CMPT 745
Software Engineering

Software Design Foundations

Nick Sumner
wsumner@sfu.ca

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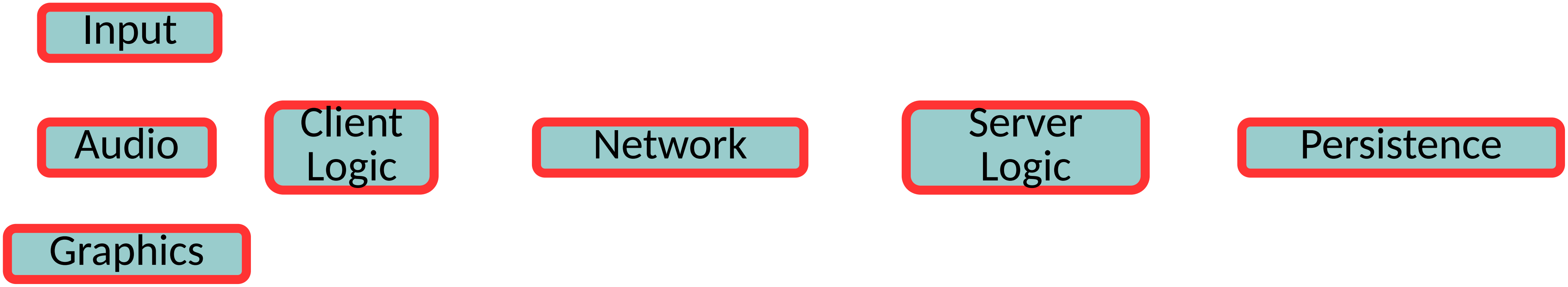
  - The components into which a problem is broken down



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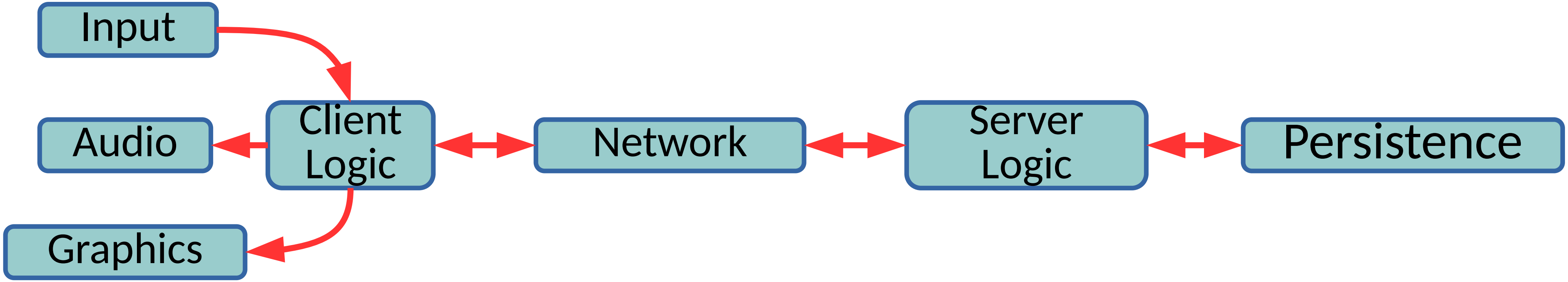

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Most programming is
"brown field" programming

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My goal is to have you able read and understand design decisions at FAANG….

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- Possible causes [Ousterhout 2018]
  - *Dependencies* – Code cannot be understood in isolation
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- Design ***complexity*** arises from many portions of code interacting
  - Think of a basket or a braid. [Hickey 2011]
    Changing one strand is hard….

What is common in good designs?

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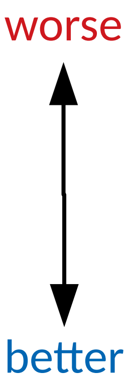
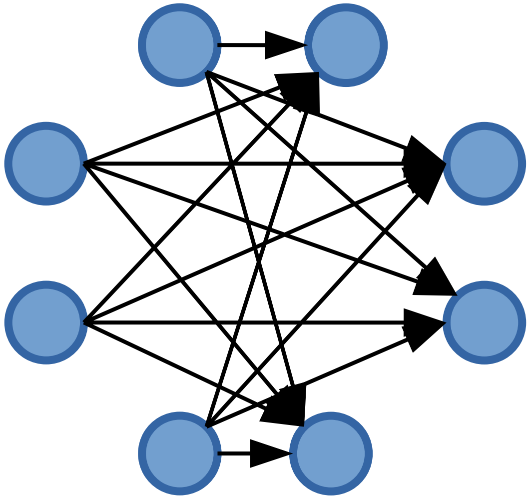
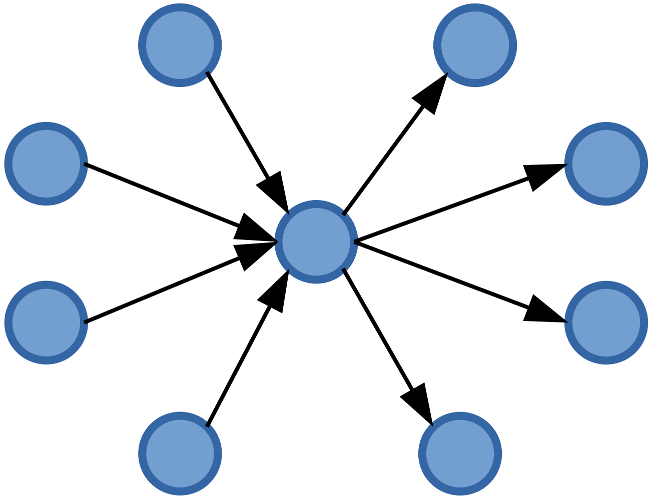




vs



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worse
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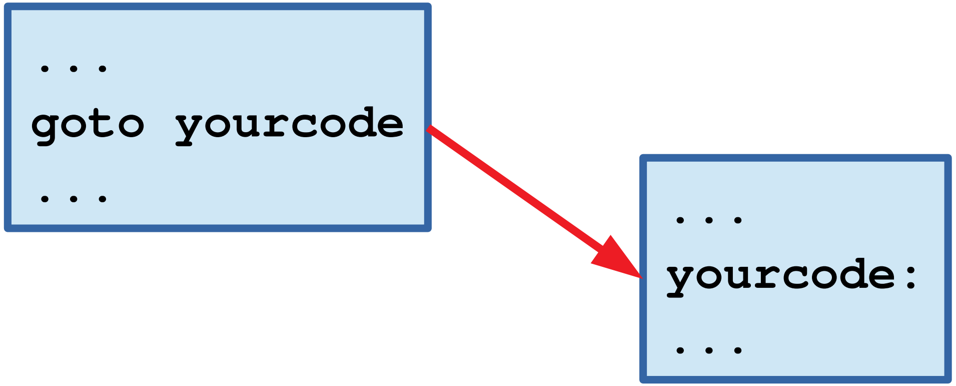

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```
int global = ...
```

```
... = global
```

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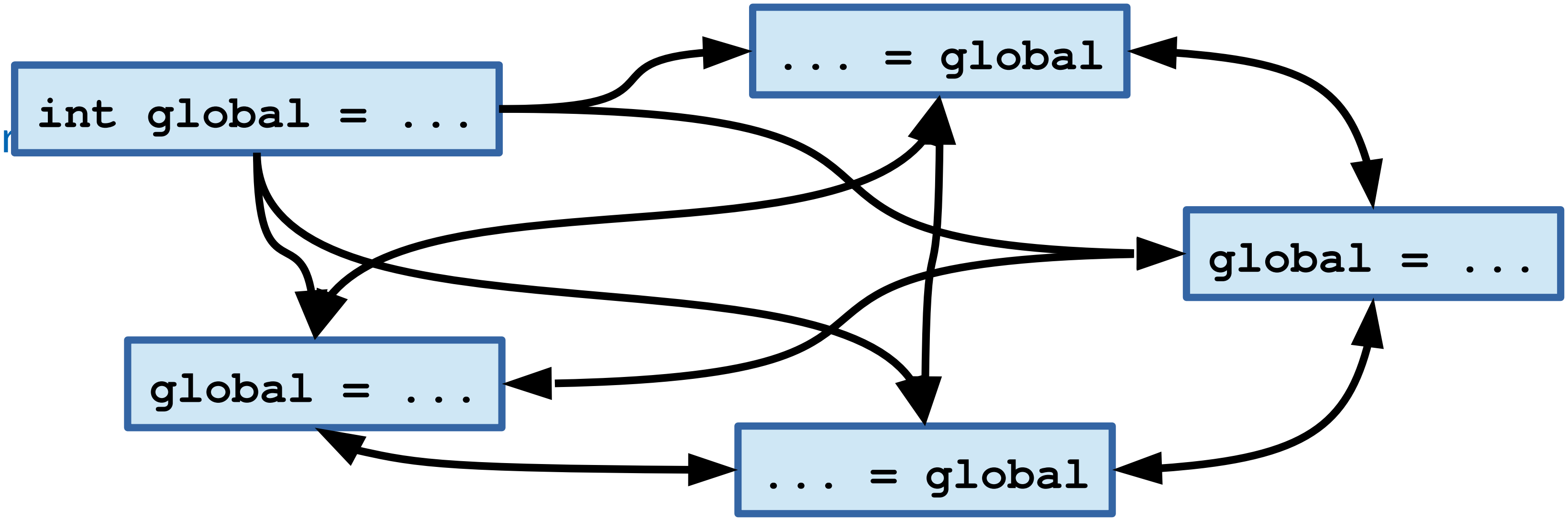

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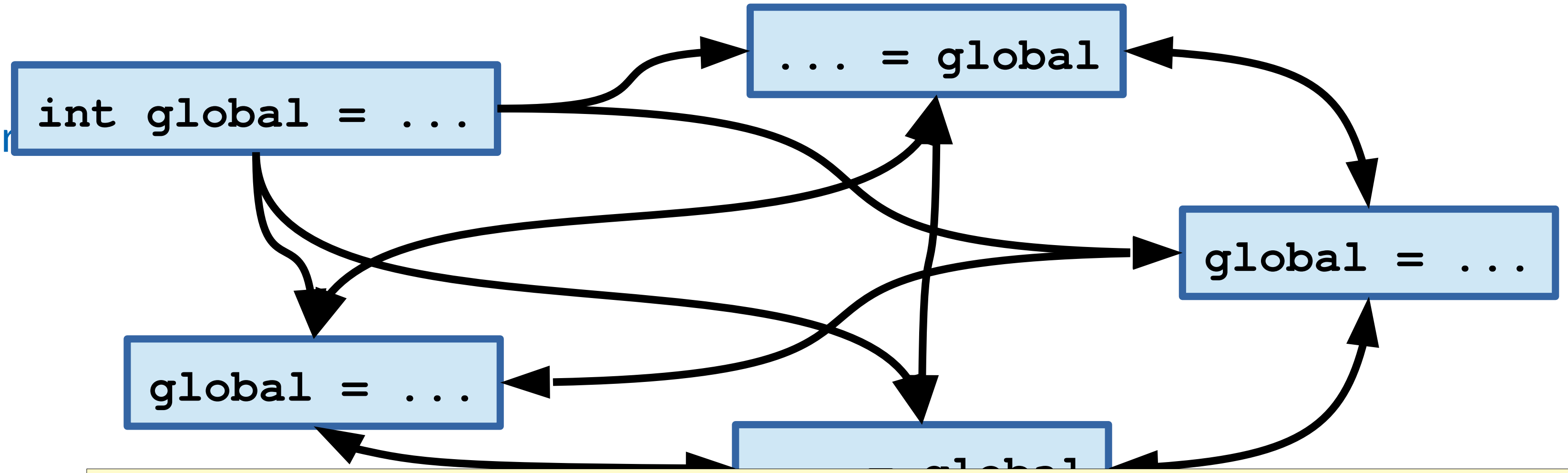

Note: “Solutions” like singletons have these constraints and worse.

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```
class Parent {
public:
  virtual void foo() { bar(); }
  virtual void bar() {}
};
```

[Bloch, “Effective Java”]

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class Parent {
public:
  virtual void foo() { bar(); }
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}
```

```
class Child : public Parent {
public:
  virtual void bar() { foo(); }
};
```

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```

Non Virtual Interfaces (NVI) help clarify & are common in C++.

```
class Parent {
public:
  void foo() { barImpl(); }
  void bar() { barImpl(); }
private:
  virtual void barImpl() = 0;
};
```

[Bloch, “Effective Java”]

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```
Cat cat = new Cat;
...
delete cat;
```

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```
Process p;
p.doStep1();
p.doStep2();
p.doStep3();
```

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Process p;
p.doStep1();
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```
Process p;
p.foo();
p.bar();
p.baz();
```

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Cat cat = new Cat;
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This is more insidious!

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- Content
- Common global data
- Subclassing
- Temporal
- Passing data to/from each other

better

```
x = foo(1,2)
```

```
def foo(a, b):
    ...
```

What is common in good designs?

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  - Content
  - Common global data
  - Subclassing
  - Temporal
  - Passing data to/from each other
  - Independence

better

What is common in good designs?

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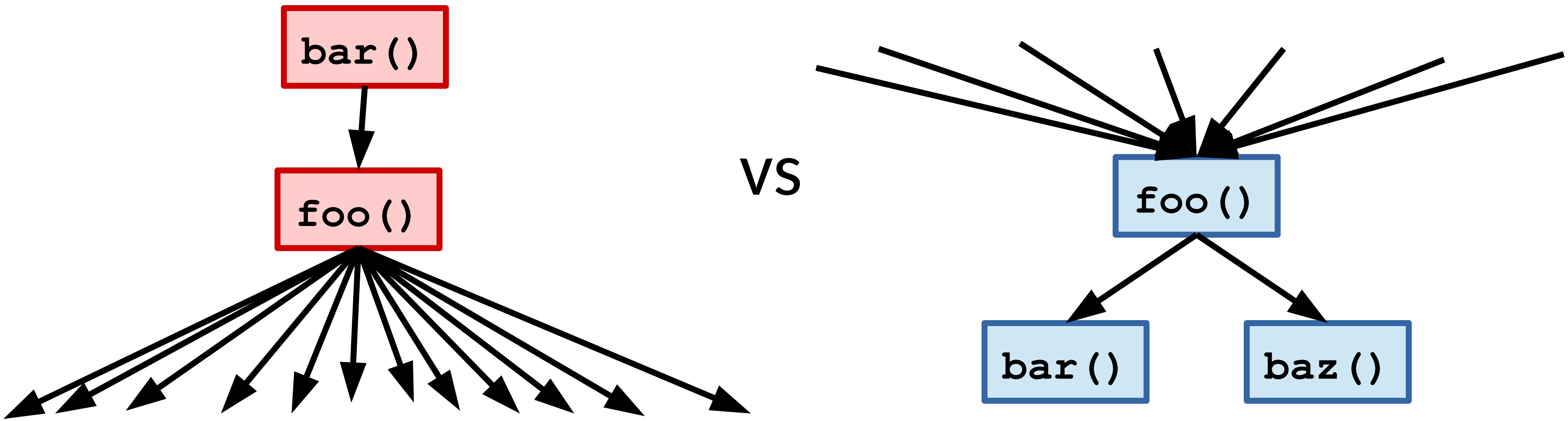

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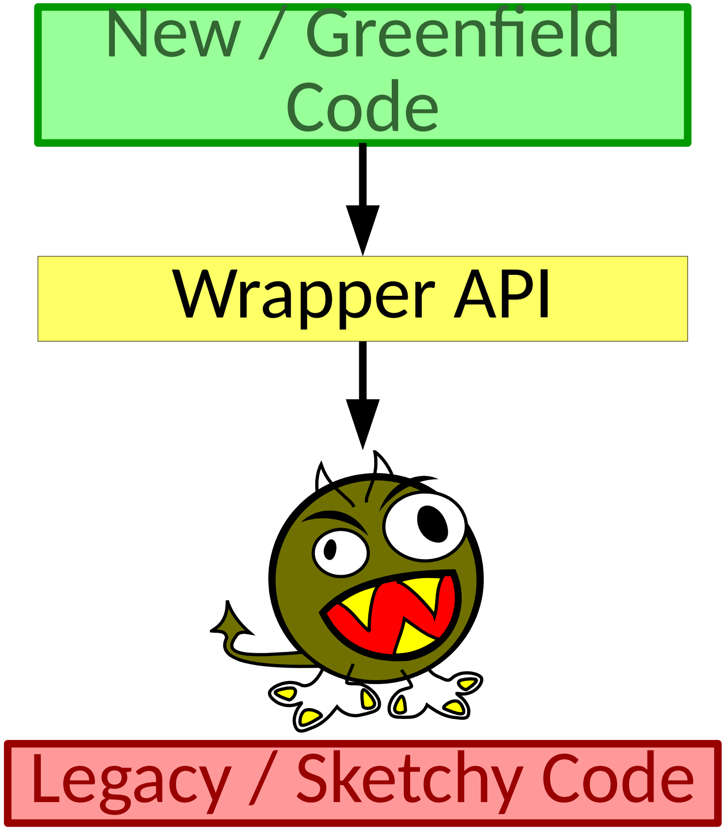
- Layers / Stratification



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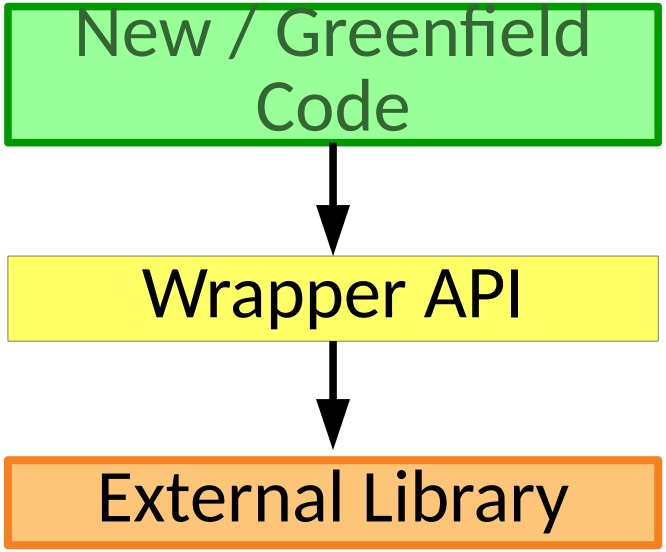

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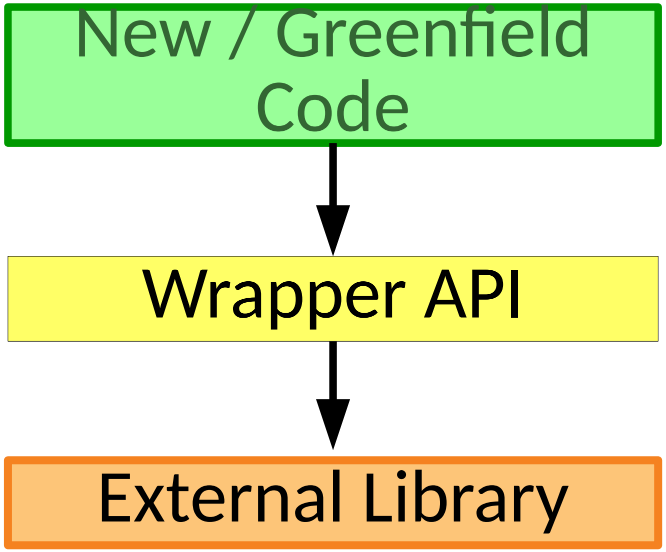
Layers are just a form of decoupling.



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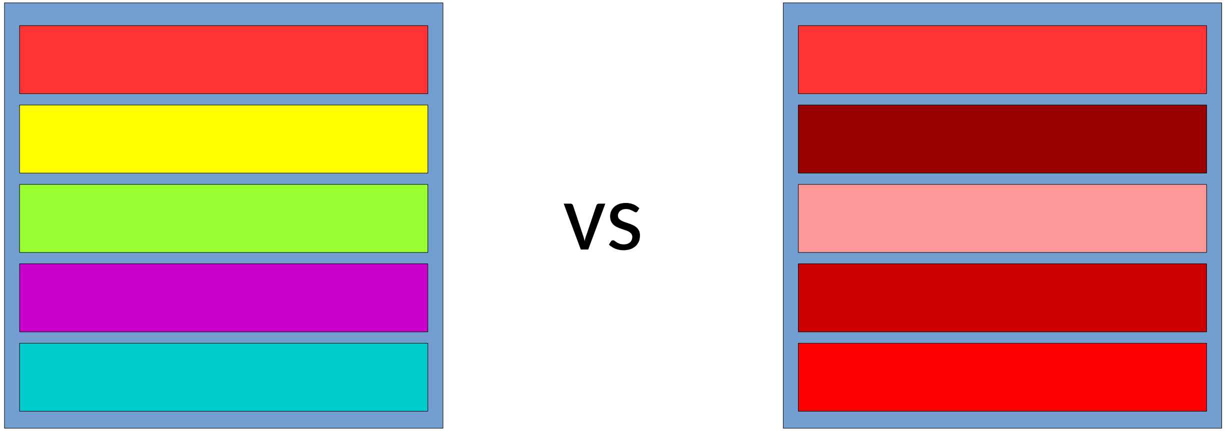

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These attributes promote ease of change

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  - Understanding and leveraging these *can* enable safe, efficient, modifiable, and clear designs
  - So we need to understand them….

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Different forms of polymorphism have different design trade offs

Polymorphism via Inheritance
(a quick review)

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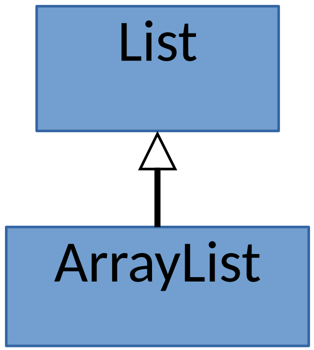

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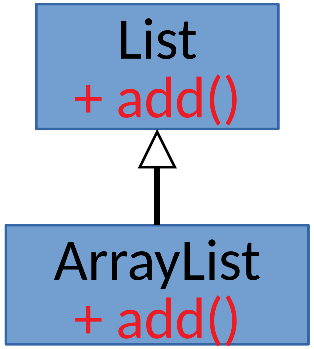

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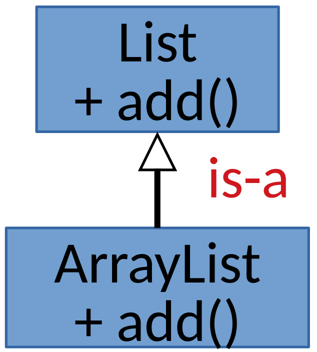

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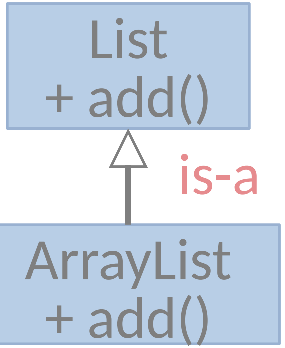


```java
List list = new ArrayList();
```

Java

```cpp
void foo(List& someList);
...
ArrayList list;
foo(list);
```

C++

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Derived is ***substitutable*** for Base

Base	Derived
A foo(B b)	C foo(D d)

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    - Arguments in the subtype may be ***more general***

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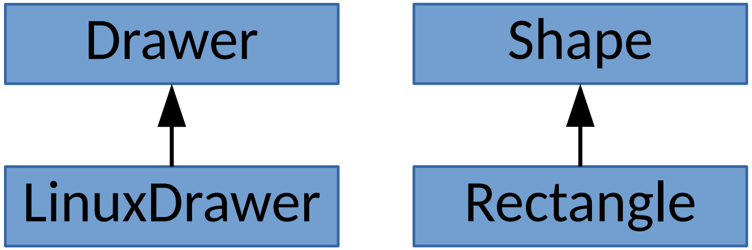

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Drawer

LinuxDrawer

Shape

Rectangle

Drawer
+ **void draw(Rectangle)**

LinuxDrawer
+ **void draw(Shape)**

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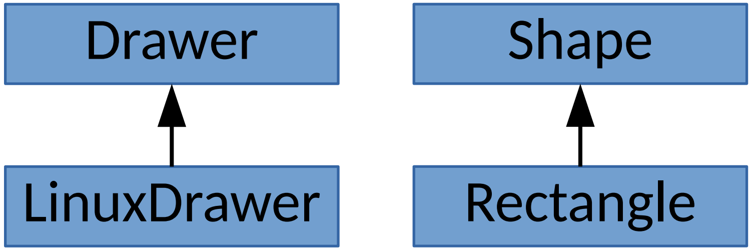

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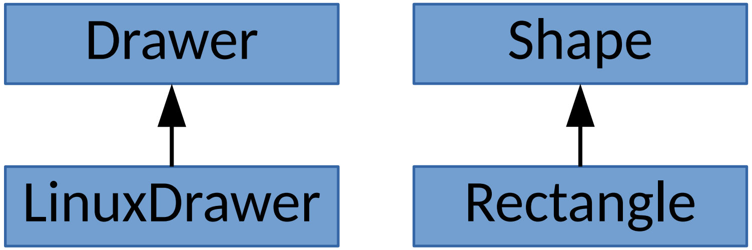

Drawer	LinuxDrawer
+ **Shape getBounds()**	+ **Rectangle getBounds()**

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    - Preconditions are not stronger

```
assert(x > 0)
```

Base
A foo(B b)

```
assert(x != 0)
```

Derived
C foo(D d)

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`assert(result != 0)`	`assert(result > 0)`

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    - Preconditions are not stronger
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    - Invariants must still hold

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- Do the *LSP* and *has-a* relationships *unambiguously* tell us how to apply inheritance?
- Every ***is-a*** relationship could instead be ***has-a***!
  - These often capture finer grained relationships
  - Break individual responsibilities into components

So why is inheritance hard?

- Do the *LSP* and *has-a* relationships *unambiguously* tell us how to apply inheritance?
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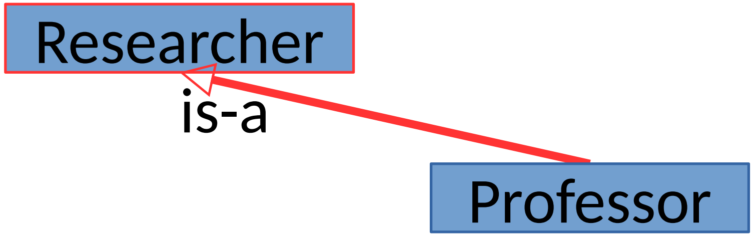

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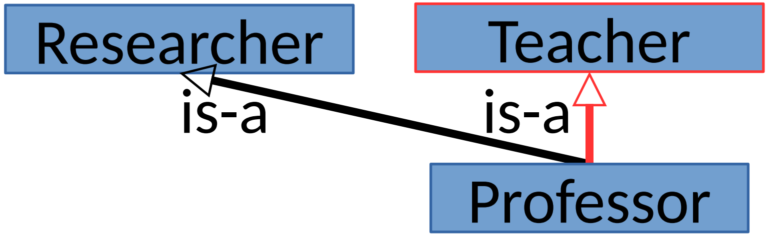

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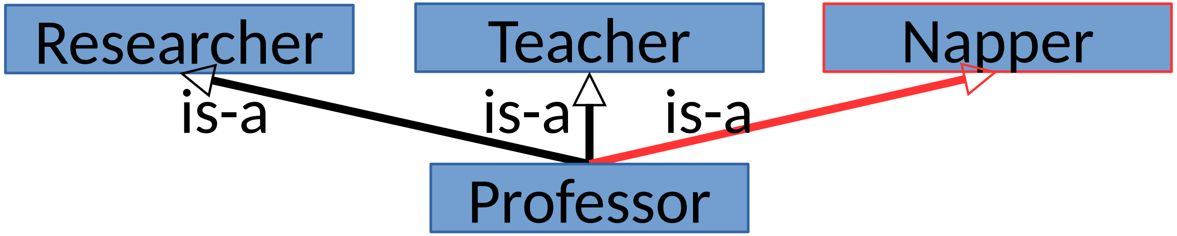

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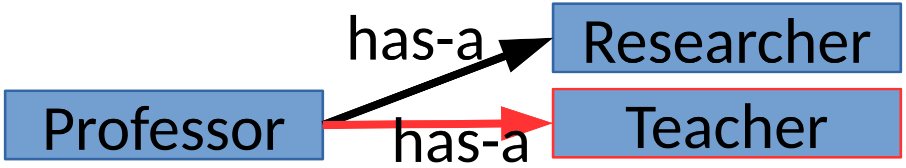

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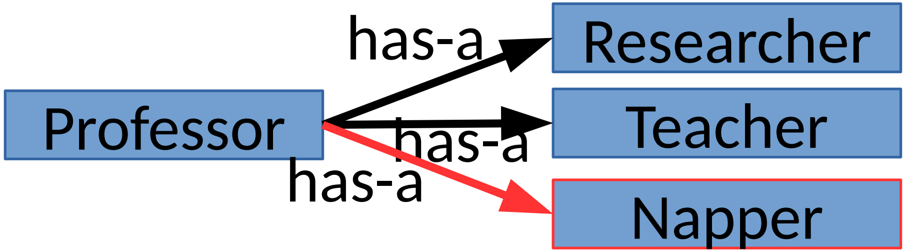

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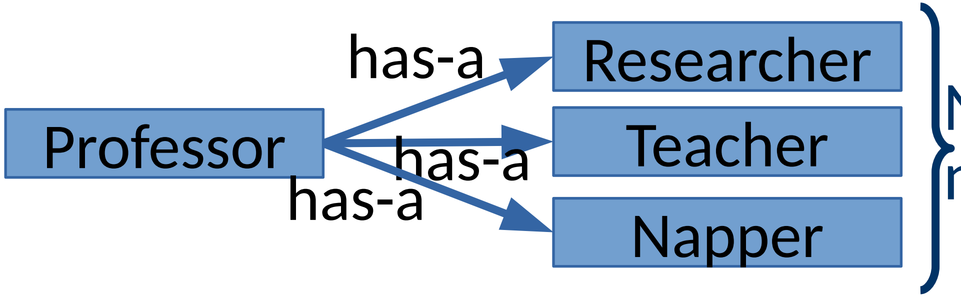

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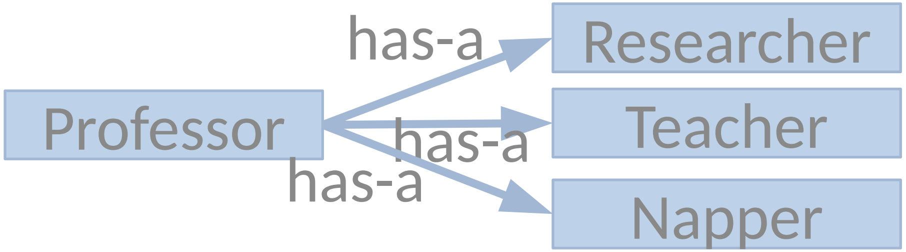

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- **Whenever *is-a* applies, you must still make a decision**

Choosing is-a or has-a

- Guide 1: Might the behavior need to change?
  - Inheritance often *precludes* it

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We will revisit this in the context of ***algebraic data types***.

So let’s try it out…

- I need
  - Many different types of animals.

This should sound familiar…

So let's try it out…

- I need
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So let’s try it out…

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What does my design look like based on the rules?

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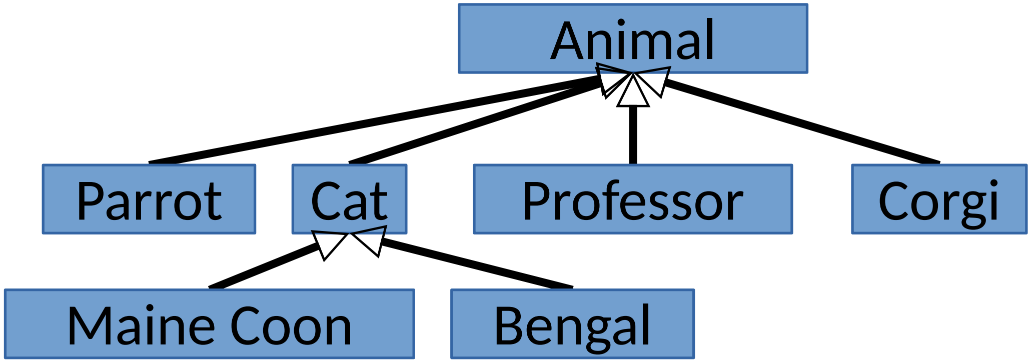

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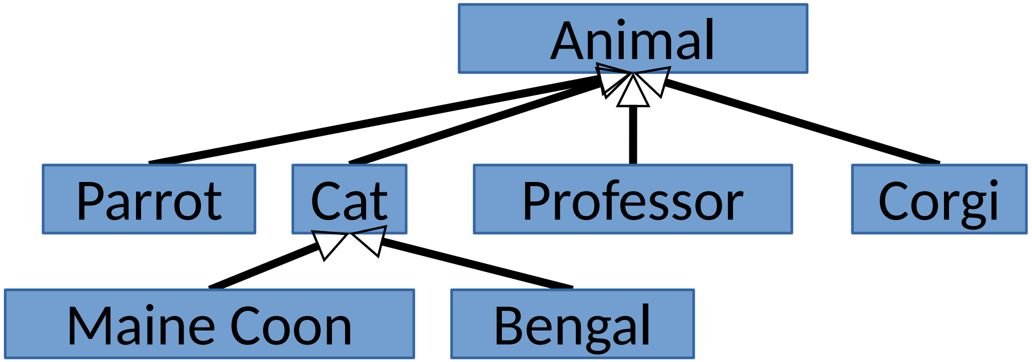

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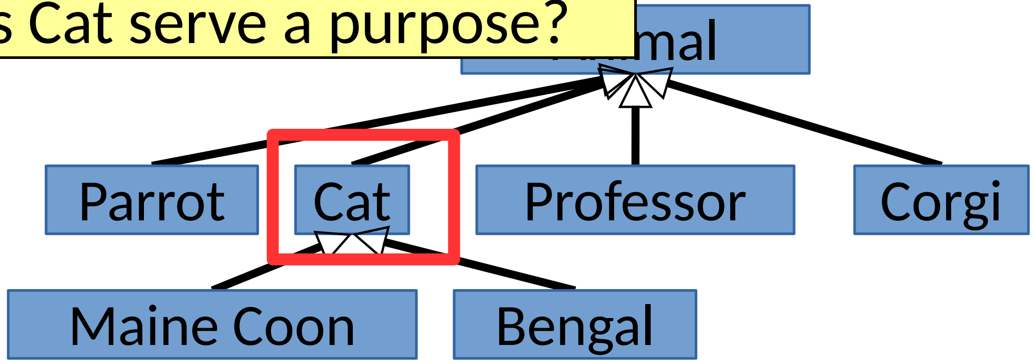
Does Cat serve a purpose?



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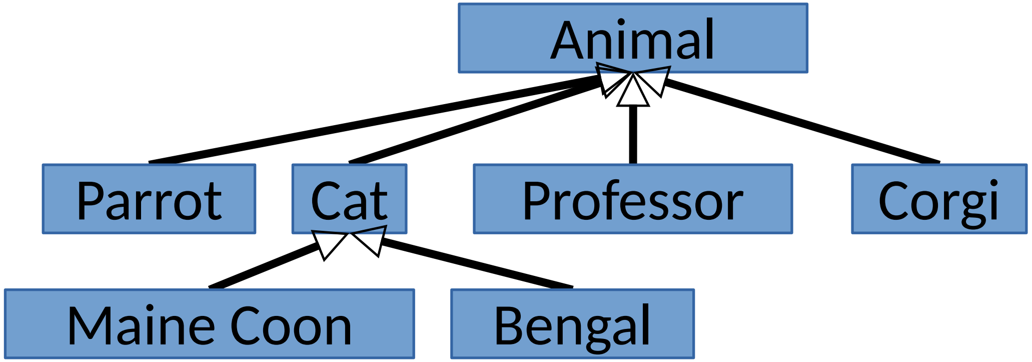

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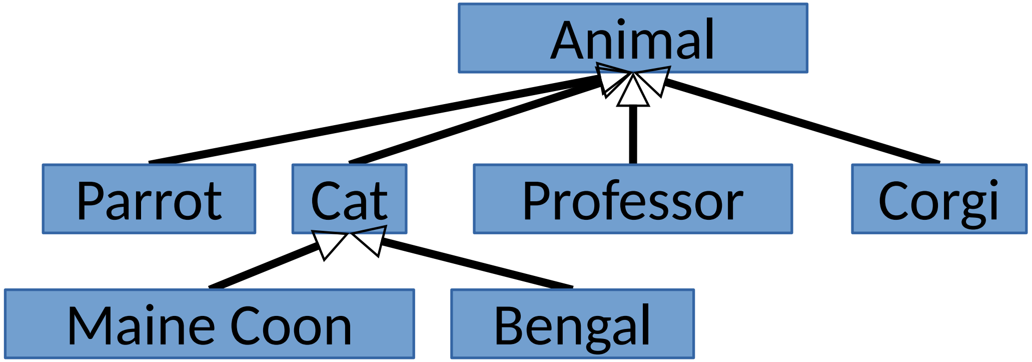

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What if I want a new Animal at run time?

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Can we do better?

If someone on my team did this multiple times,
I would consider firing them.

Hierarchies in *data* need not be
hierarchies in the *type system*!

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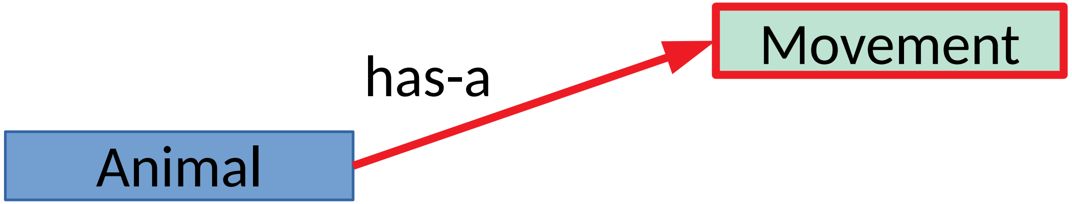

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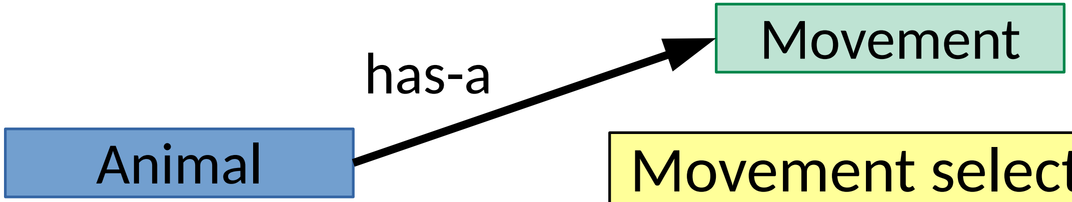

Movement selects from the ways any Animal can move.

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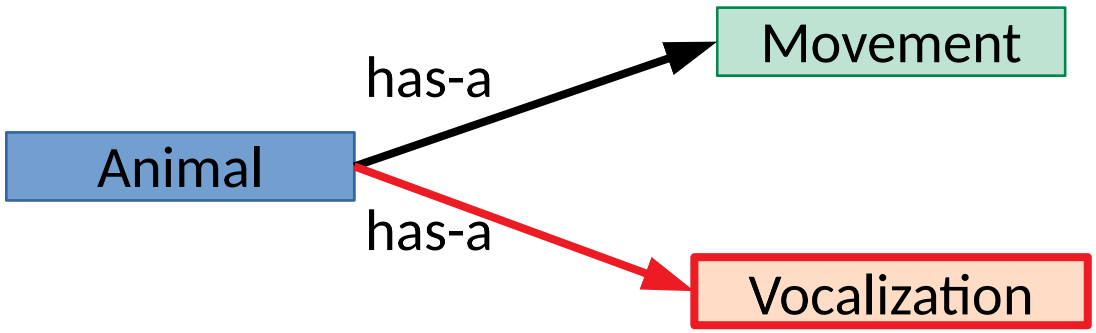

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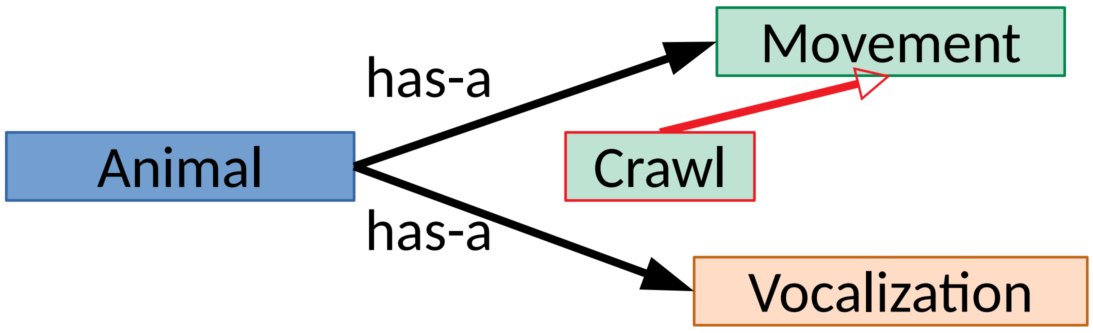

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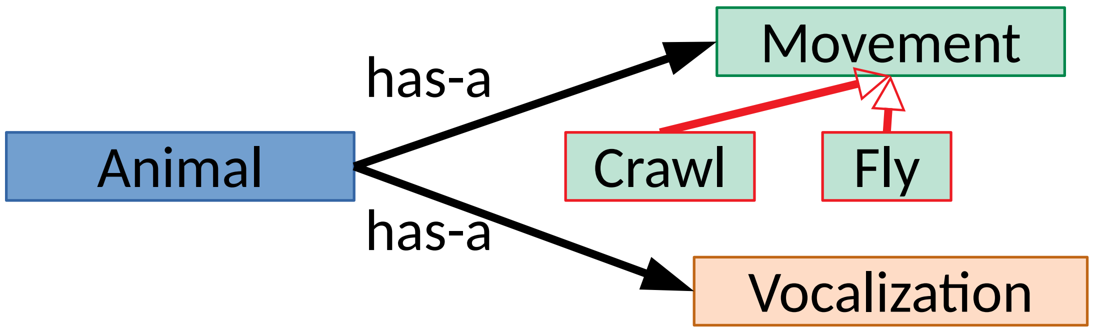

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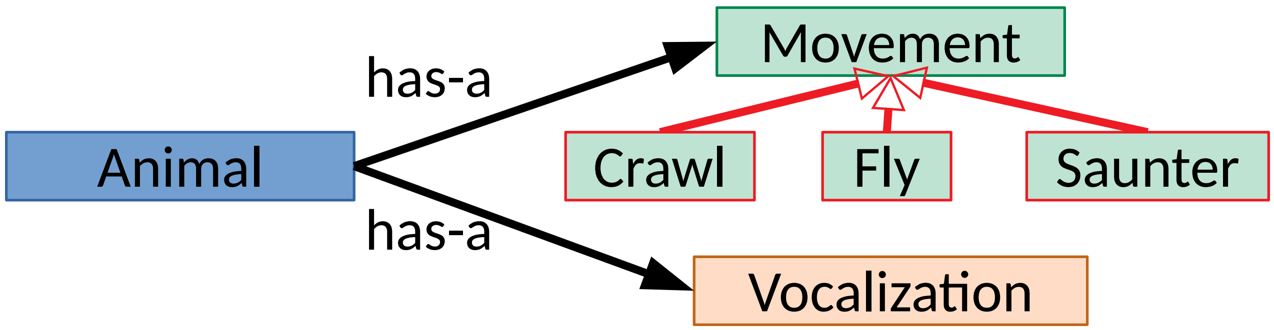

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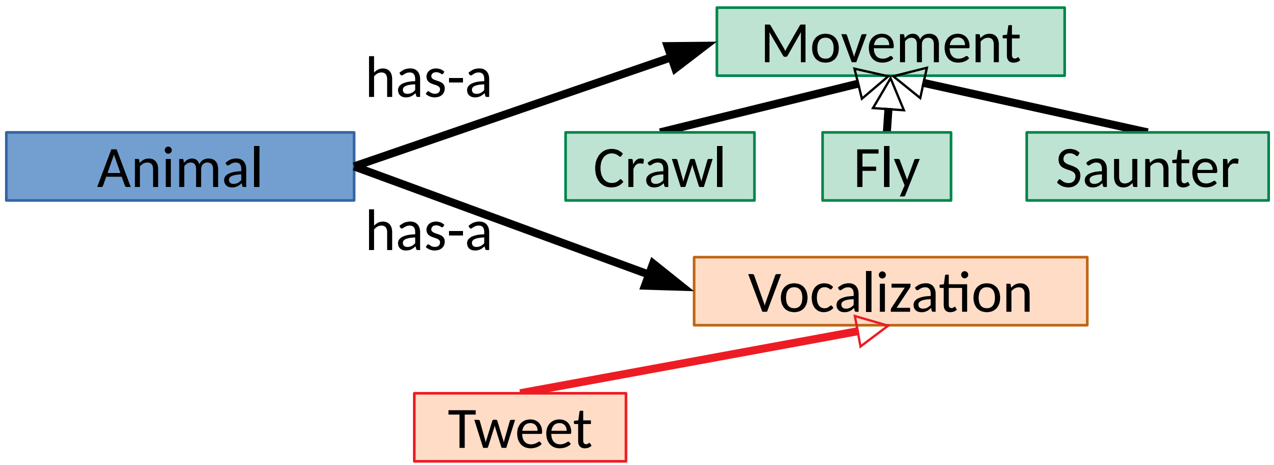

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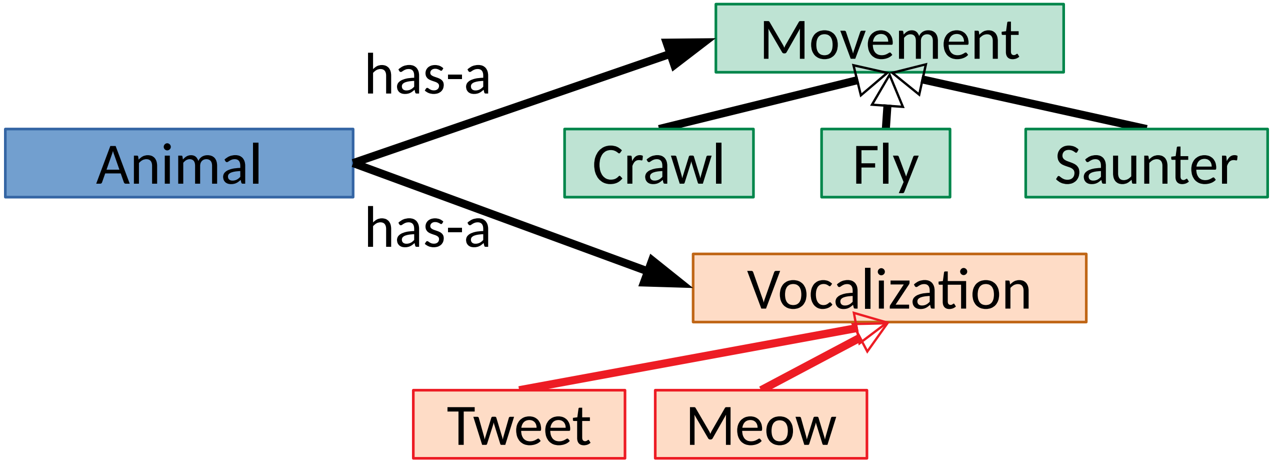

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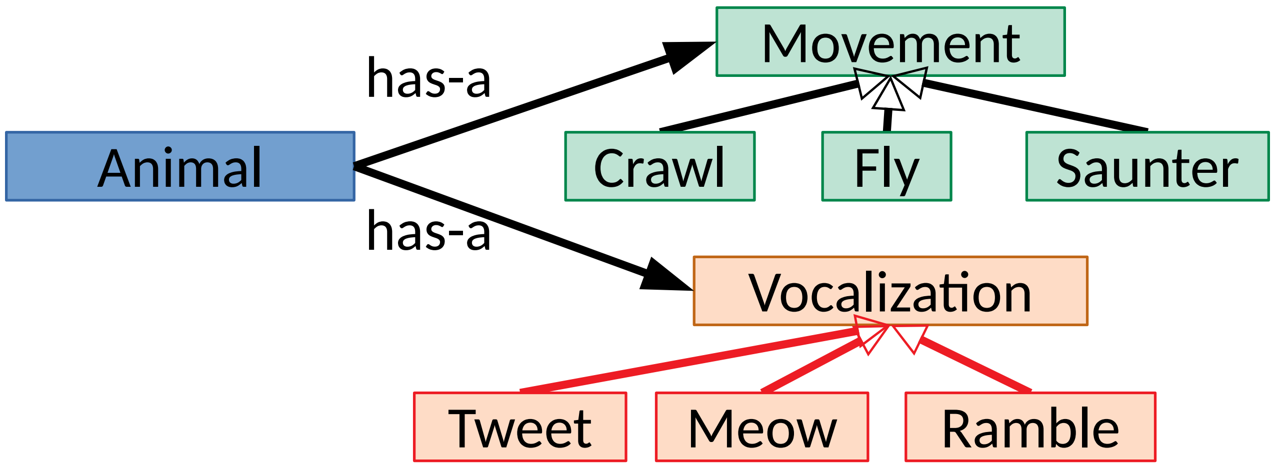

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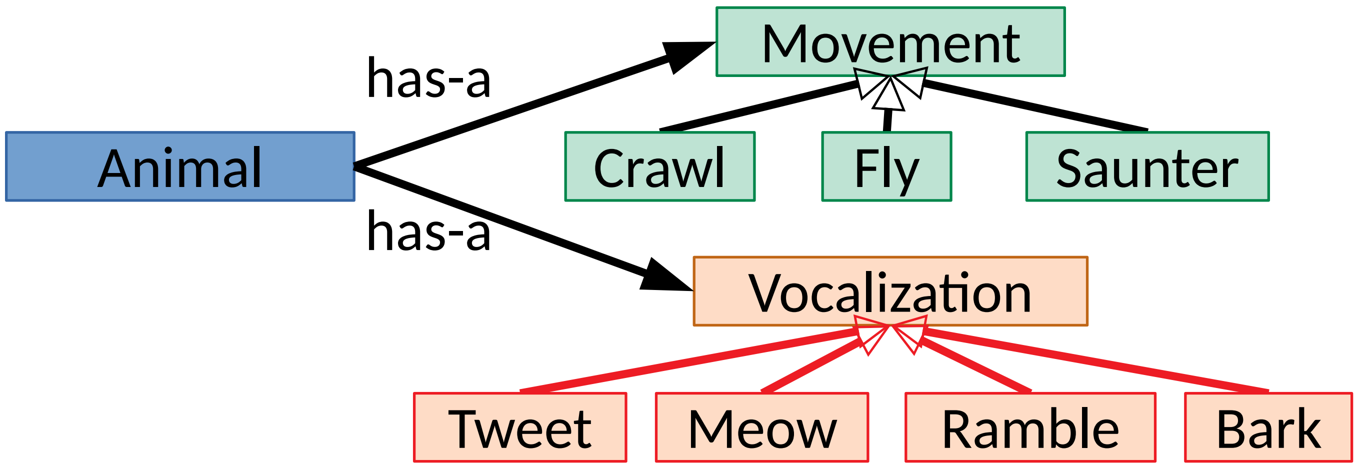

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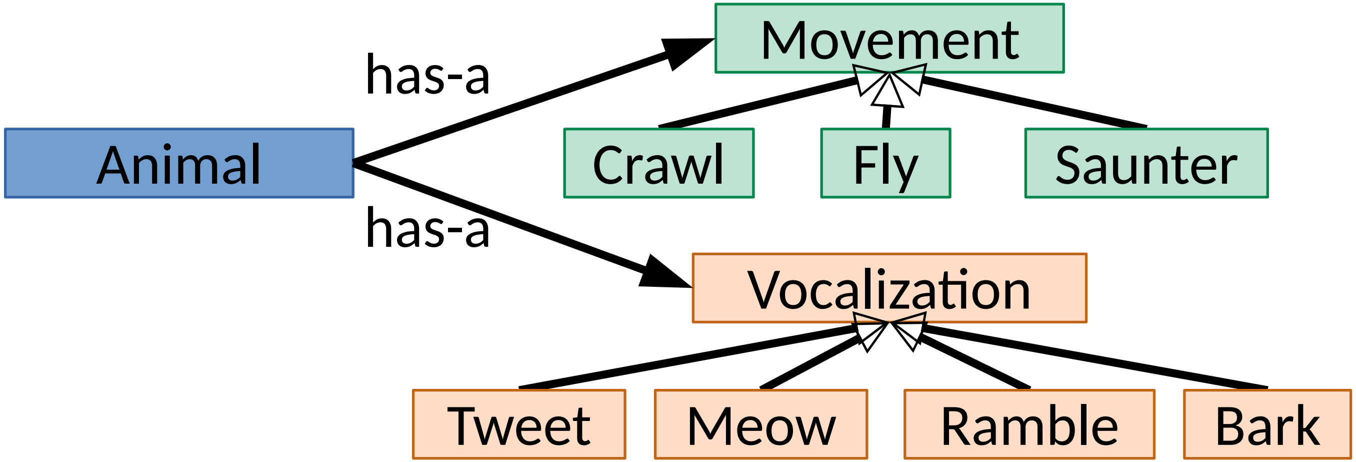
    m.move();
  }
};
```



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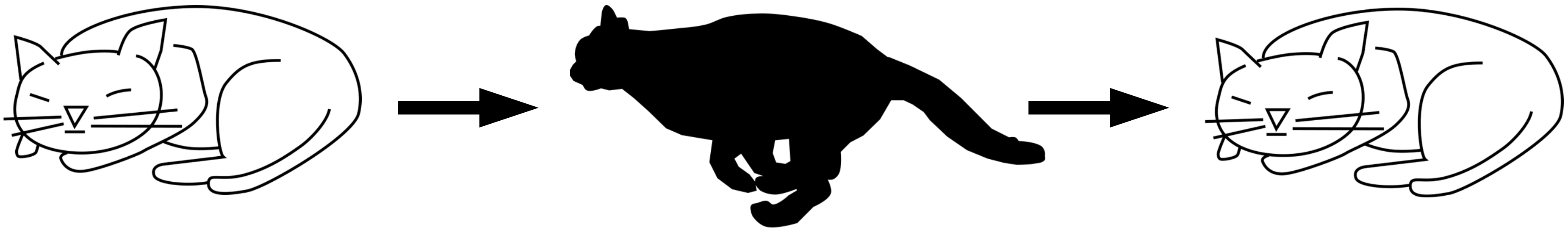

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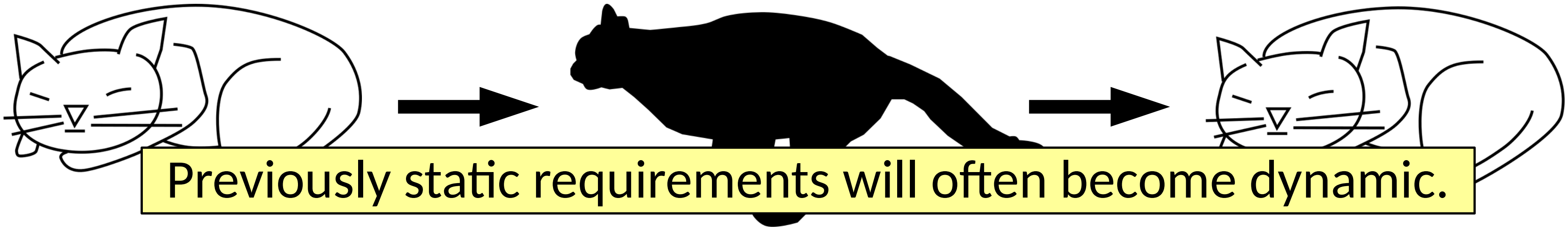

Previously static requirements will often become dynamic.

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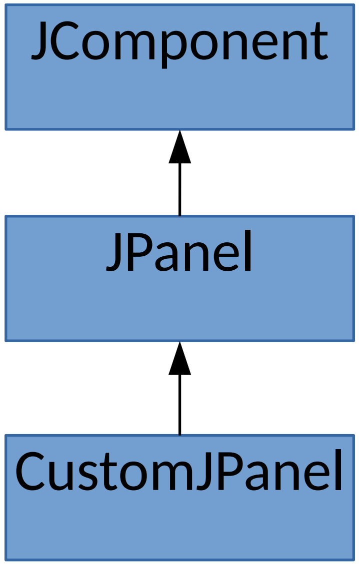
- Directly identifies & addresses risks of change in class design
- Does not focus on reusing from the base class.
  Instead makes the derived class reusable.

Violating Examples

- There a few bad examples that students & text books have brought to me



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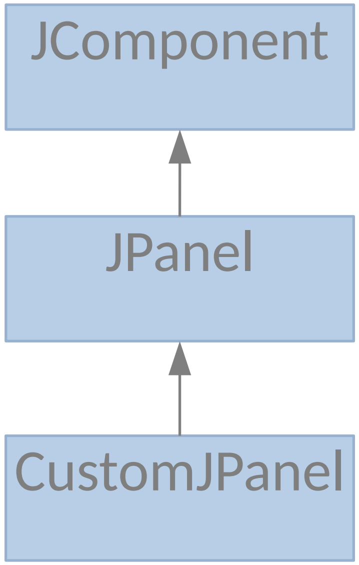

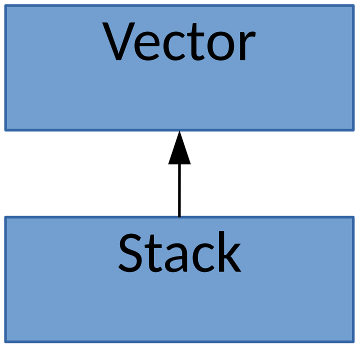

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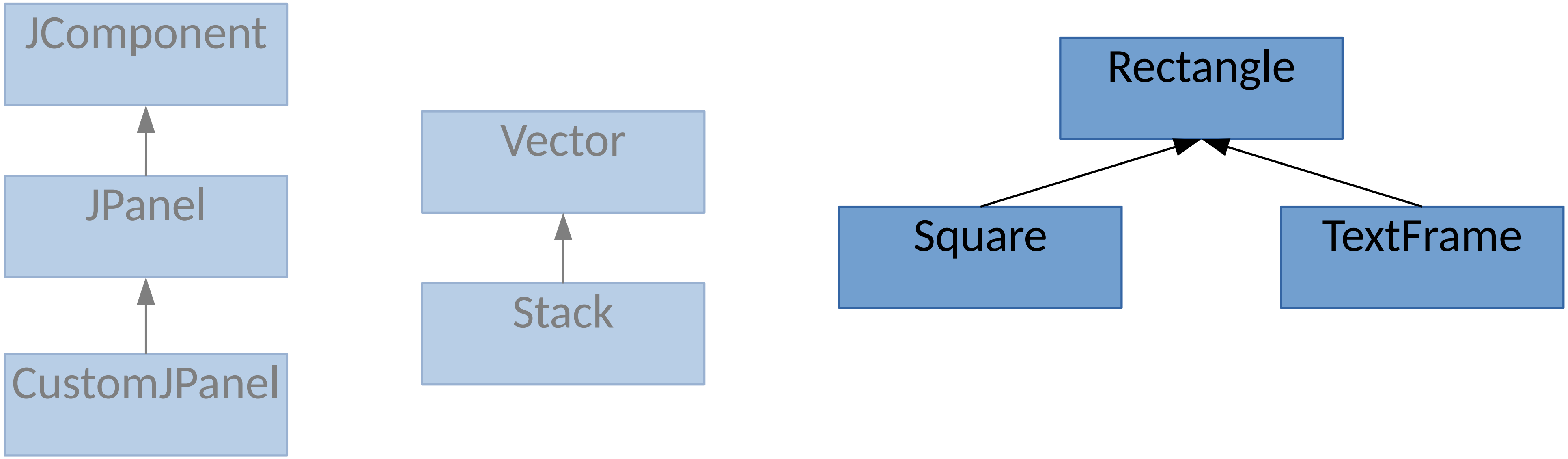

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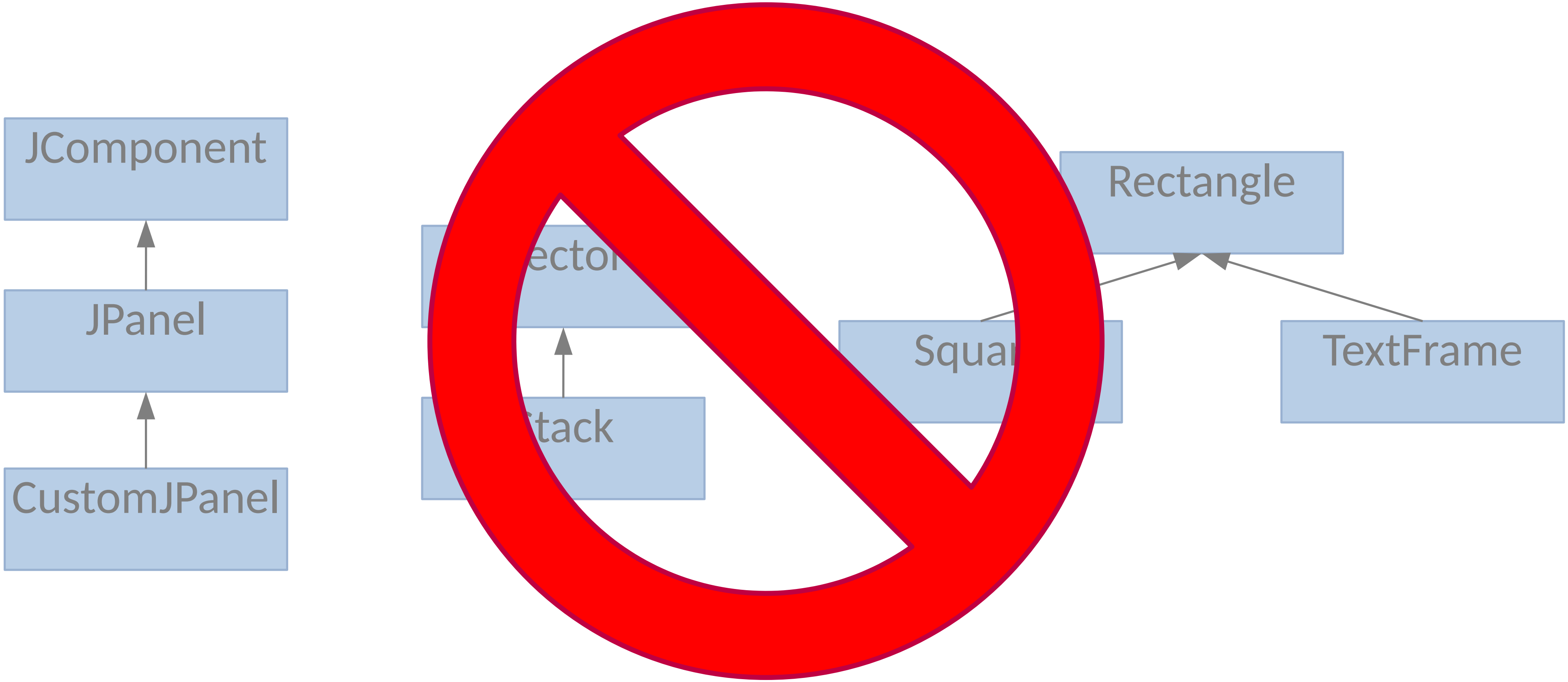

Parametric Polymorphism
(a quick review?)

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- Parametric polymorphism enables
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Java

```java
public class ArrayList<E> {...}
```

C++

```cpp
template <class E>
class vector;
```

Typescript

```typescript
class ArrayList<E> {...}
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Python

```python
T = TypeVar('T')
class SpecialList(Generic[T]):
   def __init__(self, value: T) -> None:
      ...
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std::vector<int> v1 = {1, 2, 3, 4, 5};
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C++

```cpp
std::vector<int> v
```

Parameters can sometimes be inferred.

```cpp
std::vector v1 = {1, 2, 3, 4, 5};
```

Parametric Polymorphism

- Parametric polymorphism enables
  defining generic components
  over a family of types
  using type parameters
- Enables careful ***abstraction*** of design components
  - A class/function/data structure/algorithm can be written & validated once
  - Intentions can be clearer within code

Parametric Polymorphism

- Suppose an algorithm needs to find an element in a collection & increment it.

Parametric Polymorphism

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```
void bigAlgorithm(...) {
	std::vector<int> c;
	...
	for (auto i = begin(c), e = end(c); i != e; ++i) {
		if (*i == v) {
			++*i;
			break;
		}
	}
	...
}
```

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```

This is awful.
Intentions are unclear.
Modifiability is low.
Reusability is low.

Parametric Polymorphism

- Suppose an algorithm needs to find an element in a collection & increment it.

```
void bigAlgorithm(...) {
    std::vector<int> c;
    ...
    for (auto i = begin(c),
        if (*i == v) {
            ++*i;
            break;
        }
    }
    ...
}
```

```
template<typename C, typename V>
size_t find(const C& c, const V& v) {
    for (auto& [index, element] : enumerate(c)) {
        if (element == v) {
            return index;
        }
    }
    return (size_t)-1;
}
```

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            return inc
        }
    }
    return (size_t)-1;
}
```

```
void bigAlgorithm(...) {
    std::vector<int> c;
    ...
    auto index = find(c, v);
    ++c[index];
}
```

```
void otherAlgorithm(...) {
    std::vector<string> d = ...;
    auto index = find(d, w);
    ...
}
```

Parametric Polymorphism

- Type variables can also be bounded / restricted
  - Consider `find(C,V)`, it should require that `ElementType(C) = V`
  - Restricting to subtypes / supertypes is common

Java

```
class D <T extends A & B & C> { }
class F <? extends E> { }
```

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class D <T extends A & B & C> { }
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```
public interface Map<K,V> {
  void putAll(Map<? extends K,? extends V> m)
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C++

```
template <typename T, typename=std::enable_if_t<std::is_class_v<T>>>
void foo(const T& t) {
  std::cout << "T is a class type\n";
}
```

Such constraints can be cleaner in C++20.

Parametric Polymorphism

- Type variables can also be bounded / restricted
  - Consider `find(C,V)`, it should require that `ElementType(C) = V`
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template <typename T, typename=std::enable_if_t<std::is_class_v<T>>>
void foo(const T& t) {
  std::cout << "T is a class type\n
}
```

```
template <typename C>
C::iterator_type find(const C& c, C::element_type v) {
  ...
}
```

Some scenarios are bounded by convention.

Parametric Polymorphism

- *Specialized* instances can sometimes be created
  - Sometimes domain knowledge allows more efficient implementations

Parametric Polymorphism

- *Specialized* instances can sometimes be created

```
template <class PointedTo, class Value>
class PointerValuePair {
  PointedTo* p;
  Value v;
  PointedTo* getP();
  Value getV();
};
```

Parametric Polymorphism

- *Specialized* instances can sometimes be created

```
template <class PointedTo, class Value>
class PointerValuePair {
  PointedTo* p;
  Value v;
  PointedTo* getP();
  Value getV();
};
```

```
template <class PointedTo>
class PointerValuePair<PointedTo,int> {
  uintptr_t compact;
  PointedTo* getP() {
    return reinterpret_cast<PointedTo*>(compact & ~0xFFFFFFF8);
  }
  int getV() { return compact & 0x00000007; }
};
```

Parametric Polymorphism

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```

Note, this example is still too simple to be safe.

Selecting forms of polymorphism

- Sometimes information needs to flow from a derived class to a base class.

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```
template<class T>
class Base {
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  void print() { getDerived().printImpl(); }
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};
```

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```

```
class Specific : public Base<Specific> {
public:
  void printImpl() { printf("Yo\n"); }
};
```

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public:
  void printImpl() { printf("Yo\n"); }
};
```

What other approaches could we have used?
What are the trade offs?

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Flexibility vs Efficiency

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Have those of you familiar with Java seen this before?

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```
public class LocalTime
       implements Comparable<LocalTime> {
  ...
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```

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public interface Comparable<T> {
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public interface Comparable<T> {
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This ***Curiously Recurring Template Pattern*** (CRTP)
Can help in building more robust APIs.

Selecting forms of polymorphism

- There are richer interactions between polymorphisms that enable clean & simple API design.

Selecting forms of polymorphism

- There are richer interactions between polymorphisms that enable clean & simple API design.
  - These issues are not the focus of this class
  - They are discussed more in CMPT 373
  - Feel free to ask questions about them on our discussion fora

Ad-hoc Polymorphism

Ad-hoc Polymorphism

- Ad-hoc polymorphism can occur on a case by case basis
  - Overloading
  - Type conversions / coercion
  - Type traits & type classes for flexible & structured overloading

Coercion

- Defining allowed conversions can lead to safe & intuitive APIs
- Example:
  Suppose we want APIs that can operate on contiguous collections.

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template<class E, auto N>
void foo(const E(&c)[N]);
```

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void foo(const std::array<E,N>& c);

template<class E>
void foo(const std::vector<E>& c);

void foo(const std::string& c);
```

```
template<class E, auto N>
void bar(const E(&c)[N]);

template<class E, auto N>
void bar(const std::array<E,N>& c);

template<class E>
void bar(const std::vector<E>& c);

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E>
std::vector<E>& c);

std::string& c);
```

Yuck.

Coercion

- Perhaps we can construct a new type that is conversion compatible with all desired types…

We can start by thinking what is common.

Coercion

- Perhaps we can construct a new type that is conversion compatible with all desired types…

```
template<class E>
struct Span {







    E* first;
    size_t count;
};
```

Coercion

- Perhaps we can construct a new type that is conversion compatible with all desired types…

```
template<class E>
struct Span {
    template<class E, auto N>
    Span(const std::array<E,N>& c);




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In C++, a non explicit 1 arg constructor defines a compatible conversion

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    size_t count;
};
```

```
void foo(Span<E> c);
void bar(Span<E> c);

...

std::vector v = {1, 2, 3, 4, 5};
foo(v);

int v[] = {1, 2, 3, 4, 5};
bar(v);

foo(“This works for free”);
```

This enables convenient & efficient generic APIs.

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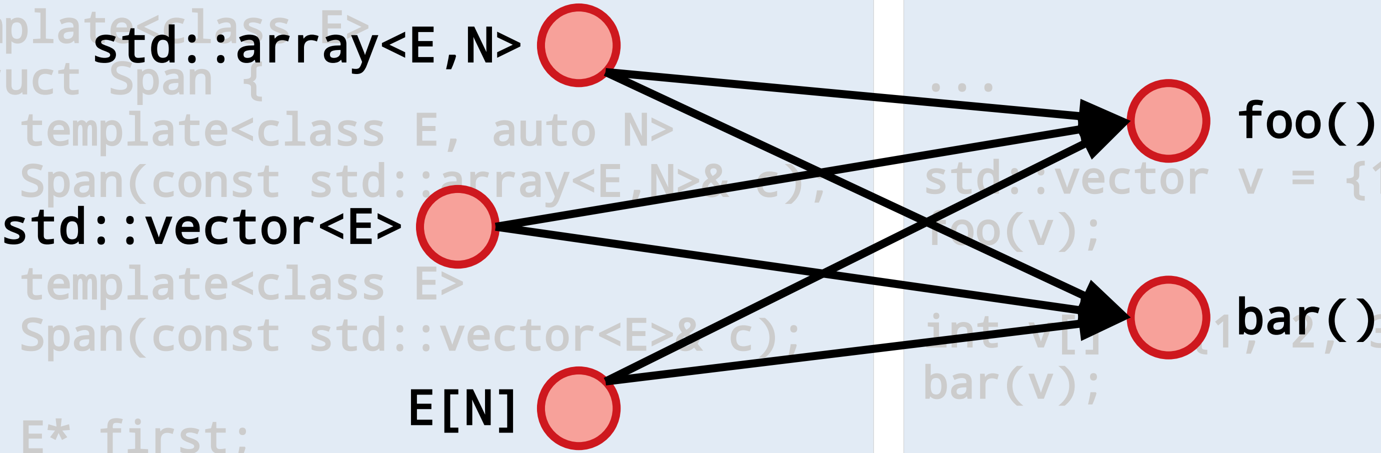


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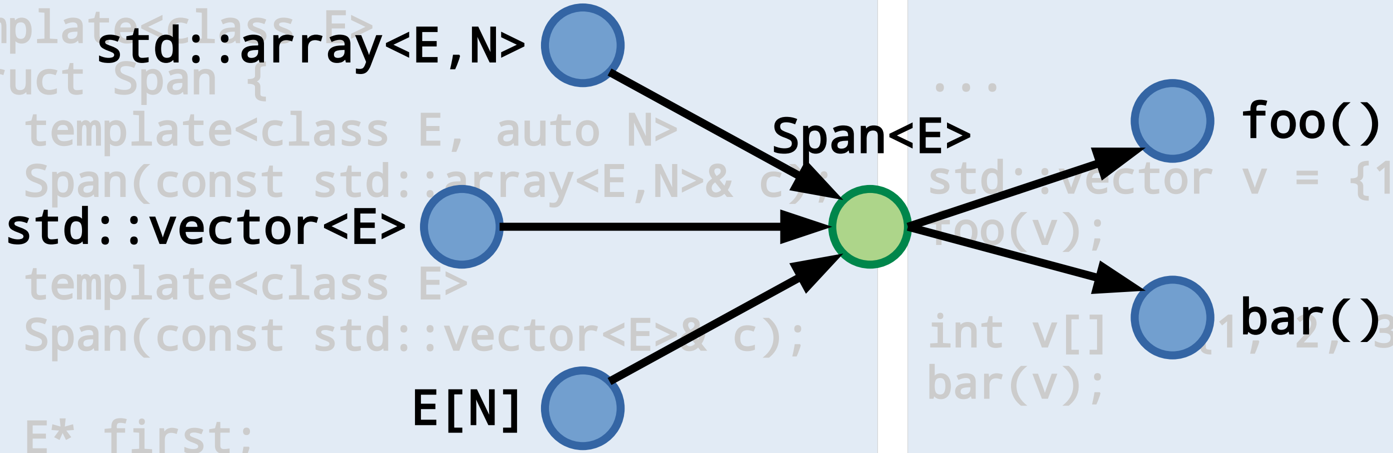
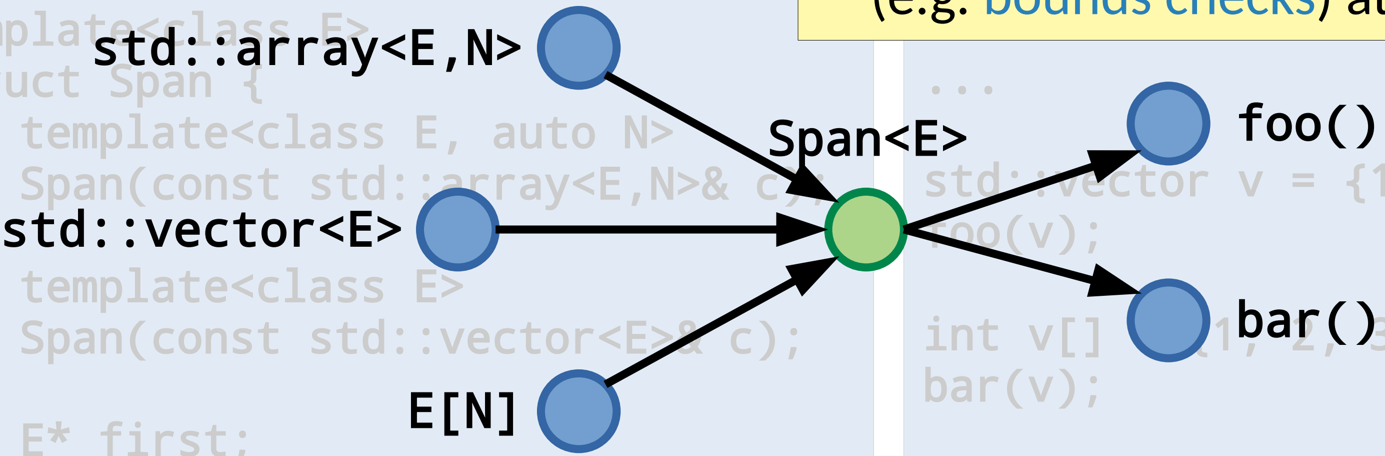


This enables convenient & efficient generic APIs.

Coercion

- Perhaps we can construct a new type that is conversion compatible with all desired types…

We can even add additional safety features (e.g. bounds checks) at this choke point!

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Type Traits

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  - How might we design a nice API?
    - Via inheritance?
    - Via parametric polymorphism?

Type Traits

- Careful use of specialization can structure overloading & extend behaviors
- Suppose we want to implement graph algorithms to traverse arbitrary data structures.
  - What constraints exist?
  - How might we design a nice API?
    - Via inheritance?
    - Via parametric polymorphism?
- ***Type traits*** and specialization can convey details about a type that enable generic algorithms
  - Specializations carry the extra details for an overload

Type Traits

```
template<typename GraphKind>
struct GraphTraits {
  using Error = typename GraphKind::ABCD;
};
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struct GraphTraits<SocialGraph> {




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struct GraphTraits<SocialGraph> {
  using NodeRef = ...;
  using ChildIterator = ...;
  static NodeRef get_entry(SocialGraph&) {...}
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};
```

```
template<class Kind, class GT=GraphTraits<Kind>>
void visualizeGraph(Kind& graph);
```

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SocialGraph g;
...
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};
```

```
template<class Kind, class GT=GraphTraits<Kind>>
void visualizeGraph(Kind& graph);
```

```
SocialGraph g;
...
visualizeGraph(g);
```

Regardless of the actual graph data structure,
or even its API,
traits allow generic algorithms to work!

Type Traits

- They are even common in the C++ standard library

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<functional>

```
namespace std {
  template< class Key >
  struct hash;
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namespace std {
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<unordered_set>

```
template<
  class Key,
  class Hash = std::hash<Key>,
  class KeyEqual = std::equal_to<Key>,
  class Allocator = std::allocator<Key>
> class unordered_set;
```

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```

This doesn't implement hashing for custom types.
What if I want to add a **`Cat`** to an **`unordered_set`**?

Type Traits

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  template< class Key >
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> class unordered_set;
```

<Cats.h>

```
namespace std {
  template<>
  struct hash<Cat> {
    std::size_t
    operator()(Cat const& s) const noexcept {
      return ...;
    }
  };
}
```

Type Traits

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namespace std {
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namespace std {
  template<>
  struct hash<Cat> {
    std::size_t
    operator()(Cat const& s) const noexcept {
      return ...;
    }
  };
}
```

```
std::unordered_set<Cat> bigBagOfCats;
```

Composition

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- The Principle of Compositionality (roughly)
  - The meaning of a complex entity is determined by the meanings of its constituents and the rules used to combine them.

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Or in software

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  - The meaning of a complex entity is determined by the meanings of its constituents and the rules used to combine them.

  Or in software

  - The meaning of a component should be clear from the meanings of its constituents and how they are used.
- But how can we achieve this? We'll look at a few approaches
  - Region / scope bounded behavior
  - Ownership
  - Algebraic data types

Region based behaviors

- Consider functions as a unit of abstraction
  - Possible incoming data
  - Behavior
  - Possible outgoing data

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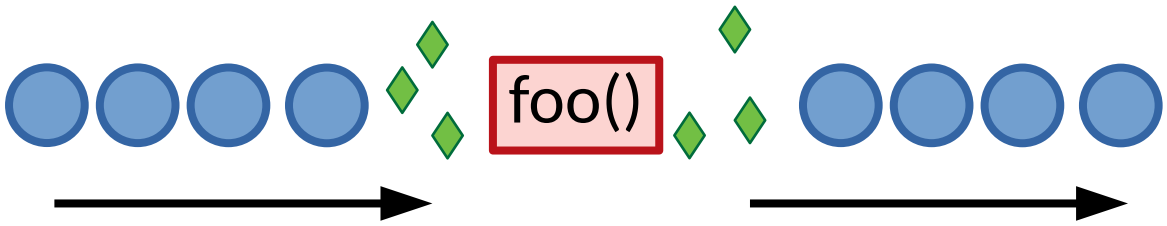

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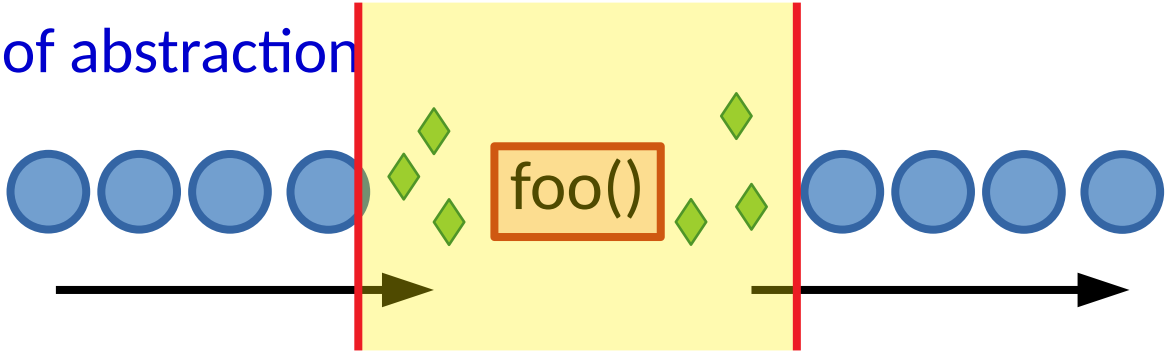

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  - Behavior
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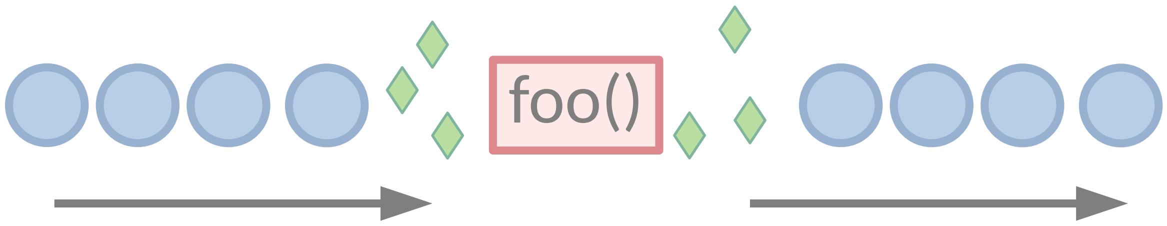
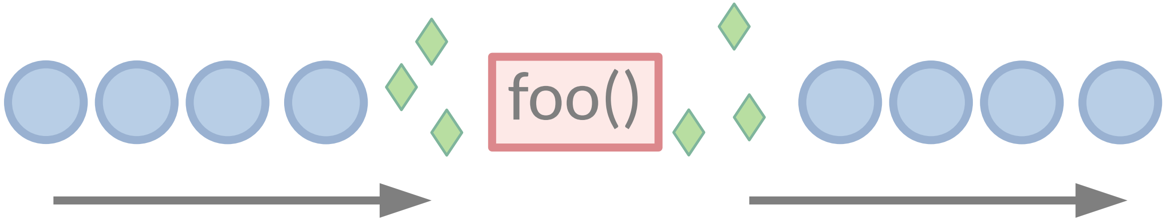


- Good abstractions tend to be *self contained*, but bad ones will leak obligations on their users

Region based behaviors

- Consider functions as a unit of abstraction
  - Possible incoming data
  - Behavior
  - Possible outgoing data



- Good abstractions tend to be *self contained*, but bad ones will leak obligations on their users

```
Mutex m;
lock(m);
...
unlock(m);
```

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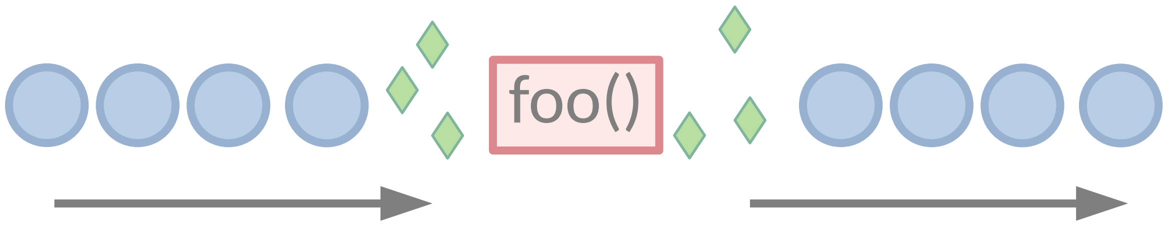

- Good abstractions tend to be *self contained*, but bad ones will leak obligations on their users

```
Mutex m;
lock(m);
...
unlock(m);
```

What if we don’t unlock the mutex?

Region based behaviors

- Modern languages enable denoting the region for an abstraction
  - Helps to bound the impact and provide composable interfaces.
  - Design the inconsistency and lack of hygiene out of a system

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- Examples
  - Java: **`synchronized`** blocks/methods, **`try`**-with-resources

```
synchronized (this){
   ...
}
```

```
try (BufferedReader br =
       new BufferedReader(new FileReader(path))) {
  return br.readLine();
}
```

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  - Python: **`with`**

```
with open(path) as infile:
    ...
```

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  - C#: **`using`**

```
using (var reader = new StreamReader(path)) {
   ...
}
```

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```
void memoryResource() {
  auto w = std::make_unique<Widget>(3, "bofrot");
  foo(*w);
}
```

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```
void memoryResource() {
  auto w = std::make_unique<Widget>(3, "bofrot");
```

Or better...

```
void memoryResource() {
  Widget w(3, "bofrot");
  foo(w);
}
```

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  - C++: RAII

```
void memoryResource() {
                                              bofrot");
```

```
void fileResource() {
  std::ofstream out{"output.txt"};
  out << "Boston cream\n";
}
```

Region based behaviors

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  - C#: **`using`**
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```
void memoryResource() {
```

```
bofrot");
```

```
void fileResource() {
```

```
std::mutex m;
void synchronization() {
  std::lock_guard<std::mutex> guard(g_pages_mutex);
  out << "Thread safe fritter\n";
}
```

Region based behaviors

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  - Python: `with`
  - C#: `using`
  - C++: RAII
  - Rust: lifetimes, borrowing, RAII, …

Ownership

- Sometimes lexical bounds are not known
  - Ownership ***designates*** whose ***responsibility*** it is to manage a resource

makes explicit & obvious

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```
std::unique_ptr<Widget>
memoryResource() {
  auto w = std::make_unique<Widget>(3, "bofrot");
  ...
  return w;
}
```

Whose responsibility is it to clean w?
When does it happen?

Ownership

- Sometimes lexical bounds are not known
  - Ownership ***designates*** whose ***responsibility*** it is to manage a resource
  - Applies when a resource has uncertain lifetimes
  - Combines region abstractions to clean up automatically

What do these signatures connote?

```
void foo(unique_ptr<Widget> w);
```

```
void foo(unique_ptr<Widget>& w);
```

```
void foo(Widget& w);
```

Algebraic Data Types

- Carefully combining types can design more inconsistent & erroneous states out of a system

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- Carefully combining types can design more inconsistent & erroneous states out of a system

```
struct Cat {
  enum Activity {RUNNING, SLEEPING};
  Activity activity;
  uint64_t runningSpeed;
};
```

What ***problems*** does this design enable?

Algebraic Data Types

- Carefully combining types can design more inconsistent & erroneous states out of a system

```
type Bool = True | False
```

Algebraic Data Types

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```
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```
type Activity = Running(int speed) | Sleeping
```

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```
type Bool = True | False
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```
type Activity = Running(int speed) | Sleeping
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Note: it is impossible to ask for the running speed of something sleeping!

Algebraic Data Types

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```
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How would you express this is C?
In C++?

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  - Sum types express disjoint alternatives
  - Product types express combinations

```
struct MapEntry { Key key; Value value; };
```

Algebraic Data Types

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- ***Algebraic Data Types*** enable the composable construction of types through combining types
  - Sum types express disjoint alternatives
  - Product types express combinations
- Note, the preferred way of extracting from an ADT is through pattern matching

```
enum Message {
    Quit,
    Move { x: i32, y: i32 },
    Write(String)
}
let msg = Message::Quit;
match msg {
    Message::Quit => {
        println!("The Quit variant has no data to destructure.")
    },
    Message::Move { x, y } => {
        println!("Move {} and {}", x, y);
    },
    Message::Write(text) => println!("Text message: {}", text),
}
```

[From the Rust Book]

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Designing Design Patterns

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- As in literature, you ***do not copy the archetype*** directly.

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Blind use of patterns is
another reason why people dislike OOP.

Note:

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!

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?

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```
...
auto result = foo(x, y, z);
...
```

What are the forms of coupling that arise?

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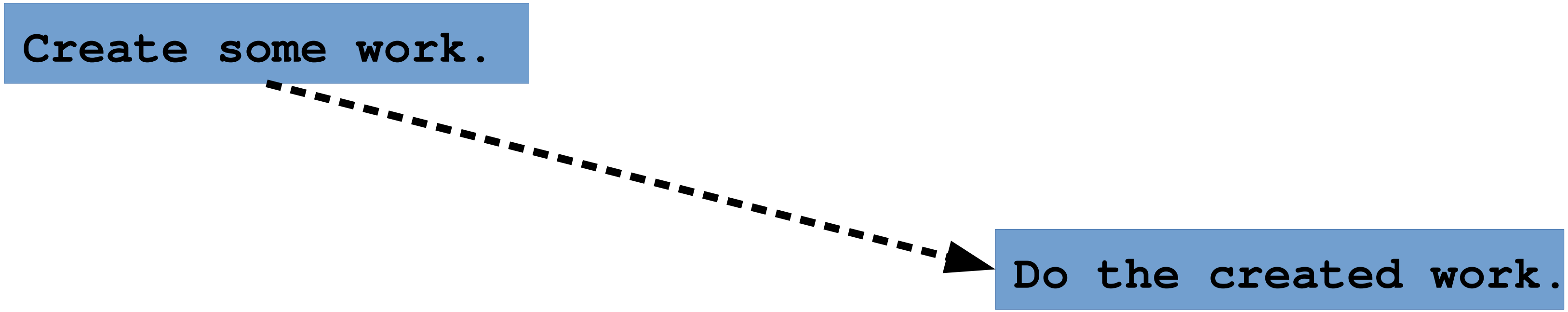

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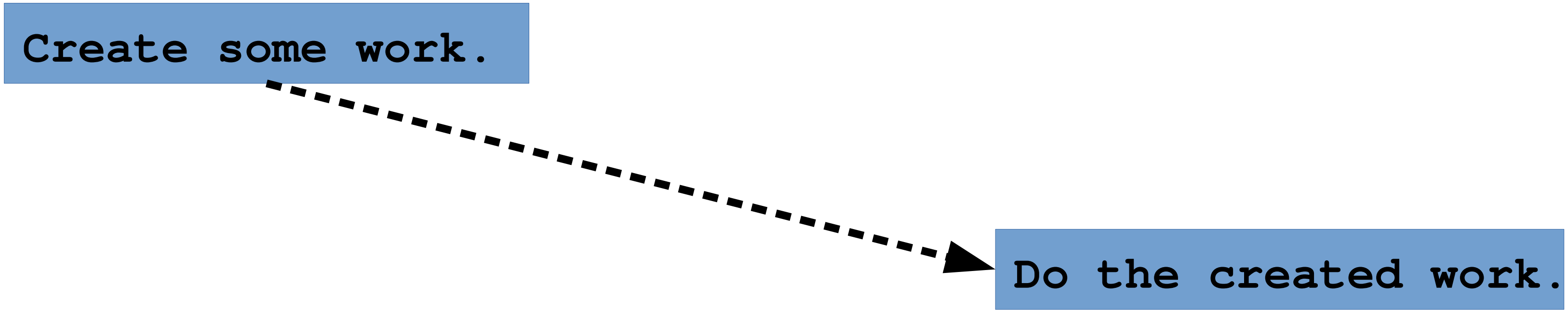

  - What interface captures this?

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?
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```
[redacted]
auto result = [redacted]([redacted]);
[redacted]
```

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?
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```
auto result = worker.doWork();
```

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?
  - Sometimes you must execute an action without any knowledge of what that action is.

```
auto result = worker.doWork();
```

```
class Work {
  // Information about work
  // ...
  Result doWork() {...}
};
```

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?
  - Sometimes you must execute an action without any knowledge of what that action is.

```
auto result = worker.doWork();
```

```
class Work {
  // Information about work
  // ...
  Result doWork() {...}
};
```

```
class OtherKindOfWork {
  Result doWork() {...}
};
```

Problem: Separate Caller & Callee

- What if we want to fully decouple actions to be taken from their call sites?
  - Sometimes you must execute an action without any knowledge of what that action is.

```
auto result = worker.doWork();
```

```
class Work {
  virtual Result doWork() = 0;
};
```

```
class WorkKind1 : public Work {
  Result doWork() override{...}
};
```

```
class WorkKind2 : public Work {
  Result doWork() override{...}
};
```

e.g. Behavioral Pattern: Command

```
class Command {
public:
  virtual void execute() = 0;
};
```

e.g. Behavioral Pattern: Command

- This is the ***command pattern***

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};
```

Why not just use a lambda?

The Command Pattern

- Benefits
  - **Decouples a request / behavior from the invoker**

The Command Pattern

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  - Invoker decides when to invoke without caring what

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...
auto result = foo(x, y, z);
...
```

The Command Pattern

- Benefits
  - Decouples a request / behavior from the invoker
  - Invoker decides when to invoke without caring what
  - Parameterizable via constructor

```
...
auto result = foo(x, y, z);
...
```

```
...
auto command = FooCommand(x, y, z);
...
```

```
command.execute();
```

The Command Pattern

- Benefits
  - Decouples a request / behavior from the invoker
  - Invoker decides when to invoke without caring what
  - Parameterizable via constructor
  - Sequences of commands can be easily batched

Problem: Add new behaviors to a set of types

- Different classes can perform the same action differently

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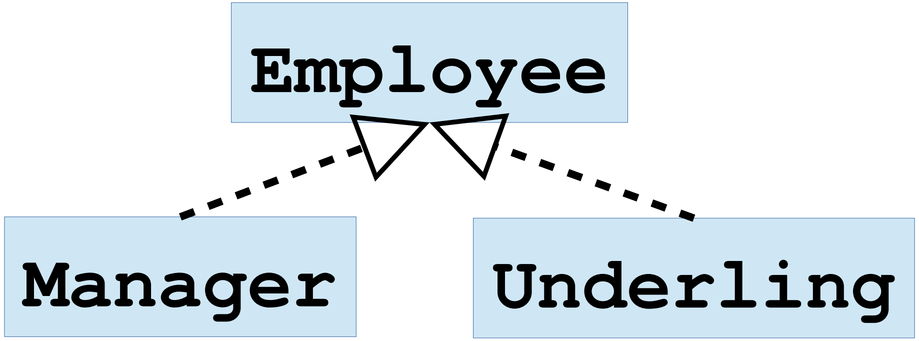
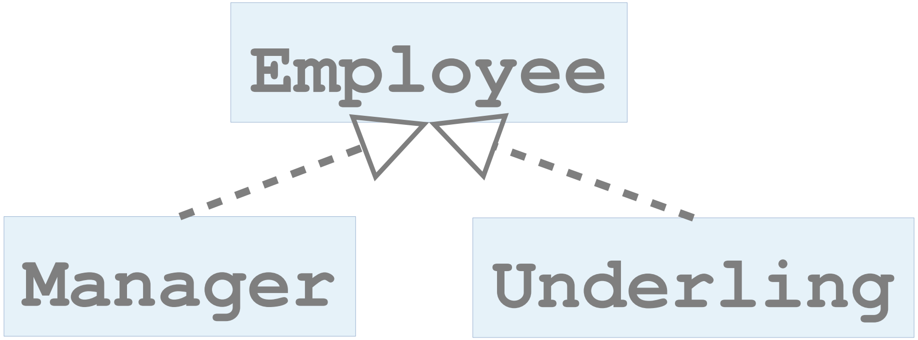


Problem: Add new behaviors to a set of types

- Different classes can perform the same action differently

```
Manager manager;
manager.updatePay();

Underling underling;
underling.updatePay();
```



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```
Manager manager;
manager.serialize();

Underling underling;
underling.serialize();
```

Problem: Add new behaviors to a set of types

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- There may be *many* different types of actions to add

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Operations for Employees

`updatePay`

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Operations for Employees

```
updatePay
serialize
```

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serialize
printPerformanceReview
...
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- Sometimes, you can't even know all of the actions in advance!

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- Different classes can perform the same action differently
- Sometimes you want to add a *new kind of action* to a set of related classes
- There may be many different types of actions to add
- Sometimes, you can't even know all of the actions in advance!

Why are these problems?

Problem: Add new behaviors to a set of types

- Let us take a look at our **`Employee`** base class...

```
class Employee {
public:
   ...
   virtual void updatePay() = 0;
   virtual void performJob() = 0;
   virtual void serialize() = 0;
   virtual void displayAvatar() = 0;
   virtual void printPerformanceReview() = 0;
   virtual void findFavoriteOfficeMate() = 0;
   virtual void procrastinate() = 0;
};
```

Problem: Add new behaviors to a set of types

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   ...
   virtual void updatePay() = 0;
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   virtua
};
```

Why does this feel so wrong?

Problem: Add new behaviors to a set of types

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   ...
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   virtua
};
```

Why does this feel so wrong?

Solutions

- We need to find a better way

Solutions

- We need to find a better way

```
Employee* employee = ...
...
auto result = employee->foo(x, y, z);
...
```

Solutions

- We need to find a better way

```
Employee* employee = [redacted]
[redacted]
auto result = employee->[redacted]([redacted]);
[redacted]
```

Solutions

- We need to find a better way

```
Employee* employee = [redacted]

auto result = employee->();
```

We want to be able to add new behaviors, so we should not need to know them

Solutions

- We need to find a better way

```
Employee* employee =
[redacted]
auto result = employee->[redacted]([redacted]);
[redacted]
```

We also want possibly different behavior for different subtypes.

Solutions

- We need to find a better way
  - What are the tools at our disposal?

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  - What are the tools at our disposal?
    - Classes
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Solutions

- We need to find a better way
  - What are the tools at our disposal?
    - Classes
    - Polymorphism
  - How can we use them to attack the problem?
    - Group related behaviors into classes
    - Invoke them when desired

Grouping Related Behavior

- How should we group related behaviors?

What does SRP dictate?

Grouping Related Behavior

- How should we group related behaviors?
  - Each offending method becomes a new class

Grouping Related Behavior

- How should we group related behaviors?
  - Each offending method becomes a new class

```
class EmployeeSerializer {
public:
   void serialize(Manager &manager);
   void serialize(Underling &underling);
};

class PerformanceReviewPrinter {
public:
   void printReview(Manager &manager);
   void printReview(Underling &underling);
};
```

How Do We Invoke It?

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```
EmployeeSerializer serializer;
std::vector<Employee*> employees;

for (auto *employee : employees) {
  serializer.serialize(*employee);
}
```

How Do We Invoke It?

```
EmployeeSerializer serializer;
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```

?

Will this work? Why?

How Do We Invoke It?

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std::vector<Employee*> employees;

for (auto *employee : employees) {
  serializer.serialize(employee);
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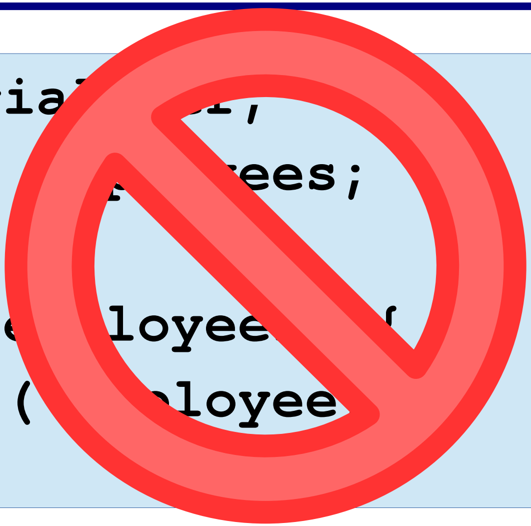
```



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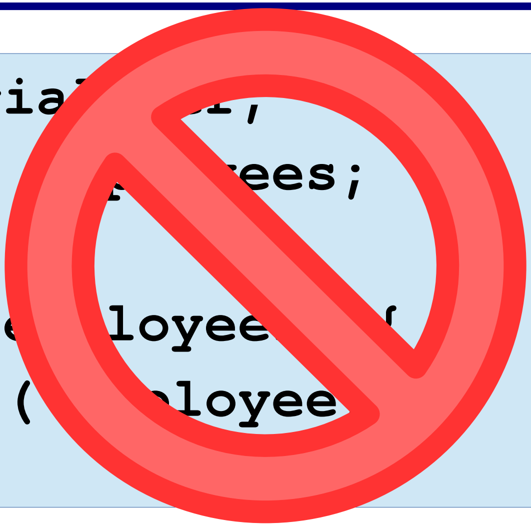

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  - We want to call a method based on *multiple dynamic types*

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But we only know that `employee` is an `Employee*`

How can we resolve the issue?

How Do We Invoke It?

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  - We want to call a method based on multiple dynamic types
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- Solution:
  - The Visitor Pattern

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  - The Visitor Pattern
  - Goal:

```
base->[redacted]([redacted]);
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base->[redacted]([redacted]);
```

Invoke the correct behavior regardless of the dynamic type!

The Visitor Pattern

Abstract away the added behaviors:

```
class EmployeeSerializer : public Visitor {
public:
  void visit(Manager &manager) override;
  void visit(Underling &underling) override;
};
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Giving behaviors a common API
allows us to use all behaviors in the same way

The Visitor Pattern

Change the original classes:

```
class Employee {
public:
  virtual void accept(Visitor &v) = 0;
}
class Manager : public Employee {
  ...
  void accept(Visitor &v) override {
    v.visit(*this);
  }
};
```

The Visitor Pattern

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class Employee {
public:
   virtual void accept(Visitor &v) = 0;
}
class Manager : public Employee {
   ...
   void accept(Visitor &v) override {
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   }
};
```

The dynamic type of **`Employee`** is known!

Calls **`visit(Manager &manager)`** here.

The Visitor Pattern

Use the new behaviors through their classes:

```
EmployeeSerializer serializer;
PerformanceReviewPrinter reviewer;
std::vector<Employee*> employees;

for (auto* employee : employees) {
  employee->accept(serializer);
  employee->accept(reviewer);
}
```

The Visitor Pattern

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EmployeeSerializer serializer;
PerformanceReviewPrinter reviewer;
std::vector<Employee*> employees;

for (auto* employee : employees) {
  employee->accept(serializer);
  employee->accept(reviewer);
}
```

What if we want a return value?

The Visitor Pattern

Use the new behaviors through their classes:

```
std::vector<Visitor*> actions;
std::vector<Employee*> employees;
...
for (auto* employee : employees) {
  for (auto* action : actions) {
    employee->accept(*action);
  }
}
```

The Visitor Pattern

- A behavioral pattern

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- Useful for adding new behaviors to a collection of related classes
  - *It also keeps those behaviors isolated!*
  - Useful for designing APIs open to extension

The Visitor Pattern

- A behavioral pattern
- Useful for adding new behaviors to a collection of related classes
- But what are the downsides?
  - Can we overcome them?

Making tradoffs

- The visitor pattern
  - makes adding new behaviors trivial
  - can leave adding new types challenging

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You can help or hurt
an open/closed design

Making tradoffs

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- What if we expect adding new types to be more common?
  - A similar pattern called the ***interpreter*** emerges
  - Each behavior is just a method of the type involved
- Choose between them by likelihood of change & maintainability
- Adding new types vs adding new behaviors is a common tension when designing maintainable software
  - This is classically known as the ***expression*** problem.

Designing Design Patterns

- Instead of memorizing them, you should be able to create them

Summary

- Careful software design focuses responsibilities & makes changes easier

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- Careful software design focuses responsibilities & makes changes easier
- Polymorphism & composition help provide clear abstractions