CS100
Introduction to Programming

Lecture 13. Object-Oriented Programming: Polymorphism

Today’s Learning objectives

- Learn and understand different ways of polymorphism
- Get the concepts behind
  - Virtual functions
  - Abstract classes
- Learn how to use them

Outline

- Review of Inheritance
- Polymorphism
  - Limitations
  - Virtual Functions
  - Abstract Classes & Function Types
  - Virtual Function Tables
  - Virtual Destructors/Constructors

Review of Inheritance

- specialization through sub classes

- child class has direct access to
  - parent member functions and variables that are
    - ???

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    - protected

Review of Inheritance

- specialization through sub classes
- child class has direct access to
  - parent member functions and variables that are:
    - public
    - protected
- parent class has direct access to:
  - **???** in the child class

Review of Inheritance

- specialization through sub classes

- child class has direct access to
  - parent member functions and variables that are:
    - public
    - protected
- parent class has direct access to:
  - **nothing** in the child class

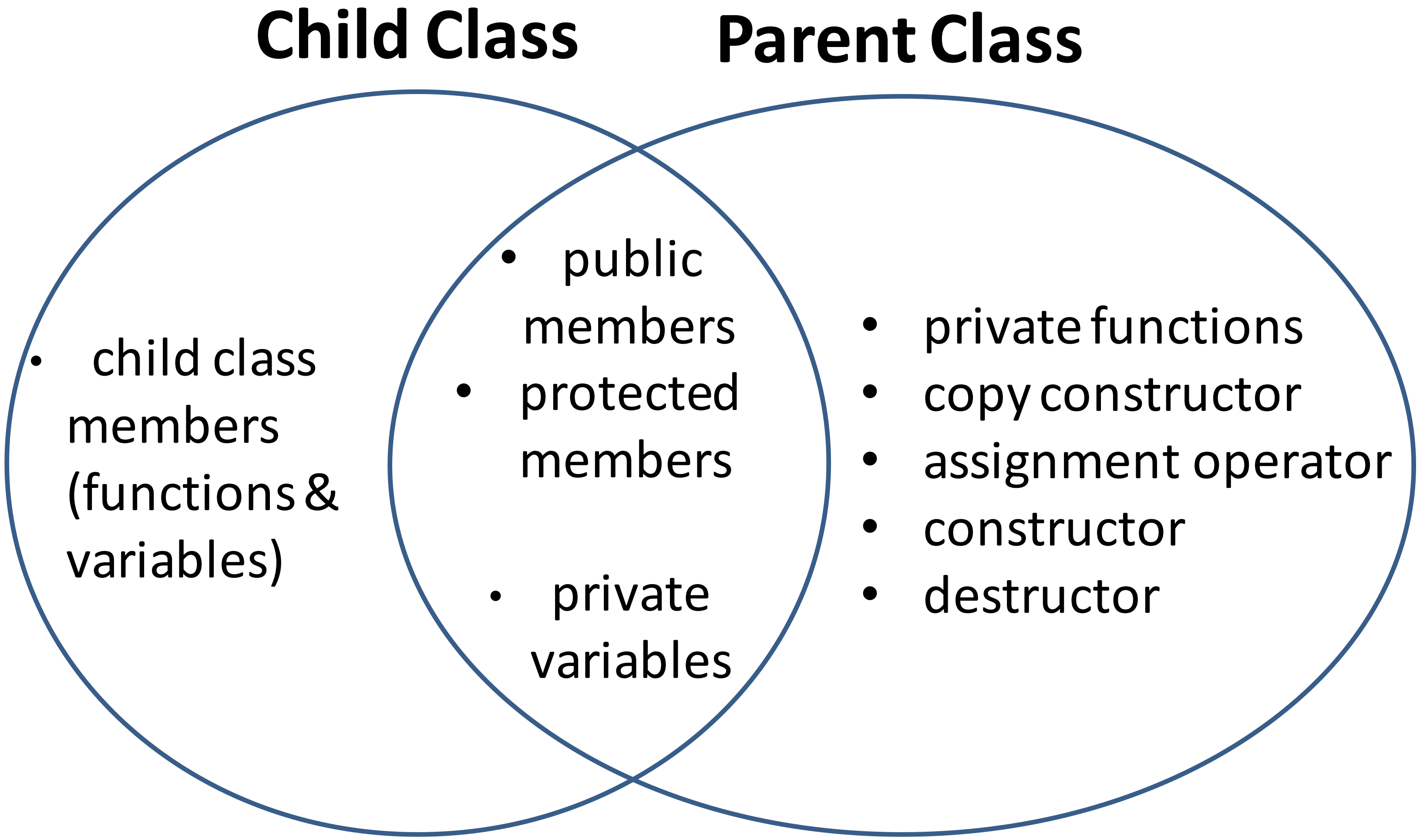
What is Inherited

Parent Class

- public members
- protected members
- private variables

- private functions
- copy constructor
- assignment operator
- constructor
- destructor

What is Inherited



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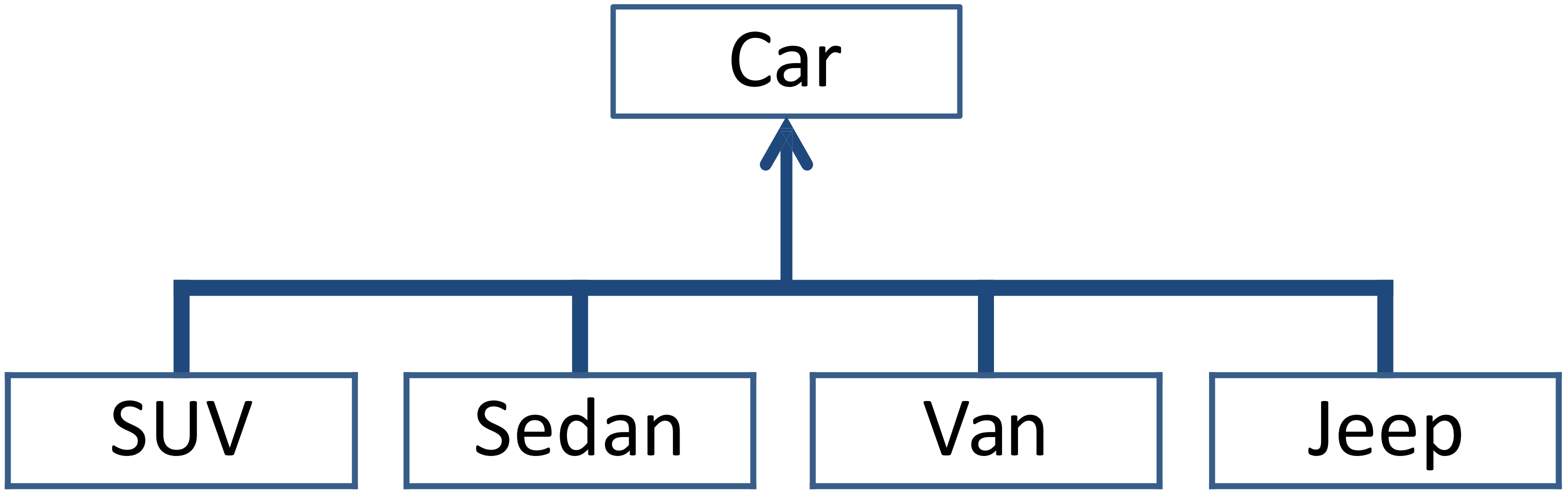
Car Example



```
class SUV:   public Car {/*etc*/};
class Sedan: public Car {/*etc*/};
class Van:   public Car {/*etc*/};
class Jeep:  public Car {/*etc*/};
```

Car Rental Example

- we want to implement a catalog of different types of cars available for rental

- how could we do this?

Car Rental Example

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- how could we do this?

- can accomplish this with a single vector
  - using ***polymorphism***

What is Polymorphism?

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- already done to an extent via ***overriding***
  - child class overrides a parent class function

What is Polymorphism?

- ability to manipulate objects in a **type-independent** way
- already done to an extent via ***overriding***
  - child class overrides a parent class function
- can take it further using subtyping, AKA ***inclusion polymorphism***

Using Polymorphism

- a pointer of a parent class type can point to an object of a child class type

```
Vehicle *vehiclePtr = &myCar;
```

- why is this valid?

Using Polymorphism

- a pointer of a parent class type can point to an object of a child class type

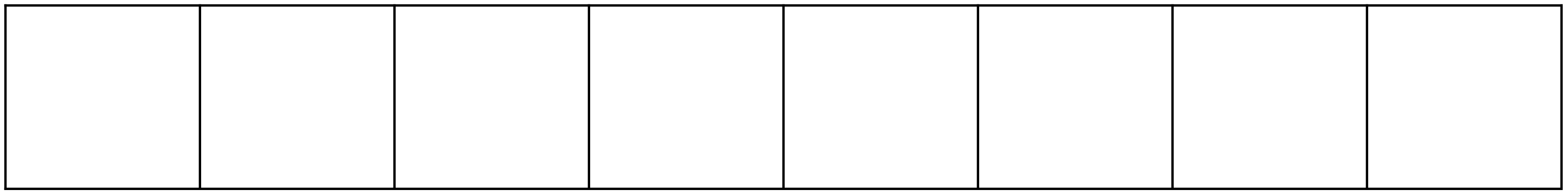
```
Vehicle *vehiclePtr = &myCar;
```

- why is this valid?
  - because **`myCar`** is-a **`Vehicle`**

Polymorphism: Car Rental

```
vector <Car*> rentalList;
```

vector of **`Car*`** objects



Polymorphism: Car Rental

```
vector <Car*> rentalList;
```

vector of **`Car*`** objects

SUV	**SUV**	**Jeep**	**Van**	**Jeep**	**Sedan**	**Sedan**	**SUV**

- can populate the vector with any of **`Car`**’s child classes

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Recall

- Class Vehicle is an example class which contains the public functions:

```
void Upgrade();
void PrintSpecs();
void Move(double distance);
```

- Class Car overrides these functions and also extends the class by:

```
void RepaintCar();
```

Limitations of Polymorphism

- parent classes **do not** inherit from child classes
  - what about public member variables and functions?

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```
Vehicle *vehiclePtr = &myCar;
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- which version of `PrintSpecs()` does this call?

```
vehiclePtr->PrintSpecs();
```

Limitations of Polymorphism

- parent classes **do not** inherit from child classes
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```
Vehicle *vehiclePtr = &myCar;
```

- which version of **`PrintSpecs()`** does this call?

```
vehiclePtr->PrintSpecs();
```

```
Vehicle::PrintSpecs()
```

Limitations of Polymorphism

- parent classes **do not** inherit from child classes
  - **not even** public member variables and functions

```
Vehicle *vehiclePtr = &myCar;
```

- will this work?

```
vehiclePtr->RepaintCar();
```

Limitations of Polymorphism

- parent classes **do not** inherit from child classes
  - **not even** public member variables and functions

```
Vehicle *vehiclePtr = &myCar;
```

- will this work?

```
vehiclePtr->RepaintCar();
```

  - NO! **`RepaintCar()`** is a function of the Car child class, not the Vehicle class

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Virtual Functions

- can grant access to child methods by using ***virtual functions***
- virtual functions are how C++ implements ***late binding***
  - used when the child class implementation is unknown or variable at parent class creation time

Late Binding

- simply put, binding is determined at run time
    - as opposed to at compile time
- in the context of polymorphism, you’re saying

  I don’t know for sure how this function is going to be implemented, so wait until it’s used and then get the implementation from the object instance.

Using Virtual Functions

- declare the function in the parent class with the keyword **`virtual`** in front

```
virtual void Drive();
```

Using Virtual Functions

- declare the function in the parent class with the keyword **`virtual`** in front

```
virtual void Drive();
```

- only use **`virtual`** with the prototype

```
// don't do this
virtual void Vehicle::Drive();
```

Using Virtual Functions

- the corresponding child class function does not require the **`virtual`** keyword

- but…

Using Virtual Functions

- the corresponding child class function does not require the **`virtual`** keyword
- should still include it, for clarity's sake
  - makes it obvious the function is virtual, even without looking at the parent class

```
// inside the Car class
virtual void Drive();
```

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Function Types – Virtual

```
virtual void Drive();
```

- parent class **must** have an implementation
  - even if it's trivial or empty
- child classes may override if they choose to
  - if not overridden, parent class definition used

Function Types – Pure Virtual

```
virtual void Drive() = 0;
```

- denote pure virtual by the "`= 0`" at the end

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- denote pure virtual by the “ `= 0`” at the end
- the parent class has **no implementation** of this function
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Function Types – Pure Virtual

```
virtual void Drive() = 0;
```

- denote pure virtual by the “ `=  0`” at the end
- the parent class has **no implementation** of this function
  - child classes **must** have an implementation
  - parent class is now an ***abstract class***

Abstract Classes

- an ***abstract class*** is one that contains a function that is ***pure virtual***

Abstract Classes

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- cannot declare abstract class objects
  - why?

Abstract Classes

- an ***abstract class*** is one that contains a function that is ***pure virtual***

- cannot declare abstract class objects
  - why?

- this means abstract classes can only be used as base classes

Applying Virtual

- Imagine a class Shape. How should we label the following functions?
  (virtual, pure virtual, or leave alone)

```
CalculateArea();
CalculatePerimeter();
Print();
SetColor();
```

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Behind the Scenes

- if our `Drive()` function is virtual, how does the compiler know which child class's version of the function to call?

vector of Car* objects

SUV	SUV	Jeep	Van	Jeep	Sedan	Sedan	SUV

Virtual Function Tables

- the compiler uses ***virtual function tables*** whenever we use polymorphism

- virtual function tables are created for:
  - what types of classes?

Virtual Function Tables

- the compiler uses ***virtual function tables*** whenever we use polymorphism

- virtual function tables are created for:
  - classes with virtual functions
  - child classes of those classes

Virtual Table Pointer

SUV	SUV	Jeep	Van	Jeep	Sedan	Sedan	Van

Virtual Table Pointer

- the compiler adds a hidden variable

SUV	SUV	Jeep	Van	Jeep	Sedan	Sedan	Van
***__vptr**	***__vptr**	***__vptr**	***__vptr**	***__vptr**	***__vptr**	***__vptr**	***__vptr**

Virtual Table Pointer

- the compiler also adds a virtual table of functions for each class

SUV	SUV	Jeep	Van	Jeep	Sedan	Sedan	Van
*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr

SUV virtual table	Jeep virtual table	Van virtual table	Sedan virtual table

Virtual Table Pointer

- each virtual table has pointers to each of the virtual functions of that class

SUV	SUV	Jeep	Van	Jeep	Sedan	Sedan	Van
*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr	*__vptr

SUV virtual table
* to SUV::Drive();

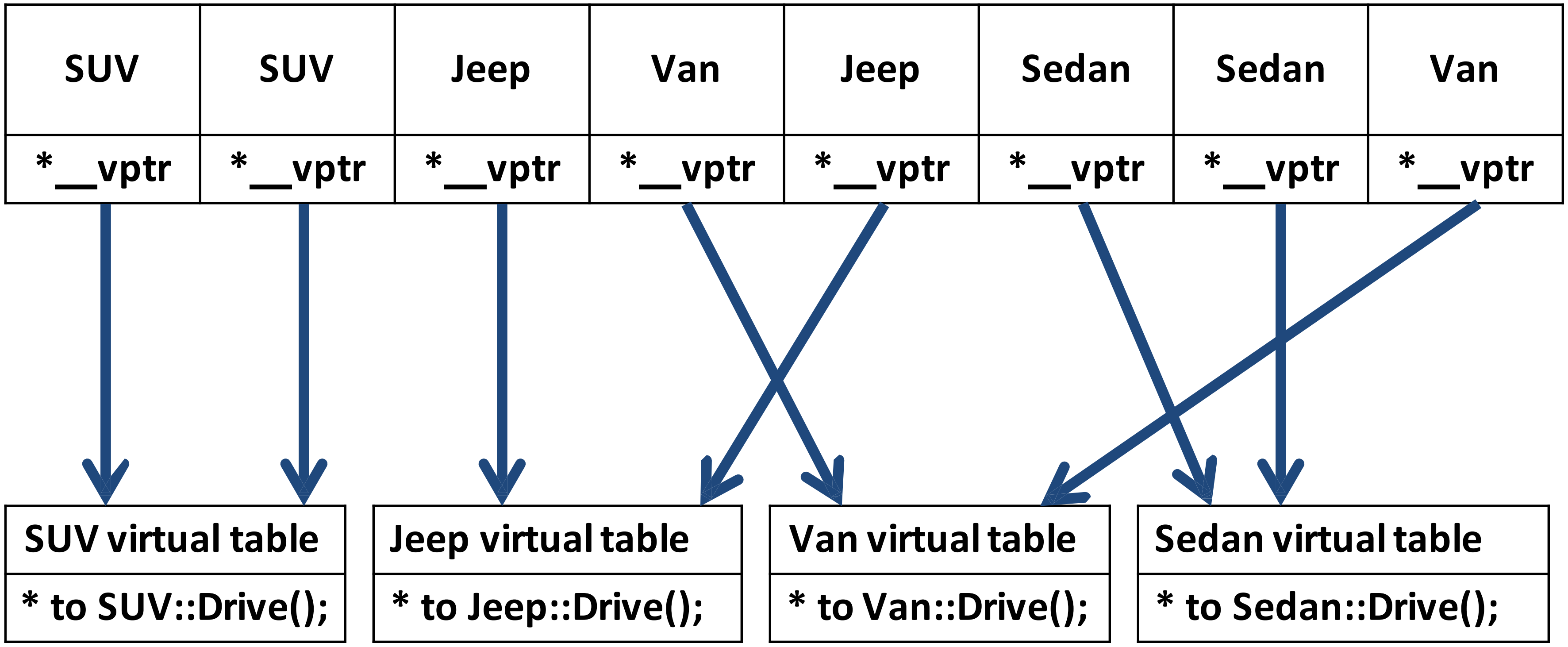
Jeep virtual table
* to Jeep::Drive();

Van virtual table
* to Van::Drive();

Sedan virtual table
* to Sedan::Drive();

Virtual Table Pointer

- the hidden variable points to the appropriate virtual table of functions



Virtual Everything!

- in Java, all functions are virtual by default
  - everything seems to work fine for Java

- why don't we make all our functions virtual in C++ classes?
  - ???

Virtual Everything!

- in Java, all functions are virtual by default
  - everything seems to work fine for Java

- why don't we make all our functions virtual in C++ classes?
  - non-virtual functions can't be overridden (in the context of parent class pointers)
  - creates unnecessary overhead

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Virtual Destructors

```
Vehicle *vehicPtr = new Car;
delete vehicPtr;
```

- for any class with virtual functions, you must declare a virtual destructor as well

- why?

Virtual Destructors

```
Vehicle *vehicPtr = new Car;
delete vehicPtr;
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- for any class with virtual functions, you must declare a virtual destructor as well

- non-virtual destructors will only invoke the base class's destructor

Virtual Constructors

- not a thing... why?

Virtual Constructors

- not a thing... why?

- we use polymorphism and virtual functions to manipulate objects **without** knowing type or having complete information about the object

- when we construct an object,
  we **have** complete information
  - there's no reason to have a virtual constructor