Object-Oriented Programming Languages

POLYMORPHISM

Read: Scott, Chapter 10.1-10.4

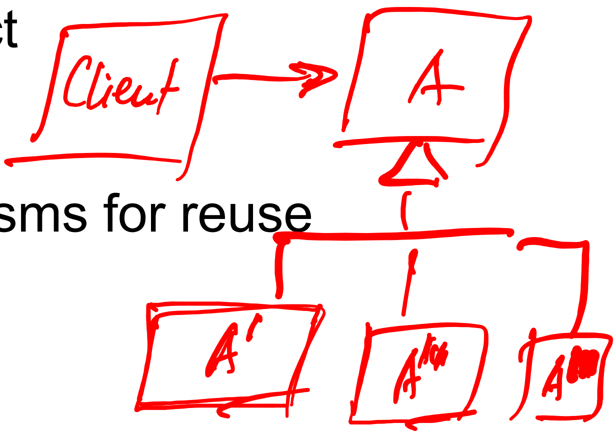
Lecture Outline

- Object-oriented programming
- Encapsulation and inheritance
- Initialization and finalization
- Subtyping and dynamic method binding

- Polymorphism

Benefits of Object Orientation

- Abstraction
  - Classes bridge the gap between concepts in the problem domain and software
  - E.g., domain concept of Customer maps to class Customer
- Encapsulation
  - Classes provide interface but hide data representation
  - Easier to understand and use
  - Can be changed internally with minimal impact
- Reuse
  - Inheritance and <u>composition</u> provide mechanisms for reuse
- Extensibility



Encapsulation and Inheritance

- Access control modifiers – public, private, and others
  - What portion of the class is visible to users?
  - Public, protected or private visibility
  - Java: Has package as default; protected is slightly different from C++
  - C++: Has friend classes and functions
  - Smalltalk and Python: all members are public
- With inheritance
  - What control does the superclass have over its fields and methods? There are different choices
  - C++: a subclass can restrict visibility of superclass members
  - C#, Java: a subclass can neither increase nor restrict visibility of superclass members

Initialization and Finalization

- Reference model for variables used in Java, Smalltalk, Python
  - Every variable is a reference to an object
  - Explicit object creation: foo b = new foo();
- Value model for variables used in C++, Modula-3, Ada-95
  - A variable can have a value that is an object
  - Object creation may be implicit: e.g. foo b;
- How are objects destroyed?

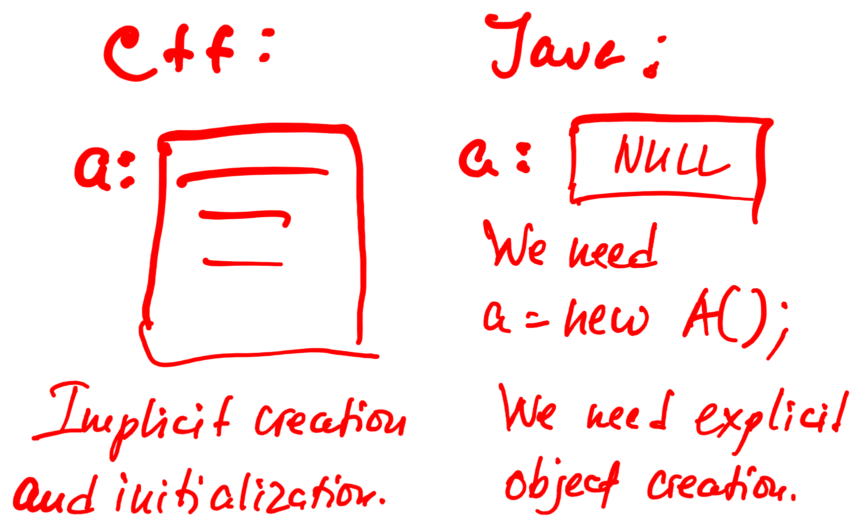
Question

- Consider the following code:

```
A a;      // a is a local variable of type A
a.m();    // We call method m on a
```

What happens in C++?

What happens in Java?



More on Implicit Creation in C++

- C++ requires that an appropriate constructor is called for every object implicitly created on the stack, e.g., **`A a;`**
- What happens here: **`foo a;`**
  - Compiler calls zero-argument constructor **`foo::foo()`**
- What happens here: **`foo a(10, ‘x’);`**
  - Calls **`foo::foo(int, char)`**

More on Implicit Creation in C++

- What happens here:

```
foo a;
foo c = a;
```

  - Calls `foo::foo()` at `foo a;` calls copy constructor `foo::foo(foo&)` at `foo c = a;`
  - `=` operator here stands for initialization, not assignment!

More on Implicit Creation in C++

- What happens here:

```
foo a, c;  // declaration
c = a;     // assignment
```

  - Calls `foo::foo()` twice at `foo a, c;` calls assignment operator `foo::operator=(foo&)` at `c = a;`
  - `=` operator here stands for assignment!

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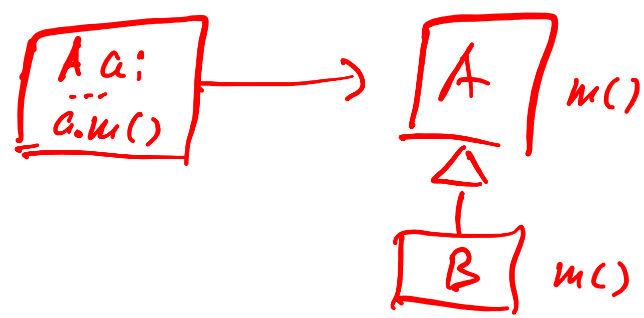
Subtyping and Dynamic Method Binding

- Subtyping and subtype polymorphism - the ability to use a subclass where a superclass is expected
- Thus, dynamic method binding (also known as dynamic dispatch) - the ability to invoke a new refined method in a context where an earlier version is expected
  - E.g., class B is a Java subclass of A
  - A a; … a.m();



Subtyping and Dynamic Method Binding

- Advantages? FLEXIBILITY, EXTENSIBILITY
- Disadvantages? PERFORMANCE PENALTY OF DISPATCH CODE

- C++: static binding is default, dynamic binding is specified with keyword virtual
- Java: dynamic binding is default, static binding is specified with final

Benefits of Subtype Polymorphism

- Covered extensively in Principles of Software
- Enables extensibility and reuse
  - E.g., we can extend a type hierarchy with no modification to the client of hierarchy
  - Reuse through inheritance or composition
- Subtype polymorphism enables the Open/closed principle (credited to Bertrand Meyer)
  - Software entities (classes, modules) should be open for extension but closed for modification

Example

- Application draws shapes on screen
- Possible solution in C

```
enum ShapeType { circle, square };
struct Shape { ShapeType t };
struct Circle
  { ShapeType t; double radius; Point center; };
struct Square
  { ShapeType t; double side; Point topleft; };
```

Example

```
void DrawAll(struct Shape *list[], int n) {
  int i;
  for (i = 0; i < n; i++) {
     struct Shape *s = list[i];
     switch (s->t) {
          case square: DrawSquare(s); break;
          case circle: DrawCircle(s); break;
          }
  }
}
```

What problems do you see here?

Example

- OO Solution in Java

```
abstract class Shape { public void draw(); }
class Circle extends Shape { … }
class Square extends Shape { … }

void DrawAll(Shape[] list) {
  for (int i=0; i < list.length; i++) {
     Shape s = list[i];
     s.draw();
  }
}
```

Benefits of Subtype Polymorphism

```
abstract class Shape { public void draw(); }
class Circle extends Shape { … }
class Square extends Shape { … }
class Triangle extends Shape { … }
```

Extending the Java code requires no changes in **`DrawAll`**! Thus, it is closed for modification.

Extending the C code triggers modifications in **`DrawAll`** (and likely many other DrawAll-like functions).

Benefits of Subtype Polymorphism

- "Science" of software design teaches **Design Patterns**
- Design patterns promote design for extensibility and reuse
- Nearly all design patterns make use of subtype polymorphism!

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Polymorphism

- Generally, refers to the mechanisms that a programming language provides, to allow for the same piece of code to be used with objects or values of multiple types
- Poly = many and morph = form
- Examples of polymorphism
  - Generic functions in Haskell
  - Templates in C++, generics in Java
  - Implicitly polymorphic foldl/foldr in Scheme
  - Other

Varieties of Polymorphism

- Subtype polymorphism
  - What we just discussed… Code can use a subclass **B** where a superclass **A** is expected
  - Standard in object-oriented languages
- Parametric polymorphism
  - Code has a type as parameter
  - Explicit parametric polymorphism
  - Implicit parametric polymorphism
  - Standard in functional programming languages
- Ad-hoc polymorphism (overloading)

Explicit Parametric Polymorphism

- Occurs in Ada, Clu, C++, Java, Haskell (type classes)
- There is an explicit type parameter
- Explicit parametric polymorphism is also known as genericity
- E.g. in C++: V is the explicit type parameter.

```
template<class V>
class list_node {
  list_node<V>* prev;
  …
}
```

```
template<class V>
class list {
  list_node<V> header;
  …
}
```

Explicit Parametric Polymorphism

- Usually (but not always!) implemented by creating multiple copies of the generic code, one for each concrete type

Code [int / V] : instantiate generic code with int argument

```
typedef list_node<int> int_list_node;
typedef list<int> int_list;
```

- Object-oriented languages usually provide both subtype polymorphism and explicit parametric polymorphism, which is referred to as generics

Explicit Parametric Polymorphism

- Generics are tricky…
- Consider this C++ code (uses the STL):

```
list<int> l;
sort(l.begin(), l.end());
```

  - Compiler produces around 2K of text of error messages, referring to code in the STL
  - The problem here is that the STL's `sort` requires a **RandomAccessIterator**, while the `list` container provides only a **Bidirectional Iterator**

On Concepts in C++ and Much More

- Thriving in a Crowded and Changing World: C++ 2006–2020
- By Bjarne Stroustrup

- https://dl.acm.org/doi/pdf/10.1145/3386320

In Java, Bounded Types Restrict Instantiations by Client

- Generic code can perform operations permitted by the bound

```
class MyList1<E extends Object> {
  void m(E p) {
    p.intValue();  //compile-time error; Object
                   //does not have intValue()
  }
}
class MyList2<E extends Number> {
  void m(E p) {
    p.intValue();//OK. Number has intValue()
  }
}
```

In Java, Bounded Types Restrict Instantiations by Client

- Instantiations respect the bound

```
class MyList2<E extends Number> {
  void m(E arg) {
    arg.intValue();//OK. Number has intValue()
  }
}
MyList2<String> ls = new MyList2<String>();
//compile-time error; String is not within
//bounds of E
MyList2<Integer> li = …
//OK. Integer is subtype of Number
```

In Haskell, Type Predicates Restrict Instantiation of Generic Functions

```
sum :: (Num a) => a -> List a -> a
sum n Nil = n
sum n (Cons x xs) = sum (n+x) xs
```

+ requires that x is an instance of Num.

- `a` is an explicit type parameter
- `(Num a)` is a predicate in type definition
- `(Num a)` constrains the types we can instantiate the generic function with

Implicit Parametric Polymorphism

- Occurs in Scheme, Python and others
- There is no explicit type parameter, yet the code works on many different types

- Usually, there is a single copy of the code, and all type checking is delayed until runtime
  - If the arguments are of type as expected by the code, code works
  - If not, code issues a type error at runtime

Implicit Parametric Polymorphism

twice in Scheme: (define (twice f x) (f (f x)))

Int -> Int   Int

(twice (lambda (x) (+ 1 x)) 1) yields ?

(Int -> Int) -> Int -> Int

type of f   type of x   type of result

--> (lambda (x) (+ 1 x)) ((lambda (x) (+ 1 x)) 1)

--> (lambda (x) (+ 1 x)) 2

--> yields 3

Implicit Parametric Polymorphism

twice in Scheme: (define (twice f x) (f (f x)))

(twice (lambda (x) (cons ‘a x)) ‘(b c)) yields ?

([Sym] → [Sym]) → [Sym] → [Sym]

yields (a a b c)

Implicit Parametric Polymorphism

twice in Scheme: (define (twice f x) (f (f x)))

(twice 2 3) yields ?

--> 2 (2 3)
--> bombs, 2 is not a function value

map, foldl, length are all implicitly parametric

Implicit Parametric Polymorphism

```
def intersect(seq1, seq2):
  res = [ ]
  for x in seq1:
    if x in seq2:
      res.append(x)
  return res
```

- As long as arguments for seq1 and seq2 are of iterable type, intersect works

Let Polymorphism

- A form of explicit parametric polymorphism
- Occurs in Haskell and in ML
  - Also known as ML-style polymorphism

let f = \x -> x in if (f True) then (f 1) else 0 1

--- f is a polymorphic function

--- At (f True) instantiates to bool->bool function

--- At (f 1) instantiates to int->int function

Let Polymorphism

let f = \x -> x in if (f True) then (f 1) else 0

- Informally, let polymorphism restricts polymorphism to functions defined at let bindings
- Disallows functions that take polymorphic functions as arguments
- Formally defined by Hindley Milner system
- Allows for type inference

Let Polymorphism

let f = \x -> x in if (f True) then (f 1) else 0

- Allows for a natural form of type inference
  - Inference "sees" the function definition at let binding before the call (use) of the function
  - Inference "generalizes" the type of the function
  - At each call in let expression body, inference replaces explicit type parameter with fresh var
- Cannot be done with a function argument

Let Polymorphism

- Contrast

(1) let f = \x -> x in if (f True) then (f 1) else 0 1

vs.

(2) (\f -> if (f True) then (f 1) else 0) (\x -> x) TYPE ERROR

- Let-bound vs. Lambda-bound polymorphism

The End