Polymorphism

OOP Principles, Virtual Members, Polymorphism

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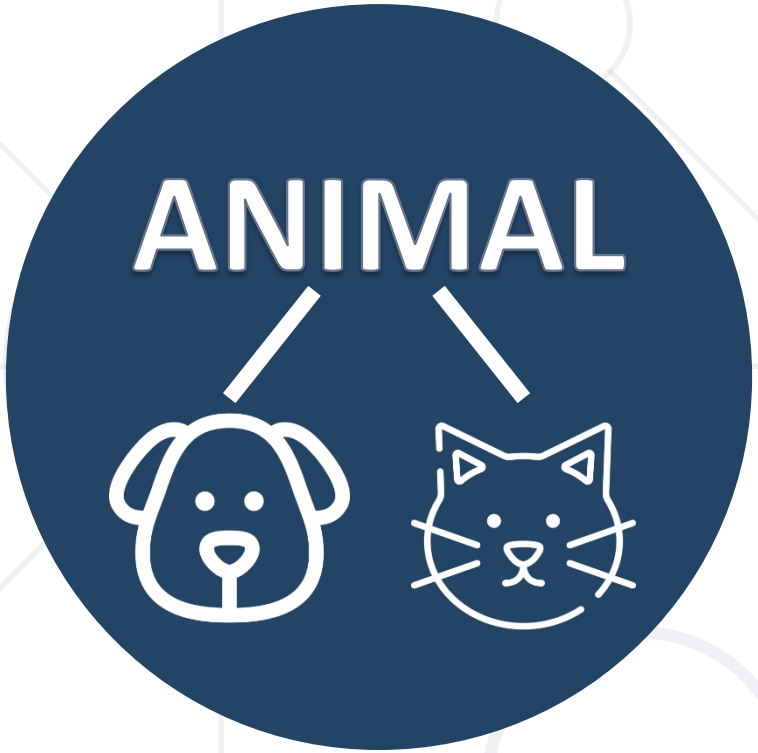
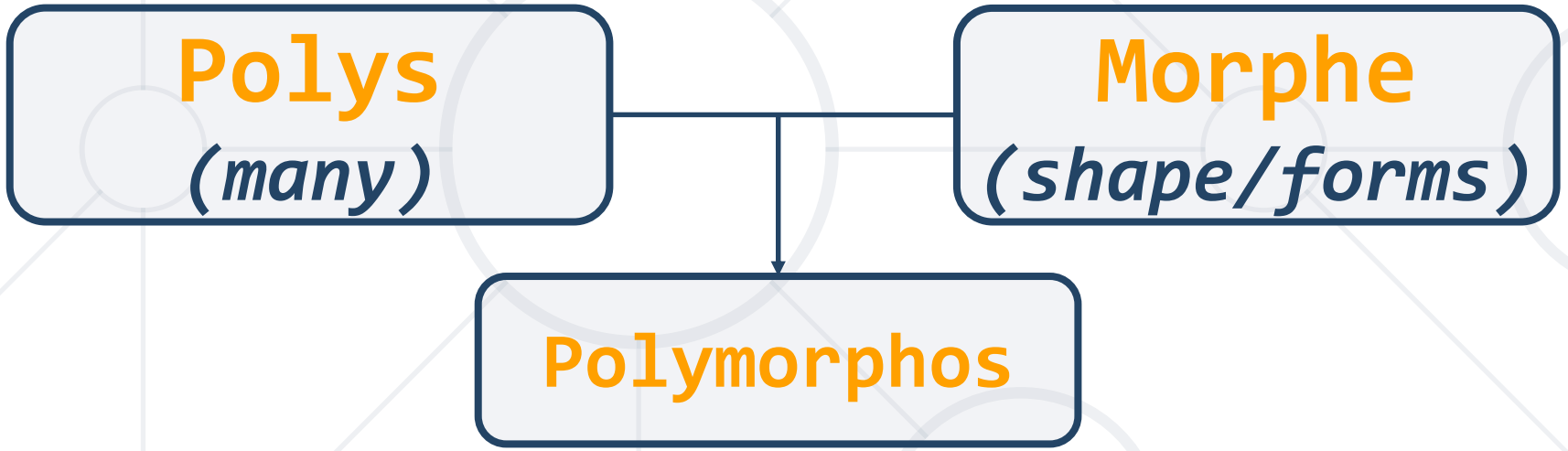
#cpp-oop



Polymorphism

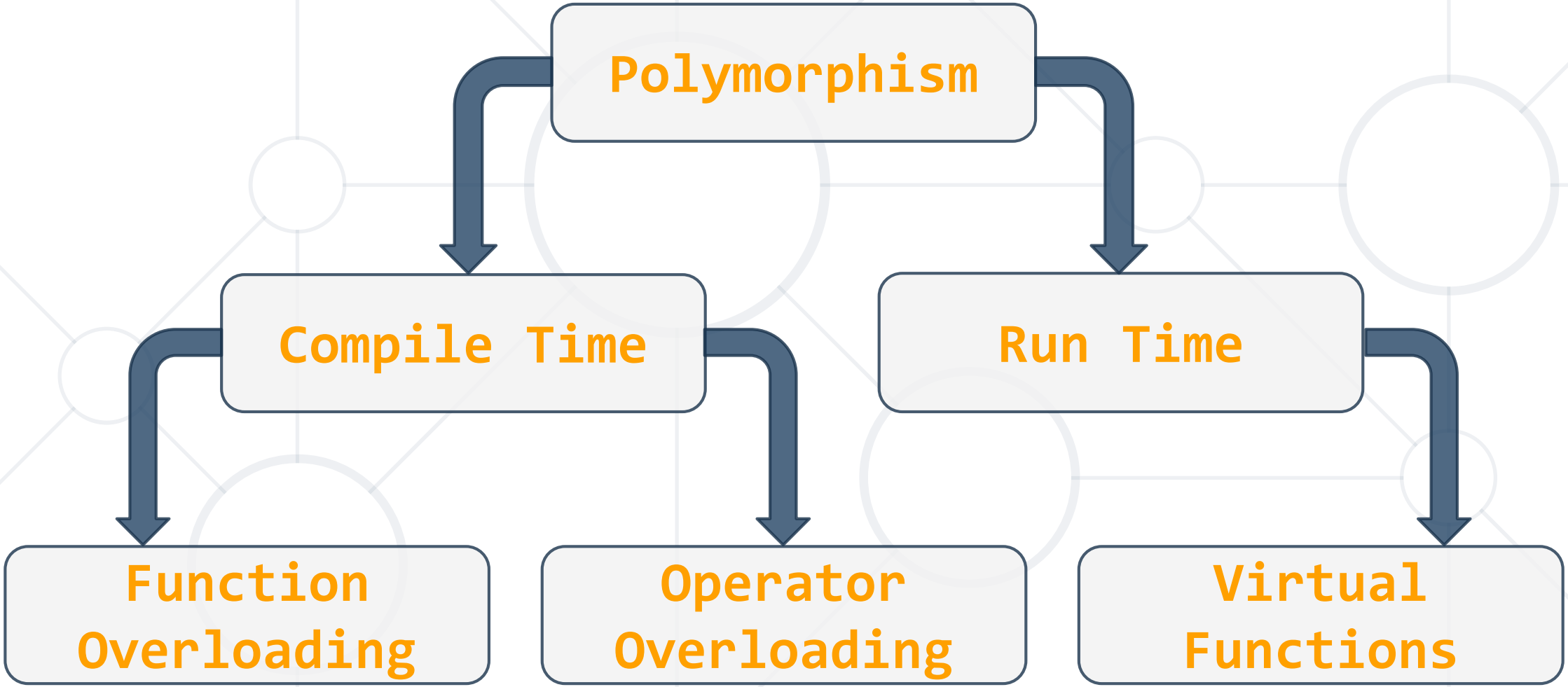
What is Polymorphism?

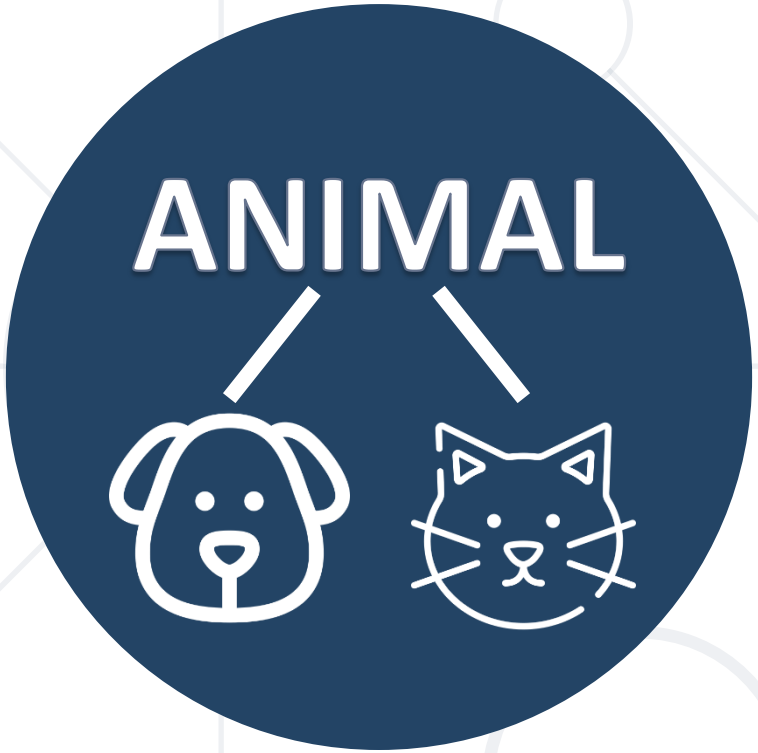
- From the Greek



- Such as a word having **several different meanings** based on the context
- Often referred to as **the third pillar of OOP**, after encapsulation and inheritance

Polymorphism Types





Compile Time Polymorphism

Compile Time Polymorphism

- Also known as Static Polymorphism
- This type of polymorphism is achieved by
  - Function overloading
  - Operator overloading
  - Template metaprogramming
- Argument lists could **differ** in
  - Number of parameters
  - Data type of parameters
  - Sequence of Data type of parameters

Rules for Overloading Method

- **Overloading** can take place in the **same class** or in its **sub-class**
- **Constructors** in C++ can be **overloaded**
- Overloaded methods must have a **different argument list**
- They may have the **same** or **different return types**

Function Overloading

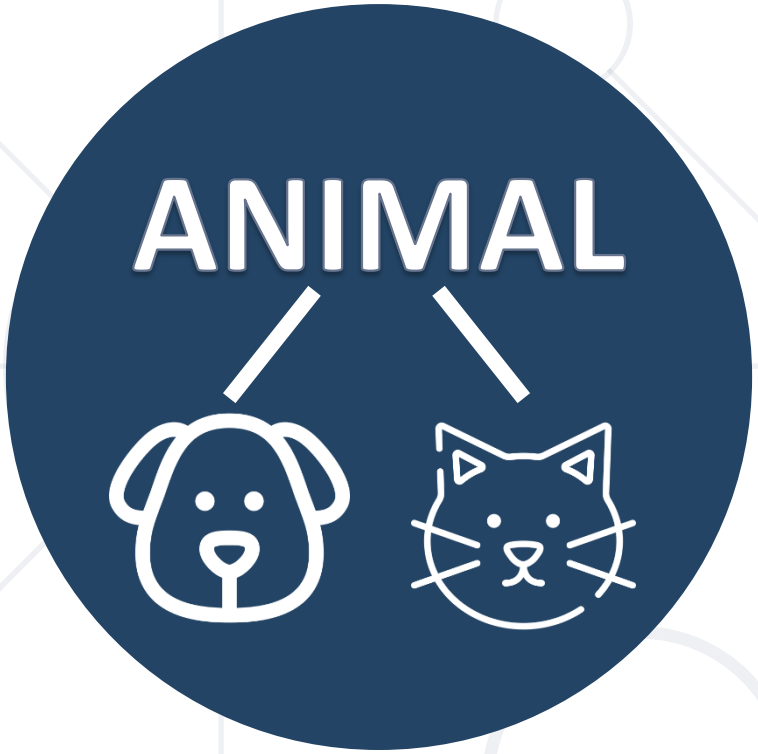
```
public:
  void func(int x)  {  // function with 1 int parameter
    cout << "value of x is " << x << endl; }
  void func(double x) {  // function with same name but 1 double parameter
    cout << "value of x is " << x << endl; }
  void func(int x, int y) {  // function with same name and 2 int parameters
    cout << "value of x and y is " << x << ", " << y << endl; }
};
int main() {
  func(13);
  func(13.2);
  func(33,43);
}
```

```
Output:
value of x is 13
value of x is 13.2
value of x and y is 33,43
```

Operator Overloading

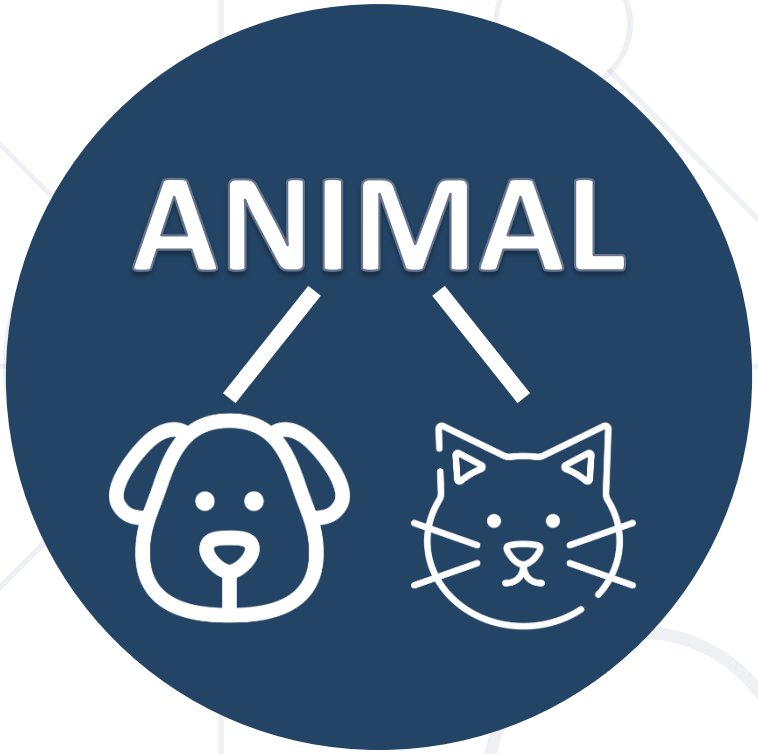
```
class Complex {
private:
  int real, imag;
public:
  Complex(int r = 0, int i=0)  { real = r; imag = i; }

  Complex operator + (Complex const &obj) { // This is automatically called when '+' is used with
    Complex res;  // between two Complex objects
    res.real = real + obj.real
    res.imag = imag + obj.imag;
    return res; }

  Void print() {count << real << " + i"<< imag << endl;
};

int main(){
  Complex c1(10, 5), c2(2,4);
  Complex c3 = c1 + c2; // An example call to "operator+"
  c3.print();
}
```

Output:
12 + i9



Compile Time Polymorphism

LIVE DEMO



Runtime Polymorphism

Runtime Polymorphism

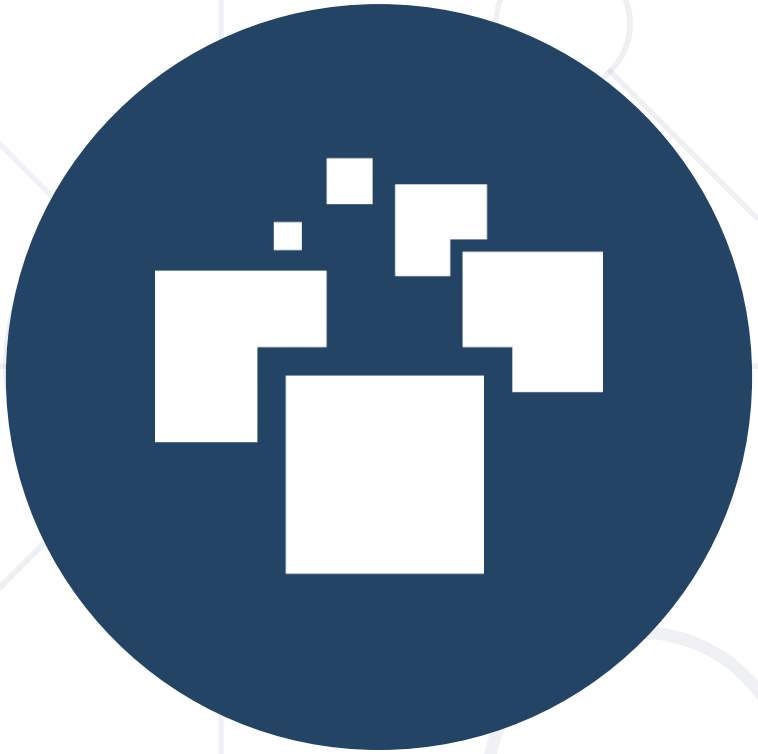
- Also known as **Dynamic Polymorphism**
- This type of polymorphism is achieved by **virtual methods**
- In order for virtual methods to be used - the function definition in the derived class must have the same definition as the one base class. That base function is said to be **overridden**

Base Pointers to Derived Objects

- **Base** pointers/references can point to **derived** objects
  - **upcast**, NO slicing – not fitting larger into smaller object
  - `Derived d; Base* p = &d;`
  - `Base* p = new Derived(); ...`
- Accesses base members, regardless of hiding

```
Airplane plane(510, 2400, 90);
Vehicle* v = &plane;
cout << v->toString() << endl; // calls Vehicle::toString()
```

  - Unless members are `virtual overrides`



Virtual Members and Overriding

virtual Members and override

- virtual methods – allow derived to change implementation
- override – placed after same-signature virtual in derived
  - Base has virtual void f()
  - Derived has virtual void f() override

```
class Vehicle {

  ...
  virtual void stop() {
    this->speed = 0;
  }
};
```

```
class Car : public Vehicle {
  ...
  virtual void stop() override {
    Vehicle::stop();
    this->parkingBrakeOn = true;
  }
};
```

Virtual Members and Base Pointers

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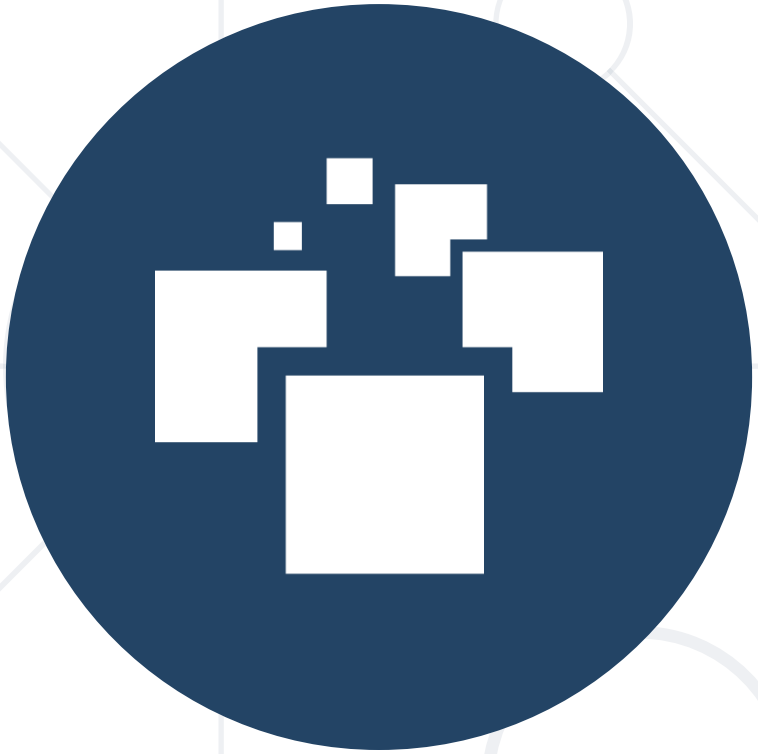
- Call **virtual** method from **base** pointer to **derived** object calls:
  - **Derived** method if there's a matching member
  - **Base** method otherwise

```
virtual void stop() { ... }                          // class Vehicle
virtual string toString() const { ... }
```

```
virtual string toString() const override { ... }     // class Airplane
virtual void stop() override { ... }
```

```
Vehicle* v = new Airplane plane(510, 2400, 90);
cout << v->toString() << endl; // calls Airplane::toString()
v->stop(); // calls Airplane::stop()
```



`virtual`, `override`, and Base Pointers

LIVE DEMO

Rules for Overriding Method

- **Overriding** can take place in **sub-class**
- **Argument list** must be the **same** as that of the **parent method**
- The overriding method must have **same return type**
- **Access modifier** cannot be more **restrictive**
- **Private**, **static** and **final** methods can **NOT** be overriden
- The overriding method **must not** throw new or broader **checked exceptions**

Quick Quiz TIME:

- Will this leak memory?

```
for (;;) {
  IndexedContainer* c =
    new IntArray(10);
  delete c;
}
```

```
class IndexedContainer { public:
  virtual int& operator[](int i) { ... };
};
class IntArray : public IndexedContainer {
int size; int* data;
public:
  IntArray(int size)
  : size(size), data(new int[size]) {}
  ~IntArray() { delete[] this->data; }

  virtual int& operator[](int i) override
  { ... }
};
```

a) Yes

b) No

c) Maybe

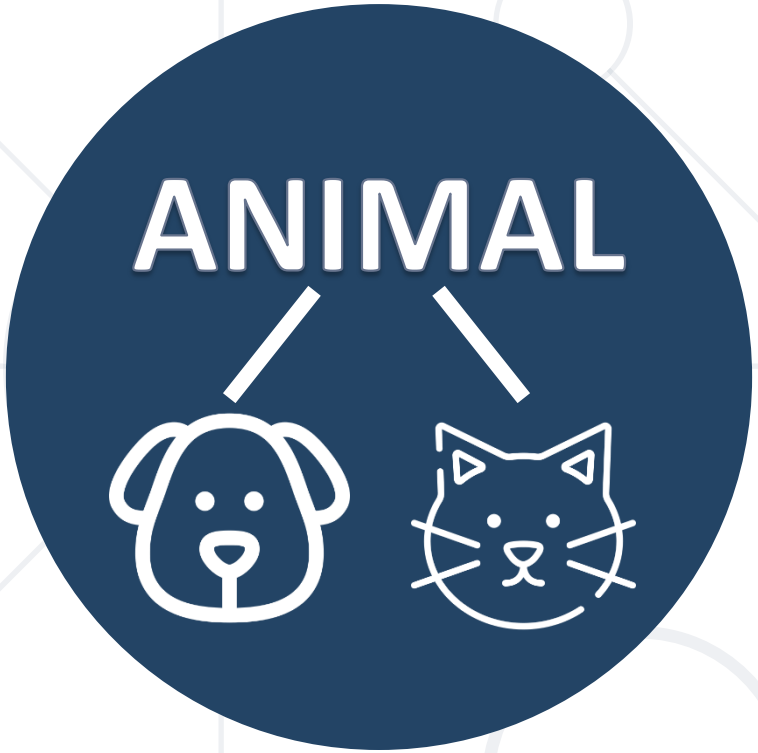
d) I don't know, can you repeat the question... ♪♫♬

C++ PITFALL: DELETE CALL ON BASE CLASS POINTER TO DERIVED CLASS, WHERE BASE HAS NO VIRTUAL DESTRUCTOR

Undefined behavior:

- **`delete`** a base class pointer
- to a derived class object
- if base has no virtual destructor

Most compilers will just call the destructor of the base class – which won't do deallocation for the derived class



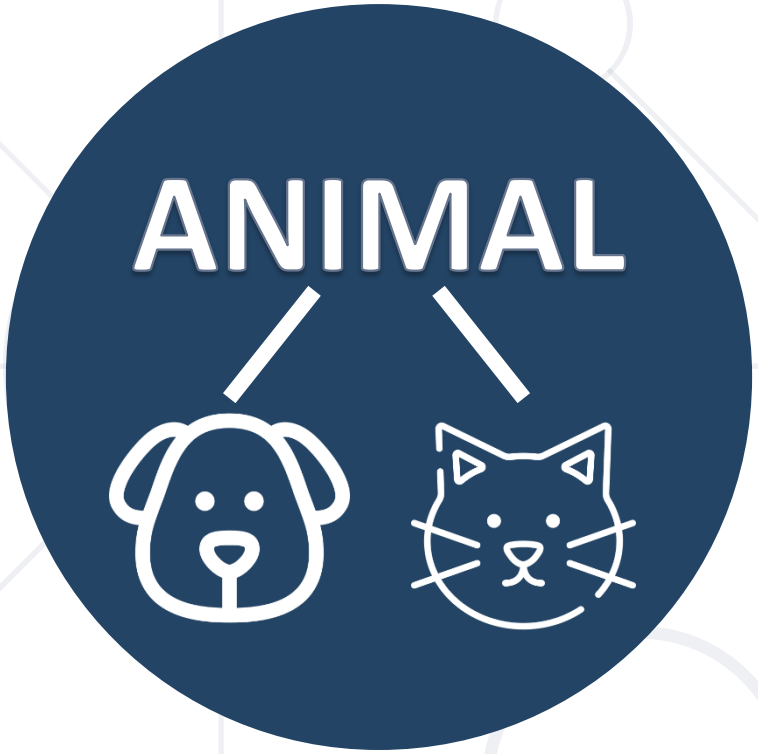
Using Polymorphism

Polymorphism

- **Base** class and **derived** class
- **`virtual`** methods in **base**, with **`overrides`** in **derived**
- **Base** pointers/references to **derived** objects, calling **`overrides`**
- **`virtual`** destructor in a base class

```
vector<Vehicle*> vehicles{
  new Airplane(...), new Car(...), new PlaygroundTrain()
};

for (auto vehiclePtr : vehicles) vehiclePtr->stop();
```



Using Polymorphism

LIVE DEMO

Polymorphism and Smart Pointers

- Smart pointers can be used as raw pointers in order to achieve polymorphism
- They are used in the same fashion

```
std::unique_ptr<Vehicle> v = std::unique_ptr<Vehicle>(new Car(50, false));
v->stop();
```

Polymorphism and Smart Pointers

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- Smart pointers could also be part of a container
  - This is the most common polymorphic approach

```
vector<Vehicle*> vehicles{
  new Airplane(...), new Car(...), new PlaygroundTrain()
};

std::vector<std::unique_ptr<Vehicle>> vehicles;
vehicles.push_back(std::unique_ptr<Vehicle>(new Car(50, false)));
…
for (const auto &vehiclePtr : vehicles) {
    vehiclePtr->stop();
}
```

Polymorphism and Smart Pointers

LIVE DEMO

Practice

Live Exercise in Class

Problem 1: Particle System

- Implement a particle system on the console simulating:
  - Raindrops (fall straight down)
  - Snowflakes (fall down & move sideways)
  - Meteorites (fall diagonally, leaving a fixed-length trace behind)
  - Lightning bolts (random downward pattern of particles, disappears as fast as each of the others does a move)
- Loop iterating **list** of `Particle*`, calls `update()` on each
  - Inherit `Particle` (`position`, `symbol`, `exists`) with the above

Specifics and Good Practices

Specifics and Good Practices

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- The `override` keyword is just a safeguard
  - No effect if a `virtual` base method exists
  - Compilation error if NO `virtual` base method
  - *Good practice: use always when intending an override*
- If class can be a base, declare a `virtual` destructor
  - `virtual ~ClassName() {}`
  - or `virtual ~ClassName() = default;`
  - *There are some exceptions to this, but it's an ok beginner rule*

Final Classes

- Inheriting from a final classes is forbidden

```
class Animal final {
   …
}
```

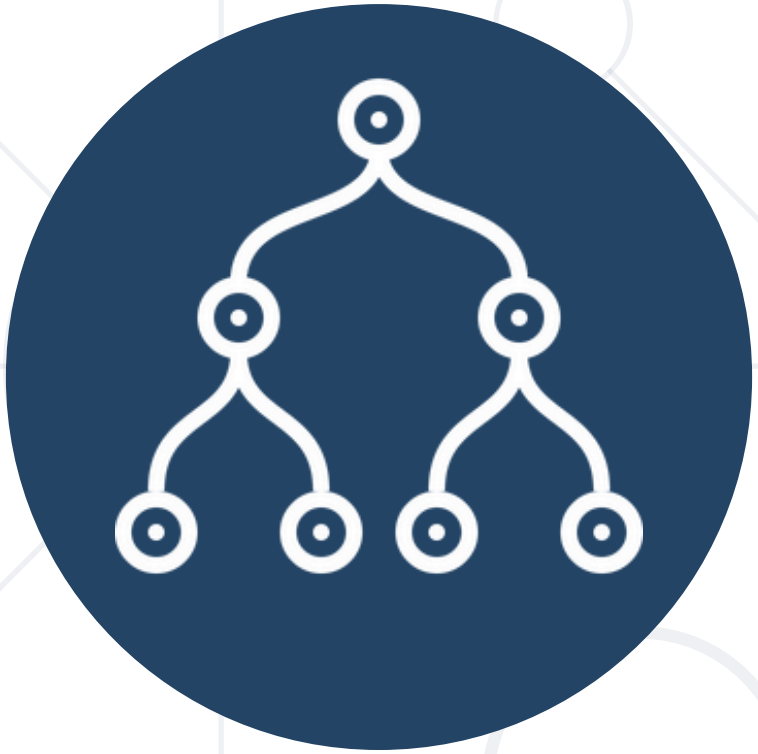
```
public class Dog :public Animal { }      // Error…
```

Final Methods

- `final` – defines a method that **can't be overridden**

```
class Animal {
      public:
virtual void eat() final { … }
}
```

```
class Dog : public Animal {
  public:
       void eat() override {}
// Error…
}
```



Inheritance in Memory

Why Base Pointers Work

Objects in Memory

- Fields in memory follow declaration order (usually)
  - "Padding" is auto-added to make size multiple of the biggest primitive data type used in the object.

```
class Organism {
float weight; bool eatsPlants; bool eatsAnimals;
public:
Organism(float w, bool p, bool a) : weight(w), eatsPlants(p), eatsAnimals(a) {}
};
```

```
Organism o(42, true, false);
```

Address	...	0x6afe4c…0x6afe4f	0x6afe50	0x6afe51	0x6afe52	0x6afe53	...
Byte	...	42	true	false	padding	padding	...

Inheritance in Memory

- **Base** class members inserted at start of **derived** object

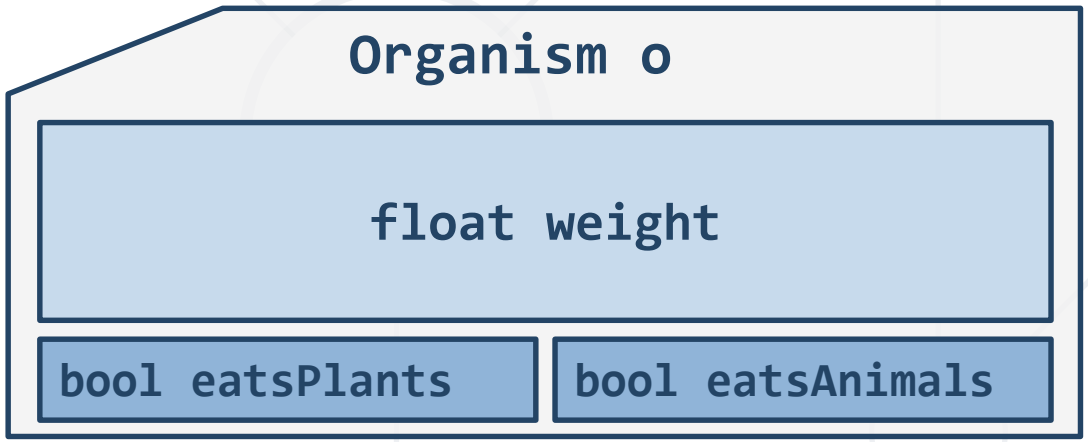
```
class Spider : public Organism {
  int numLegs; float weight; // NOTE: hiding weight field from Organism
public:
  Spider(int l, float w) : Organism(w, false, true), numLegs(l), weight(w) {}
};
```

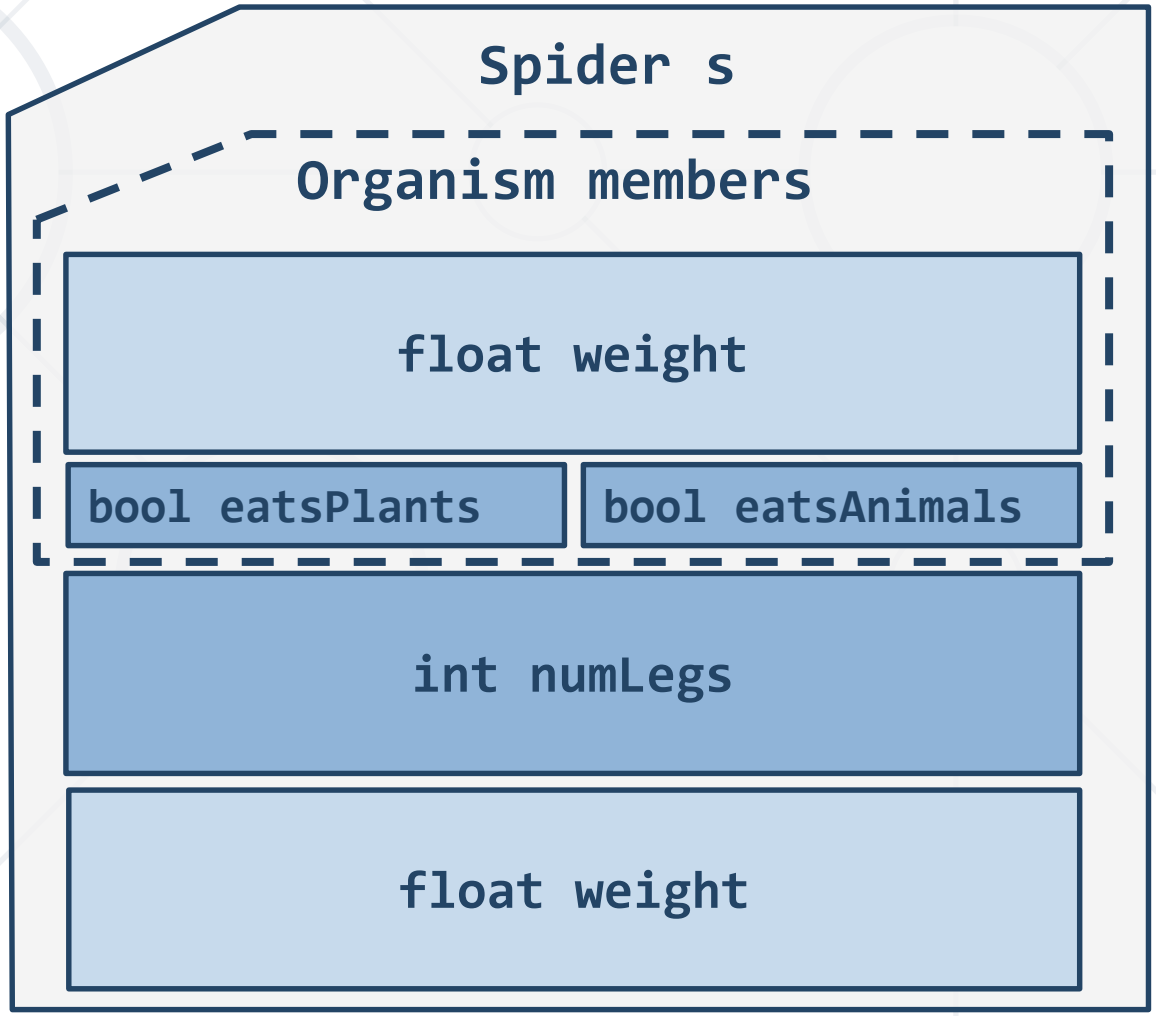
```
Spider s(6, 0.1);
```

Inheritance & Hidden Fields - Memory

```
class Organism {
float weight; bool eatsPlants;
bool eatsAnimals; ...
};
```

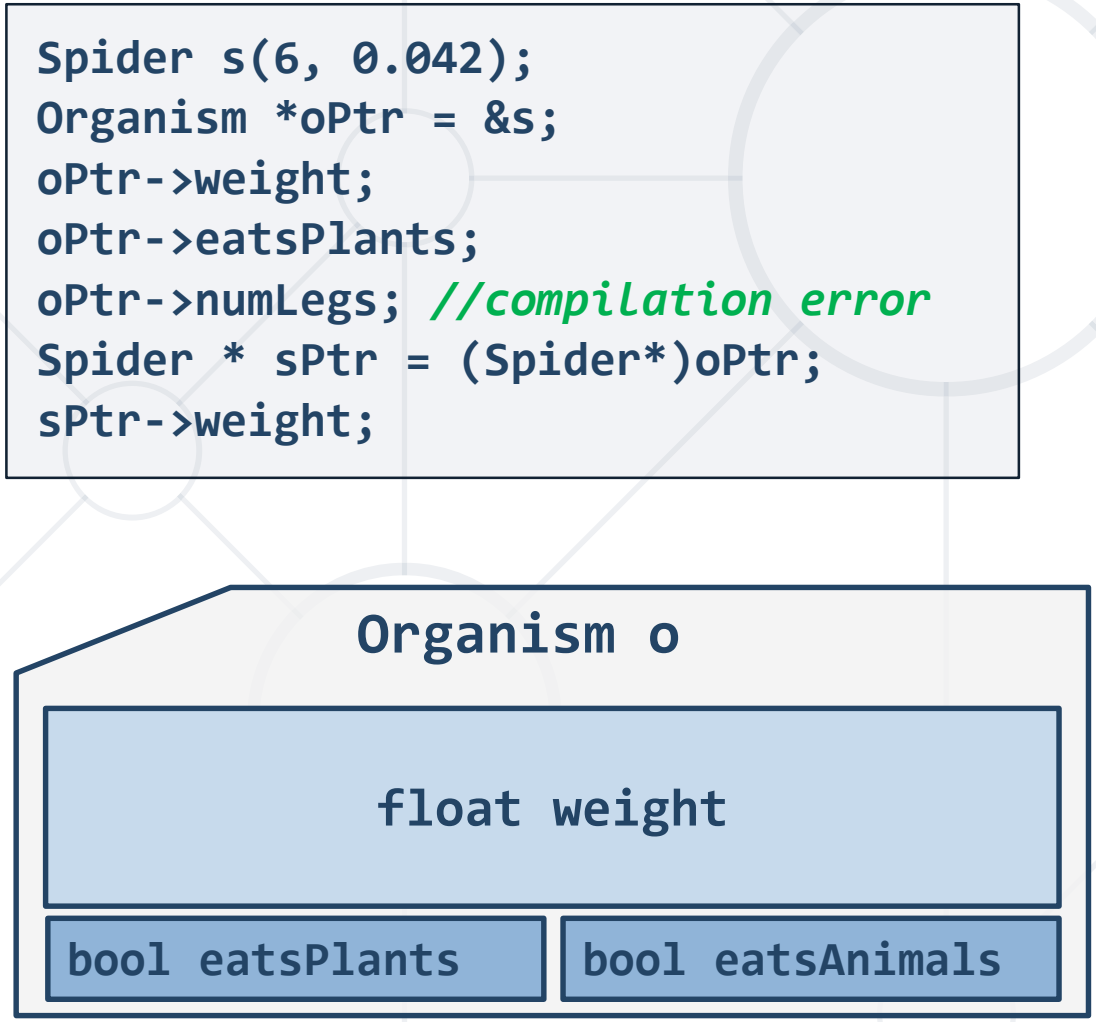
```
class Spider : public Organism {
  int numLegs; float weight;
  ...
};
```

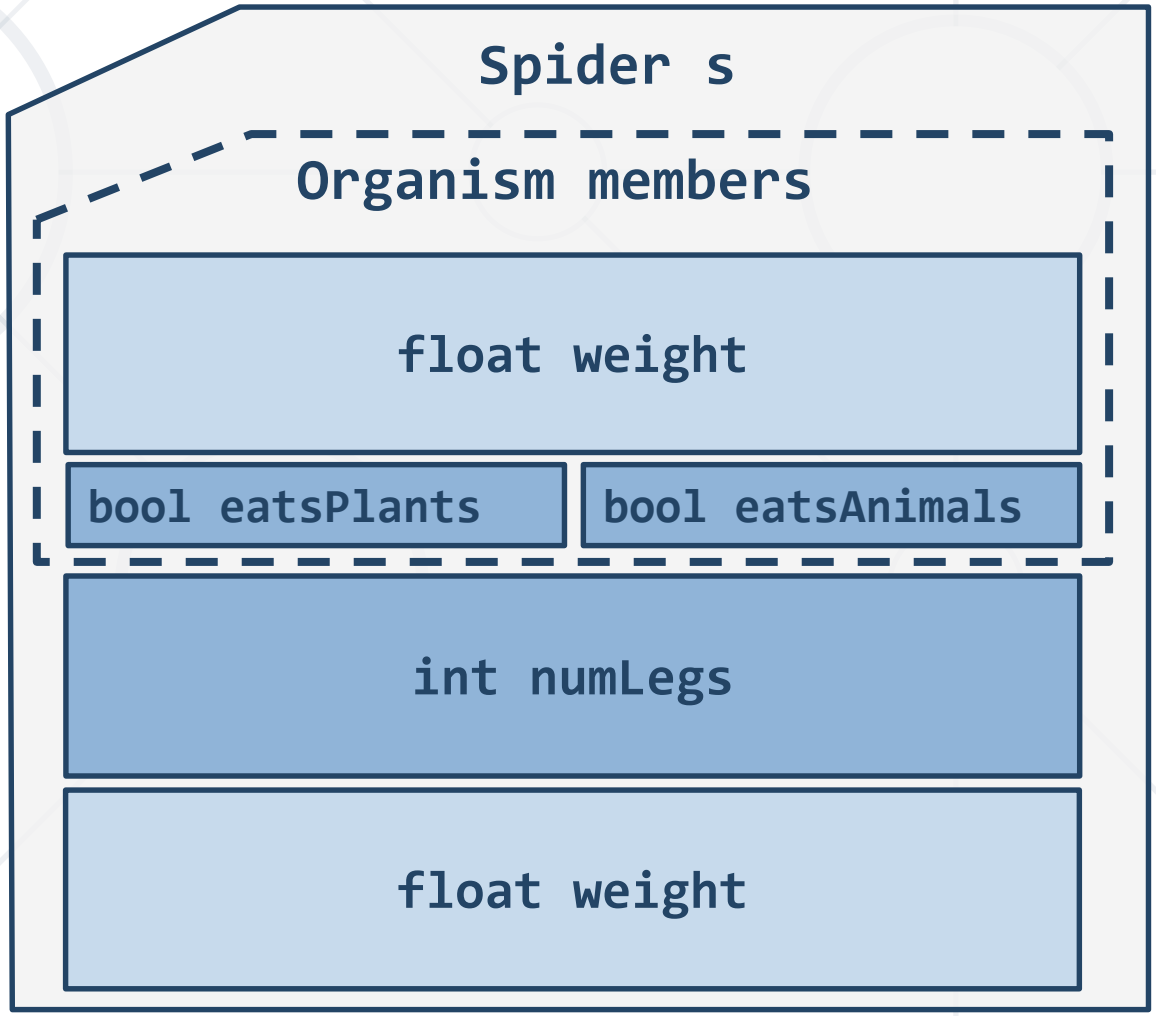


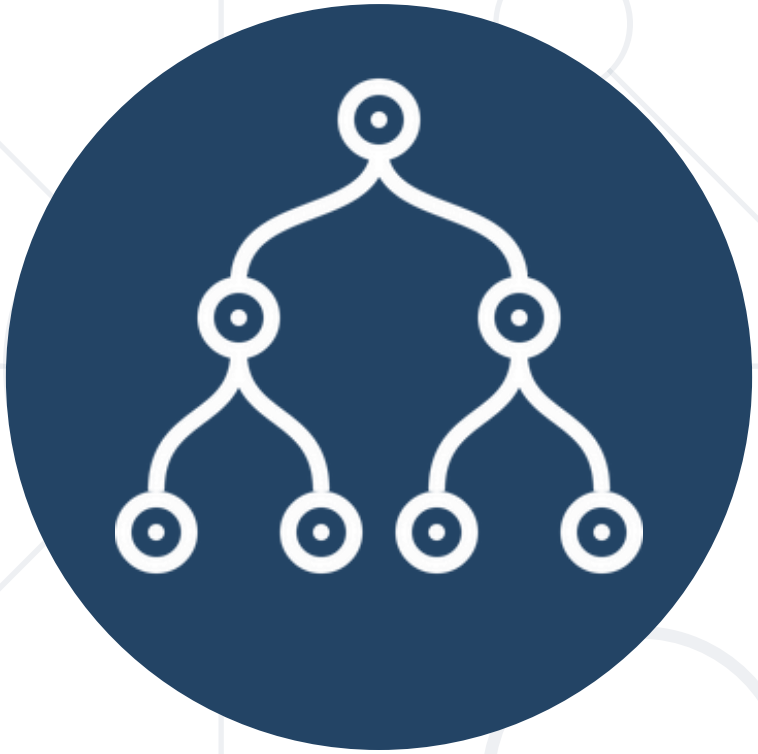


Inheritance & Hidden Fields - Pointers

```
Spider s(6, 0.042);
Organism *oPtr = &s;
oPtr->weight;
oPtr->eatsPlants;
oPtr->numLegs; //compilation error
Spider * sPtr = (Spider*)oPtr;
sPtr->weight;
```







Inheritance in Memory

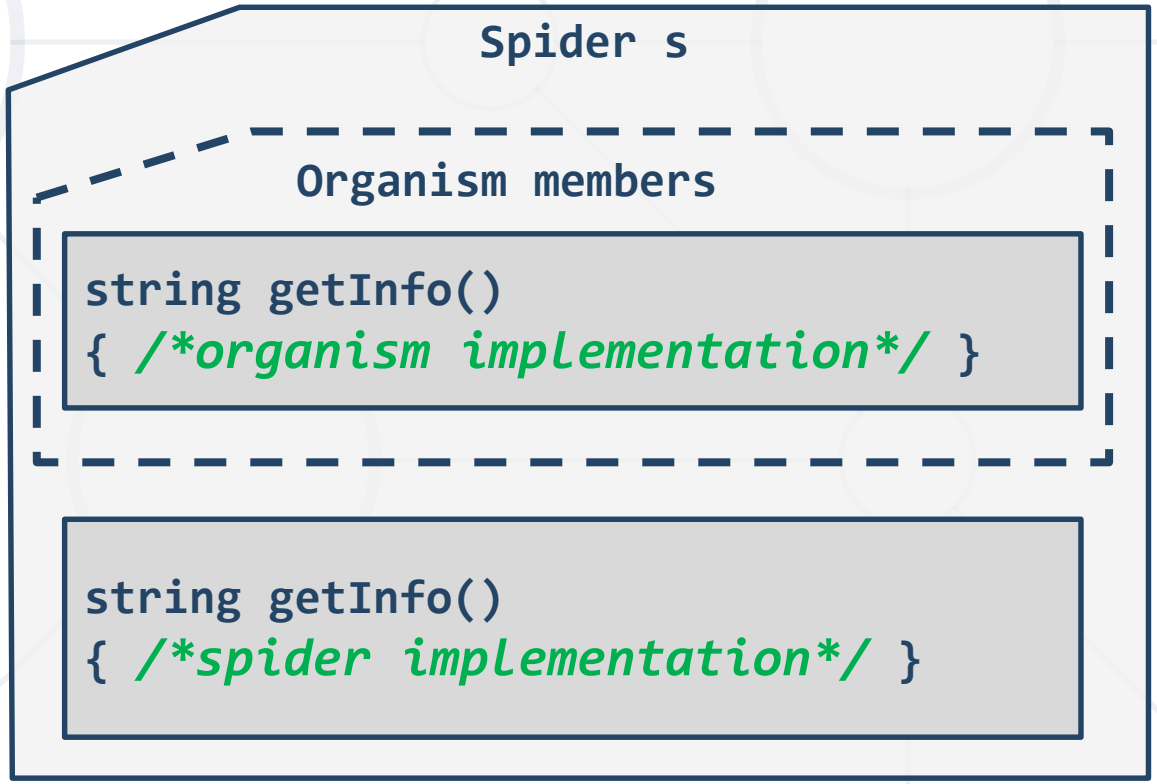
LIVE DEMO

Hidden Methods in Memory - NO virtual


```
class Organism { ...
  string getInfo() const {
    ...
  }
};
```

```
class Spider : public Organism { ...
  string getInfo() const {
    ...
  }
};
```

```
Spider s;
Organism *oPtr = &s;
oPtr->getInfo();
Spider *sPtr = &s;
sPtr->getInfo();
```

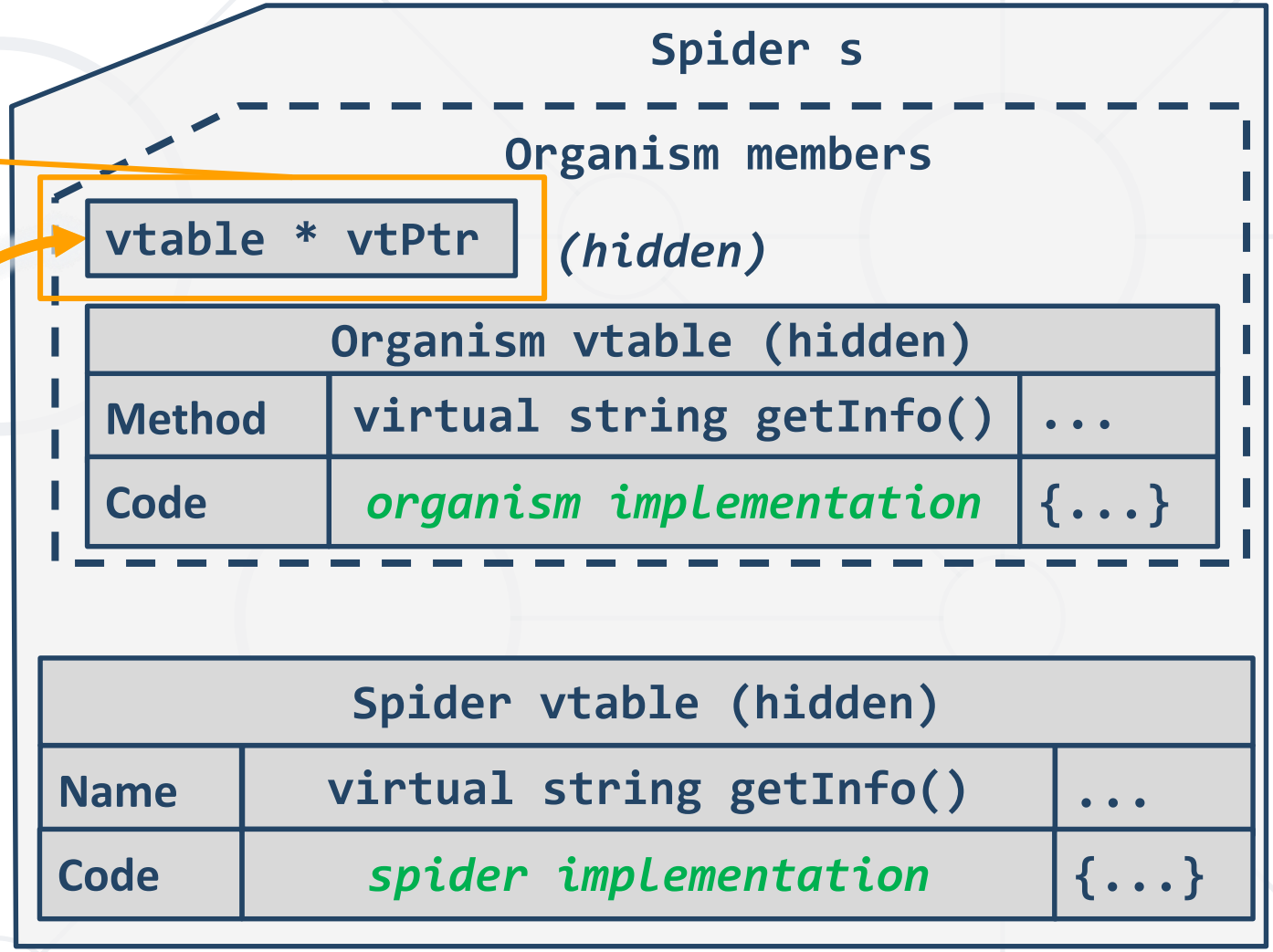


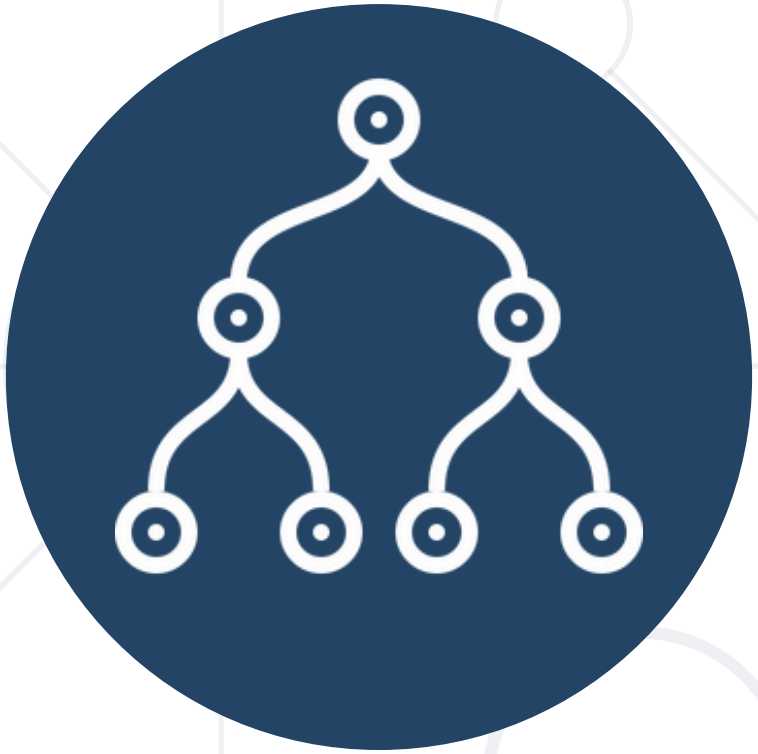
virtual Methods in Memory

```
class Organism { ...
  virtual string getInfo() const {
    ...
  }
};
```

```
class Spider : public Organism {
  virtual string getInfo() const {
    ...
  }
};
```

```
Spider s;
Organism *oPtr = &s;
oPtr->getInfo();
Spider *sPtr = &s;
sPtr->getInfo();
```





Plymorphism in Memory

LIVE DEMO

Summary

- Polymorphism - **Definition** and **Types**
- Override Methods
- Overload Methods
- **Virtual members** allow polymorphism
  - Treating objects as base pointers/references
  - Objects behave according to their overrides

Questions?

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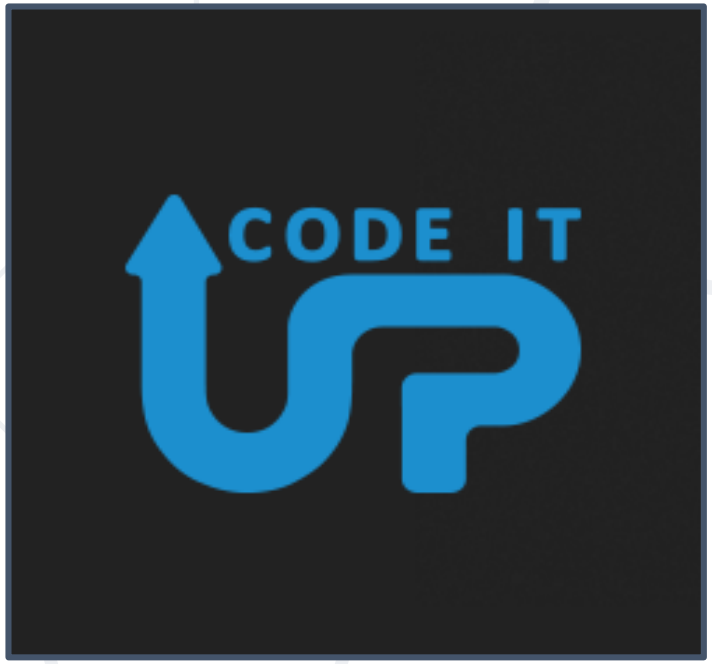

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