Objects in C++

Objects, with dynamic lookup of virtual functions

C++ Object System

- Object-oriented features
  1. Classes and Data Abstraction
  2. Encapsulation
  3. Inheritance
     1. Single and multiple inheritance
     2. Public and private base classes
  4. Objects, with dynamic lookup of virtual functions
  5. Subtyping
     1. Tied to inheritance mechanism

Polymorphism in C++

- Runtime polymorphism
  - Virtual functions
- Compile-time polymorfism
  - (parametric polymorfism)
  - templates

Run-time Polymorphism

- **Run-time polymorphism**: implemented with **dynamic lookup of virtual functions**
- ***Dynamic lookup***: a method is selected dynamically, at run time, according to the implementation of the object that receives a message
  - not some static property of the pointer or variable used to name the object
- The important property of dynamic lookup is that **different objects may implement the same operation differently**

Virtual functions

- Member functions are either
  - Virtual, if explicitly declared or inherited as virtual
  - Non-virtual otherwise
- Virtual members
  - Are accessed by indirection through ptr in object
  - May be *overridden* in derived (sub) classes
- Non-virtual functions
  - Are called in the usual way. *Just ordinary functions*.
  - May be redefined in derived classes (overloading through *redefining*)
- Pay overhead only if you use virtual functions

Sample class: one-dimen. points

```
class Pt {
  public:
    Pt(int xv);                      Overloaded constructor
    Pt(Pt* pv);
    int getX();                      Public read access to private data
    virtual void move(int dx);       Virtual function
   protected:
     void setX(int xv);              Protected write access
   private:
     int x;                          Private member data
   };
```

Sample derived class

```
class ColorPt: public Pt {
  public:
    ColorPt(int xv,int cv);
    ColorPt(Pt* pv,int cv);
    ColorPt(ColorPt* cp);
    int getColor();
    virtual void move(int dx);
    virtual void darken(int tint);
  protected:
    void setColor(int cv);
  private:
    int color;
 };
```

Overloaded constructor

Non-virtual function

Virtual functions

Protected write access

Private member data

Sample derived class

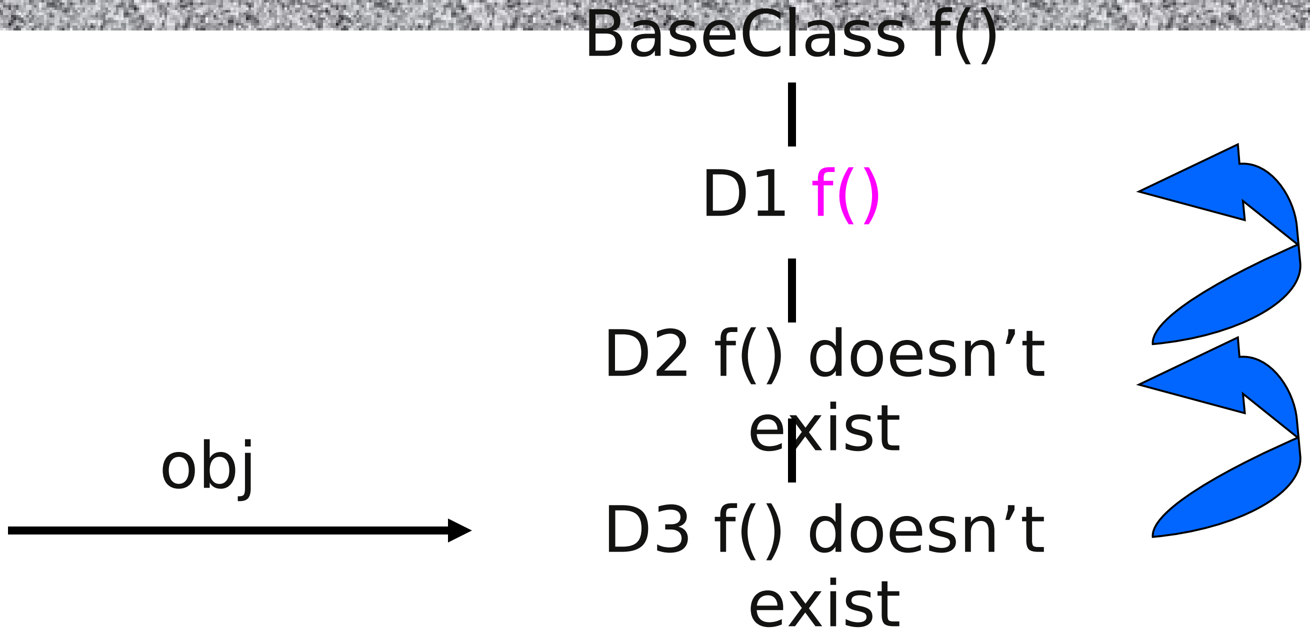
```
/* ----Definitions of Member Functions --------*/

void ColorPt::darken(int tint) { color += tint; }

void ColorPt::move(int dx) {
Pt::move(dx); this->darken(1);
}
```

Virtual functions and *indirection (1)*

- C++ allows a base class pointer to point to a derived class object
- Upon method invocation, the method of the derived object is called
- This leads to generic alghoritms using base class pointers

```
Pt*  ptr = new ColorPt;
ptr->move();
delete(ptr);
```

Virtual functions and *indirection (2)*



BaseClass f()

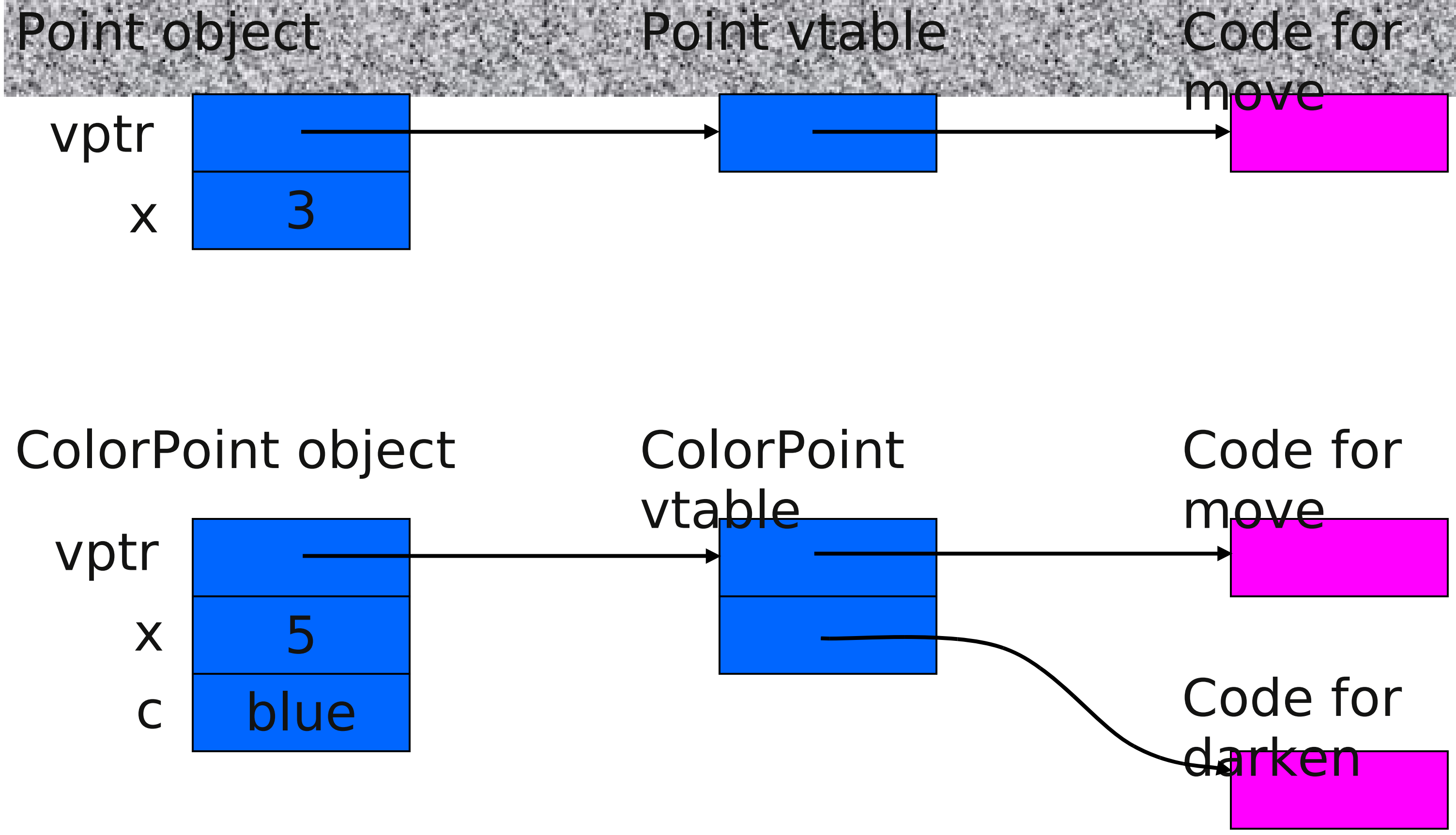
D1 f()

D2 f() doesn’t exist

obj

D3 f() doesn’t exist

Run-time representation



Point object

vptr

x

3

Point vtable

Code for move

ColorPoint object

vptr

x

5

c

blue

ColorPoint vtable

Code for move

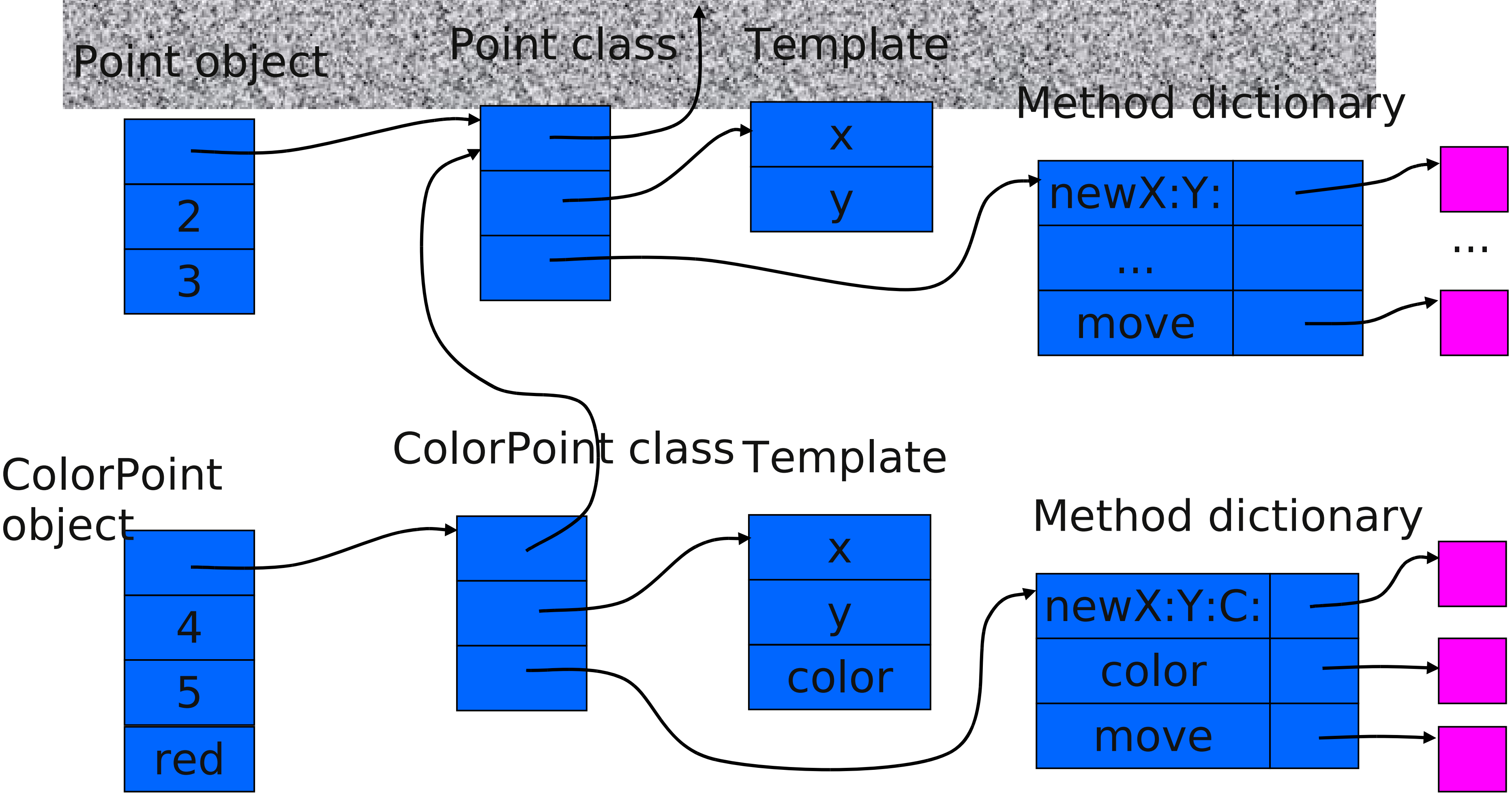
Code for darken

Virtual pointers

Virtual tables

Function code

Compare to Smalltalk



Why is C++ lookup simpler?

- Smalltalk has no static type system
  - Code p message:pars could refer to any object
  - Need to find method using pointer from object
  - Different classes will put methods at different place in method dictionary
- C++ type gives compiler some superclass
  - Offset of data, fctn ptr same in subclass and superclass
  - Offset of data and function ptr known at compile time
  - Code p->move(x) compiles to equivalent of

    (*(p->vptr[1]))(p,x) if move is first fctn in vtable

data passed to member function; see next slic

Calls to virtual functions

- One member function may call another

```
class A {
    public:
        virtual  int  f (int x);
        virtual  int  g(int y);
};
int A::f(int x) { … g(i) …;}
int A::g(int y) { … f(j) …;}
```

- How does body of f call the right g?
  - If g is redefined in derived class B, then inherited f must call B::g

“This” pointer

- Code is compiled so that member function takes “object itself” as first argument

  Code int A::f(int x) { … g(i) …;}

  compiled as int A::f(A *this, int x) { … this->g(i) …;}

- “this” pointer may be used in member function
  - Can be used to return pointer to object itself, pass pointer to object itself to another function, ...

Non-virtual functions

- How is code for non-virtual function found?
- Same way as ordinary "non-member" functions:
  - Compiler generates function code and assigns address
  - Address of code is placed in **symbol table**
  - At call site, address is taken from symbol table and placed in compiled code
  - *But* some special scoping rules for classes
- Overloading
  - Remember: overloading is resolved at compile time
  - This is different from run-time lookup of virtual function

Scope rules in C++

- Scope qualifiers
  - binary :: operator, ->, and .
  - class::member, ptr->member, object.member
- A name outside a function or class,
  - not prefixed by unary :: and not qualified refers to global object, function, enumerator or type.
- A name after X::, ptr-> or obj.
  - where we assume ptr is pointer to class X and obj is an object of class X
  - refers to a member of class X or a base class of X

Virtual vs Overloaded Functions

```
class parent { public:
    void printclass() {printf("p ");};
    virtual void printvirtual() {printf("p ");};   };
class child : public parent { public:
    void printclass() {printf("c ");};
    virtual void printvirtual() {printf("c ");};    };
main() {
    parent p;  child c; parent *q;
    p.printclass(); p.printvirtual(); c.printclass(); c.printvirtual();
    q = &p;  q->printclass(); q->printvirtual();
    q = &c;  q->printclass(); q->printvirtual();
}
```

Output: p p c c p p **p** c

Function call binding

- Early binding (C,C++)
  - At compile time
- Late binding (C++)
  - At runtime
  - Mighty. But less effficient
    - 1 more assembler statement per call
    - Slight memory consuption due to the VPTRs