TDDE18 & 726G77

Inheritance & Polymorphism

Christoffer Holm

Department of Computer and information science

LINKÖPING UNIVERSITY

1 `std::vector`
2 Inheritance
3 Polymorphism
4 More on Polymorphism
5 Type information
6 Exceptions
7 Command-line argument

LINKÖPING UNIVERSITY

std::vector

Storage

- Linked storage
- Sequential Storage

`std::vector`

Storage

- Linked storage
  - Nodes linked together with pointers.
  - This is what we did in the List lab.
  - Very slow to access values in the middle of the collection since we have to loop from the beginning every time.
- Sequential Storage

`std::vector`

Storage

- Linked storage
- Sequential Storage
  - If we place everything next to each other in memory, then we know where each element is.
  - This is faster for accessing values in the middle.
  - However, it is now slower to insert values between two values and at the beginning.
  - This is how `std::vector` works!

std::vector

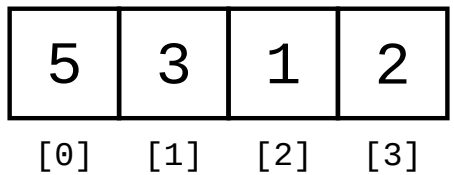
Sequential Storage

```
std::vector<int> v {5, 3, 1, 2};
```

std::vector

Sequential Storage

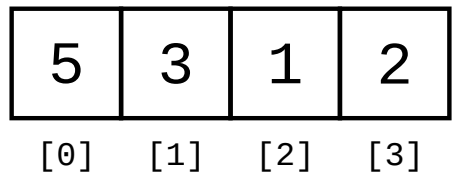
```
std::vector<int> v {5, 3, 1, 2};
```



std::vector

Sequential Storage

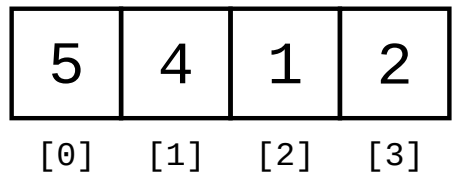
```
v.at(1) = 4;
```



std::vector

Sequential Storage

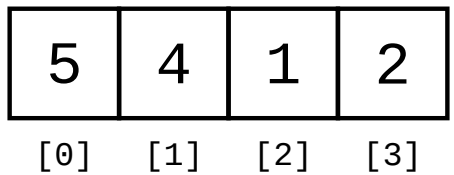
```
v.at(1) = 4;
```



std::vector

Sequential Storage

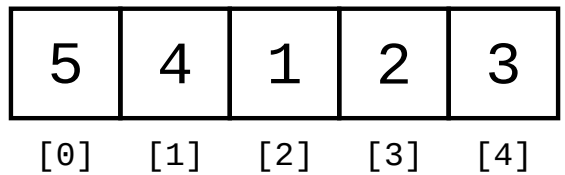
```
v.push_back(3);
```



std::vector

Sequential Storage

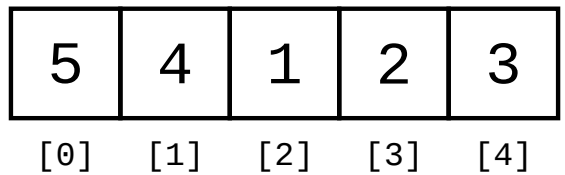
```
v.push_back(3);
```



std::vector

Sequential Storage

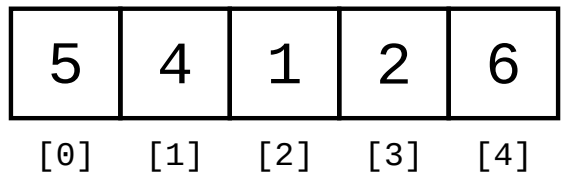
```
v.back() = 6;
```



std::vector

Sequential Storage

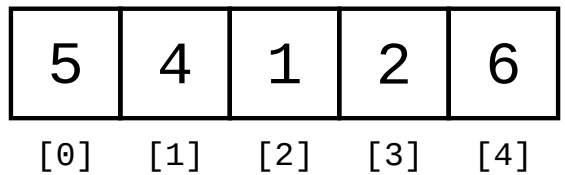
```
v.back() = 6;
```



std::vector

Sequential Storage

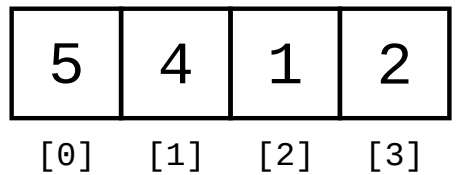
```
v.pop_back();
```



std::vector

Sequential Storage

```
v.pop_back();
```



`std::vector`

Sequential Storage

- `std::vector` is defined in `#include <vector>`
- Declared like this: `std::vector<T>`.
- A `std::vector<T>` contains a sequence of values that has the data type `T`.
- For example: `std::vector<int>` is a vector that stores integers.

`std::vector`

Sequential Storage

- Each element in a `std::vector` is indexed, beginning with `0` being the first element.
- Element `i` in vector `v` can be accessed with either `v[i]` or `v.at(i)`.
- `v.at(i)` will check that element `i` exists, so it is preferred over `v[i]`.
- First element can be accessed with `v.front()` and last with `v.back()`.

`std::vector`

Sequential Storage

- It is possible to insert values at the end with `v.push_back(3)`.
- To remove the last element, you write `v.pop_back()`.
- To see how many elements there are, write `v.size()`.

std::vector

Looping through

```
vector<string> words {...};
for (int i{0}; i < words.size(); ++i)
{
  cout << words.at(i) << endl;
}
```

std::vector

Looping through

```
vector<string> words {...};
for (string word : words)
{
  cout << word << endl;
}
```

std::vector

Looping through

```
vector<string> words {...};
for (string const& word : words)
{
  cout << word << endl;
}
```

`std::vector`

Looping through

- There are multiple ways to loop through a `vector`
- The first is to use a counter that goes through each index in order.
- The second way is what's know as a *range based for-loop*.
- A range based for-loop looks like this: `for (int e : v)`

`std::vector`

Looping through

- You can read it as: Loop through `v`, for each iteration the current element is stored in `e`.
- However, each element is *copied* into `e`.
- `for (int& e : v)` does not copy the element in to `e`, and it allows us to change the values inside the loop.
- Since copying is unnecessary for most cases where we want to read the elements, it is recommended that you loop through `v` like this: `for (int const& e : v)`

std::vector

Example

```
#include <vector>
#include <iostream>
using namespace std;
int main()
{
  vector<int> values{};
  int value{};

  // read values until ctrl+D
  while (cin >> value)
  {
    values.push_back(value);
  }

  // double each value
  for (int& e : values)
  {
    e = 2*e;
  }
}
```

LINKÖPING UNIVERSITY

Inheritance

```
class Rectangle
{
public:
  Rectangle(double w, double h)
    : width{w}, height{h} { }

  double area() const
  {
    return height * width;
  }
  double get_height() const
  {
    return height;
  }
  double get_width() const
  {
    return width;
  }
private:
  double width;
  double height;
};
```

```
class Triangle
{
public:
  Triangle(double w, double h)
    : width{w}, height{h} { }

  double area() const
  {
    return height * width / 2;
  }
  double get_height() const
  {
    return height;
  }
  double get_width() const
  {
    return width;
  }
private:
  double width;
  double height;
};
```

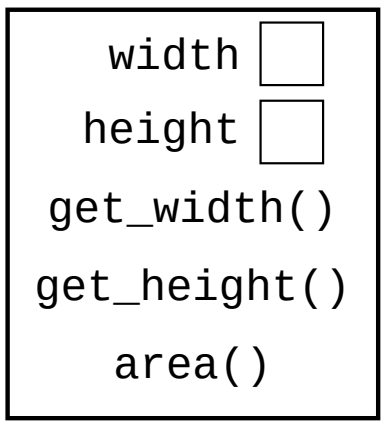
Inheritance

Is there a problem?

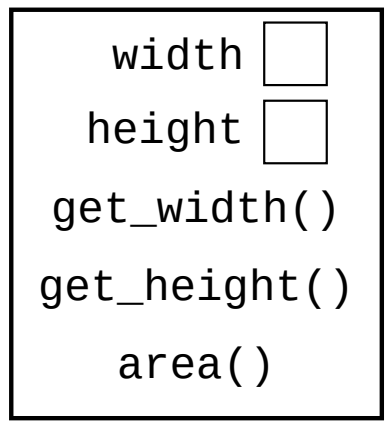
- There is a lot of code repetition here.
- We want to factor out common code, just as we did with similar functions.
- In the example above, `Rectangle` and `Triangle` share everything except the implementation of `area()`.
- How do we do this?

Inheritance

What is inheritance?



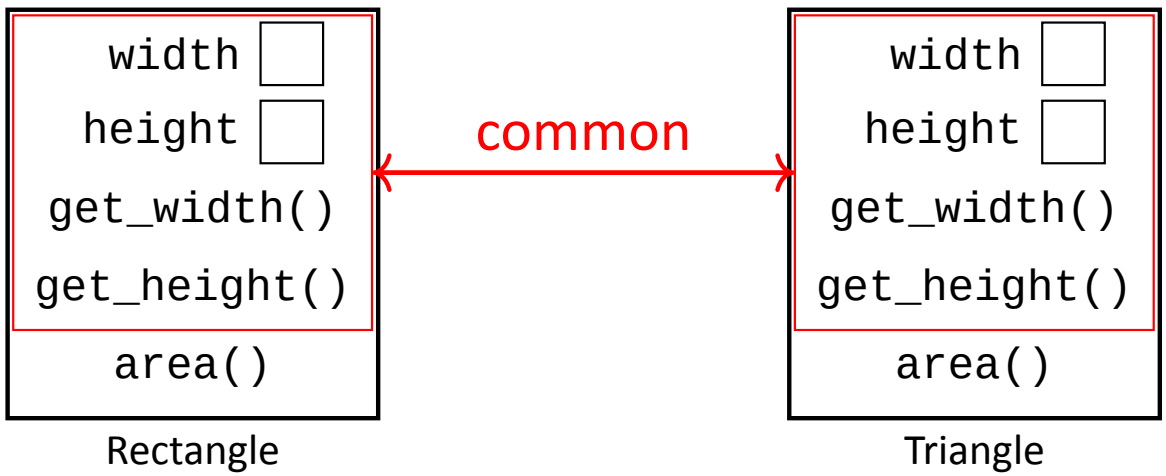
Rectangle



Triangle

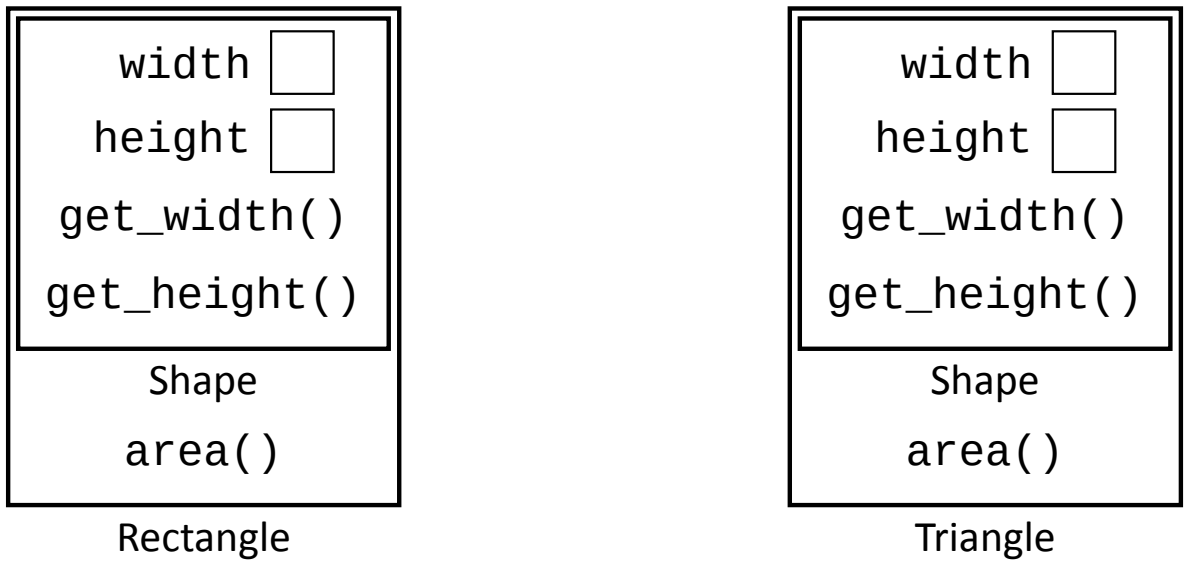
Inheritance

What is inheritance?



Inheritance

What is inheritance?



Inheritance

Terminology

- The class that contains the shared functionality is called a *Base class*.
- A class that inherits another class (a base class) is called a *Derived class*.
- A derived class inherits all the members (both functions and variables) from its base class.
- Sometimes we say that the derived class *extends* the base class, i.e. it takes everything from the base class and then add more things on top of that.

Inheritance

Syntax

```
class Base
{
  // ...
};

class Derived : public Base
{
  // ...
};
```

Inheritance

Syntax

- `Derived` *inherits* from `Base`.
- This is done by adding `: public Base` at the end of the class declaration.
- I.e. by writing: `class Derived : public Base`

Inheritance

```
// common code
class Shape
{
public:

  Shape(double w, double h)
    : width{w}, height{h} { }

  double get_height() const
  {
    return height;
  }

  double get_width() const
  {
    return width;
  }

private:

  double width;
  double height;
};
```

Inheritance

```
// common code
class Shape
{
public:

  Shape(double w, double h)
    : width{w}, height{h} { }

  double get_height() const
  {
    return height;
  }

  double get_width() const
  {
    return width;
  }

private:

  double width;
  double height;
};
```

```
class Rectangle : public Shape
{
public:
  Rectangle(double w, double h)
    : width{w}, height{h} { }

  double area() const
  {
    return width * height;
  }
};

class Triangle : public Shape
{
public:
  Triangle(double w, double h)
    : width{w}, height{h} { }

  double area() const
  {
    return width * height / 2;
  }
};
```

Inheritance

```
Shape.cc: In constructor ‘Rectangle::Rectangle(double, double)’:
Shape.cc: error: ‘double Shape::width’ is private within this context
     : width{w}, height{h} { }
       ^~~~~
Shape.cc: note: declared private here
   double width;
          ^~~~~
Shape.cc: error: ‘double Shape::height’ is private within this context
     : width{w}, height{h} { }
                 ^~~~~~
Shape.cc: note: declared private here
   double height;
          ^~~~~~
```

Inheritance

Delegating constructor

- `width` and `height` are `private` in `Shape`.
- This means that `Rectangle` does not have access to them.
- The constructor can therefore not initialize those members.
- But, we can call the constructor of `Shape` which does in fact have access to them to initalize these objects.
- You do this by adding `Shape{w, h}` to the start of the member initialization list.

Inheritance

Delegating constructor

```
Rectangle(double w, double h)
  : Shape{w, h} { }
```

Inheritance

```
// common code
class Shape
{
public:

  Shape(double w, double h)
    : width{w}, height{h} { }

  double get_height() const
  {
    return height;
  }

  double get_width() const
  {
    return width;
  }

private:

  double width;
  double height;
};
```

```
class Rectangle : public Shape
{
public:
  Rectangle(double w, double h)
    : Shape{w, h} { }

  double area() const
  {
    return width * height;
  }
};

class Triangle : public Shape
{
public:
  Triangle(double w, double h)
    : Shape{w, h} { }

  double area() const
  {
    return width * height / 2;
  }
};
```

Inheritance

```
Shape.cc: In member function ‘double Rectangle::area() const’:
Shape.cc: error: ‘double Shape::width’ is private within this context
     return width * height;
            ^~~~~
Shape.cc: note: declared private here
   double width;
          ^~~~~
Shape.cc: error: ‘double Shape::height’ is private within this context
     return width * height;
                    ^~~~~~
Shape.cc: note: declared private here
   double height;
          ^~~~~~
```

Inheritance

`protected`

- As mentioned before; `width` and `height` are `private` in `Shape`.
- This means that neither `Rectangle::area` nor `Triangle::area` have access to these variables.
- There are two ways to solve it: replace each access to `width` with `get_width()` and likewise for `height`,
- **OR** we make sure that `width` and `height` are available for `Rectangle` and `Triangle`.

Inheritance

```
// common code
class Shape
{
public:

  Shape(double w, double h)
    : width{w}, height{h} { }

  double get_height() const
  {
    return height;
  }

  double get_width() const
  {
    return width;
  }

protected:

  double width;
  double height;
};
```

```
class Rectangle : public Shape
{
public:
  Rectangle(double w, double h)
    : Shape{w, h} { }

  double area() const
  {
    return width * height;
  }
};

class Triangle : public Shape
{
public:
  Triangle(double w, double h)
    : Shape{w, h} { }

  double area() const
  {
    return width * height / 2;
  }
};
```

Inheritance

`protected`

- `protected` is the third and final access specifier for members in a class.
- It is the same as `private`, but with one difference: these members are also accessible by all derived classes.
- Which means: `protected` things are secrets kept within the family (inheritance hierarchy), while `private` things are secrets kept by the individual (class).

Inheritance

Data members in derived class

```
class Named_Rectangle : public Rectangle
{
public:
  Named_Rectangle(int width, int height, std::string const& name)
    : Rectangle{width, height}, name{name}
  { }
private:
  std::string name{};
};
```

Inheritance

Initialization & Destruction

```
Named_Rectangle r {12, 13, "My Rectangle"};
```

Inheritance

Initialization & Destruction

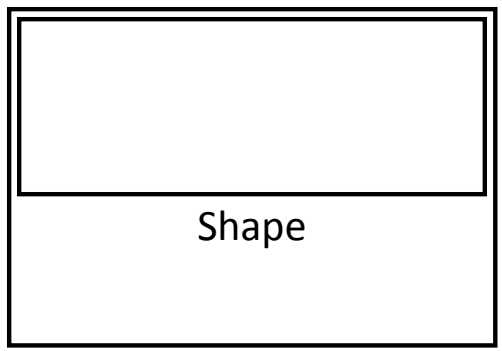
```
Named_Rectangle r {12, 13, "My Rectangle"};
```

Named_Rectangle

Inheritance

Initialization & Destruction

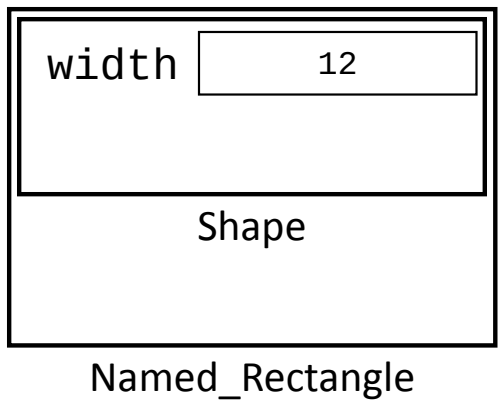
```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Inheritance

Initialization & Destruction

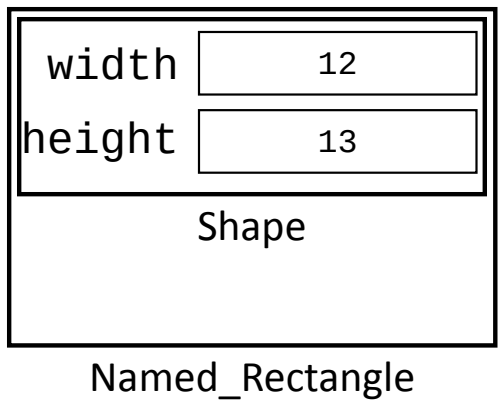
```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Inheritance

Initialization & Destruction

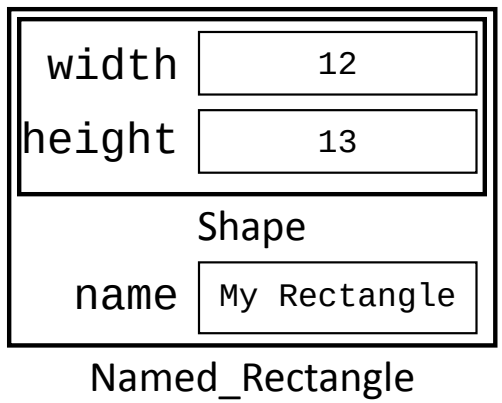
```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Inheritance

Initialization & Destruction

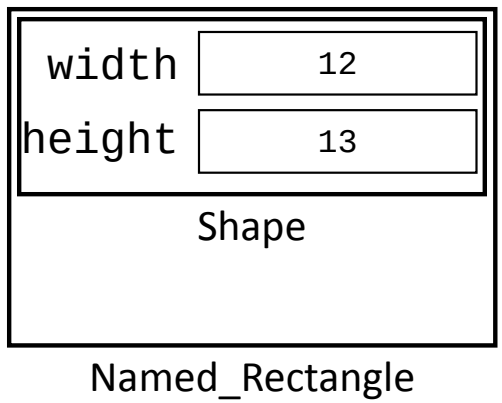
```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Inheritance

Initialization & Destruction

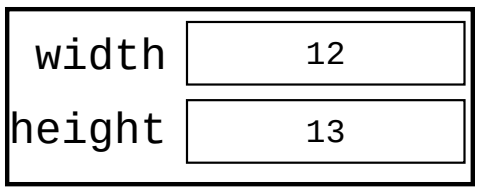
```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Inheritance

Initialization & Destruction

```
Named_Rectangle r {12, 13, "My Rectangle"};
```

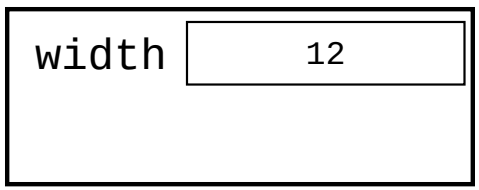


Shape

Inheritance

Initialization & Destruction

```
Named_Rectangle r {12, 13, "My Rectangle"};
```



Shape

Inheritance

Initialization & Destruction

```
Named_Rectangle r {12, 13, "My Rectangle"};
```

Shape

Inheritance

Initialization & Destruction

```
Named_Rectangle r {12, 13, "My Rectangle"};
```

Inheritance

Initialization & Destruction

- The top base class of the hierarchy will be constructed first and then its derived class.
- Each data member will be construct top-to-bottom in declaration order (irregardless of the order in the data member initialization list).
- The objects will be destructed in reverse order of construction by first destroying each data member bottom-to-top and then recursively destroying the base class.

Inheritance

Binding to references

```
void print_height(Triangle& triangle)
{
  cout << triangle.get_height() << endl;
}

void print_height(Rectangle& triangle)
{
  cout << triangle.get_height() << endl;
}
```

Inheritance

Binding to references

```
void print_height(Shape& shape)
{
  cout << shape.get_height() << endl;
}
```

Inheritance

Binding to references

- The implementation for both versions of `print_height()` are exactly the same.
- Since `get_height()` for `Rectangle` and `Triangle` is implemented in `Shape`, we can get away with just looking at the `Shape` part of the objects.
- By taking the parameter as a `Shape&` we can bind both `Rectangle` and `Triangle` in the same function.

Inheritance

`area()`

```
void print_area(Shape& shape)
{
  cout << shape.area() << endl;
}
```

Inheritance

`area()`

```
Shape.cc: In function ‘void print_area(Shape&)’:
Shape.cc: error: ‘class Shape’ has no member named ‘area’
   cout << shape.area() << endl;
                 ^~~~
```

Inheritance

`area()`

- The parameter `shape` is of type `Shape&`, meaning we can only access things that resides in `Shape`.
- This means that we cannot call `area` since it hasn't been declared in `Shape`.

Inheritance

Let's add `area()` to `Shape`

```
class Shape
{
public:
  // ...
  double area() const
  {
    return 0;
  }
  // ...
};
```

```
class Rectangle : public Shape
{
public:
  // ...
  double area() const
  {
    return width * height;
  }
  // ...
};
```

Inheritance

Let's add `area()` to `Shape`

```
int main()
{
  Rectangle r {10, 15};
  cout << print_area(r) << endl; // print 0
}
```

Inheritance

Let's add `area()` to `Shape`

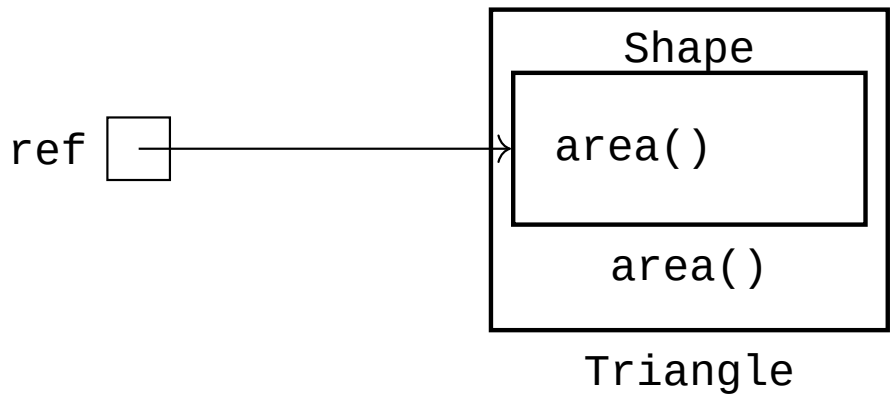
- We can solve the problem by adding `area()` to `Shape`!
- However this poses a new problem. In `print_area()` we always call `Shape::area()`.
- This is not what we want, we want to call the `area()` function of whichever type we pass in to the function...
- This problem can be solved with *Polymorphism*!

LINKÖPING UNIVERSITY

Polymorphism

Many forms

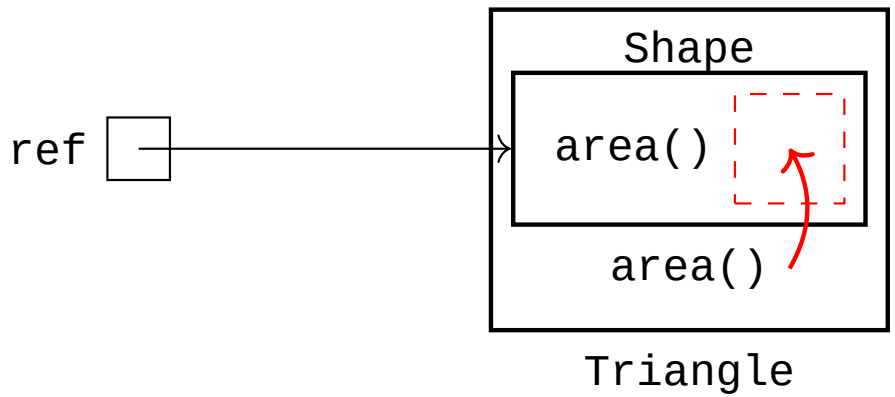
```
Triangle r{...};
Shape& ref {r};
```



Polymorphism

Many forms

```
Triangle r{...};
Shape& ref {r};
```



Polymorphism

Many forms

- The way we solve the problem with `print_area()` calling the wrong version is by letting derived classes override the functionality of `Shape::area()`.
- I.e. we want the implementation of `Shape::area()` to be replaceable,
- because then the derived class could simply replace the implementation of `area()` in `Shape` with its own implementation of `area()`.
- This is done by declaring `Shape::area()` as `virtual`.

Polymorphism

Many forms

```
class Shape
{
public:
  // ...
  virtual double area() const
  {
    return 0;
  }
  // ...
};
```

Polymorphism

Now it works!

```
int main()
{
  Rectangle r {10, 15};
  cout << print_area(r) << endl; // prints 150
}
```

Polymorphism

Now it works!

```
int main()
{
  Rectangle r {10, 15};
  cout << print_area(r) << endl; // prints 150
}
```

It works!!

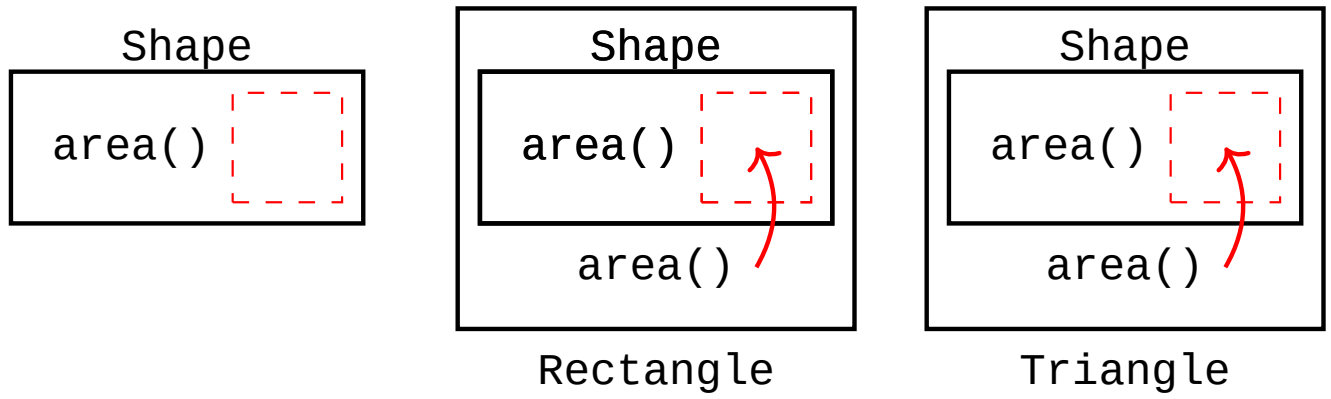
Polymorphism

When can we use polymorphism?

```
Shape s{};
Rectangle r{10, 15};
Triangle  t{3, 4};

Shape* ptr {&s};
ptr->area(); // returns 0

ptr = &r;
ptr->area(); // returns 150

ptr = &t;
ptr->area(); // returns 6
```

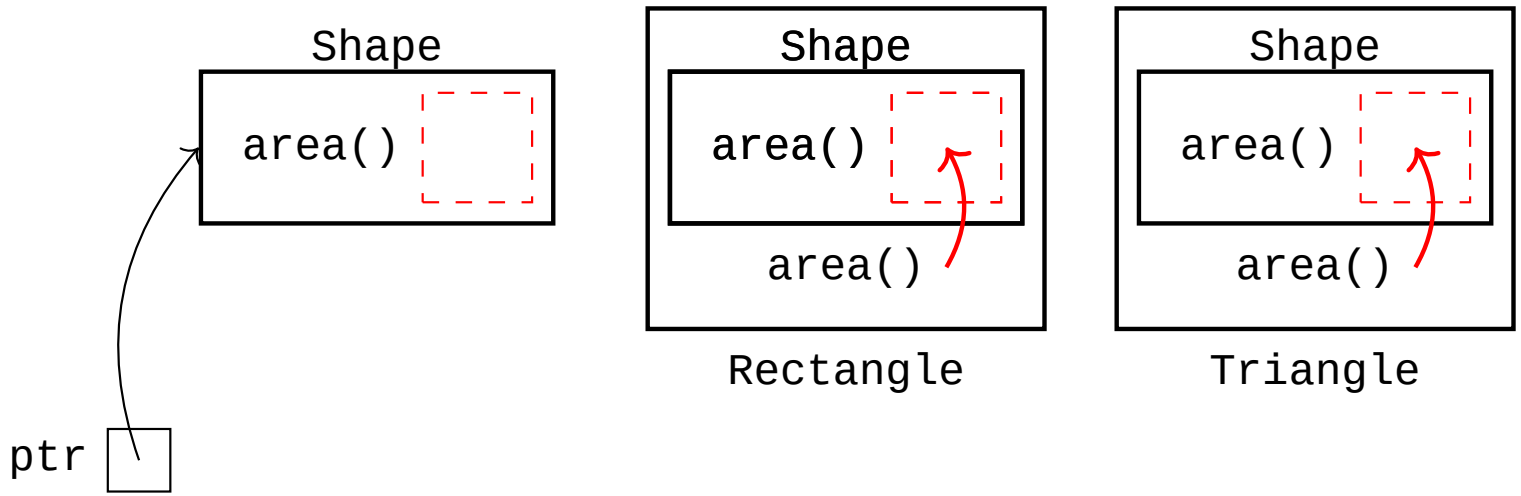
Polymorphism

Pointers & Polymorphism



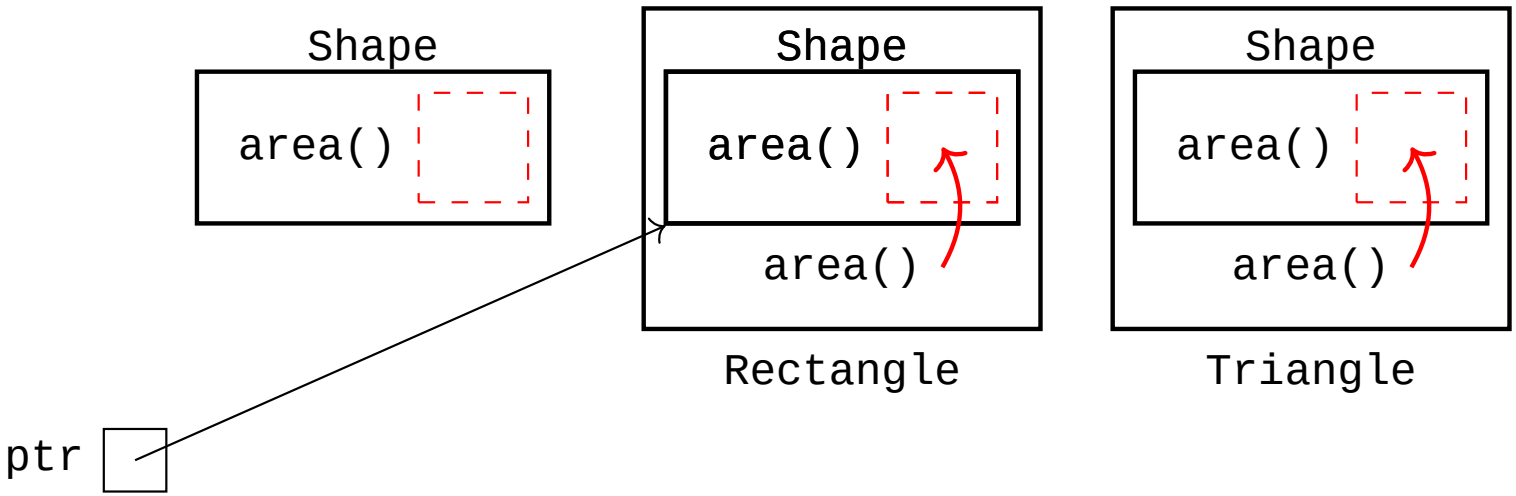
Polymorphism

Pointers & Polymorphism



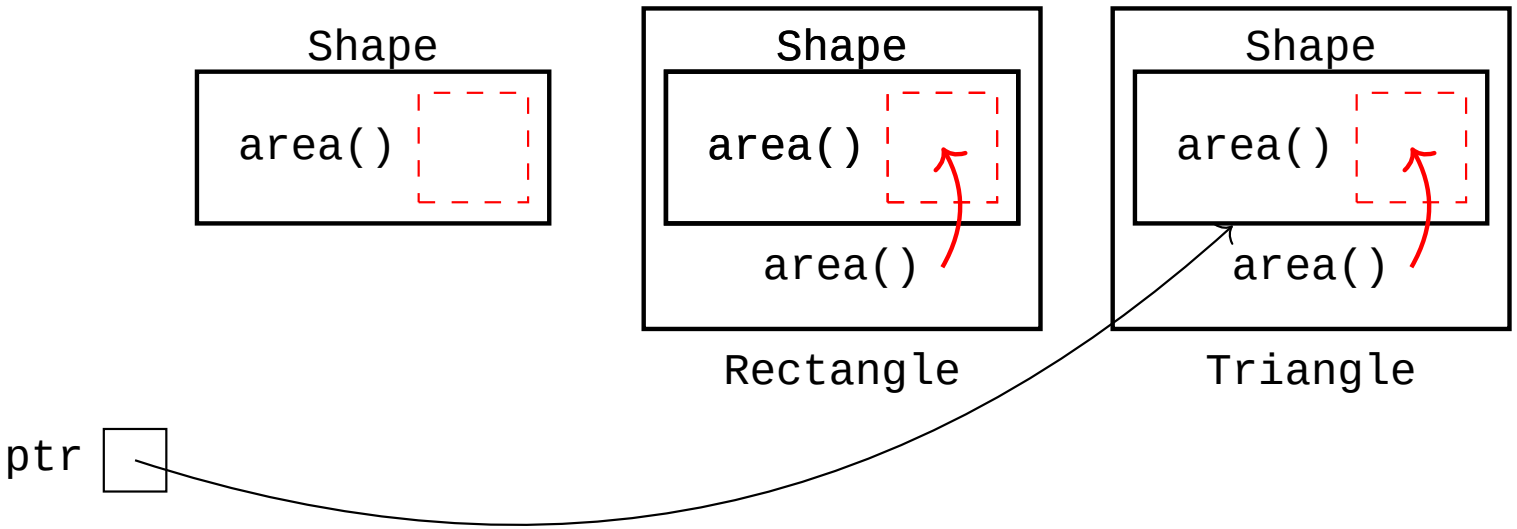
Polymorphism

Pointers & Polymorphism



Polymorphism

Pointers & Polymorphism



Polymorphism

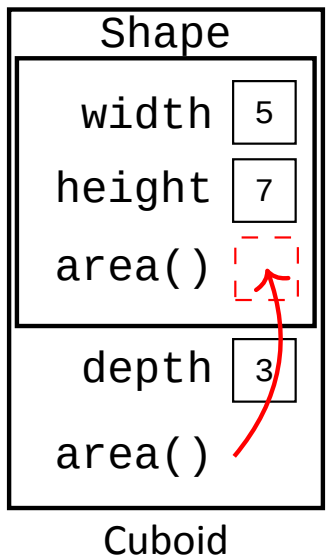
There are pitfalls...

```
class Cuboid : public Shape
{
public:
  Cuboid(double width, double height, double depth)
    : Shape{width, height}, depth{depth}
  { }

  double area() const
  {
    return 2.0 * (width * height + width * depth + height * depth);
  }

private:
  double depth;
};
```

Polymorphism

There are pitfalls...

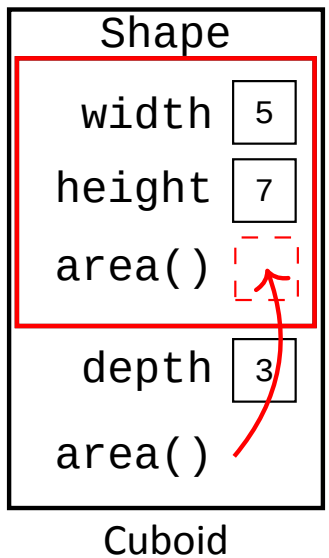
```
Cuboid c{5, 7, 3};
Shape s {c}; // slicing
```



Polymorphism

There are pitfalls...

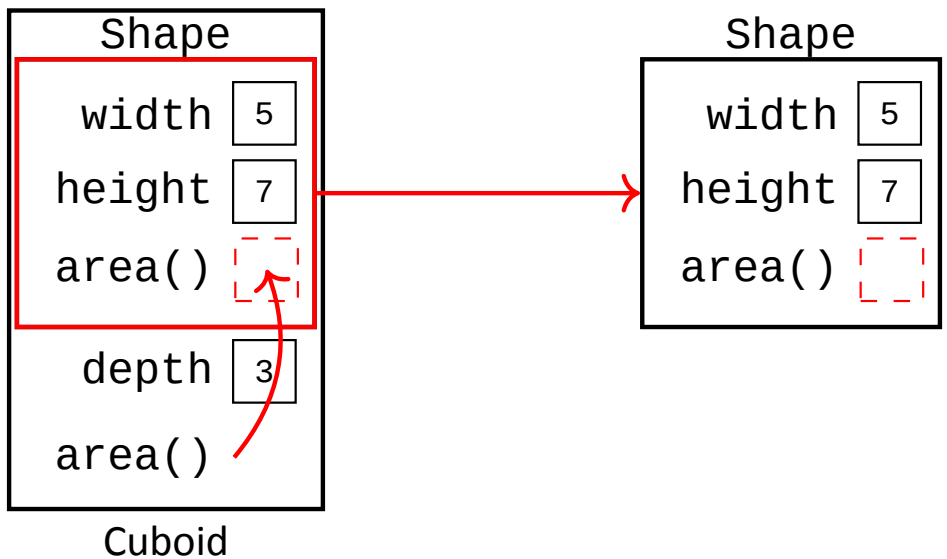
```
Cuboid c{5, 7, 3};
Shape s {c}; // slicing
```



Polymorphism

There are pitfalls...

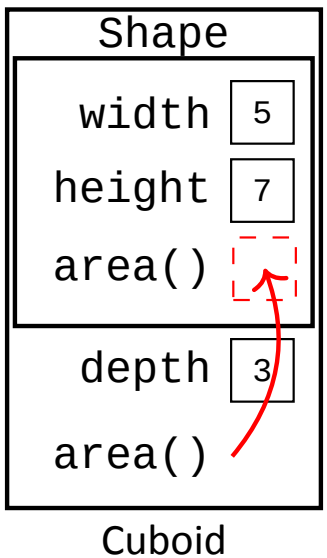
```
Cuboid c{5, 7, 3};
Shape s {c}; // slicing
```

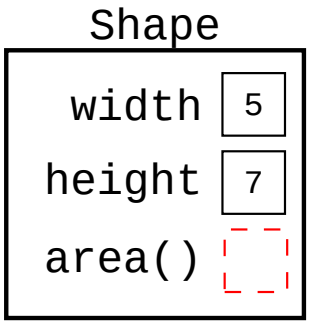


Polymorphism

There are pitfalls...

```
Cuboid c{5, 7, 3};
Shape s {c}; // slicing
```





Polymorphism

There are pitfalls...

- It is possible to copy from a derived type into a the Base class
- However, a variable has a fixed size, so when the derived class has more members than the base class, these will be lost.
- This is called *slicing* since we slice away everything that does not fit in the `Shape`-object.

Polymorphism

There are pitfalls...

```
Cuboid c {2,3,4};
Shape  s {c};
cout << s.area() << endl; // prints 0
```

Polymorphism

There are pitfalls...

```
Cuboid c {2,3,4};
Shape& s {c};
cout << s.area() << endl; // prints 24
```

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer => Call the member function

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer => Call the member function
3. that is non-virtual

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer => Call the member function
3. that is non-virtual => Call the member function

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer => Call the member function
3. that is non-virtual => Call the member function
4. otherwise

Polymorphism

Rule of thumb

When calling a member function:

1. through a non-reference => Call the member function
2. through a non-pointer => Call the member function
3. that is non-virtual => Call the member function
4. otherwise => Call the overriden version

Polymorphism

Conclusion

Always use pointers or references when dealing with polymorphic objects!

Polymorphism

Conclusion

- If we always use pointers of references:
- we are guaranteed to always call the correct version,
- we avoid the problems with slicing,
- we don’t have to copy objects if not necessary.

Polymorphism

Another good reason for using polymorphism

```
std::vector<Shape*> shapes {
  new Triangle{3, 4},
  new Rectangle{5, 6},
  new Cube{3, 5, 7}
};

for (Shape* shape : shapes)
{
  cout << shape->area() << endl;
}
```

Polymorphism

Another good reason for using polymorphism

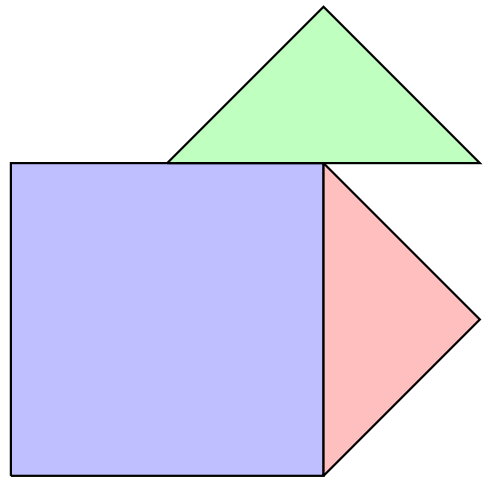
- If we have a shared base class with `virtual` functions:
- We can have base class pointer to objects of derived classes
- This means we can store different types inside an `std::vector`.
- This is useful because we can now iterate over objects of different types and get different results based on the “real” type of the objects.

LINKÖPING UNIVERSITY

More on Polymorphism

Example

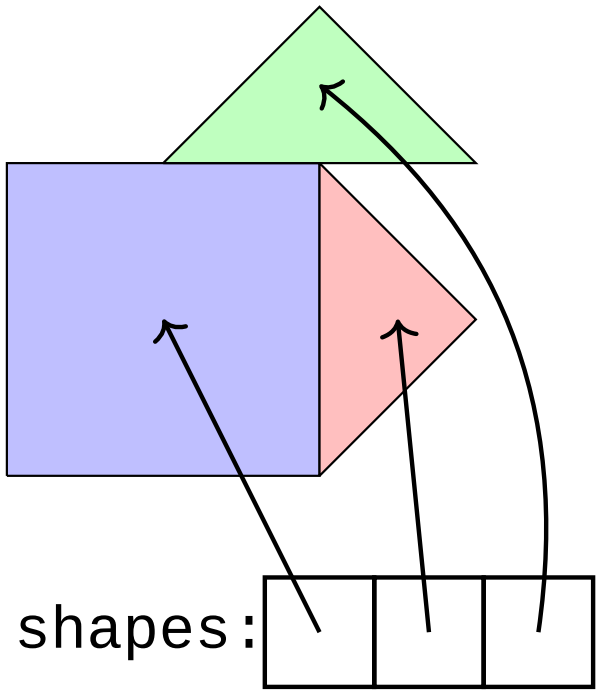
```
class Complex_Shape : public Shape
{
public:
  // ...
  double area() const
  {
    double sum{0.0};
    for (Shape* shape : shapes)
    {
      sum += shape->area();
    }
    return sum;
  }
private:
  std::vector<Shape*> shapes;
};
```



More on Polymorphism

Example

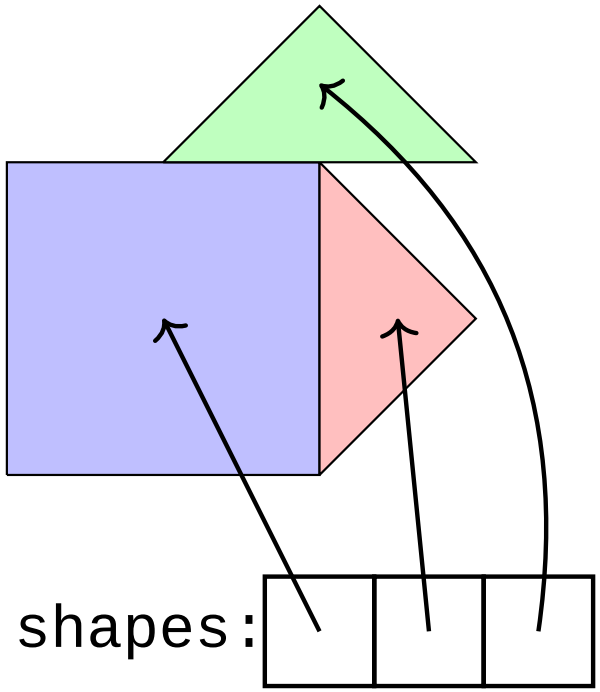
```
class Complex_Shape : public Shape
{
public:
  // ...
  double area() const
  {
    double sum{0.0};
    for (Shape* shape : shapes)
    {
      sum += shape->area();
    }
    return sum;
  }
private:
  std::vector<Shape*> shapes;
};
```



More on Polymorphism

Example

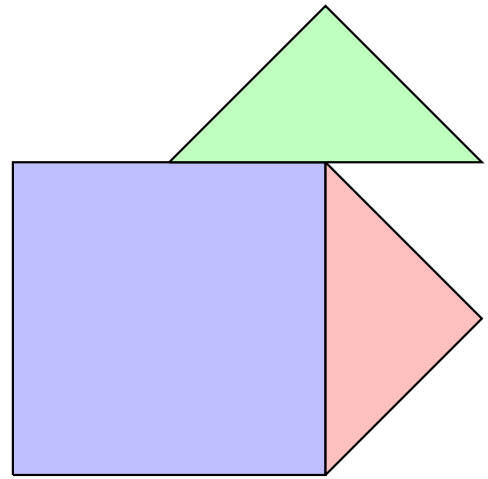
```
{
  Complex_Shape shape { ... };
  cout << shape.area() << endl;
} // what happens here?
```



More on Polymorphism

Example

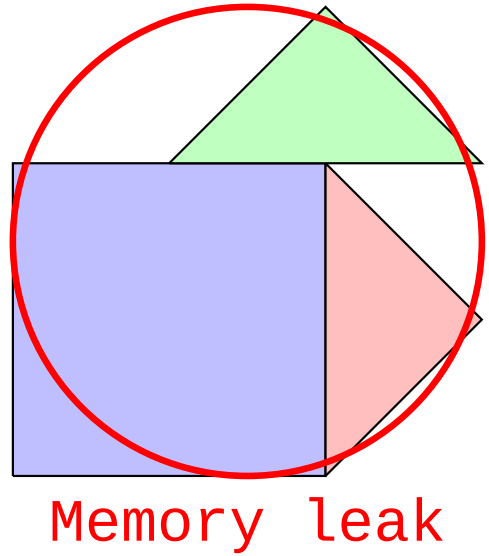
```
{
  Complex_Shape shape { ... };
  cout << shape.area() << endl;
} // what happens here?
```



More on Polymorphism

Example

```
{
  Complex_Shape shape { ... };
  cout << shape.area() << endl;
} // what happens here?
```



More on Polymorphism

So we create a destructor!

```
class Complex_Shape : public Shape
{
public:
  // ...
  ~Complex_Shape()
  {
    for (Shape* shape : shapes)
    {
      delete shape;
    }
  }
  // ...
};
```

More on Polymorphism

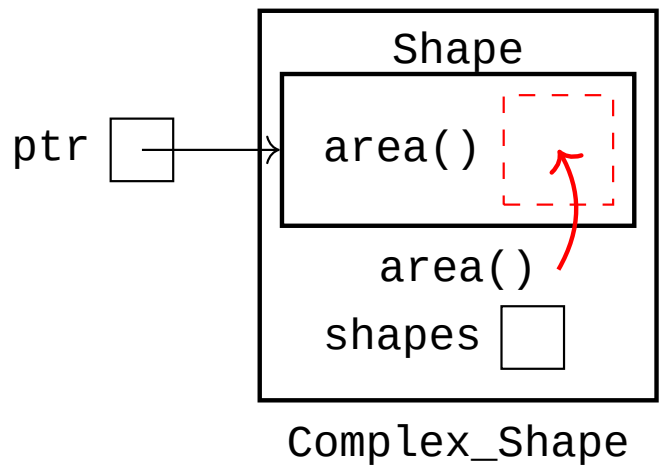
So we create a destructor!

- When having manually managed memory in a vector we have to delete it manually in the destructor.
- So of course we need one for `Complex_Shape` since it keeps a record of various shapes.

More on Polymorphism

What about now?

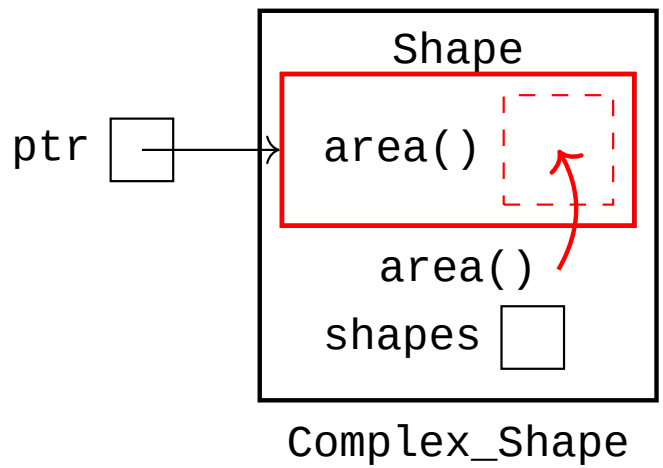
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

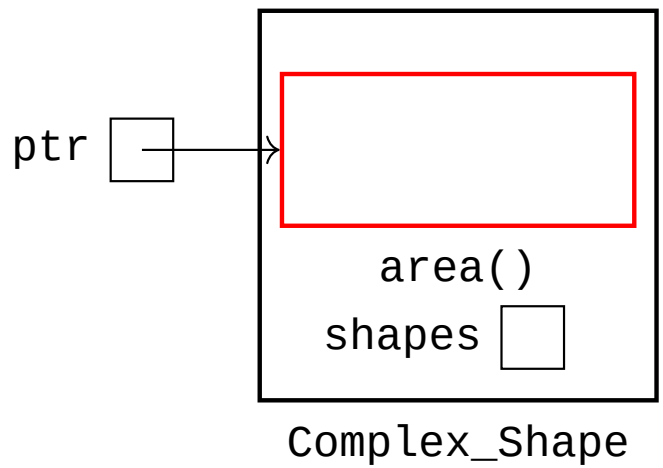
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

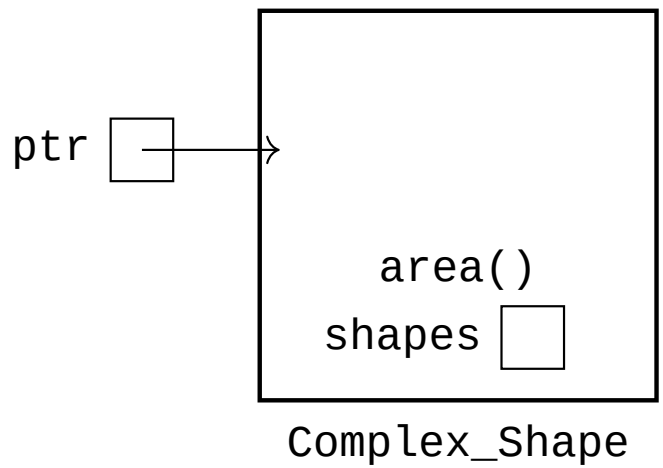
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

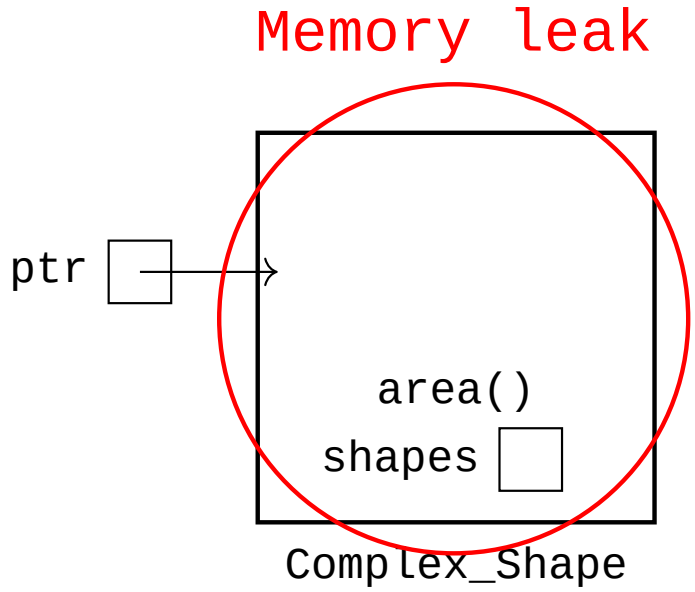
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

- When deleting `ptr` the compiler only sees the `Shape`-portion of the object.
- This means that it will call the destructor for `Shape`, even though it is really a `Complex_Shape`.
- So the problem is essentially that the compiler gets tricked into thinking you are working with a `Shape` object.
- We solved this problem earlier by adding `virtual` to our functions.

More on Polymorphism

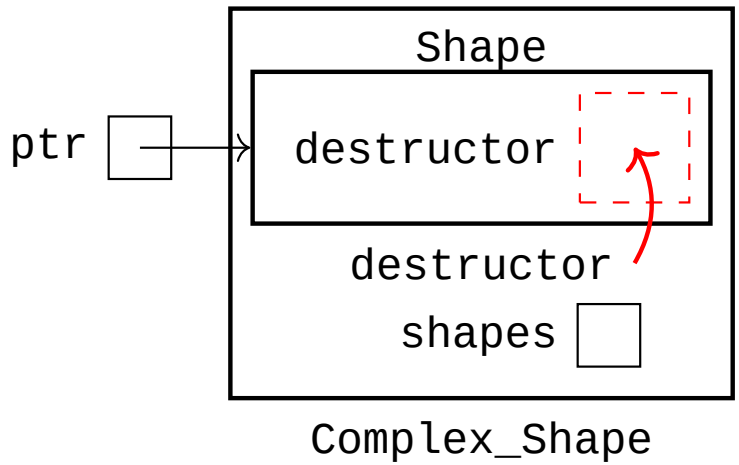
`virtual`-destructor

```
class  Shape
{
public:

  // ...
  virtual ~Shape() = default;
  // ...
};
```

More on Polymorphism

What about now?

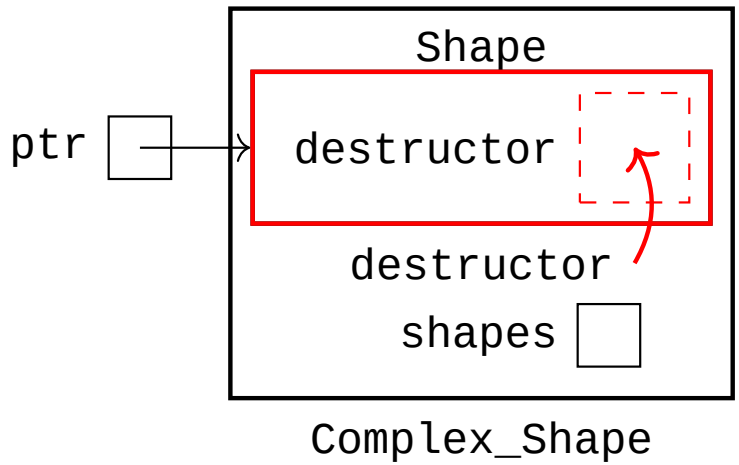
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

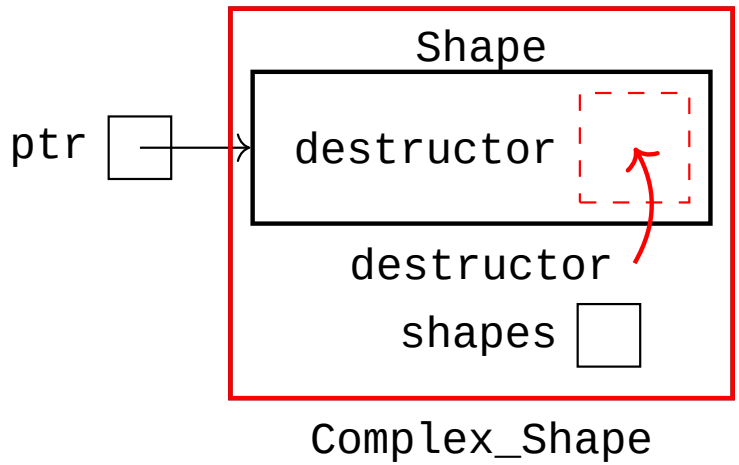
```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

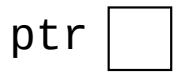
What about now?

```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



More on Polymorphism

What about now?

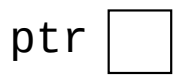



```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```

More on Polymorphism

What about now?

```
Shape* ptr {new Complex_Shape{...}};
delete ptr;
```



Nice!

More on Polymorphism

What about now?

- By declaring the destructor as `virtual` we are allowing derived classes to override the behaviour with their own implementation.
- This means that whenever the destructor is called through a pointer or a reference it will call the appropriate destructor.
- **Note:** The destructor of a class must also destroy the base class, but this is handled by the compiler so we don’t have to think about it.

More on Polymorphism

Conclusion

Always declare the destructor of a polymorphic base class as virtual!

More on Polymorphism

Sometimes humans make mistakes...

```
class My_Shape : public Shape
{
public:
  // ...
  double arae()
  {
    return 10.0;
  }
  // ...
};
```

More on Polymorphism

Sometimes humans make mistakes...

```
Shape* ptr {new My_Shape{}};
cout << ptr->area() << endl;
delete ptr;
```

More on Polymorphism

Sometimes humans make mistakes...

```
Shape* ptr {new My_Shape{}};
cout << ptr->area() << endl; // prints 0 (?!)
delete ptr;
```

More on Polymorphism

Sometimes humans make mistakes...

```
class My_Shape : public Shape
{
public:
  // ...
  double arae()
  {
    return 10.0;
  }
  // ...
};
```

Aha! A misspelling!

More on Polymorphism

Sometimes humans make mistakes...

```
class My_Shape : public Shape
{
public:
  // ...
  double area()
  {
    return 10.0;
  }
  // ...
};
```

More on Polymorphism

Sometimes humans make mistakes...

```
Shape* ptr {new My_Shape{}};
cout << ptr->area() << endl;
delete ptr;
```

More on Polymorphism

Sometimes humans make mistakes...

```
Shape* ptr {new My_Shape{}};
cout << ptr->area() << endl; // STILL 0 ?!
delete ptr;
```

More on Polymorphism

Sometimes humans make mistakes...

```
class My_Shape : public Shape
{
public:
  // ...
  double area() const
  {
    return 10.0;
  }
  // ...
};
```

We forgot const!

More on Polymorphism

Sometimes humans make mistakes...

```
Shape* ptr {new My_Shape{}};
cout << ptr->area() << endl; // prints 10
delete ptr;
```

More on Polymorphism

Sometimes humans make mistakes...

- When overriding virtual functions the signature must match *exactly*
- The name, the parameters, specifiers etc. it all must match with the base class version of the function.
- If it doesn't, the compiler will create a normal function in the derived class with these new properties.
- This is not a syntax error, it is just a semantic error.
- We have to make sure they match otherwise the compiler gets confused...

More on Polymorphism

Can’t the compiler help us with these simple mistakes?

```
class My_Shape : public Shape
{
public:
  // ...
  double arae() override
  {
    return 10.0;
  }
  // ...
};
```

More on Polymorphism

Can’t the compiler help us with these simple mistakes?

```
shape.cc: error: ‘double My_Shape::arae()’ marked ‘override’,
 but does not override
     double arae() override
            ^~~~
```

More on Polymorphism

Can’t the compiler help us with these simple mistakes?

- If you mark a member function as `override` you tell the compiler that you intended for this member function to override a virtual function in the base class.
- This means that the compiler will check whether or not it succeded in overriding the function.
- If something is wrong, the compiler tell us and we can fix it!
- If we don’t use override, the code might compile with the wrong behaviour which is really bad.

More on Polymorphism

Rule of thumb

Always mark functions that are meant to override as override!

More on Polymorphism

Let's go back to Shape

```
class  Shape
{
public:

  // ...
  virtual ~Shape() = default;
  virtual double area() const
  {
    return 0;
  }
  // ...
};
```

More on Polymorphism

Let's go back to `Shape`

- Does it really make sense that `Shape::area` returns `0`?
- What does it mean to take the area of a general shape?
- Wouldn't it be better to just skip the implementation?

More on Polymorphism

pure-virtual function

```
class  Shape
{
public:

  // ...
  virtual ~Shape() = default;
  virtual double area() const = 0;
};
```

More on Polymorphism

pure-virtual function

- You can add `= 0` at the end of a virtual function declaration to mark it as a *pure-virtual* function.
- This means that this function doesn't have an implementation.

More on Polymorphism

Abstract class

A class is *abstract* if it contains one or more pure-virtual functions

More on Polymorphism

Abstract class

```
Shape s1{1, 3};  // Error: abstract
Triangle t{1,3}; // OK: not abstract
Shape s2{t};     // Error: abstract
Shape& s3{t};    // OK: reference allowed
Shape* s4{&t};   // OK: pointer allowed
```

More on Polymorphism

Abstract class

- No object of an abstract class is allowed to exist.
- This means that we cannot create `Shape` in any way possible.
- The reason is that it contains functions that would crash the program if called (because they do not have an implementation).

More on Polymorphism

Abstract class

- We can however have a pointer or reference of type `Shape` since these may refer to a derived class of `Shape`.
- All derived classes of an abstract class are also abstract classes until all pure-virtual functions have been overriden.
- Abstract classes are meant to represent general concept that are used as a base class to more concrete things (such as specific shapes).

More on Polymorphism

Importing things from the base class

```
class Shape
{
public:

  Shape(double w, double h)
    : width{w}, height{h}
  {
  }

  // ...

protected:

  double width;
  double height;
};
```

```
class Rectangle : public Shape
{
public:

  // create an identical constructor
  // as the one in Shape
  using Shape::Shape;

  // make width public in Rectangle
  using Shape::width;

private:

  // make height private in Rectangle
  using Shape::height;
};
```

LINKÖPING UNIVERSITY

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static:

Dynamic:

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static:

Dynamic:

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static: Shape*

Dynamic:

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static: Shape*

Dynamic:

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static: Shape*

Dynamic: Triangle

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static: Shape*

Dynamic: Triangle

Type information

Static vs Dynamic type

```
Shape* ptr {new Triangle{3, 5}};
cout << ptr->area() << endl;

delete ptr;
ptr = new Rectangle{3, 5};
```

Static: Shape*

Dynamic: Rectangle

Type information

Static vs Dynamic type

- The *static* type of a variable is the type it is declared as (it never changes)
- The *dynamic* type is the type of the object a pointer points to
- The dynamic type can change to any class in the hierarchy of the static type.

Type information

Example

```
class Cuboid : public Shape
{
public:
  // ...
  virtual double volume() const
  {
    return width * height * depth;
  }
  //...
};
```

Type information

Example

```
Shape* ptr {new Cuboid{3, 4, 5}};

// doesn't work, volume is not
// declared in Shape
cout << ptr->volume() << endl;
```

Type information

Example

- Which functions you can call is directly related to the static type.
- I.e. it doesn't matter that the dynamic type of `ptr` is `Cuboid`, we can't call `volume` through a `Shape` pointer.
- Therefore we must, temporarily change the static type to match the dynamic type.

Type information

Example

```
Shape* ptr {new Cuboid{3, 4, 5}};

cout << static_cast<Cuboid*>(ptr)->volume()
     << endl;
```

Type information

Example

- We can use `static_cast` to (temporarily) change `ptr` into a `Cuboid*`, that way we can call `volume()`.
- But this is very dangerous...

Type information

When it all comes crashing down...

```
Shape* ptr {new Rectangle{3, 4}};

cout << static_cast<Cuboid*>(ptr)->volume()
     << endl;
```

Type information

When it all comes crashing down...

```
Shape* ptr {new Rectangle{3, 4}};

cout << static_cast<Cuboid*>(ptr)->volume()
     << endl;
```

Segmentation Fault

Type information

When it all comes crashing down...

- We can cast `ptr` to a pointer to any derived class,
- However, this becomes a problem if the type we are casting to is not compatible with the dynamic type...
- This will, in most cases, lead to the crashing of your program...
- Would be nice if we could check first if it was possible before we cast...

Type information

`dynamic_cast`

```
Shape* ptr1 {new Cuboid{3, 4, 5}};
Shape* ptr2 {new Rectangle{3, 4}};

Cuboid* c1 {dynamic_cast<Cuboid*>(ptr1)};
Cuboid* c2 {dynamic_cast<Cuboid*>(ptr2)};

// c1 is a pointer to a valid Cuboid object

// c2 == nullptr, since ptr2 does not
// point to a valid Cuboid object
```

Type information

`dynamic_cast`

- `dynamic_cast` is like `static_cast`, but before it performs the conversion it will test that the dynamic type is compatible (i.e. is derived from or equal to the type we are casting to)
- if they are compatible it will return a valid pointer with the specified static type,
- if they are not compatible it will return `nullptr`.

Type information

Checking if dynamic type is compatible

```
Shape* ptr {...};

Cuboid* cuboid {dynamic_cast<Cuboid*>(ptr)};
if (cuboid != nullptr)
{
  // only print volume if it is a cuboid
  cout << cuboid->volume() << endl;
}
```

Type information

Also works with references!

```
Cuboid c {3,4,5};
Shape& s {c};

cout << dynamic_cast<Cuboid&>(s).volume() << endl;
```

Type information

Also works with references!

```
Rectangle r {3,4};
Shape& s {c};

cout << dynamic_cast<Cuboid&>(s).volume() << endl;
```

Type information

Also works with references!

```
$ g++ shape.cc
$ ./a.out
terminate called after throwing an instance of 'std::bad_cast'
  what():  std::bad_cast
Aborted (core dumped)
```

LINKÖPING UNIVERSITY

Exceptions

What just happend?!

Exceptions

What just happend?!

- References cannot be empty

Exceptions

What just happend?!

- References cannot be empty
- What do we do to signal error?

Exceptions

What just happend?!

- References cannot be empty
- What do we do to signal error?
- Exceptions!

Exceptions

Model

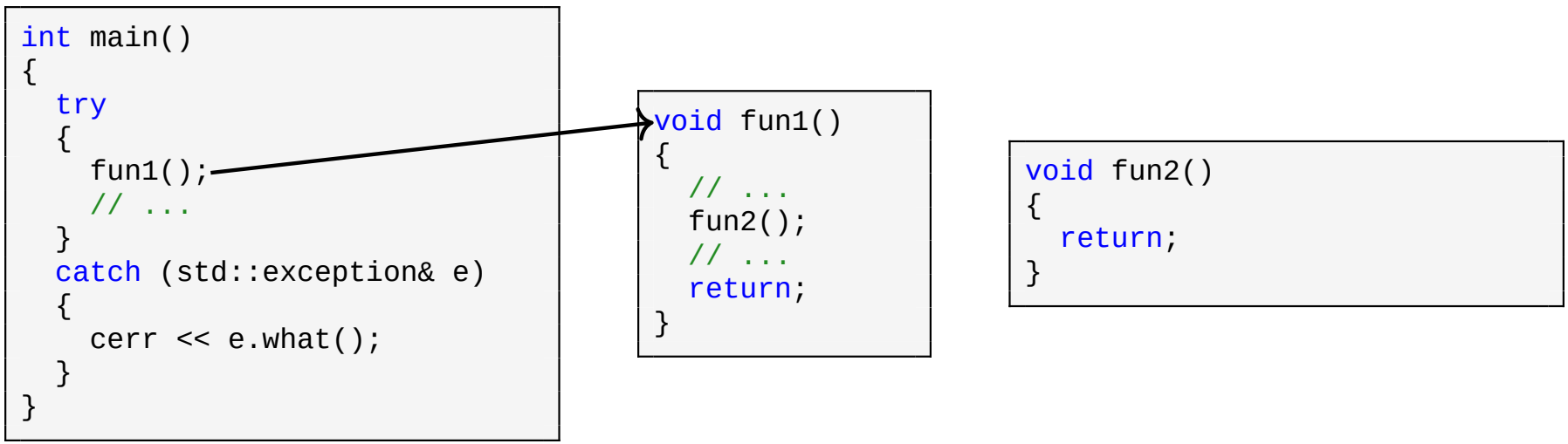
```
int main()
{
  try
  {
    fun1();
    // ...
  }
  catch (std::exception& e)
  {
    cerr << e.what();
  }
}
```

```
void fun1()
{
  // ...
  fun2();
  // ...
  return;
}
```

```
void fun2()
{
  return;
}
```

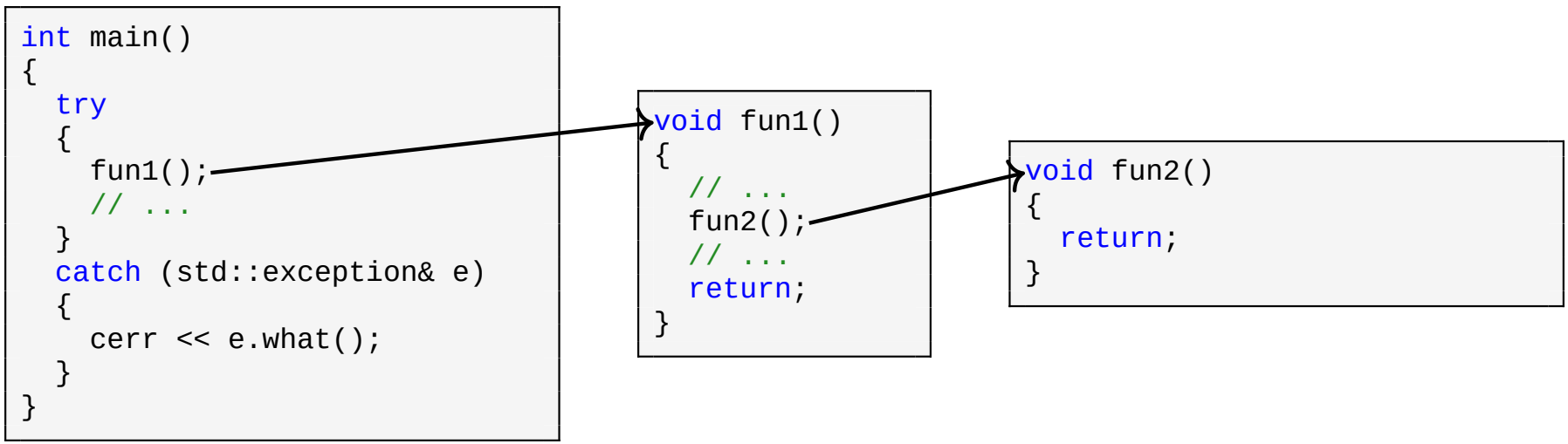
Exceptions

Model



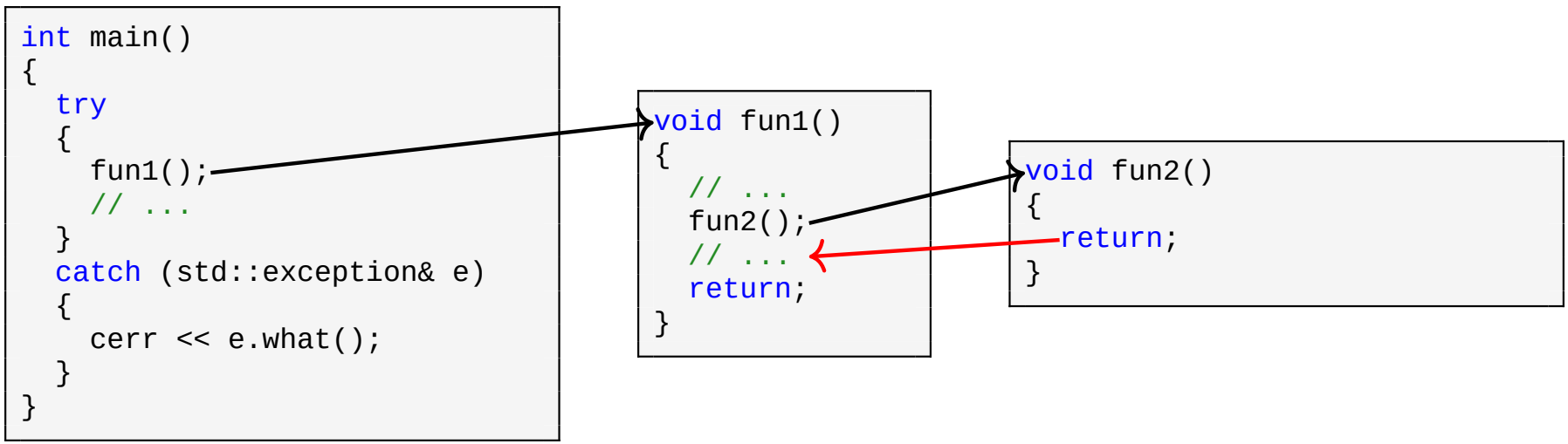
Exceptions

Model



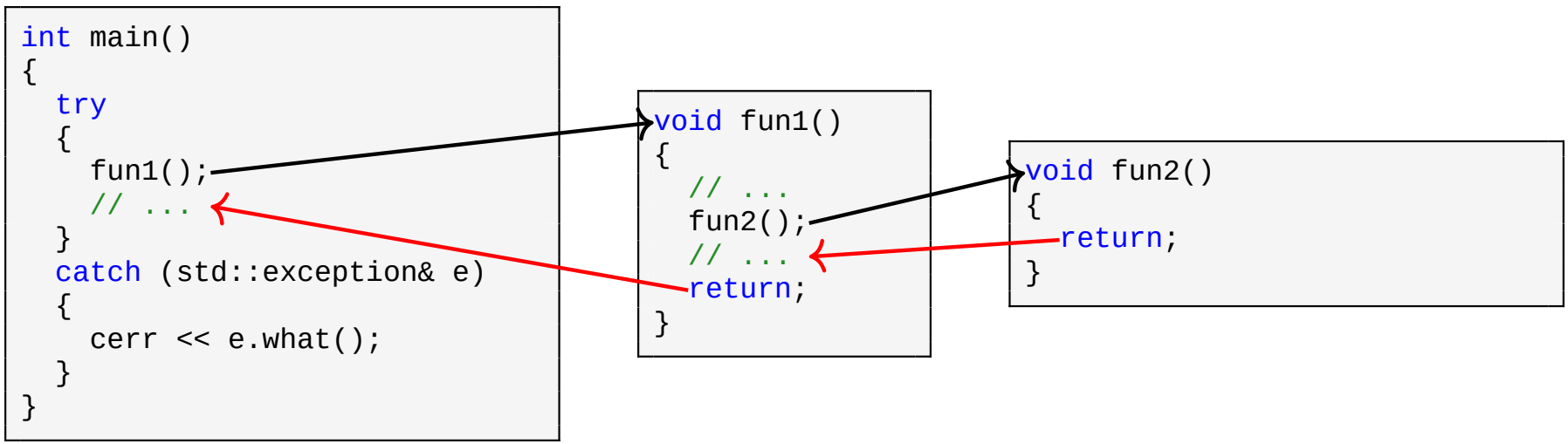
Exceptions

Model



Exceptions

Model



Exceptions

Model

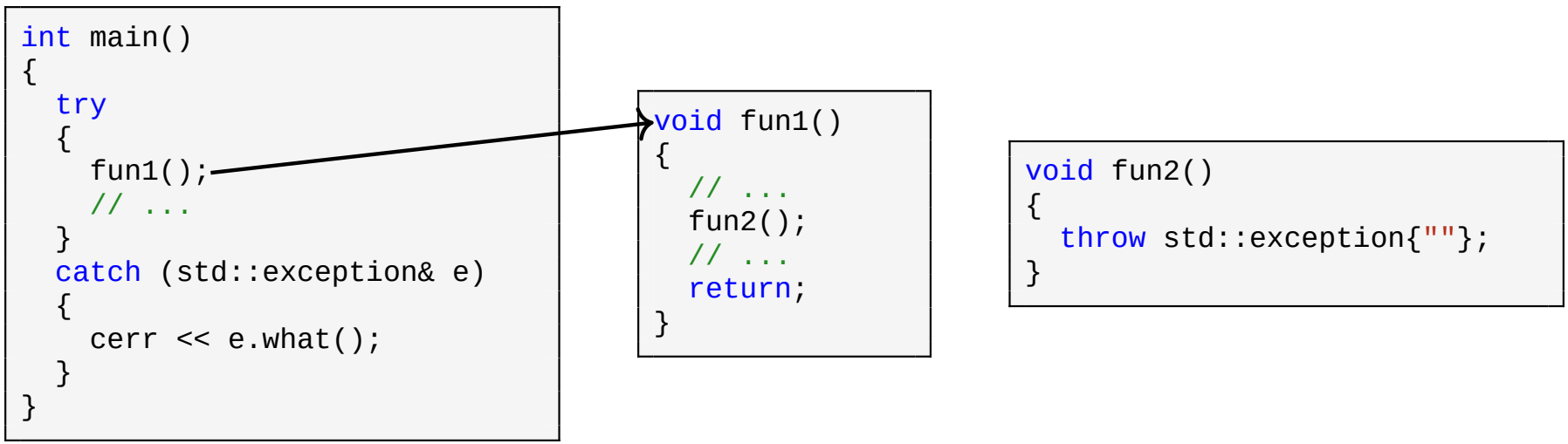
```
int main()
{
  try
  {
    fun1();
    // ...
  }
  catch (std::exception& e)
  {
    cerr << e.what();
  }
}
```

```
void fun1()
{
  // ...
  fun2();
  // ...
  return;
}
```

```
void fun2()
{
  throw std::exception{""};
}
```

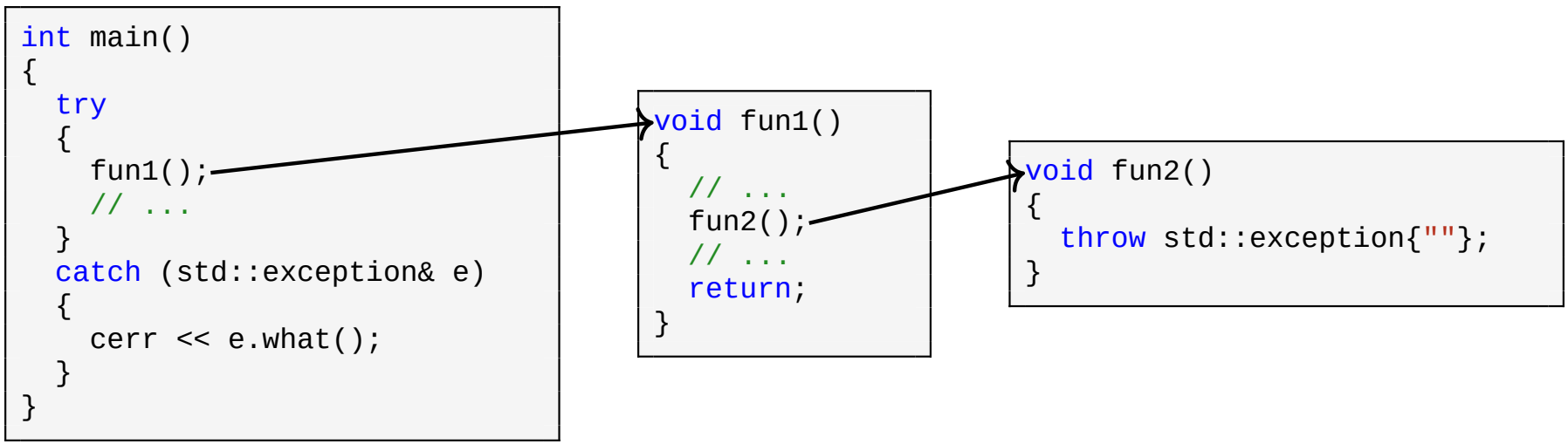
Exceptions

Model



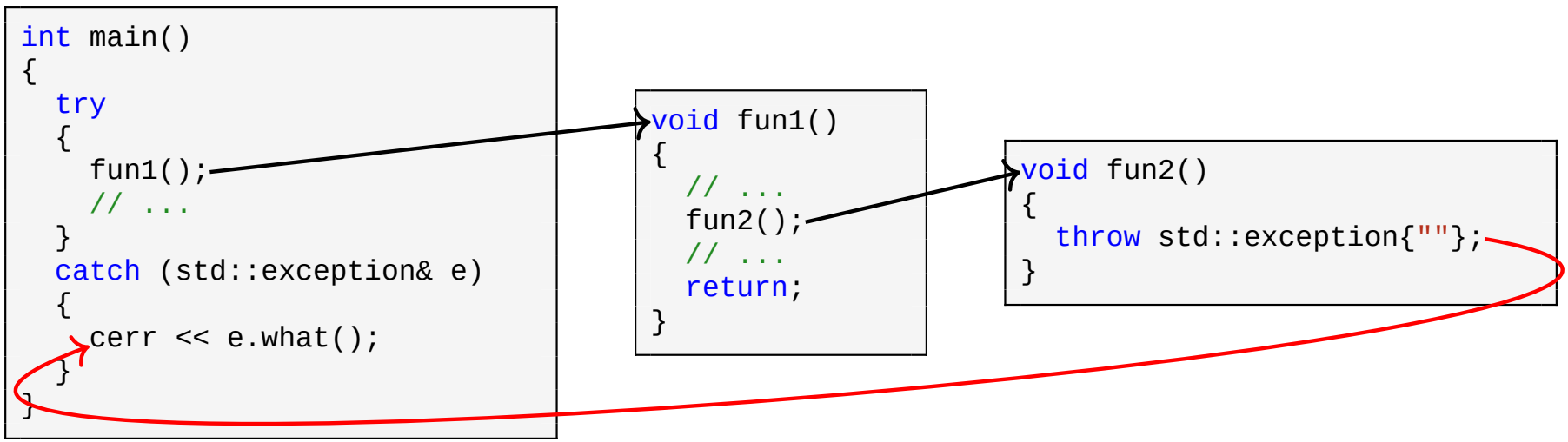
Exceptions

Model



Exceptions

Model



Exceptions

Model

- An exception is an object we *throw*.
- Throwing an exception will abort the current function,
- it will move backwards in the function call chain until it hits a *try-catch* block.
- Throwing is seperate from returning.
- We should only throw exceptions when something went wrong.

Exceptions

dynamic_cast

```
#include <stdexcept>

int main()
{
  Rectangle r {3,4};
  Shape& s {c};

  try
  {
    cout << dynamic_cast<Cuboid&>(s).volume()  << endl;
  }
  catch (std::bad_cast& e)
  {
    cout << "s is not a Cuboid!" << endl;
  }
  catch (std::exception& e)
  {
    cout << "Unknown error." << endl;
  }
}
```

LINKÖPING UNIVERSITY

Command-line argument

Calling a program with arguments

```
$ ./a.out a b c
```

Command-line argument

Calling a program with arguments

```
$ ./a.out a b c
```

Arguments: a, b, c

Command-line argument

Calling a program with arguments

- Unix-systems are based on calling programs with various arguments,
- This is in fact what “commands” are in the terminal: programs that takes arguments.
- But how do we read these arguments in our own programs?

Command-line argument

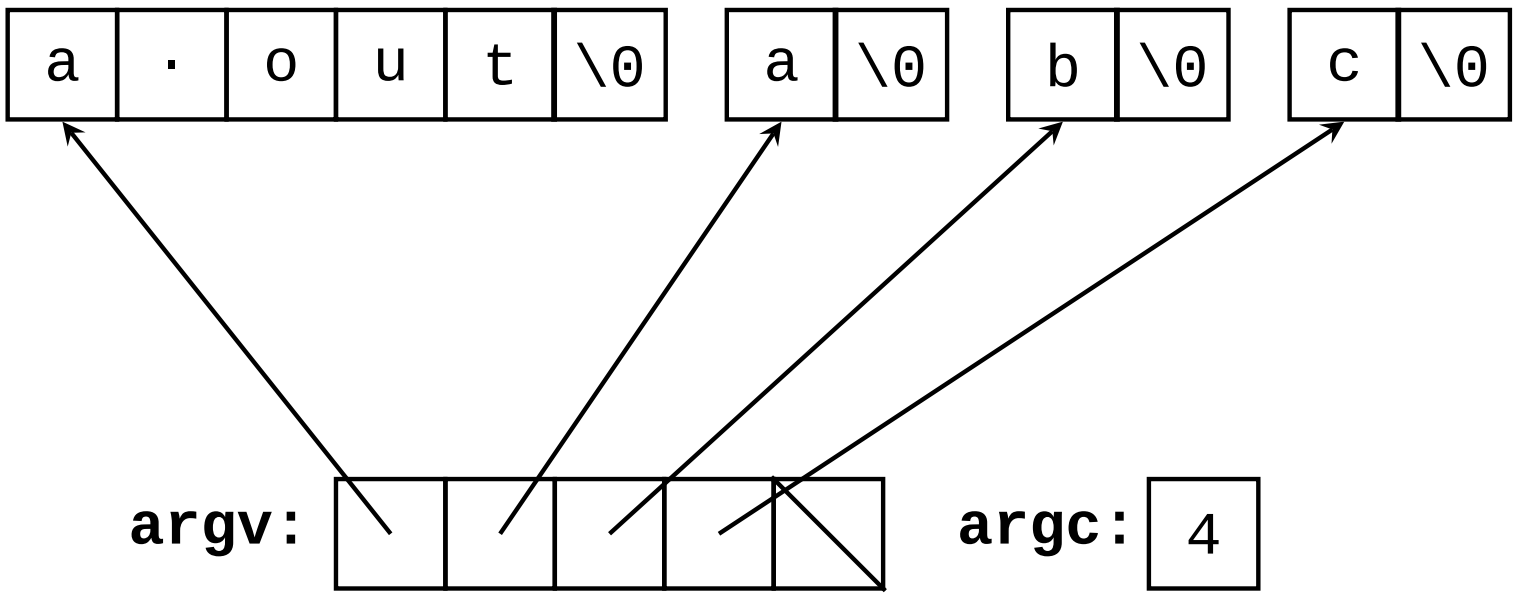
Reading arguments

```
int main(int argc, char* argv[])
{
  // argc = number of arguments passed to the program
  // argv = a pointer to an array of pointers to C-strings
}
```

Command-line argument

`argv`

```
$ a.out a b c
```



Command-line argument

`argv`

- The arguments are passed into your program as C-strings.
- A C-string is an array of `char`.
- It is called a C-string because this is how strings work in C.
- The end of a C-string is indicated with the special character `'\0'`.
- **Note:** The name of the executable file is the argument at index `0`.

Command-line argument

Example

```
int main(int argc, char** argv)
{
  for (int i{0}; i < argc; ++i)
  {
    cout << argv[i] << endl;
  }
}
```

Command-line argument

Example

```
$ ./a.out 10 20 30
./a.out
10
20
30
```

Command-line argument

Example

- We can access the `i`:th argument with `argv[i]`.
- Notice that these are strings!
- How do we interpret them as something else?

Command-line argument

Converting arguments

- `std::stoi(argv[1])` - convert `argv[1]` to `int`
- `std::stod(argv[1])` - convert `argv[1]` to `double`
- Using `std::stringstream`:

```
std::stringstream ss{};
ss << argv[1];

int number;
ss >> number;
```

Command-line argument

Cool trick

```
vector<string> args { argv, argv + argc };
// now all arguments reside in the vector
// as std::string instead of C-strings
```

www.liu.se

LINKÖPING UNIVERSITY