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Subtyping

(Dynamic Polymorphism)

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References

- PFPL
  - Chapter 24 Structural Subtyping
  - Chapter 27 Inheritance
- TAPL (pdf)
  - Chapter 15 Subtyping
- [Concepts in PLs]

Subtyping and Inheritance

- Interface
  - The external view of an object
- Subtyping
  - Relation between interfaces
- Implementation
  - The internal representation of an object
- Inheritance
  - Relation between implementations

Various Object-Oriented Languages

- Pure dynamically-typed OO languages
  - Object implementation and run-time lookup
  - Class-based languages (Smalltalk)
  - Prototype-based languages (Self, JavaScript)
- Statically-typed OO languages
  - C++
    - using static typing to eliminate search
    - problems with C++ multiple inheritance
  - Java
    - using Interfaces to avoid multiple inheritance

Smalltalk

- Developed at Xerox PARC: Smalltalk-76, -80
- Object metaphor extended and refined
  - Used some ideas from Simula, but very different lang
  - Everything is an **object**, even a class
  - All operations are “messages to objects”
- Terminology

Object	Instance of some class	**Class**	Defines behavior of its object
Selector	Name of a message	**Message**	Selector together with parameter values
Method	Code used by a class to respond to message	**Instance variable**	Data stored in object
Subclass	Class defined by giving incremental modifications to some superclass		

Smalltalk: Example

add instance variable

- Point class

class name	Point
super class	Object
class var	pi
instance var	x y
class messages and methods	
<...names and code for 3 methods, i.e. newX:Y:, newOrigin, initialize>	
instance messages and methods	
<...names and code for 5 methods i.e. x:y:, moveDx:Dy:, x, y, draw>	

- ColorPoint class

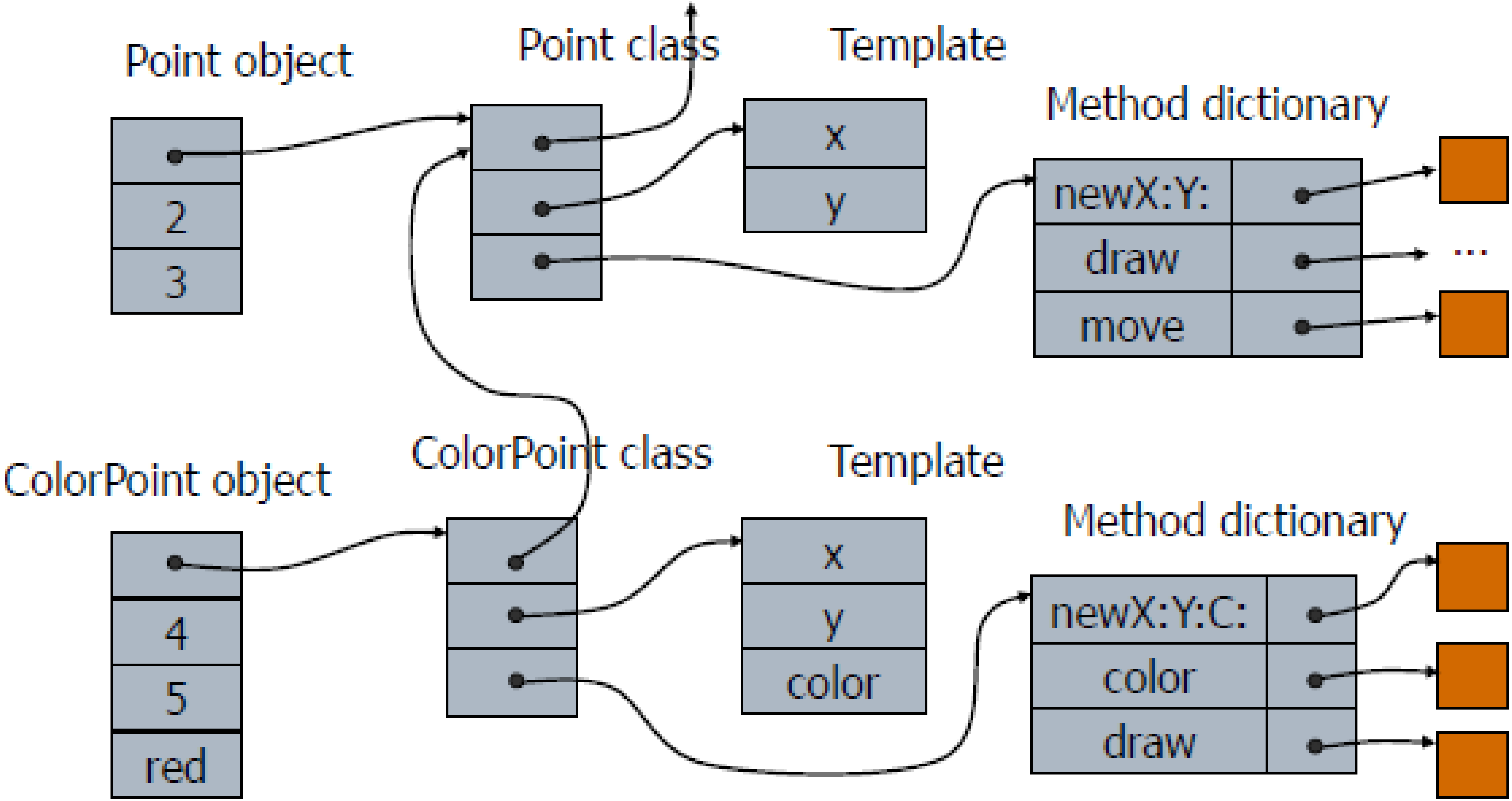
class name	ColorPoint
super class	Point
class var	
instance var	color
class messages and methods	
newX:xv Y:yv C:cv <...code...>	
instance messages and methods	
color <...code...> draw <...code...>	

override

override

add method

Smalltalk: Run-time Representation



This is a schematic diagram meant to illustrate the main idea. Actual implementations may differ.

Smalltalk Summary

- Class
  - creates objects that share methods
  - pointers to template, dictionary, parent class
- Objects: created by a class, contains instance variables
- Encapsulation
  - methods public, instance variables hidden
- Subtyping: implicit, no static type system
- Inheritance: subclasses, self, super

  Single inheritance in Smalltalk-76, Smalltalk-80

Smalltalk: Object Interfaces

- Interface
  - The messages understood by an object
- Example: point

  x:y: set x,y coordinates of point

  moveDx:Dy: method for changing location

  x returns x-coordinate of a point

  y returns y-coordinate of a point

  draw display point in x,y location on screen
- The interface of an object is its *type*

Smalltalk: Subtyping

- If interface A contains all of interface B, then A objects can also be used B objects.

Point	ColorPoint
x:y:	x:y:
moveDx:Dy:	moveDx:Dy:
x	x
y	y
draw	color
	draw

ColorPoint interface contains Point
ColorPoint is a subtype of Point

Subtyping and Inheritance

- Smalltalk/JavaScript subtyping is implicit
  - Not a part of the programming language
  - Important aspect of how systems are built

- Inheritance is explicit
  - Used to implement systems
  - No forced relationship to subtyping

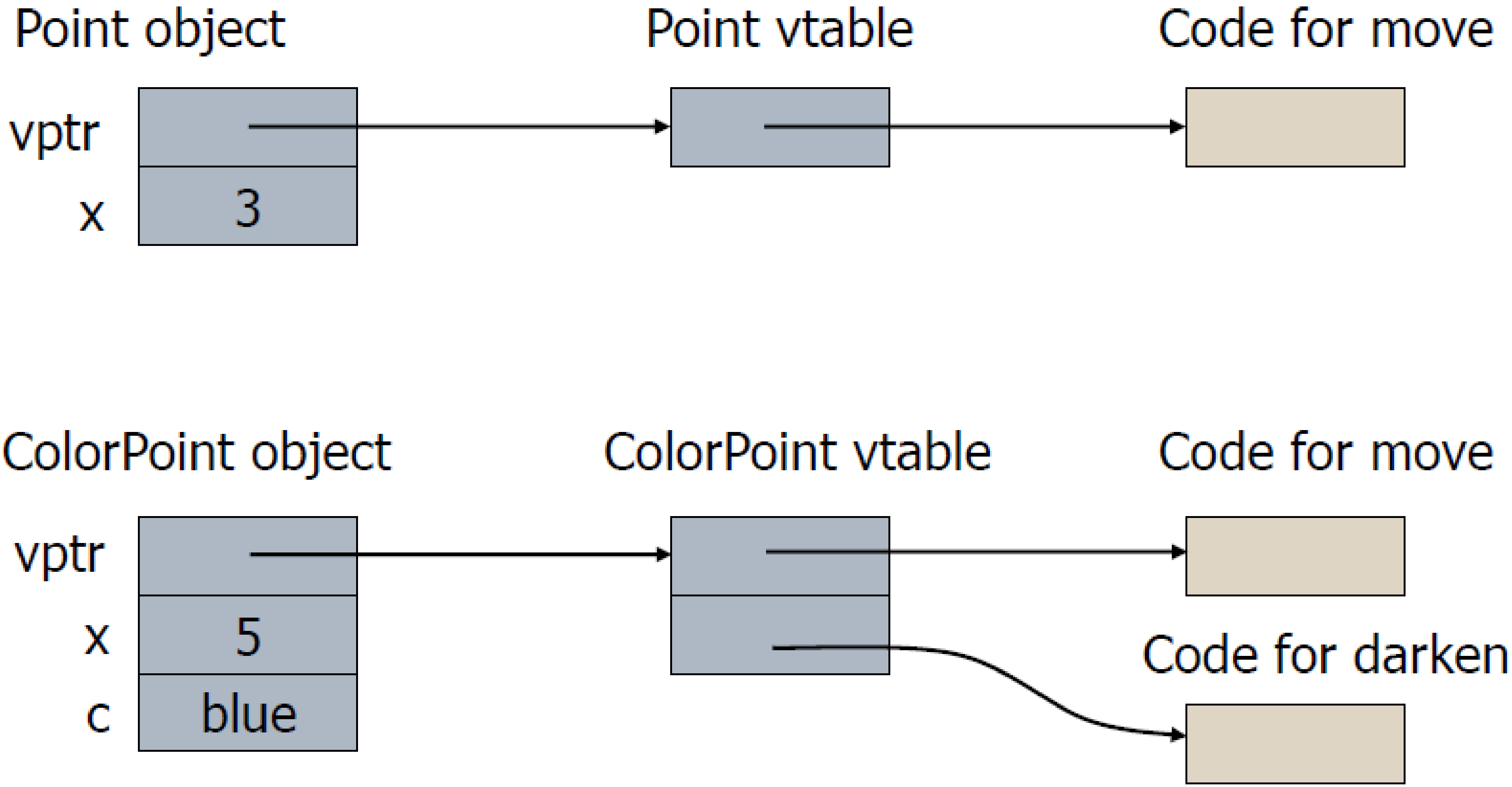
C++

- C++ is an object-oriented extension of C, Bell Labs
- Object-oriented features
  - Classes
  - Objects, with dynamic lookup of virtual functions
  - Inheritance
    - Single and multiple inheritance
    - Public and private base classes
  - Subtyping
    - Tied to inheritance mechanism
  - Encapsulation
    - Public, private, protected visibility

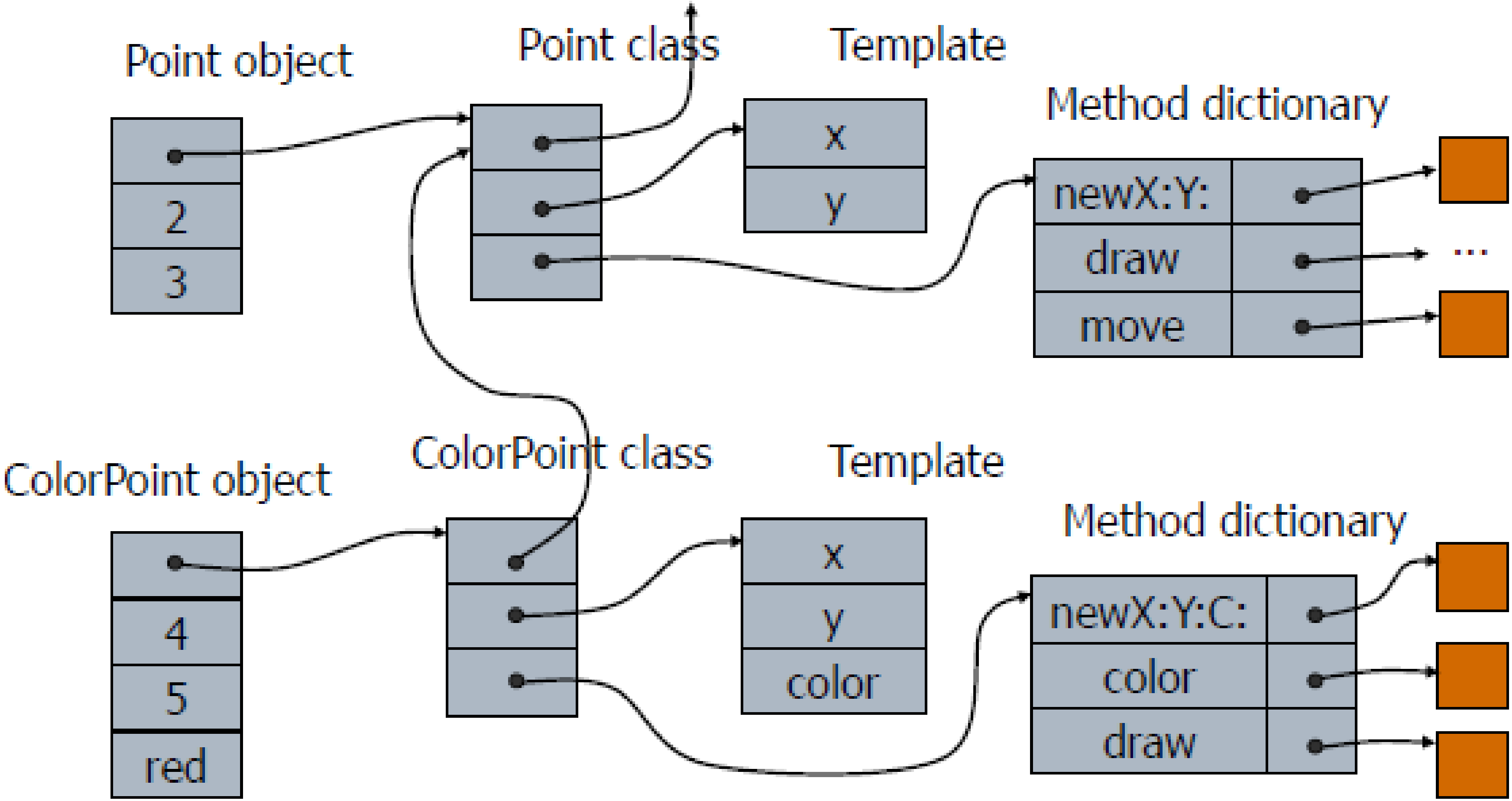
C++: Virtual functions

- Member functions are either
  - Virtual, if explicitly declared or inherited as virtual
  - Non-virtual otherwise
- Virtual functions
  - Accessed by indirection through ptr in object
  - May be redefined in derived (sub) classes
- Non-virtual functions
  - Are called in the usual way. *Just ordinary functions*.
  - Cannot redefine in derived classes (except overloading)
- Pay overhead only if you use virtual functions

Run-time Representation



Compare to Smalltalk/JavaScript



This is a schematic diagram meant to illustrate the main idea. Actual implementations may differ.

Multiple Inheritance

- Name clashes

```
class A {
  public:
    virtual void f() { … }
};
class B {
  public:
    virtual void f() { … }
};
class C : public A, public B{…};
…
  C* p;
  p->f(); // error
```

- Implicit resolution
  - Language resolves name conflicts with arbitrary rule
- Explicit resolution (C++)
  - Programmer must explicitly resolve name conflicts
- Disallow name clashes
  - Programs are not allowed to contain name clashes

No solution is always best

Multiple Inheritance

- Name clashes

```
class A {
  public:
    virtual void f() { … }
};
class B {
  public:
    virtual void f() { … }
};
class C : public A, public B{…};
…
  C* p;
  p->f(); // error
```

- Rewrite class C to call A::f explicitly

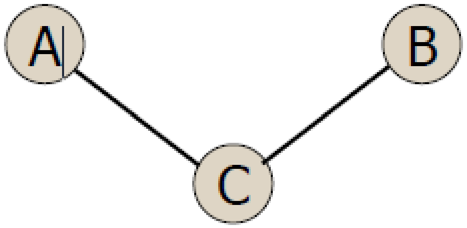
  => eliminate ambiguity

```
class C : public A, public B{
  public:
    void virtual f() {
       A::f();
    }
```

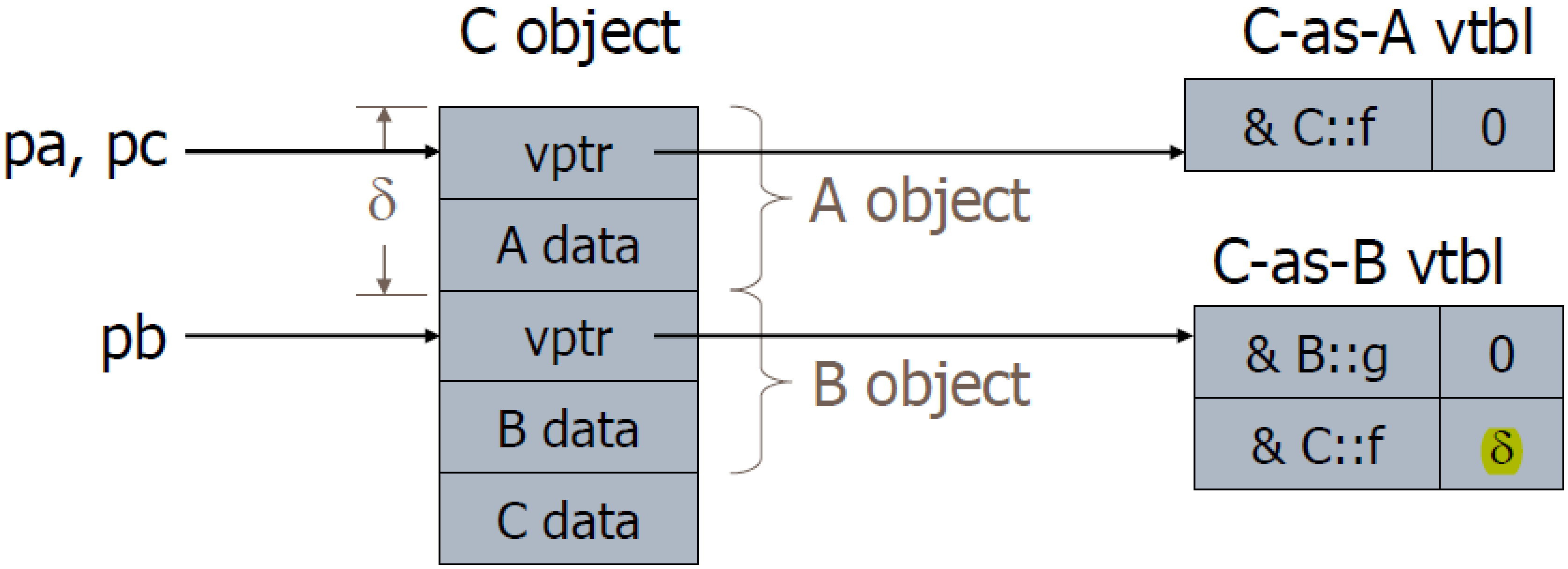
vtable for Multiple Inheritance

```
class A {
  public:
    virtual void f();
};
class B {
  public:
    int y;
    virtual void g();
    virtual void f();
};
```

```
class C : public A, public B{
  public:
    int z;
    virtual void f();
};
C *pc = new C;
B *pb = pc;
A * pa=pc;
```



pa, pb, pc point to same object, but different static types.



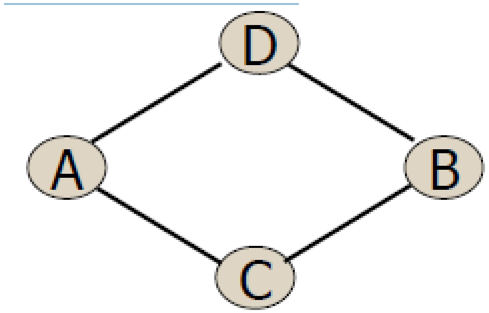
C-as-A vtbl

& C::f	0

C-as-B vtbl

& B::g	0
& C::f	δ

Diamond Inheritance in C++



- Standard base classes
  - D members appear twice in C
- Virtual base classes

  class A : public virtual D { … }

  - Avoid duplication of base class members
  - Require additional pointers so that D part of A, B parts of object can be shared
- C++ multiple inheritance is complicated in because of desire to maintain efficient lookup

C++ Subtyping

- Subtyping in principle
  - A <: B if every A object can be used without type error whenever a B object is required
- C++: A <: B if class A has public base class B
  - Independent classes not subtypes

Function Subtyping

- Subtyping principle
  - A <: B if an A expression can be safely used in any context where a B expression is required
- Subtyping for function results (Covariance)
  - If A <: B, then $C \rightarrow A <: C \rightarrow B$
- Subtyping for function arguments (Contravariance)
  - If A <: B, then $B \rightarrow C <: A \rightarrow C$
- Terminology
  - Covariance(协变): A <: B implies F(A) <: F(B)
  - Contravariance(逆变): A <: B implies F(B) <: F(A)

Subtyping Principles

- Products
  - Width subtyping(一个较宽的元组类型是一个较窄的元组类型的子类型)

$$\frac{i > j}{[m_1 : \tau_1, \ldots, m_i : \tau_i] <: [m_1 : \tau_1, \ldots, m_j : \tau_j]}$$

  - Depth subtyping (Covariance)

$$\frac{\sigma_i <: \tau_i}{[m_1 : \sigma_1, \ldots, m_j : \sigma_j] <: [m_1 : \tau_1, \ldots, m_j : \tau_j]}$$

  - Function subtyping

$$\frac{\sigma' <: \sigma \qquad \tau <: \tau'}{\sigma \to \tau <: \sigma' \to \tau'}$$

Java

- 1990-95   James Gosling and others at Sun
- Syntax similar to C++
- Object
  - has fields and methods
  - is allocated on heap, not run-time stack
  - accessible through reference (only ptr assignment)
  - garbage collected
- Dynamic lookup
  - Similar in behavior to other languages
  - Static typing => more efficient than Smalltalk
  - Dynamic linking, interfaces => slower than C++

Inheritance

- Similar to Smalltalk, C++
- Subclass inherits from superclass
  - Single inheritance only (but Java has interfaces)
- Some additional features
  - Conventions regarding *super* in constructor and *finalize* methods
  - Final classes and methods cannot be redefined

Interfaces vs Multiple Inheritance

- C++ multiple inheritance
  - A single class may inherit from two base classes
  - Constraints of C++ require derived class representation to resemble *all* base classes
- Java interfaces
  - A single class may implement two interfaces
  - No inheritance (of implementation) involved
  - Java implementation (discussed later) does not require similarity between class representations

Subtyping

- Primitive types
  - Conversions: int -> long, double -> long, …
- Class subtyping similar to C++
  - Subclass produces subtype
  - Single inheritance => subclasses form tree
- Interfaces
  - Completely abstract classes
    - no implementation
  - Multiple subtyping
    - Interface can have multiple subtypes (implements, extends)
- Arrays
  - Covariant subtyping – not consistent with semantic principles