(B b); // (X) Not OK! A does not know B's object size

  void bar(B *b) {
    b->baz(); // (X) Not OK! A does not know about B's members
  }
  B *data1; // OK
  B &data2; // OK
  B data3; // (X) Not OK! A does not know B's object size
};

class B {
public:
  void baz() { … }
  A *data;
};
```

Inheritance

- Basic syntax
  - `class Child : public Parent { … };`
  - Actually there are also private and protected inheritance – nevermind, you are not going to use them. Just don't forget to use 'public' keyword
- Calling base class constructor in initializer lists
  - `Child(int arg1, int arg2)`
    `: Parent(arg1), … { … }`
- Calling base class functions
  - `Parent::foo(…);`

Inheritance

from [2]

```
class Person {
public:
  Person(int ssn, const string &name) : ssn(ssn), name(name) {}
  const string &getName() const { return name; }
  int getSSN() const { return ssn; }
  void print() const { cout << ssn << ", " << name }

private:
  int ssn;
  string name;
};

class Student : public Person {
public:
  Student(int ssn, const string &name, double gpa) : Person(ssn, name), gpa(gpa) {}
  double getGPA() const { return gpa; }
  void print() const { Person::print(); cout << ", " << gpa; } // override

private:
  double gpa;
};
```

Dynamic Dispatch

- Java always uses the runtime type to decide which method to use
- But C++ uses the static type by default

```
Student s(123456789, "Jane", 4.0);
s.print();          // calls Student::print

Person &p1 = s;      // p1 and s are same object
p1.print();          // calls Person::print!

Person *p2 = &s;      // p2 points to s
p2->print();          // calls Person::print!
```

Virtual Functions

- You need a 'virtual' keyword to tell the compiler this function should use dynamic dispatch
- In Java, all functions are virtual functions

```
class Person {
public:
  …
  virtual void print() const { cout << ssn << ", " << name }
  …
};

class Student : public Person {
public:
  …
  virtual void print() const { Person::print(); cout << ", " << gpa; }
  …
};
```

This can be omitted in child class

from [2]

The Big Three Revisited

- In a subclass, the default Big Three are constructed if you don't explicitly define them
- Copy constructor
  – Invokes copy constructor on the base class(es)
  – And then invokes copy constructors on each of newly added members
- operator=
  – Invokes operator= on the base class(es)
  – And then invokes operator= on each of newly added members
- Destructor
  – Invokes destructors on each of newly added members
  – And then invokes destructor on the base class(es)

Virtual Destructor

- In a base class, the destructor should be declared virtual
  – Otherwise the base class portion of the object will not be deleted if it is deleted through base class pointer/reference

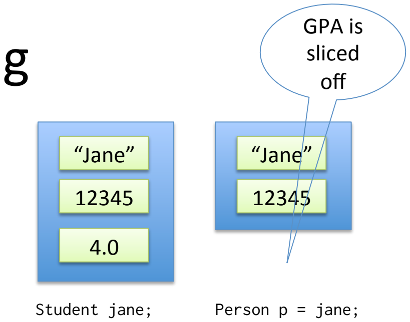
```
class Person {
public:
  …
  virtual ~Person() { … }
  …
};

Student *tom = new Student("123456", "Tom", 3.0);
Person *p = tom;

// If ~Person() is declared non-virtual, this will not delete the base class
portion of the object
delete p;
```

Abstract Methods and Classes

- C++ equivalent of Java abstract methods and classes
  - Abstract classes cannot be instantiated
- In C++, a method is abstract if:
  - It is declared virtual
  - The declaration is followed by =0
  - ex) `virtual double area() const = 0;`
- In C++, a class is abstract if:
  - It has at least one abstract method

Slicing

- You can access child classes by pointers and references of base classes
- But you can't use base classes objects to access child classes



from [2]

```
Student jane(12345, "Jane", 4.0);
Person p(54321, "Bob");
p = jane; // object is sliced!
p.print();

void print(Person p) { p.print(); }
print(jane); // call-by-value, so object is sliced!
```

Type Conversions

- C++-style casts
  - static_cast
    - Similar to C-style cast
  - dynamic_cast
    - Can only be used with pointers and references to classes (or with void*)
    - Performs a runtime check if the cast is correct; returns NULL if incorrect
  - const_cast
    - Manipulates the constness of the object pointed by a pointer, either to be set or to be removed
  - reinterpret_cast
    - Converts any pointer type to any other pointer type
    - Simple binary copy of the value from one pointer to the other
- LLVM-style casts
  - cast, dyn_cast, cast_or_null, dyn_cast_or_null

Type Conversions

```
class Base {};
class Derived: public Base {};

Base *pb = new Base;

// C-style cast
Derived *pd = (Derived*) pb;

// static_cast
Derived *pd = static_cast<Derived*>(pb);

// dynamic_cast
Derived *pd = dynamic_cast<Derived*>(pb); // returns NULL if failed
if (!pd) cout << "Type casting failed!";

// const_cast
void printStr (char *str) {
  cout << str << '\n';
}
const char *c = "Hello world";
printStr(const_cast<char*>(c)); // removes constness to pass it to printStr
```

Multiple Inheritance

- Don't use this unless you really need to…
  - Has many tricky aspects
  - You don't need to use this in your code in COS320
- We are not going to cover the details here

from [2]

```
class Person : public Printable, public Serializable { … };
class Student : virtual public Person { … };
class Employee : virtual public Person { … };
class StudentEmployee : public Student, public Employee { … };
```

References

- [1] Brian Kernighan, COS333 lecture notes, 2013.
- [2] Mark Allen Weiss, C++ for Java Programmers, Pearson Prentice Hall, 2004.
- [3] Scott Meyers, Effective C++ Third Edition, Addison-Wesley, 2005.