Virtual functions – concepts

- Virtual: exists in essence though not in fact
- Idea is that a virtual function can be "used" before it is defined
  - And it might be defined many, many ways!
- Relates to OOP concept of polymorphism
  - Associate many meanings to one function
- Implemented by dynamic binding
  - A.k.a. late binding – happens at run-time

Polymorphism example: figures

- Imagine classes for several kinds of figures
  - Rectangles, circles, and ovals (to start)
  - All derive from one base class: `Figure`
- All "`Figure`" objects inherit: `void draw()`
  - Of course, each one implements it differently!

```
Rectangle r;
Circle c;
r.draw(); // Calls Rectangle class's draw()
c.draw(); // Calls Circle class's draw
```

- Nothing new here yet …

Figures example cont. – center()

- Consider that base class `Figure` has functions that apply to "all" figures
- e.g., `center()`: moves figure to screen center
  - Erases existing drawing, then re-draws the figure
  - So `Figure::center()` uses `draw()` to re-draw
- But which draw() function will be used?
  - We're implementing base class center() function, so we have to use the base class draw() function. Right?
- Actually, it turns out the answer depends on how `draw()` is handled in the base class

Poor solution: base works hard

- Figure class tries to implement draw to work for all (known) figures
  - First devise a way to identify a figure's "type"
  - Then `Figure::draw()` uses conditional logic:

```
if ( /* the Figure is a Rectangle */ )
     Rectangle::draw();
else if ( /* the Figure is a Circle */ )
     Circle::draw();
...
```

- But what if a new kind of figure comes along?
  - e.g., how to handle a derived `class Triangle`?

Better solution: virtual function

- Base class declares that the function is virtual:

```
virtual void draw() const;
```

- Remember it means `draw()` exists in essence
- Such a declaration tells compiler “I don’t know how this function is implemented, so wait until it is used in a program, and then get its implementation from the object *instance*.”
- The instance will exist in fact (eventually)
  - Therefore, so will the implementation at that time!
- Function “binding” happens late – dynamically

Another virtual function example (Sale, DiscountSale, Display 15.11)

- Record-keeping system for auto parts store
  - Track sales, compute daily gross, other stats
  - All based on data from individual bills of sale
- Problem: lots of different types of bills
- Idea – start with a very general `Sale` class that has a *virtual* `bill()` function:

```
virtual double bill() const;
```

- Rest of idea – many different types of sales will be added later, and each type will have its own version of the `bill()` function

Sale functions: savings and op <

```
double Sale::savings(const Sale &other) const
   {
       return (bill() - other.bill());
   }

bool operator < (const Sale &first,
                 const Sale &second)
   {
       return (first.bill() < second.bill());
   }
```

- Notice both functions use member function `bill()`!

A class derived from Sale

```
class DiscountSale : public Sale {
public:
  DiscountSale();
  DiscountSale(double price,
                    double discount);
  double getDiscount() const;
  void setDiscount(double newDiscount);
  double bill() const;  // implicitly virtual
private:
  double discount;          // inherits price
};
```

DiscountSale's bill() function

- First note – it is automatically virtual
  - Inherited trait, applies to *any* descendants
  - Also note – rude not to declare it explicitly
- Of course, definition never says virtual:

```
double DiscountSale::bill() const {
    double fraction = discount/100;
    return (1 - fraction)*getPrice();
}
```

  - Must use access method as price is private

The power of virtual is actual!

- e.g., base class `Sale` written long before derived class `DiscountSale`
- Sale had members `savings` and ‘<’ before there was any idea of class `DiscountSale`
- Yet consider what the following code does

```
DiscountSale d1, d2;
d1.savings(d2); // calls Sale's savings function
```

- In turn, class `Sale`’s `savings` function uses class `DiscountSale`’s `bill` function.

Wow!

Clarifying some terminology

- Recall that overloading ≠ redefining
- Now a new term – overriding means *redefining* a *virtual* function
- Polymorphism is an OOP concept
  - Overriding gives many meanings to one name
- Dynamic binding is what makes it all work
- "Thus," as Savitch puts it, "polymorphism, late binding, and virtual functions are really all the same topic."

Why not all virtual functions?

- Philosophy issue: pure OOP vs. efficiency
  - All functions are virtual by default in another popular programming language (Java) – there must take steps to make functions non-virtual
  - C++ default is non-virtual – programmer must explicitly declare (except when inherited trait)
- Virtual functions have more "overhead"
  - More storage – for class virtual function table
  - Slower – a look-up step; less optimization

Simpler polymorphism demo (~mikec/cs32/demos/figures)

- Base: `Figure` has `virtual void print()`
  - `print()` is used in `printAt(lines)`
- Derived: `Rectangle` *just* overrides `print()`
- Which `print()` is used in the following code?

```
Figure *ptr = new Rectangle,
       &ref = *new Rectangle('Q', 5, 10, 4);
ptr->printAt(1); ref.printAt(1);
```

- What if `print()` was not declared `virtual`?
- What if line 2 above just had `ref`, not `&ref`?
  - To know why, see "slicing" … a few slides from now

"Pure virtual" and abstract classes

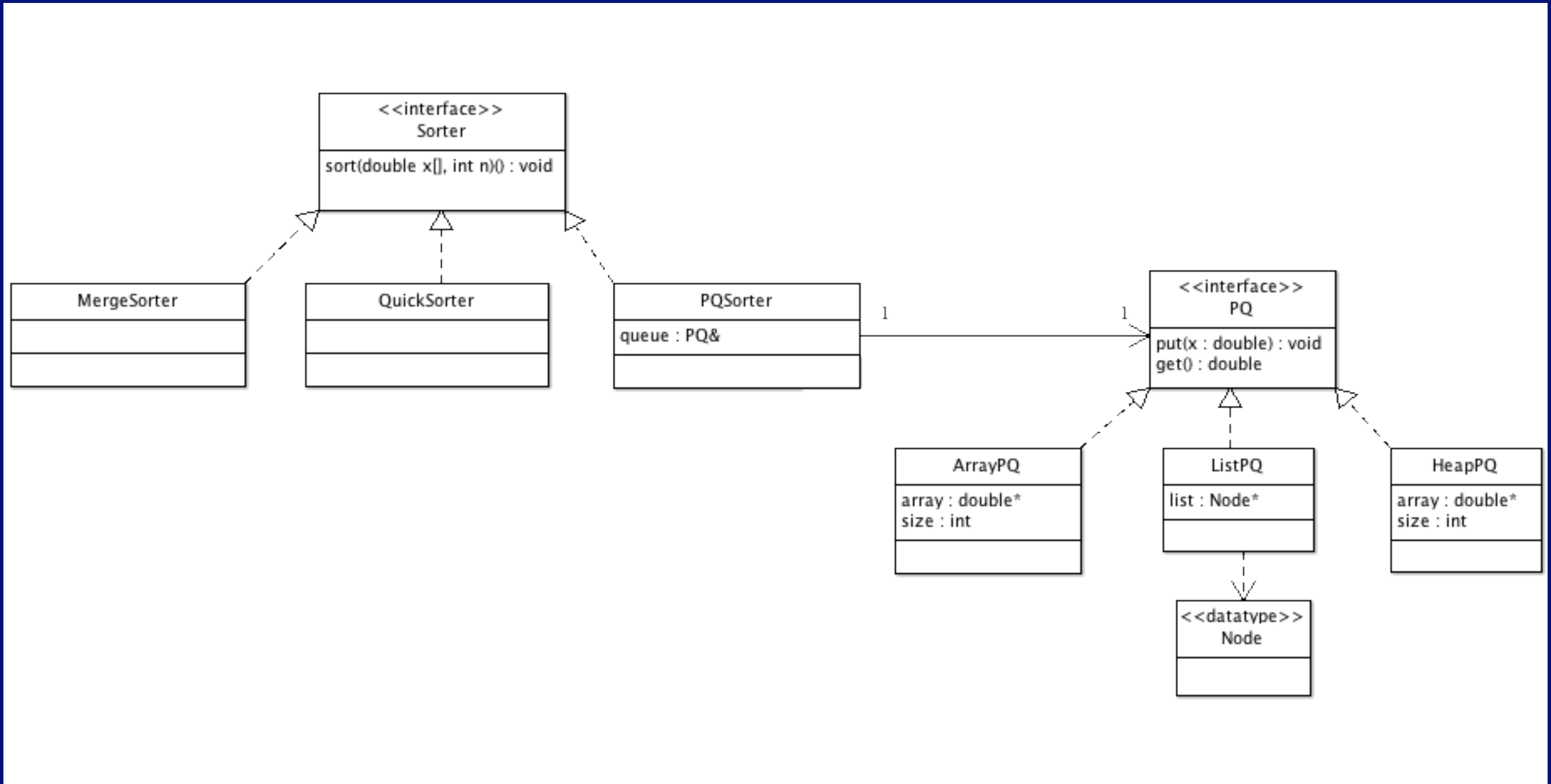
- Actually class Figure's print() function is useless
  - It should have been a pure virtual function:

```
virtual void draw() const = 0;
```

  - Says not defined in this class – means any derived class must define its own version, or be abstract itself
- A class with one or more pure virtual functions is an abstract class – so *it can only be a base class*
  - An actual instance would be an incomplete object
  - So *any instance must be a derived class instance*

A sorting hierarchy

See …/demos/sorting



Types when inheritance is involved

- Consider: `void func (Sale &x) {…}` or similarly: `void func (Sale *xp) {…}`
  - What type of object is x (or *xp), really? Is it a Sale?
  - Or is it a DiscountSale, or even a CrazyDiscountSale?
- Just Sale members are available
  - But might be virtual, and Sale might even be abstract
  - `&` and `*` variables allow polymorphism to occur
- Contrast: `void func (Sale y) {…}`
  - What type of object is y? It's a Sale. Period.
  - Derived parts are "sliced" off by Sale's copy ctor
  - Also in this case, Sale cannot be an abstract class

Type compatibility example

```
class Pet {
public:  // pls excuse bad info hiding
   string name;
   virtual void print();
};

class Dog : public Pet {
public:
   string breed;
   virtual void print();
};
```

- Consider:
  ```
  Dog d; Pet p;
  d.name = "Tiny";
  d.breed = "Mutt";
  p = d; // "slicing" here
  ```
  - All okay – a Dog "is a" Pet
- Reverse is not okay
  - A Pet might be a Bird, or …
- And `p.breed`? Nonsense!
- Also see `slicing.cpp` at `~mikec/cs32/demos/`

Destructors should be virtual

- Especially if class has virtual functions
- Derived classes might allocate resources via a base class reference or pointer:

```
Base *ptrBase = new Derived;
... // a redefined function allocates resources
delete ptrBase;
```

- If dtor not virtual, derived dtor is not run!
- If dtor is virtual – okay: run derived dtor, immediately followed by base dtor

Casting and inherited types

- Consider again: `Dog d; Pet p;`
- "Upcasting" (descendent to ancestor) is legal:

```
p = d; // implicitly casting "up"
p = static_cast<Pet>(d); // like (Pet)d
```

  - But objects sliced if not pointer or reference
- Other way ("downcasting") is a different story:

```
d = static_cast<Dog>(p); // ILLEGAL
```

  - Can only do by pointer and *dynamic cast* :

```
Pet *pptr = new Dog; // we know it's a Dog
Dog *dptr = dynamic_cast<Dog*>(pptr)
```

  - But can be dangerous, and is rarely done

Multiple inheritance and virtual

- Idea: a `ClockRadio` is a `Radio` *and* an `AlarmClock`
  - But what if class `Radio` and class `AlarmClock` are both derived from another class, say `Appliance`?
  - Doesn't each derived object contain an `Appliance` portion?
  - So wouldn't a `Clockradio` have two copies of that portion, and how can such a scheme possibly work properly?
- Answer: it can work, but only by using *virtual* inheritance!

```
class Radio : virtual public Appliance;
class AlarmClock : virtual public Appliance;
class ClockRadio : public Radio, public AlarmClock;
```

  - Now a `Clockradio` has just one `Appliance` portion, not two
- See demo code in `~mikec/cs32/demos/`[`multi-inherit`]
- But note: hierarchy is still messed up, and still lots of chances for ambiguity – best to avoid multi-inheritance!

How do virtual functions work?

- Not exactly magic, but safe to consider it so
- `virtual` tells compiler to "wait for instructions" until the function is used in a program
- So the compiler creates a virtual function table for the class, with pointers to all virtual functions
- In turn, every *object* of such a class will be made to store a pointer to its own class's virtual function table – try …`/demos/sizeofvirtual.cpp`
- At runtime: follow the pointers to find the code!