CS 430
Spring 2019

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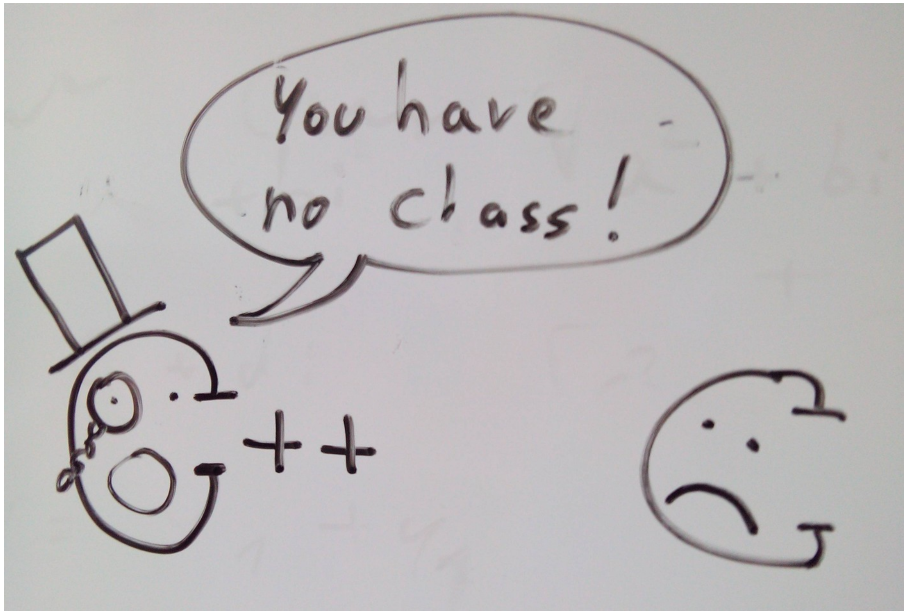
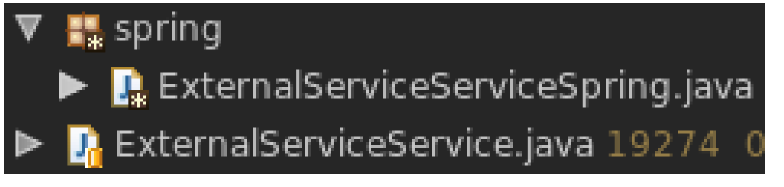


Abstraction and Object-Oriented Programming

Abstraction

- Abstraction is a fundamental concept in CS
- Textbook definition: "*a view or representation of an entity that includes only the most significant attributes*"
- Mathematical notion: "*equivalence classes*"
- Practical reality: the first line of defense against software complexity!
- Key: finding the most appropriate level of abstraction



org.apache.xmlrpc.server

Interface RequestProcessorFactoryFactory

All Known Implementing Classes:

RequestProcessorFactoryFactory.RequestSpecificProcessorFactoryFactory, RequestProcessorFactoryFactory.StatelessProcessorFactoryFactory

Types of abstraction

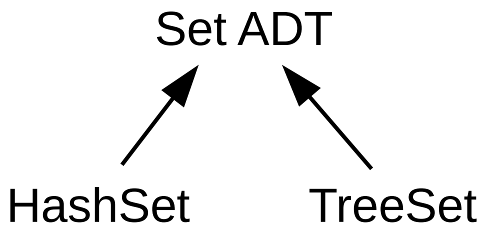
- Process abstraction
  - Structured (block) syntax
  - Subprograms and modules
- Data abstraction
  - Abstract data types and interfaces
    - Polymorphism and generics
  - Encapsulation and information hiding
    - Classes and objects
    - Inheritance

Abstract data types

- Abstract data type (ADT)
  - Set of values (carrier set)
  - List of supported operations
    - Common operations: constructor, accessors, iterators, destructors
  - Not specified: underlying representation
    - Exists purely as a mathematical construct
- Examples
  - List: `append(value), get(index), remove(index)`
  - Stack: `push(value), pop`
  - Set: `add(value), isMember(value), union(otherSet)`
  - Map: `store(key, value), lookup(key)`
  - Floating-point: `add, sub, mul, div, sqrt`

Abstract data types

- Concrete data type
  - Implementation of an ADT on a computer
  - Specifies value size and format
  - Often supports only a subset of values from the ADT
  - Most languages support user-defined concrete data types
- Examples (in Java)
  - List: `ArrayList`, `LinkedList`
  - Set: `HashSet`, `TreeSet`
  - Floating-point: `float`, `double`



Abstract data types

- Abstract data types can be implemented in **some** programming languages as data types
  - Easier w/ encapsulation mechanisms
  - Even easier w/ information hiding mechanisms
  - Information hiding implies encapsulation (but not converse)

Design issues

- Encapsulation: how is related code and data grouped?
  - Header files, namespaces, packages, modules, etc.
  - Structs, unions, classes, interfaces
  - Modularity and readability; extensibility and maintainability
- Information hiding: should underlying data be exposed?
  - Levels: public, private, protected
  - Public fields vs. getters and setters
  - Convenience/writability vs. safety and extensibility
- Polymorphism: is parameterization possible?
  - Specifying parameters
  - Specifying restrictions on the parameters
  - Power/expressivity vs. readability

Encapsulation

- Advantages
  - Organization
  - Separate compilation
  - Avoiding name collisions

- Physical vs. logical encapsulation
  - Contiguous vs. non-contiguous code

Encapsulation

	Physical	Logical
Naming	Java Class Java Package	Ruby Class Ada Package C++ Namespace Ruby Module
Non-naming	.c, .cpp, or .h file	
Grouping only	.h file	Ruby Module C++ Namespace
Information hiding	.c or .cpp file Java Class Java Package	Ruby Class Ada Package

Original table courtesy of Dr. Chris Fox

Object-oriented programming

- Inheritance
  - Original motivation: code re-use
  - Parent/superclass vs. child/derived/subclass
  - “Pure” vs. hybrid
  - Overriding methods
  - Single vs. multiple inheritance (simplicity vs. power)
  - Static vs. dynamic dispatch (speed vs. power)
  - Abstract methods and classes
  - Non-overridable methods: "final" methods in Java

Dispatch

```
public class DispatchTest1
{
    void foo(Object o) { System.out.println("foo(Object)"); }
    void foo(String s) { System.out.println("foo(String)"); }
    void bar(Object o) {
        foo(o);
    }
    public static void main(String[] args) {
        (new DispatchTest1()).bar("What gets run?");
    }
}
```

What will this program print?

Dispatch

```
public class DispatchTest1
{
    void foo(Object o) { System.out.println("foo(Object)"); }
    void foo(String s) { System.out.println("foo(String)"); }
    void bar(Object o) {
        foo(o);
    }
    public static void main(String[] args) {
        (new DispatchTest1()).bar("What gets run?");
    }
}

public class DispatchTest2
{
    static class A {
        void foo() { System.out.println("A.foo()"); }
    }
    static class B extends A {
        void foo() { System.out.println("B.foo()"); }
    }
    void bar(A a) {
        a.foo();
    }
    public static void main(String[] args) {
        (new DispatchTest2()).bar(new B());
    }
}
```

What about this one?

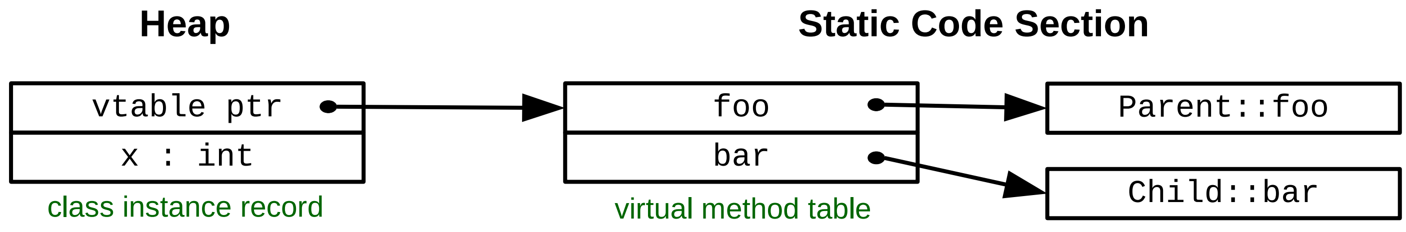
Dispatch

```
public class StaticDispatchTest
{
    void foo(Object o) { System.out.println("foo(Object)"); }
    void foo(String s) { System.out.println("foo(String)"); }
    void bar(Object o) {
        foo(o);
    }
    public static void main(String[] args) {
        (new StaticDispatchTest()).bar("What gets run?");
    }
}

public class DispatchTest3
{
    static class A {
        static void foo() { System.out.println("A.foo()"); }
    }
    static class B extends A {
        static void foo() { System.out.println("B.foo()"); }
    }
    void bar(A a) {
        a.foo();
    }
    public static void main(String[] args) {
        (new DispatchTest3()).bar(new B());
    }
}
```

How about now?

Object-oriented implementation

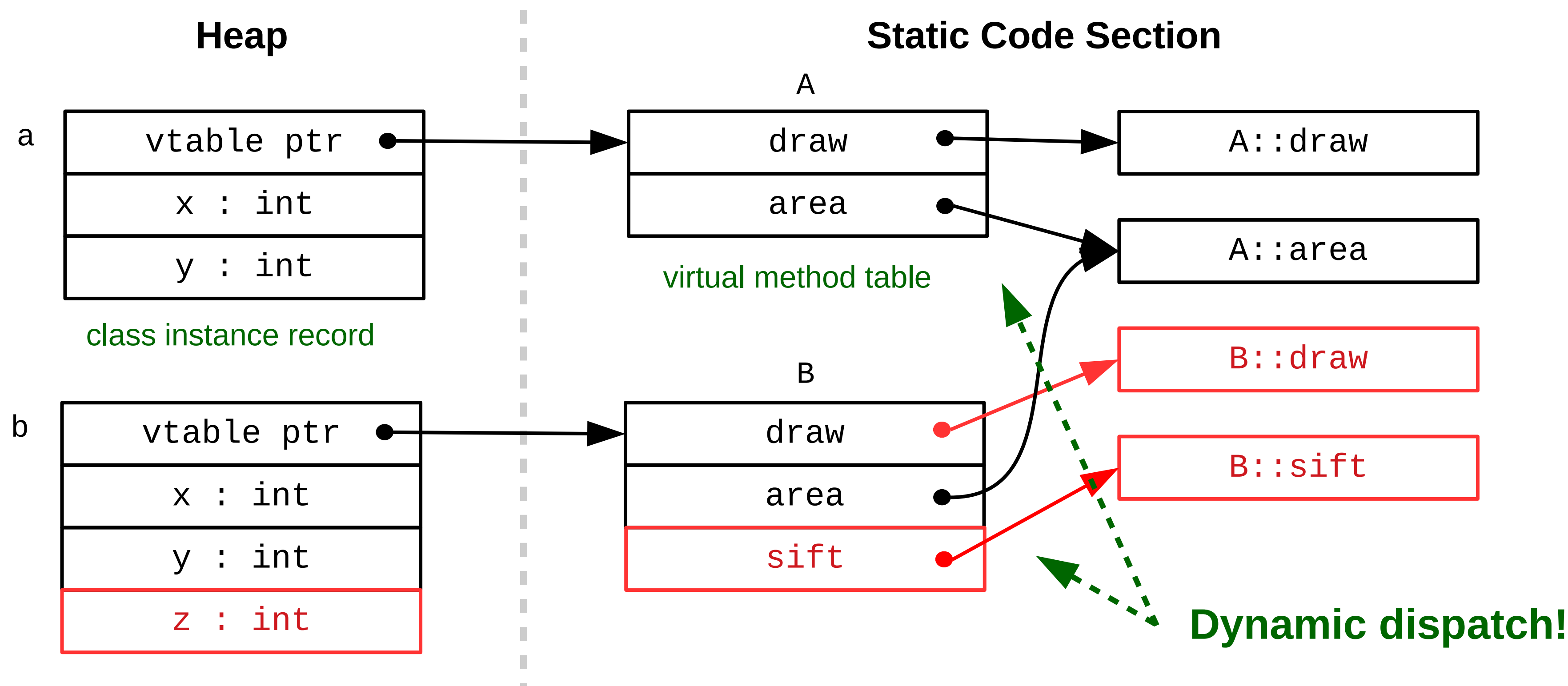
- Dispatch
  - Static dispatch: all method calls can be resolved at compile time
  - Dynamic dispatch: polymorphic method calls resolved at run time
  - Single vs. multiple dispatch (one object's type vs. multiple objects' type)
- Class instance record
  - List of member variables for objects w/ vtable pointer
  - Subclass CIR is a copy of the parents' with (potentially) added fields
- Virtual method table (*vtable*)
  - List of methods w/ pointers to implementations
  - Often implemented directly (no CIR) with a single VPTR member field



Object-oriented implementation

```
public class A {
    public int x, y;
    public void draw() { … }
    public int area() { … }
}

a = new A();
```

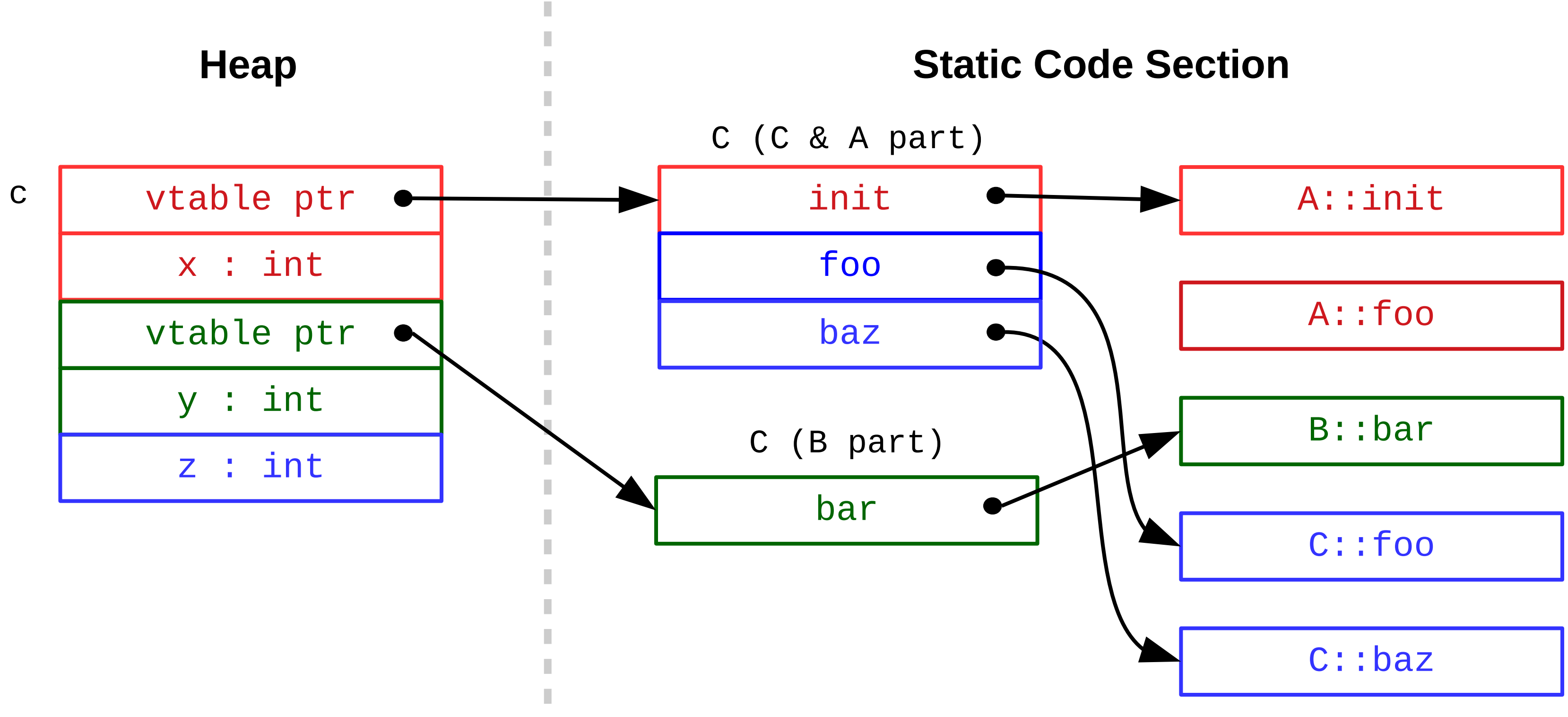
```
public class B extends A {
    public int z;
    public void draw() { … }
    public void sift() { … }
}

b = new B();
```



Multiple inheritance

```
class A {
  public:
    int x;
    virtual void init() { … }
    virtual void foo() { … }
}
class B {
  public:
    int y;
    virtual void bar { … }
}
```

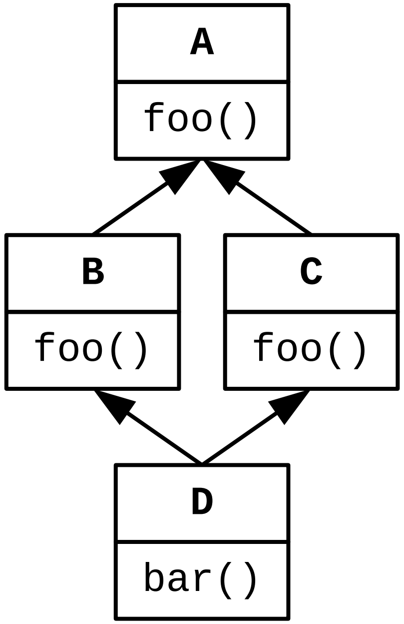
```
class C : public A, public B {
  public:
    int z;
    virtual void foo() { … }
    virtual void baz() { … }
}

c = new C();
```



Multiple inheritance

- Diamond problem
  - If D inherits from B and C with common ancestor A, and all except D implement method “foo,” which is called?

```
class D : public B, C {
  public:
    void bar() {
        foo();  // which foo?
    }
}
```



C++ solution: use ordering from definition
(so B’s foo here)

Java solution #1: only inherit interfaces
(so **no** foo here)

Java solution #2: compiler error
(Java 8 adds default methods for interfaces)

Inheritance and the stack

- How to handle class instance records on stack in case of copying to a superclass variable?
  - No space for subclass data
  - Object slicing: remove subclass data
  - Causes a loss of information!

```
class A { int x; }
class B inherits A { int y; }

B b = new B();
A a = b;            // copy; A's CIR is smaller
                    // b.y is lost!
                    // no way to cast a back
```

Templates vs. generics

- Templates (C++)
  - Compiles different versions w/ mangled names
- Generics (Java)
  - Type erasure: compiler changes generic type to Object and inserts runtime casts (expensive!)
  - No runtime difference between `HashSet<String>` and `HashSet<Integer>`
    - Example: no arrays of generics (array members must be type-checked at runtime)
  - Only one set of static member data

```
template <class T>
class Foo {
    T data;
  public:
    void bar(T x) {
        this.data = x;
    }
}
```

Templates in C++

```
class Foo<T> {
    T data;
    void bar(T x) {
        this.data = x;
    }
}
```

Generics in Java

Reflection

- A language with reflection provides runtime access to type and structure metadata
  - Sometimes with the ability to **modify** the structure
  - Often incurs a severe runtime penalty because of data structures required
- Examples:
  - Ruby: `methods` and `send`
  - Java: `java.lang.Class` and `java.lang.reflect.Method`

```
"Hello".send(
  "str".methods
       .grep(/upcase/)[0])
```

Reflection in Ruby

```
try {
    System.out.println("str".getClass()
                            .getMethod("toUpperCase")
                            .invoke("Hello"));
}
catch (NoSuchMethodException ex)     {}
catch (IllegalAccessException ex)    {}
catch (InvocationTargetException ex) {}
```

Reflection in Java

History of OOP

- Simula (1967): data abstractions for simulation and modeling
- Smalltalk (1980): objects and messages
- C++ (1985): originally “C with classes”
- Java (1995) and C# (2000): goal was “C++ but better”
- Ruby (1996): pure, dynamic OOP language
- Most modern languages have some form of OOP
  - Abstract data types
  - Inheritance
  - Dynamic binding

Abstraction in C++

- Classes and structs
- Stack or heap allocation
- Manual memory management: constructors and destructors
- Header file and implementation file
- Visibility: public (default for structs) or private (default for classes)
  - "Friend" functions for private access outside class
- All forms of polymorphism (parametric via **templates**)
- Static dispatch by default (override via “`virtual`” keyword)
- Multiple inheritance w/ resolution via inheritance order
- Namespaces for naming and encapsulation
- No reflection by default

Abstraction in Java

- Classes similar to C++
- Single inheritance tree (rooted at Object)
- No stack allocation (everything on heap)
- Automatic memory management
- Visibility modifiers required (`public`, `private`, `protected`, `package`)
- No separate header file
- All forms of polymorphism (parametric via **generics**)
- Dynamic dispatch by default (override via “`static`” keyword)
- Interfaces for pseudo-multiple inheritance
- Packages for naming and encapsulation
- Reflection via `java.lang.reflect` package

Abstraction in Ruby

- “Pure” OOP: everything is an object!
- Dynamic classes
- Members can be added/removed at run time
- Multiple definitions of a single class allowed
- Keywords for function visibility (public by default)
- All data is private
  - "@" symbol for instance variables
  - Attributes accessed through methods
- Polymorphism and dispatch via dynamic types; no overloading
  - “Duck” typing: if it has the required methods, it’s a valid parameter
- Modules for encapsulation and multiple inheritance (mixins)
- Built-in reflection

Language comparison

Table 12.1 *Designs*

DESIGN ISSUE/ LANGUAGE	SMALLTALK	C++	OBJECTIVE-C	JAVA	C#	RUBY
Exclusivity of objects	All data are objects	Primitive types plus objects	Primitive types plus objects	Primitive types plus objects	Primitive types plus objects	All data are objects
Are subclasses subtypes?	They can be and usually are	They can be and usually are if the derivation is public	They can be and usually are	They can be and usually are	They can be and usually are	No subclasses are subtypes
Single and multiple inheritance	Single only	Both	Single only, but some effects with protocols	Single only, but some effects with interfaces	Single only, but some effects with interfaces	Single only, but some effects with modules
Allocation and deallocation of objects	All objects are heap allocated; allocation is explicit and deallocation is implicit	Objects can be static, stack dynamic, or heap dynamic; allocation and deallocation are explicit	All objects are heap dynamic; allocation is explicit and deallocation is implicit	All objects are heap dynamic; allocation is explicit and deallocation is implicit	All objects are heap dynamic; allocation is explicit and deallocation is implicit	All objects are heap dynamic; allocation is explicit and deallocation is implicit
Dynamic and static binding	All method bindings are dynamic	Method binding can be either	Method binding can be either	Method binding can be either	Method binding can be either	All method bindings are dynamic
Nested classes?	No	Yes	No	Yes	Yes	Yes
Initialization	Constructors must be explicitly called	Constructors are implicitly called	Constructors must be explicitly called	Constructors are implicitly called	Constructors are implicitly called	Constructors are implicitly called