Proper Inheritance

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Abstract

All essential behavior of our software must be documented, and yet there are important advantages, with respect to development, verification and testing, performance, and stability, for leaving the behavior for some combinations of inputs and initial conditions undefined. What is and is not defined behavior should therefore be readily discernible from the contract, especially when creating contracts that must span classes related by inheritance.

In this two-part talk, we begin by reviewing components, interfaces and contracts in general, and the significance of ***narrow*** versus ***wide*** contracts. In the second part, we go on to explore <u>three</u> kinds of inheritance: (1) ***Interface Inheritance*** resulting from pure-virtual functions, (2) ***Structural Inheritance*** resulting from non-virtual functions, and (3) ***Implementation Inheritance*** resulting from non-pure virtual functions. Proper contracts involving each of these distinct forms have different criteria that must be addressed. The three kinds of inheritance are compared, and their relative utility is explained. What's more, several common uses of inheritance that are provably improper are summarily debunked.

What’s The Problem?

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- It requires the designer to delineate logical behavior precisely, while managing the physical dependencies on other subordinate components.

What’s The Problem?

Large-Scale C++ Software Design is Multi-Dimensional:

- It involves many subtle *logical* and *physical* aspects.
- It requires an ability to isolate and modularize logical functionality within discrete, fine-grain physical components.
- It requires the designer to delineate logical behavior precisely, while managing the physical dependencies on other subordinate components.
- It requires attention to numerous logical and physical rules that govern sound software design.

Purpose of this Talk

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Review:

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1. Components –

Our fundamental unit of *logical* and *physical* design

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2. Interfaces and contracts (in general)

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2. Interfaces and contracts (in general)

3. *Narrow* versus *Wide* contracts (in particular)

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Review:

1. Components –

   Our fundamental unit of *logical* and *physical* design

2. Interfaces and contracts (in general)
3. *Narrow* versus *Wide* contracts (in particular)
4. Explore these basic ideas in the context **inheritance**.

Outline

1. Components (review)

   Modularity, Logical/Physical Dependencies, & Level numbers

2. Interfaces and Contracts (review)

   Syntax versus Semantics & *Essential Behavior*

3. Narrow versus Wide Contracts (review)

   The Significance of *Undefined Behavior*

4. Proper Inheritance

   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

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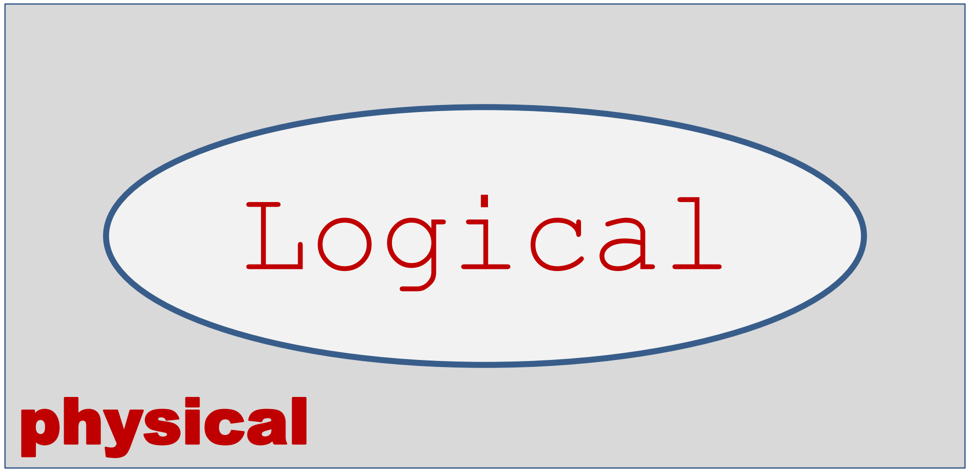
Logical versus Physical Design

What distinguishes *Logical* from *Physical* Design?



Logical versus Physical Design

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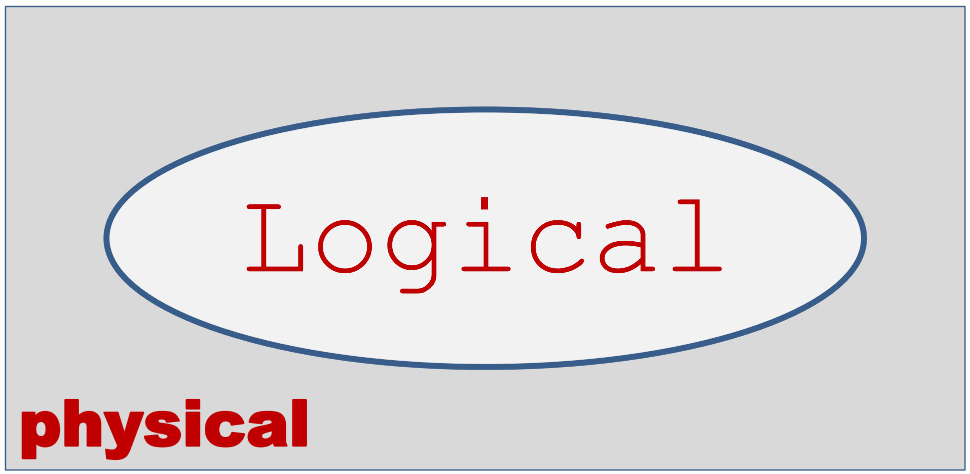

Logical: Classes and Functions

1. Components (review)

Logical versus Physical Design

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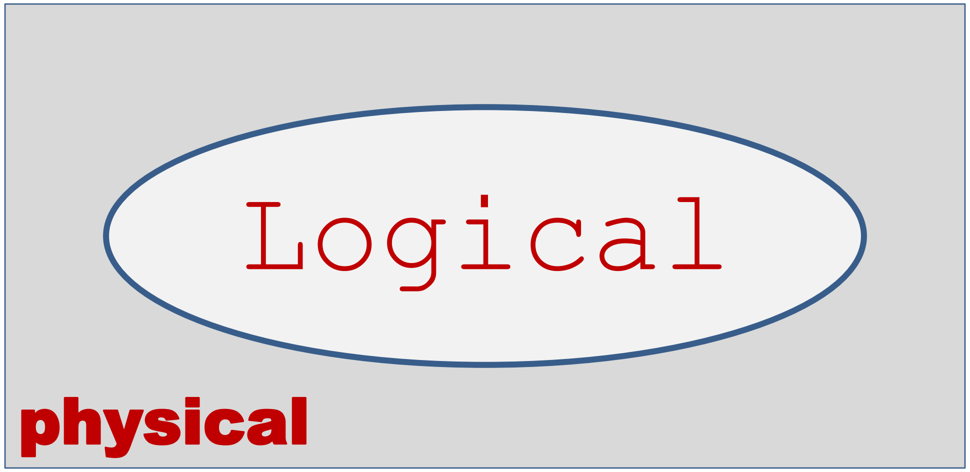
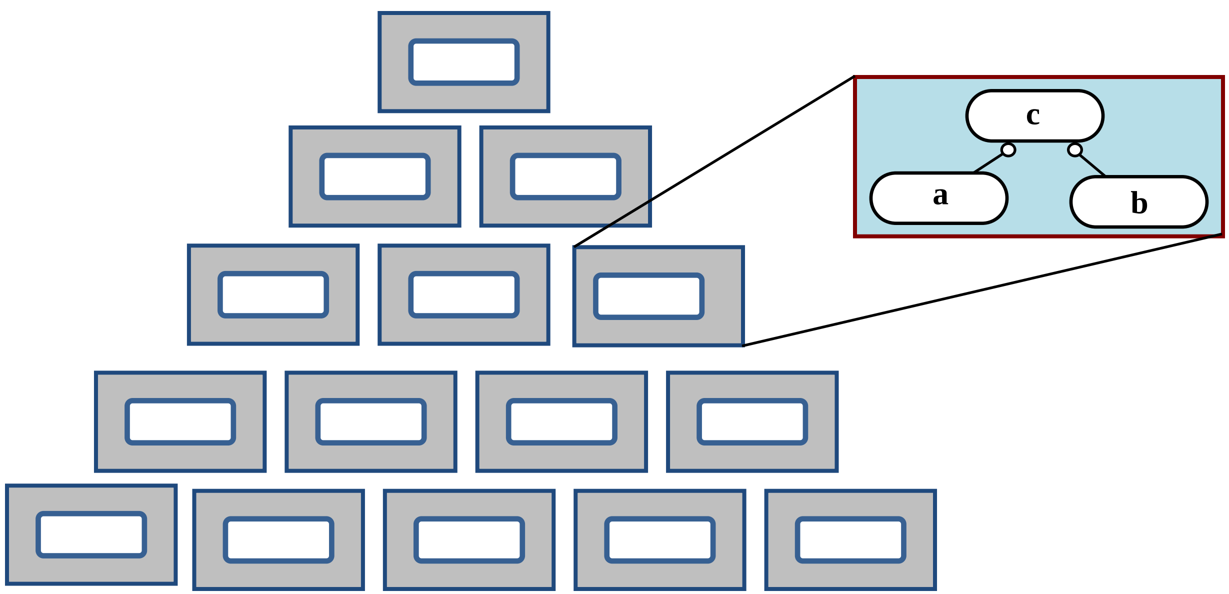


Logical: Classes and Functions
Physical: Files and Libraries

Logical versus Physical Design

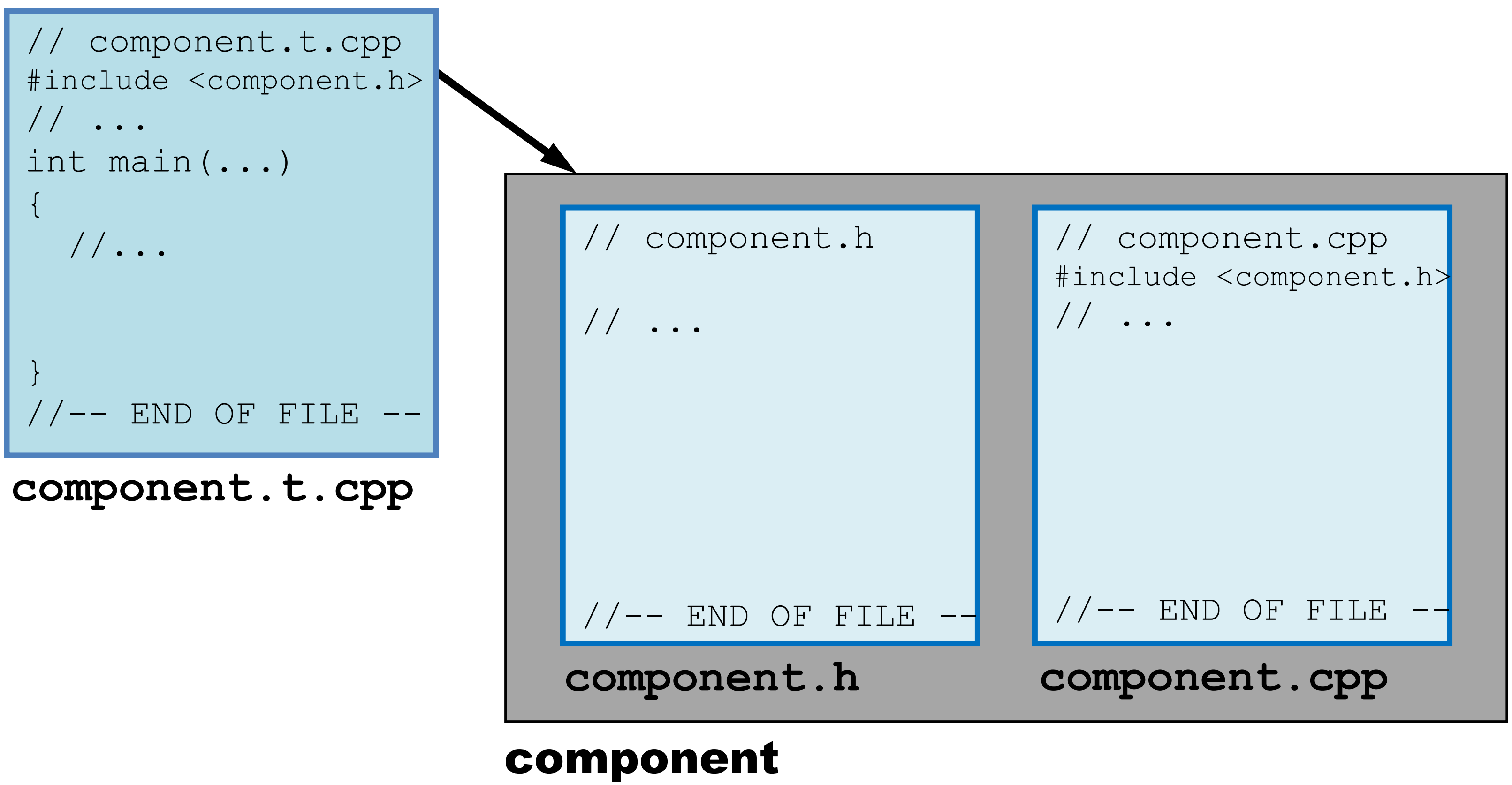
Logical content aggregated into a *Physical* hierarchy of ***components***



1. Components (review)

Component: Uniform Physical Structure

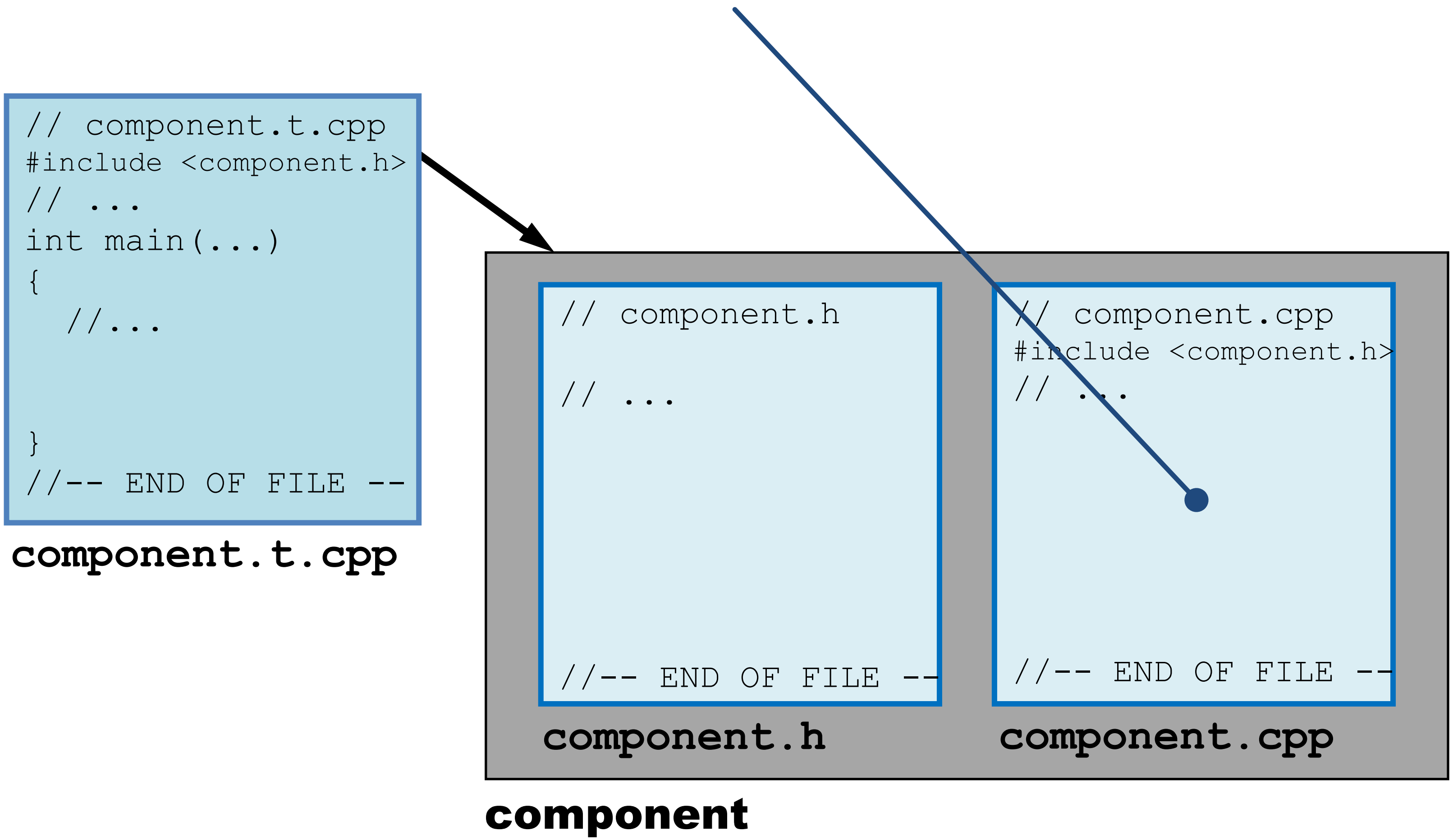
A Component Is Physical



1. Components (review)

Component: Uniform Physical Structure

Implementation



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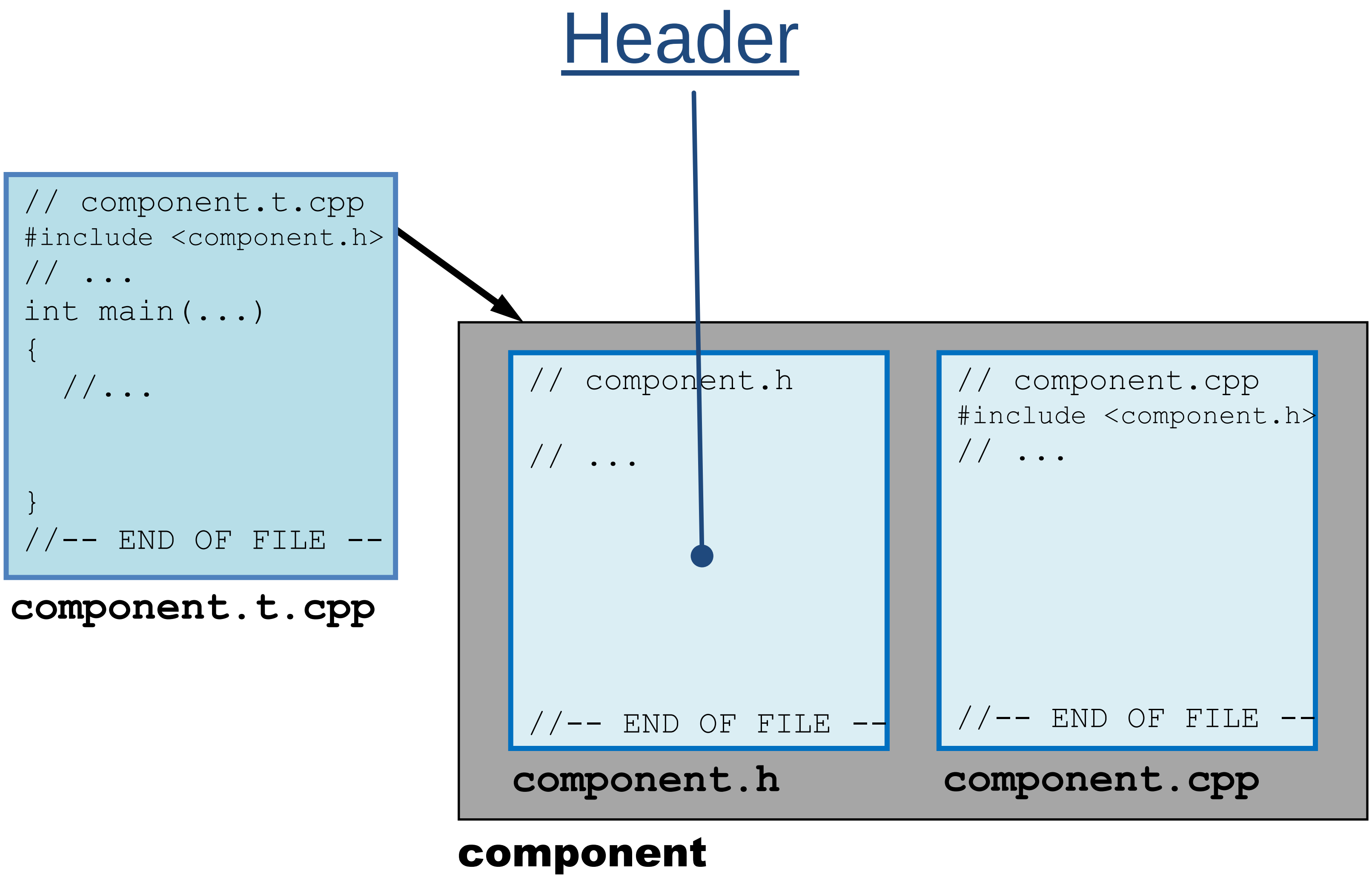

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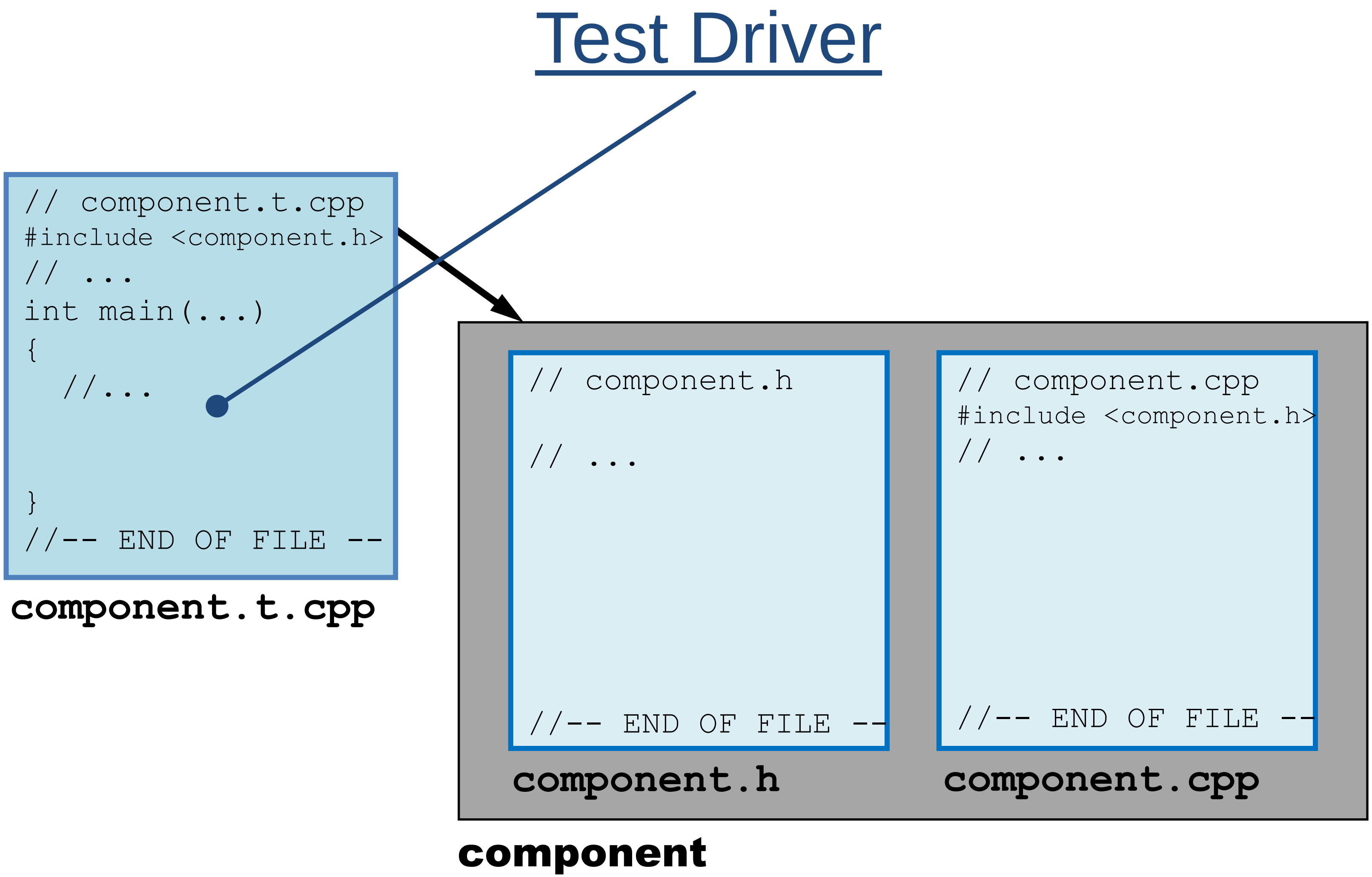
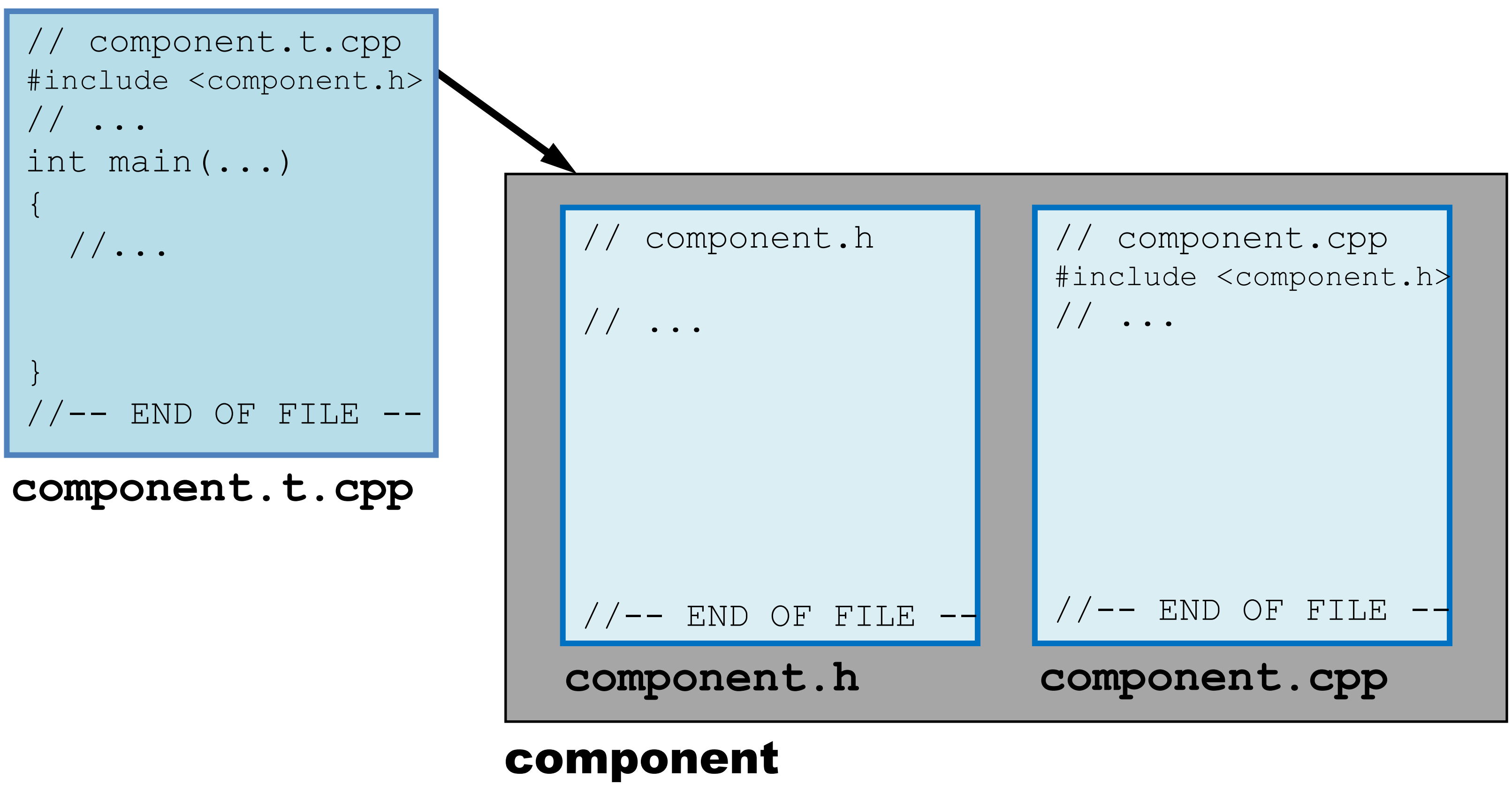


1. Components (review)

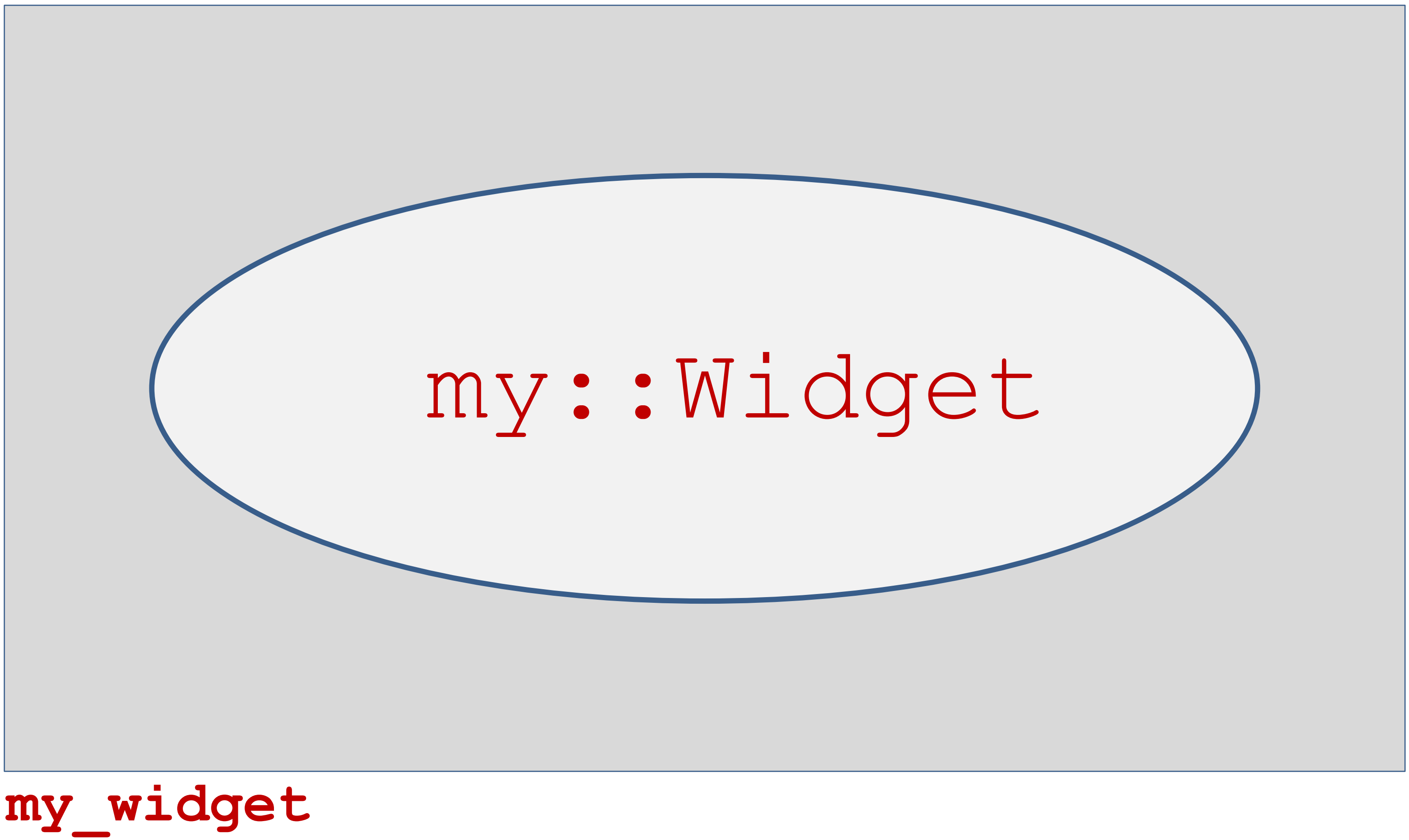
Component: Uniform Physical Structure

<u>The</u> Fundamental Unit of Design



1. Components (review)

Component: Not Just a `.h`/`.cpp` Pair



Component: Not Just a `.h`/`.cpp` Pair

There are four Properties…

Component: Not Just a `.h`/`.cpp` Pair

1. The **`.cpp`** file includes its **`.h`** file as the first substantive line of code.

EVEN IF THE .CPP IS OTHERWISE EMPTY!

1. Components (review)

Component: Not Just a `.h/.cpp` Pair

1. The **`.cpp`** file includes its **`.h`** file as the first substantive line of code.
2. All logical constructs having external *linkage* defined in a **`.cpp`** file are declared in the corresponding **`.h`** file.
3. All constructs having external or dual *bindage* declared in a **`.h`** file (if defined at all) are defined within the component.
4. A component's functionality is accessed via a **`#include`** of its header, and never via a forward (**`extern`**) declaration.

Component: Not Just a `.h/.cpp` Pair

1. The **`.cpp`** file includes its **`.h`** file as the first substantive line of code.

2. All logical

We could easily spend 20 minutes on this slide alone!

Avoid Global Namespace Pollution

Achieve Logical/Physical Modularity

Enable *Efficient* Extraction of Physical Dependencies

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Avoid Global Namespace Pollution

Achieve Logical/Physical Modularity

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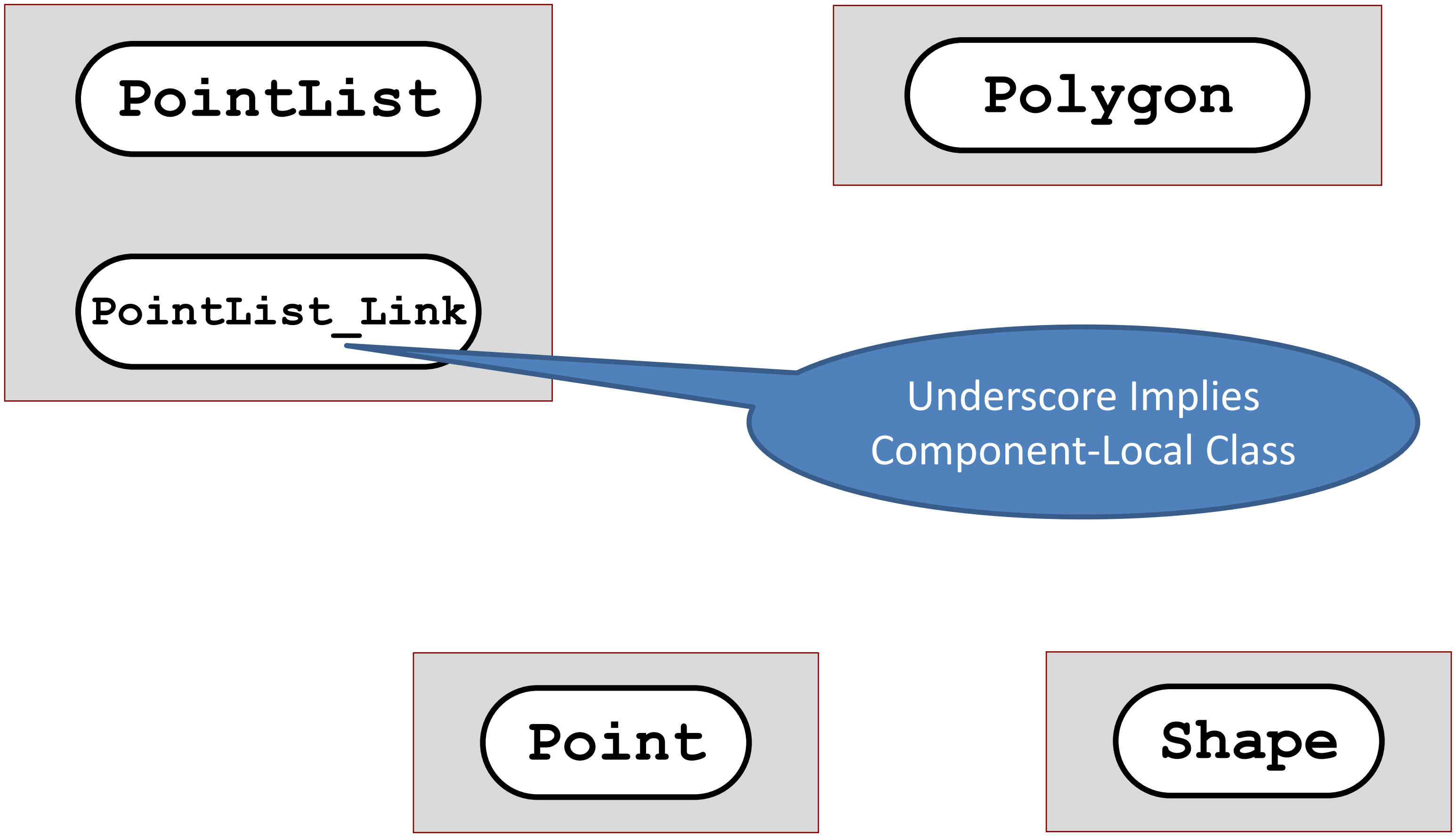
For much more see:

ADVANCED LEVELIZATION TECHNIQUES

1. Components (review)

Logical Relationships



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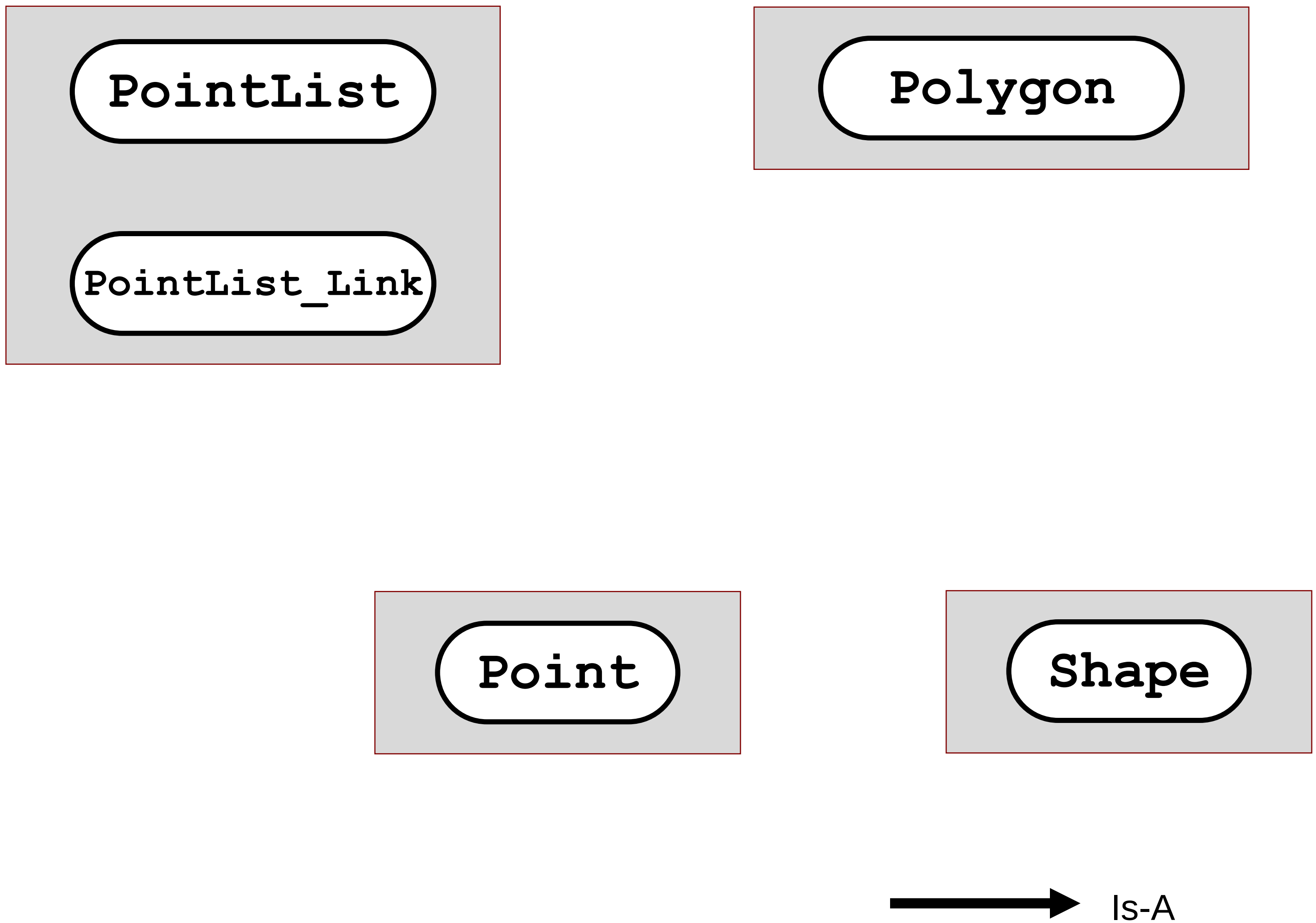
Logical Relationships



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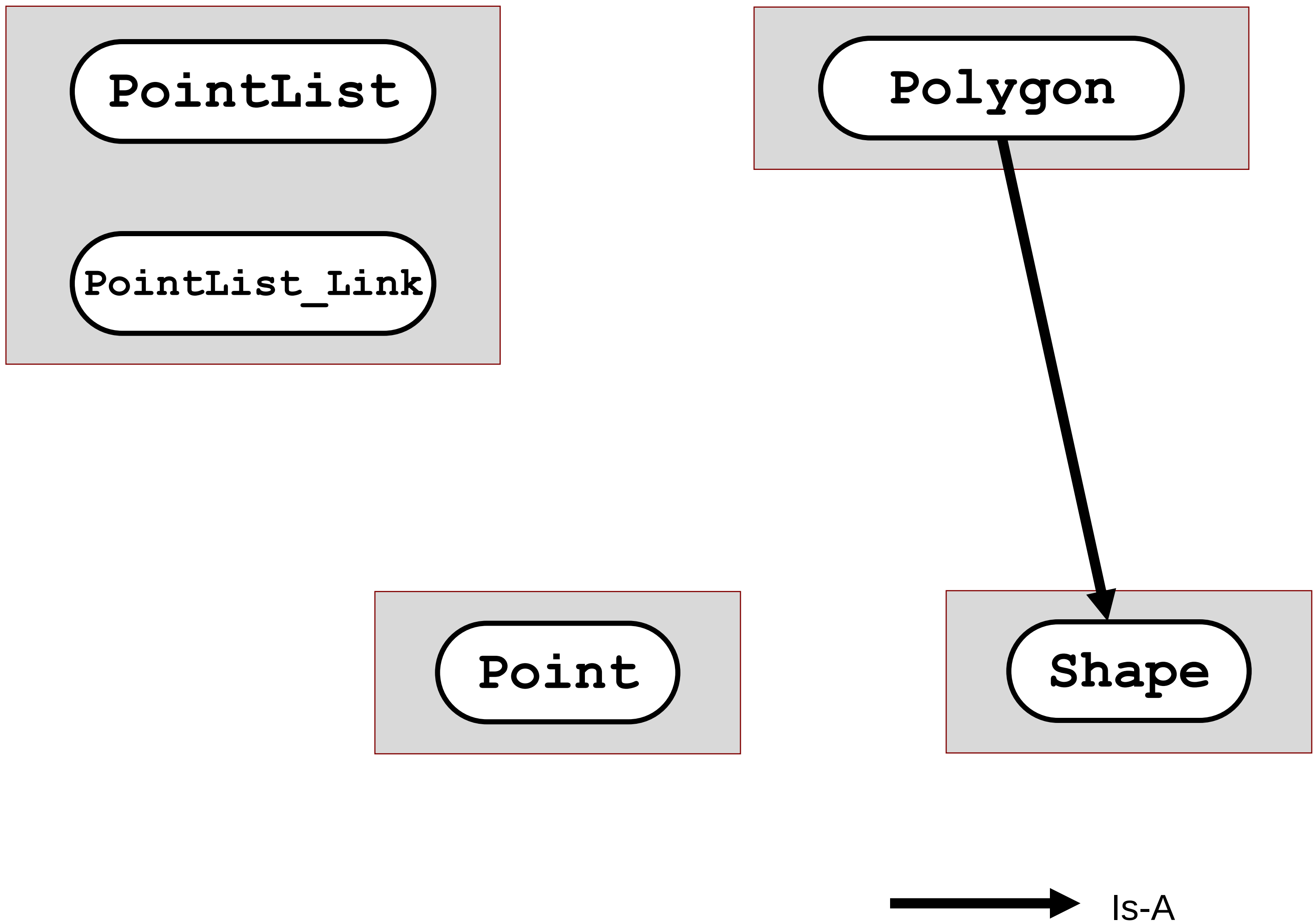

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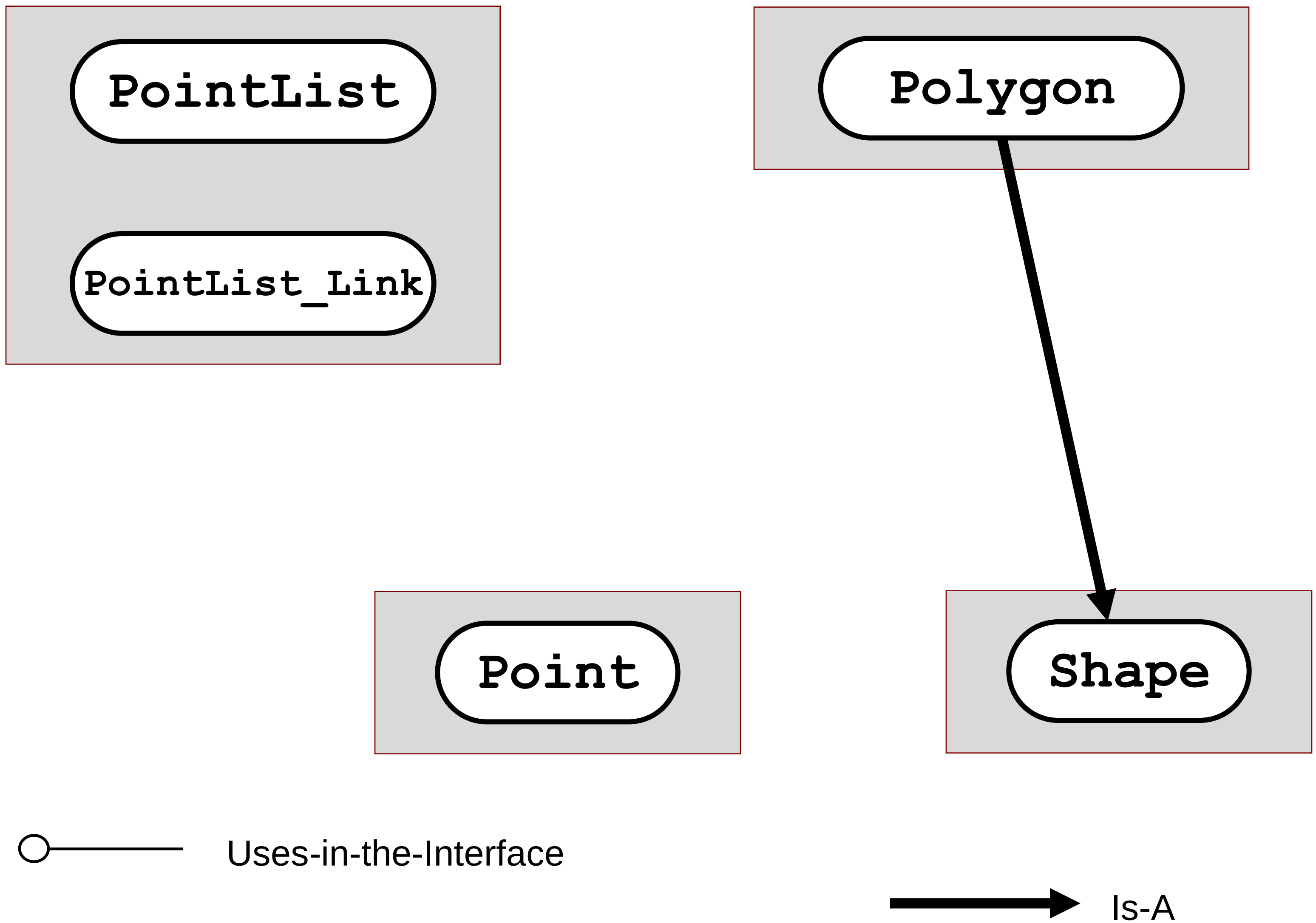
Logical Relationships



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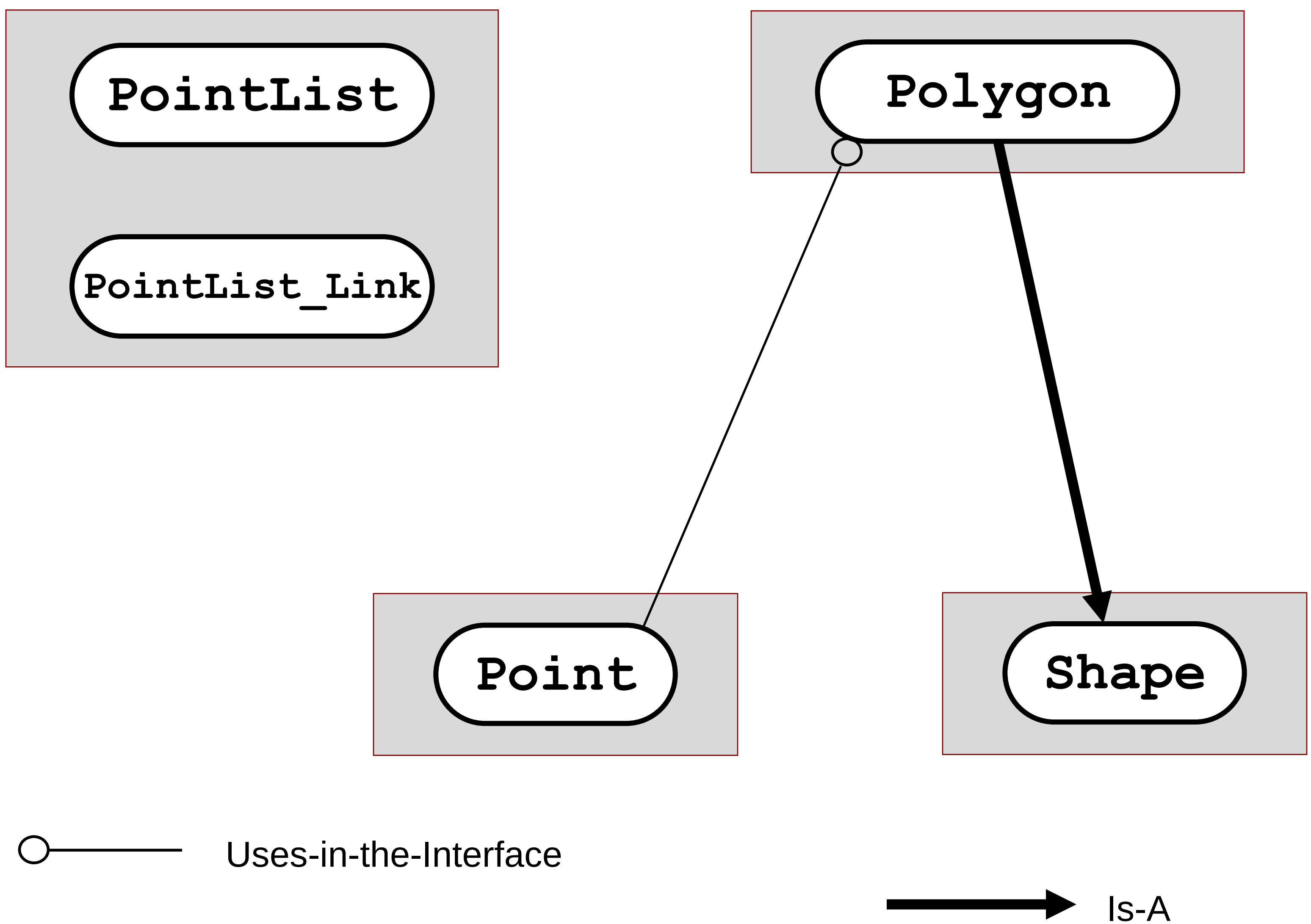

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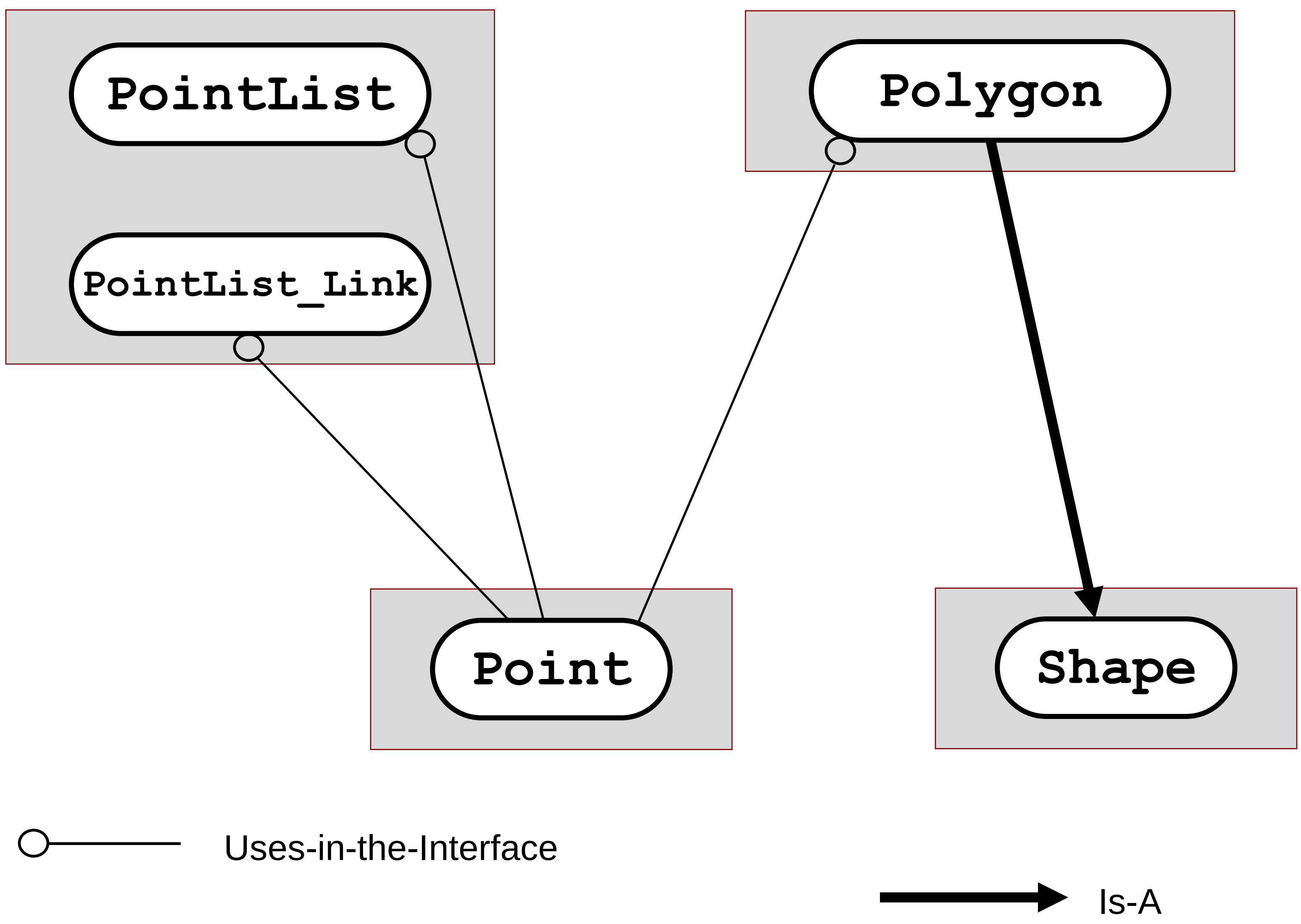

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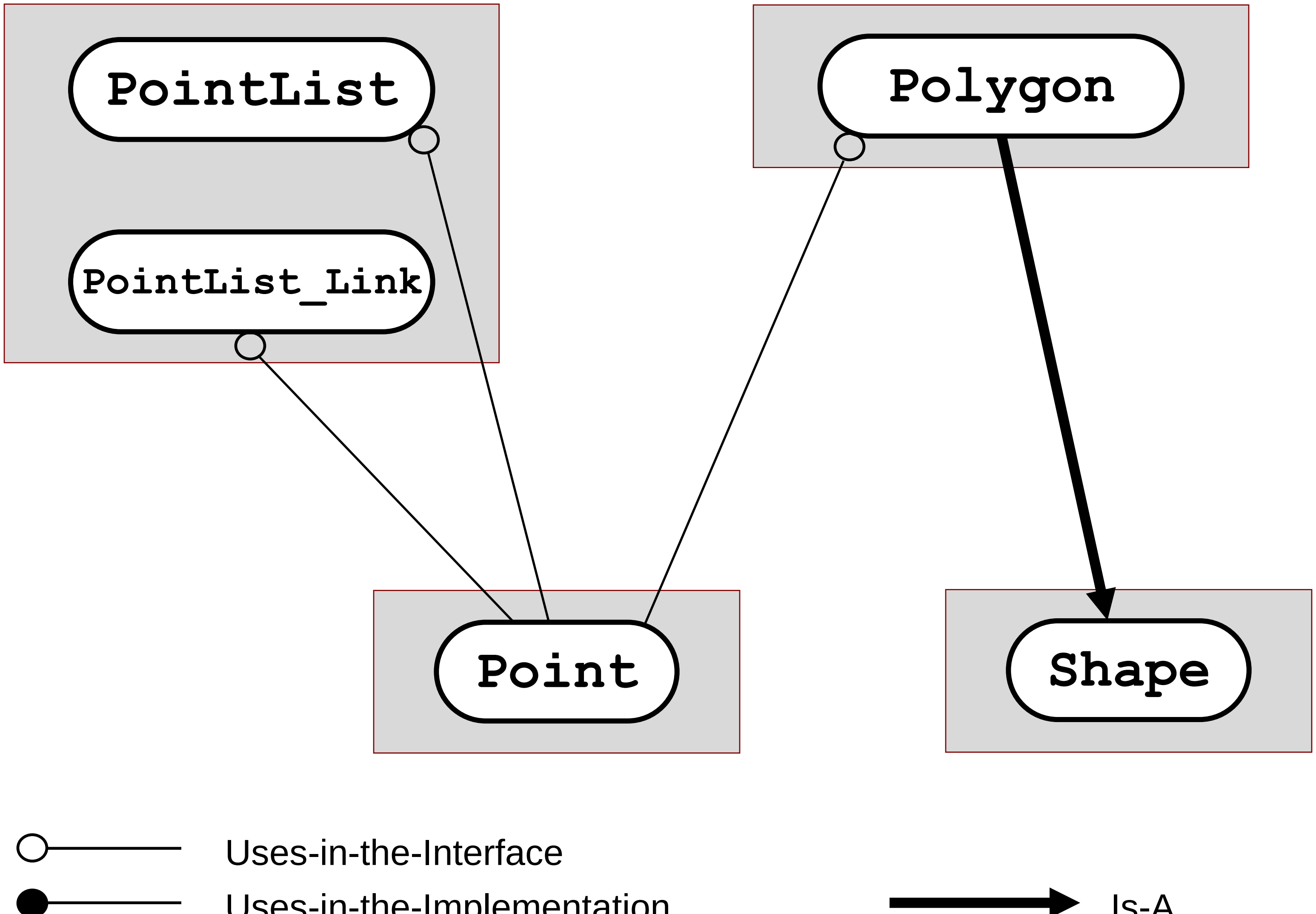

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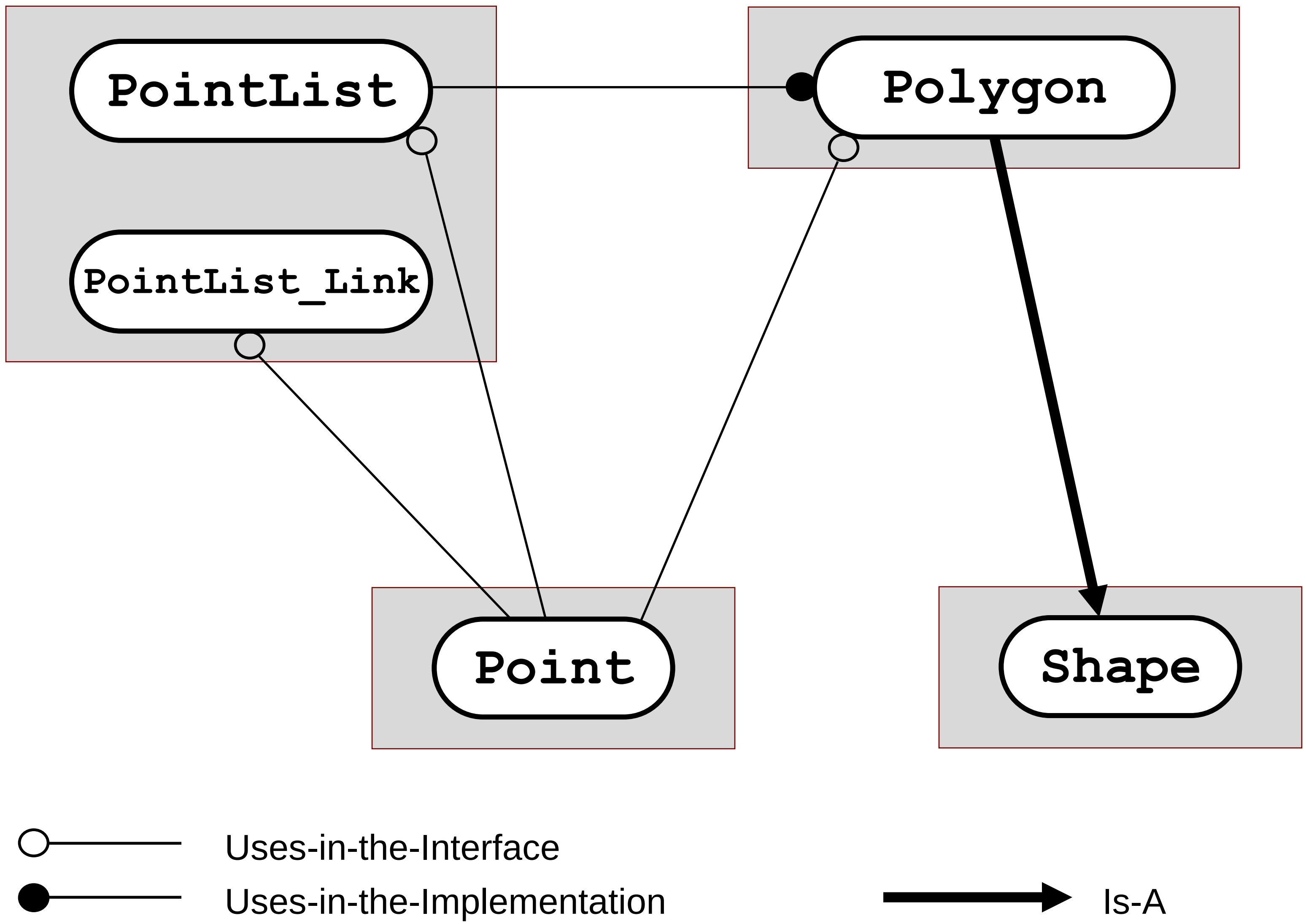

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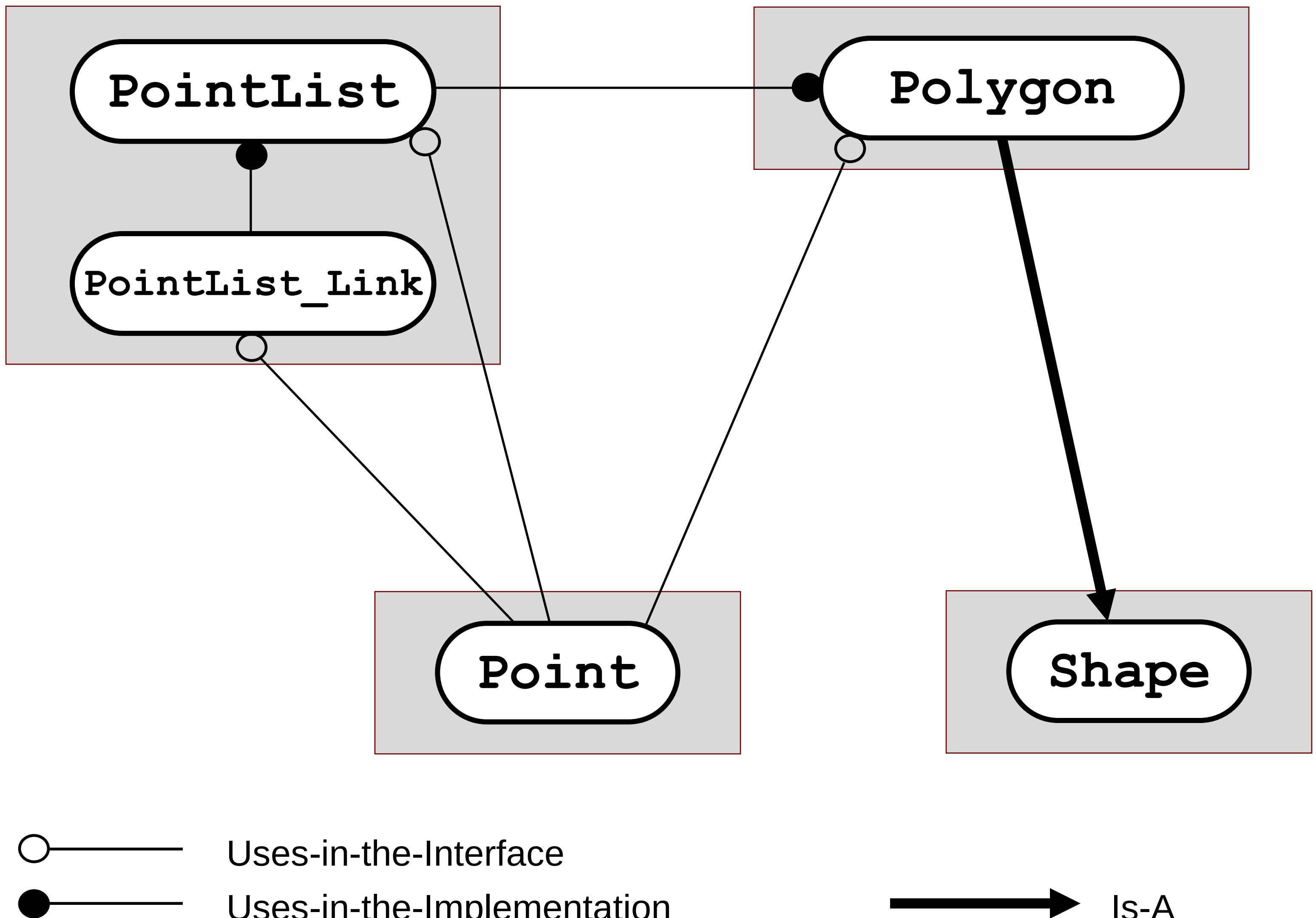

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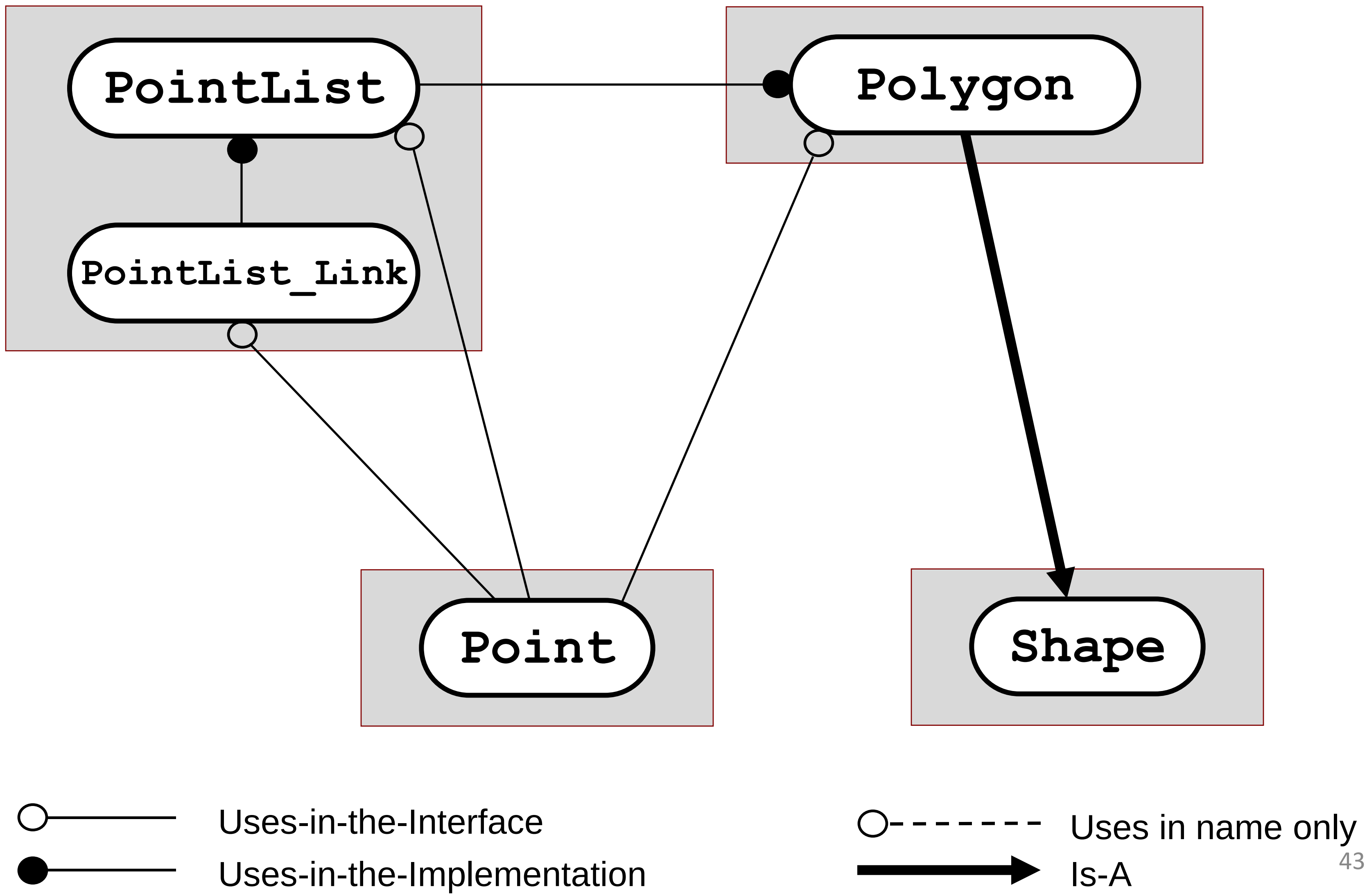

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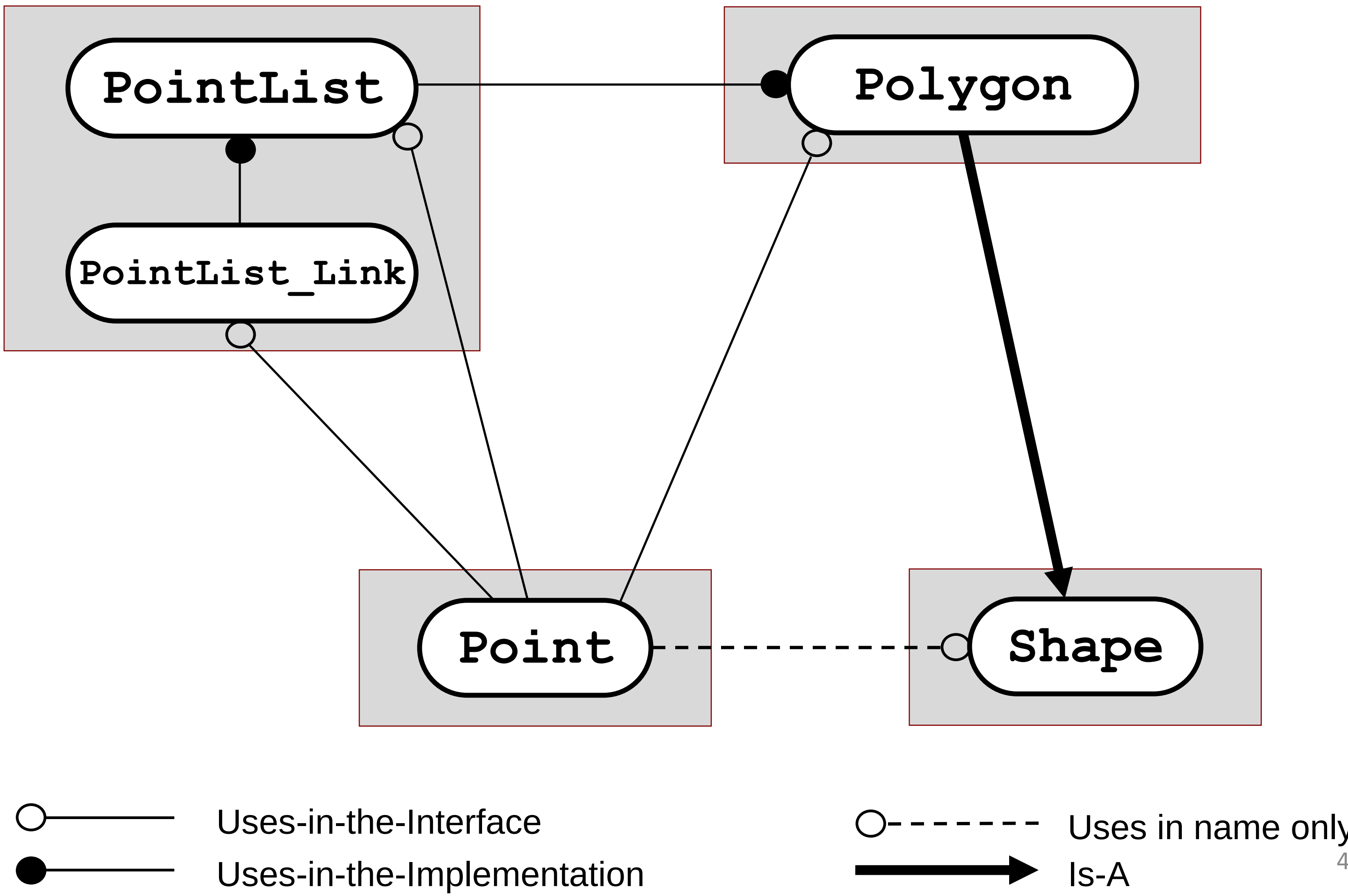
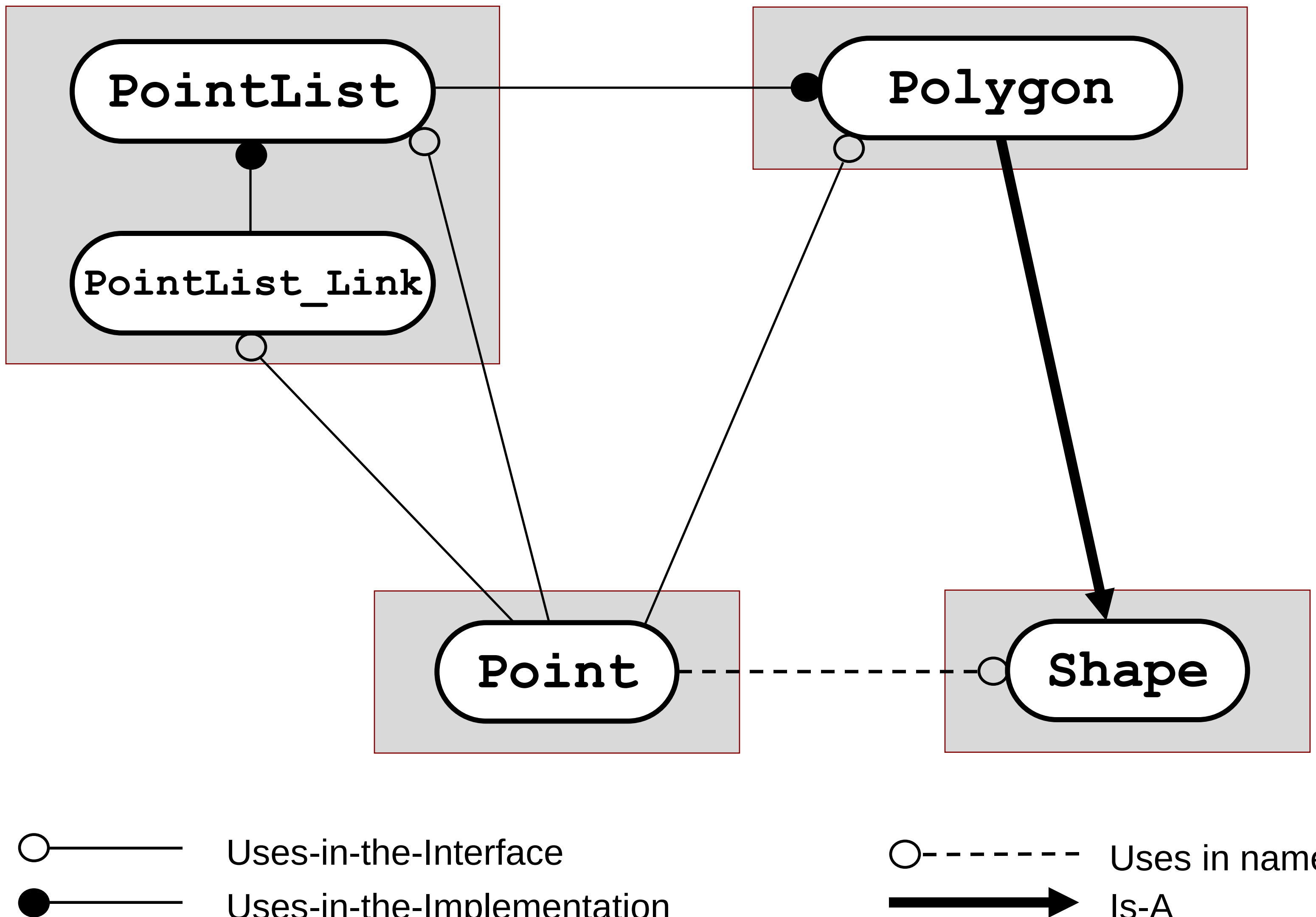


Implied Dependency



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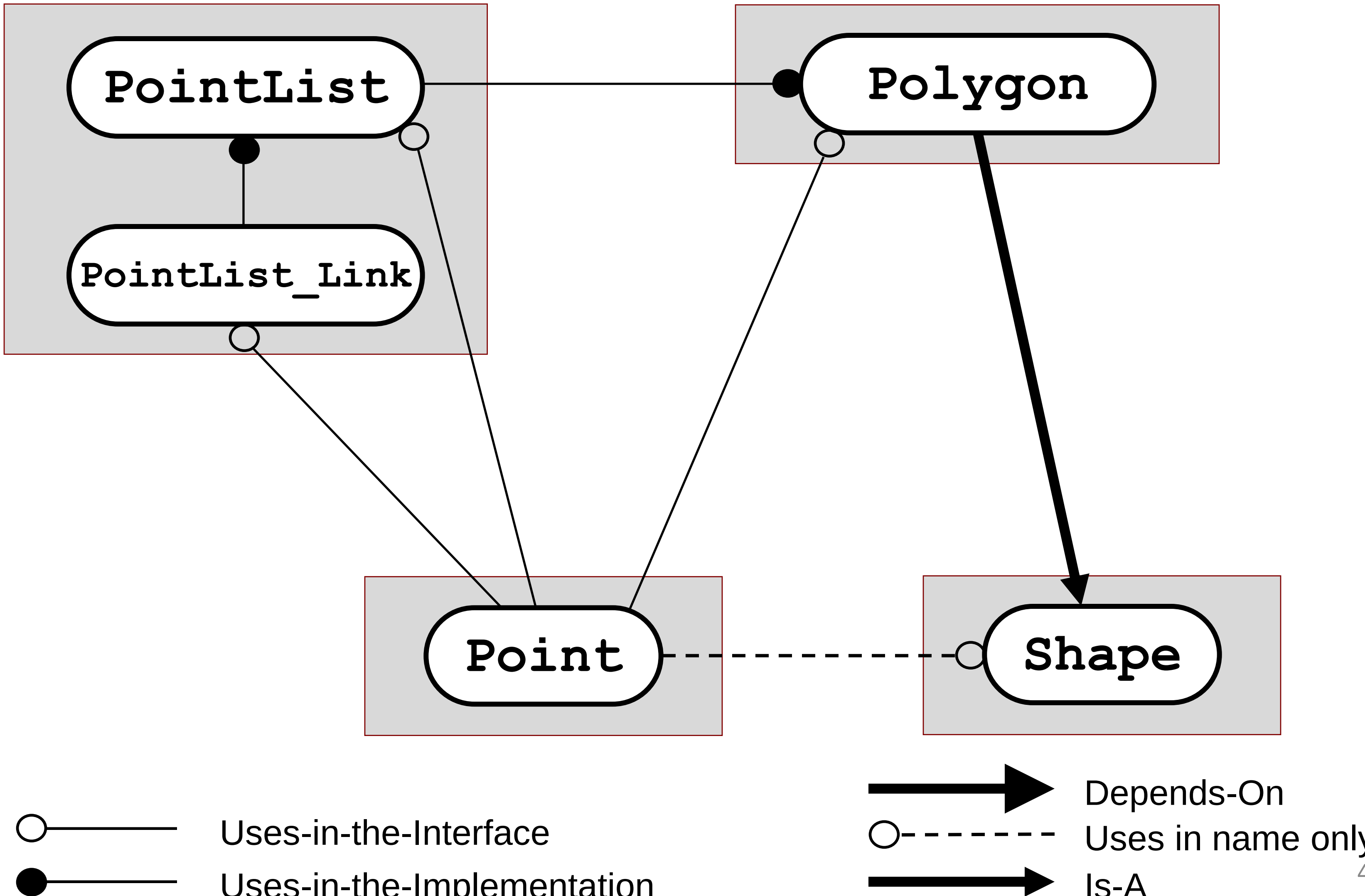

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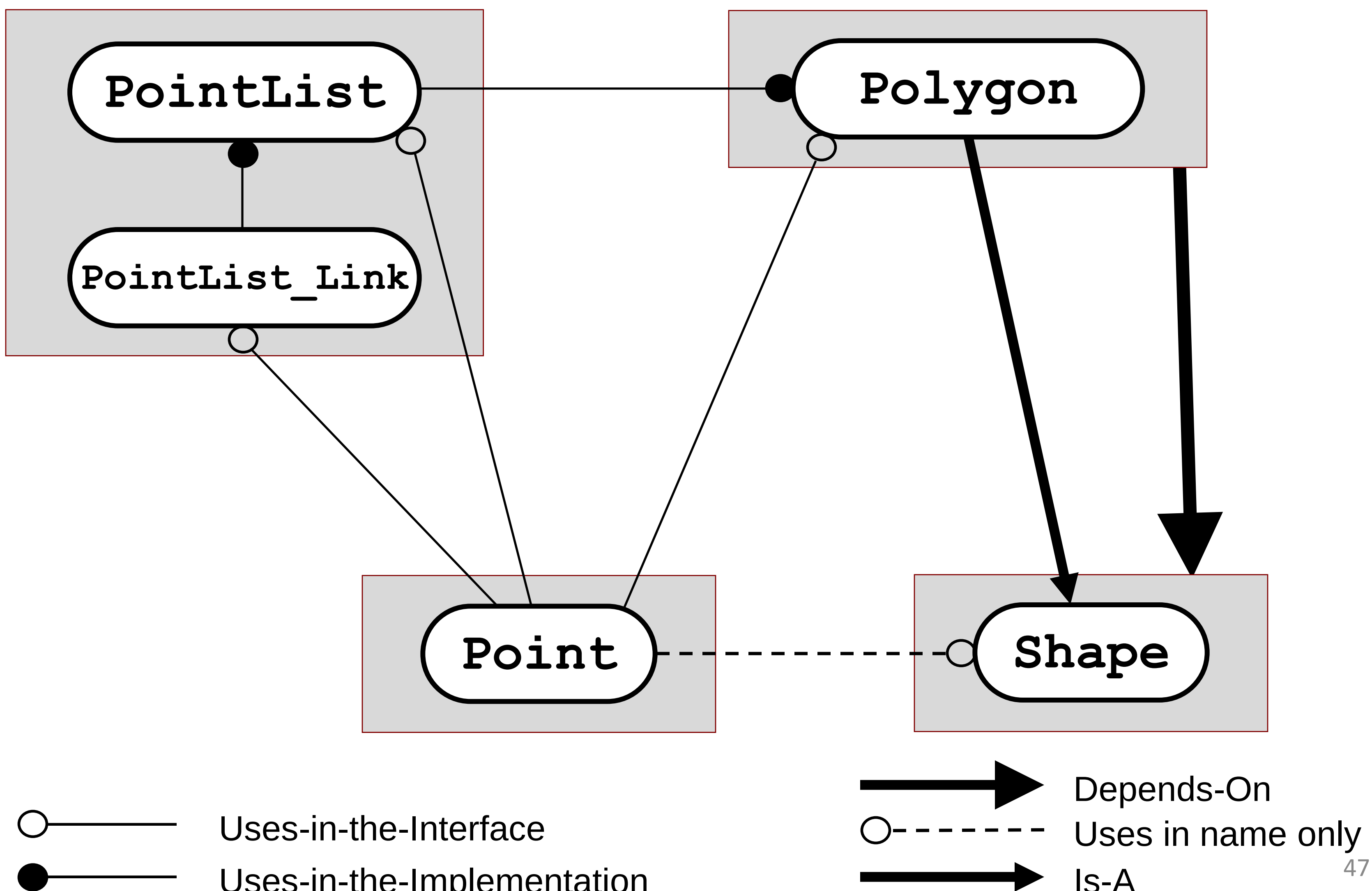

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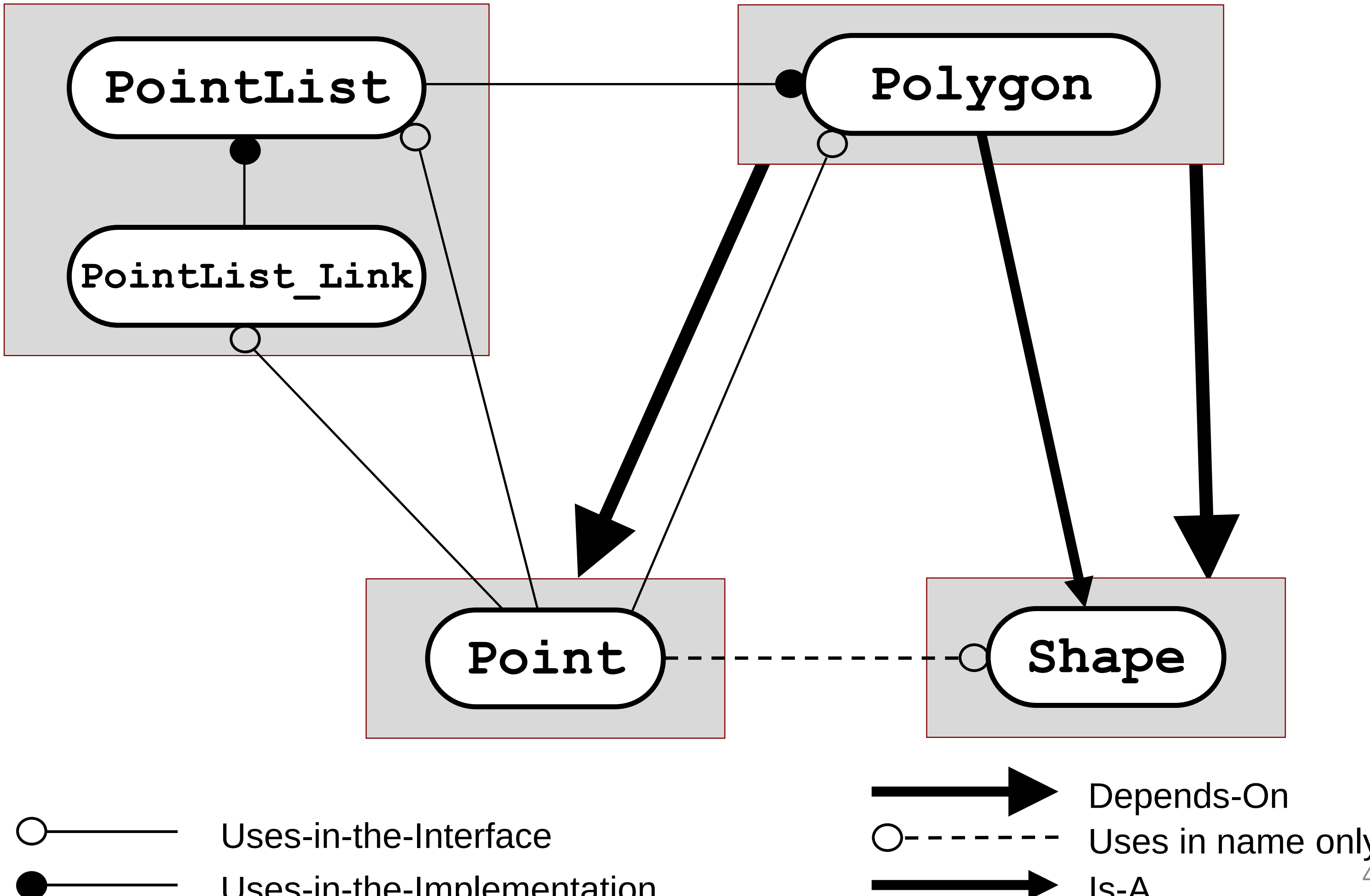

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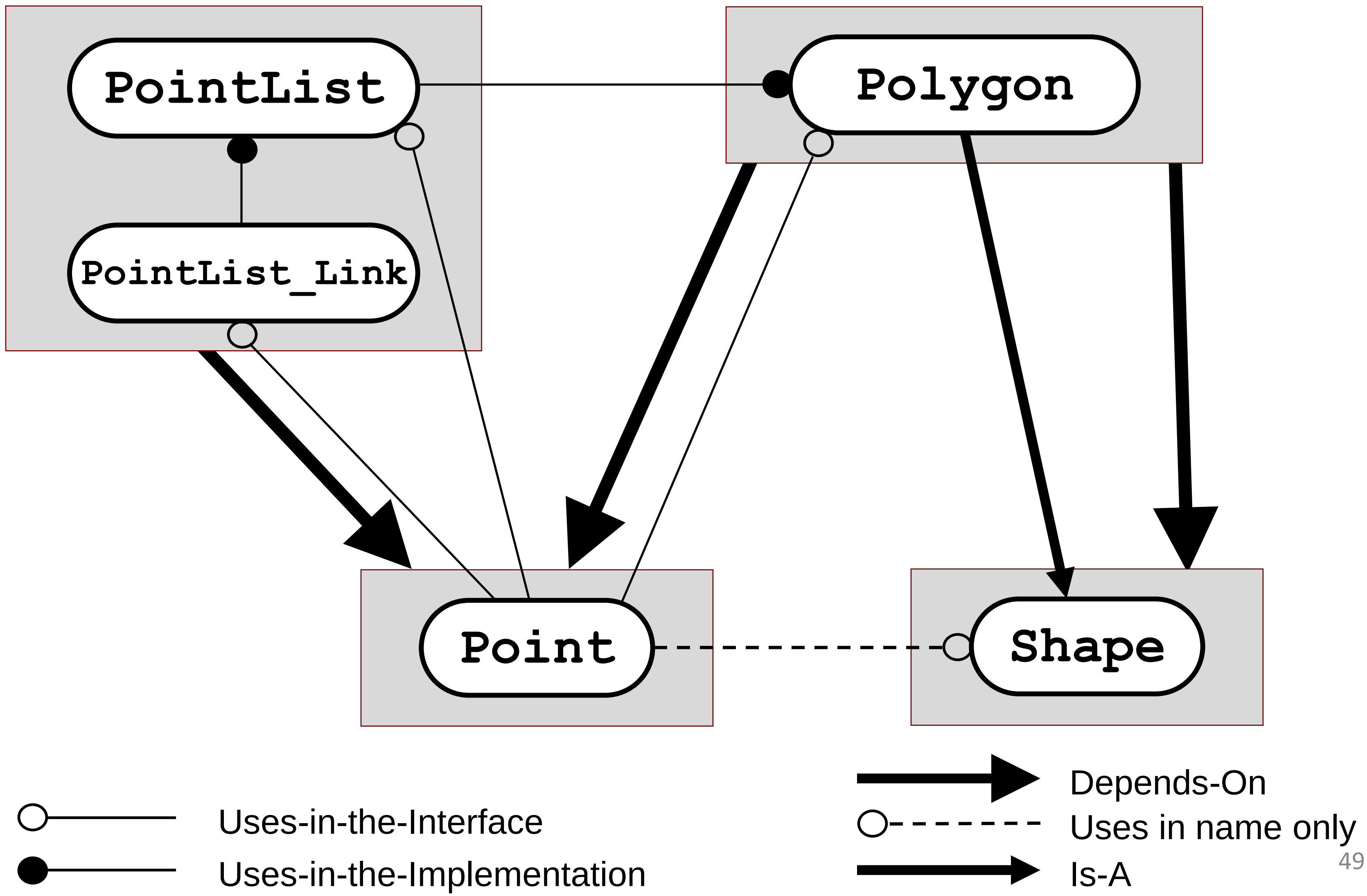

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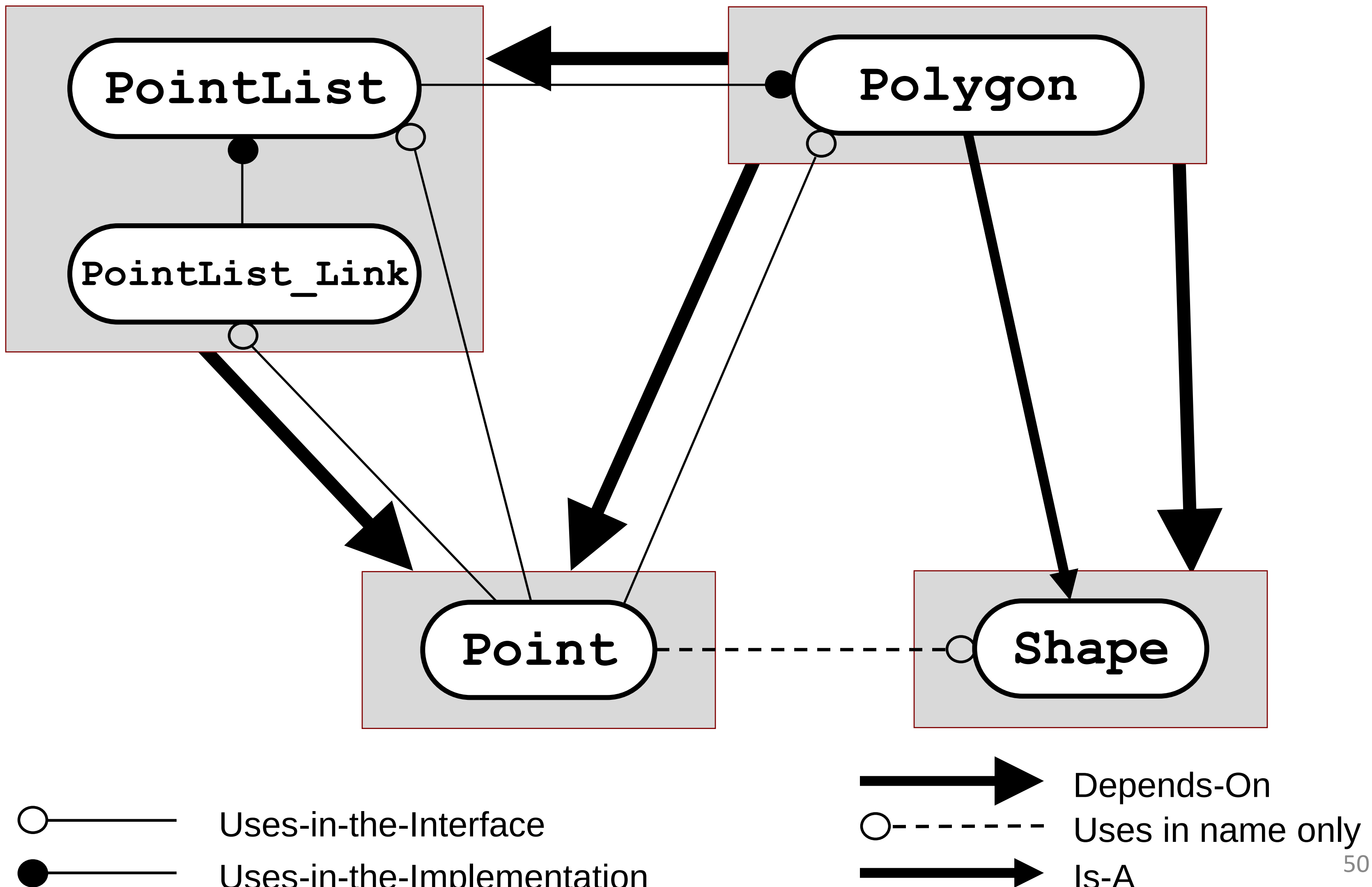

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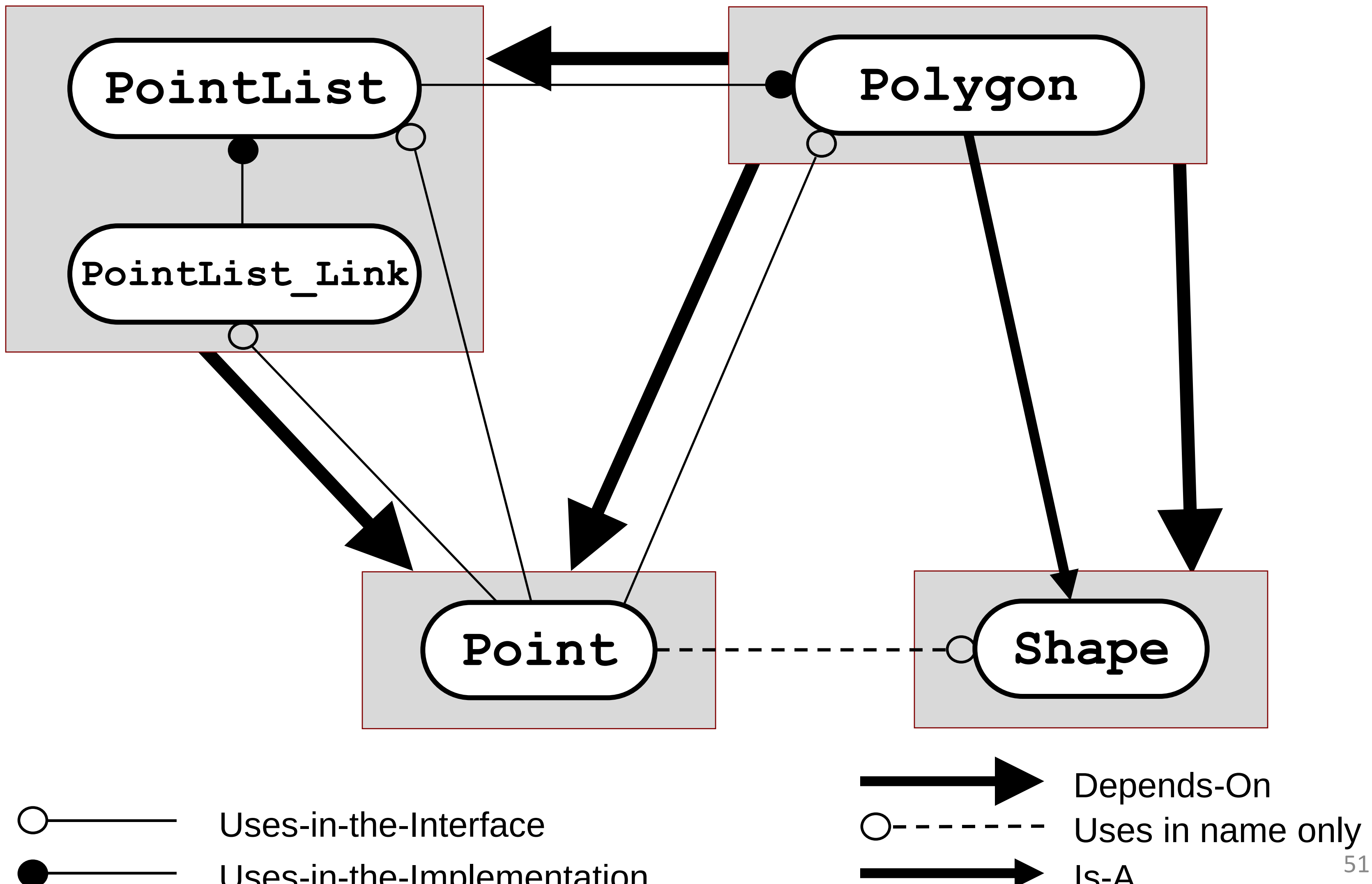
Level Numbers



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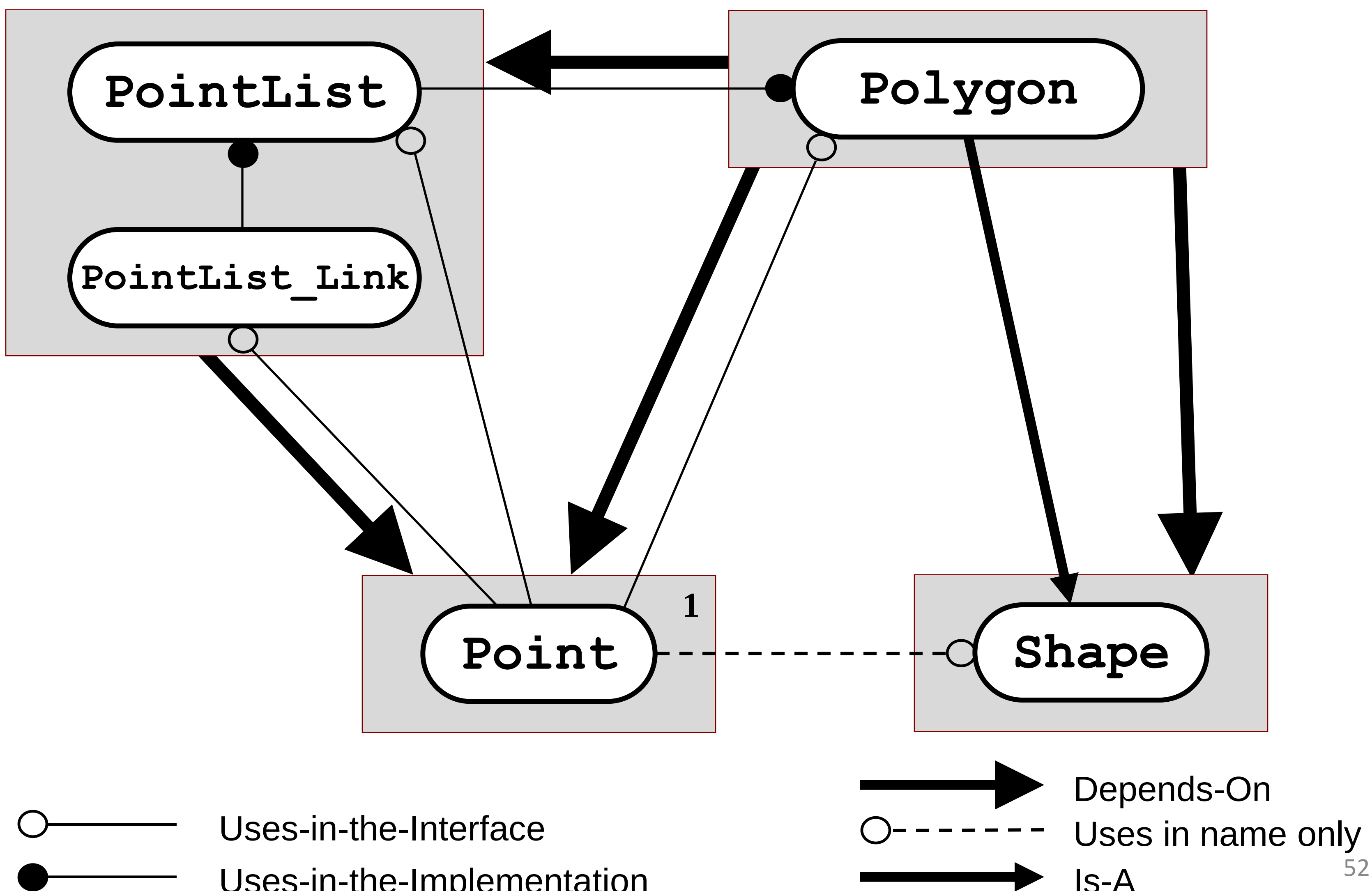

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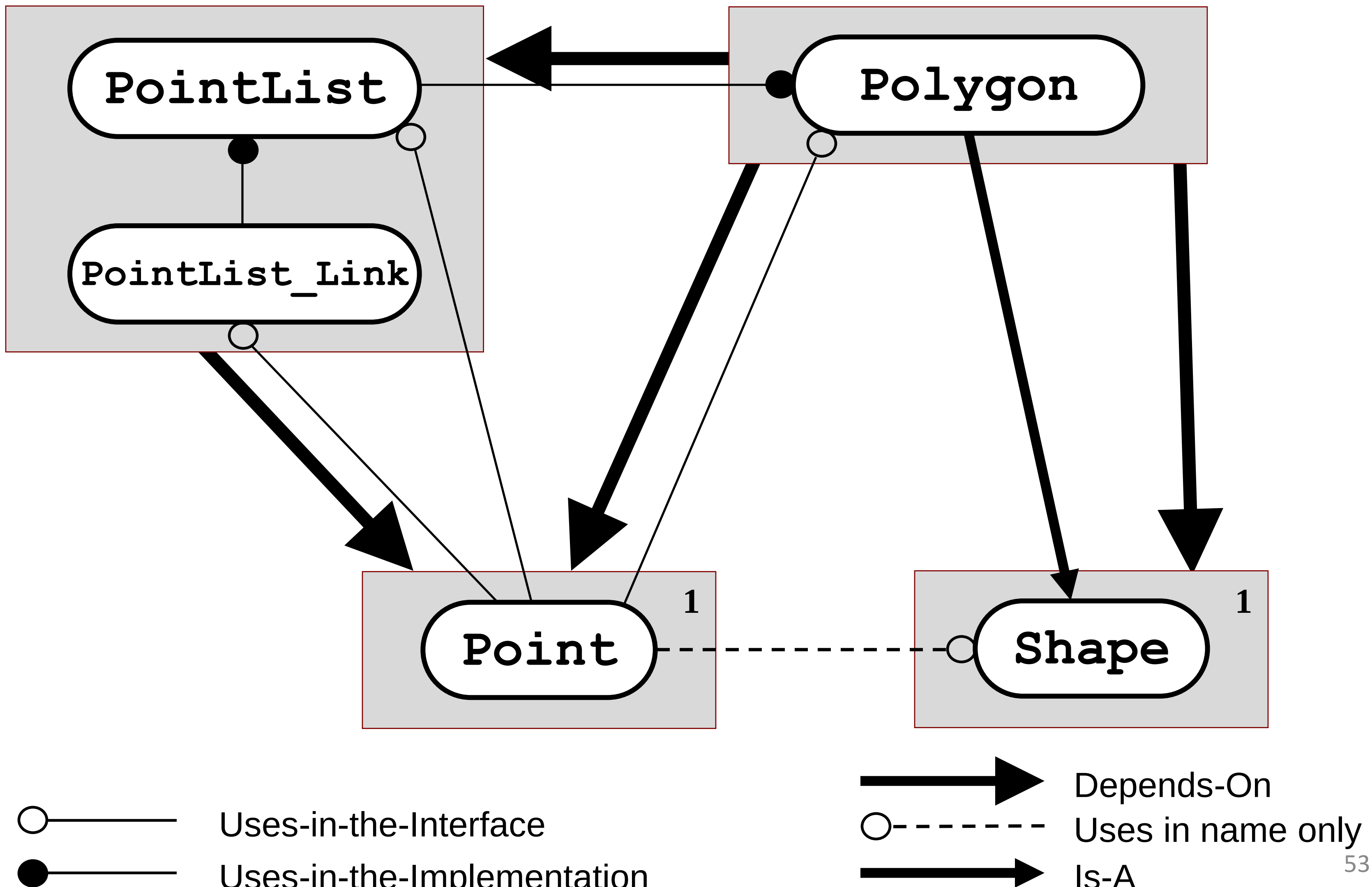

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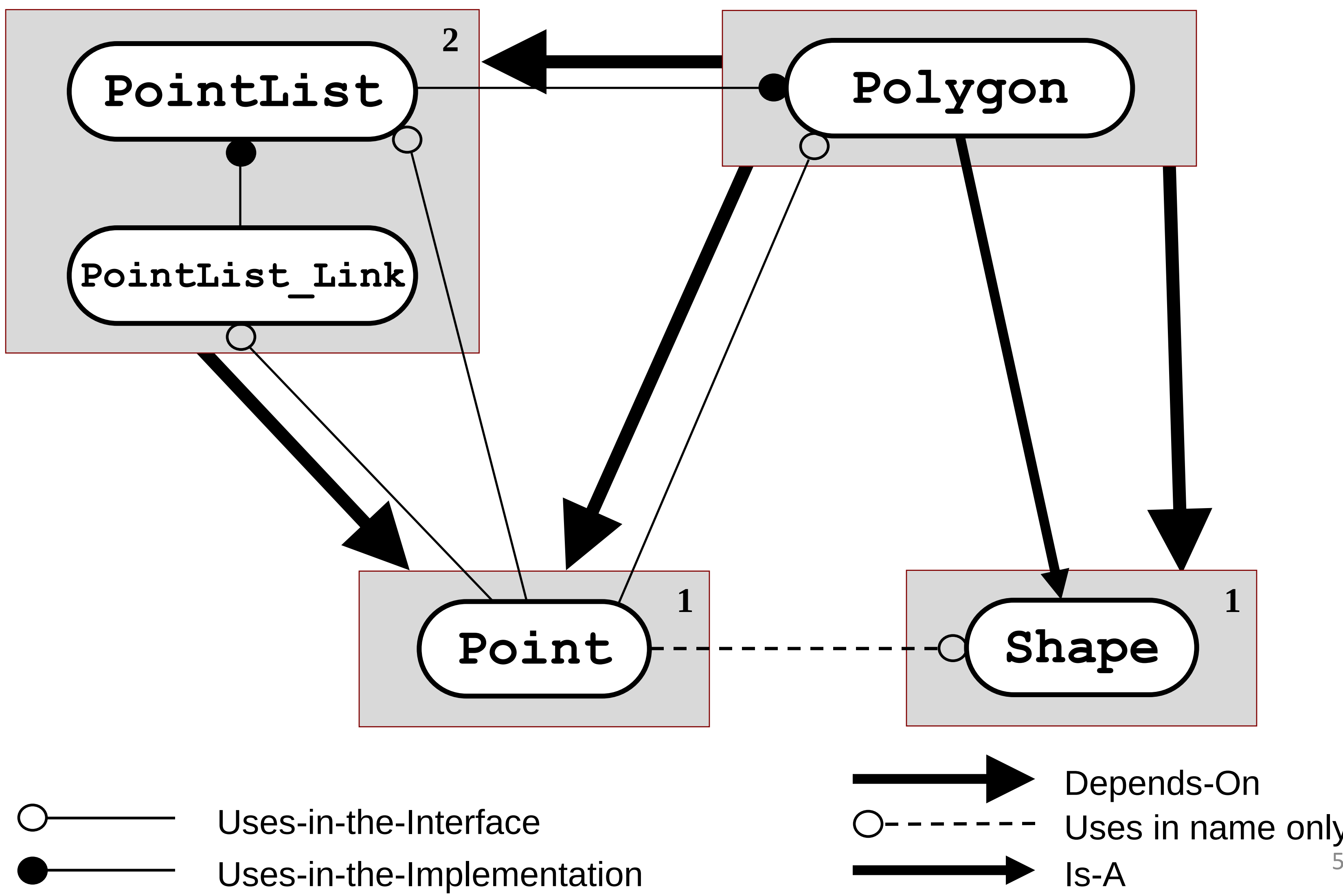

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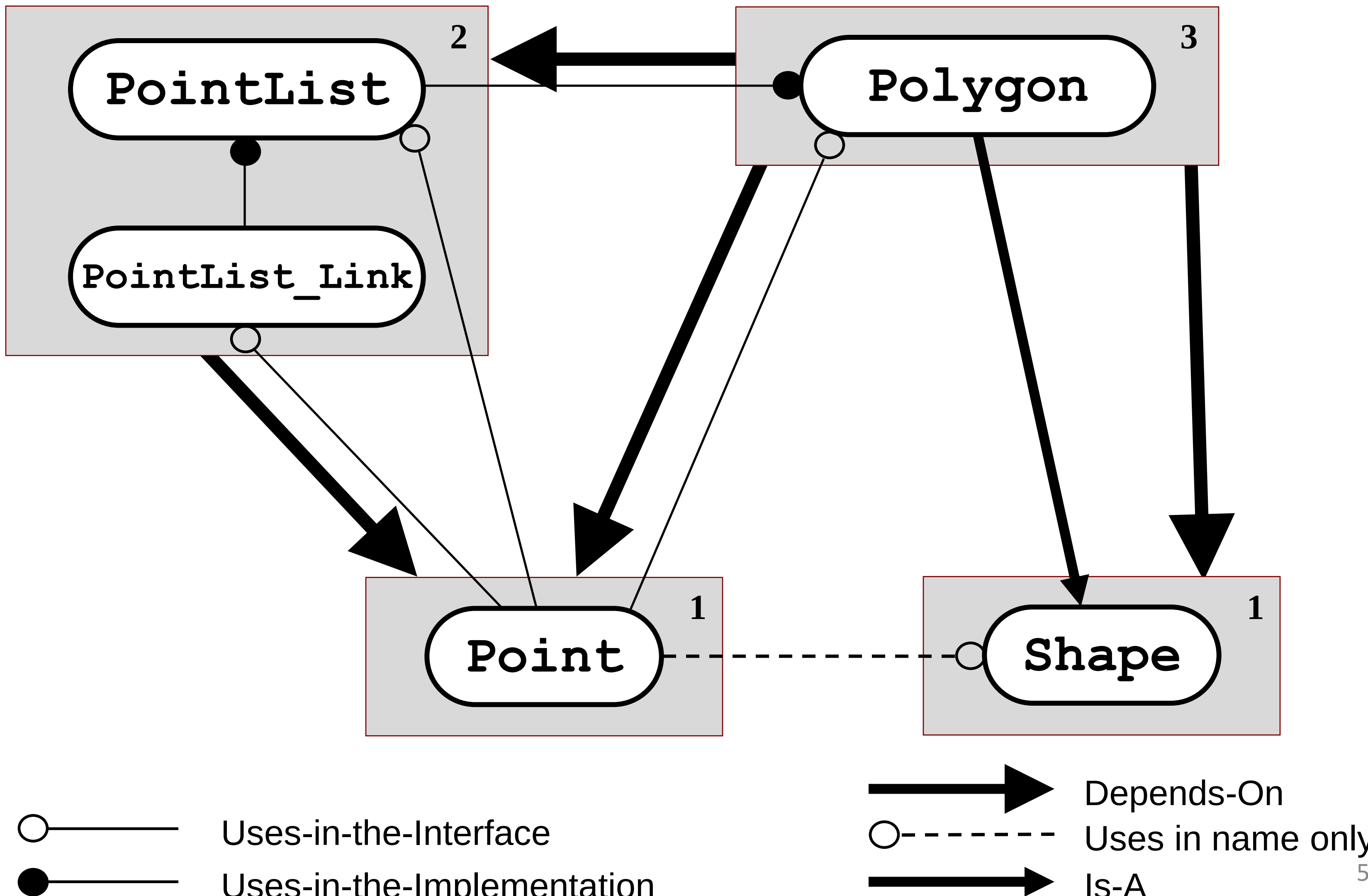

1. Components (review)

Essential Physical Design Rules

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There are two:

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There are two:

1. No *Cyclic* Physical Dependencies!

Essential Physical Design Rules

There are two:

1. No *Cyclic* Physical Dependencies!

2. No *Long-Distance* Friendships!

1. Components (review)

End of Section

Questions?

What Questions are we Answering?

- What distinguishes *Logical* and *Physical* Design?
- What is the first of the (four) fundamental properties of a **`.h/.cpp`** pair that make it a component?
- Which of these fundamental properties helps us extract physical dependencies efficiently? Extra credit: Why? How?
- What are the (four) logical-relationship annotations?
- Which logical relationship does not imply a physical one?
- How do we infer physical relationships (*Depends-On*) from logical ones?
- What do we mean by the term *level number*?
- What are the (two) *quintessential* physical design rules?

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2. Interfaces and Contracts (review)

   Syntax versus Semantics & *Essential Behavior*

3. Narrow versus Wide Contracts (review)

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Interfaces and Contracts

What do we mean by *Interface* versus *Contract* for

- *A Function?*
- *A Class?*
- *A Component?*

Interfaces and Contracts

Function

```
std::ostream& print(std::ostream& stream,
                    int           level          =  0,
                    int           spacesPerLevel  =  4) const;
```

Interfaces and Contracts

Function

```
std::ostream& print(std::ostream& stream,
                    int            level          =  0,
                    int            spacesPerLevel =  4) const;
```

Types Used In the Interface

Interfaces and Contracts

Function

```
std::ostream& print(std::ostream& stream,
                    int           level          =  0,
                    int           spacesPerLevel =  4) const;
    // Format this object to the specified output 'stream' at the (absolute
    // value of) the optionally specified indentation 'level' and return a
    // reference to 'stream'.  If 'level' is specified, optionally specify
    // 'spacesPerLevel', the number of spaces per indentation level for
    // this and all of its nested objects.  If 'level' is negative,
    // suppress indentation of the first line.  If 'spacesPerLevel' is
    // negative, format the entire output on one line, suppressing all but
    // the initial indentation (as governed by 'level').  If 'stream' is
    // not valid on entry, this operation has no effect.
```

Interfaces and Contracts

Class

```
class Date {

    //…
  public:
      Date(int year, int month, int day);

                                                      .
      Date(const Date& original);

      // …
};
```

Interfaces and Contracts

Class

```
class Date {

   //…
  public:
      Date(int year, int month, int day);

      Date(const Date& original);

      // …
};
```

Public Interface

.

Interfaces and Contracts

Class

```
class Date {



    //…
  public:
      Date(int year, int month, int day);



      Date(const Date& original);

      // …
};
```

Interfaces and Contracts

Class

```
class Date {
    // This class implements a value-semantic type representing
    // a valid date in history between the dates 0001/01/01 and
    // 9999/12/31 inclusive.

    //…

  public:
    Date(int year, int month, int day);




    Date(const Date& original);


    // …
};
```

Interfaces and Contracts

Class

```
class Date {
    // This class implements a value-semantic type representing
    // a valid date in history between the dates 0001/01/01 and
    // 9999/12/31 inclusive.

    //…

  public:
      Date(int year, int month, int day);
          // Create a valid date from the specified 'year', 'month', and
          // 'day'.  The behavior is undefined unless 'year'/'month'/'day'
          // represents a valid date in the range [0001/01/01 .. 9999/12/31].

      Date(const Date& original);


      // …
};
```

Interfaces and Contracts

Class

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class Date {
    // This class implements a value-semantic type representing
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  public:
    Date(int year, int month, int day);
        // Create a valid date from the specified 'year', 'month', and
        // 'day'.  The behavior is undefined unless 'year'/'month'/'day'
        // represents a valid date in the range [0001/01/01 .. 9999/12/31].

    Date(const Date& original);
        // Create a date having the value of the specified 'original' date.

    // …
};
```

Interfaces and Contracts

Component

```
class Date {
    // …
  public:
    // …
};
bool operator==(const Date& lhs, const Date& rhs);

bool operator!=(const Date& lhs, const Date& rhs);

std::ostream& operator<<(std::ostream& stream, const Date& date);
```

Interfaces and Contracts

Component

```
class Date {
    // …
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```

```
bool operator==(const Date& lhs, const Date& rhs);

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```

"Public" Interface

Interfaces and Contracts

Component

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  public:
    // …
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```

Interfaces and Contracts

Component

```
class Date {
    // …
  public:
    // …
};

bool operator==(const Date& lhs, const Date& rhs);
    // Return 'true' if the specified 'lhs' and 'rhs' dates have the same
    // value, and 'false' otherwise.  Two 'Date' objects have the same
    // value if their respective 'year', 'month', and 'day' attributes
    // have the same value.

bool operator!=(const Date& lhs, const Date& rhs);

std::ostream& operator<<(std::ostream& stream, const Date& date);
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Interfaces and Contracts

Component

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class Date {
    // …
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bool operator==(const Date& lhs, const Date& rhs);
    // Return 'true' if the specified 'lhs' and 'rhs' dates have the same
    // value, and 'false' otherwise.  Two 'Date' objects have the same
    // value if their respective 'year', 'month', and 'day' attributes
    // have the same value.

bool operator!=(const Date& lhs, const Date& rhs);
    // Return 'true' if the specified 'lhs' and 'rhs' dates do not have the
    // same value, and 'false' otherwise.  Two 'Date' objects do not have
    // the same value if any of their respective 'year', 'month', and 'day'
    // attributes do not have the same value.

std::ostream& operator<<(std::ostream& stream, const Date& date);
```

Interfaces and Contracts

Component

```
class Date {
    // …
  public:
    // …
};

bool operator==(const Date& lhs, const Date& rhs);
    // Return 'true' if the specified 'lhs' and 'rhs' dates have the same
    // value, and 'false' otherwise.  Two 'Date' objects have the same
    // value if their respective 'year', 'month', and 'day' attributes
    // have the same value.

bool operator!=(const Date& lhs, const Date& rhs);
    // Return 'true' if the specified 'lhs' and 'rhs' dates do not have the
    // same value, and 'false' otherwise.  Two 'Date' objects do not have
    // the same value if any of their respective 'year', 'month', and 'day'
    // attributes do not have the same value.

std::ostream& operator<<(std::ostream& stream, const Date& date);
    // Format the value of the specified 'date' object to the specified
    // output 'stream'  as  'yyyy/mm/dd', and return a reference to 'stream'.
```

2. Interfaces and Contracts (review)

Preconditions and Postconditions

2. Interfaces and Contracts (review)

Preconditions and Postconditions

Function

Preconditions and Postconditions

Function

```
double sqrt(double value);
    // Return the square root of the specified ‘value’.
    // The behavior is undefined unless ‘0 <= value’.
```

Preconditions and Postconditions

Function

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Preconditions and Postconditions

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Precondition

Preconditions and Postconditions

Function

```
double sqrt(double value);
    // Return the square root of the specified 'value'.
    // The behavior is undefined unless '0 <= value'.
```

Precondition

For a Stateless Function:
Restriction on *syntactically legal* inputs.

Preconditions and Postconditions

Function

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double sqrt(double value);
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Preconditions and Postconditions

Function

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Postcondition

Preconditions and Postconditions

Function

```
double sqrt(double value);
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Postcondition

For a Stateless Function:
What it "returns."

2. Interfaces and Contracts (review)

Preconditions and Postconditions

Object Method

Preconditions and Postconditions

Object Method

- Preconditions: What must be true of both (object) state and method inputs; otherwise the behavior is <u>**undefined**</u>.

2. Interfaces and Contracts (review)

Preconditions and Postconditions

Object Method

- Preconditions: What must be true of both (object) state and method inputs; otherwise the behavior is **undefined**.

- Postconditions: What must happen as a function of (object) state and input if all Preconditions are satisfied.

2. Interfaces and Contracts (review)

Preconditions and Postconditions

Object Method

a.k.a.

Essential

Behavior

- Precond e of both (object) otherwis ed.

- Postconditions: What must happen as a function of (object) state and input if all Preconditions are satisfied.

Note that ***Essential Behavior*** refers to a superset of ***Postconditions*** that includes **behavioral guarantees**, such as **runtime complexity.**

➢Precond... e of both (object)... otherwis... ed.

a.k.a. Essential Behavior

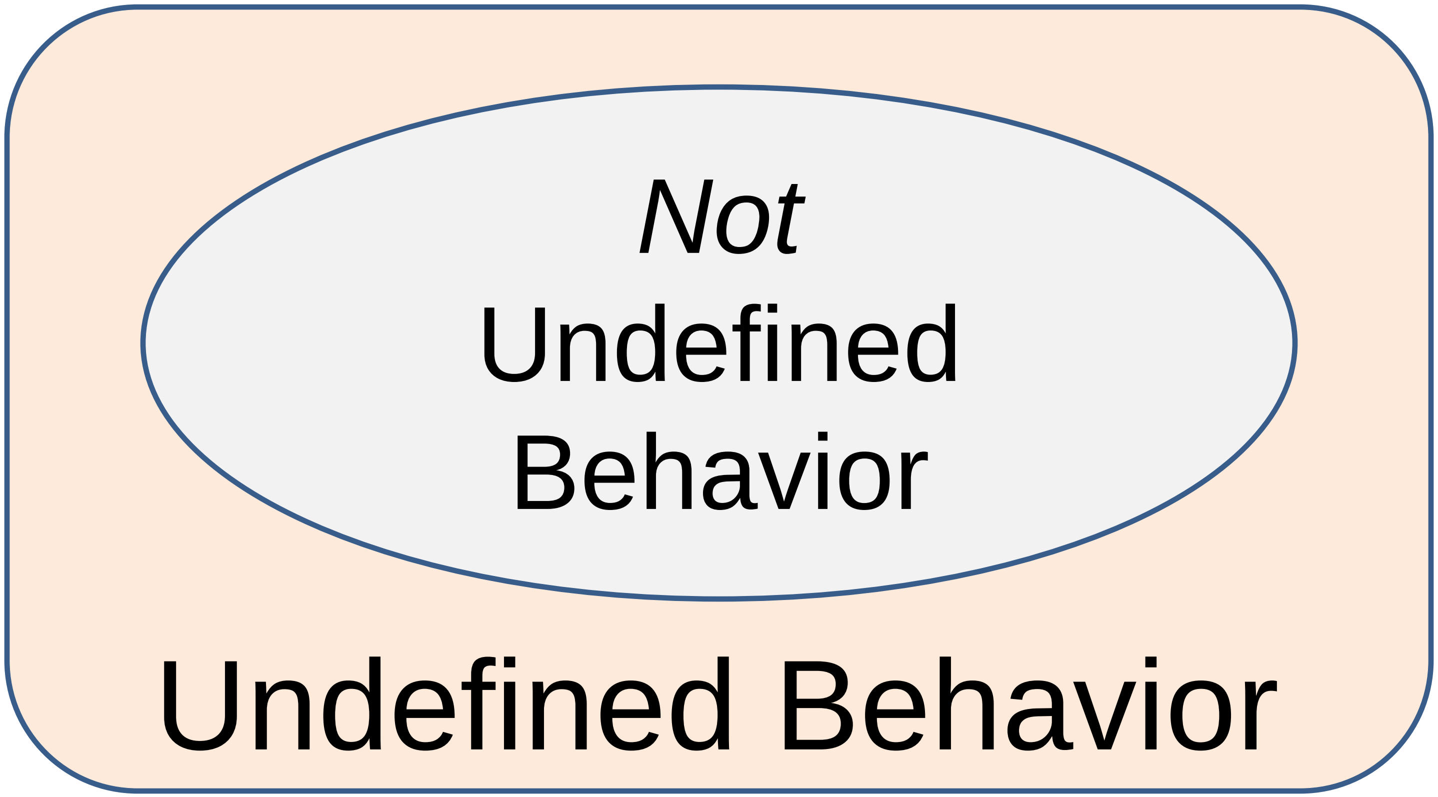
➢Postconditions: What must happen as a function of (object) state and method inputs if all preconditions are satisfied.

Observation By

Kevlin Henny

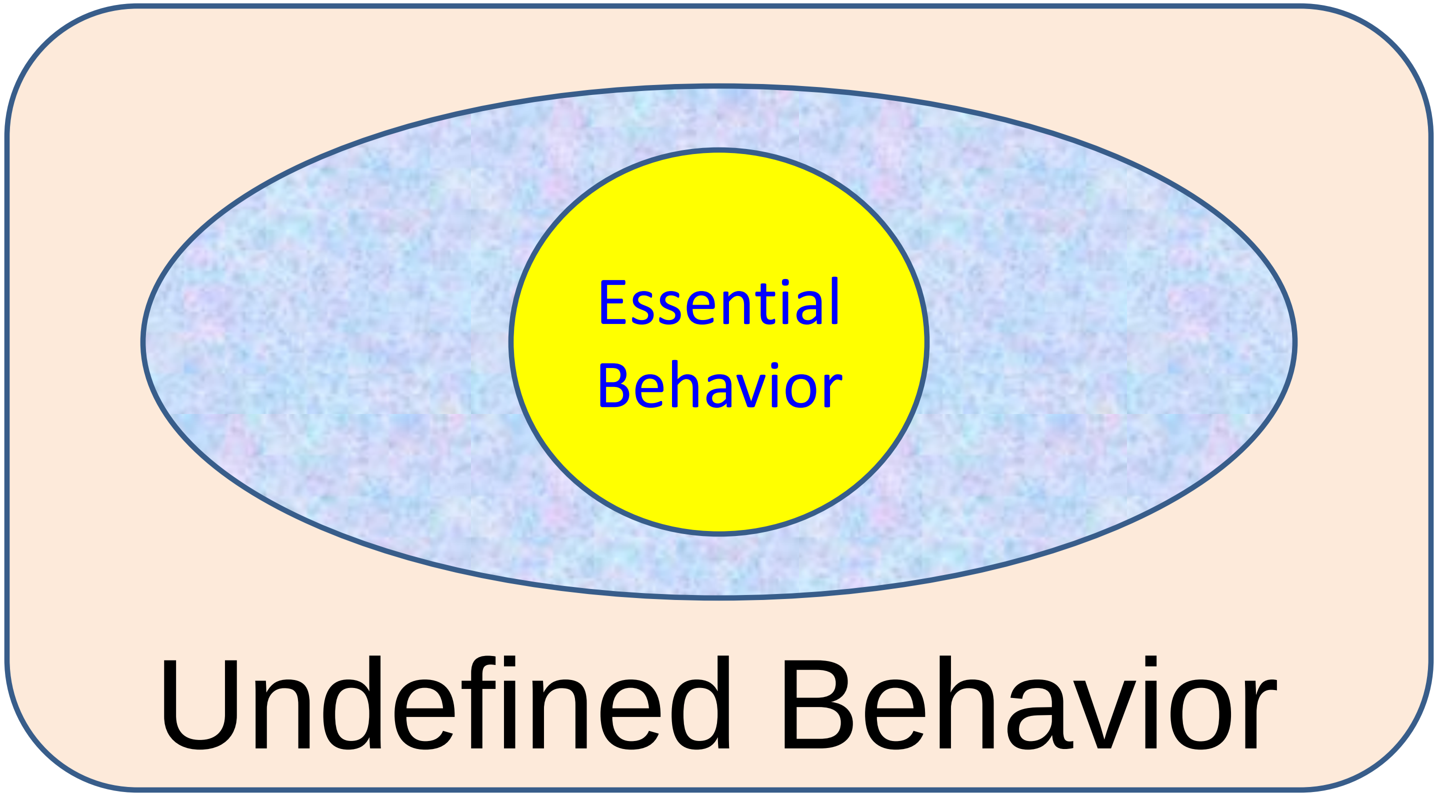
Preconditions and Postconditions

Defined & Essential Behavior



Preconditions and Postconditions

Defined & Essential Behavior



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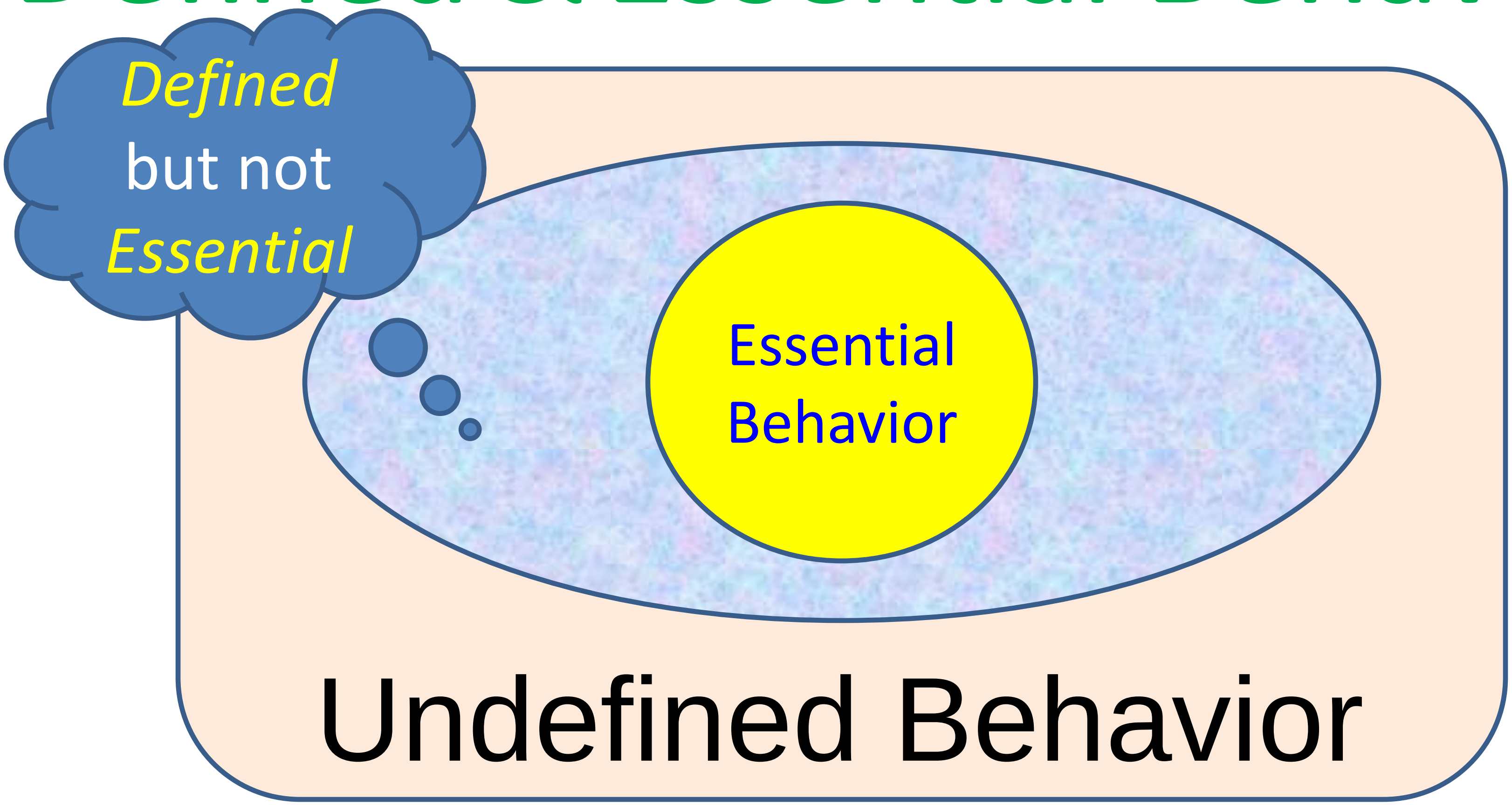

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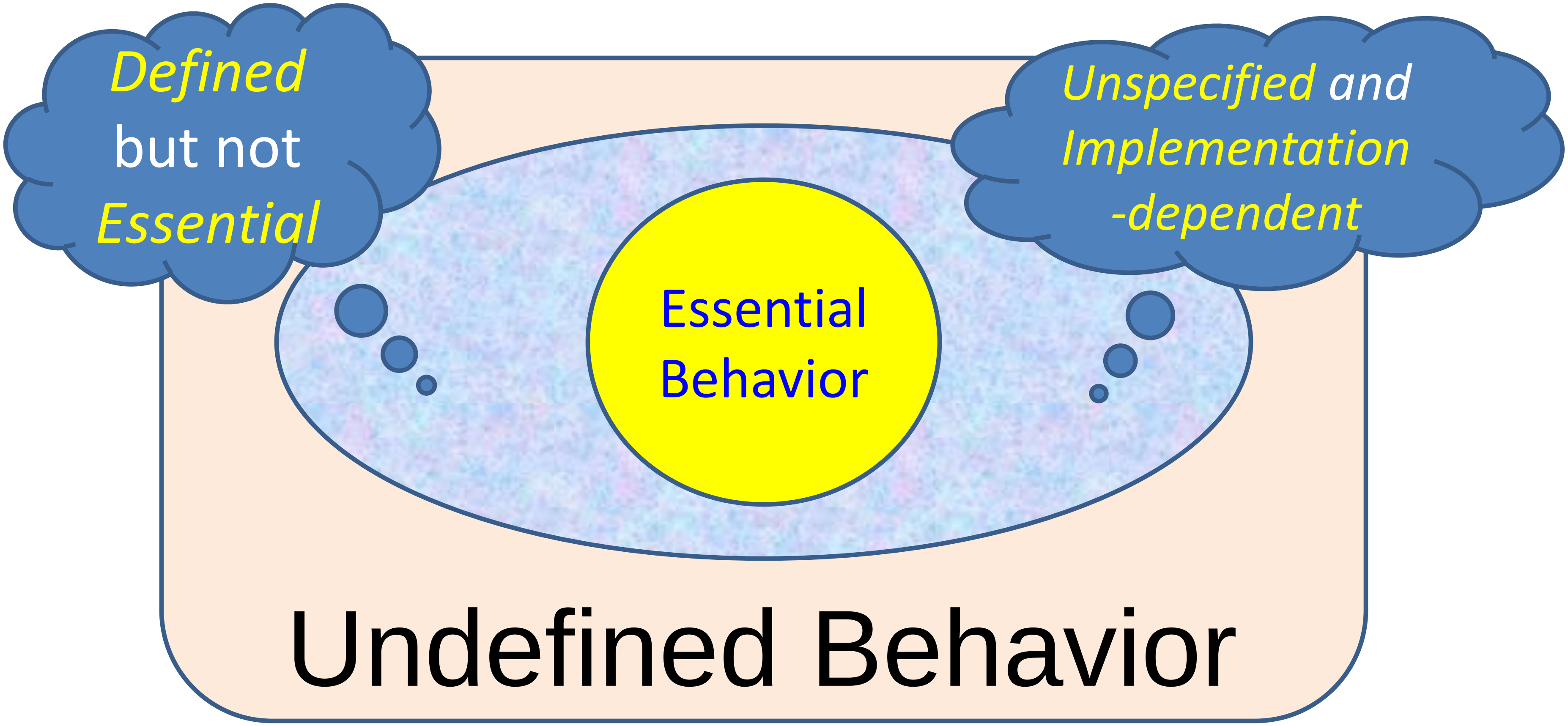

2. Interfaces and Contracts (review)

Preconditions and Postconditions

Defined & Essential Behavior

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std::ostream& print(std::ostream& stream,
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2. Interfaces and Contracts (review)

Preconditions and Postconditions

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2. Interfaces and Contracts (review)

Preconditions and Postconditions

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2. Interfaces and Contracts (review)

Preconditions and Postconditions

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Preconditions and Po

Defined & Essenti

Any
Undefined
Behavior?

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Preconditions and Po

Defined & Essenti

Any Non-Essential Behavior?

```
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Hint

Preconditions and Po

Defined & Essenti

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Non-Essential
Behavior?

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// the initial indentation (as governed by 'level'). **If 'stream' is**
// **not valid on entry, this operation has no effect.**

Preconditions and Postconditions

Defined & Essential Behavior

```
class Date {
    // This class implements a value-semantic type representing
    // a valid date in history between the dates 0001/01/01 and
    // 9999/12/31 inclusive.

    //…

  public:
      Date(int year, int month, int day);
          // Create a valid date from the specified 'year', 'month', and
          // 'day'.  The behavior is undefined unless 'year'/'month'/'day'
          // represents a valid date in the range [0001/01/01 .. 9999/12/31].

      Date(const Date& original);
          // Create a date having the value of the specified 'original' date.
      // …
};
```

Preconditions and Postconditions

Defined & Essential Behavior

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    // This class implements a value-seman
    // a valid date in history between the
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Any Undefined Behavior?

Preconditions and Postconditions

Defined & Essential Behavior

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Preconditions and Postconditions

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Preconditions and Postconditions

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    Date(int year, int month, int day);
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        // 'day'.  The behavior is undefined
        // represents a valid date in the range [0001/0          9/12/31].

    Date(const Date& original);
        // Create a date having the value of the specified 'original' date.
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Any
Undefined
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Preconditions and Postconditions

(Object) Invariants

```
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Preconditions and Postconditions

(Object) Invariants

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class Date {
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    // a valid date in history between the dates 0001/01/01 and
    // 9999/12/31 inclusive.

    //...
  p
                                                    e.
};
```

Question: Must the code itself <u>preserve</u> *invariants* even if one or more *preconditions* of the method's contract is violated?

Preconditions and Postconditions

(Object) Invariants

```
class Date {
   // This class implements a value-semantic type representing
   // a valid date in history between the dates 0001/01/01 and
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2. Interfaces and Contracts (review)

Preconditions and Postconditions

(Object) Invariants

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    Date(const Date& original);
        // Create a date having the value of the specified 'original' date.
    // …
};
```

Answer: **No!**

d Postconditions

ariants

What happens when behavior is undefined is **undefined!**

emantic type representing
he dates 0001/01/01 and

Answer: **No!**

```
public:
    Date(int year, int month, int day);
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        // Create a date having the value of the specified 'original' date.
    // …
};
```

2. Interfaces and Contracts (review)

Design by Contract

Design by Contract

(DbC)

"If you give me valid input*, I will behave as advertised; otherwise, all bets are off!"

*including state

Design by Contract

Documentation

There are five aspects:

1. What it does.
2. What it returns.
3. *Essential Behavior*.
4. *Undefined Behavior*.
5. Note that…

Design by Contract

Documentation

There are five aspects:

1. **What it does.**
2. What it returns.
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Design by Contract

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There are five aspects:

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Design by Contract

Documentation

There are five aspects:

1. What it does.
2. What it returns.
3. ***Essential Behavior.***
4. *Undefined Behavior.*
5. Note that…

2. Interfaces and Contracts (review)

Design by Contract

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Design by Contract

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There are five aspects:

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2. Interfaces and Contracts (review)

Design by Contract

Verification

Design by Contract

Verification

- **Preconditions:**

Design by Contract

Verification

- **Preconditions:**
  - ✓ RTFM (Read the Manual).

Design by Contract

Verification

- **Preconditions:**
  - ✓ RTFM (Read the Manual).
  - ✓ Assert (only in ‘*debug*’ or ‘*safe*’ mode).

DEFENSIVE PROGRAMMING

Design by Contract

Verification

- **Preconditions:**
  - ✓ RTFM (Read the Manual).
  - ✓ Assert (only in '*debug*' or '*safe*' mode).
- **Postconditions:**

Design by Contract

Verification

- **Preconditions:**
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  - Assert (only in '*debug*' or '*safe*' mode).
- **Postconditions:**
  - Component-level test drivers.

Design by Contract

Verification

- **Preconditions:**
  - RTFM (Read the Manual).
  - Assert (only in '*debug*' or '*safe*' mode).
- **Postconditions:**
  - Component-level test drivers.
- **Invariants:**

Design by Contract

Verification

- **Preconditions:**
  - ✓ RTFM (Read the Manual).
  - ✓ Assert (only in '*debug*' or '*safe*' mode).
- **Postconditions:**
  - ✓ Component-level test drivers.
- **Invariants:**
  - ✓ Assert invariants in the destructor.

Contracts and Exceptions

Preconditions *always* Imply Postconditions:

Contracts and Exceptions

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- **If a function cannot satisfy its contract (given valid preconditions) it must not return normally.**

Contracts and Exceptions

Preconditions *always* Imply Postconditions:

- **If a function cannot satisfy its contract (given valid preconditions) it must not return normally.**
- **`abort()` should be considered a viable alternative to `throw` in virtually all cases (if exceptions are disabled).**

Contracts and Exceptions

Preconditions *always* Imply Postconditions:

- **If a function cannot satisfy its contract (given valid preconditions) it must not return normally.**
- **`abort()` should be considered a viable alternative to `throw` in virtually all cases (if exceptions are disabled).**
- Good library components are *exception agnostic (via RAII).*

End of Section

Questions?

What Questions are we Answering?

- What do we mean by *Interface* versus *Contract* for a *function*, a *class*, or a *component?*
- What do we mean by *preconditions*, *postconditions*, and *invariants*?
- What do we mean by *essential* & *undefined behavior*?
- Must the code itself <u>*preserve*</u> invariants even if one or more *preconditions* of the contract are violated?
- What is the idea behind *Design-by-Contract (DbC)*?
- How do we <u>*document*</u> the contract for a function?
- How can clients <u>*ensure*</u> that preconditions are satisfied?
- How do we <u>*guarantee*</u> that postconditions are satisfied?
- How can we <u>*test*</u> to make sure invariants are preserved?
- What <u>*must*</u> be true if a client satisfies all preconditions?

Outline

1. Components (review)

   Modularity, Logical/Physical Dependencies, & Level numbers

2. Interfaces and Contracts (review)

   Syntax versus Semantics & *Essential Behavior*

3. Narrow versus Wide Contracts (review)

   The Significance of *Undefined Behavior*

4. Proper Inheritance

   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

Outline

1. Components (review)
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   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

Narrow versus Wide Contracts

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Pejorative terms:

Narrow versus Wide Contracts

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- ***Fat*** Interface (4. Proper Inheritance)

Narrow versus Wide Contracts

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- ***Fat*** Interface (4. Proper Inheritance)
- ***Large*** (Non-Primitive) Interface

Narrow versus Wide Contracts

Pejorative terms:

- ***Fat*** Interface (4. Proper Inheritance)
- ***Large*** (Non-Primitive) Interface
- ***Wide*** Contract

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

What should happen with the following call?

```
int x = std::strlen(0);
```

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

What should happen with the following call?

```
int x = std::strlen(0);
```

How about it must return 0?

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
    if (!s) return 0;
    // …
}
```

Wide

How about it must return 0?

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
    if (!s) return 0;
    // …
}
```

Wide

Likely to mask a defect

How about it must return 0?

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
    if (!s) return 0;
    // ...
}
```

} Wide

Likely to mask a defect

How about it must return 0?

More Code Runs Slower!

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

What should happen with the following call?

```
int x = std::strlen(0);
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Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

What should happen with the following call?

```
int x = std::strlen(0);
```

Undefined Behavior

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
    assert(s);
    // …
}
```

Narrow

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
      // ...
}
```

Narrow

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int strlen(const char *s)
{
        //
}
```

Narrow

Just Don't Pass 0!

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

Should

```
Date::setDate(int, int, int);
```

Return a status?

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

Should

```
Date::setDate(int, int, int);
```

Return a status?

Absolutely Not!

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

I “know” this date is valid (It’s my birthday)!

```
date.setDate(3, 8, 59);
```

Therefore, why should I bother to check status?

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

I “know” this date is valid (It’s my birthday)!

```
date.setDate(3, 8, 59);
```

Therefore, why should I bother to check status?

```
date.setDate(1959, 3, 8);
```

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

I "know" this date is valid (It's my birthday)!

```
date.setDate(3, 8, 59);
```

Therefore, why should I bother to check status?

```
date.setDate(1959, 3, 8);
```

Double Fault!!

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

- Returning status implies a *wide* contract.

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

- Returning status implies a *wide* contract.
- Wide contracts prevent defending against such errors in any build mode.

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
void Date::setDate(int y,
                   int m,
                   int d)
{

    d_year  = y;
    d_month = m;
    d_day   = d;
}
```

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
void Date::setDate(int y,
                   int m,
                   int d)
{
    assert(isValid(y,m,d));
    d_year  = y;
    d_month = m;
    d_day   = d;
}
```

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
void Date::setDate(int y,
                   int m,
                   int d)
{
    assert(isValid(y,m,d));
    d_year  = y;
    d_month = m;
    d_day   = d;
}
```

Narrow Contract:
Checked ***Only*** In
"Debug Mode"

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int Date::setDateIfValid(int y,
                         int m,
                         int d)
{
    if (!isValid(y, m, d)) {
        return !0;
    }
    d_year  = y;
    d_month = m;
    d_day   = d;
    return 0;
}
```

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

```
int Date::setDateIfValid(int y,
                         int m,
                         int d)
{
    if (!isValid(y, m, d)) {
        return !0;
    }
    d_year  = y;
    d_month = m;
    d_day   = d;
    return 0;
}
```

Wide Contract:
Checked in
Every Build Mode

Narrow versus Wide Contracts

Narrow Contracts Imply *Undefined Behavior*:

- What should happen when the behavior is undefined?

```
TYPE& vector::operator[](int idx);
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```
TYPE& vector::at(int
```

Bad Idea!

Narrow versus Wide Contracts

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void insert(int idx, const TYPE& value);
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if (idx < 0)         idx = 0;
if (idx > length())  idx = length();
```

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if (idx < 0)              idx = 0;
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idx = abs(idx) % (length() + 1);
```

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More Code

Runs Slower!

Narrow versus Wide Contracts

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```
if (id          0;
if (id      idx = length();
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```

Would Serve Only To Mask Defects

...ide Contracts

Na... ...ndefined Behavior:

Sh...

What happens when behavior is undefined is **undefined!**

...const TYPE& value);

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```
if (                    ...0;
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...Serve Only ... To M...

Undefined Behavior

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Should the behavior for

```
void insert(int idx, const TYPE& value);
```

be defined when `idx` is greater than `length()` or less than zero? Answer: **No!**

```
assert(0 <= idx); assert(idx <= length());
```

Narrow versus Wide Contracts

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Should the behavior for

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DEFENSIVE PROGRAMMING

See the **`bsls_assert`** component.

3. Narrow versus Wide Contracts (review)

Appropriately Narrow Contracts

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Appropriately Narrow Contracts

Narrow, but not too narrow.

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Appropriately Narrow Contracts

Narrow, but not too narrow.

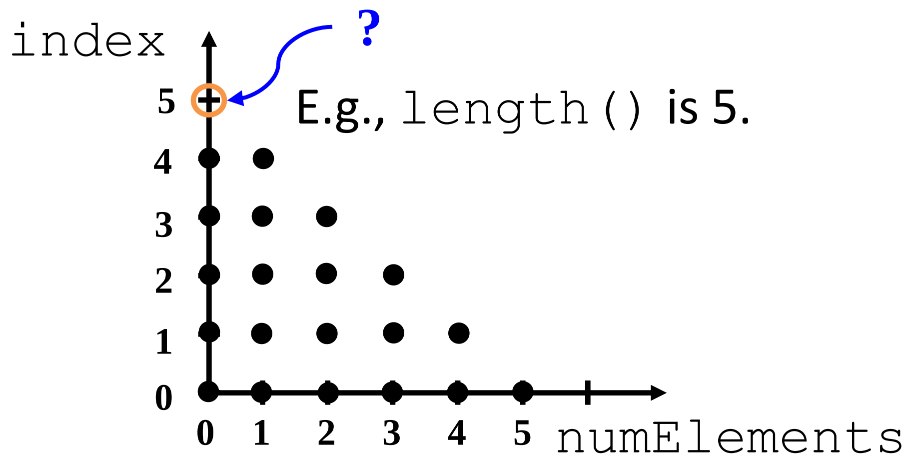
Should the behavior for

```
void replace(int index,
             const TYPE& value,
             int numElements);
```

be defined when `index` is `length()` and `numElements` is zero?

3. Narrow versus Wide Contracts (review)

Appropriately Narrow Contracts



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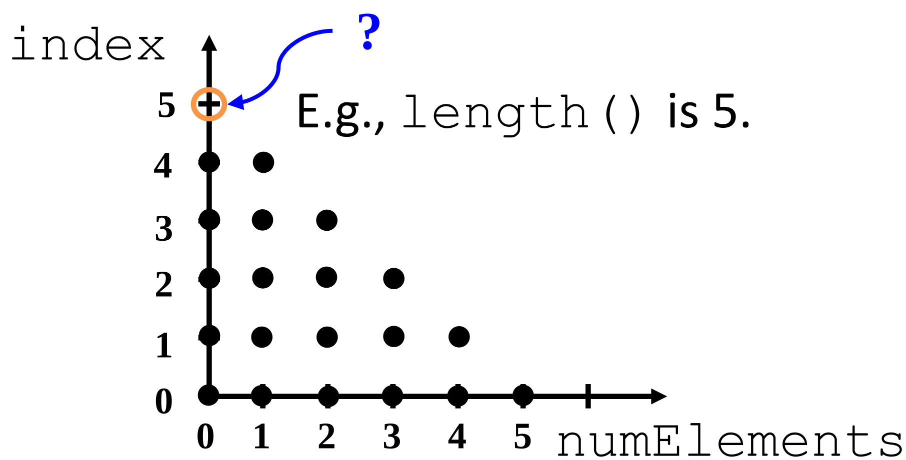


```
void replace(int index,
             const TYPE& value,
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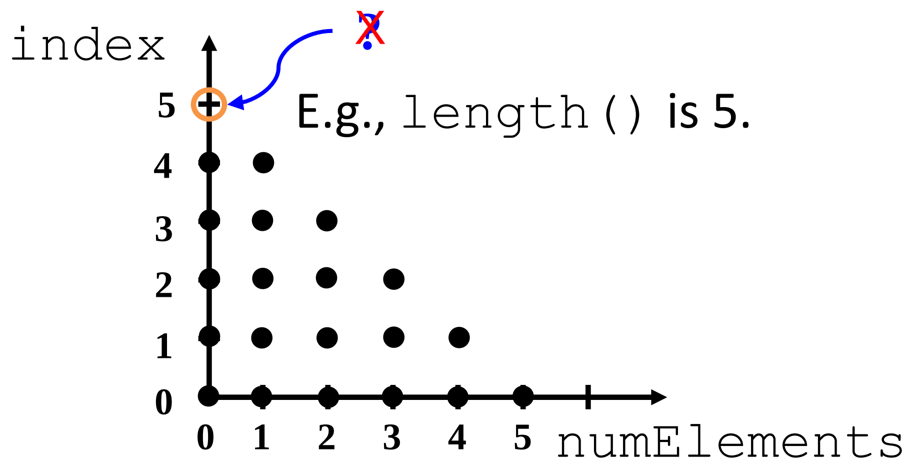
{
  assert(0 <= index);
  assert(0 <= numElements);
  assert(index + numElements <= length());
  // …
}
```

Appropriately Narrow Contracts

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3. Narrow versus Wide Contracts (review)

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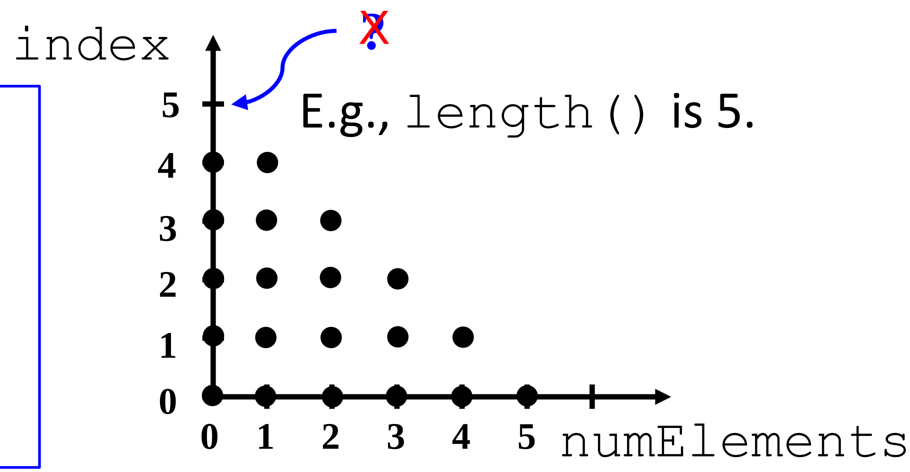
Now a client would have to check for this special case.

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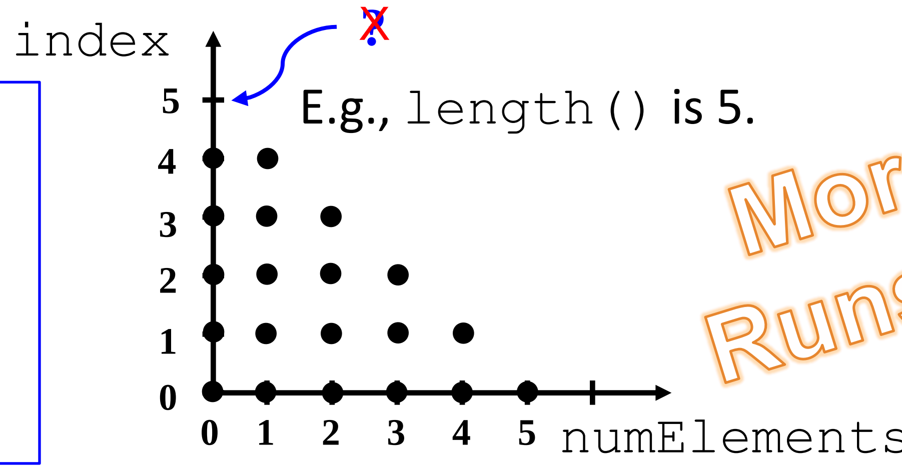

More Code Runs Slower!

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Appropriately Narrow Contracts

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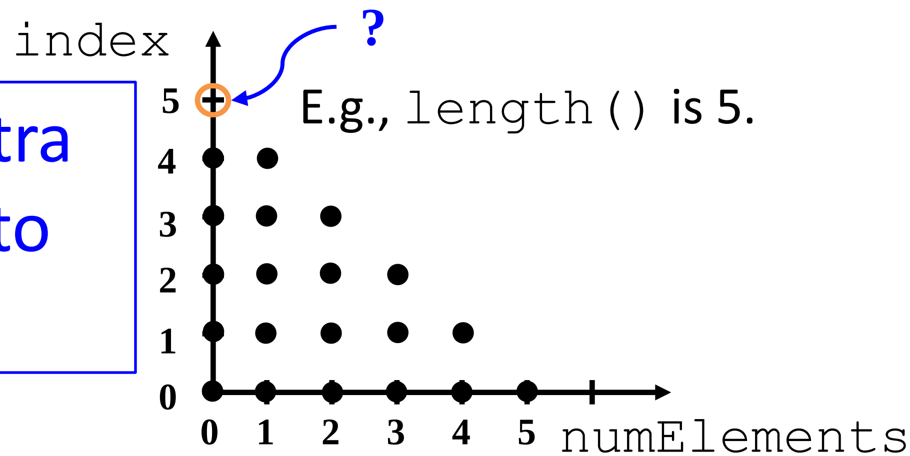


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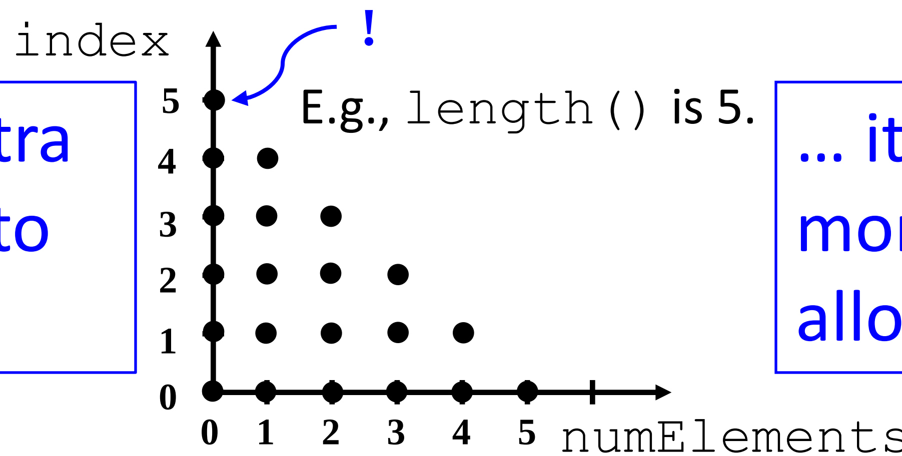

… it is naturally more efficient to allow it.

```
void replace(int index,
             const TYPE& value,
             int numElements)
{
  assert(0 <= index);
  assert(0 <= numElements);
  assert(index + numElements <= length());
  // …
}
```

3. Narrow versus Wide Contracts (review)

End of Section

Questions?

3. Narrow versus Wide Contracts (review)

What Questions are we Answering?

- What do we mean by a *narrow* versus a *wide* contract?
  - Should `std::strlen(0)` be required to do something reasonable?
  - Should `Date::setDate(int, int, int)` return a status?
- What should happen when the behavior is undefined?
  - Should what happens be part of the component-level contract?
- What about the behavior for these specific interfaces:
  - Should `operator[](int index)` check to see if `index` is less than zero or greater than `length()`?
    - And what should happen if `index` is out of range?
  - Should `insert(int index, const TYPE& value)` be defined when **`index`** is greater than **`length()`** or less than zero?
  - Should `replace(int index, const TYPE& value, int numElements)` be defined when `index` is `length()` and `numElements` is zero?
- What do we mean by *Defensive Programming (DP)*?

Outline

1. Components (review)

   Modularity, Logical/Physical Dependencies, & Level numbers

2. Interfaces and Contracts (review)

   Syntax versus Semantics & *Essential Behavior*

3. Narrow versus Wide Contracts (review)

   The Significance of *Undefined Behavior*

4. Proper Inheritance

   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

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Three Kinds of Inheritance

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Public,
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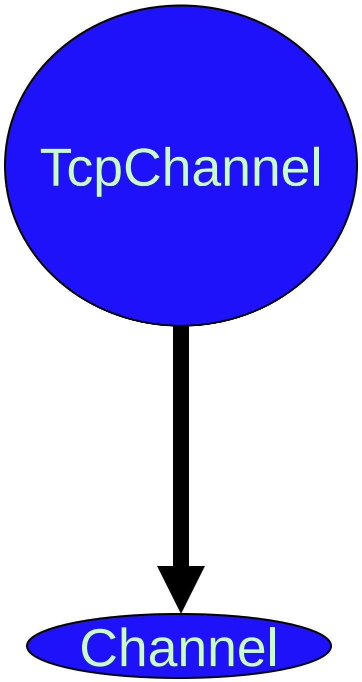
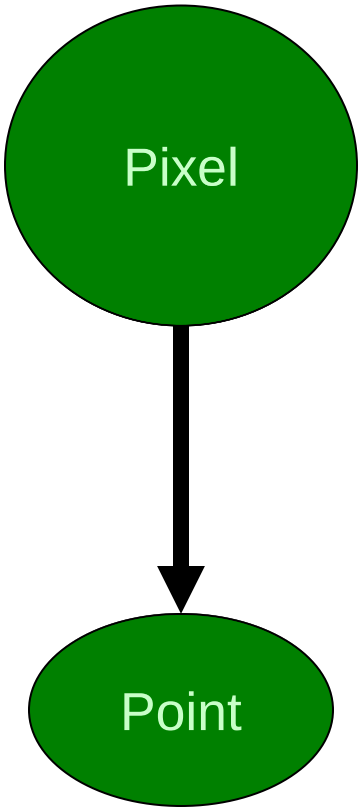
Interface Inheritance




```
class TcpChannel : public Channel {
    /* … */
  public:
    // … (creators)
    virtual int read(char *buffer, int numBytes) {…}
    virtual int write(const char *buffer, int numBytes) {…}
};
```

```
class Channel  {
  public:
    virtual ~Channel() { }
    virtual int read(char *buffer, int numBytes) = 0;
    virtual int write(const char *buffer, int numBytes) = 0;
};
```

Structural Inheritance

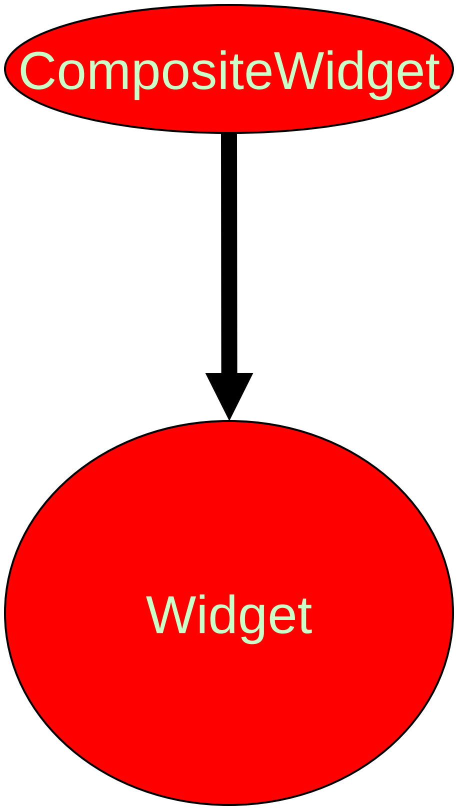



```
class Pixel : public Point {
  public:
    enum Color { RED, GREEN, BLUE };
  private:
     Color d_color;
  public:
    // … (creators)
    void setColor(Color color) { /* … */ }
    Color color ( ) const { /* … */ }
};
```

```
class Point  {
   int d_x;
   int d_y;
  public:
    // … (creators)
    void setX(int x) { /* … */ }
    void setY(int y) { /* … */ }
    int x() const { /* … */ }
    int y() const { /* … */ }
};
```

4. Proper Inheritance

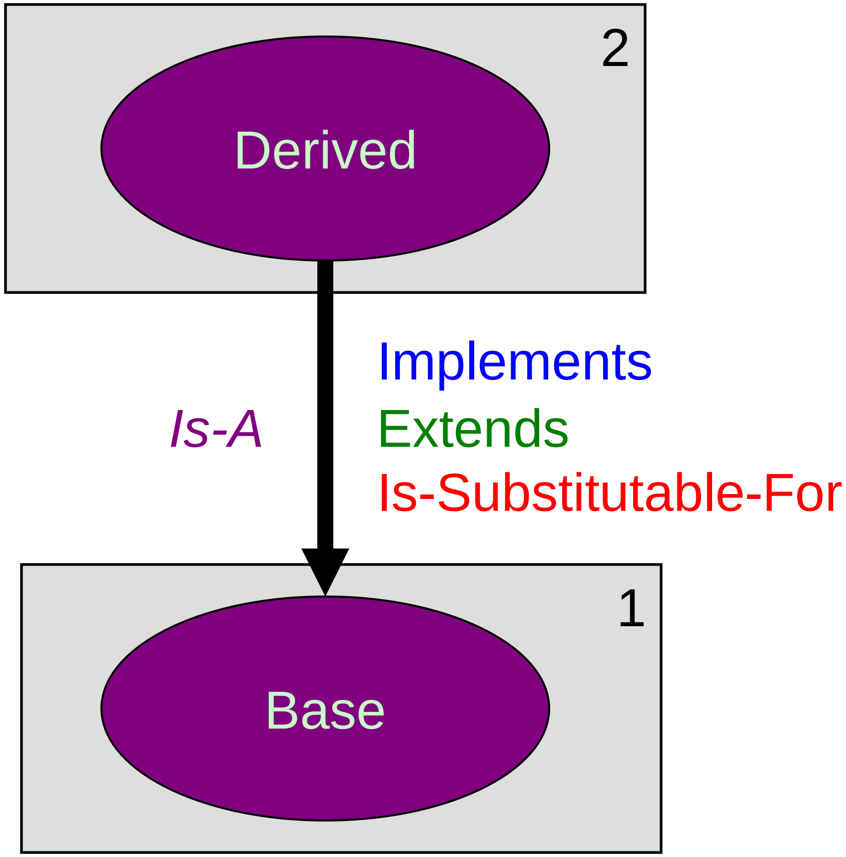
Implementation Inheritance




```
class CompositeWidget : public Widget {
    // …
  public:
    // … (creators)
    virtual const char *widgetCategory() const { return "COMP"; }
    virtual int numChildren() const { /* … */ }
    // …
};
```

```
class Widget  {
    Point d_origin;
    // …
  public:
    // … (creators)
    virtual bool isNameable() const { return false; }
    virtual const char *instanceName() const { return 0; }
    virtual bool hasLocation() const { return true; }
    virtual Point origin() const { return d_origin; }
    virtual const char *widgetCategory() const { return "LEAF"; }
    virtual int numChildren const { return 0; }
    // …
};
```

What Is Proper Inheritance?



What Is Proper Inheritance?

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  - What does it mean?

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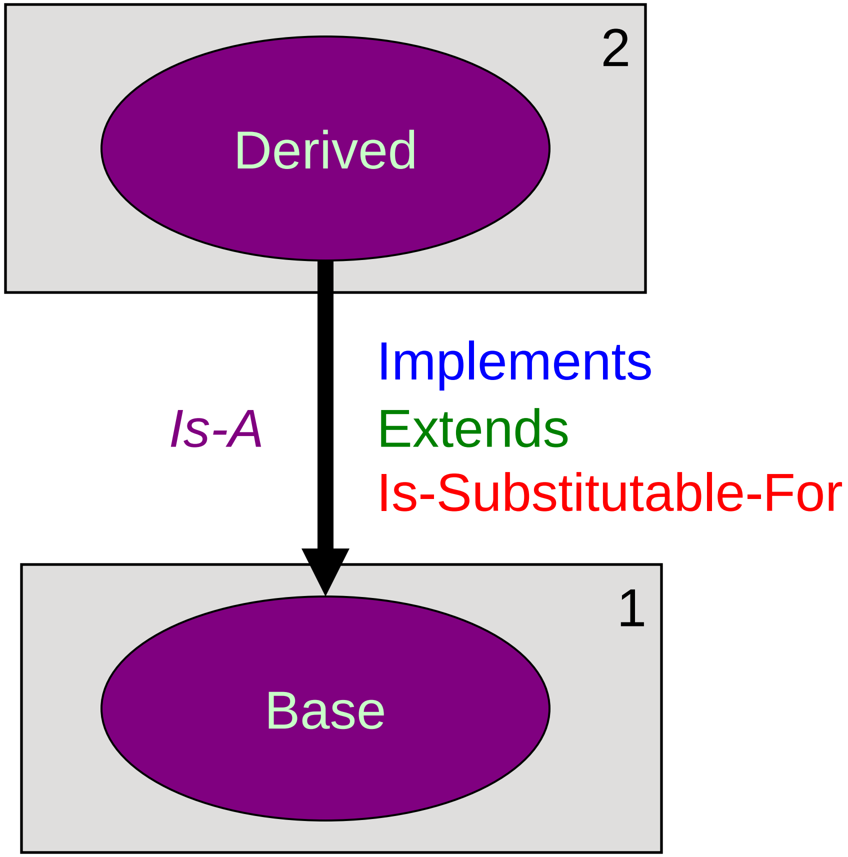
  - Of what?
  - What criteria?

What Is Proper Inheritance?



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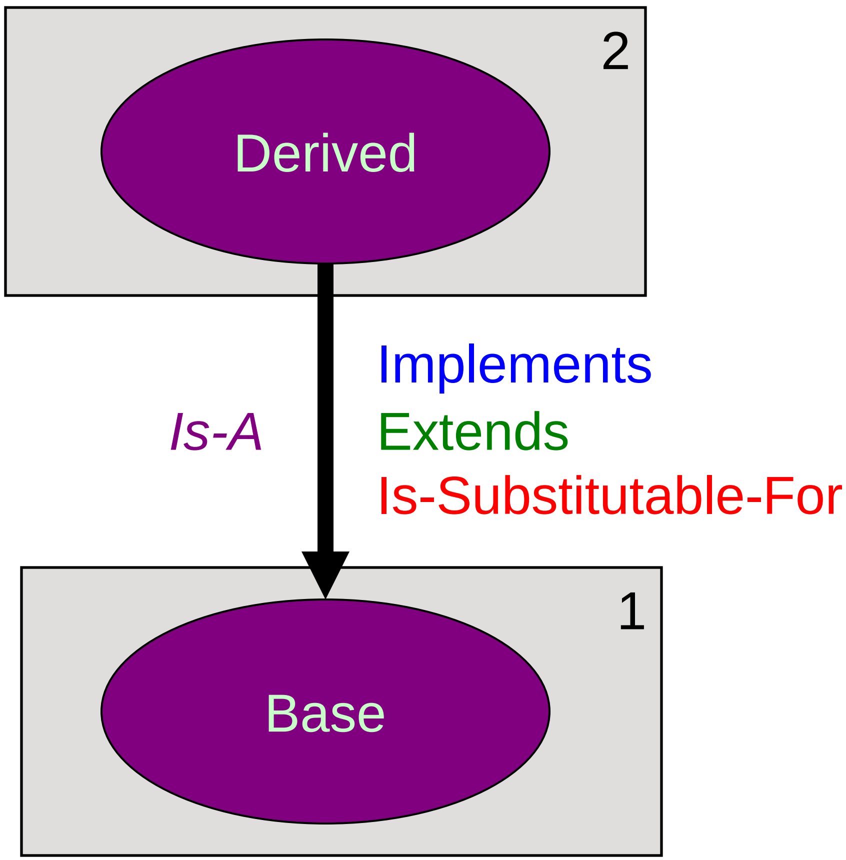

The *Is-A* Relation:

The implementation of a ***derived*** class ***must*** satisfy (simultaneously) its own contract, as well as that of "each" ***base*** class.

What Is Proper Inheritance?

What about the following ***general property*:**

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For inheritance to be ***proper***, any operation that can be invoked on a derived-class ***object*** via a base-class pointer (or reference) must behave **identically** if we replace that base-class pointer (or reference) with a corresponding derived-class one.

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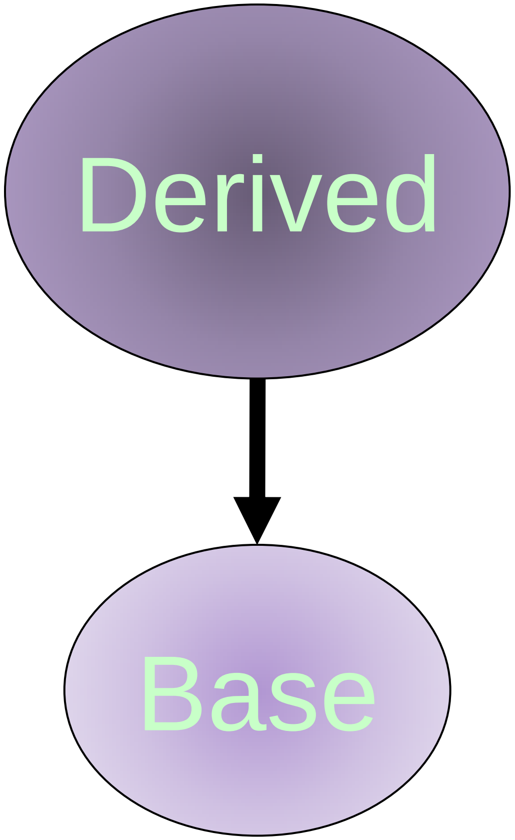

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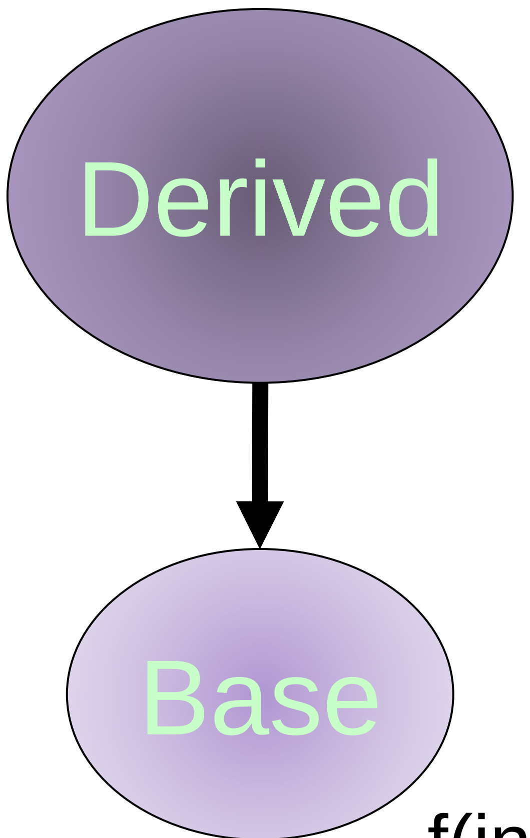
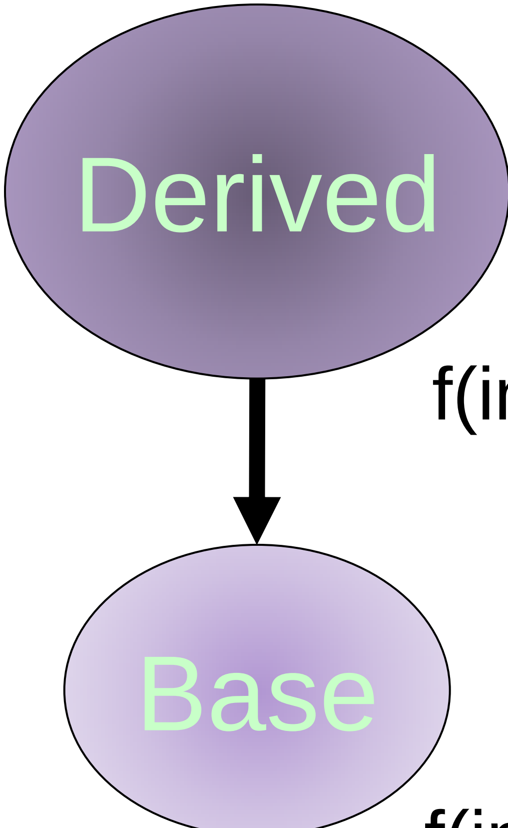


f(int, double, const char *)

What Is Proper Inheritance?



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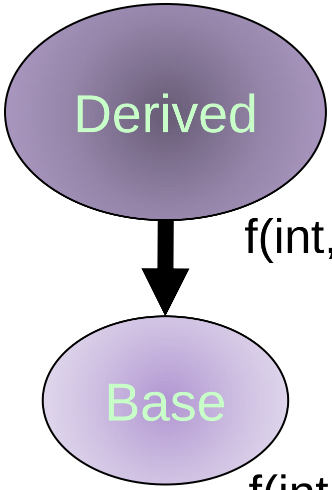

f(int, double, const char *)

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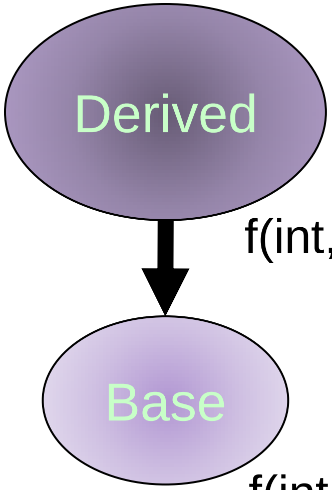
What Is Proper Inheritance?

Derived *dp = new Derived();



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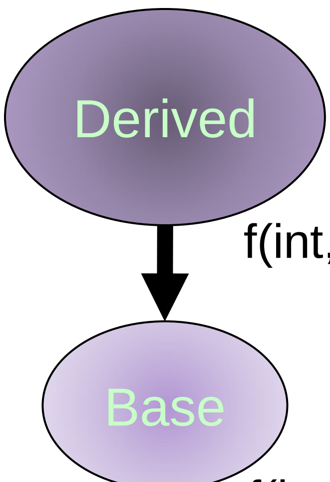

f(int, double, const char *)

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```
0x002130:
0x002138:
0x002140:
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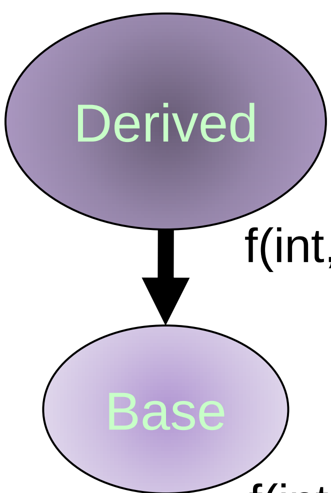

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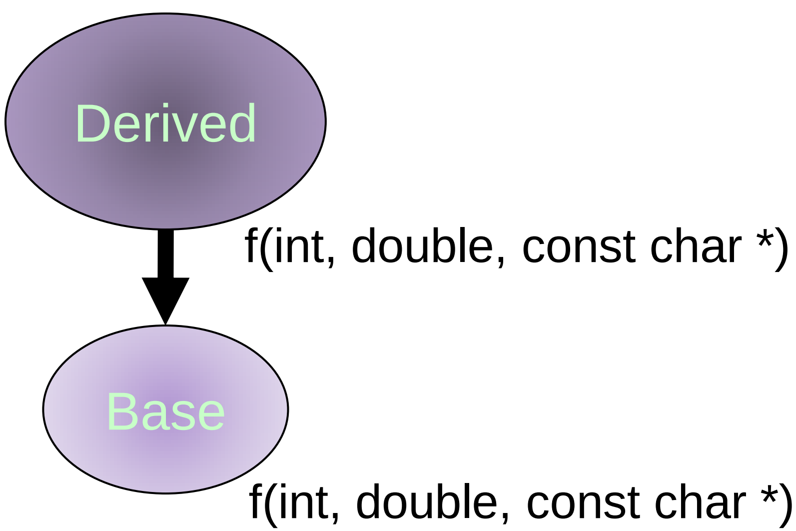

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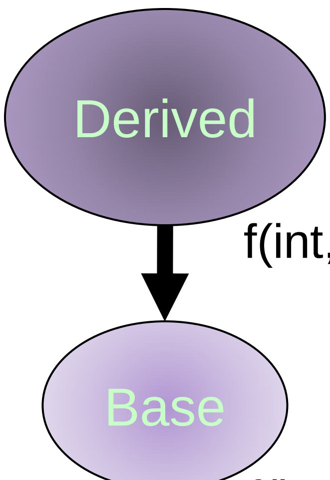
0x002170:

Object
of type
Derived

What Is Proper Inheritance?

Derived *dp = new Derived();   // dp = 0x002140



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Object

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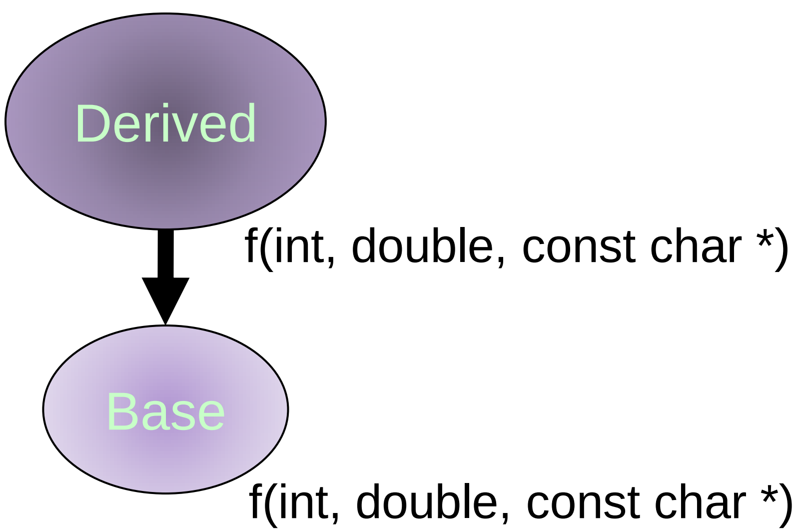
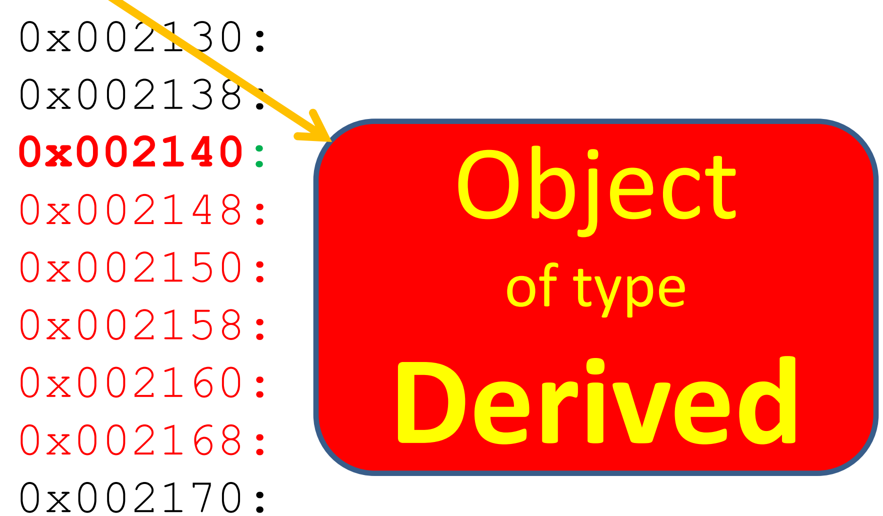
What Is Proper Inheritance?

Derived *dp = new Derived(); // dp = 0x002140

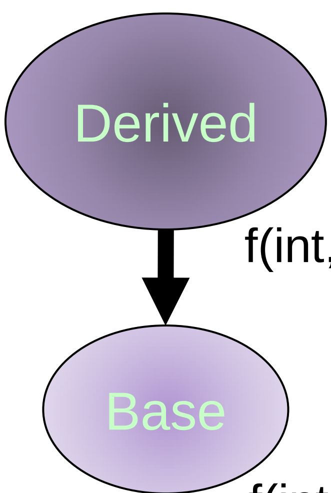




What Is Proper Inheritance?

```
Derived *dp = new Derived();      // dp = 0x002140

Base    *bp  = dp;                // bp = 0x002140
```



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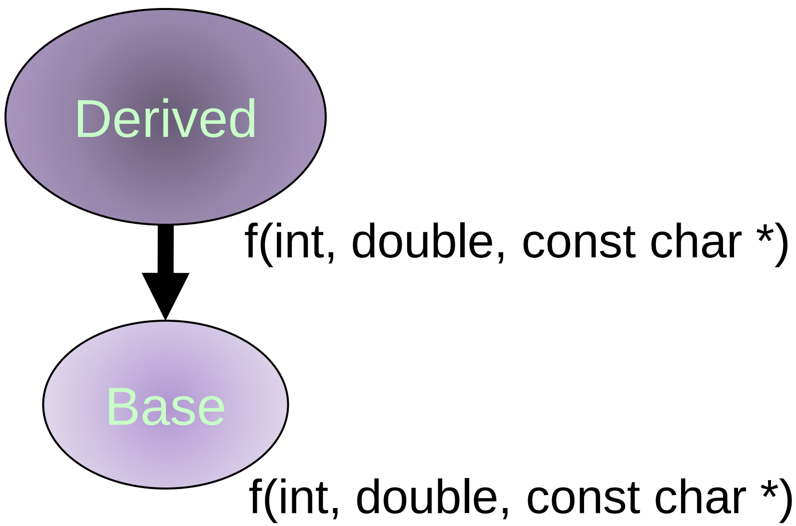

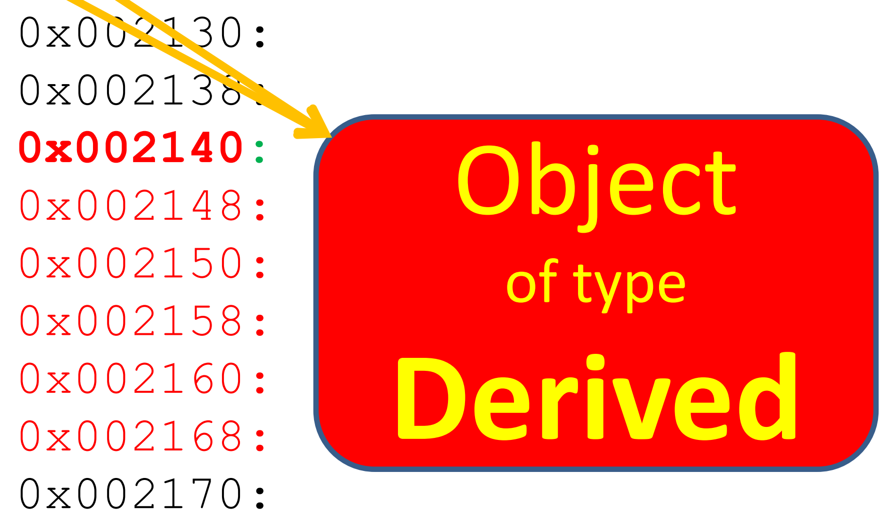

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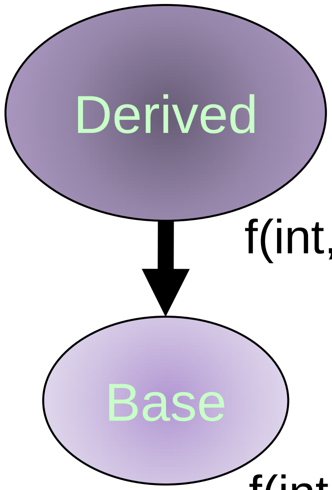

Derived: f(int, double, const char *)

Base: f(int, double, const char *)

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0x002130:
0x002138:
0x002140:
0x002148:
0x002150:
0x002158:
0x002160:
0x002168:
0x002170:
```

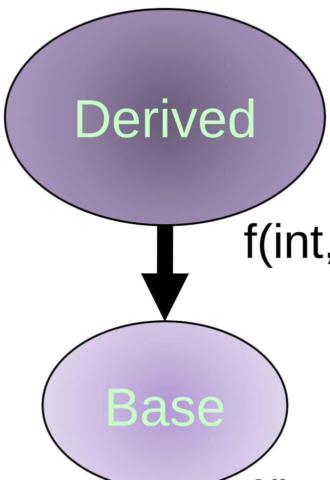
Object of type **Derived**

What Is Proper Inheritance?

```
Derived *dp = new Derived();      // dp = 0x002140

Base    *bp  = dp;                // bp = 0x002140
```

```
bp->f(1, 2.0, “three”);
```



f(int, double, const char *)

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0x002130:
0x002138:
0x002140:
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Object
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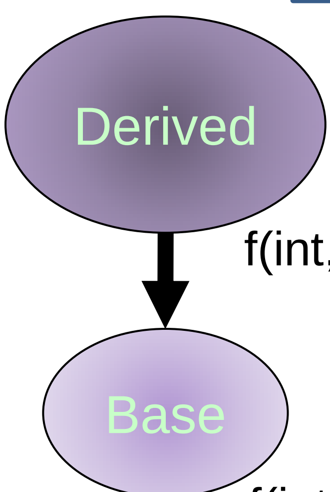

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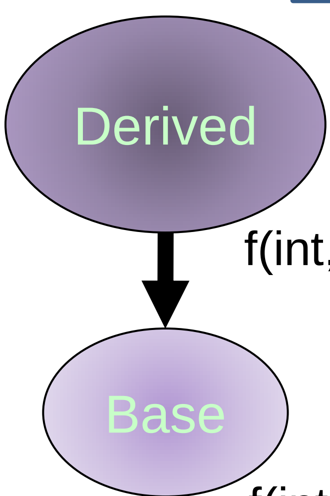
Identical Behavior



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Object
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What Is Proper Inheritance?

What about the following ***general property:***

For inheritance to be ***proper***, any operation that can be invoked on a derived-class ***object*** via a base-class pointer (or reference) must behave **identically** if we replace that base-class pointer (or reference) with a corresponding derived-class one.

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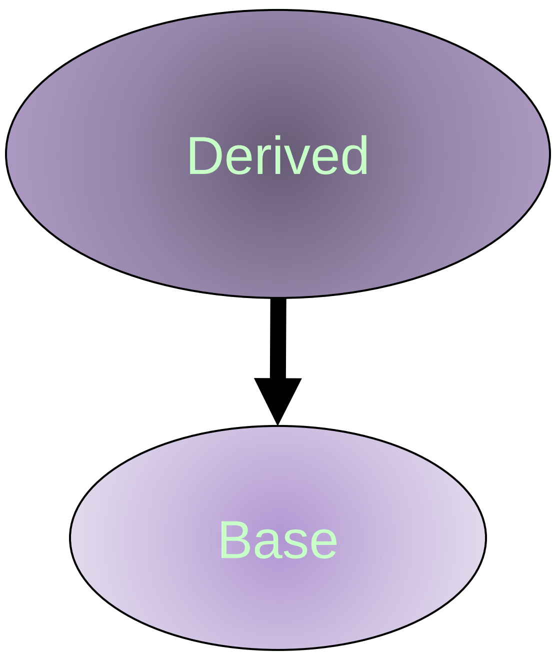
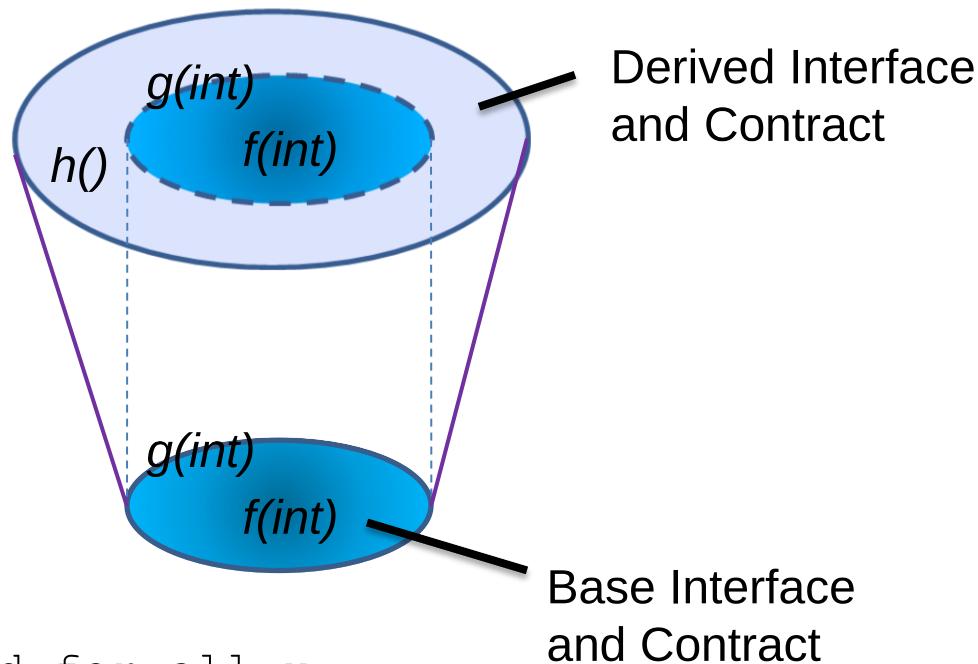
Note that this is how virtual functions behave!

What Is Proper Inheritance?

```
Derived::f(int x);   // Defined for all x.
Derived::g(int x);   // Defined for all x.
Derived::h();        // Note: not accessible from Base class.
```






```
Base::f(int x);   // Defined for all x.
Base::g(int x);   // Defined only for 0 <= x.
```

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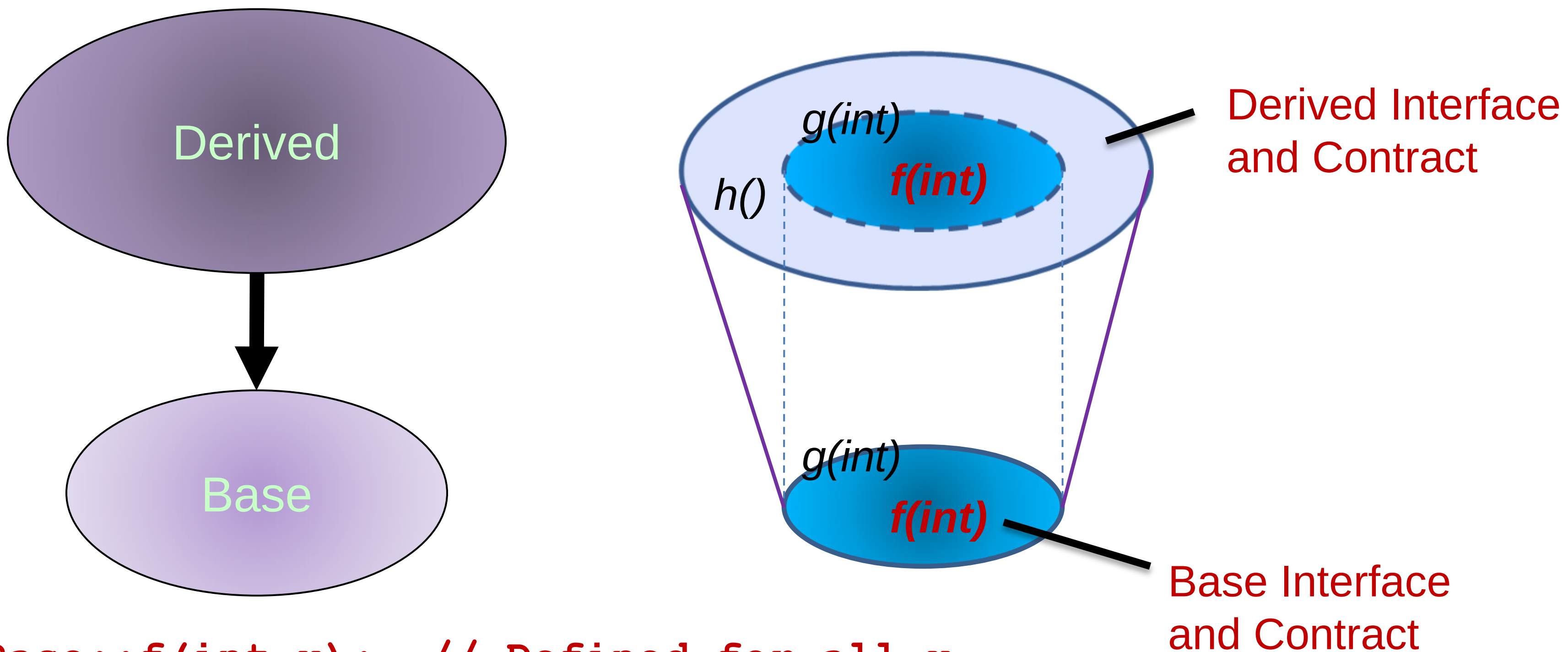


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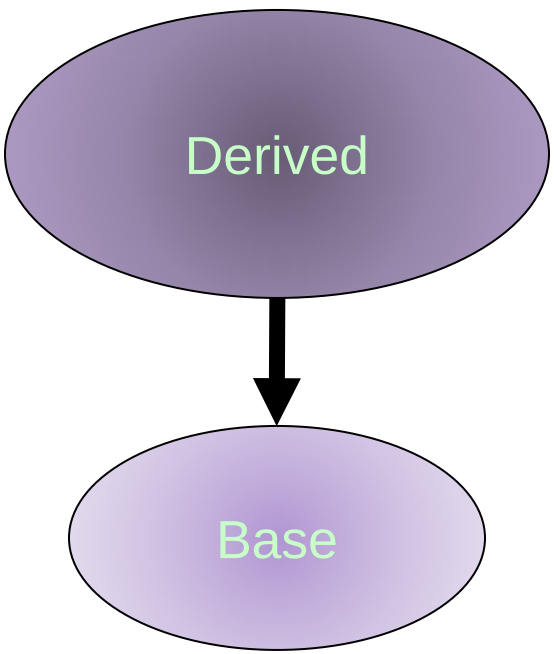

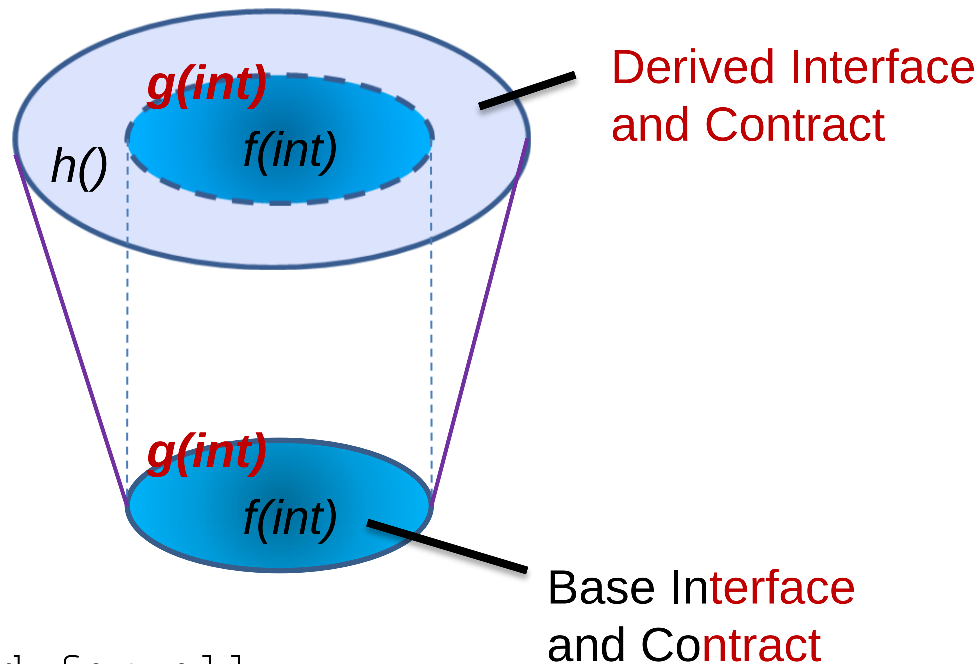


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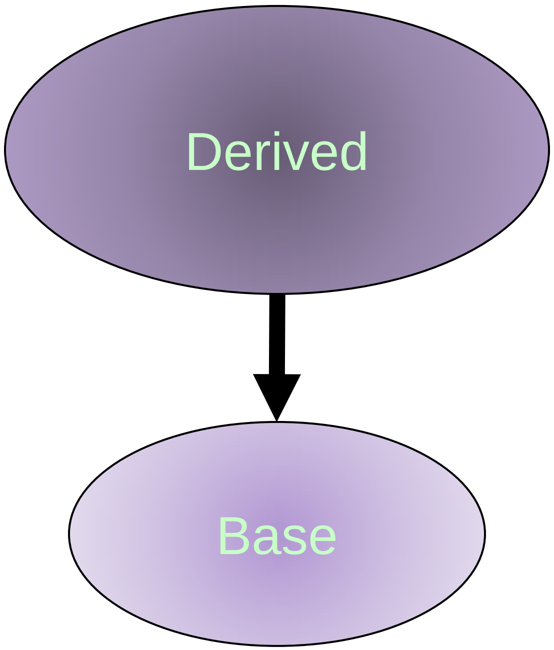

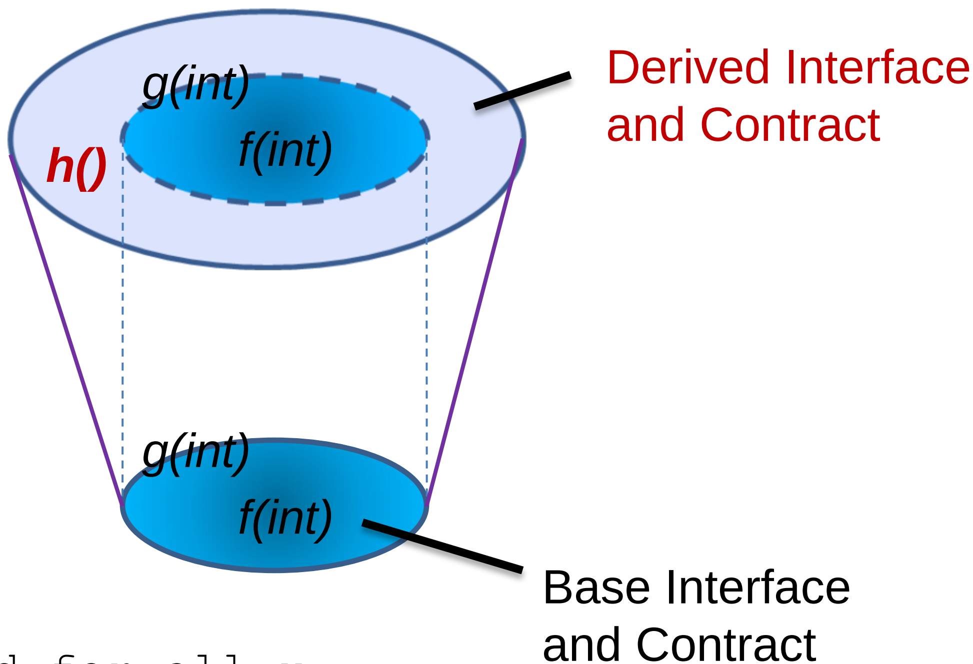


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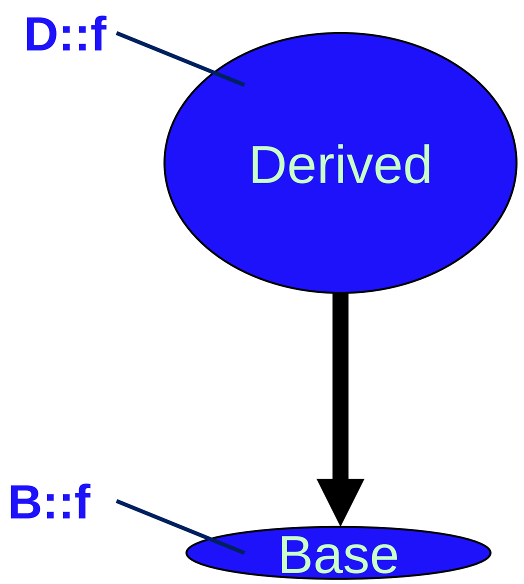
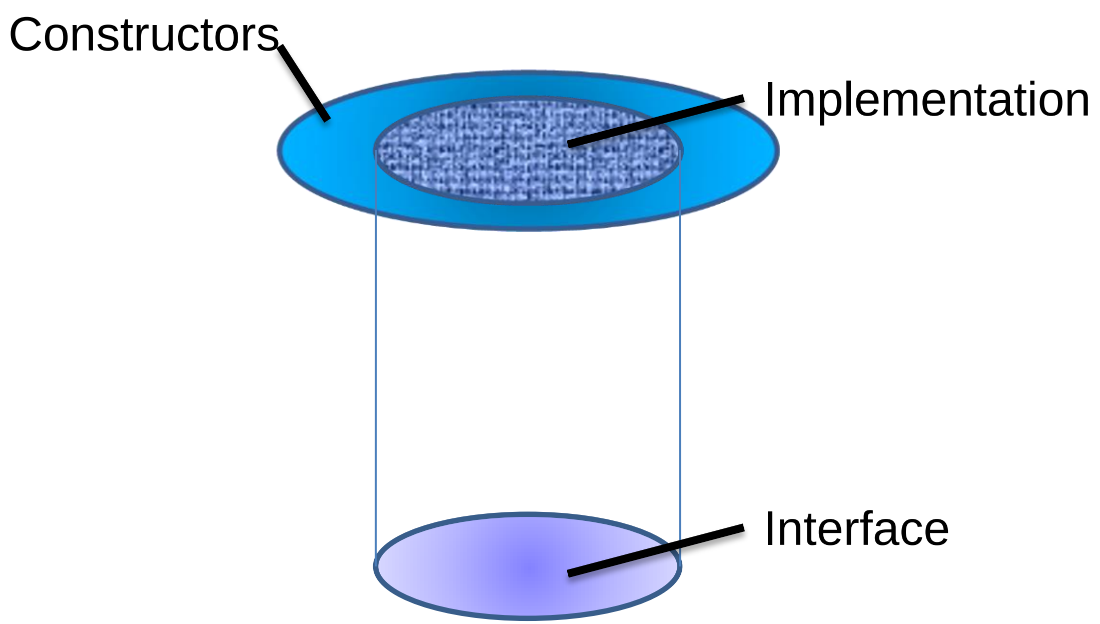
Pure Interface Inheritance

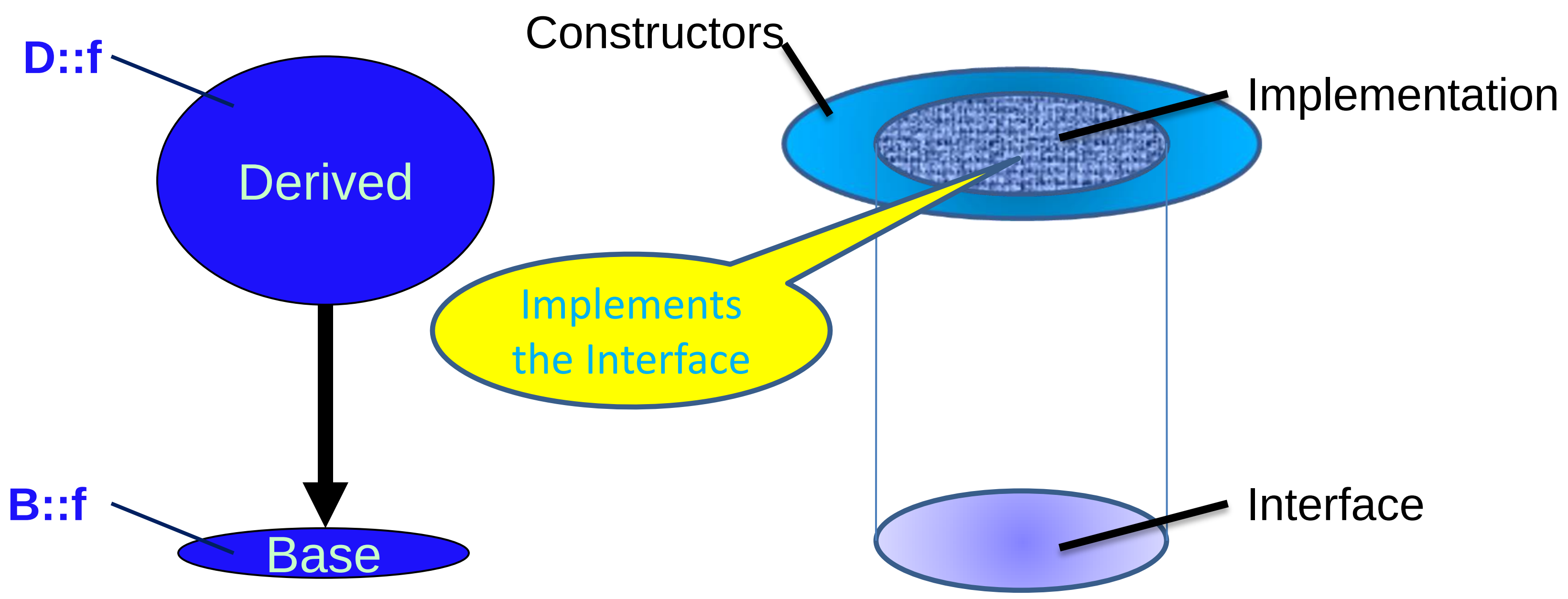




For each function **D::f** in the derived class overriding a virtual one **B::f** in the base class, the (documented) ***preconditions*** of **D::f** must be **no stronger** than those for **B::f**, and the ***postconditions*** **no weaker**.

4. Proper Inheritance

Pure Interface Inheritance



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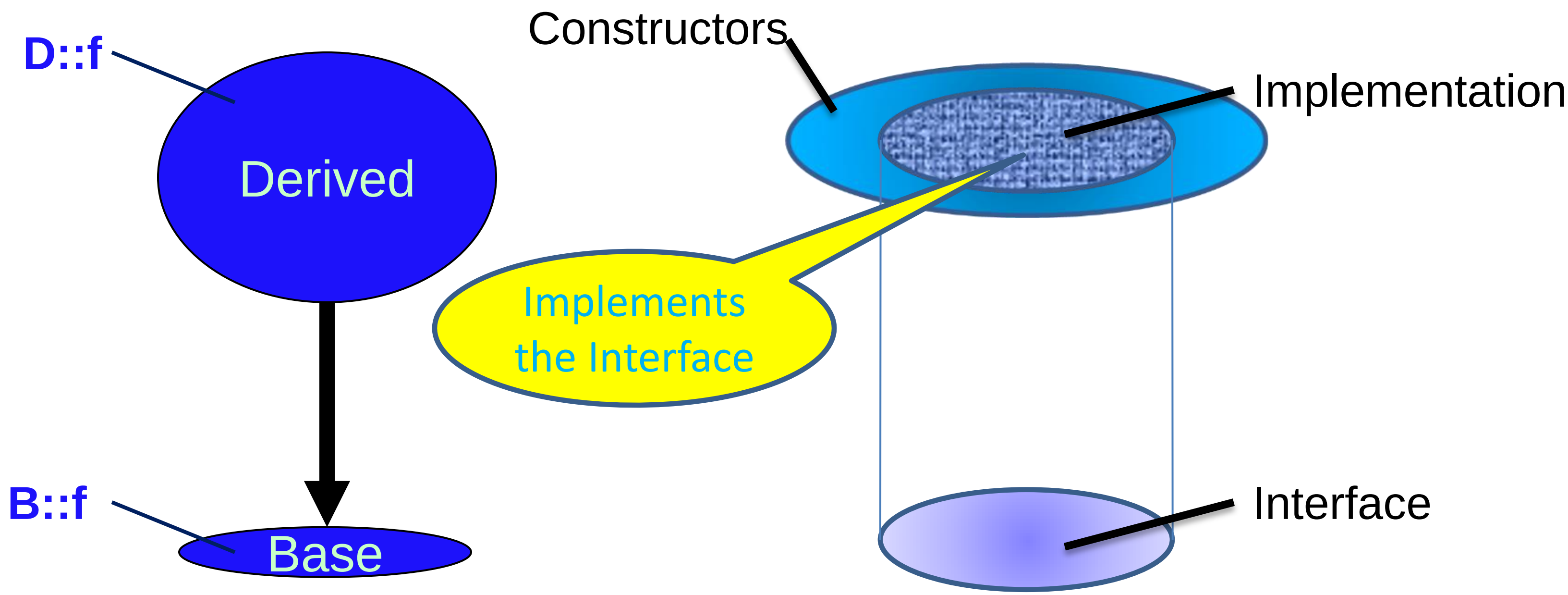

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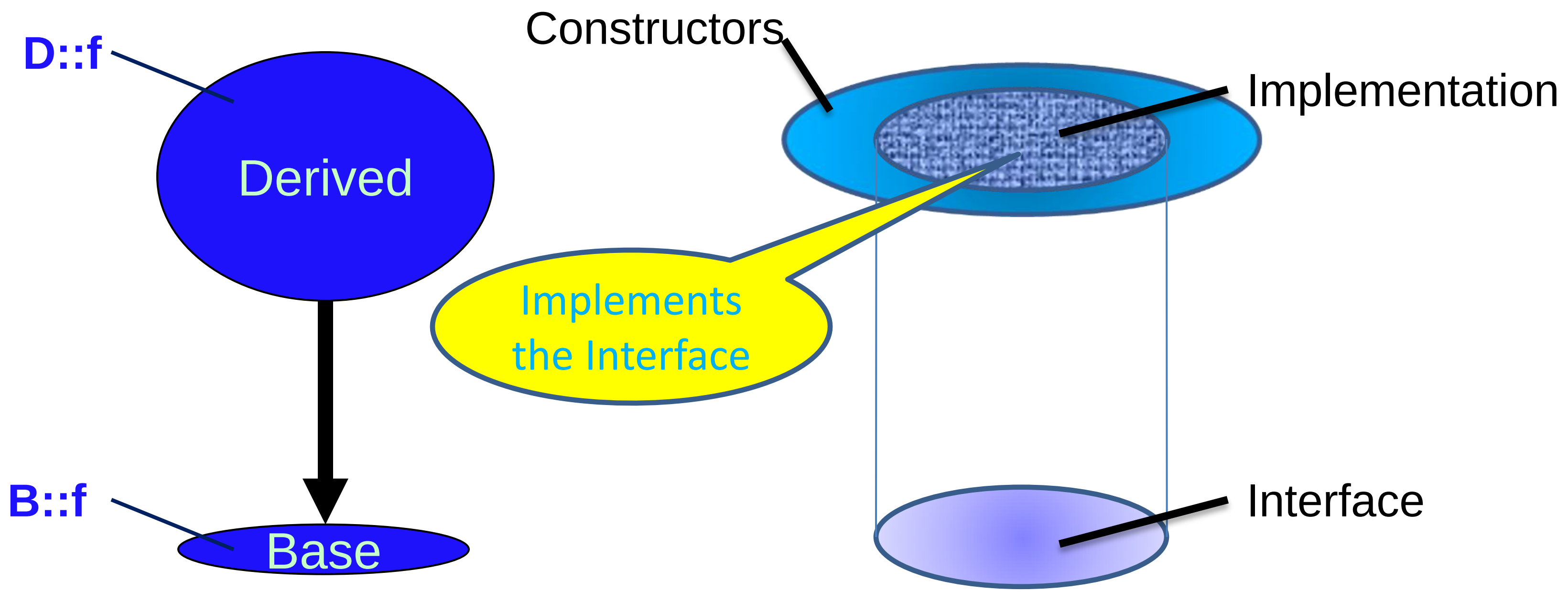

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4. Proper Inheritance

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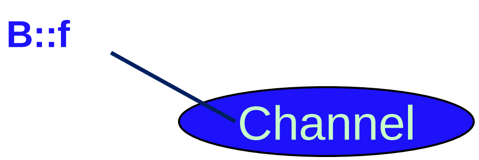
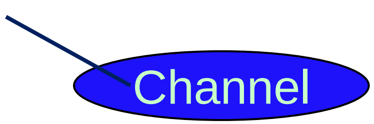


4. Proper Inheritance

Pure Interface Inheritance

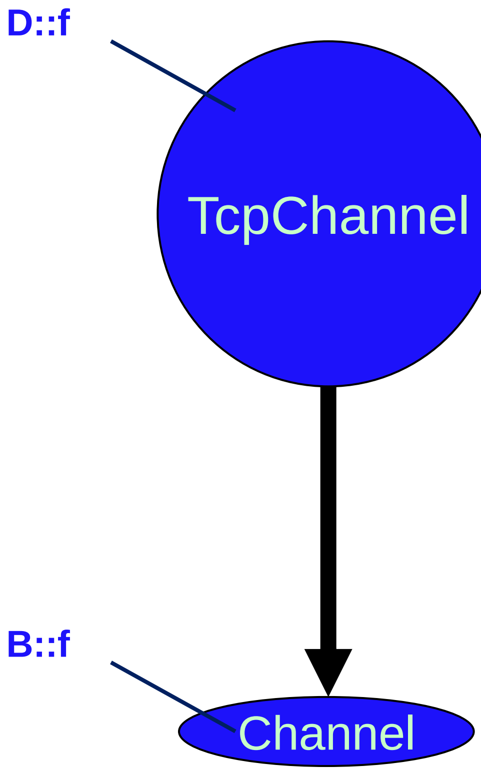
B::f




```
virtual int write(const char *buffer, int numBytes) = 0;
    // Write the specified 'numBytes' from the specified
    // 'buffer'.  Return 0 on success, and a non-zero value
    // otherwise.  The behavior is undefined unless
    // '0 <= numBytes <= 32767'.
```

4. Proper Inheritance

Pure Interface Inheritance

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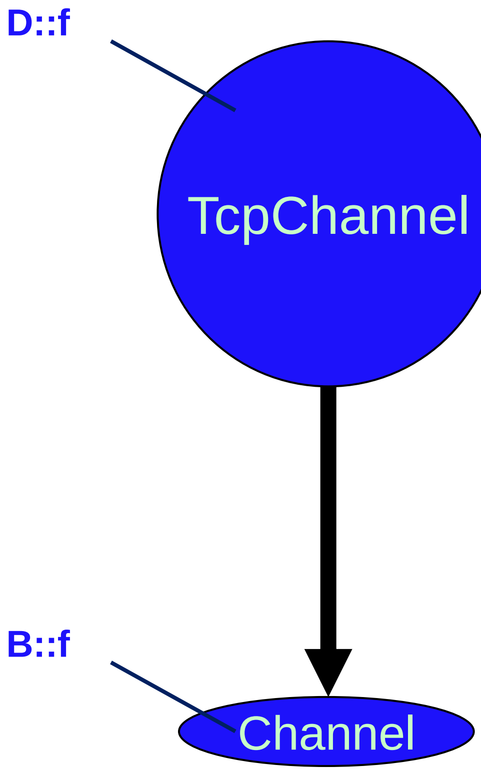


```
virtual int write(const char *buffer, int numBytes);
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    // 'numBytes' from the specified 'buffer'.  Return 0 on
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```
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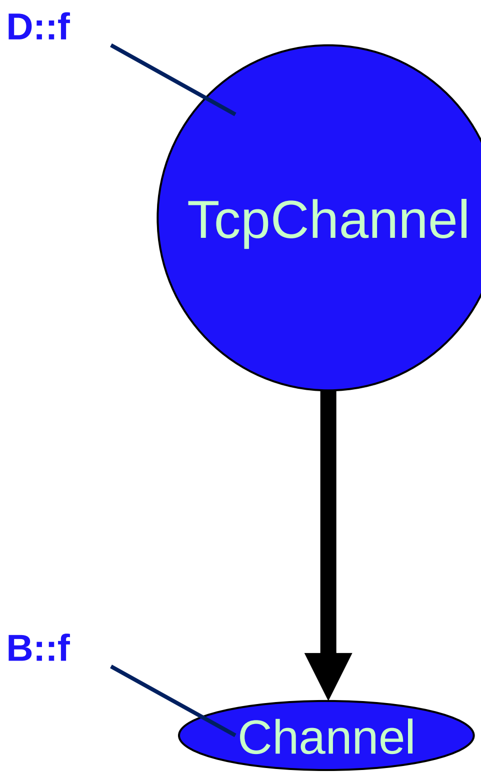


```
virtual int write(const char *buffer, int numBytes);
    // Write to this TCP/IP channel the specified
    // 'numBytes' from the specified 'buffer'.  Return 0 on
    // success, 1 if '0 != numBytes % 4', and a negative
    // value otherwise.
```

```
virtual int write(const char *buffer, int numBytes) = 0;
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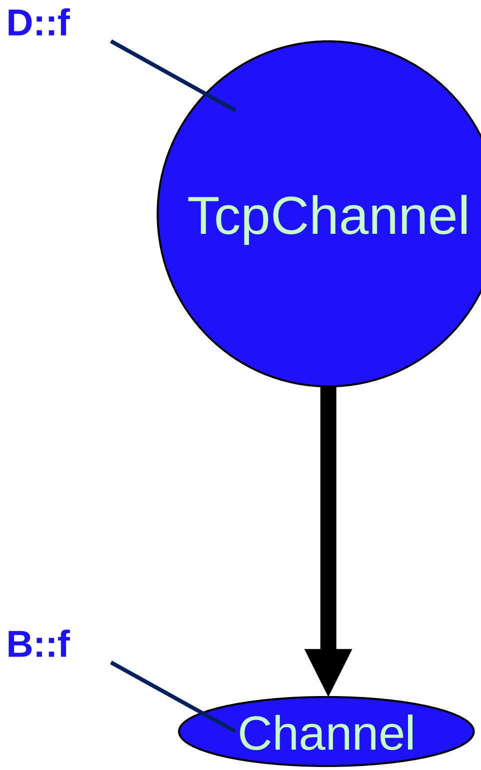


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    // 'numBytes' from the specified 'buffer'.  Return 0 on
    // success, and a non-zero value otherwise.  Note that
    // this functionality is not yet implemented on Windows;
    // on that platform, this function always returns -1.
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What Is a Proper Subtype/Subclass?

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(OOPSLA '87)

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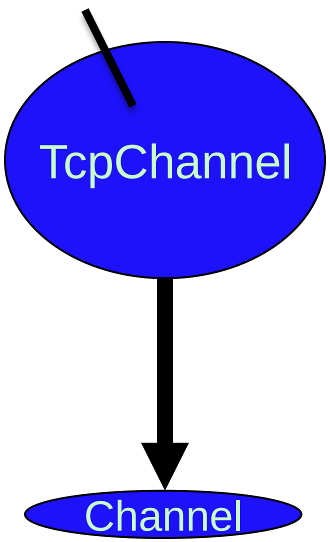
Can ***create*** it.



Interface
Inheritance

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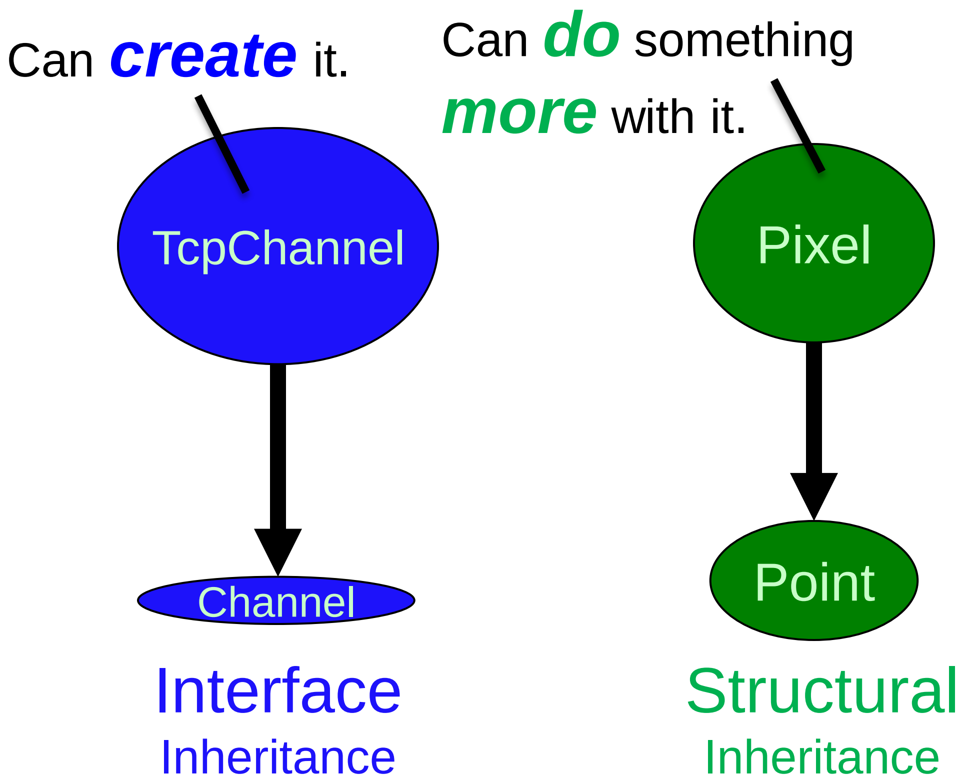

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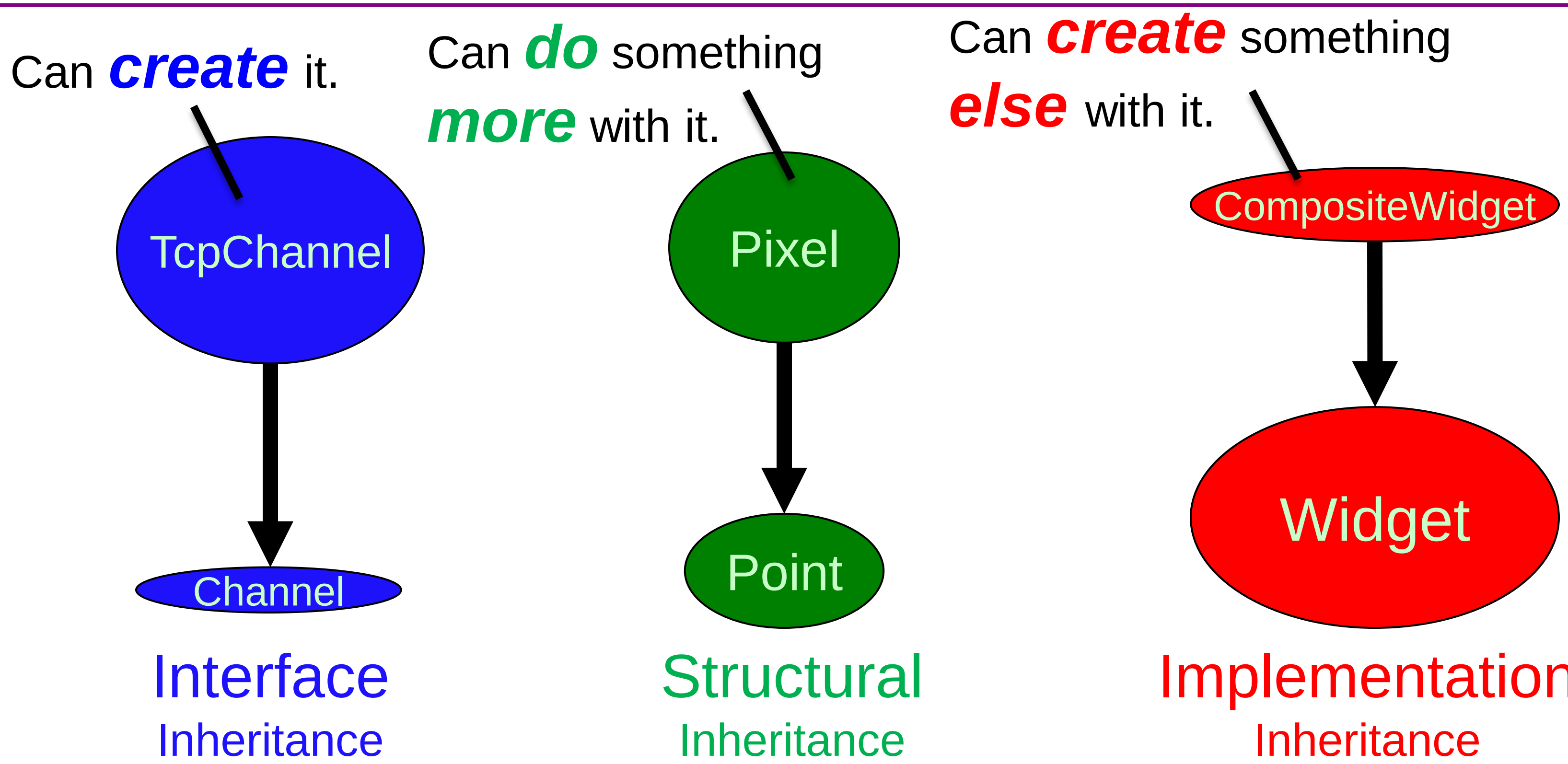

4. Proper Inheritance

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- Does **LSP** apply to all *three* kinds of inheritance?
- Does **LSP** have any other practical applications?
- Let's have a look…

What Is Liskov Substitution?

"If for each object o_1 of type S there is an object o_2 of type T such that for all programs P defined in terms of T, the behavior of P is unchanged when o_1 is substituted for o_2, then S is a subtype of T." – *Barbara Liskov* (OOPSLA '87)

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main()
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    Fool f0(false);
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void p(const Bool& x, const Bool& y, …) { /* … */ }
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(by this definition)

`Fool` is a "subtype" of `Bool` and vice versa!

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If, *for each* "derived-class" object $\mathbf{o_1}$ of type **S**, *there exists* a "base-class" object $\mathbf{o_2}$ of type **T** *such that*, *for <u>all</u>* programs **P** defined in terms of type **T**, the behavior of **P** is <u>unchanged</u> when the "derived-class" object $\mathbf{o_1}$ is substituted for the "base-class" object $\mathbf{o_2}$, then **S** is a subtype of **T**.

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If, *for each* "derived-class" object **d** of type **D**, *there exists* a "base-class" object **b** of type **B** *such that*, *for all* programs **P** defined in terms of type **B**, the behavior of **P** is unchanged when the "derived-class" object **d** is substituted for the "base-class" object **b**, then **D** is a subtype of **B**.

What Is Liskov Substitution?

"If for each object o_1 of type S there is an object o_2 of type T such that for all programs P defined in terms of T, the behavior of P is unchanged when o_1 is substituted for o_2, then S is a subtype of T." – *Barbara Liskov* (OOPSLA '87)
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"If for each object o_1 of type S there is an object o_2 of type T such that for all programs P defined in terms of T, the behavior of P is unchanged when o_1 is substituted for o_2, then S is a subtype of T." – *Barbara Liskov* (OOPSLA '87)

If, *for each* "derived-class" object $\mathbf{o_1}$ of type **S**, *there exists* a "base-class" object $\mathbf{o_2}$ of type **T** *such that*, *for all* programs **P** defined in terms of type **T**, the behavior of **P** is unchanged when the "derived-class" object $\mathbf{o_1}$ is substituted for the "base-class" object $\mathbf{o_2}$, then **S** is a subtype of **T**.

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What Is Liskov Substitution?

If, *for each* object **d** of type **D**, *there exists* an object **b** of type **B** *such that*, *for all* programs **P** defined in terms of **B**, the behavior of **P** is unchanged when **d** is substituted for **b**, then **D** is a subtype of **B**.

```
class Bool {
    bool d_v;
  public:
    Bool(int x) : d_v(x) { }
    operator bool() const {return d_v;}
};
```

```
class Fool : public Bool {
  public:
    Fool(int x) : Bool(!x) { }
};
```

```
void p(const Bool& x, const Bool& y, …) { /* … */ }
```

```
main()
{
    Bool b0(false);
    Bool b1(true);
    // …
    p(b0, b1, …);
}
```

```
main()
{
    Fool f0(false);
    Fool f1(true);
    // …
    p(f1, f0, …);
}
```

Type Bool

Subtype Fool

What Is Liskov Substitution?

If, *for each* object **d** of type **D**, *there exists* an object **b** of type **B** *such that*, *for all* programs **P** defined in terms of **B**, the behavior of **P** is unchanged when **d** is substituted for **b**, then **D** is a subtype of **B**.

```
class Bool {
    bool d_v;
  public:
    Bool(int x) :
    operator bool
};
```

```
                    public Bool {

                    x) : Bool(!x) { }
```

```
void p(const                    { /* … */ }
```

```
main()
{
    Bool b(
    Bool b1
    // …
    p(b0, b
}
```

```
            alse);
            ue);

            …);
```

Necessary, but Not Sufficient, for Inheritance.

Type Bool

Subtype Fool

What Is Liskov Substitution?

If, *for each* object **d** of type **D**, *there exists* an object **b** of type **B** *such that*, *for all* programs **P** defined in terms of **B**, the behavior of **P** is unchanged when **d** is substituted for **b**, then **D** is a subtype of **B**.

(by this definition)

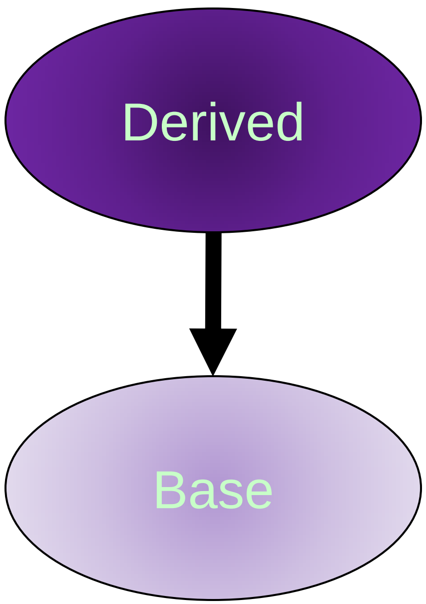
Every *empty* type is a "subtype" of all types!

What Is Proper Inheritance?

Recall the following ***general property:***

For inheritance to be ***proper***, any operation that can be invoked on a derived-class ***object*** via a base-class pointer (or reference) must behave **identically** if we replace that base-class pointer (or reference) with a corresponding derived-class one.

What Is Proper Inheritance?

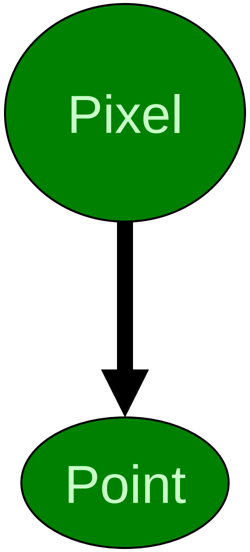



```
void example(Derived *pDerived)
{
    Base *pBase = pDerived;

#ifdef  USE_DERIVED_CLASS_INTERFACE

    pDerived->someMethod(/* … */);

    int result = someFunction(*pDerive);


#else

    pBase->someMethod(/* … */);

    int result = someFunction(*pBase);


#endif
```

Same Behavior

4. Proper Inheritance

Pure Structural Inheritance

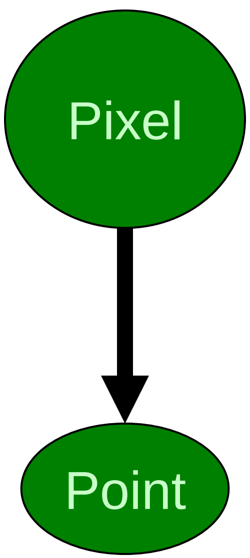



```
#ifdef USE_BASE_CLASS_INTERFACE
    typedef Point Type;
#else
    typedef Pixel Type;
#endif

void anyProgram(Type *p);

void main()
{
    Pixel pixel(1, 2, Pixel::BLUE);
    anyProgram(&pixel);
}

using std::cout;  // (We do this only
using std::endl;  //  in test drivers.)
```

4. Proper Inheritance

Pure Structural Inheritance

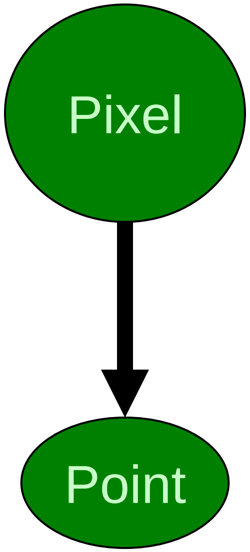
```
void anyProgram(Type *p)
{
    cout << p->x() << endl;
}
```




```
int Point::x() const
{
    return d_x;
}
```

Pure Structural Inheritance

```
void anyProgram(Type *p)
{
    p->setY(10);
}
```

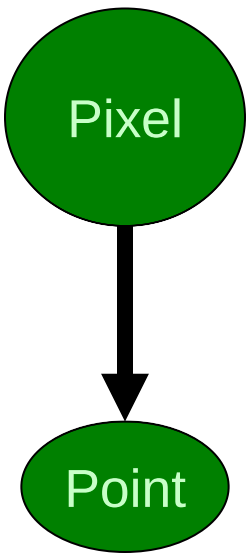



```
void Point::setY(int y)
{
    d_y = y;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

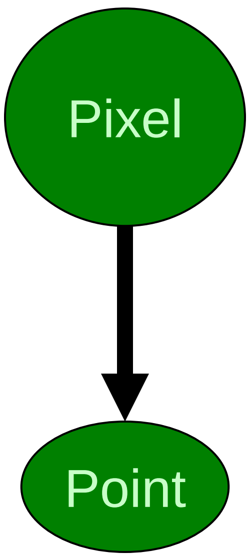
```
void anyProgram(Type *p)
{
    cout << p->color() << endl;
}
```




```
Pixel::Color Pixel::color() const
{
    return d_color;
}
```

Pure Structural Inheritance

```
void anyProgram(Type *p)
{
    p->setY(10);
}
```

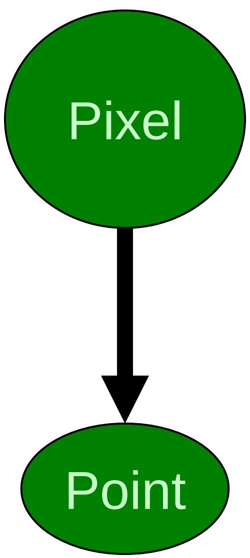



```
void Pixel::setY(int y)
{
    cout << "Pixel::setY(int y)" << endl;
    d_y = y;
}
```

```
void Point::setY(int y)
{
    d_y = y;
}
```

Pure Structural Inheritance

```
void anyProgram(Type *p)
{
    p->setY(10);
}
```




```
void Pixel::setY(int y)
{
    cout << "Pixel::setY(int y)" << endl;
    d_y = y;
}
```

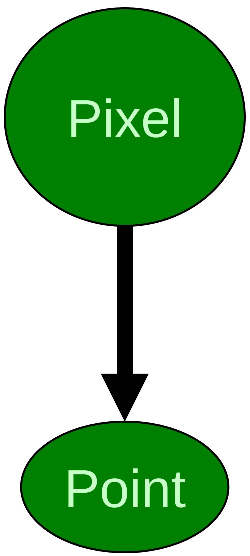
!

```
void Point::setY(int y)
{
    d_y = y;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    static int s_numSetY;
  public:
    // …
};
```

```
void anyProgram(Type *p)
{
     p->setY(10);
}
```



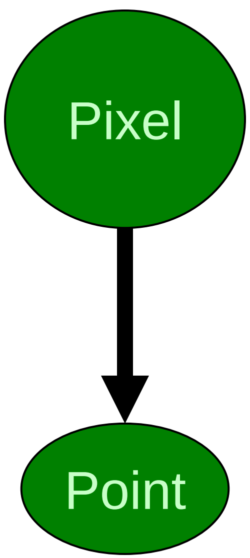

```
void Pixel::setY(int y)
{
     ++s_numSetY; // Pixel class data
     d_y = y;
}
```

```
void Point::setY(int y)
{
    d_y = y;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    static int s_numSetY;
  public:
    // …
};
```

```
void anyProgram(Type *p)
{
     p->setY(10);
     cout <<  p->numSetY() << endl;
}
```

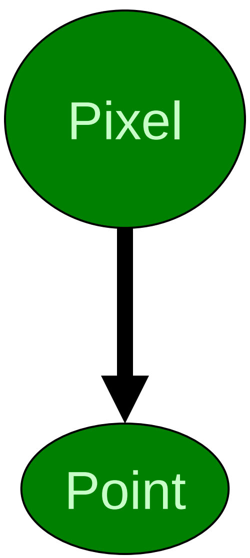



```
void Pixel::setY(int y)
{
     ++s_numSetY; // Pixel class data
     d_y = y;
}
int Pixel::numSetY() { return s_numSetY; }

void Point::setY(int y)
{
    d_y = y;
}
```

4. Proper Inheritance

Pure Structural Inheritance

```
void anyProgram(Type *p)
{
    p->setY(10);
}
```

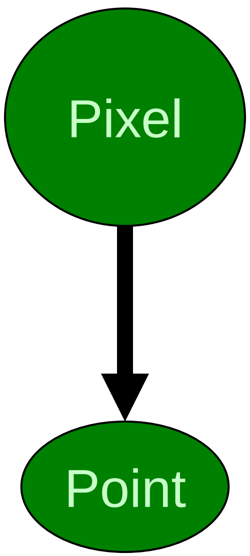



```
void Pixel::setY(int y)
    // Set the y-coordinate of this object to the absolute value of the
    // specified 'y'.  The behavior is undefined unless 'INT_MIN < y'.
{
     d_y =  y < 0 ? -y : y;
}

void Point::setY(int y)
    // Set the y-coordinate of this object to the specified 'y'.
    // The behavior is undefined unless '0 <= y'.
{
    d_y = y;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```



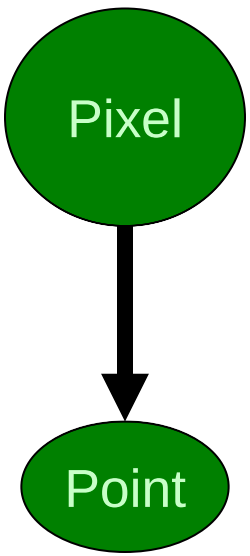

```
const Pixel& Pixel::self() const
{
    return *this;
}
```

```
const Point& Point::self() const
{
    return *this;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > sizeof(Point)) ?
        cout << "It's not a Point!" << endl;
}
```




```
const Pixel& Pixel::self() const
{
    return *this;
}
```

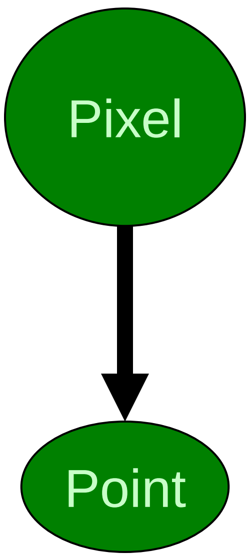
```
const Point& Point::self() const
{
    return *this;
}
```

4. Proper Inheritance

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > 8) // sizeof(Point)
        cout << "It's not a Point!" << endl;
}
```




```
const Pixel& Pixel::self() const
{
    return *this;
}
```

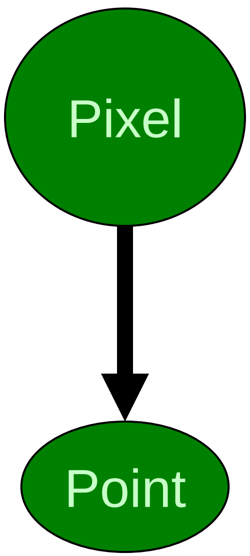
```
const Point& Point::self() const
{
    return *this;
}
```

4. Proper Inheritance

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > 8) // sizeof(Point)
        cout << "It's not a Point!" << endl;
}
```



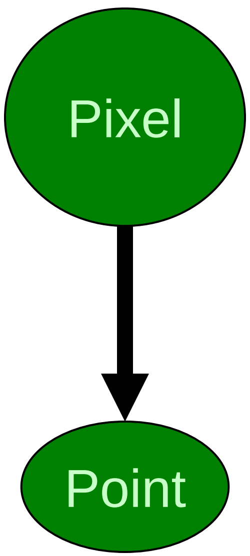

```
const Pixel& Pixel::self() const
{
    return *this;
}
```

```
const Point& Point::self() const
{
    return *this;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > 8) // sizeof(Point)
        cout << "It's not a point!" << endl;
}
```



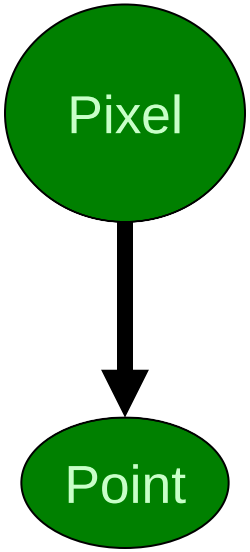

```
const Pixel& Pixel::self() const
{
    return *this;
}
```

```
const Point& Point::self() const
{
    return *this;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```



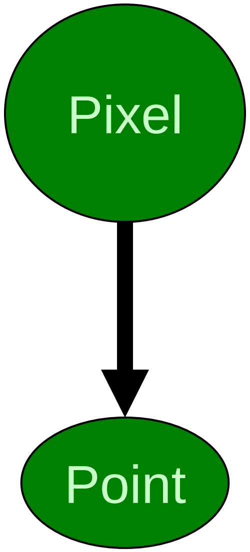

```
const Pixel& Pixel::self() const
{
    return *this;
}
```

```
const Point& Point::self() const
{
    return *this;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof p->self() > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```




```
const Pixel& Pixel::self() const
{
    return *this;
}
```

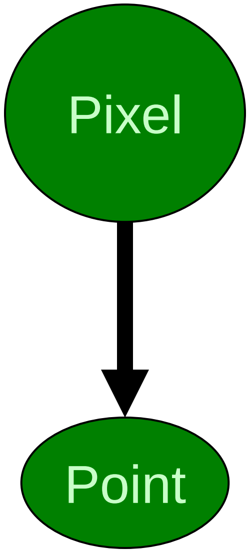
!

```
const Point& Point::self() const
{
    return *this;
}
```

Pure Structural Inheritance

```
class Pixel : public Point {
    // …
    Color d_color;
    // …
};
```

```
void anyProgram(Type *p)
{
    if (sizeof *p > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```

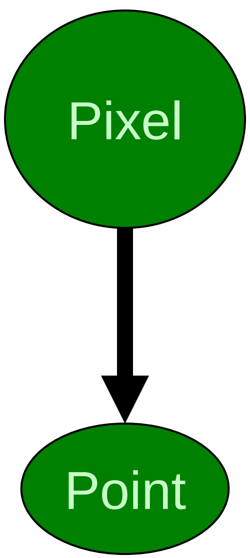


Pure Structural Inheritance

```
class Pixel : public Point {
    // ...
    Color d_color;
    // ...
};
```

!

```
void anyProgram(Type *p)
{
    if (sizeof *p > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```

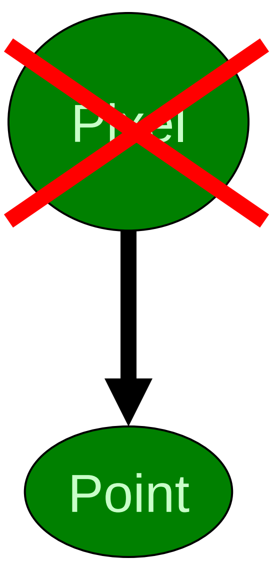


Pure Structural Inheritance

```
class Pixel : public Point {
    // ...
    Color d_color;
    // ...
};
```

!

```
void anyProgram(Type *p)
{
    if (sizeof *p > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```

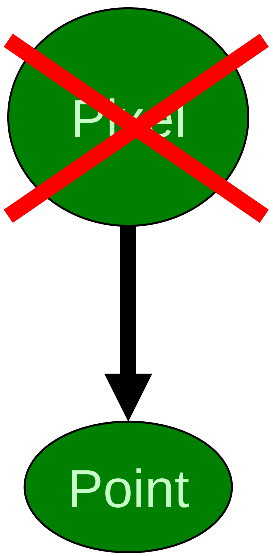


Pure Structural Inheritance

```
class Pixel : public Point {
    // ...
    Color d_color;
    // ...
};
```

!

```
void anyProgram(Type *p)
{
    if (sizeof *p > sizeof(Point))
        cout << "It's not a Point!" << endl;
}
```



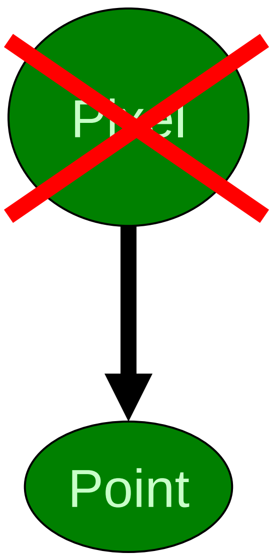
Proper ***Structural*** Inheritance *extends functionality*, but does **not** extend the object's footprint.

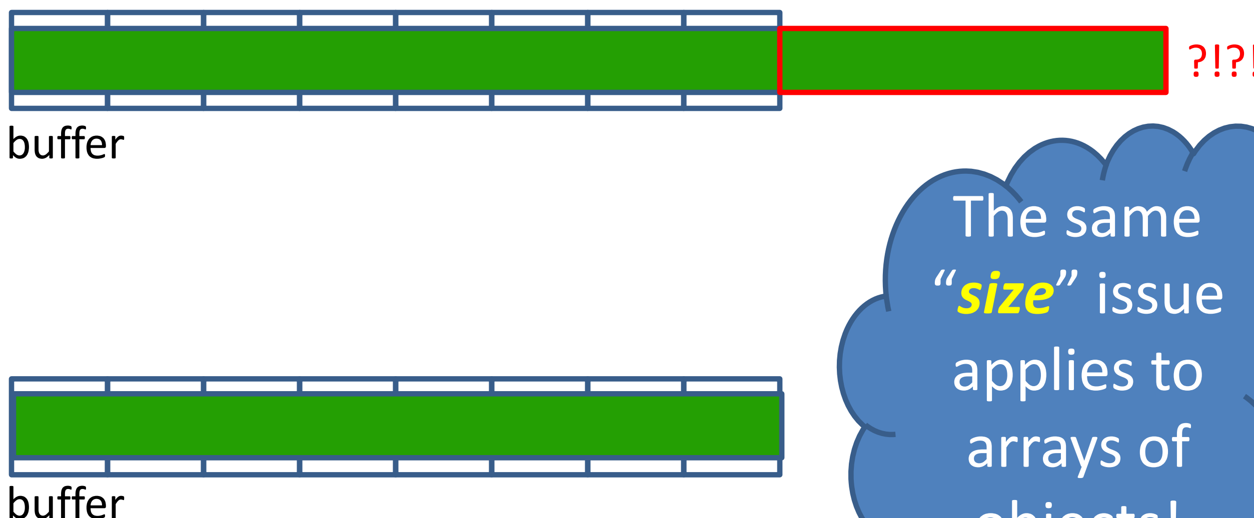
Pure Structural Inheritance

```
class Pixel : public Point {
    // ...
    Color d_color;
    // ...
};
```

!

```
void anyProgram(Type *p)
{
    double alignmentHack;  // Don't do it!
    char buffer[sizeof(Point)];
    (Type *)&buffer = *p;
}
```

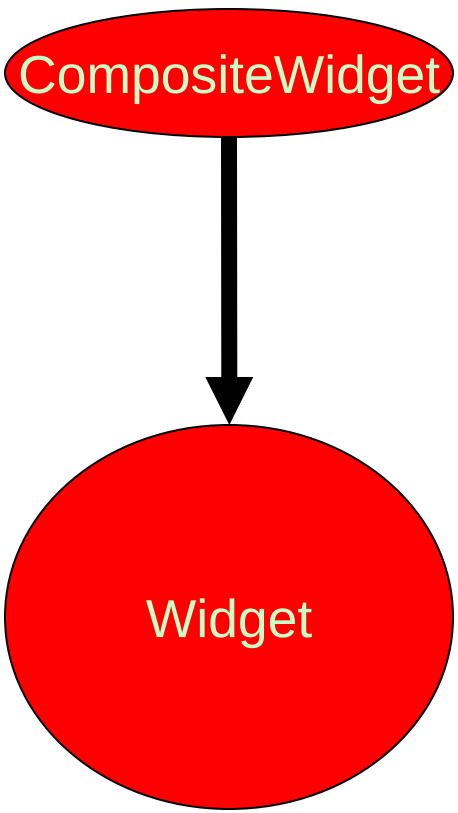




The same "***size***" issue applies to arrays of objects!

4. Proper Inheritance

Implementation Inheritance



Implementation hierarchies are *highly problematic!*

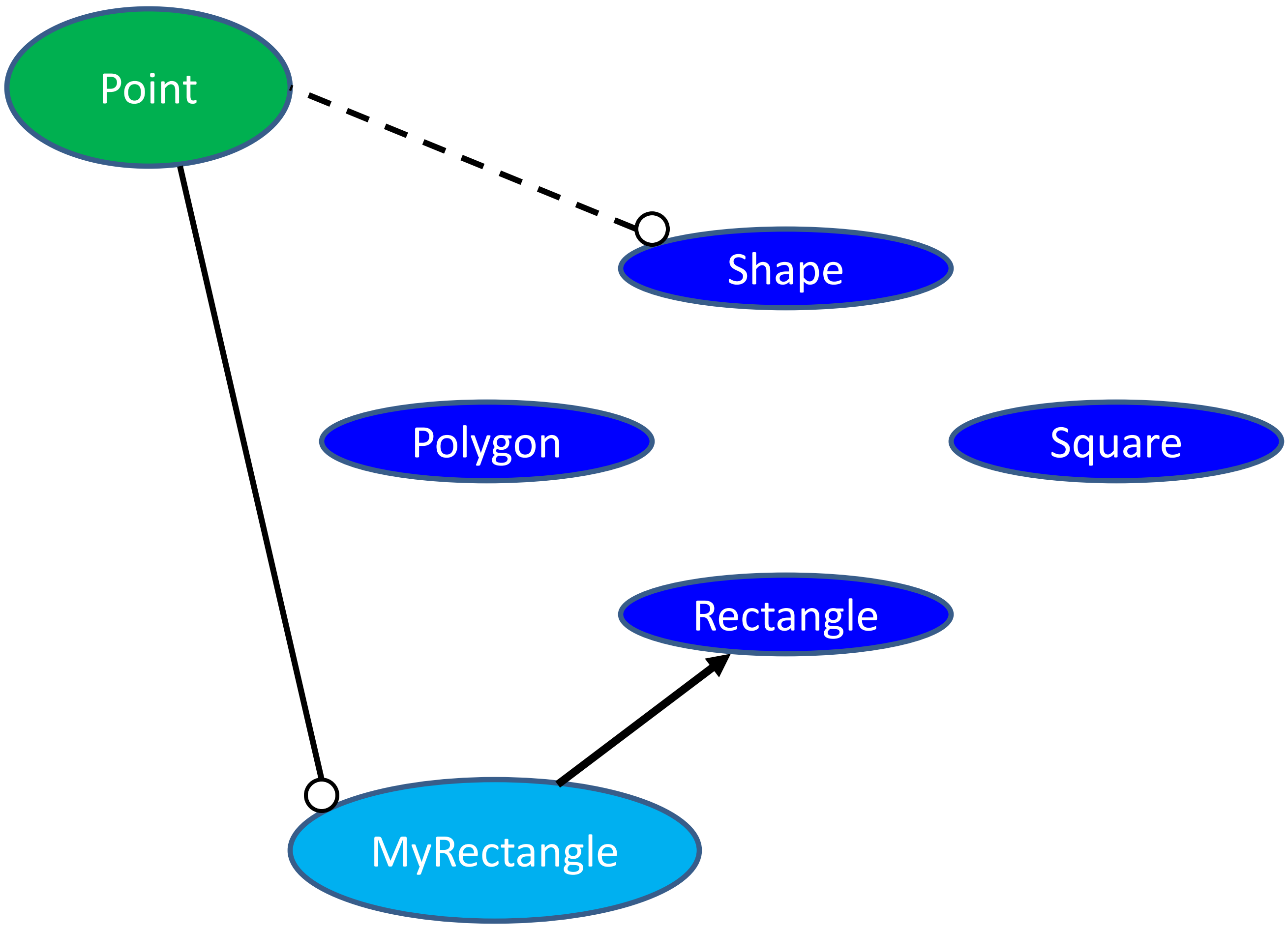
Incorporating implementation with interface inheritance:

- Makes software brittle, inflexible, and hard to maintain.
- Exposes public clients to physical (compile- and link-time) dependencies on the shared implementation.
- Adds nothing that cannot be done with pure interface inheritance and layering.

Its *only* value is as a syntactic expedient!

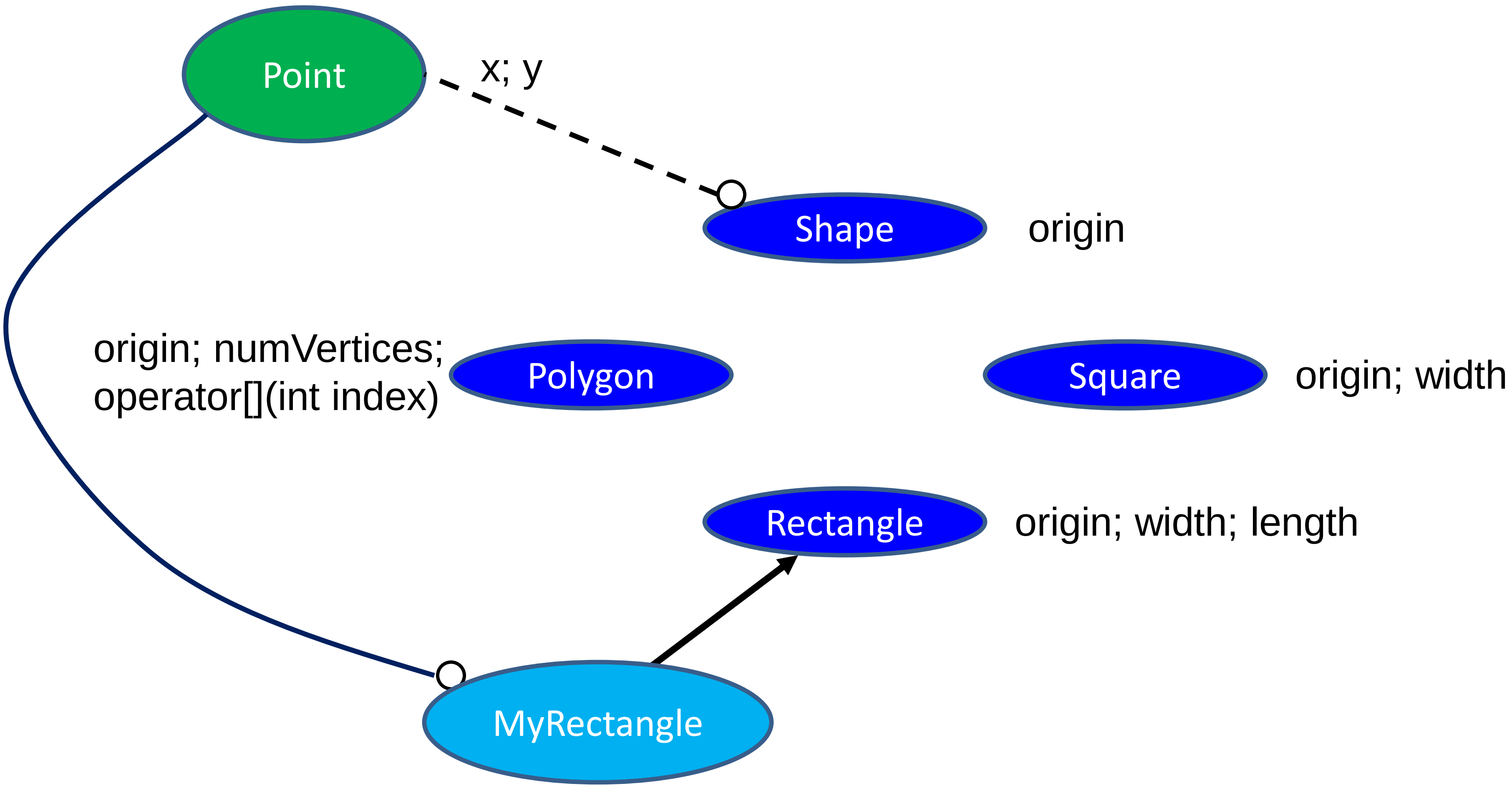
4. Proper Inheritance

Using Interface Inheritance Effectively

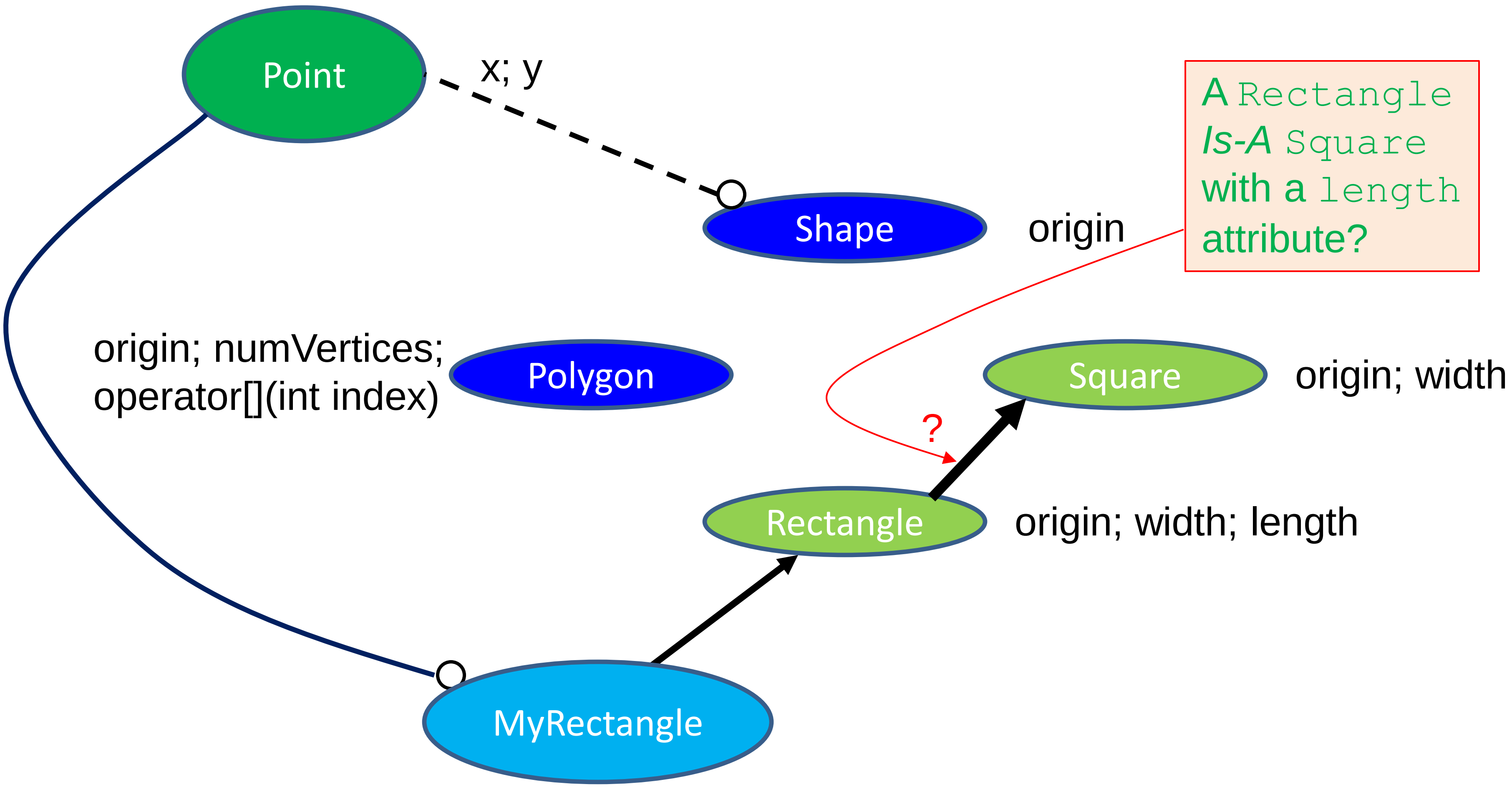


4. Proper Inheritance

Using Interface Inheritance Effectively

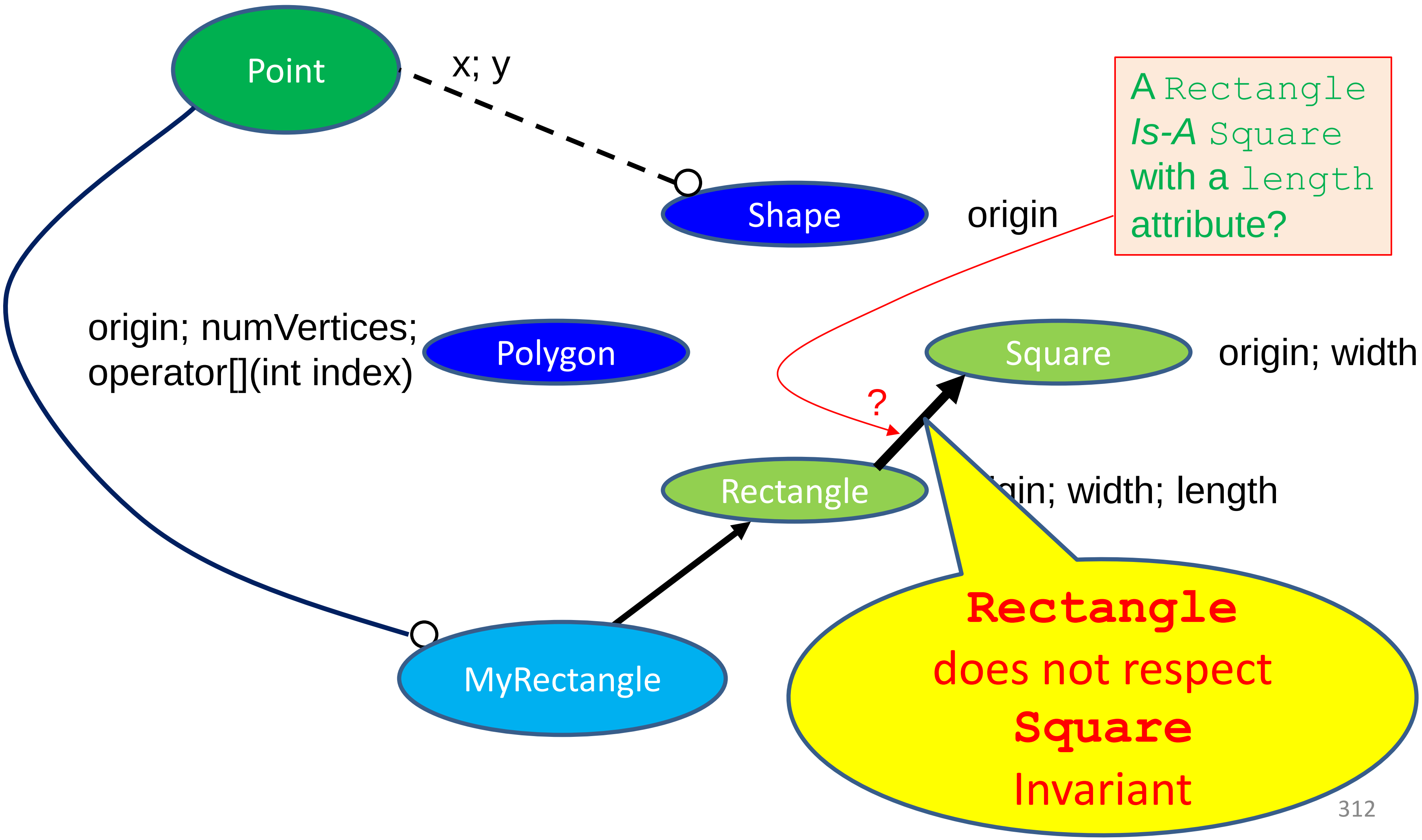


Using Interface Inheritance Effectively

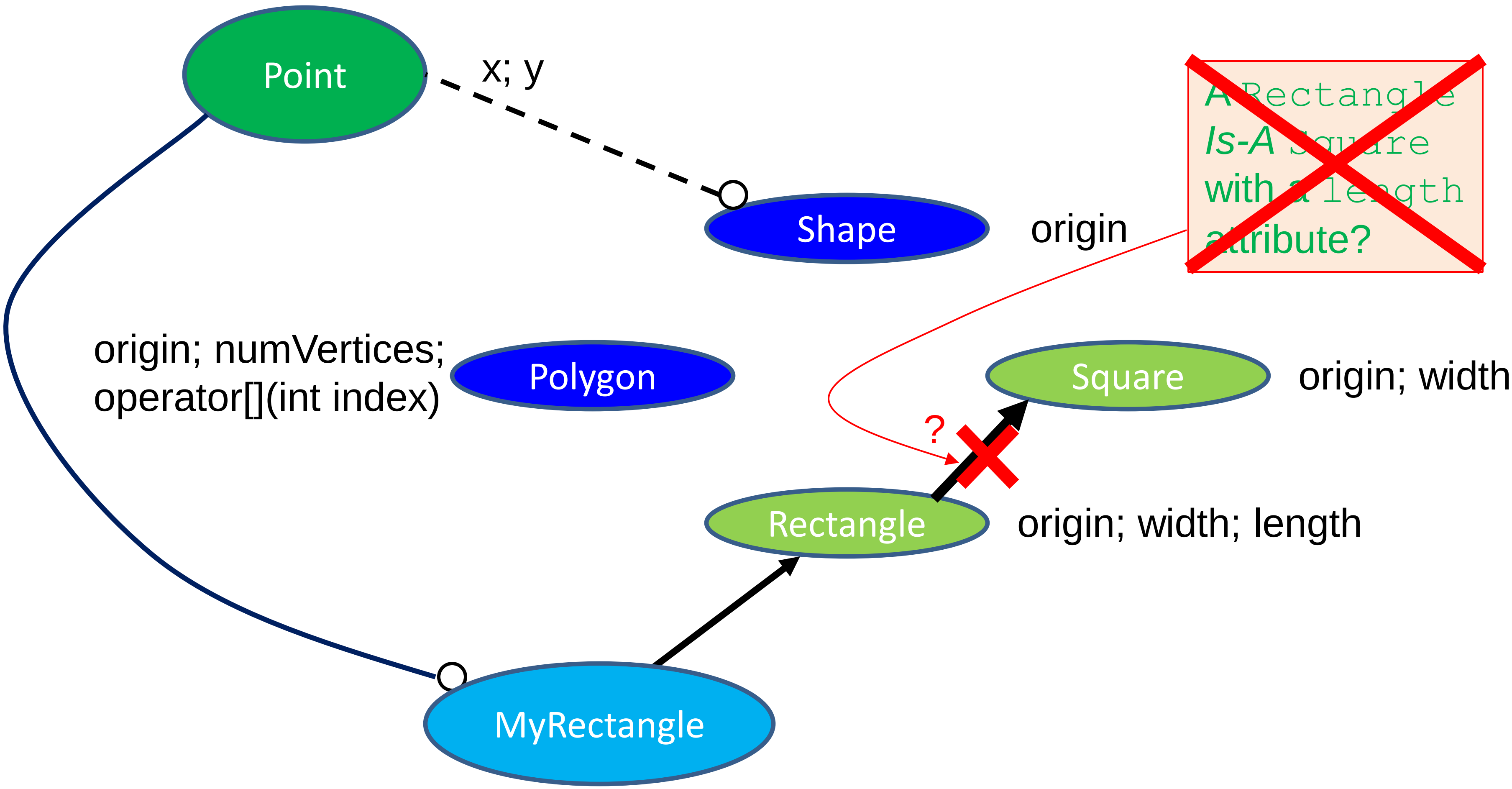


4. Proper Inheritance

Using Interface Inheritance Effectively

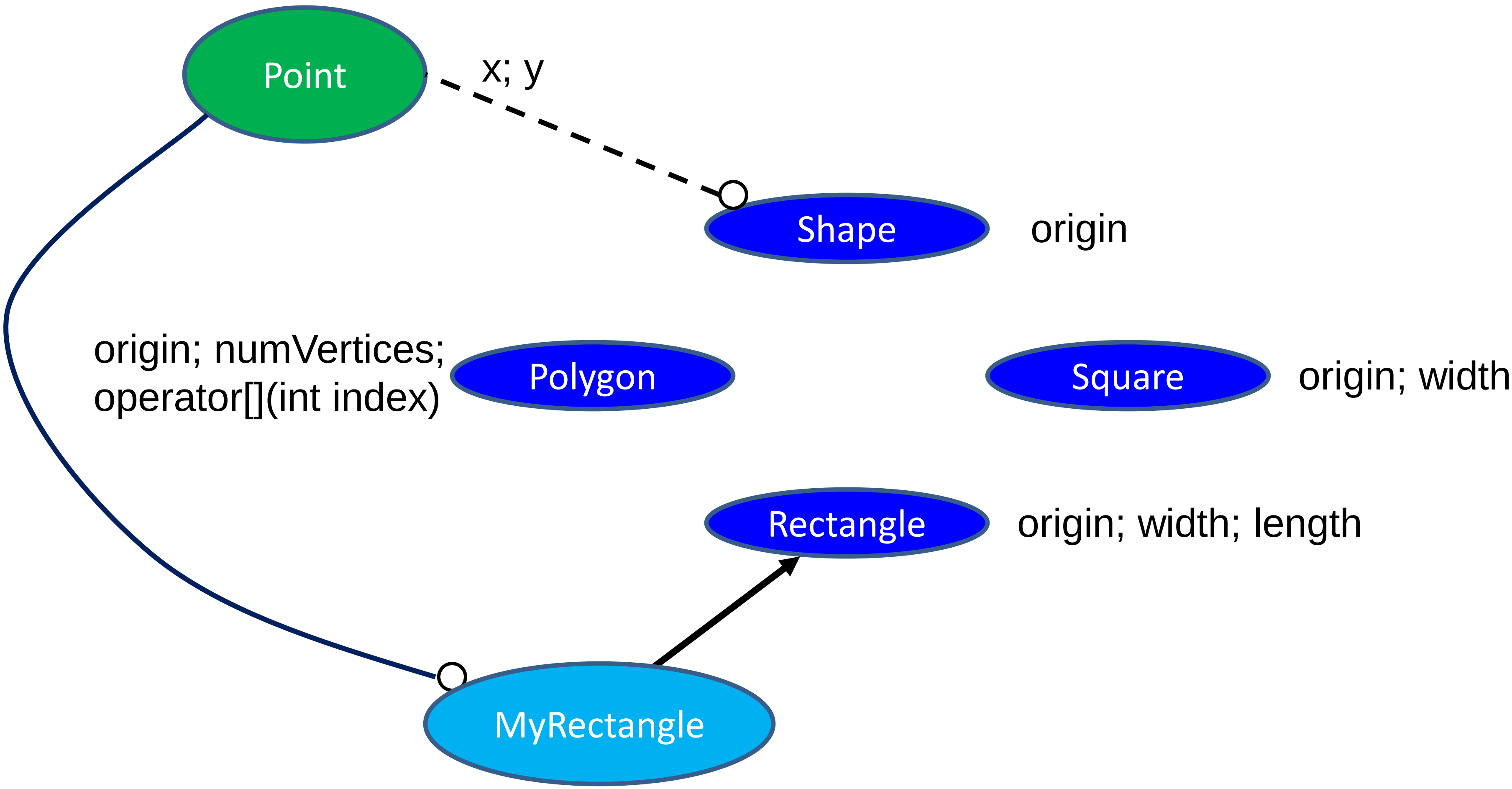


Using Interface Inheritance Effectively



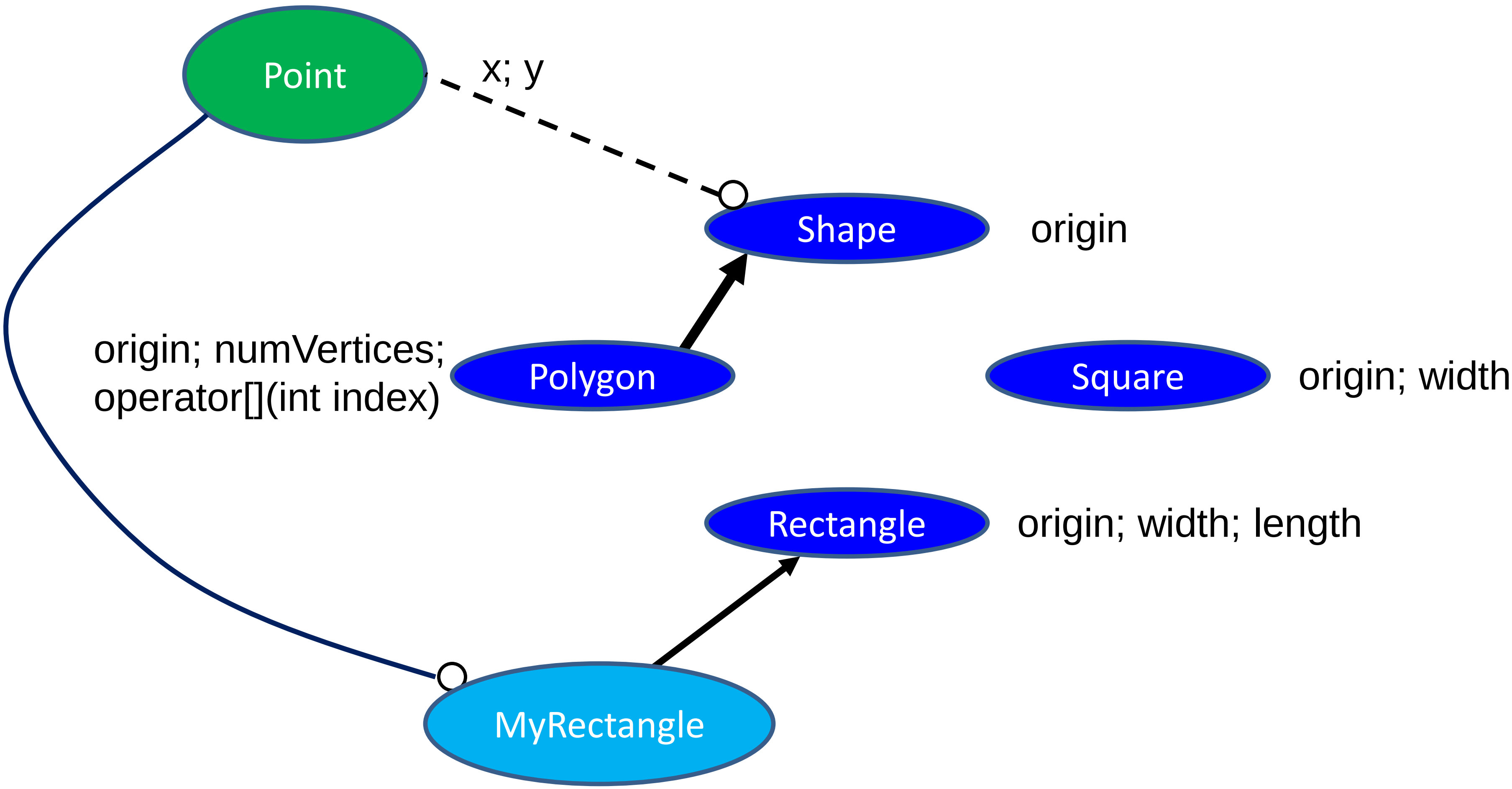
4. Proper Inheritance

Using Interface Inheritance Effectively

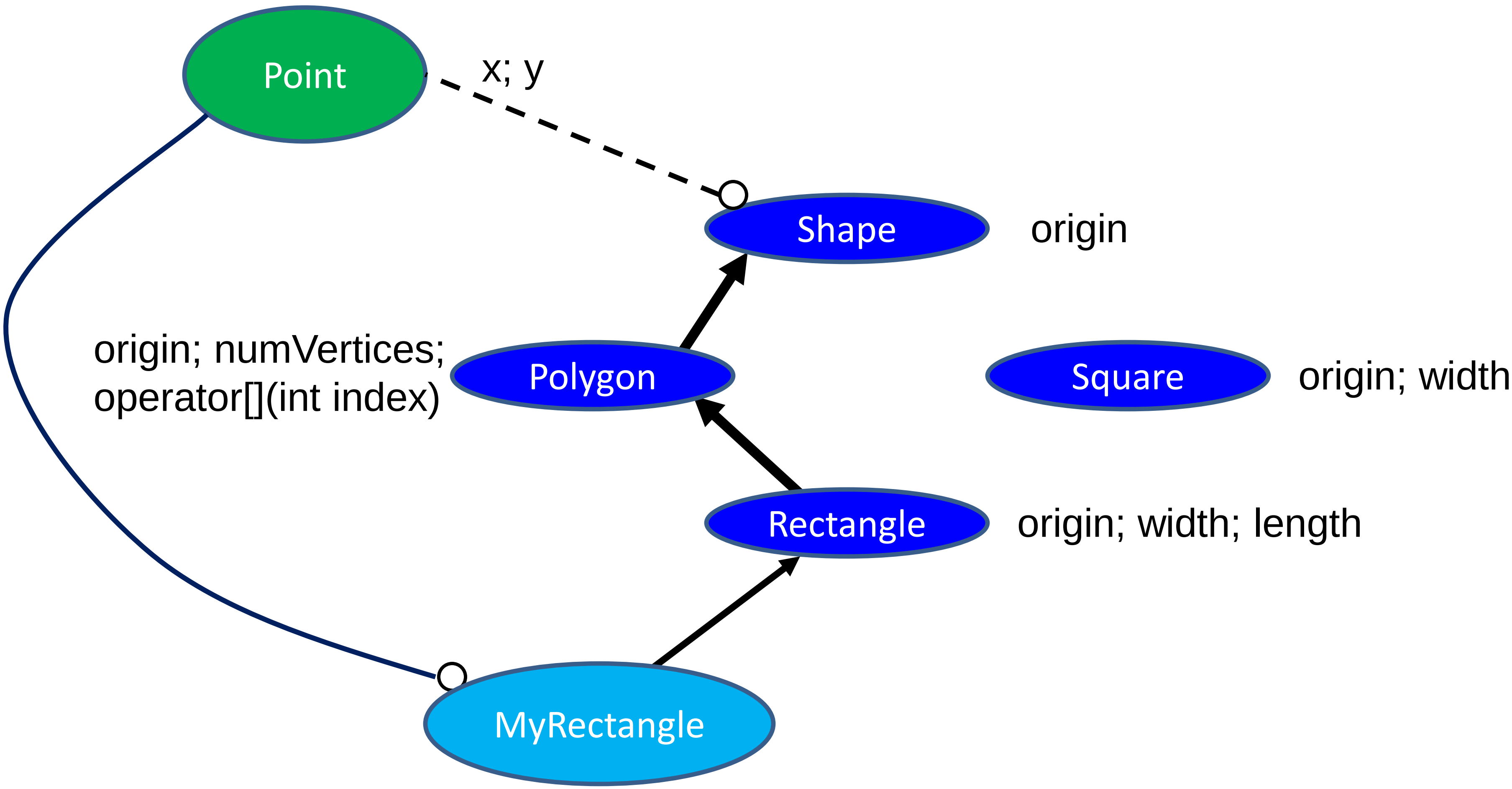


4. Proper Inheritance

Using Interface Inheritance Effectively

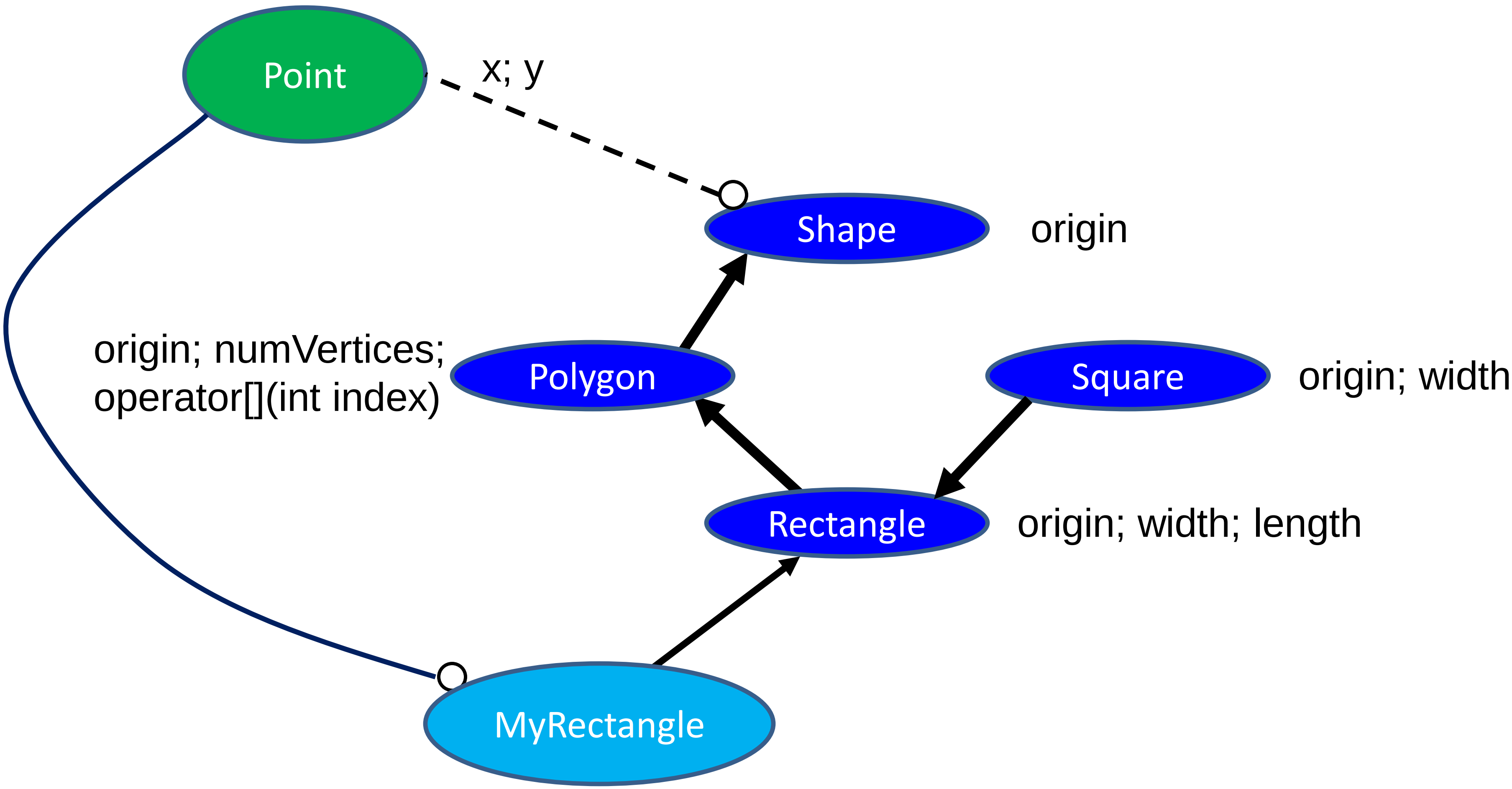


Using Interface Inheritance Effectively

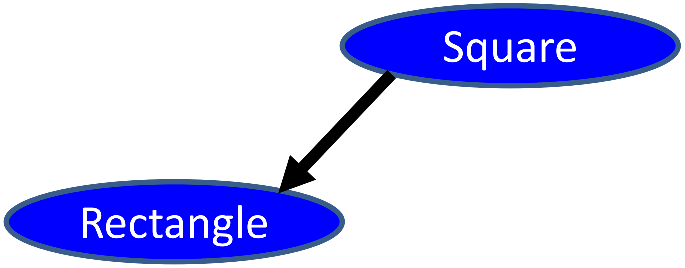


4. Proper Inheritance

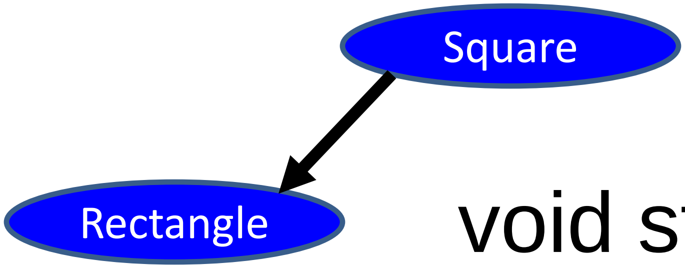
Using Interface Inheritance Effectively



Using Interface Inheritance Effectively

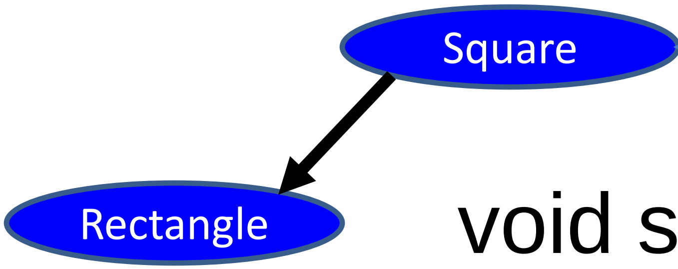


Using Interface Inheritance Effectively



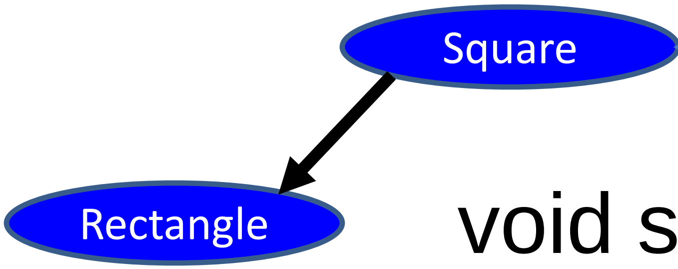

```
void stretchBy1(Rectangle *r)
{



}
```

Using Interface Inheritance Effectively



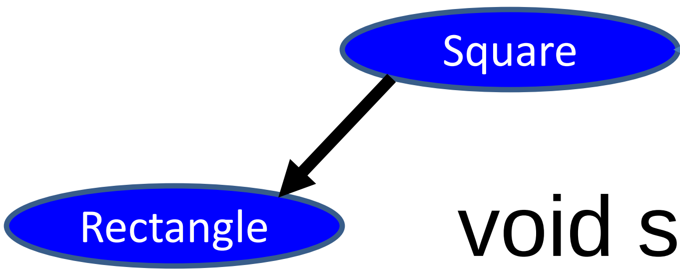

```
void stretchBy1(Rectangle *r)
{



}
```

Using Interface Inheritance Effectively



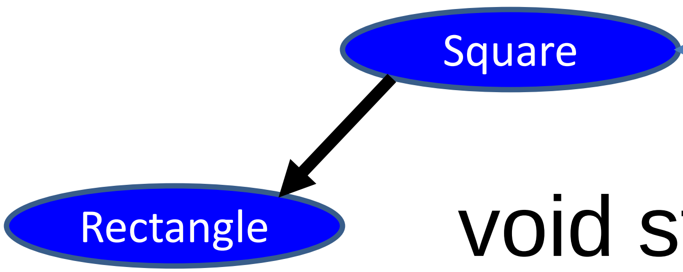

```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();



}
```

Using Interface Inheritance Effectively




```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();



}
```

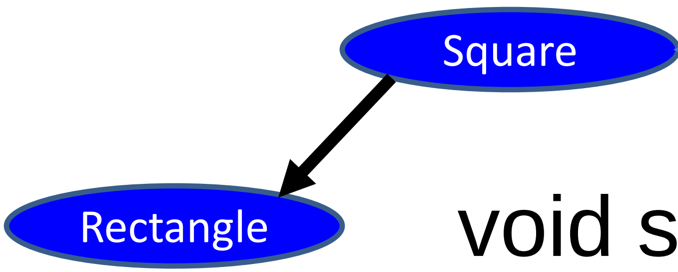
Using Interface Inheritance Effectively




```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();
    r->setLength(len + 1);


}
```

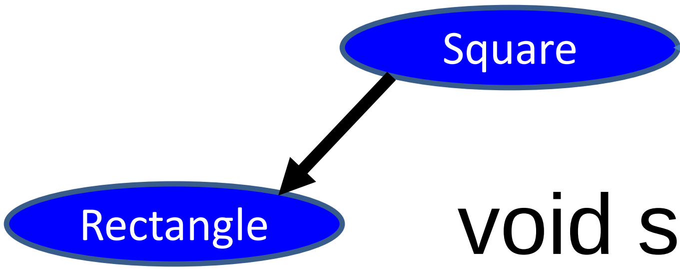
4. Proper Inheritance

Using Interface Inheritance Effectively



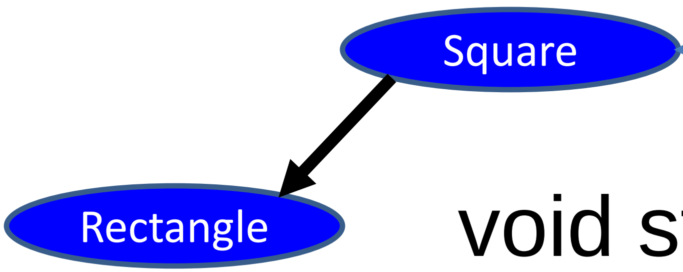

```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();
    r->setLength(len + 1);
    assert(wid      == r->width());

}
```

Using Interface Inheritance Effectively




```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();
    r->setLength(len + 1);
    assert(wid     == r->width());
    assert(len + 1 == r->length());
}
```

Using Interface Inheritance Effectively

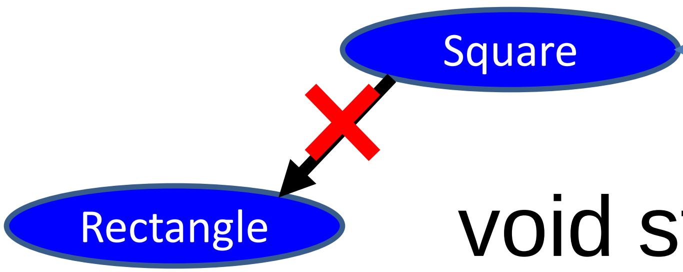



```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();
    r->setLength(len + 1);
    assert(wid      == r->width());
    assert(len + 1 == r->length());
}
```

Either **Assert** or **No Longer Square**

4. Proper Inheritance

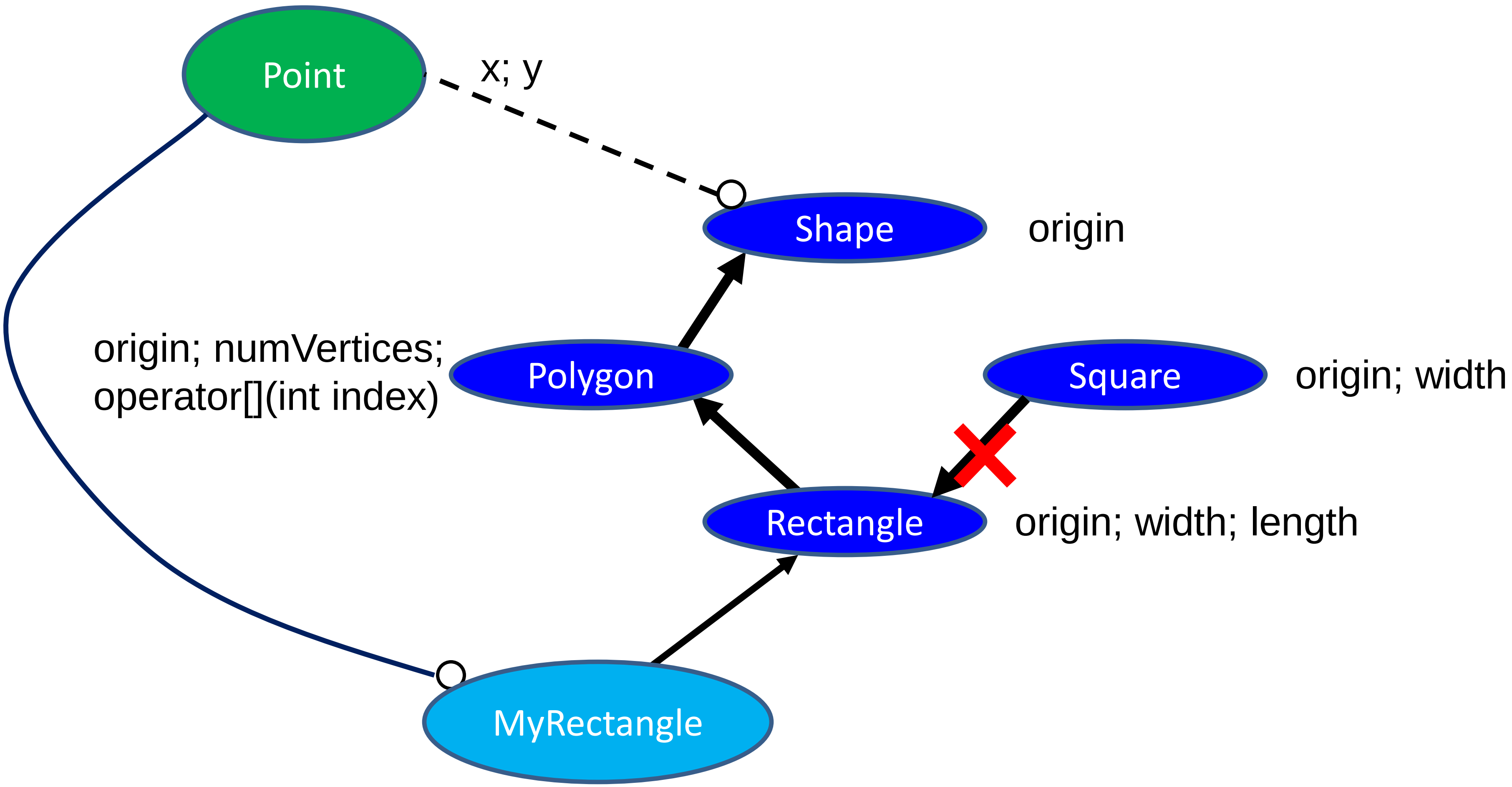
Using Interface Inheritance Effectively




```
void stretchBy1(Rectangle *r)
{
    int wid = r->width();
    int len = r->length();
    r->setLength(len + 1);
    assert(wid     == r->width());
    assert(len + 1 == r->length());
}
```

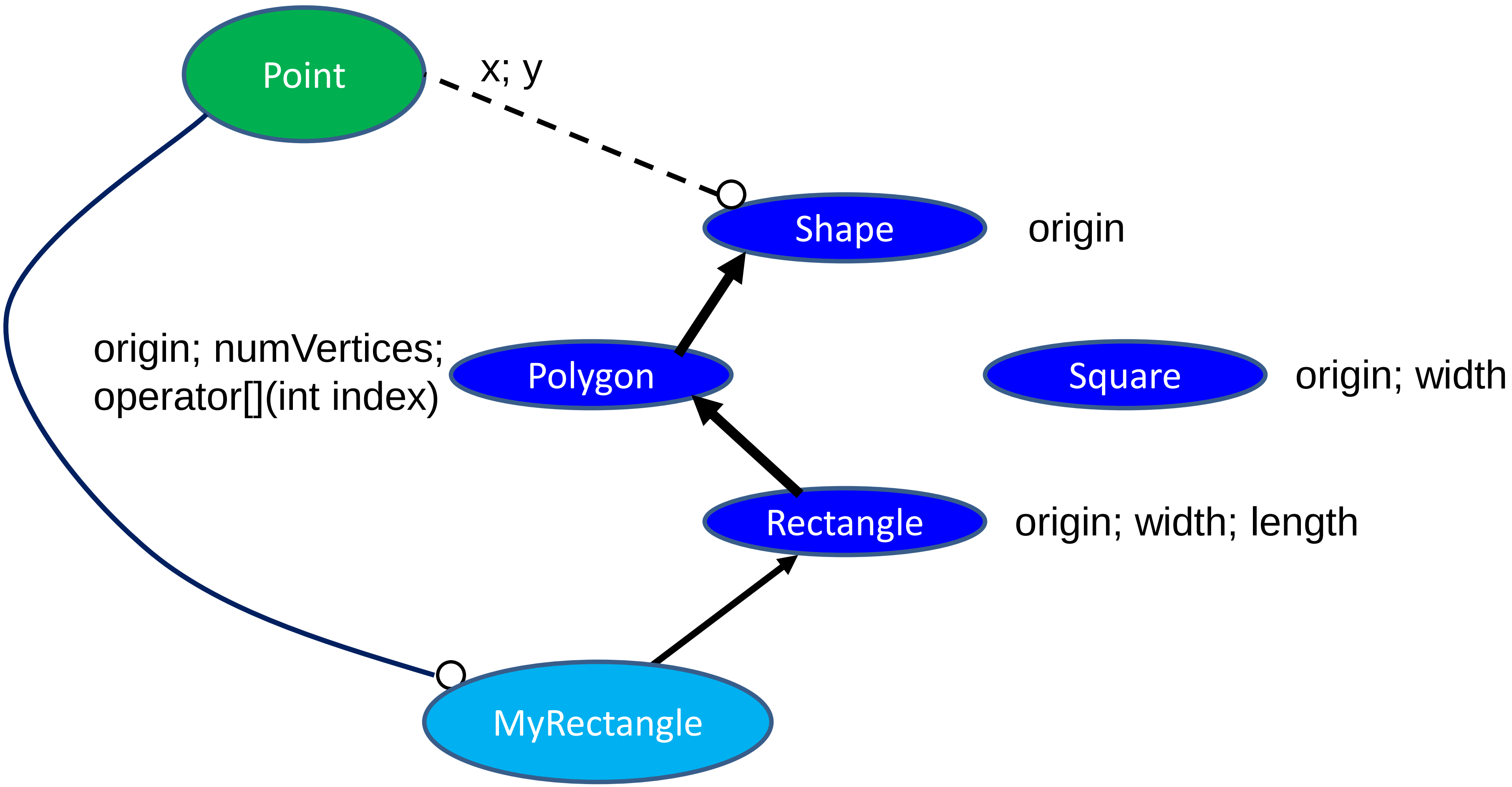
Either **Assert** or **No Longer Square**

Using Interface Inheritance Effectively



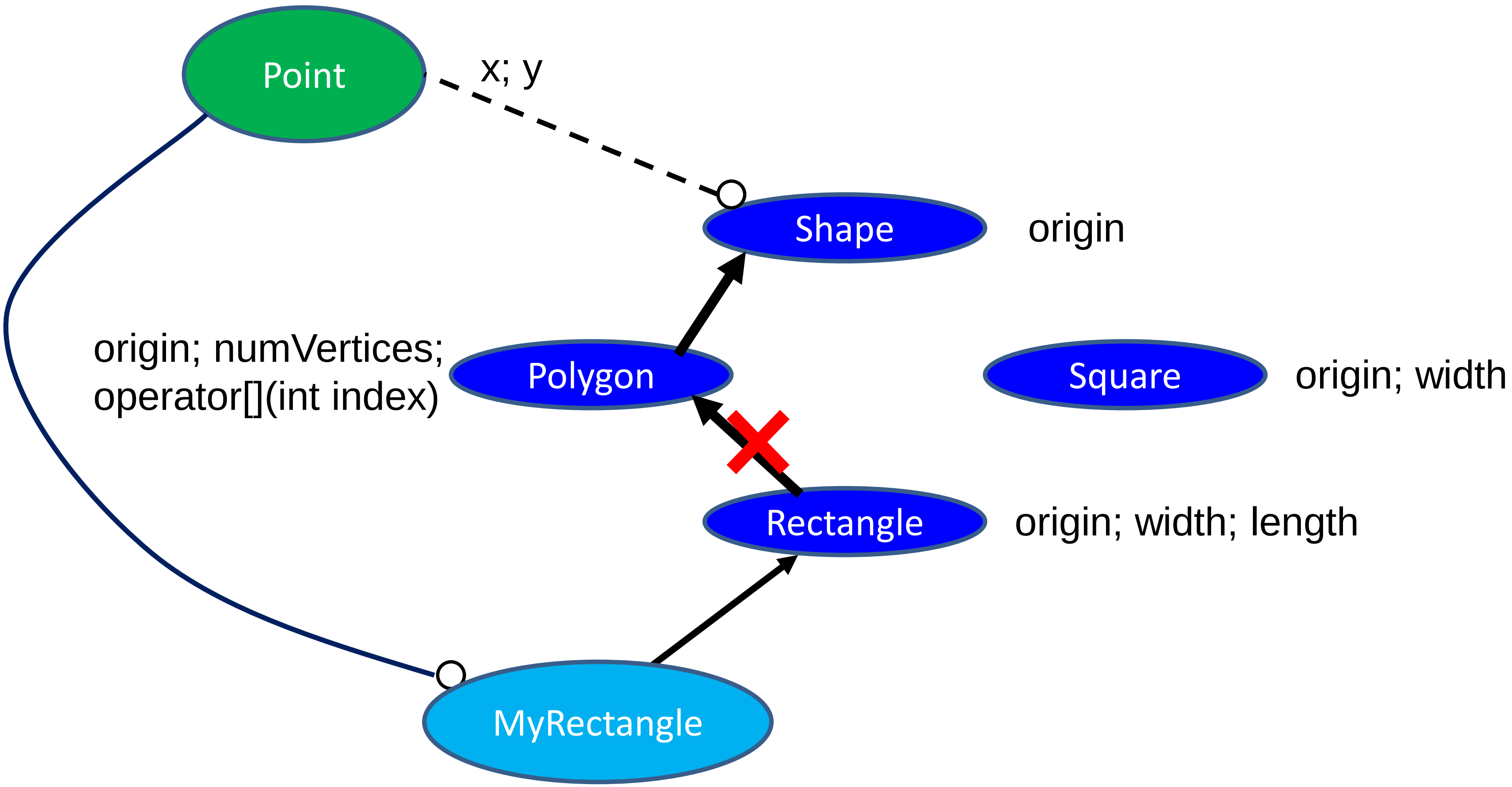
4. Proper Inheritance

Using Interface Inheritance Effectively

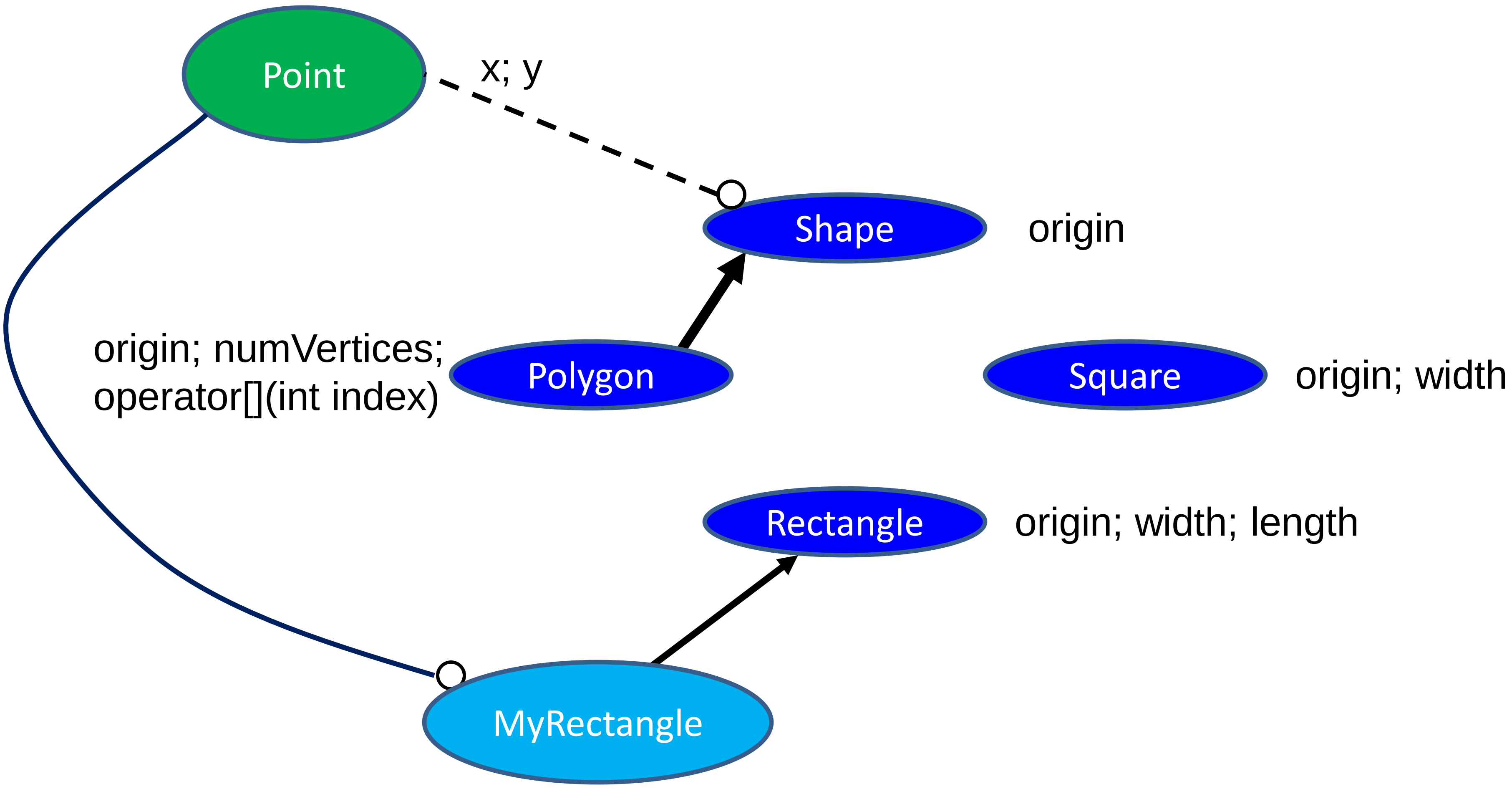


4. Proper Inheritance

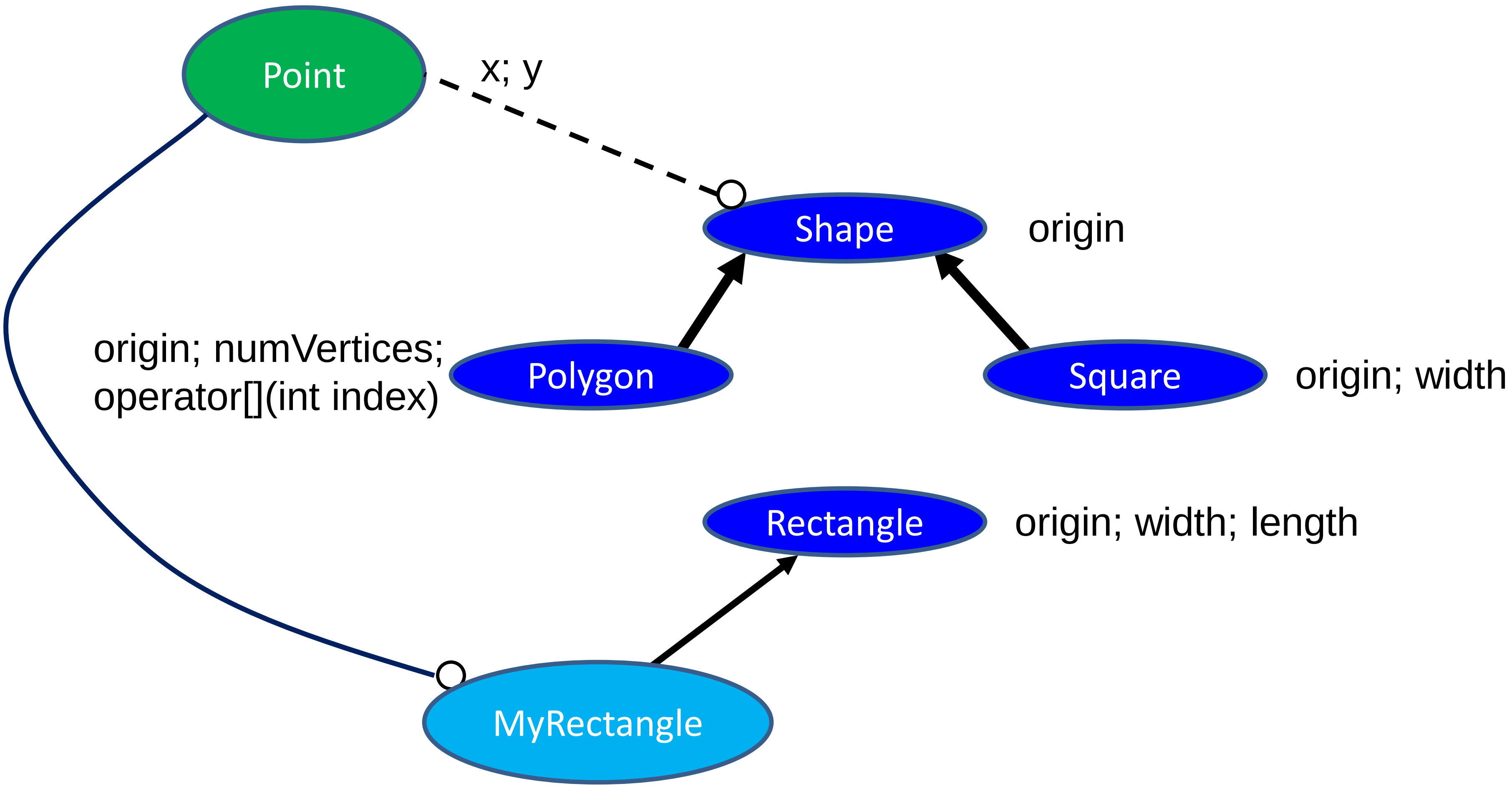
Using Interface Inheritance Effectively



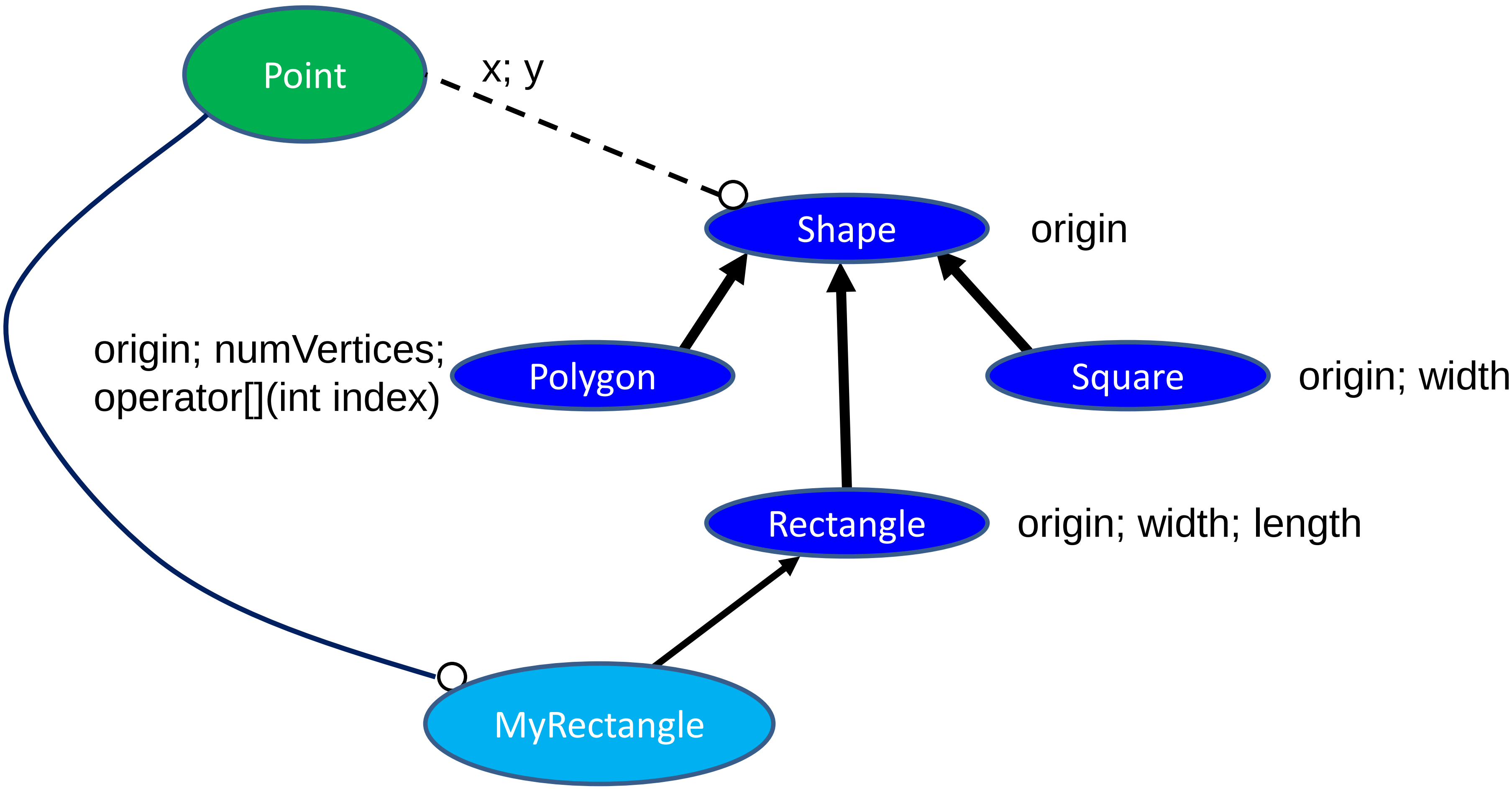
Using Interface Inheritance Effectively



Using Interface Inheritance Effectively



Using Interface Inheritance Effectively



4. Proper Inheritance

Using Interface Inheritance Effectively

TheirPolygon()

(Concrete)
TheirPolygon

YourSquare()

(Concrete)
YourSquare

MyRectangle()

(Concrete)
MyRectangle

void setSide(int side)

(Modifiable)
Square

ConstSquare

int side() const

void setWidth(int width)
void setLength(int length)

(Modifiable)
Rectangle

ConstRectangle

int width() const
int length() const

void appendVertex(const Point& v)
void removeVertex(int i)

(Modifiable)
Polygon

ConstPolygon

Point vertex(int i) const
int numVertices() const

void setOrigin(const Point& v);

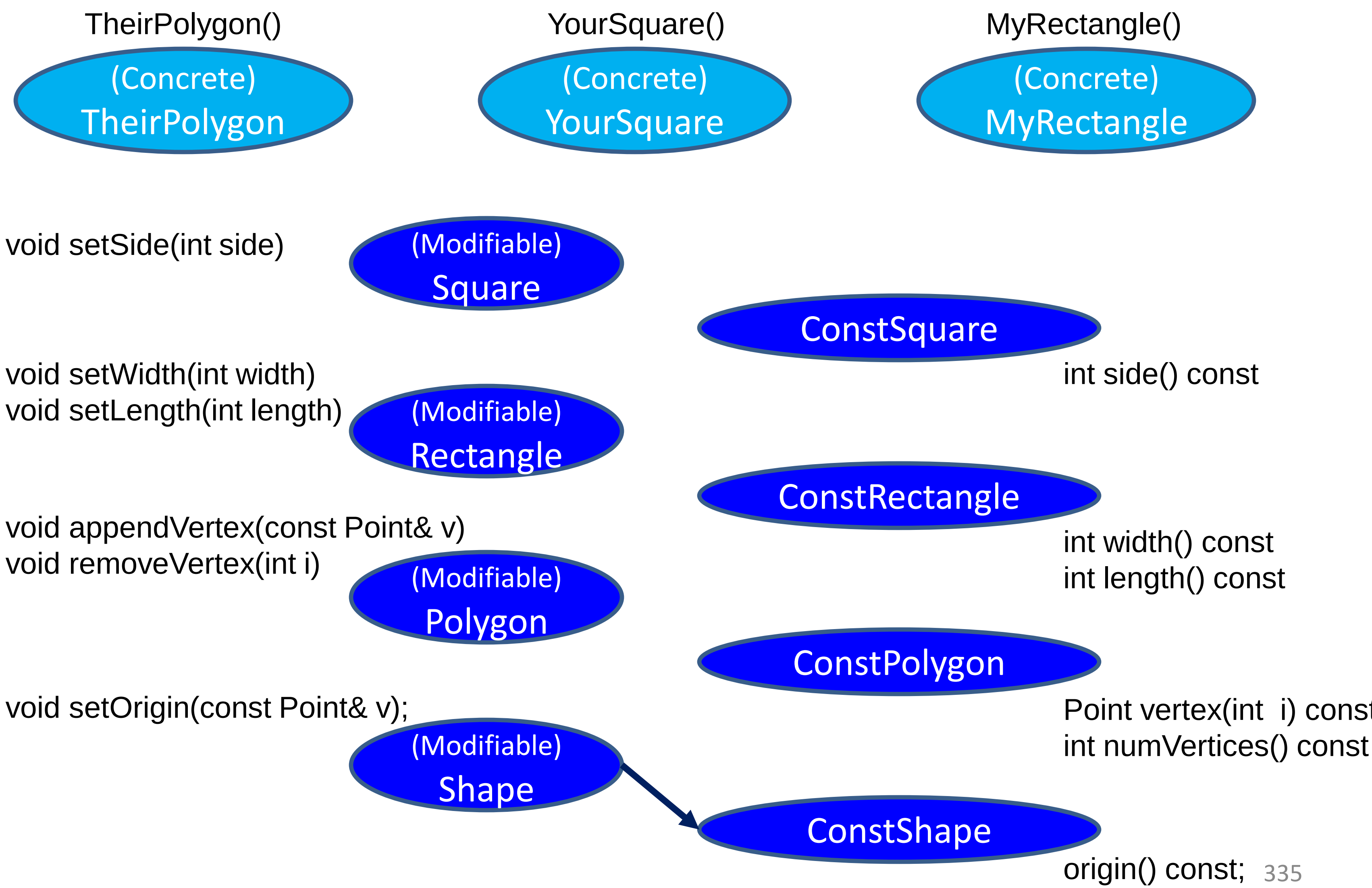
(Modifiable)
Shape

ConstShape

origin() const;

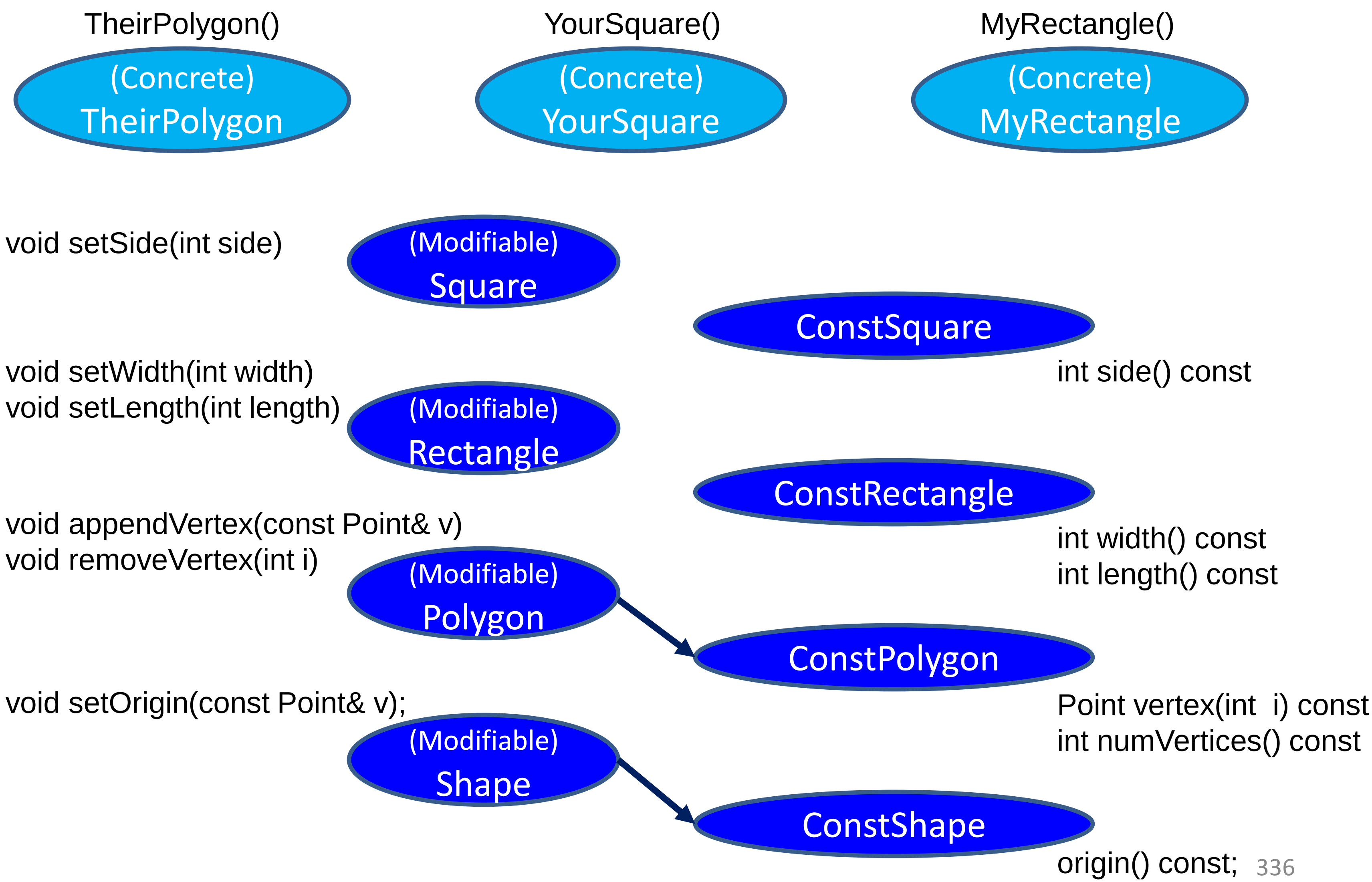
4. Proper Inheritance

Using Interface Inheritance Effectively



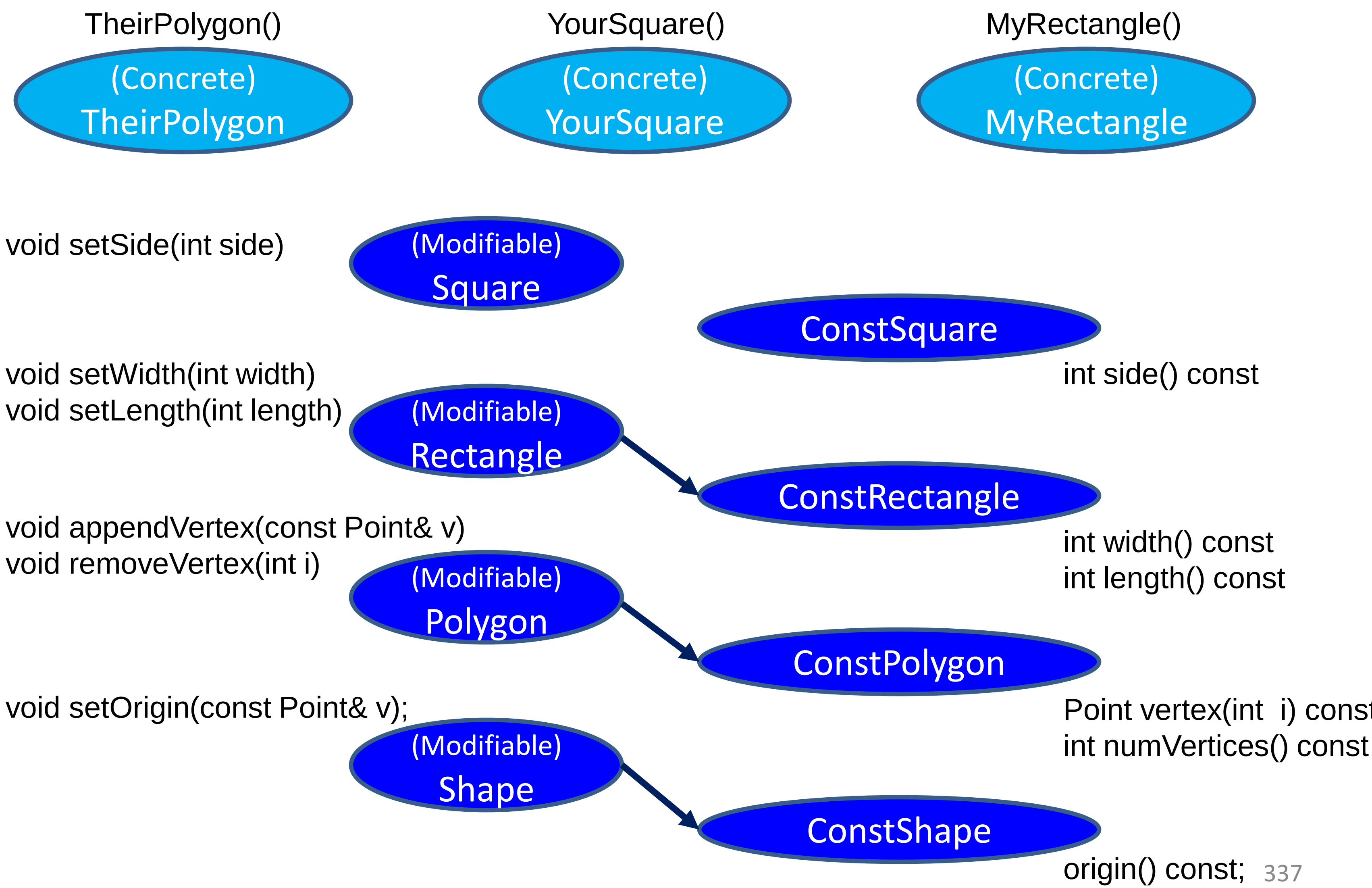
4. Proper Inheritance

Using Interface Inheritance Effectively



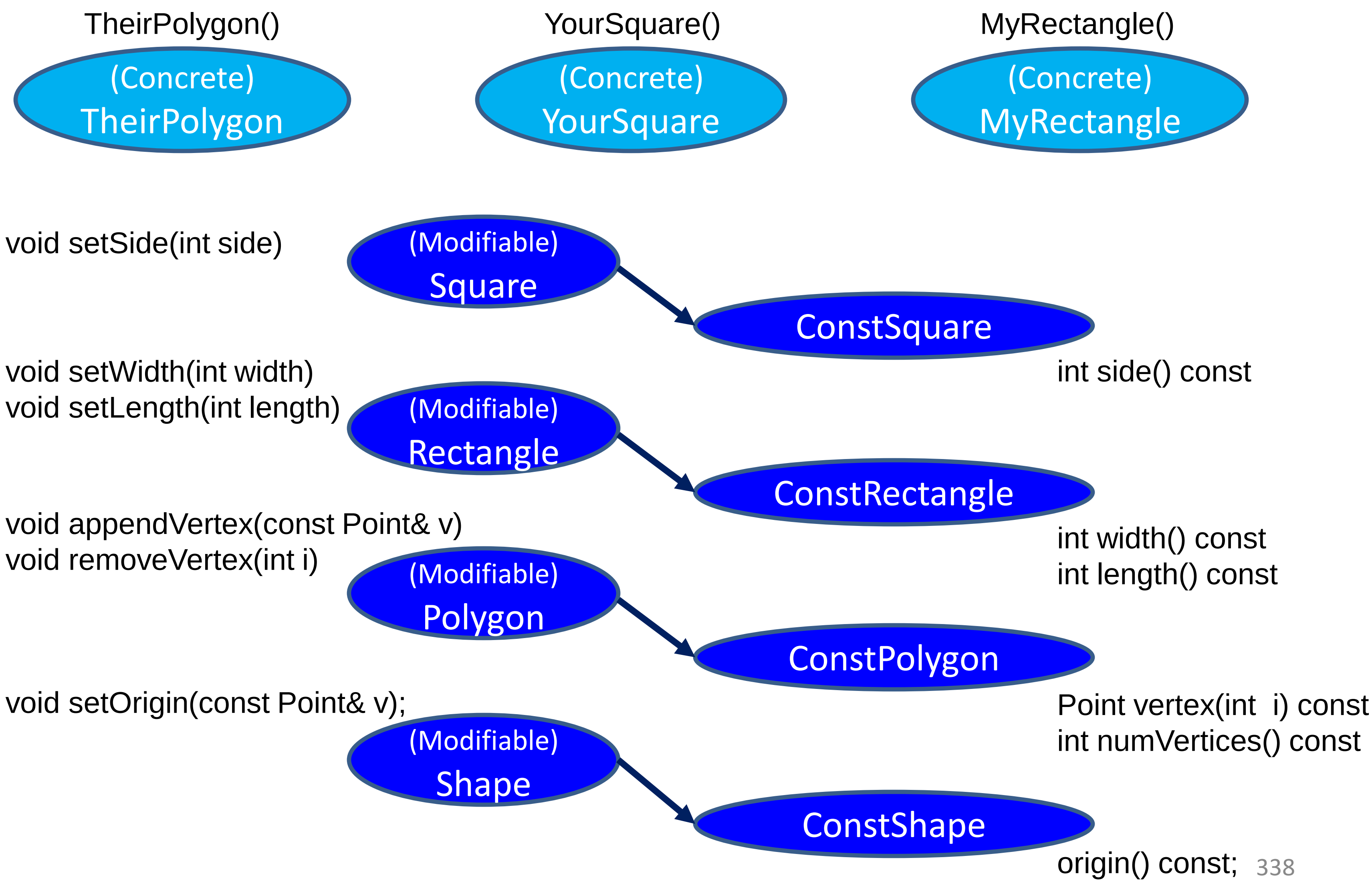
4. Proper Inheritance

Using Interface Inheritance Effectively



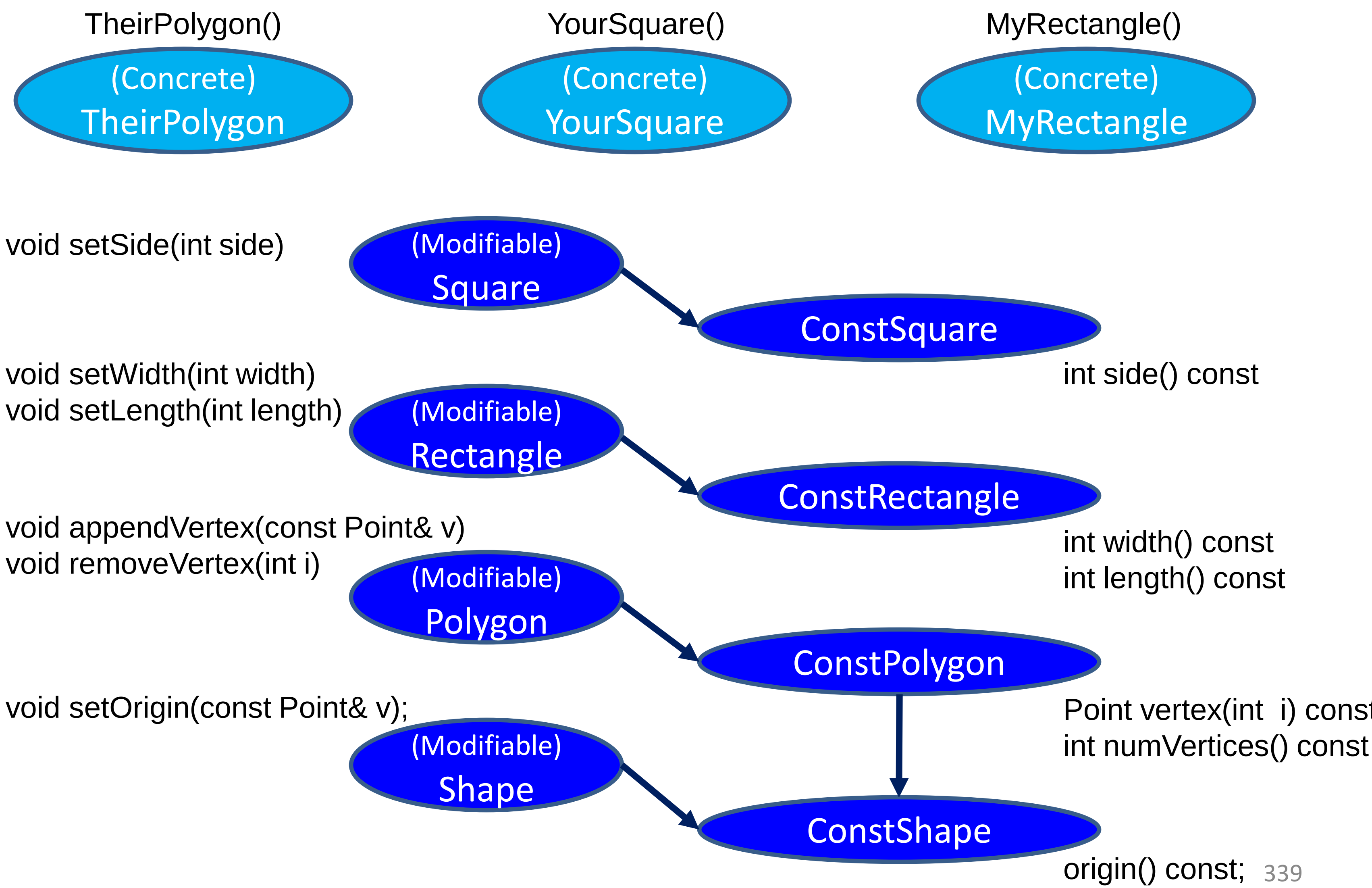
4. Proper Inheritance

Using Interface Inheritance Effectively

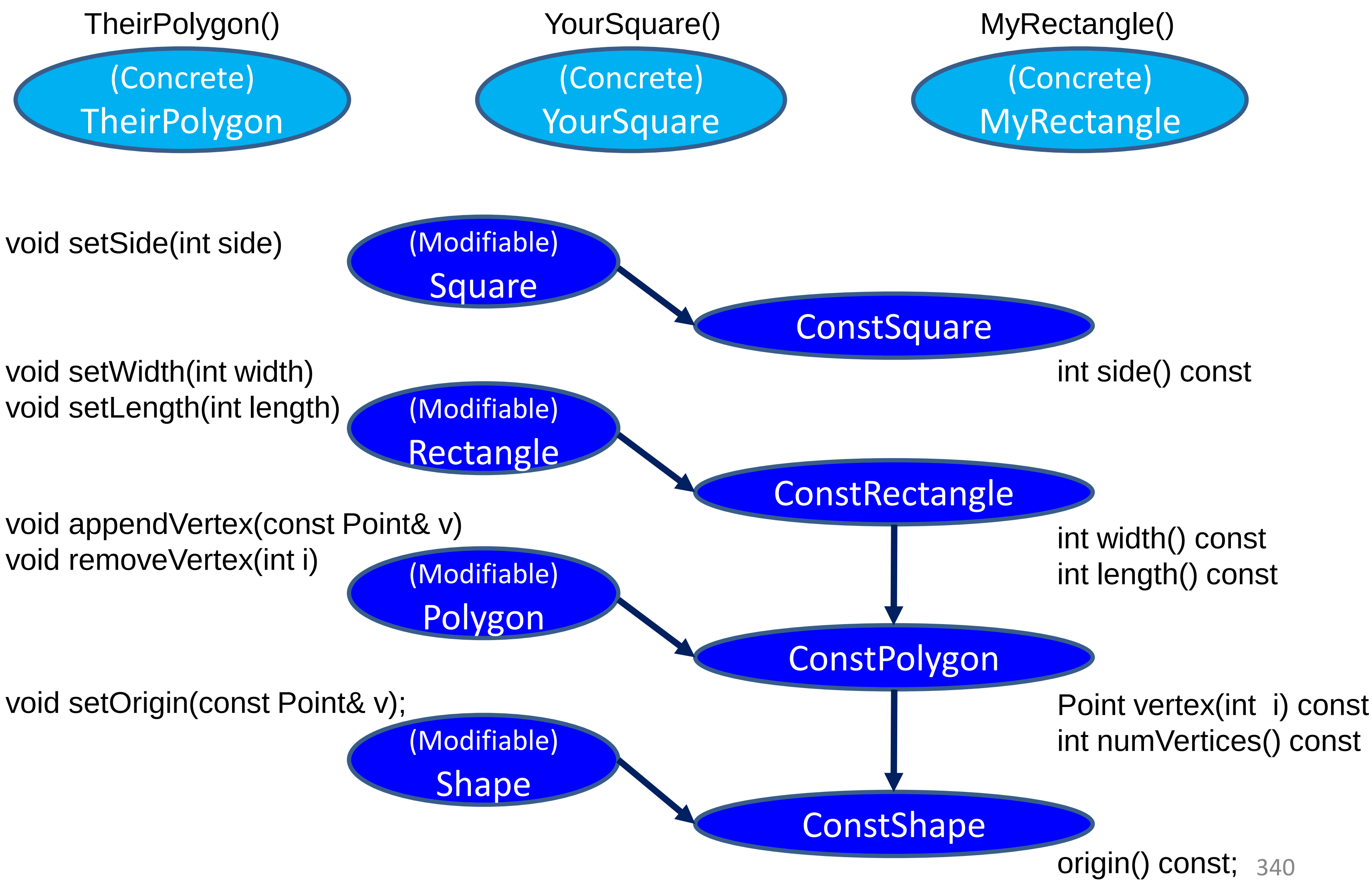


4. Proper Inheritance

Using Interface Inheritance Effectively

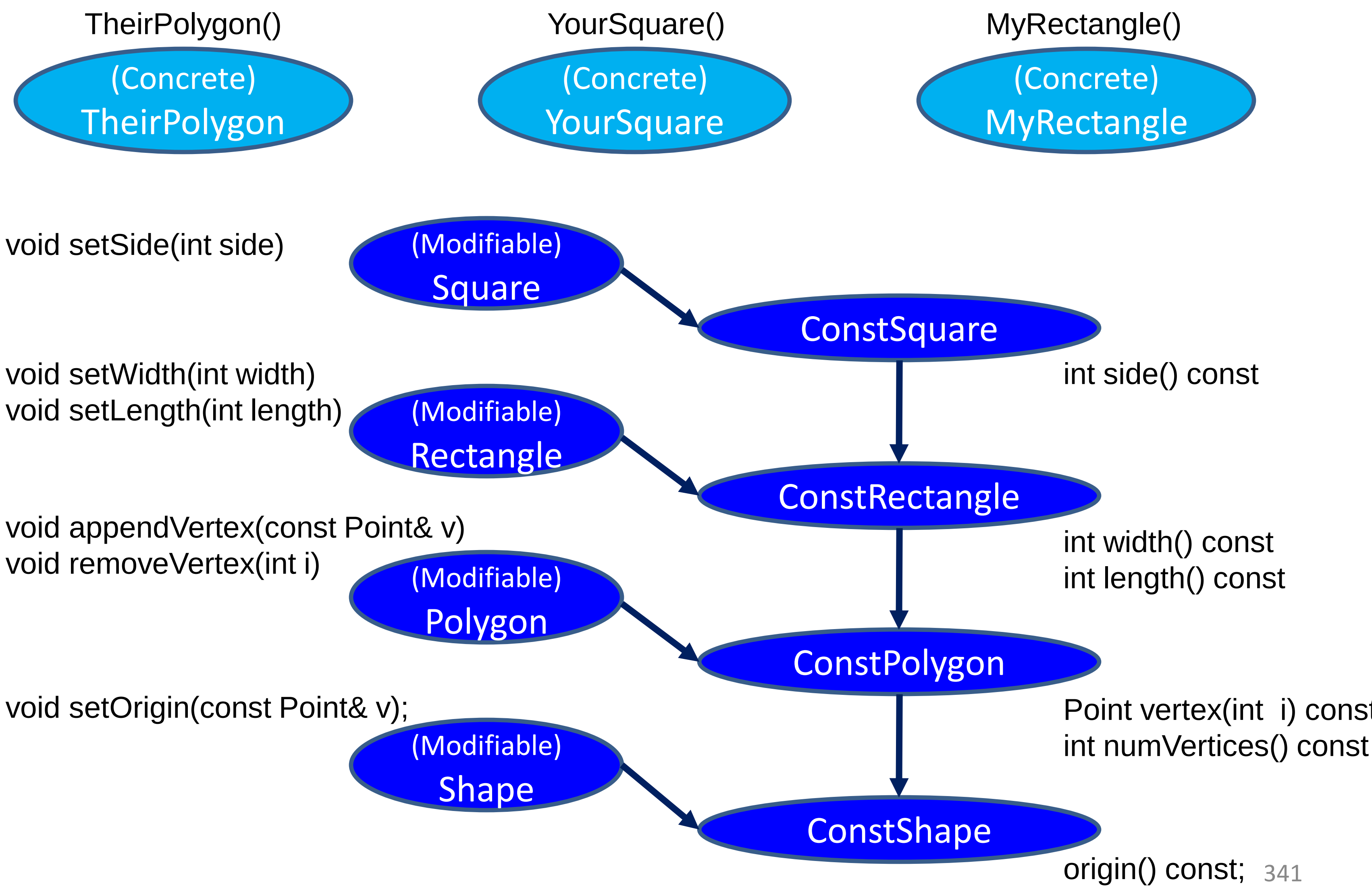


Using Interface Inheritance Effectively



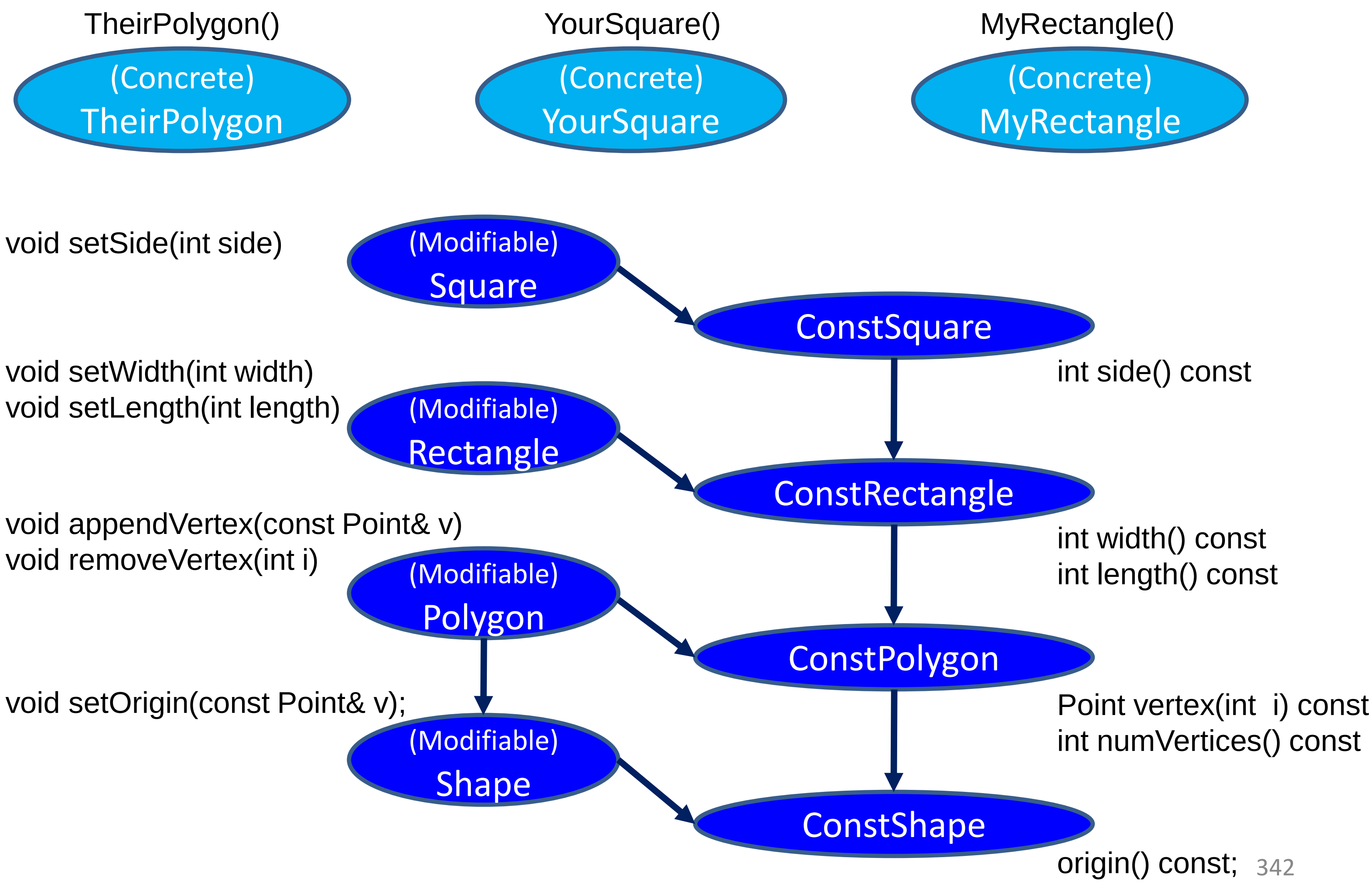
4. Proper Inheritance

Using Interface Inheritance Effectively



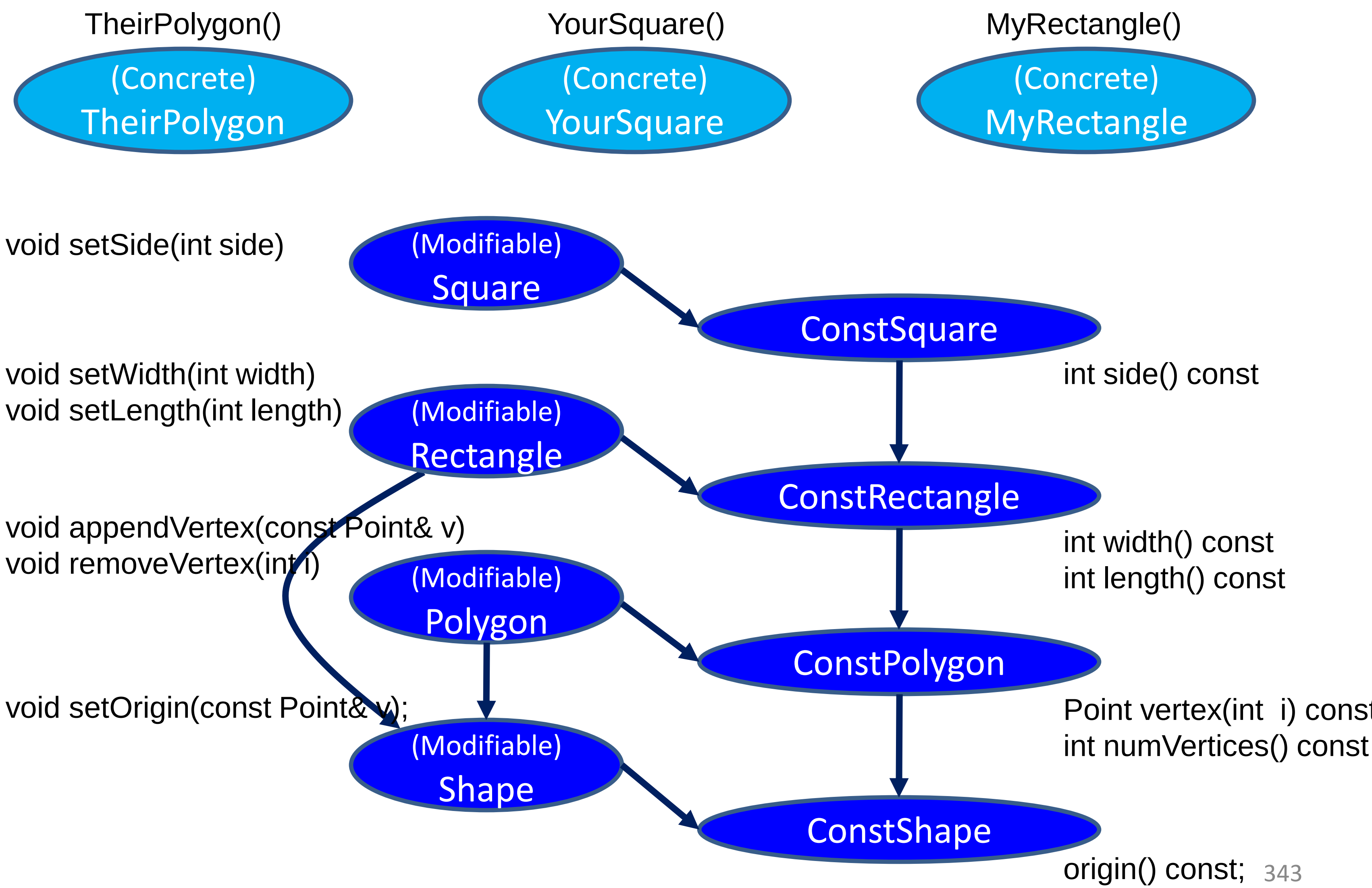
4. Proper Inheritance

Using Interface Inheritance Effectively



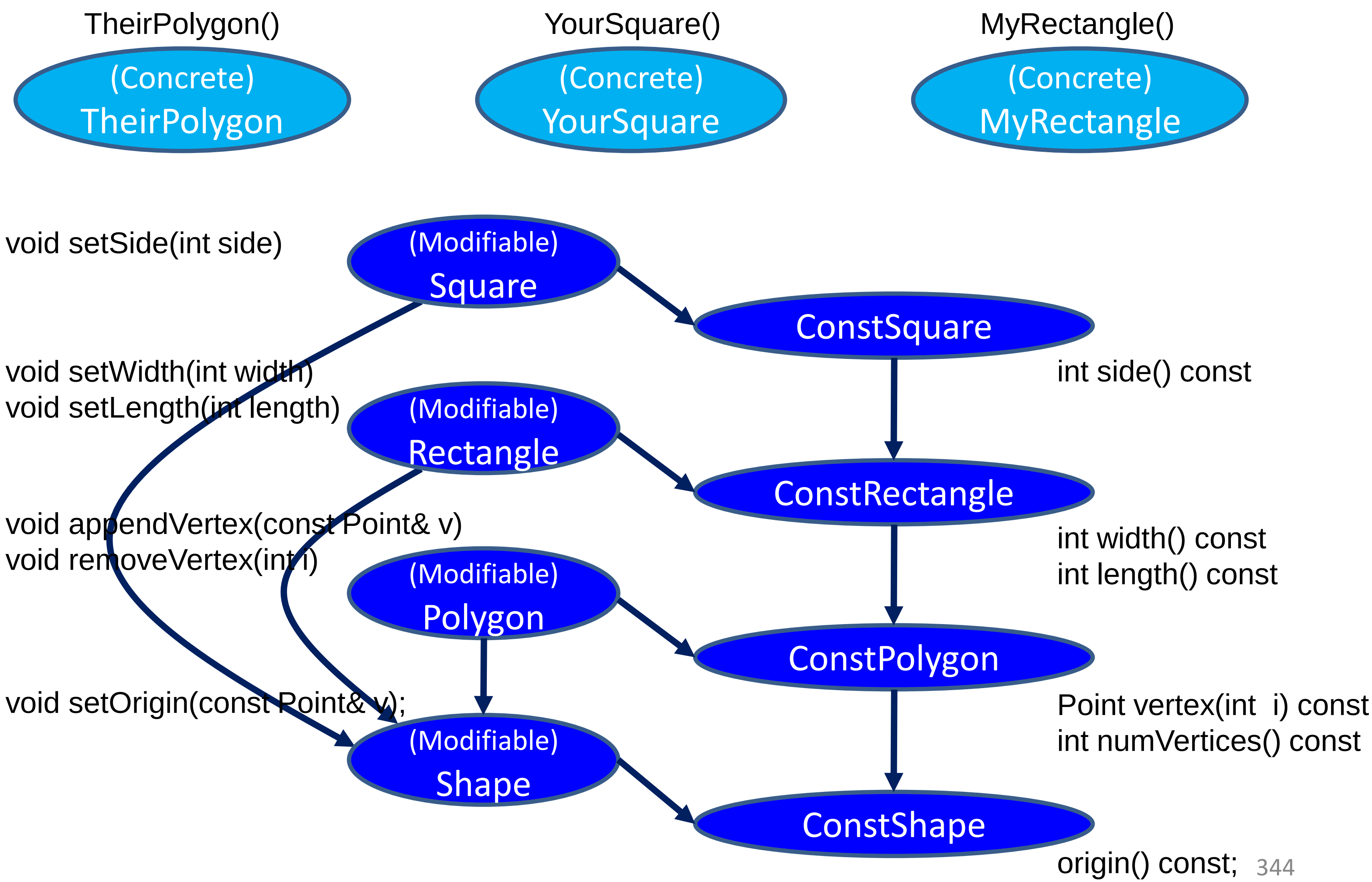
4. Proper Inheritance

Using Interface Inheritance Effectively

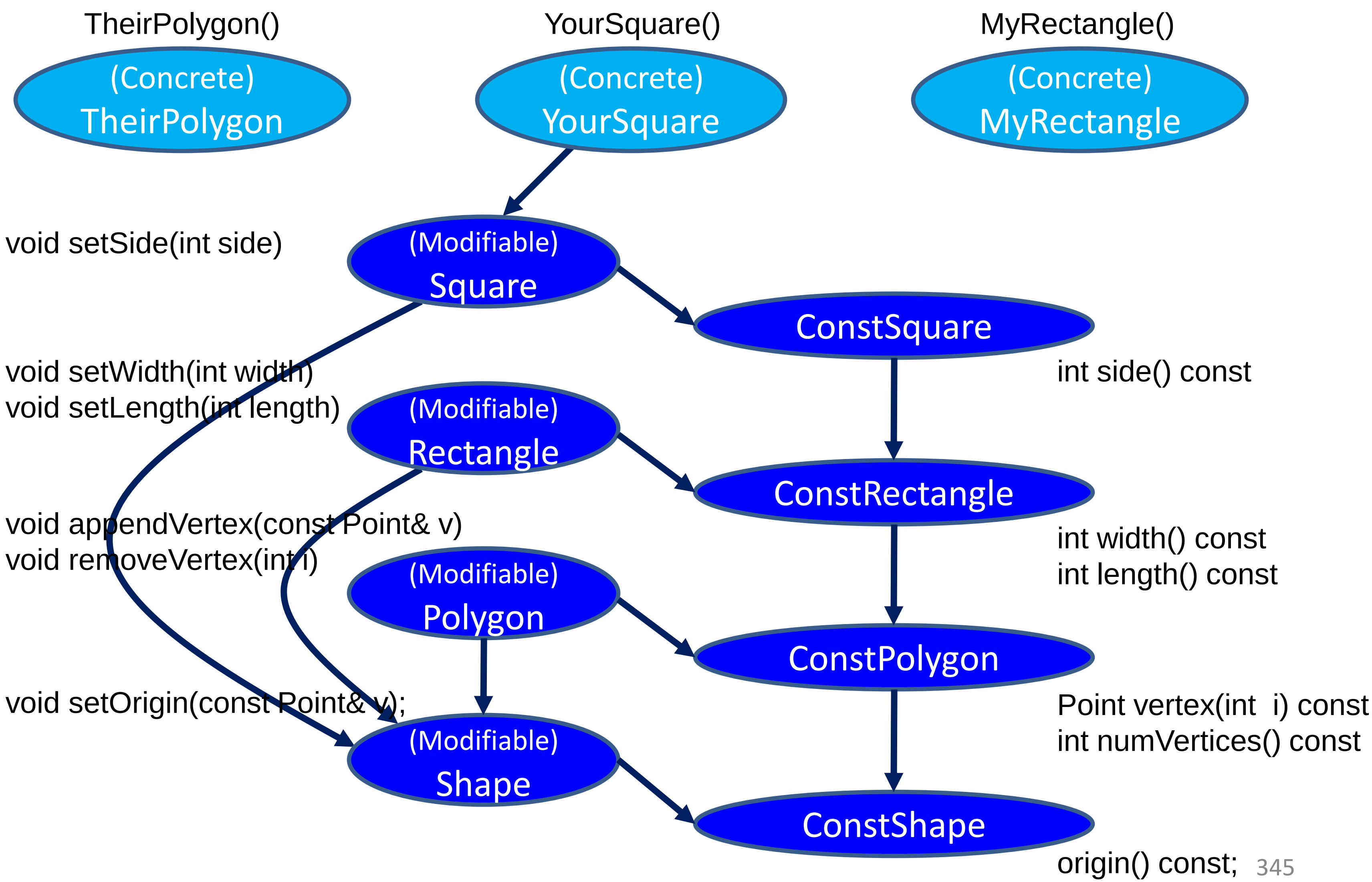


4. Proper Inheritance

Using Interface Inheritance Effectively

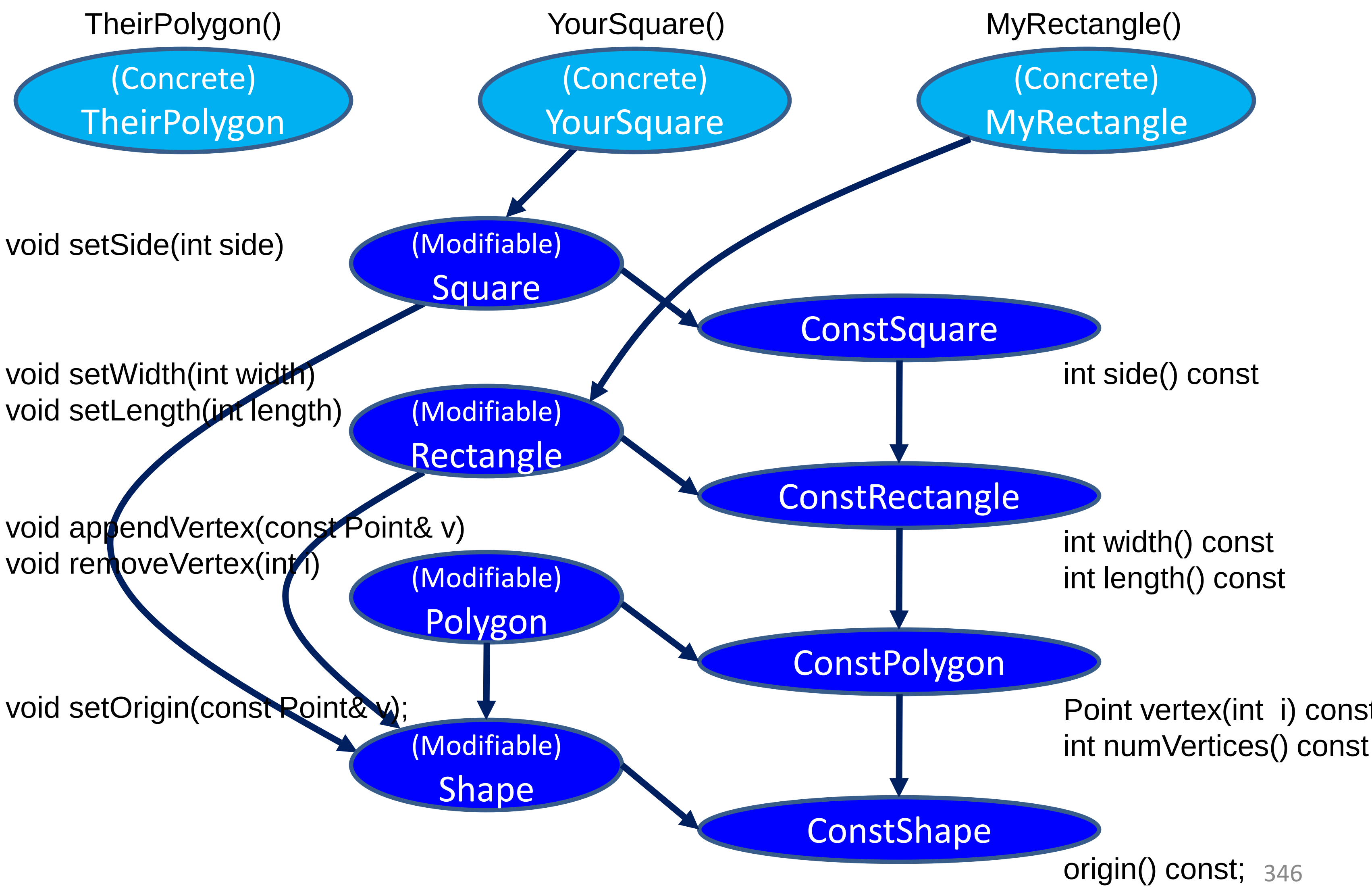


Using Interface Inheritance Effectively

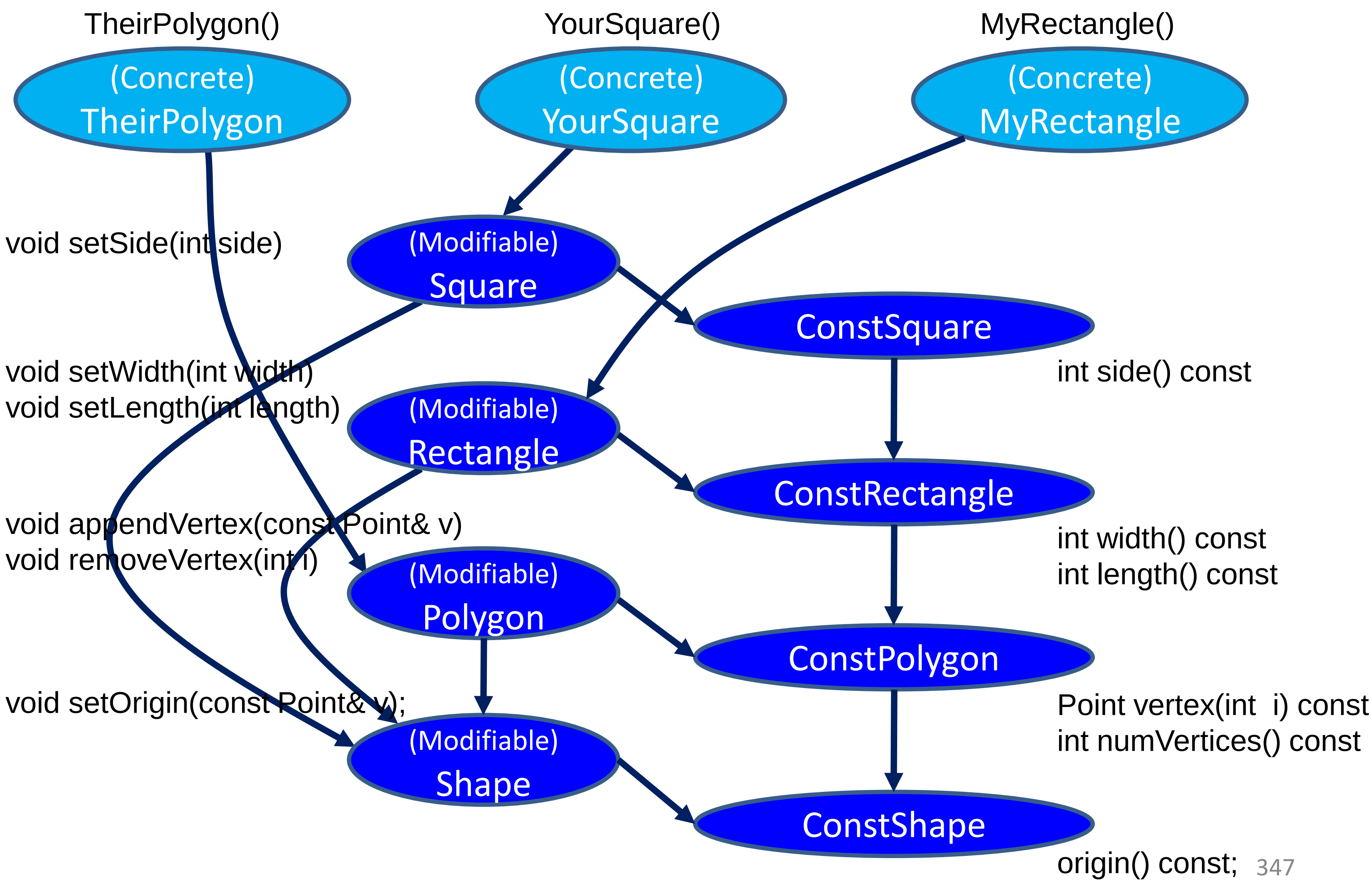


4. Proper Inheritance

Using Interface Inheritance Effectively



Using Interface Inheritance Effectively



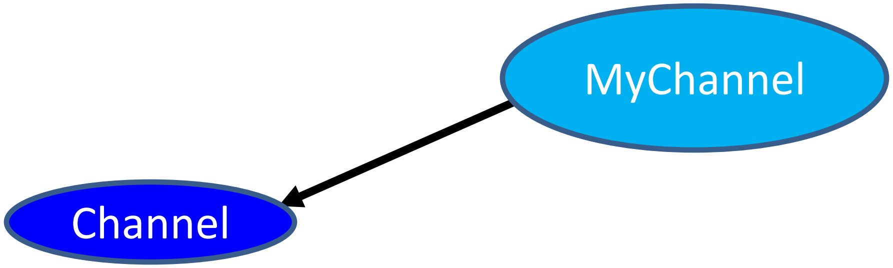
Using Interface Inheritance Effectively

The principal clients of
Interface Inheritance
are **both** the
PUBLIC CLIENT
and the
DERIVED-CLASS AUTHOR.

Using Interface Inheritance Effectively


```
int write(const char *b, int n);
int read(char *b, int n);
```

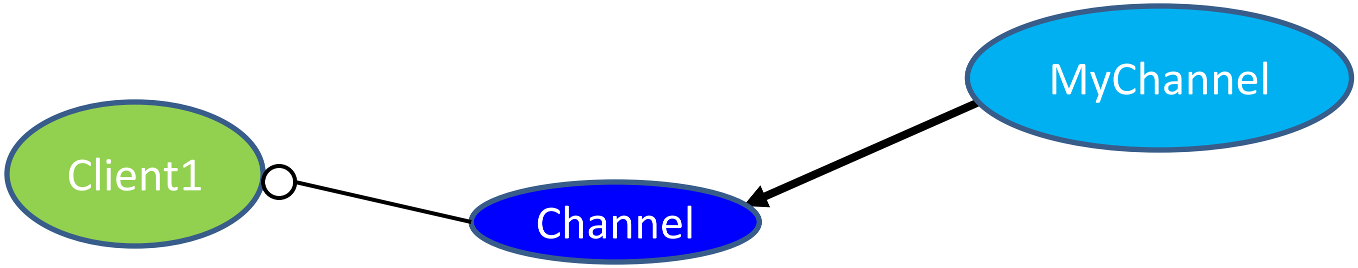
Using Interface Inheritance Effectively



int write(const char *b, int n);
int read(char *b, int n);

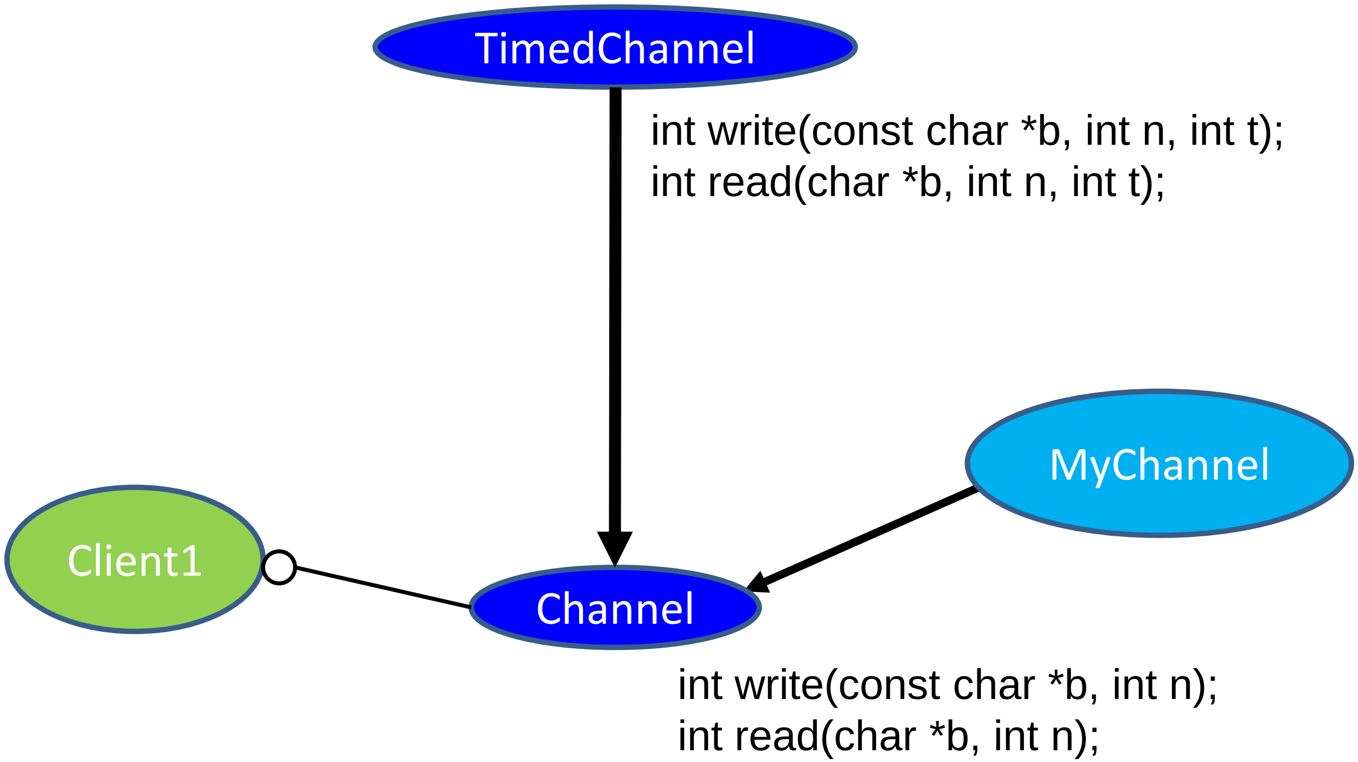
4. Proper Inheritance

Using Interface Inheritance Effectively



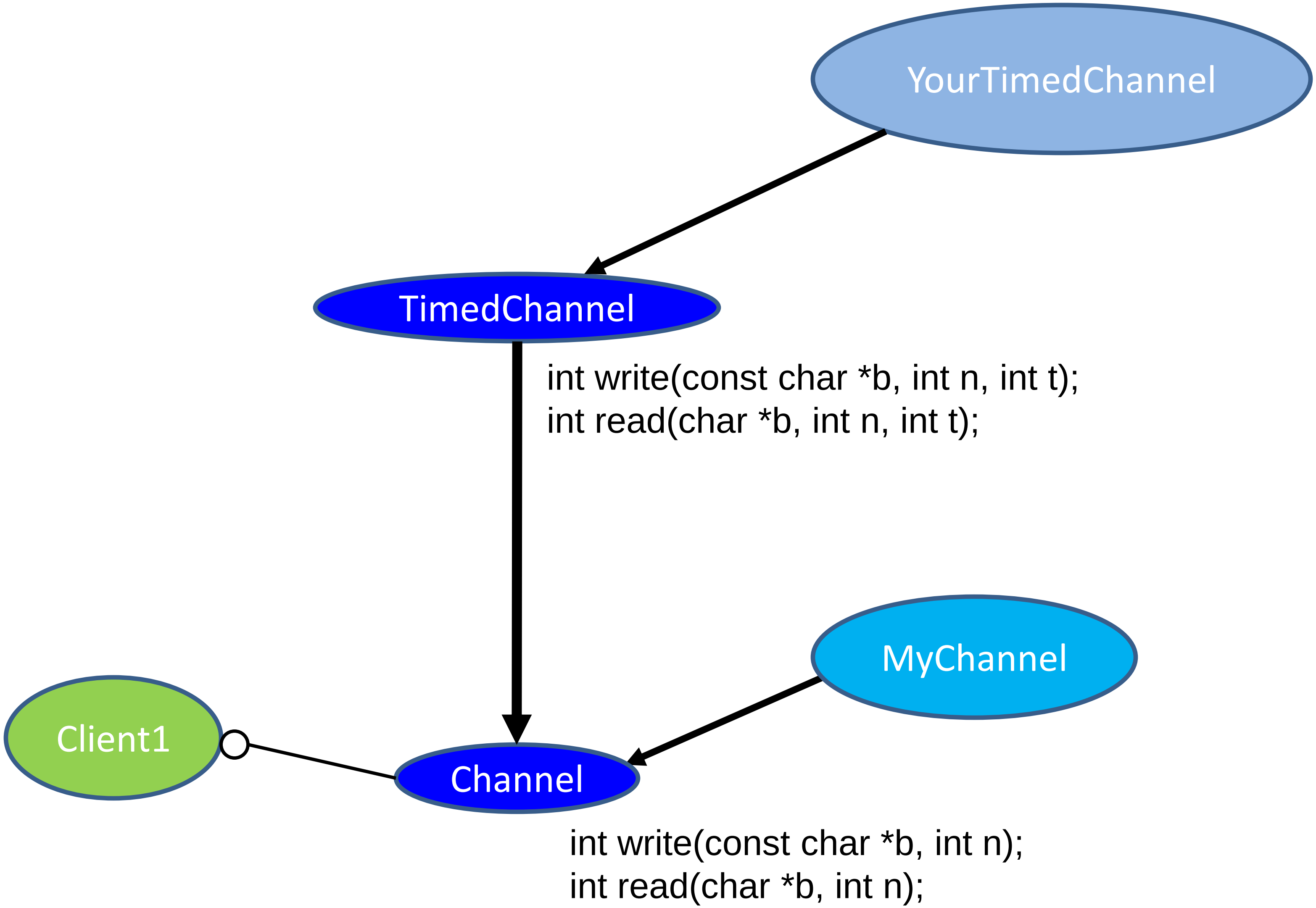
int write(const char *b, int n);
int read(char *b, int n);

Using Interface Inheritance Effectively



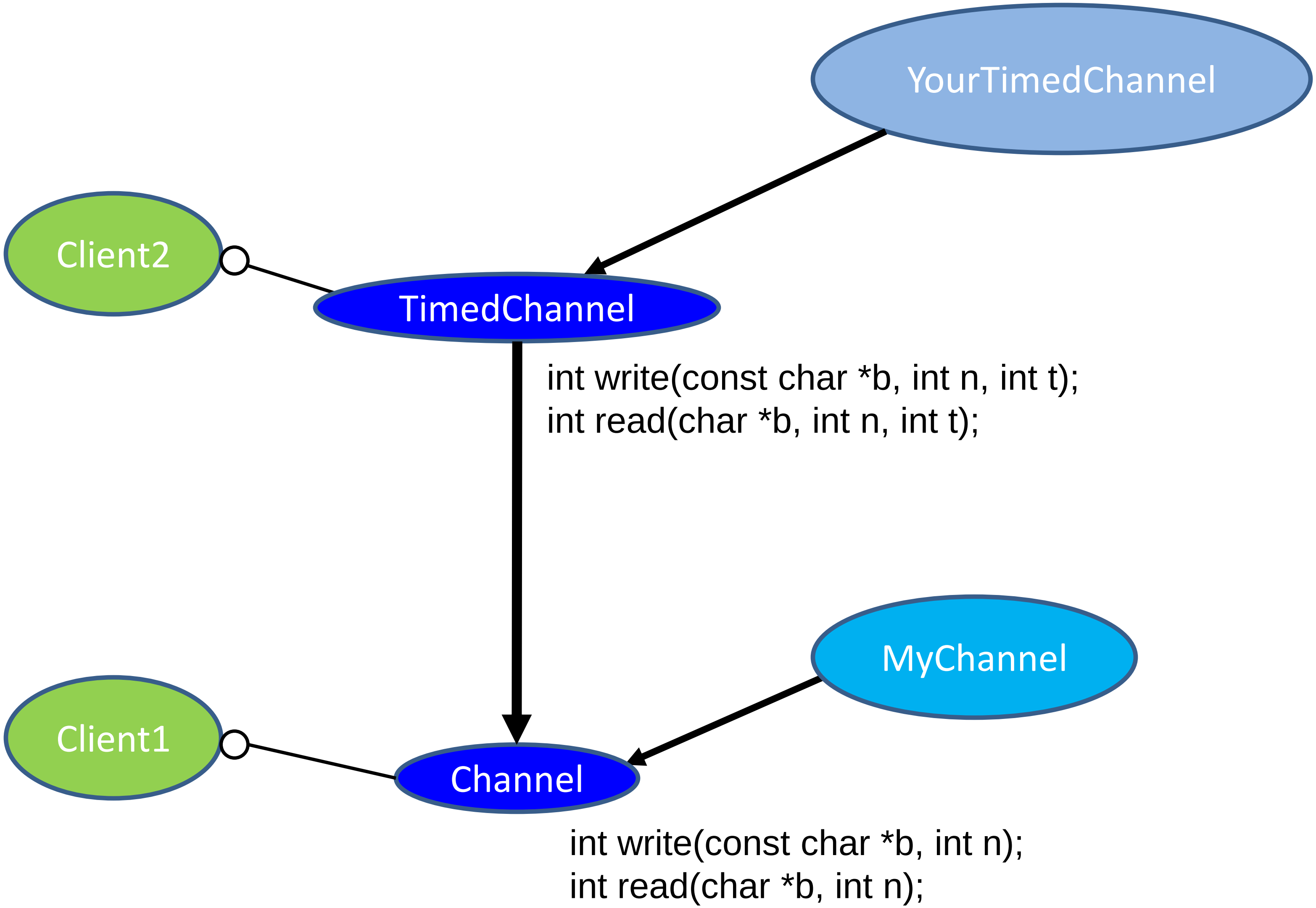
4. Proper Inheritance

Using Interface Inheritance Effectively



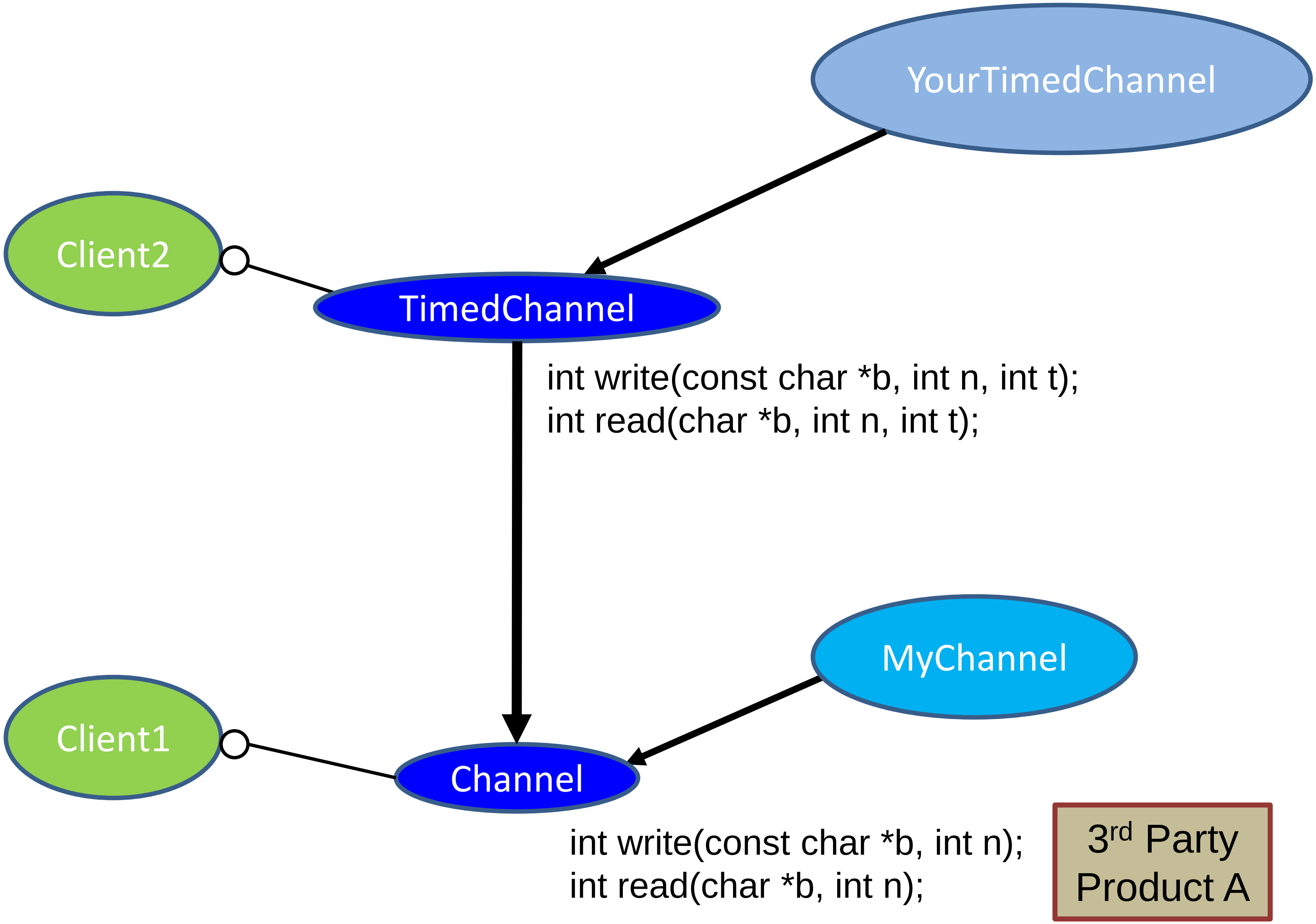
4. Proper Inheritance

Using Interface Inheritance Effectively

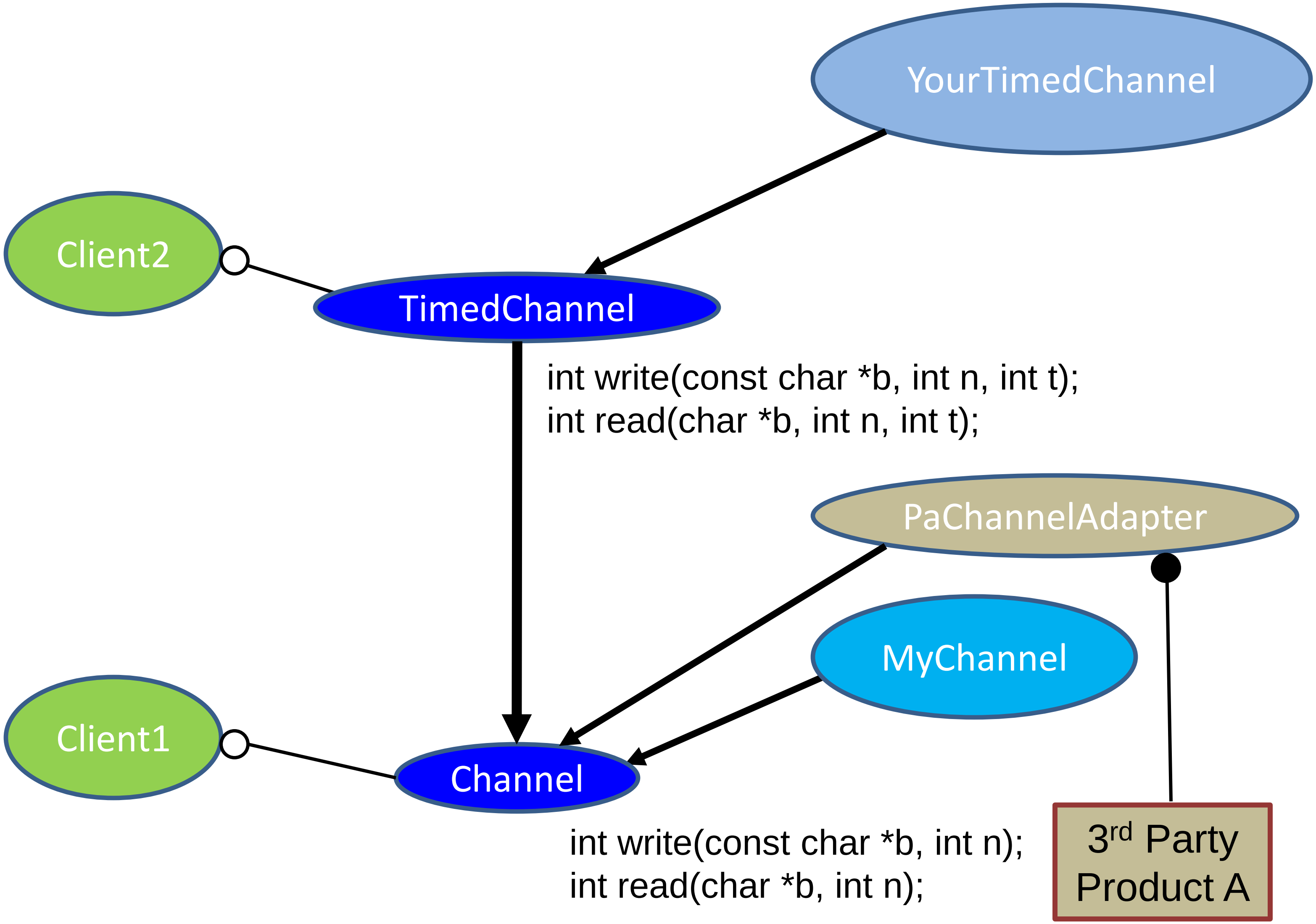


4. Proper Inheritance

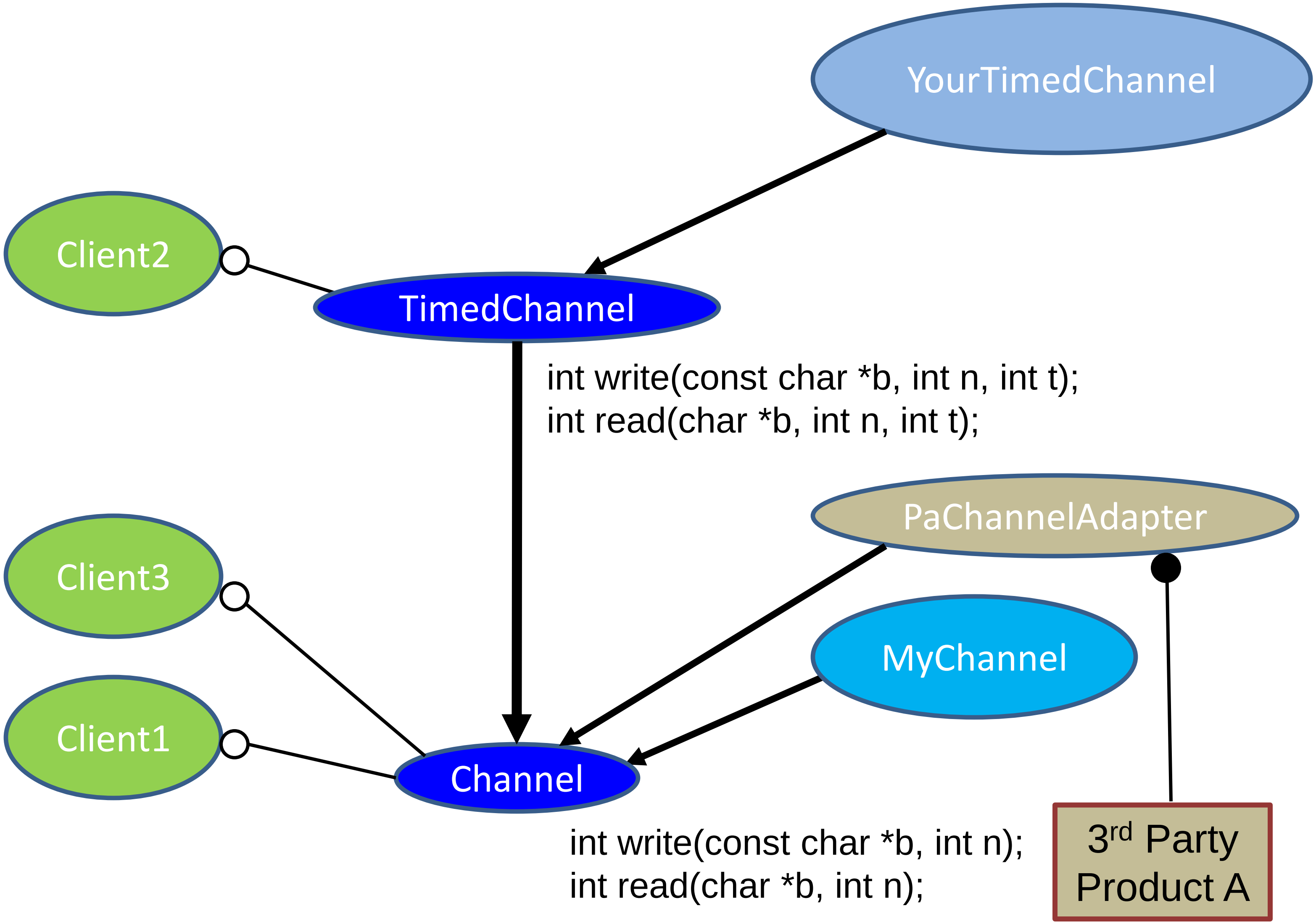
Using Interface Inheritance Effectively



Using Interface Inheritance Effectively

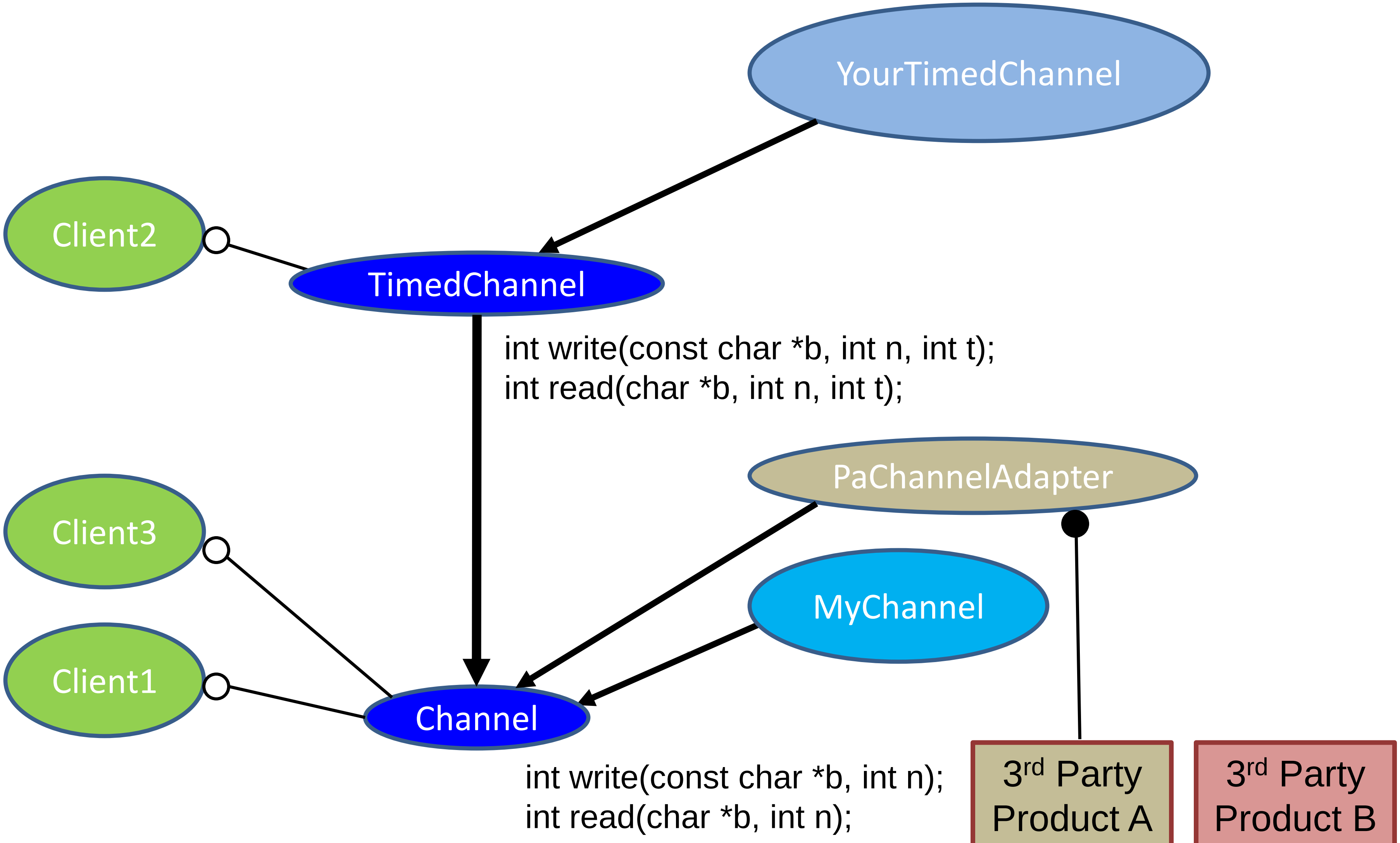


Using Interface Inheritance Effectively



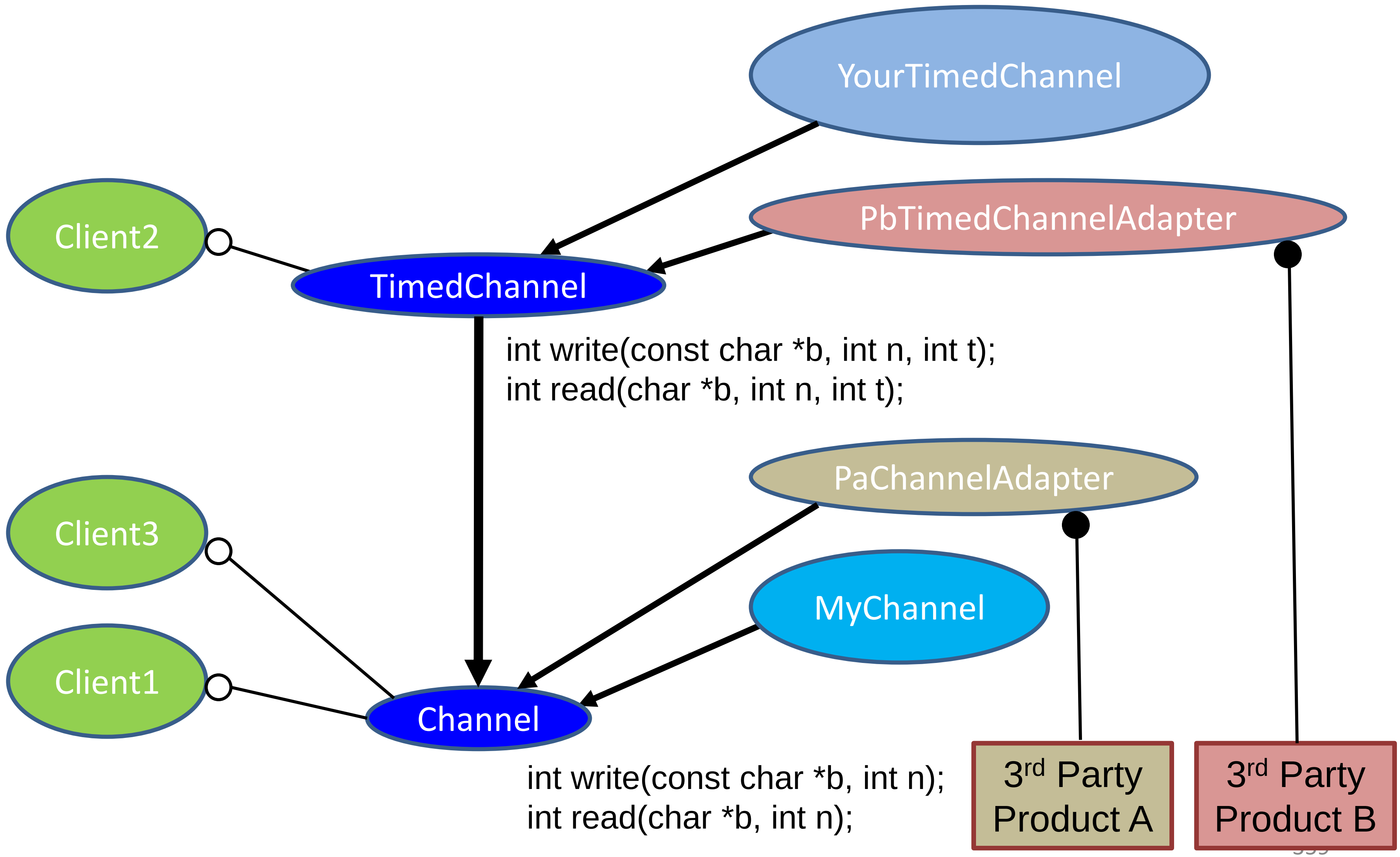
4. Proper Inheritance

Using Interface Inheritance Effectively



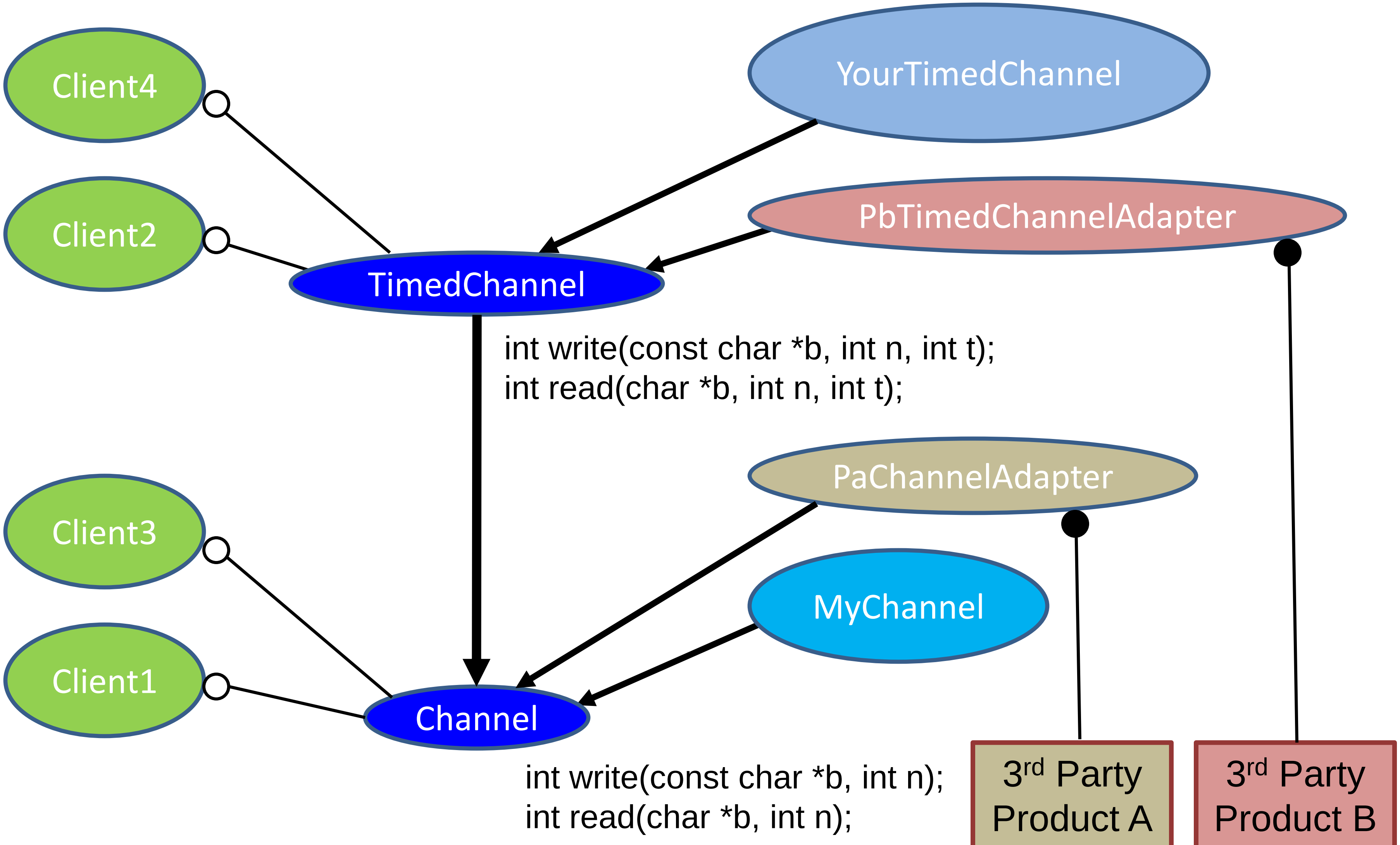
4. Proper Inheritance

Using Interface Inheritance Effectively



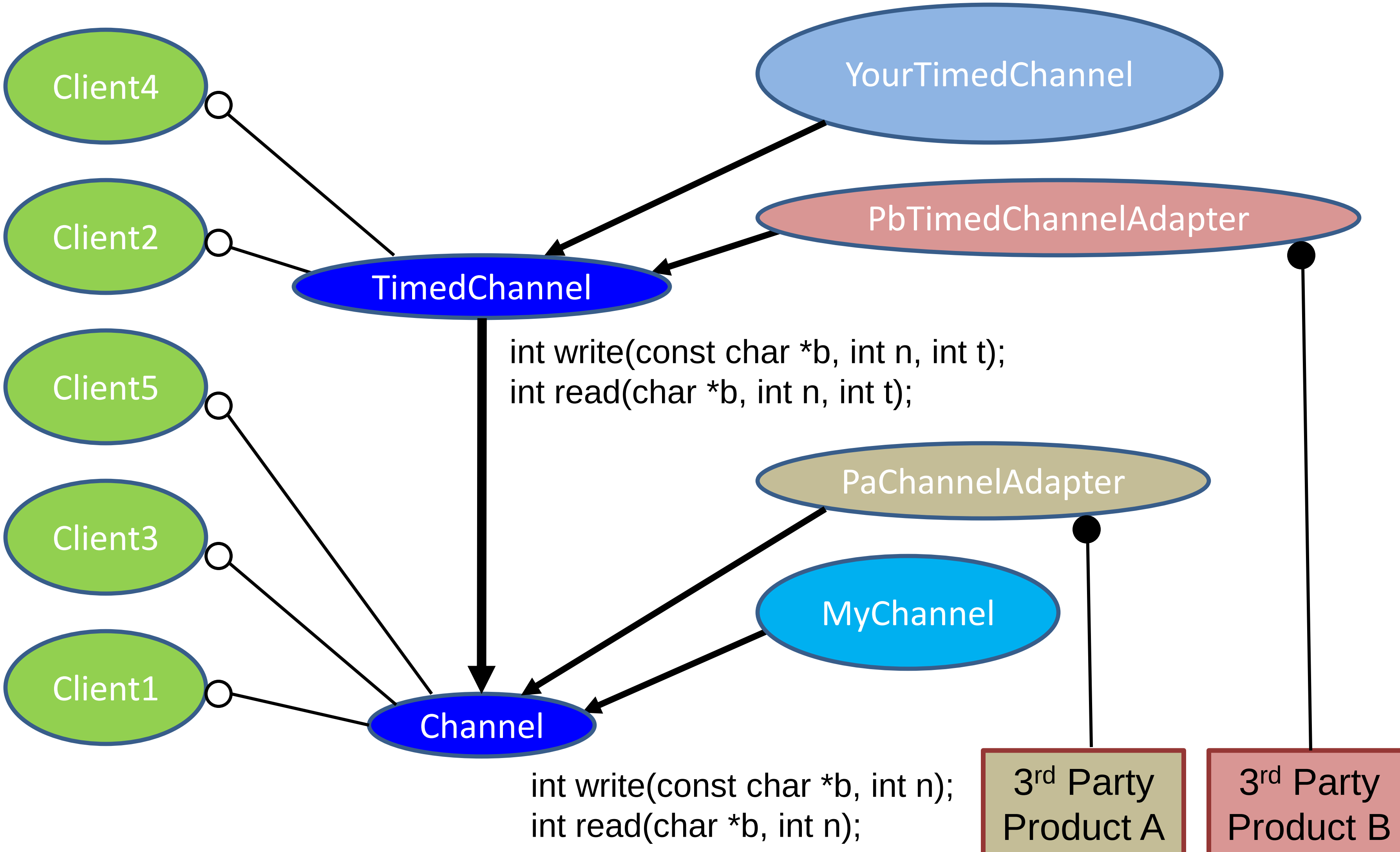
4. Proper Inheritance

Using Interface Inheritance Effectively

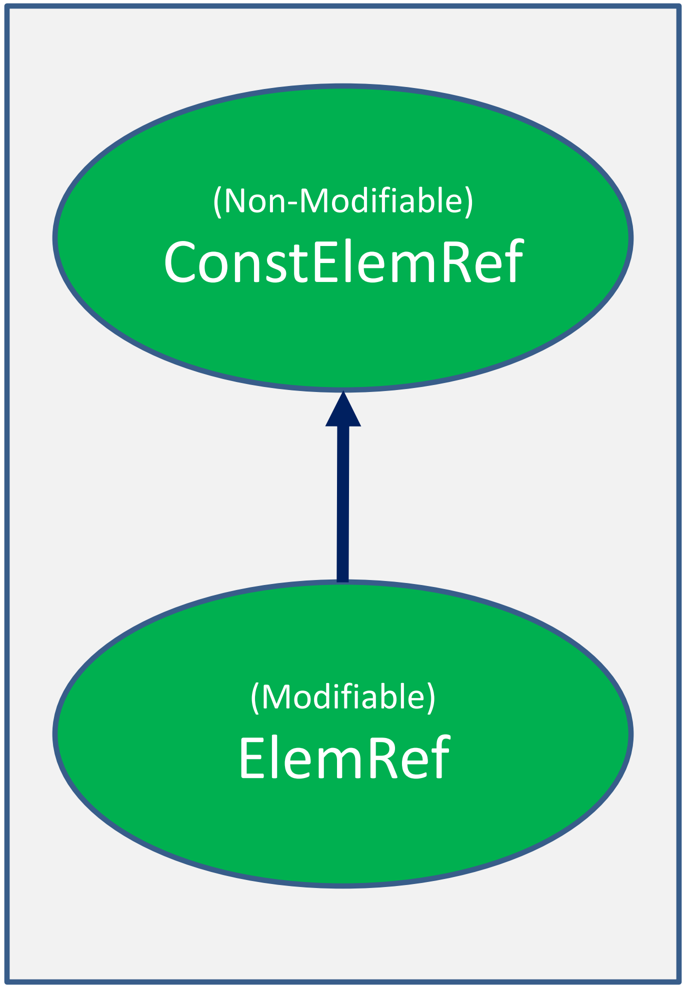


4. Proper Inheritance

Using Interface Inheritance Effectively

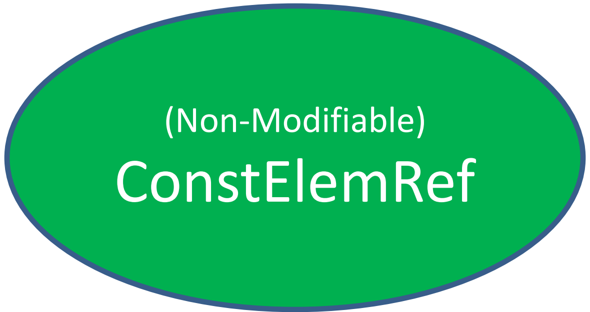


Using Structural Inheritance Effectively



4. Proper Inheritance

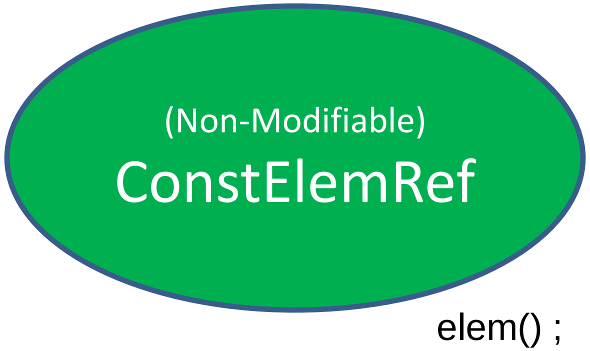
Using Structural Inheritance Effectively



elem() ;

```
template <class TYPE>
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;

    friend class ElemRef<TYPE>;  //  Note friendship

  private: // Not Implemented.                    TBD
    ConstElemRef& operator=(Const ConstElemRef&);

  public:
    // CREATORS
    ConstElemRef(const TYPE *elem);
    ConstElemRef(const ConstElemRef& ref);
    ~ConstElemRef();

    // ACCESSORS
    const TYPE& elem() const;
};
```

Using Structural Inheritance Effectively

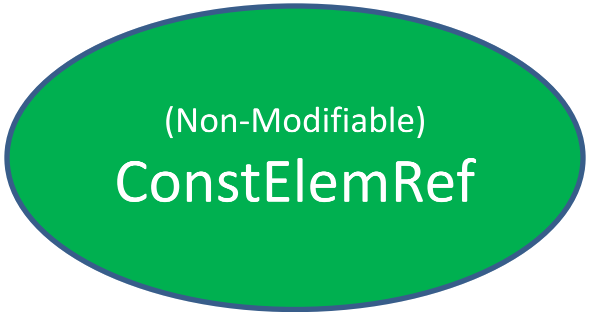



```
template <class TYPE>
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;

    friend class ElemRef<TYPE>;  //  Note friendship

  private: // Not Implemented.                              TBD
    ConstElemRef& operator=(Const ConstElemRef&);

  public:
    // CREATORS
    ConstElemRef(const TYPE *elem);
    ConstElemRef(const ConstElemRef& ref);
    ~ConstElemRef();

    // ACCESSORS
    const TYPE& elem() const;
};
```

Single Pointer Data Member

4. Proper Inheritance

Using Structural Inheritance Effectively



elem() ;

Derived Class
Declared Friend

```
template <class TYPE>
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;

    friend class ElemRef<TYPE>;  //  Note friendship

  private: // Not Implemented.                             TBD
    ConstElemRef& operator=(Const ConstElemRef&);

  public:
    // CREATORS
    ConstElemRef(const TYPE *elem);
    ConstElemRef(const ConstElemRef& ref);
    ~ConstElemRef();

    // ACCESSORS
    const TYPE& elem() const;
};
```

Using Structural Inheritance Effectively

(Non-Modifiable)
ConstElemRef

elem() ;

Copy Assignment
Not Implemented

```
template <class TYPE>
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;

    friend class ElemRef<TYPE>;  // Note friendship

  private: // Not Implemented.                    TBD
    ConstElemRef& operator=(Const ConstElemRef&);

  public:
    // CREATORS
    ConstElemRef(const TYPE *elem);
    ConstElemRef(const ConstElemRef& ref);
    ~ConstElemRef();

    // ACCESSORS
    const TYPE& elem() const;
};
```

4. Proper Inheritance

Using Structural Inheritance Effectively

(Non-Modifiable)

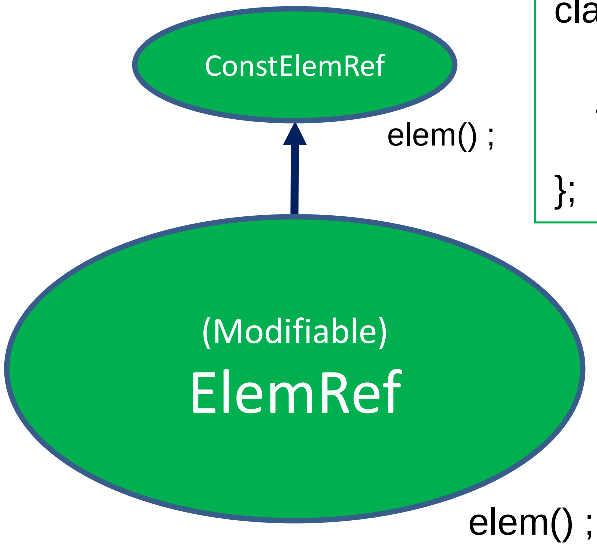
ConstElemRef

elem() ;

Read-Only Access

```
template <class TYPE>
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;

    friend class ElemRef<TYPE>;  //  Note friendship

  private: // Not Implemented.                                  TBD
    ConstElemRef& operator=(Const ConstElemRef&);

  public:
    // CREATORS
    ConstElemRef(const TYPE *elem);
    ConstElemRef(const ConstElemRef& ref);
    ~ConstElemRef();

    // ACCESSORS
    const TYPE& elem() const;
};
```

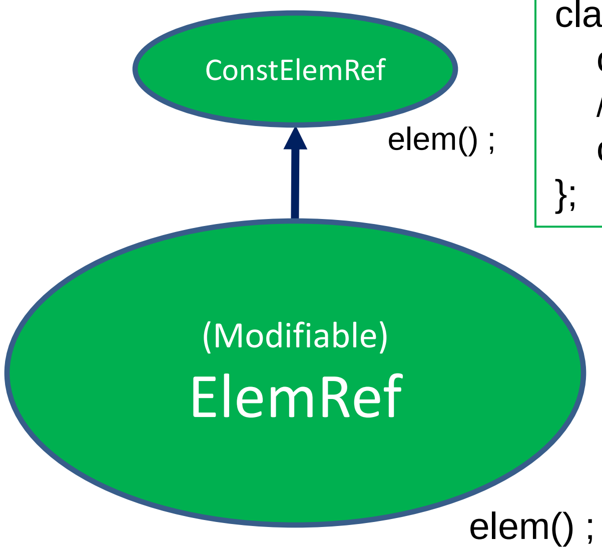
Using Structural Inheritance Effectively




```
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;
    // …
    const TYPE& elem() const;
};
```

```
template <class TYPE>
class ElemRef<TYPE> : public ConstElemRef<TYPE> {
  public:
    // CREATORS
    ElemRef(TYPE *elem);
    ElemRef(const ElemRef& ref);
    ~ElemRef();

    // MANIPULATORS
    ElemRef& operator=(const ElemRef&); // Fine.   TBD

    // ACCESSORS
    TYPE& elem() const;
};
```

Using Structural Inheritance Effectively

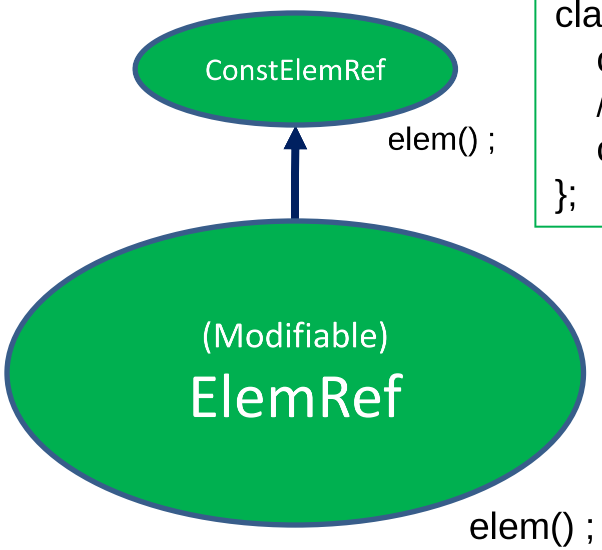



```
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;
    // …
    const TYPE& elem() const;
};
```

Public Structural Inheritance

```
template <class TYPE>
class ElemRef<TYPE> : public ConstElemRef<TYPE> {
  public:
    // CREATORS
    ElemRef(TYPE *elem);
    ElemRef(const ElemRef& ref);
    ~ElemRef();

    // MANIPULATORS
    ElemRef& operator=(const ElemRef&); // Fine.   TBD

    // ACCESSORS
    TYPE& elem() const;
};
```

Using Structural Inheritance Effectively



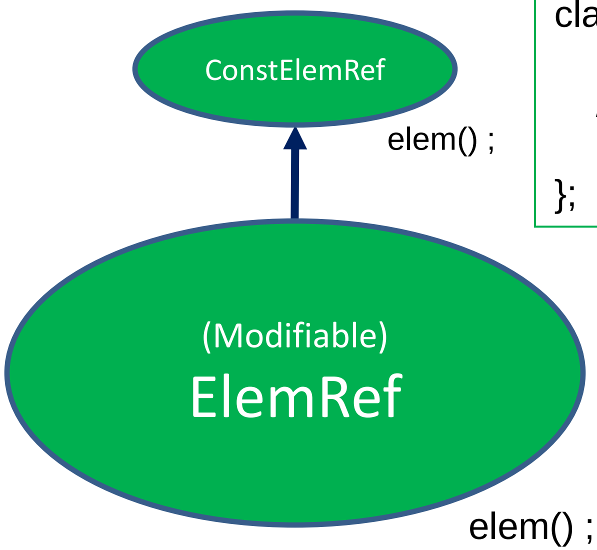

```
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;
    // …
    const TYPE& elem() const;
};
```

No Additional Member Data

```
template <class TYPE>
class ElemRef<TYPE> : public ConstElemRef<TYPE> {
  public:
    // CREATORS
    ElemRef(TYPE *elem);
    ElemRef(const ElemRef& ref);
    ~ElemRef();

    // MANIPULATORS
    ElemRef& operator=(const ElemRef&); // Fine.   TBD

    // ACCESSORS
    TYPE& elem() const;
};
```

4. Proper Inheritance

Using Structural Inheritance Effectively




```
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;
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    const TYPE& elem() const;
};
```

Copy Assignment Implemented

```
template <class TYPE>
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    ElemRef(TYPE *elem);
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```
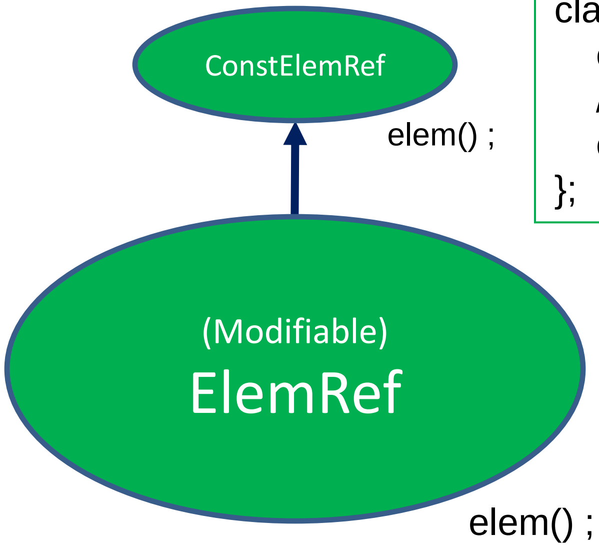

Using Structural Inheritance Effectively




```
class ConstElemRef<TYPE> {
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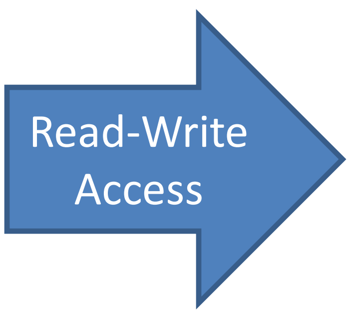


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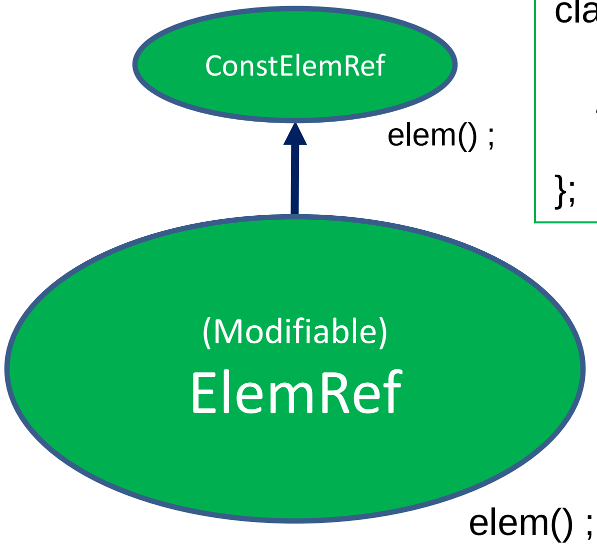
Using Structural Inheritance Effectively




```
class ConstElemRef<TYPE> {
    const TYPE *d_elem_p;
    // …
    const TYPE& elem() const;
};
```

```
template <class T
class ElemRef<T
  public:
    // CREATORS
    ElemRef(TYPE
    ElemRef(const
    ~ElemRef();

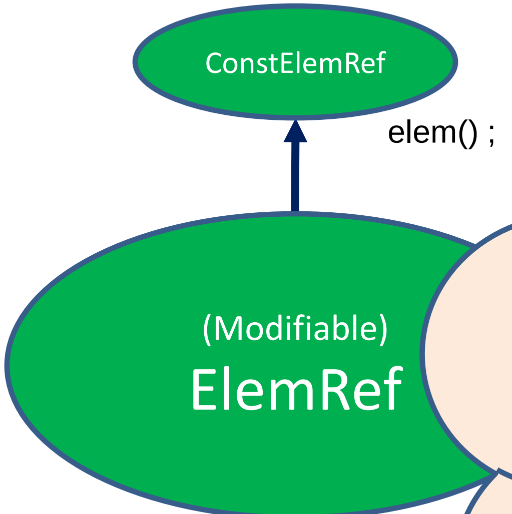
    // MANIPULATOR
    ElemRef& operat                                    Fine.   TBD

    // ACCESSORS
    TYPE& elem() const;
};
```

An
`ElemRef`
Is-A
`ConstElemRef`
with
“Write Access”

Read-Write Access

Using Structural Inheritance Effectively



class C

An
`std::iterator`
Is-A
`std::const_iterator`
with
"Write Access"

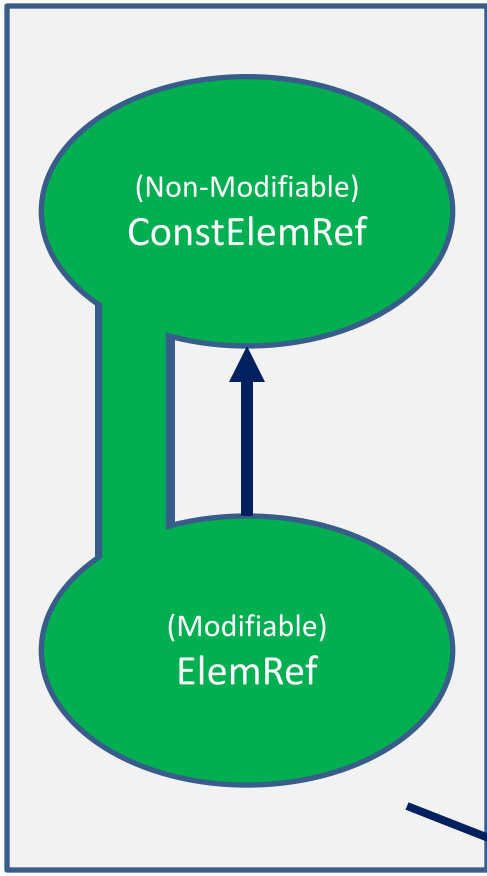
Read-Write
Access

```
    El            op                    mRef&); // Fine.   TBD

    // ACCESSORS
    TYPE& elem() co
};
```

4. Proper Inheritance

Using Structural Inheritance Effectively



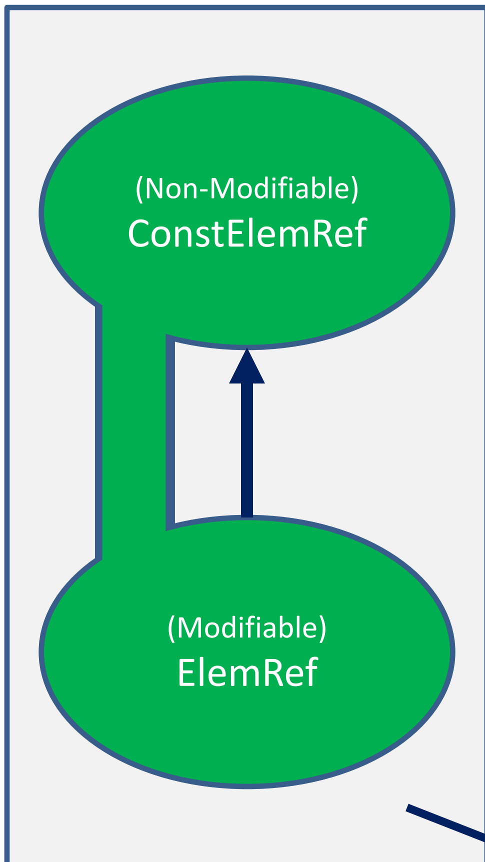

```
const TYPE& ConstElemRef::elem() const
{
    return *d_elem_p;
}
```

```
TYPE& ElemRef::elem() const
{
    return *const_cast<TYPE *>(d_elem_p);
}
                    // Note use of friendship as well.
```

Note: same component due to friendship.

4. Proper Inheritance

Using Structural Inheritance Effectively



Note we are casting-away **`const`**

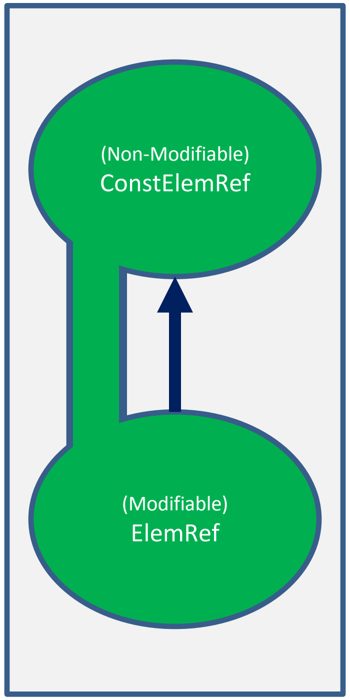
```
const TYPE& ConstElemRef::ele
{
    return *d_elem_p;
}
```

```
TYPE& ElemRef::elem() const
{
    return *const_cast<TYPE *>(d_elem_p);
}
                        // Note use of friendship as well.
```

Note: same component due to friendship.

Using Structural Inheritance Effectively

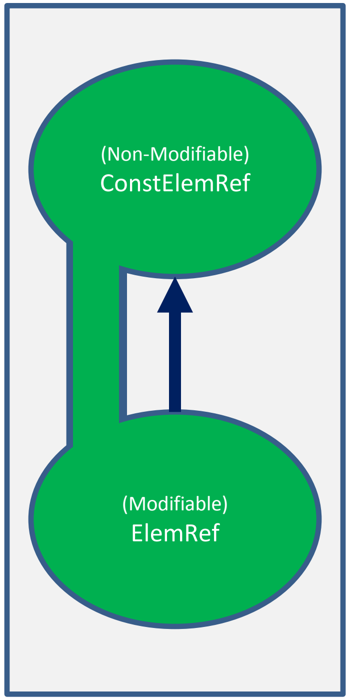
Be especially careful to ensure `const`-correctness when `const`-casting is involved.



Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;   // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
```



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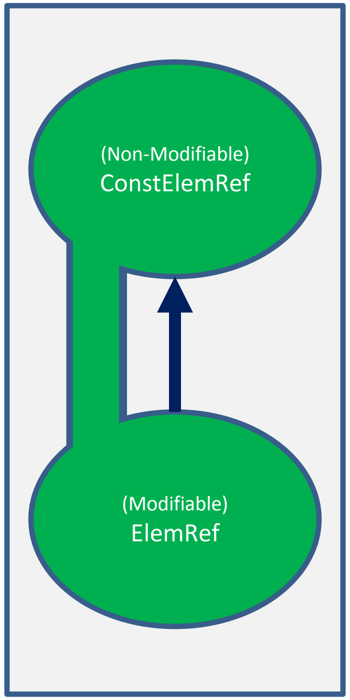


```
template < class TYPE>
void f(const TYPE& constElem)
{
```

Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;   // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
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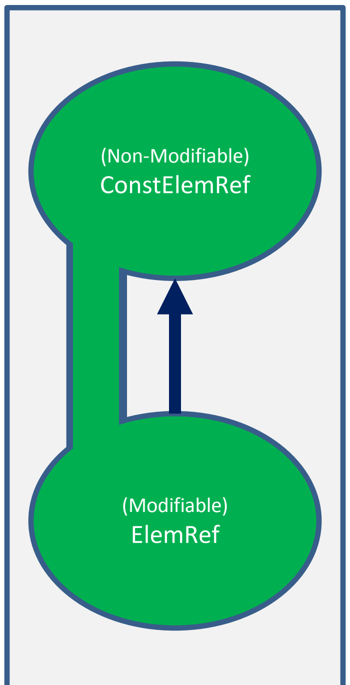
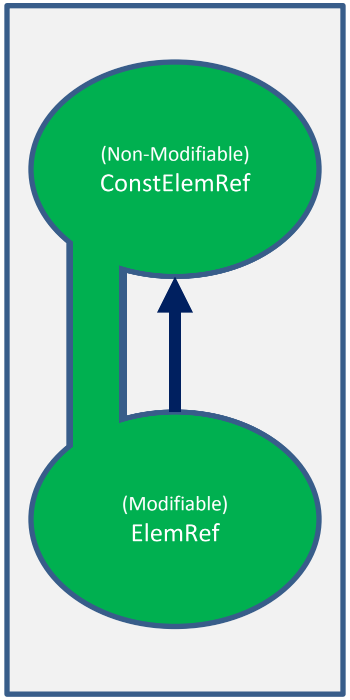



```
template < class TYPE>
void f(const TYPE& constElem)
{
    TYPE dummy;
```

Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;    // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
```

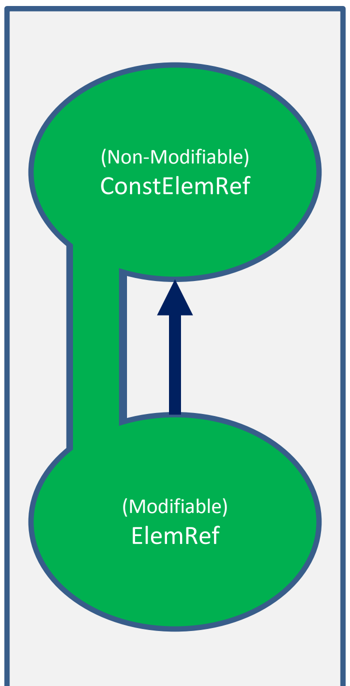



```
template < class TYPE>
void f(const TYPE& constElem)
{
    TYPE dummy;
    ElemRef er(&dummy);
```

Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;   // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
```

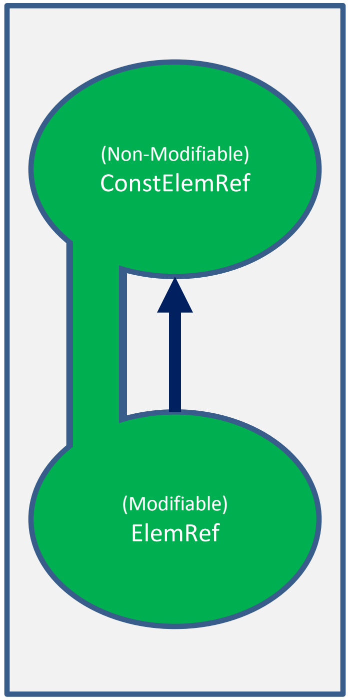



```
template < class TYPE>
void f(const TYPE& constElem)
{
    TYPE dummy;
    ElemRef er(&dummy);

    ConstElemRef cer(&constElem);
```

Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;   // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
```

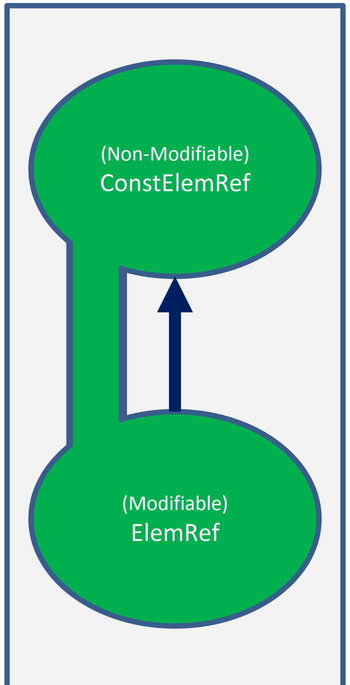



```
template < class TYPE>
void f(const TYPE& constElem)
{
    TYPE dummy;
    ElemRef er(&dummy);

    ConstElemRef cer(&constElem);

    g(&er, cer);  // Rebind (modifiable) 'ElemRef' 'er'.
```

Using Structural Inheritance Effectively

Be especially careful to ensure `const`-correctness when `const`-casting is involved.

```
void g(ConstElemRef *cer1,  const ConstElemRef& cer2)
{
    *cer1 = cer2;   // Enable const-correctness violation due to slicing.
}  // Assumes copy assignment is enabled on the ConstElemRef base class.
```




```
template < class TYPE>
void f(const TYPE& constElem)
{
    TYPE dummy;
    ElemRef er(&dummy);

    ConstElemRef cer(&constElem);

    g(&er, cer);  // Rebind (modifiable) 'ElemRef' 'er'.

    er.elem() = TYPE();  // Clobber 'constElem'.
```

Using Structural Inheritance Effectively

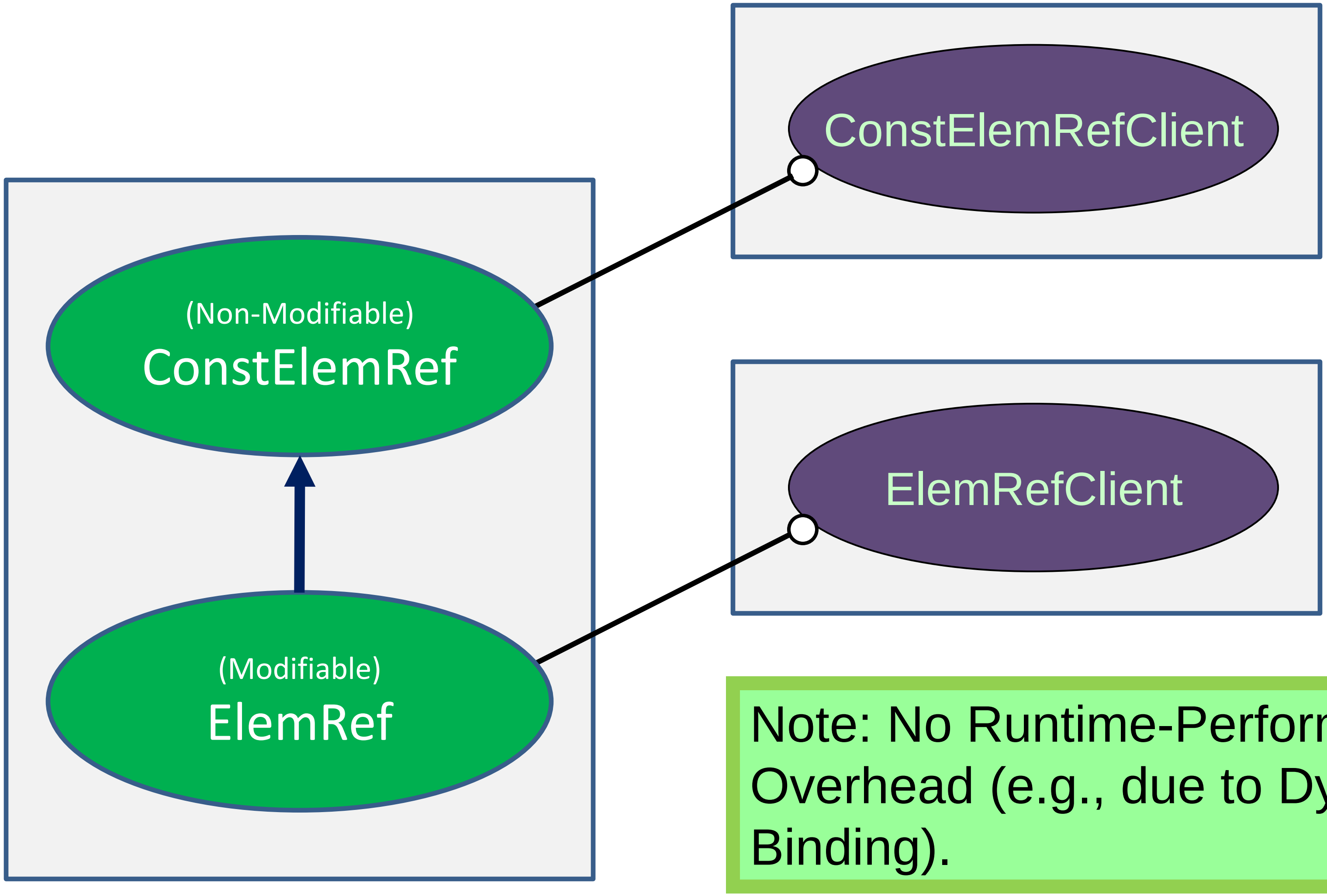
The principal client of

Structural Inheritance

is the

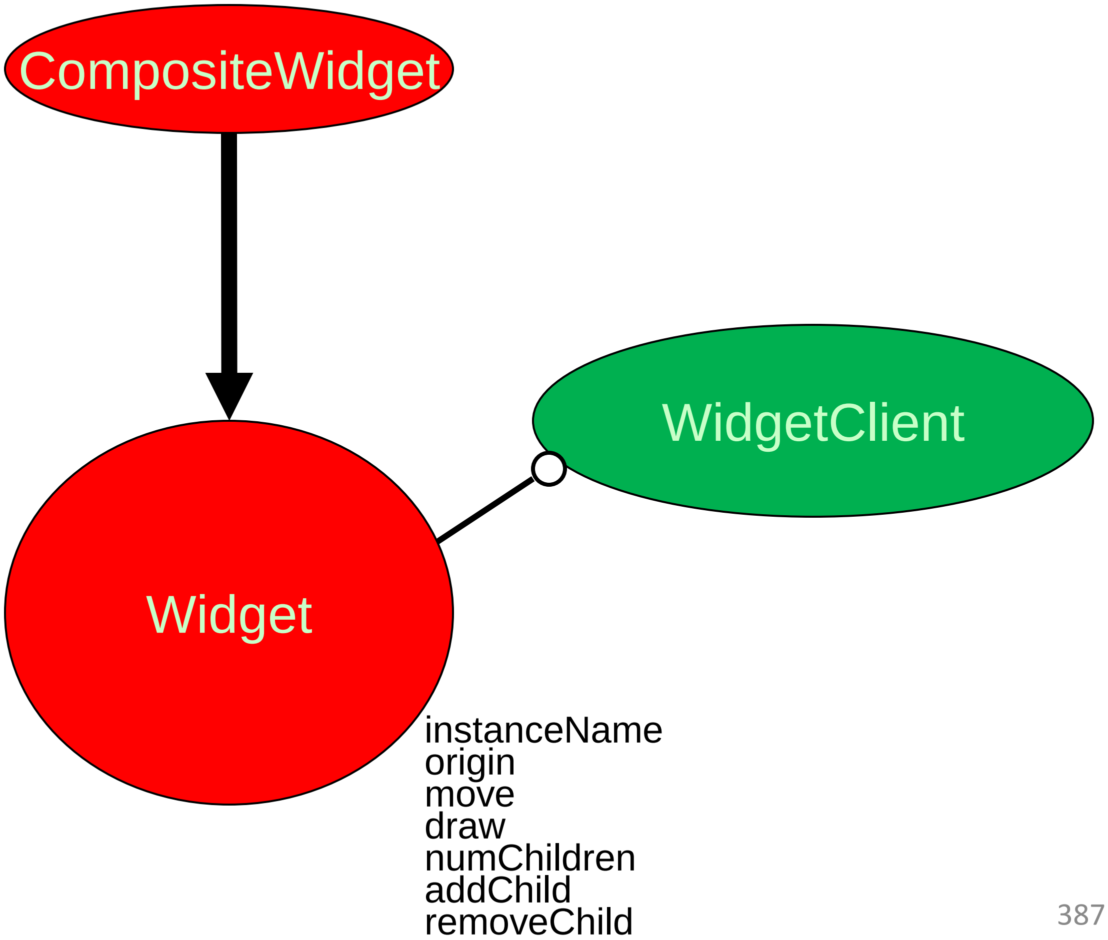
PUBLIC CLIENT.

Using Structural Inheritance Effectively



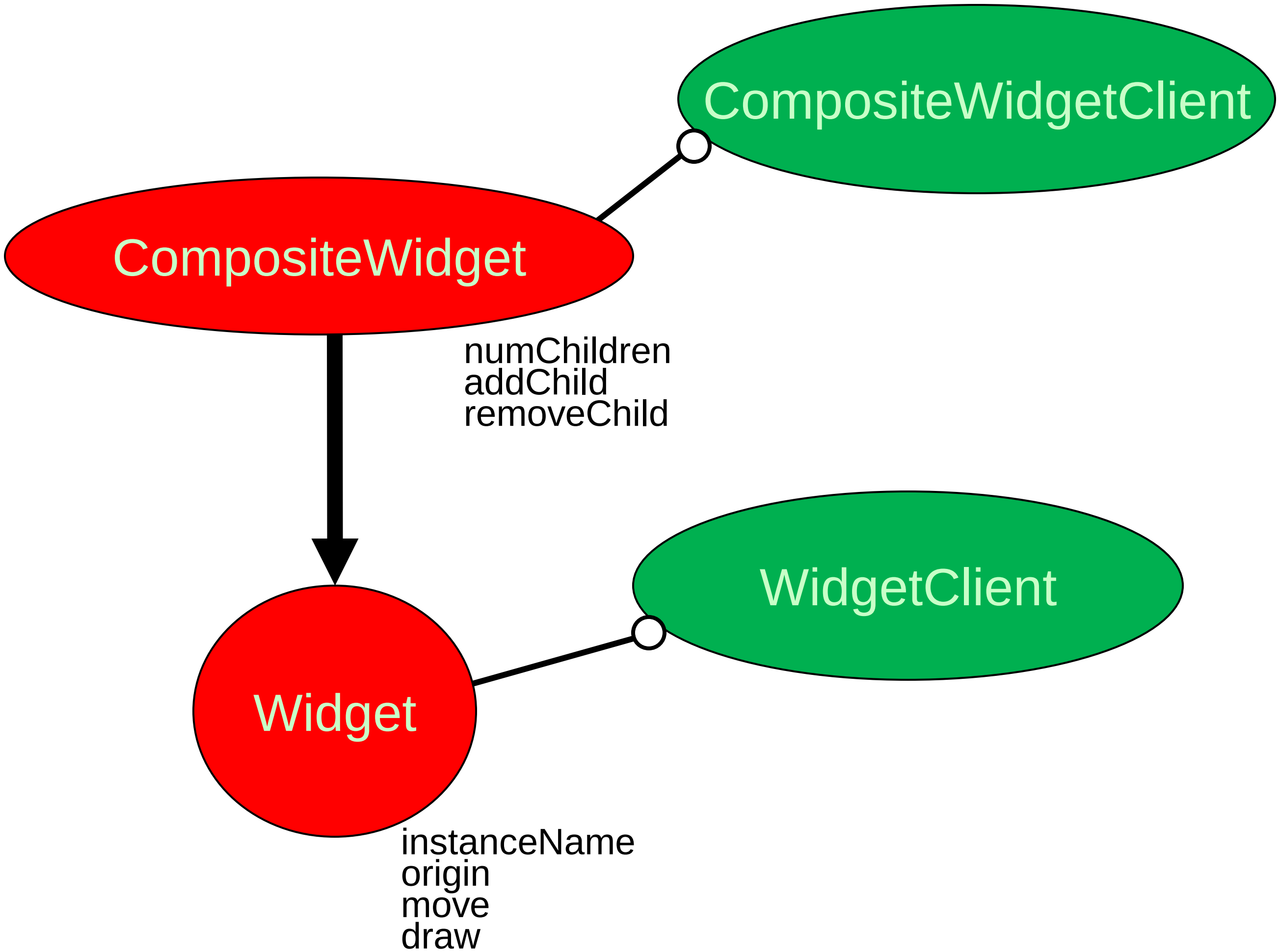
Note: No Runtime-Performance Overhead (e.g., due to Dynamic Binding).

Using Implementation Inheritance Effectively

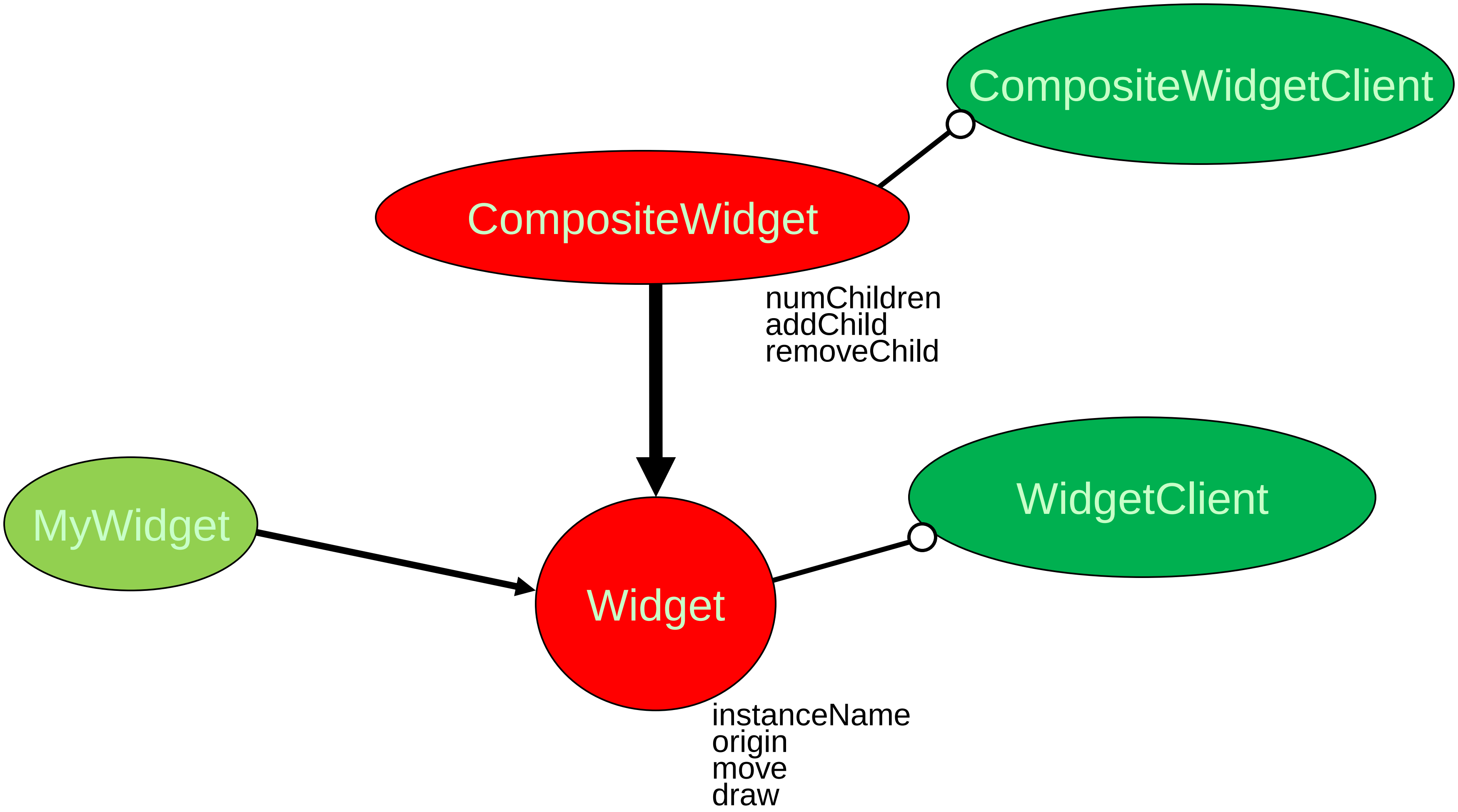


4. Proper Inheritance

Using Implementation Inheritance Effectively

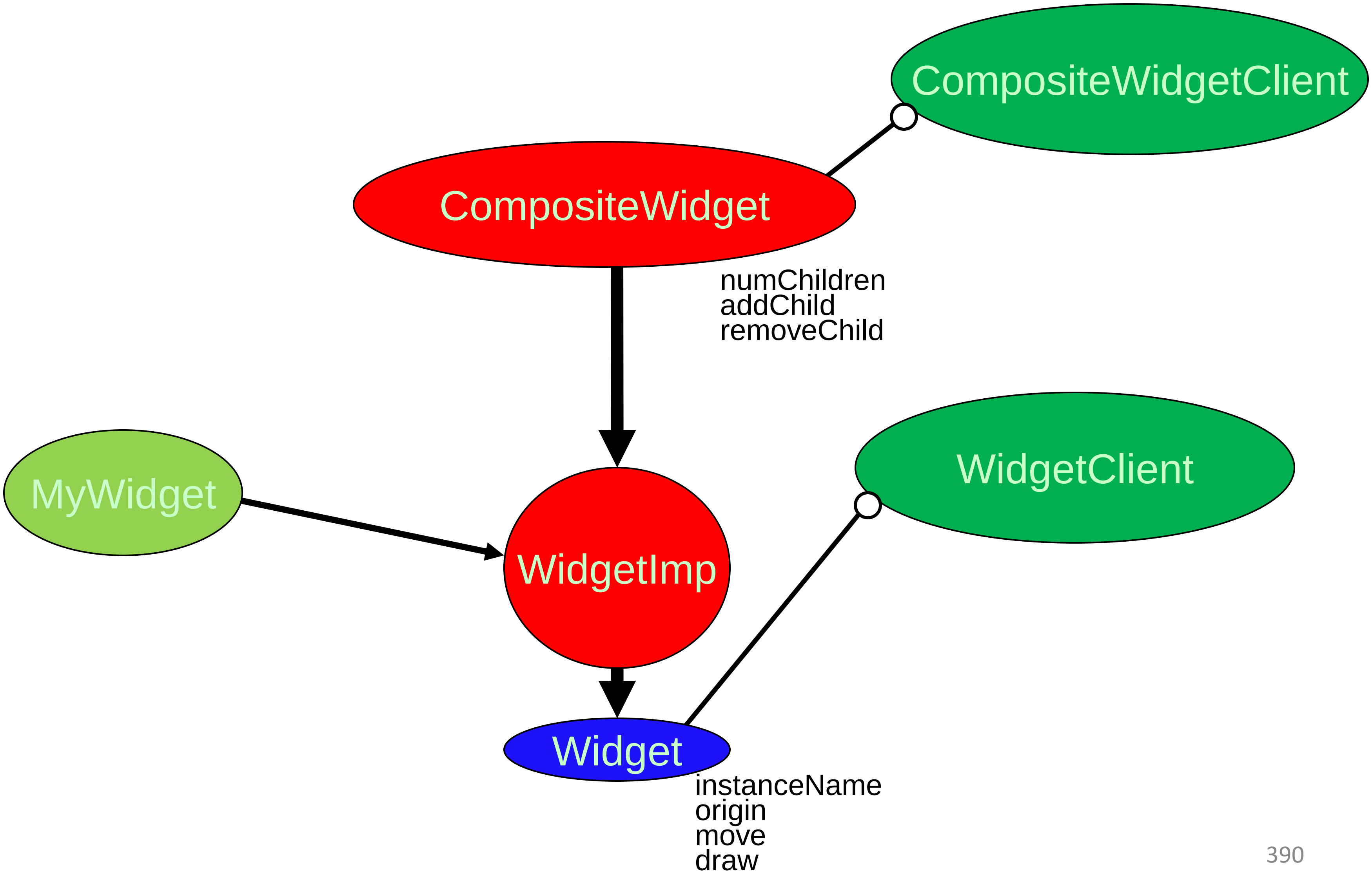


Using Implementation Inheritance Effectively



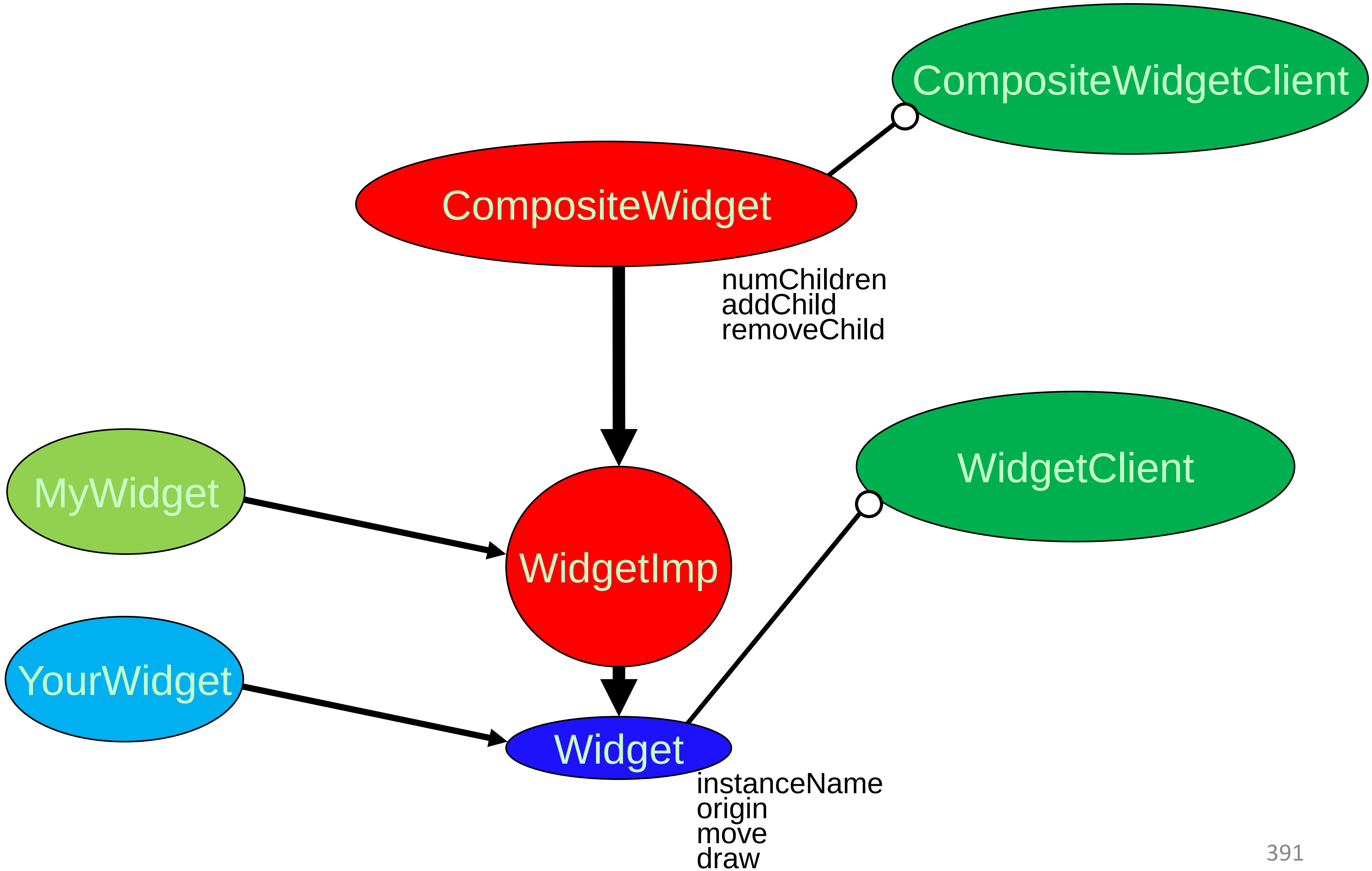
4. Proper Inheritance

Using Implementation Inheritance Effectively



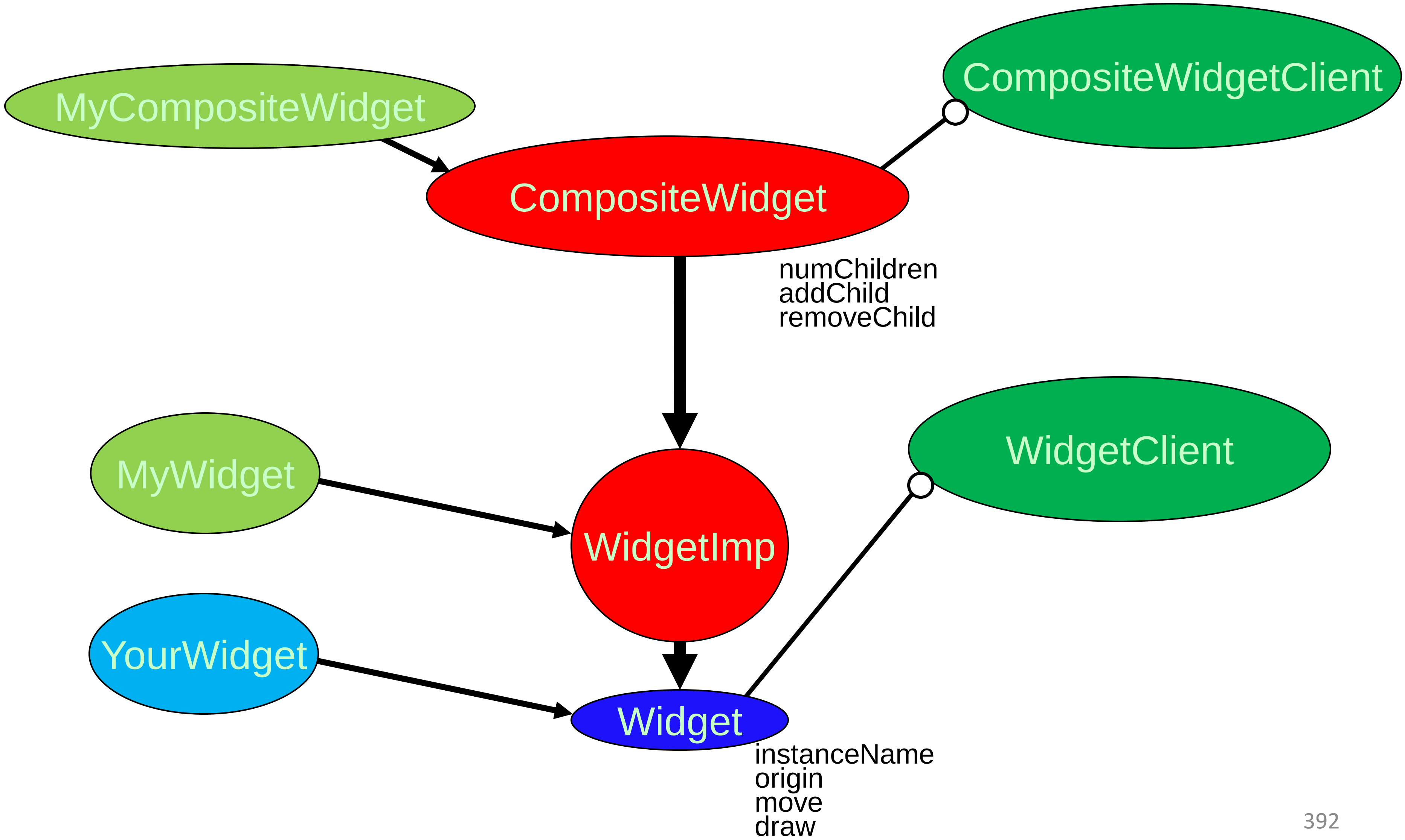
4. Proper Inheritance

Using Implementation Inheritance Effectively



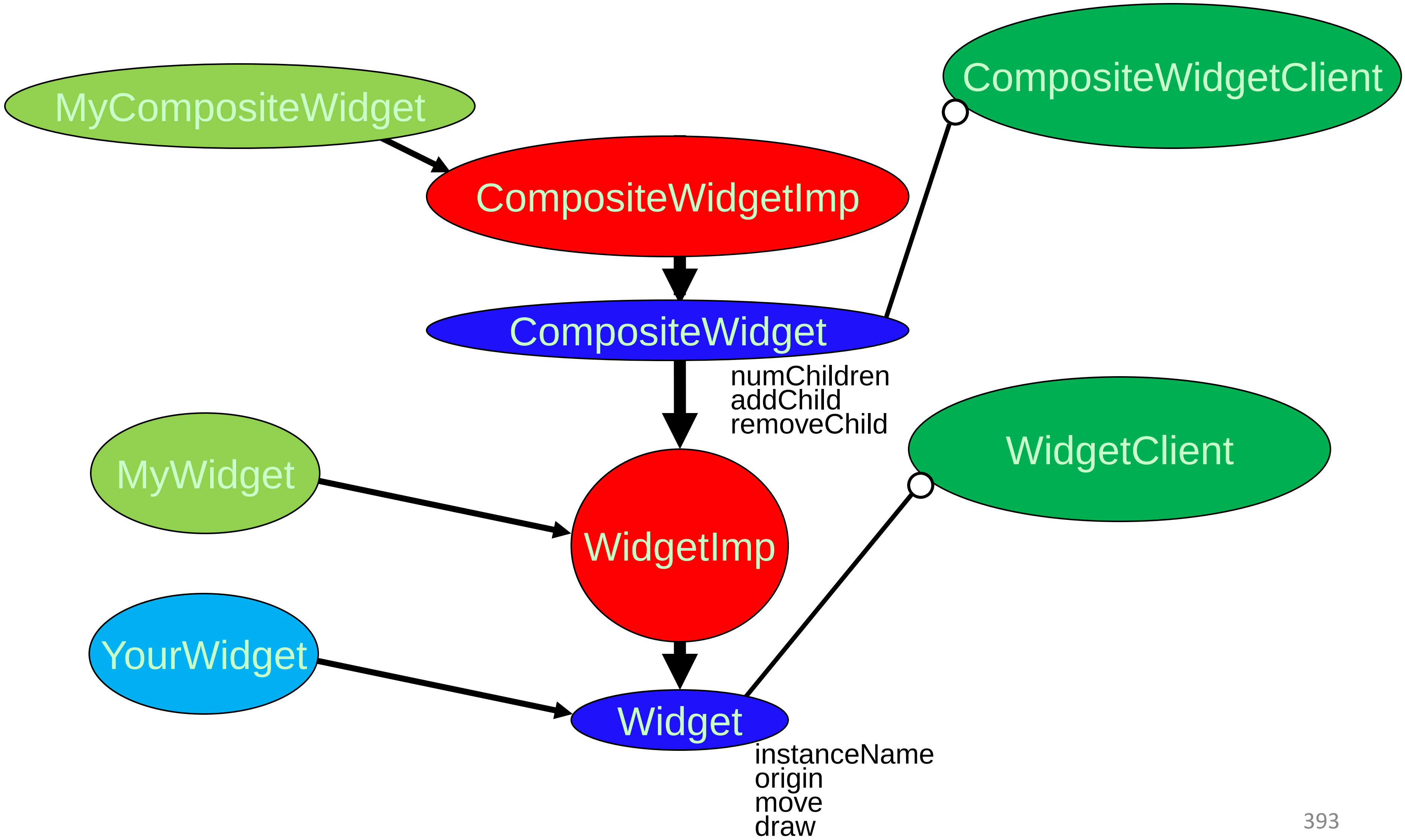
4. Proper Inheritance

Using Implementation Inheritance Effectively

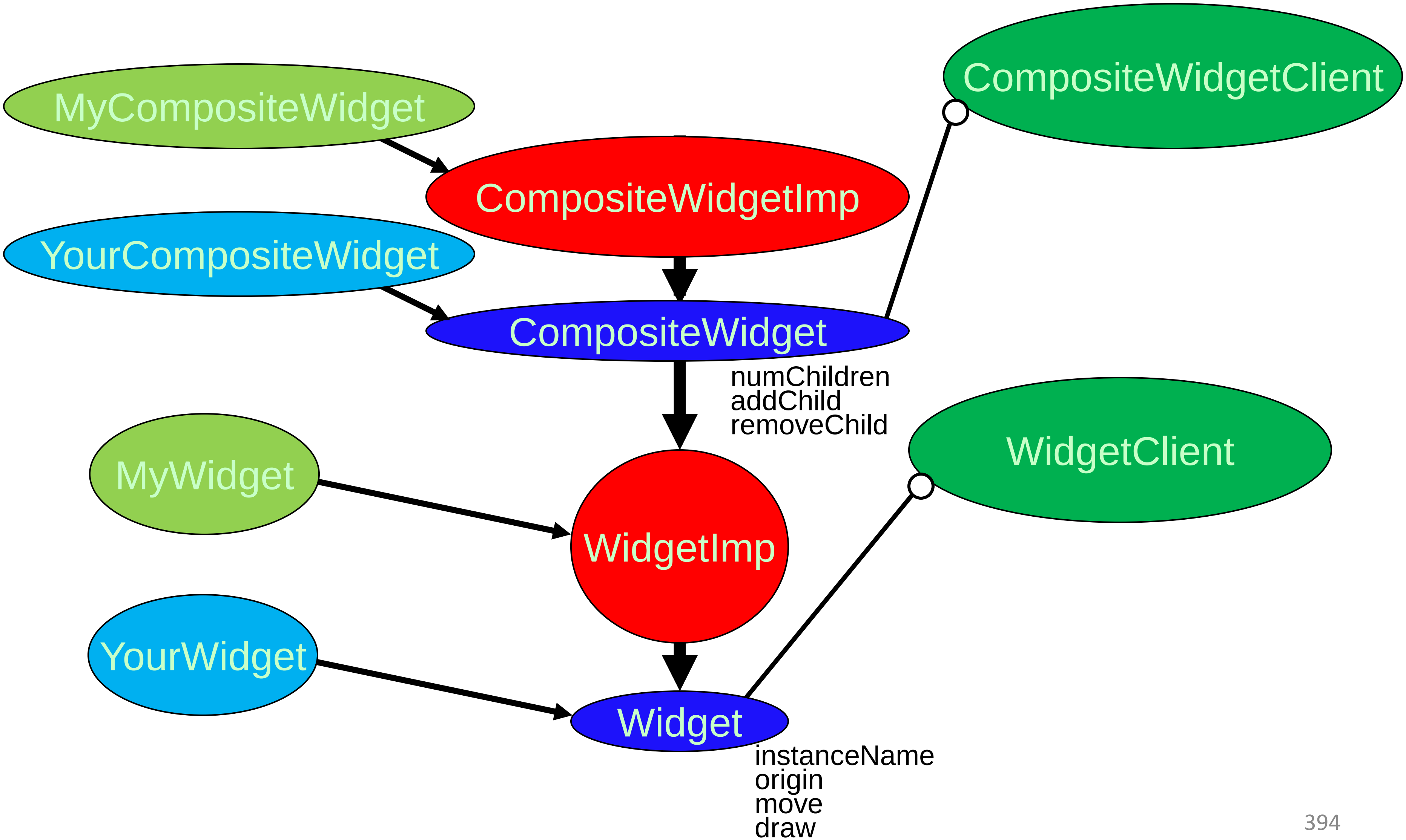


4. Proper Inheritance

Using Implementation Inheritance Effectively

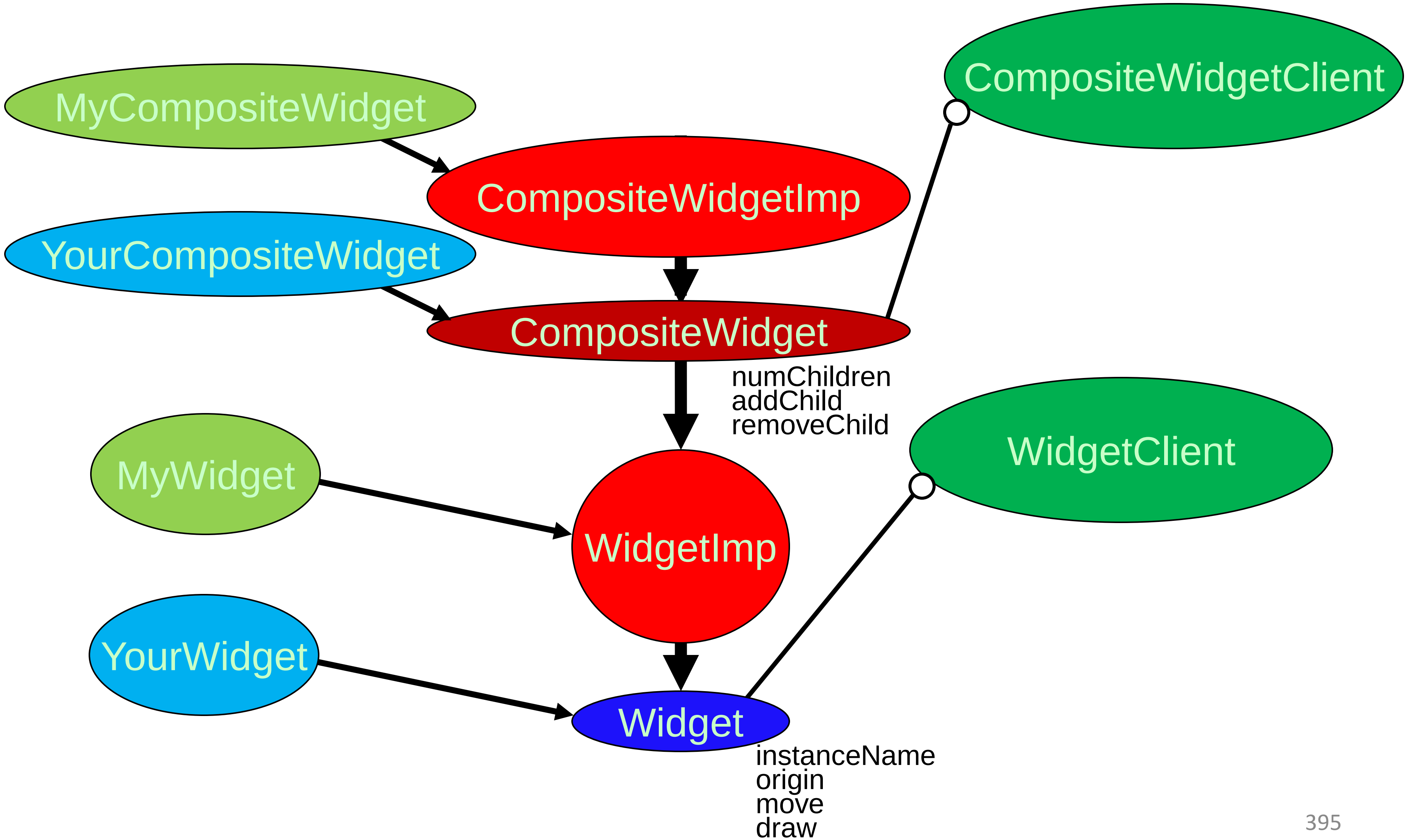


Using Implementation Inheritance Effectively



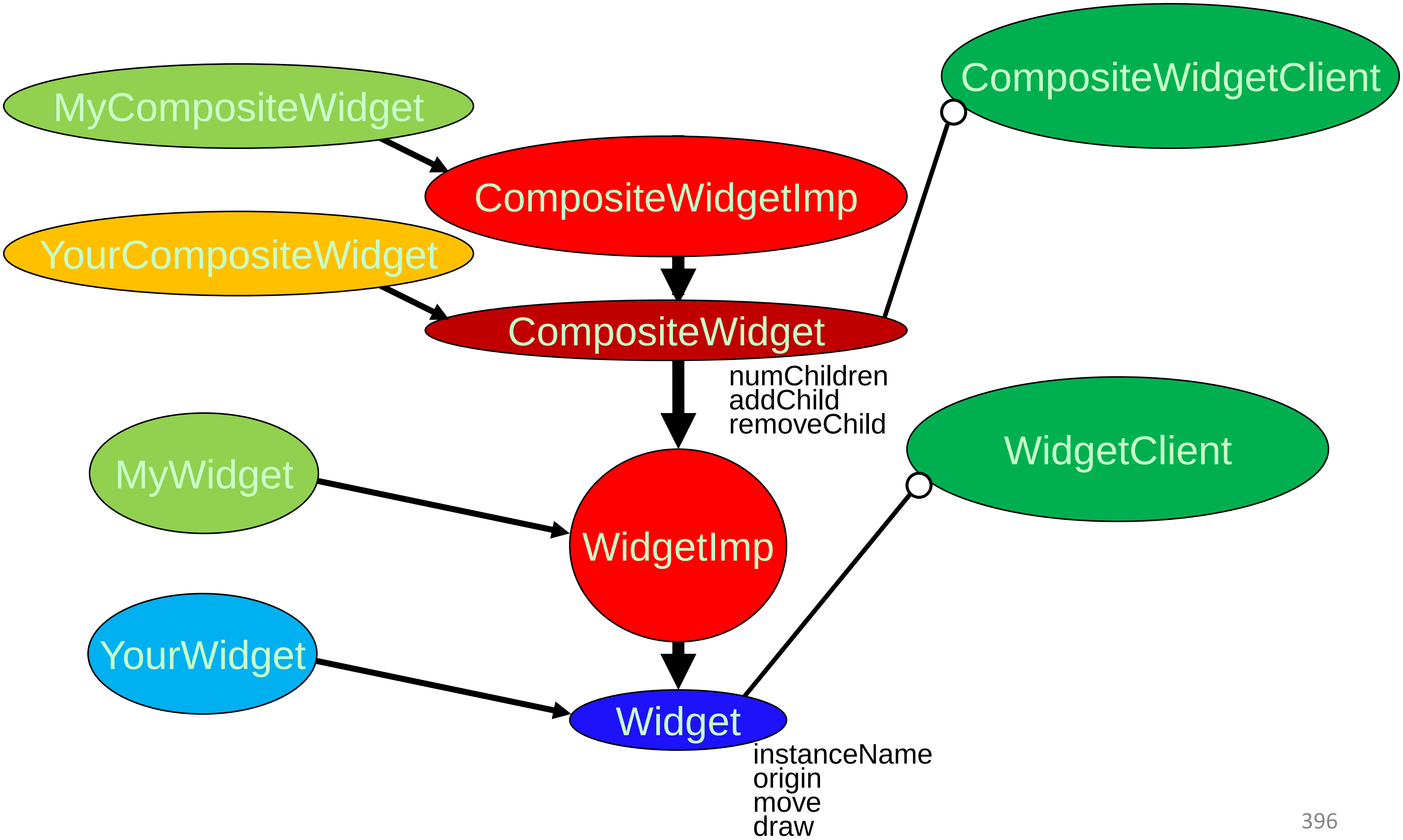
4. Proper Inheritance

Using Implementation Inheritance Effectively



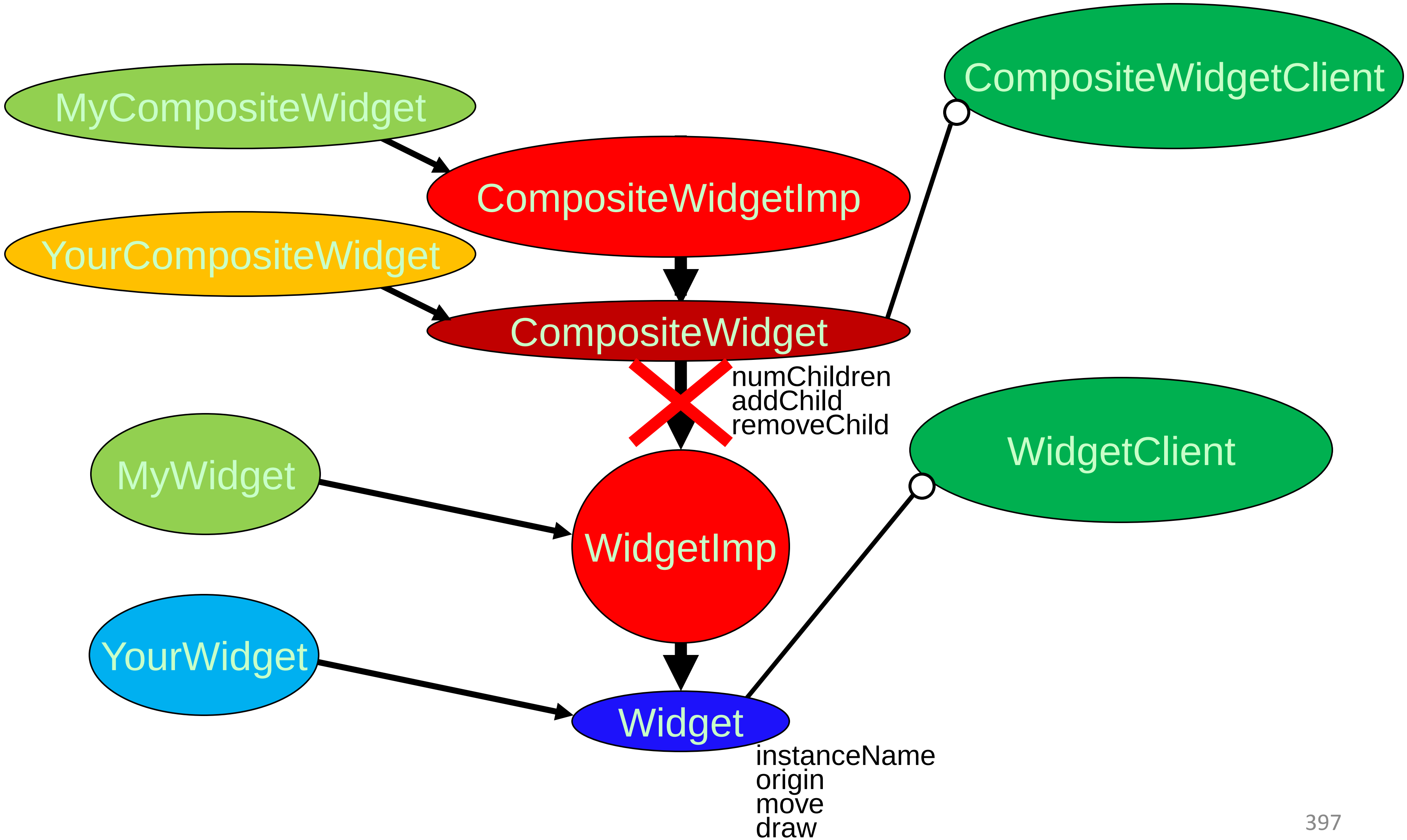
4. Proper Inheritance

Using Implementation Inheritance Effectively



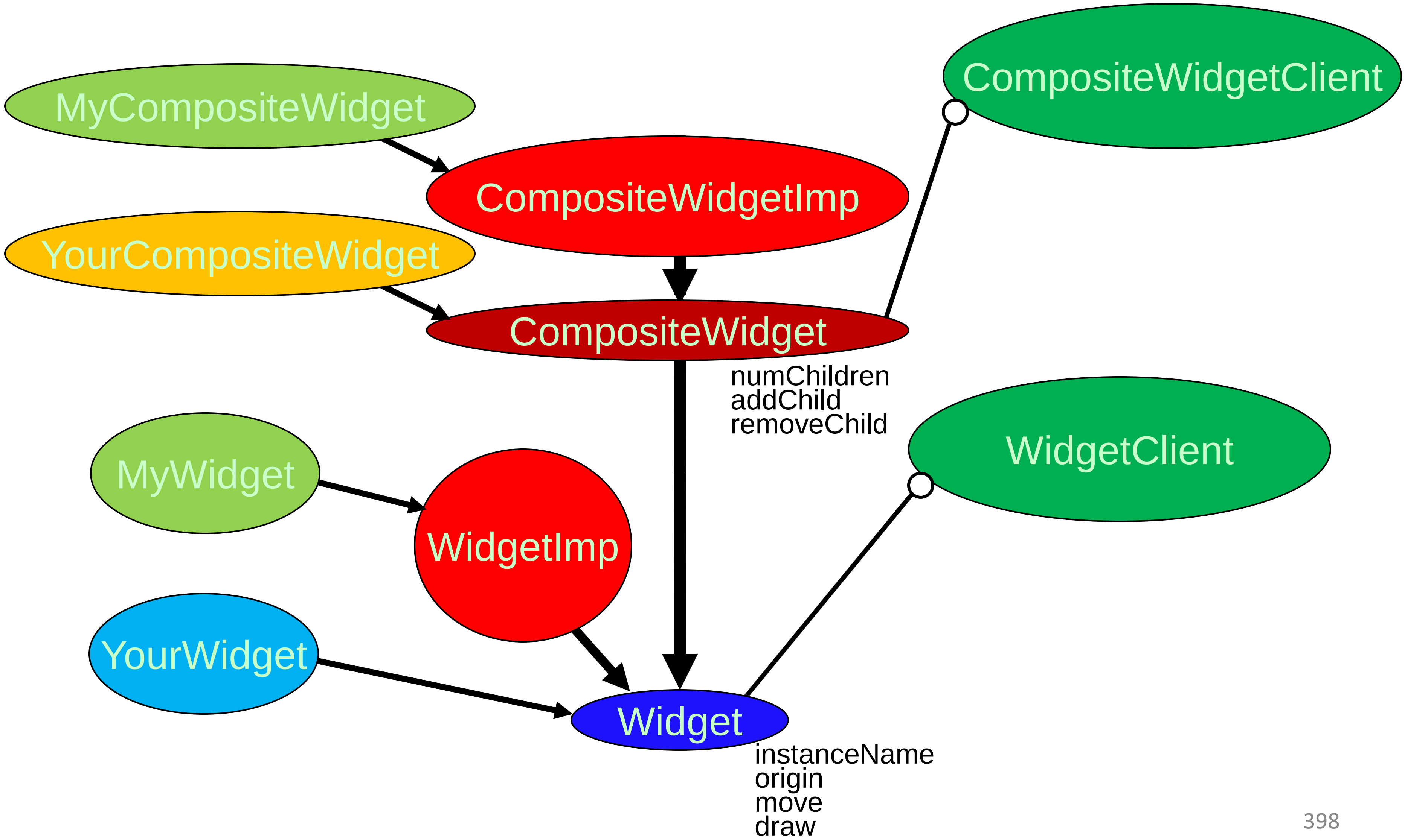
4. Proper Inheritance

Using Implementation Inheritance Effectively



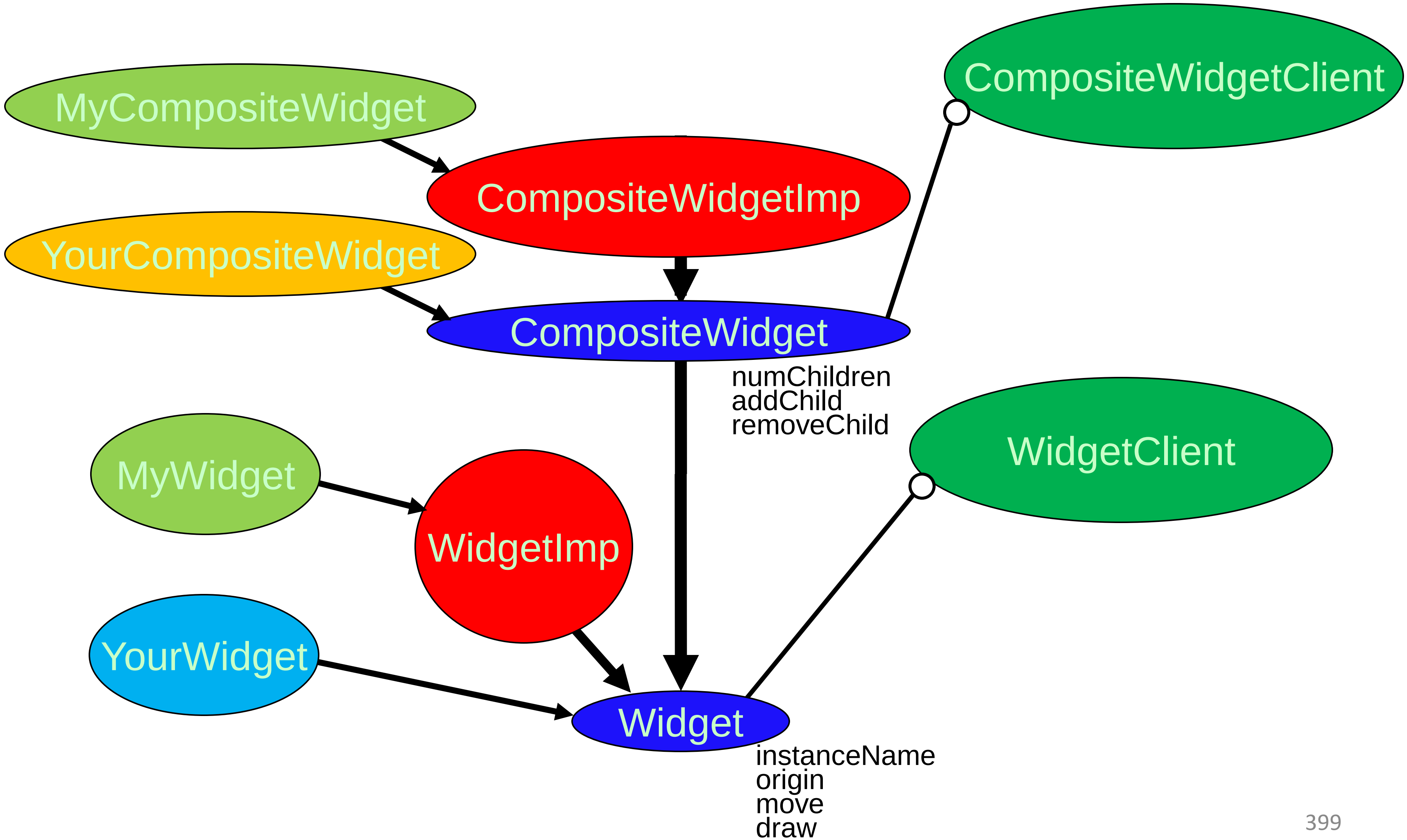
4. Proper Inheritance

Using Implementation Inheritance Effectively



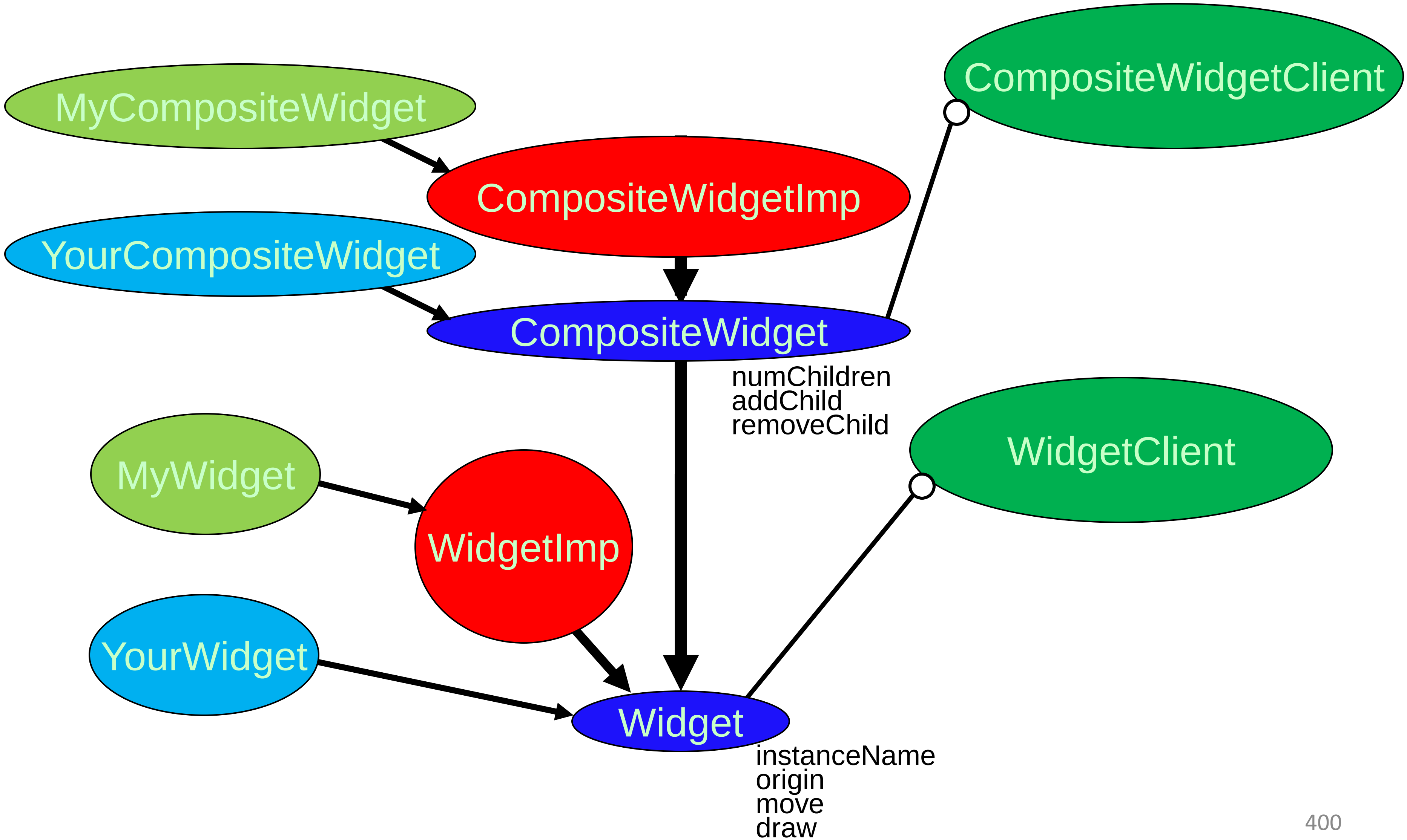
4. Proper Inheritance

Using Implementation Inheritance Effectively



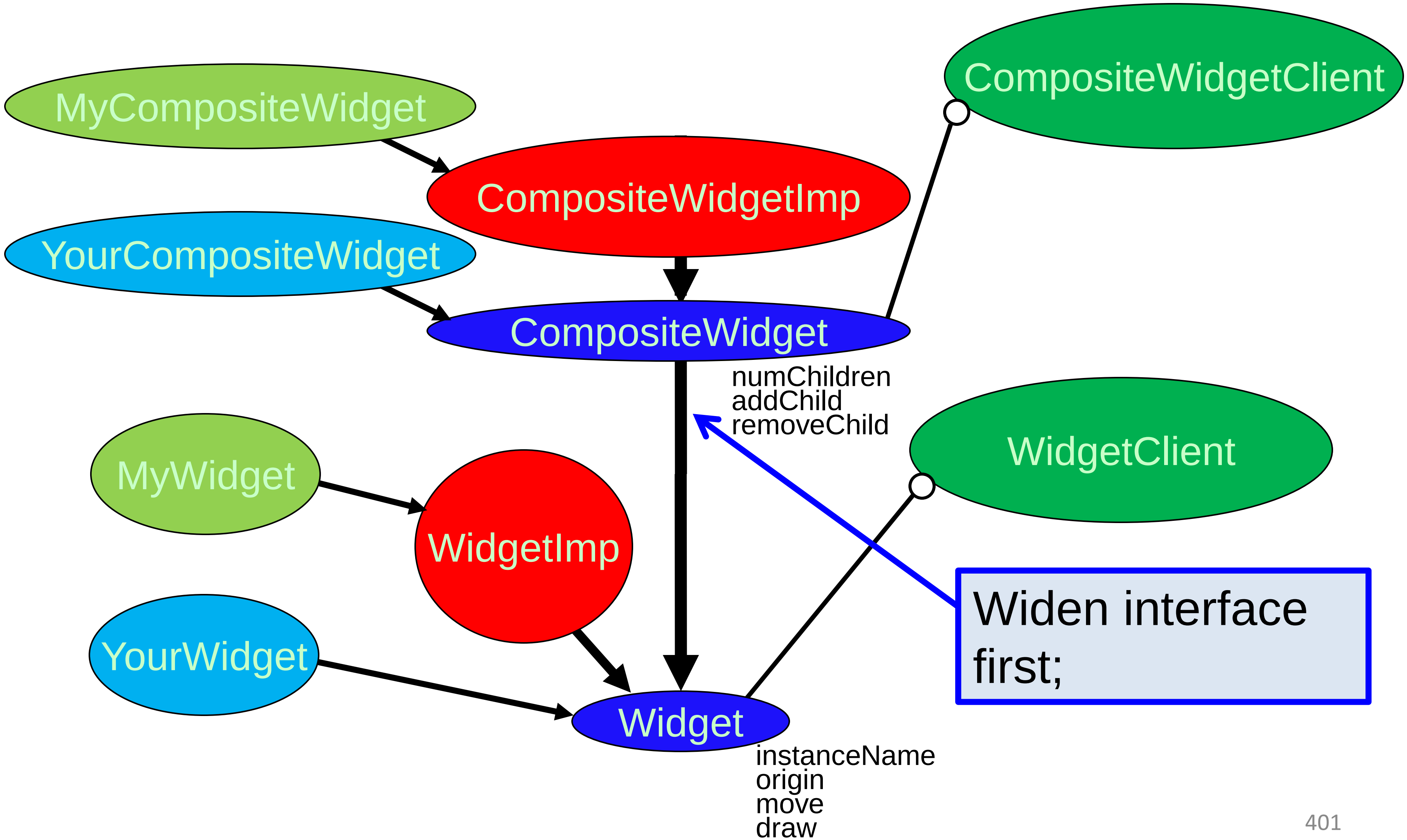
4. Proper Inheritance

Using Implementation Inheritance Effectively



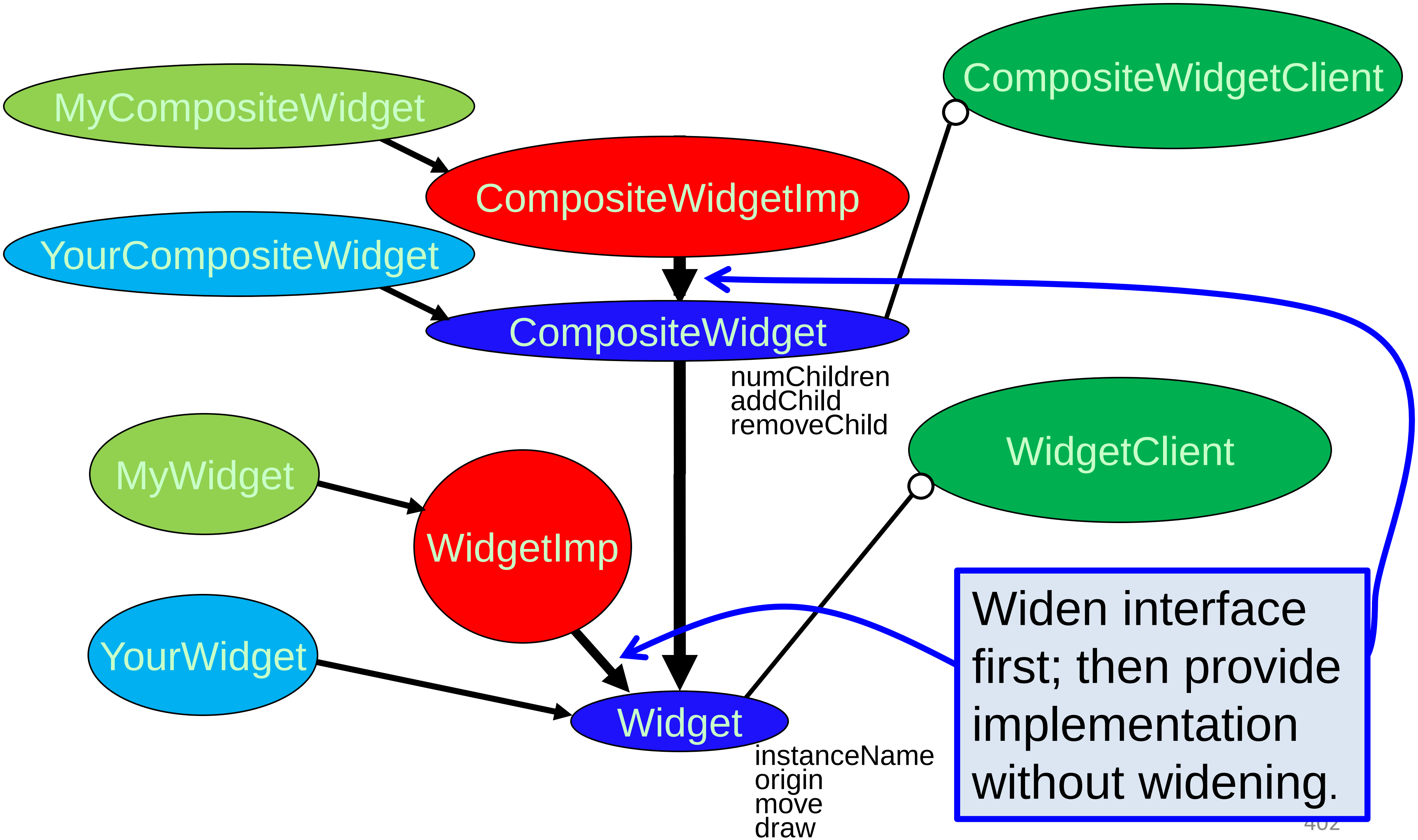
4. Proper Inheritance

Using Implementation Inheritance Effectively



4. Proper Inheritance

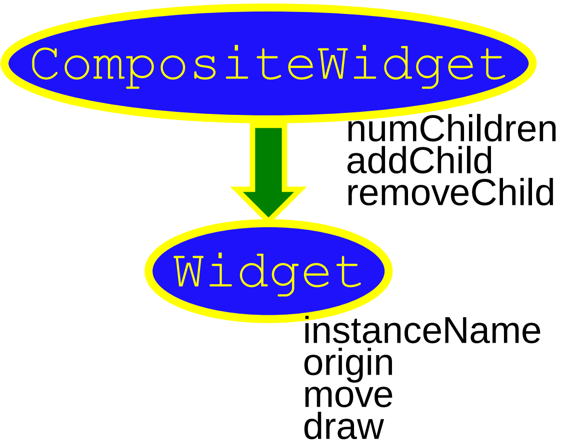
Using Implementation Inheritance Effectively



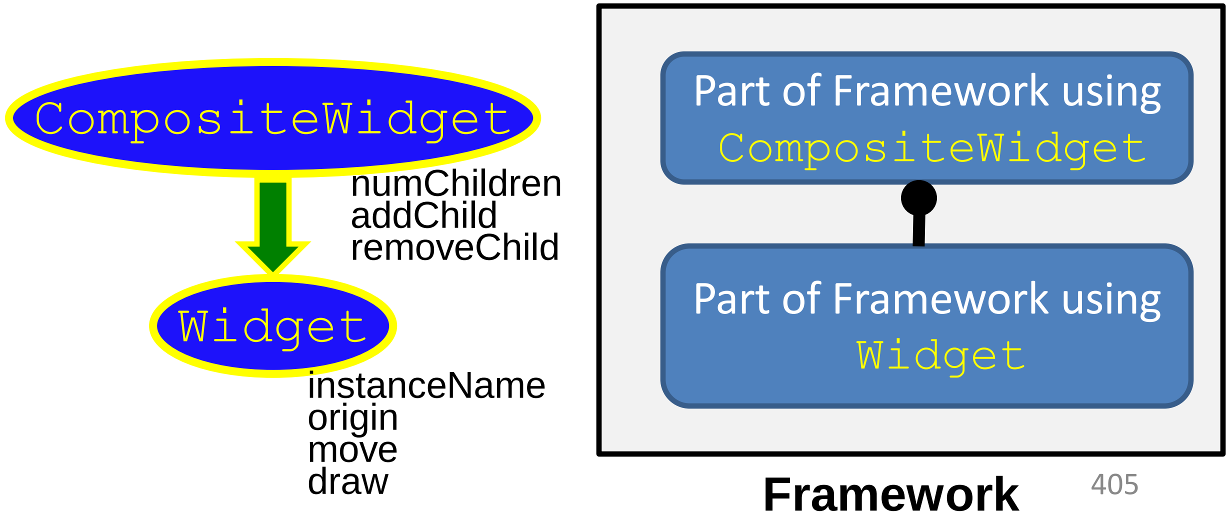
Using Implementation Inheritance Effectively

The principal client of
Implementation Inheritance
is the
DERIVED-CLASS AUTHOR.

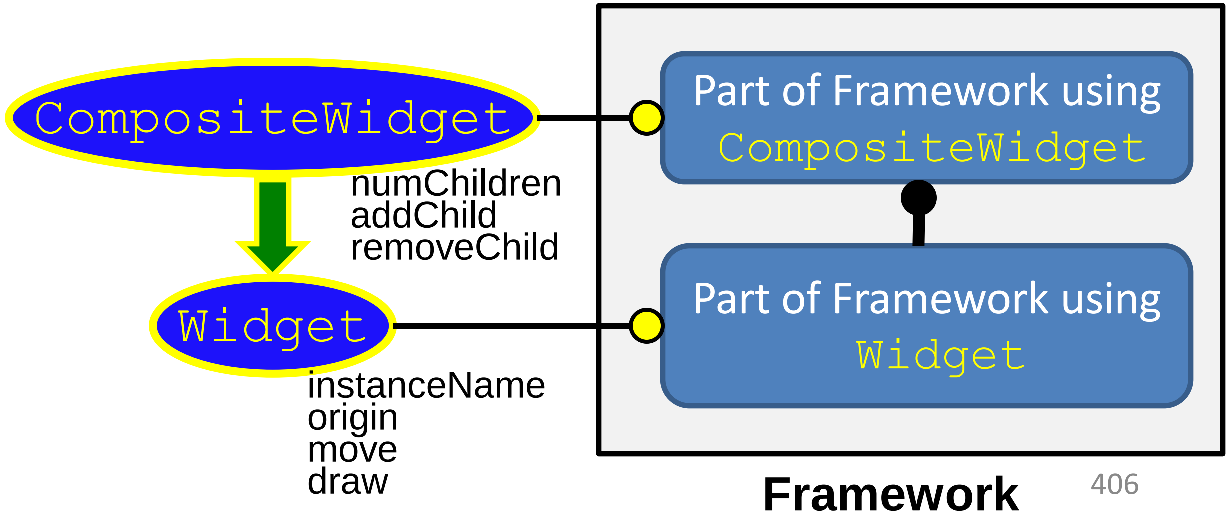
Using Implementation Inheritance Effectively



Using Implementation Inheritance Effectively



Using Implementation Inheritance Effectively



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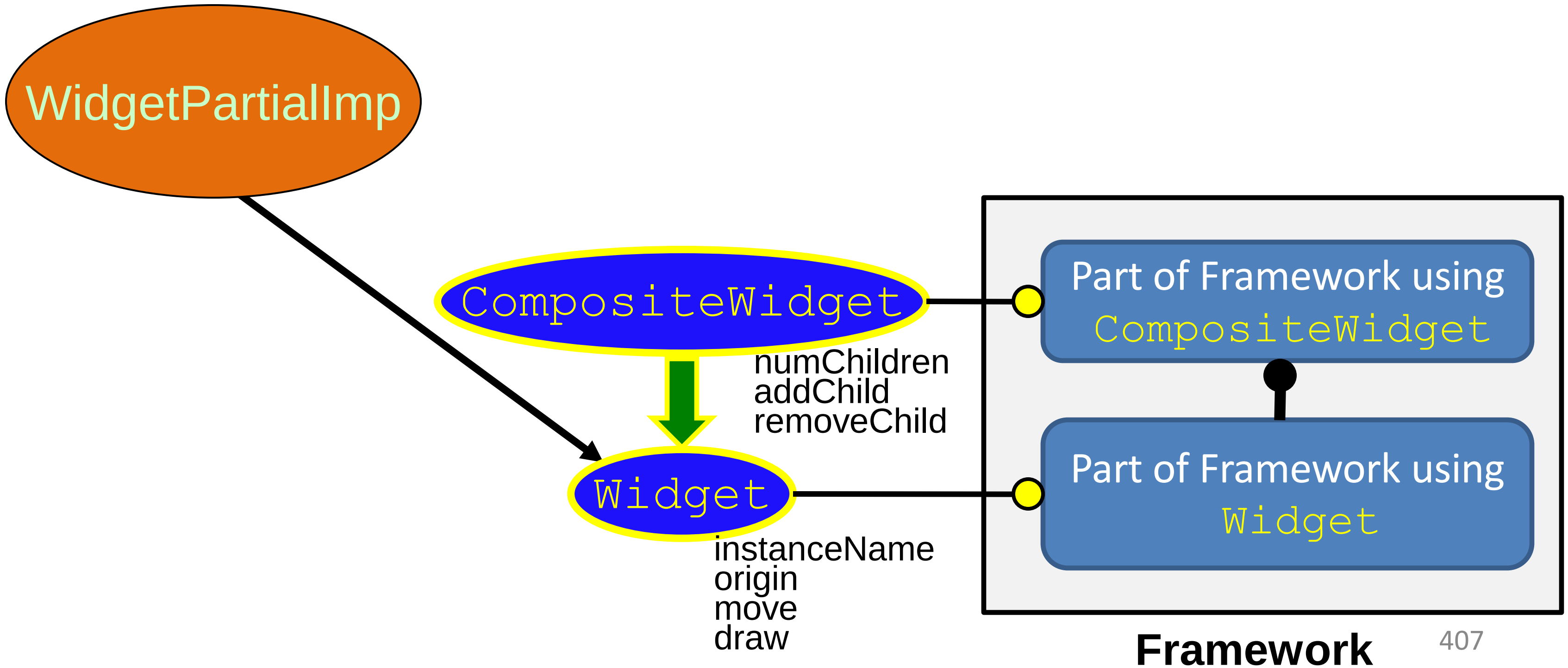

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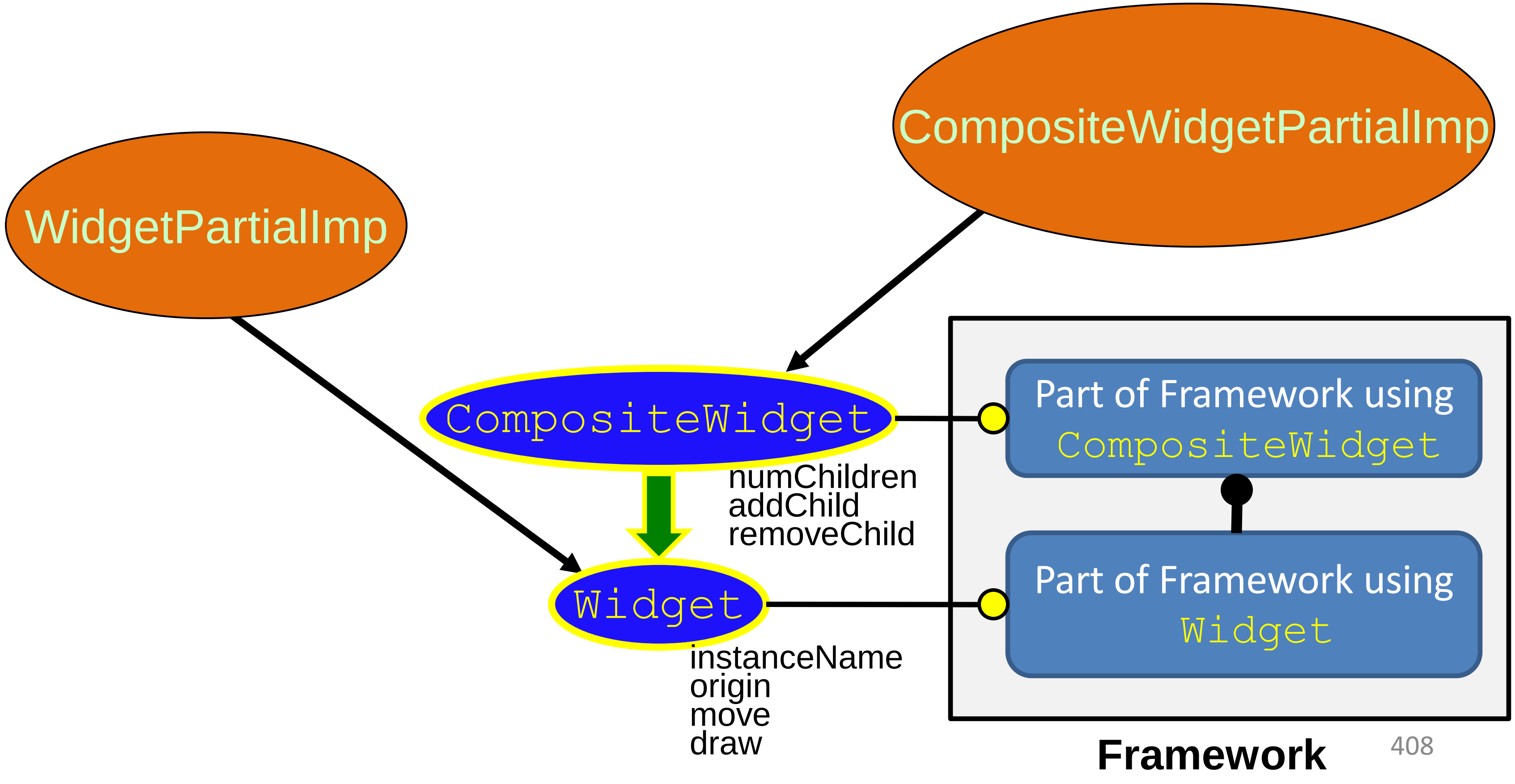

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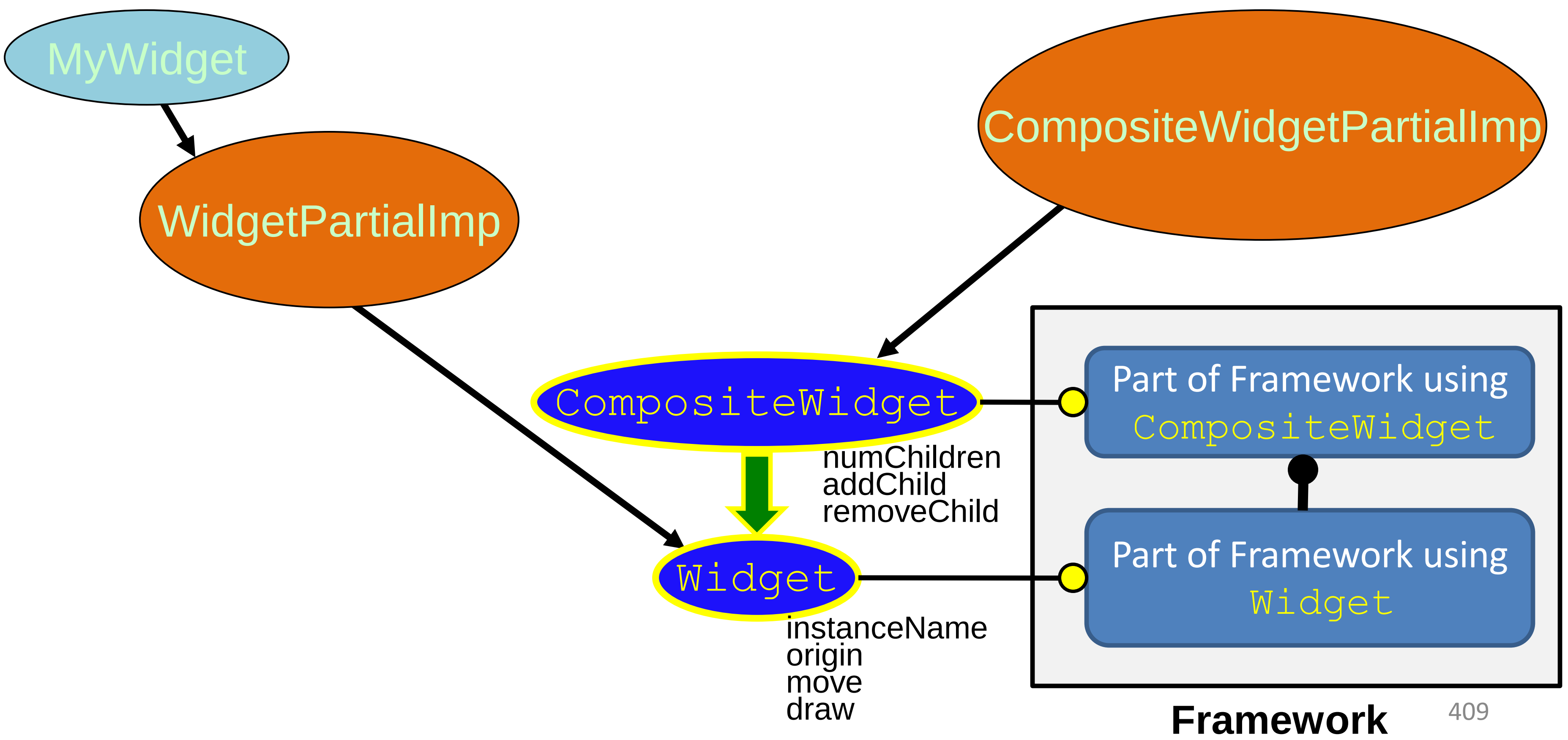
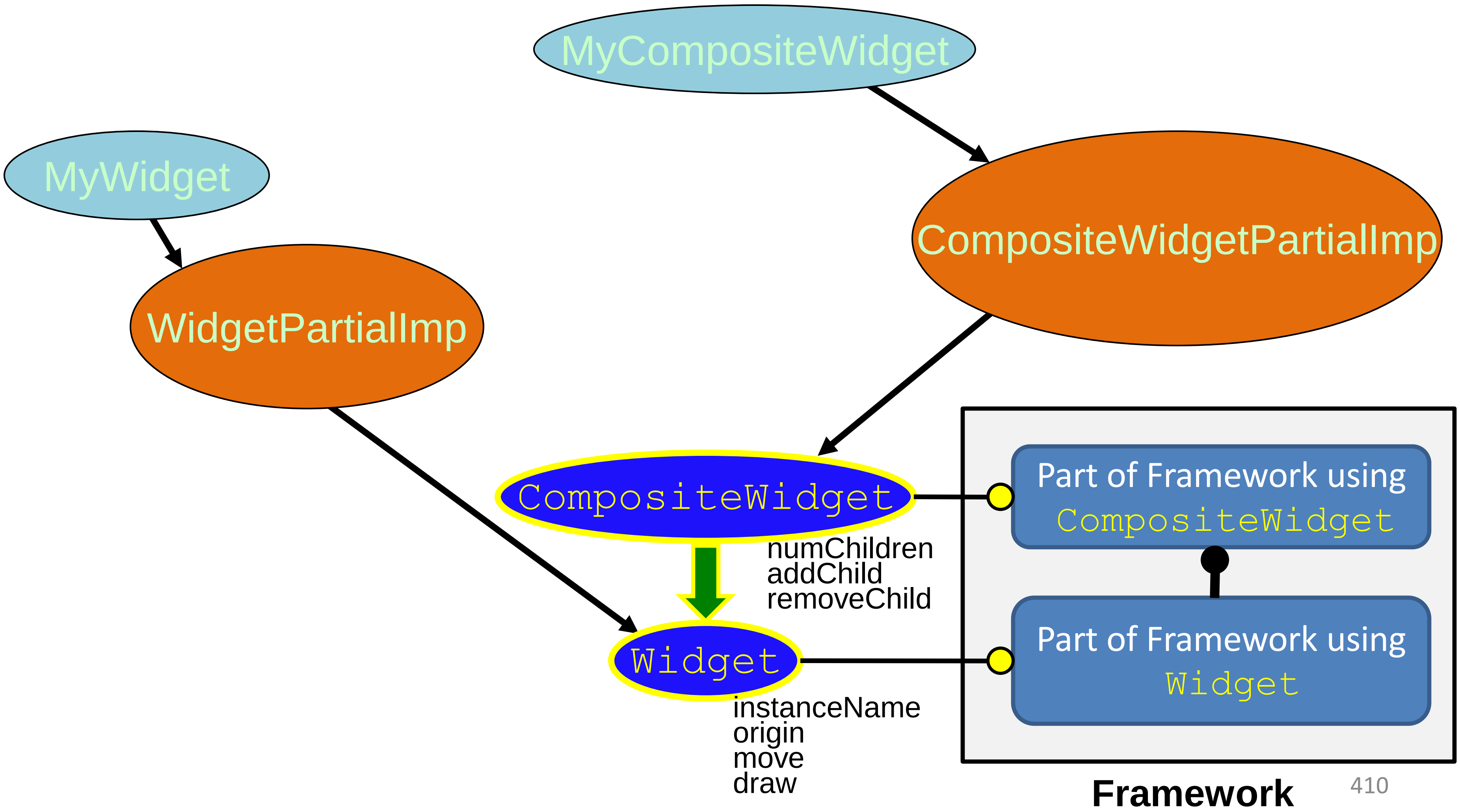


4. Proper Inheritance

Using Implementation Inheritance Effectively



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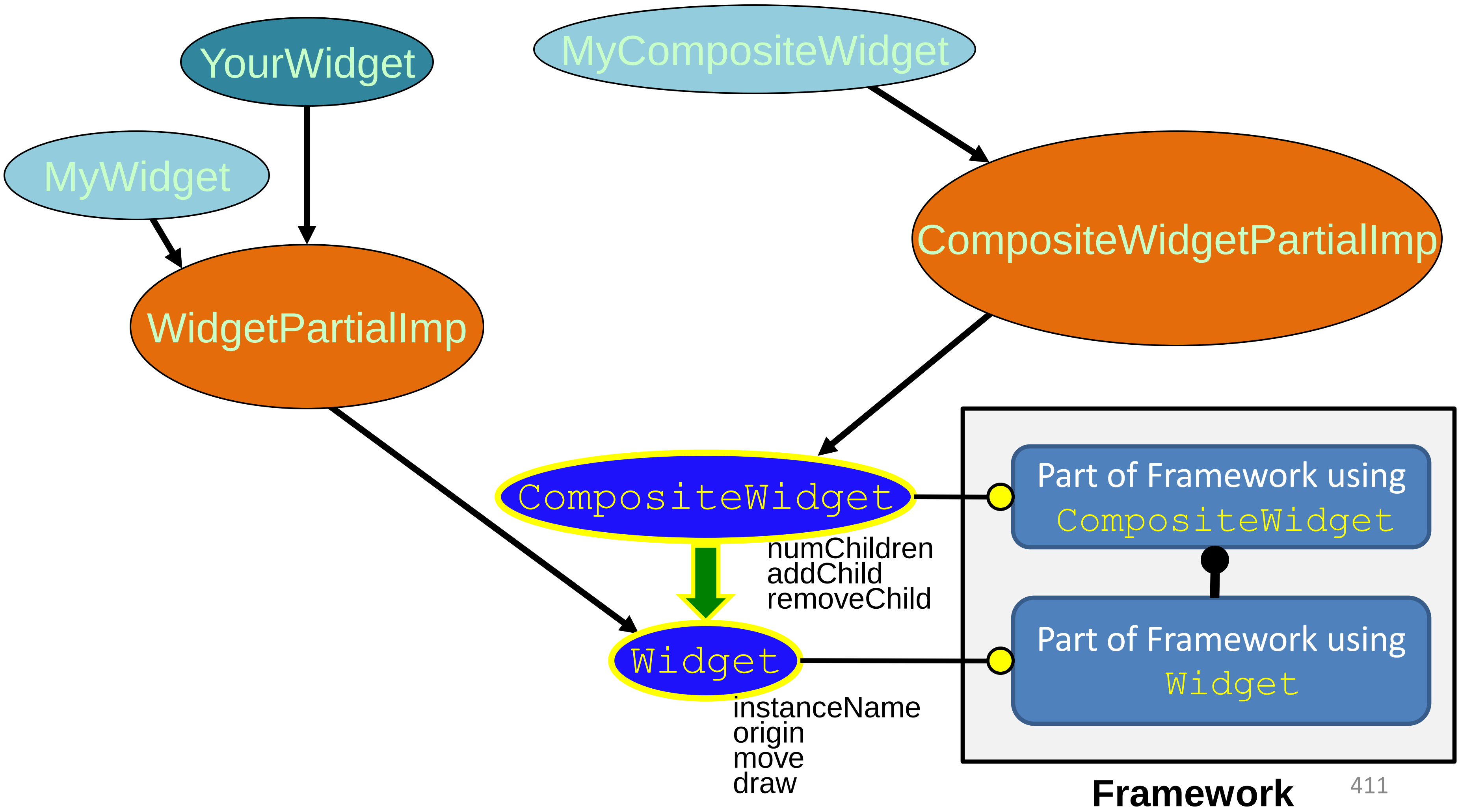

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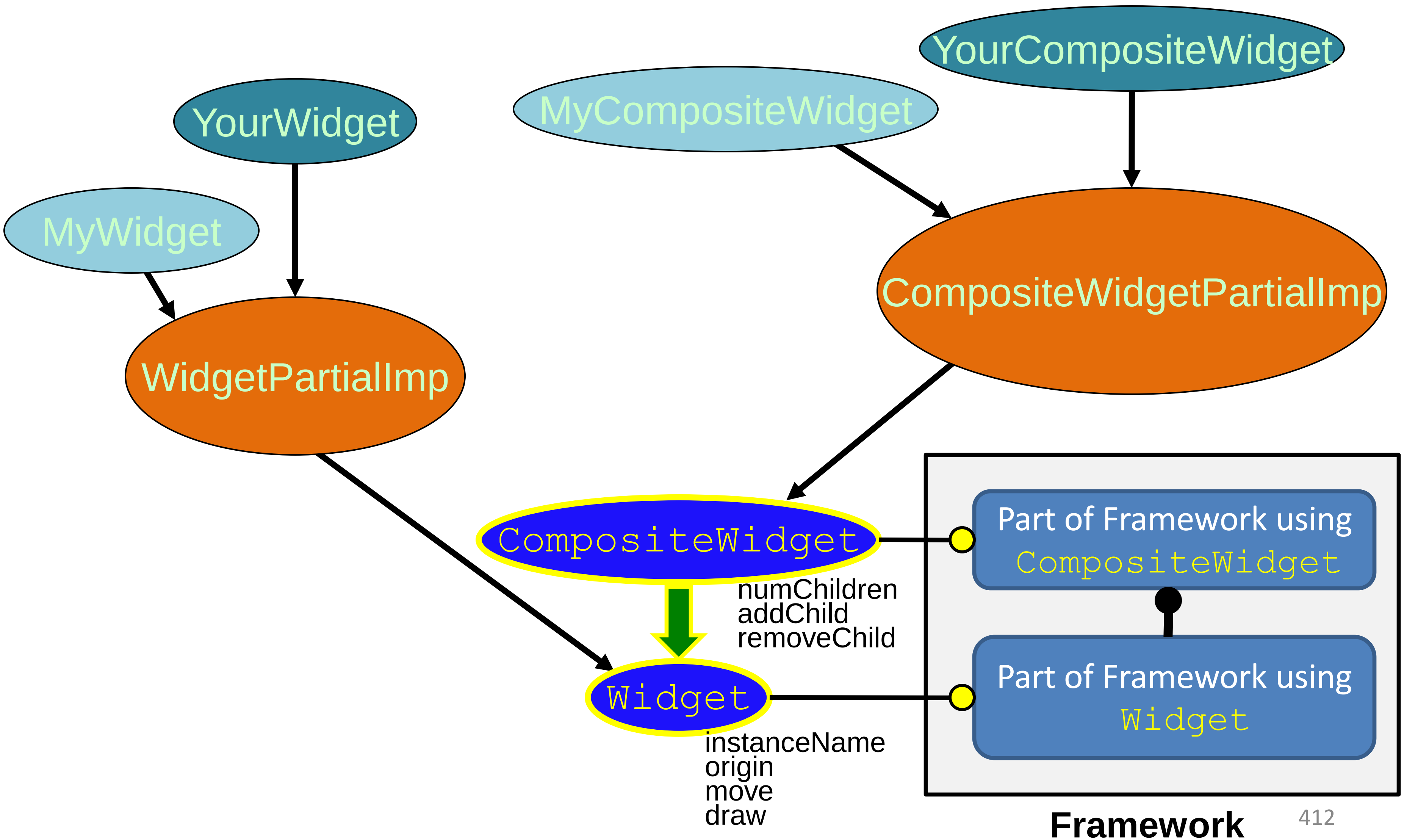

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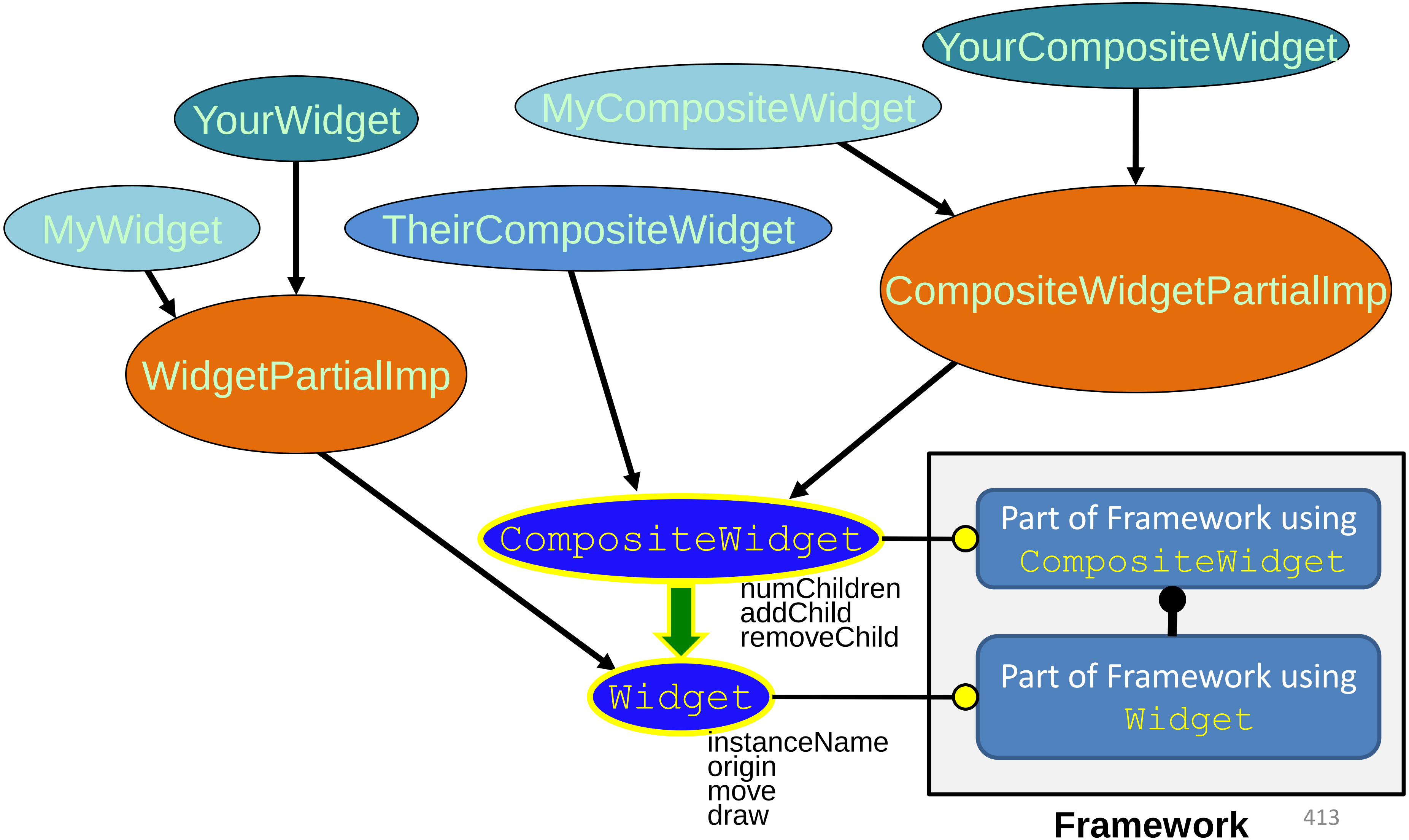
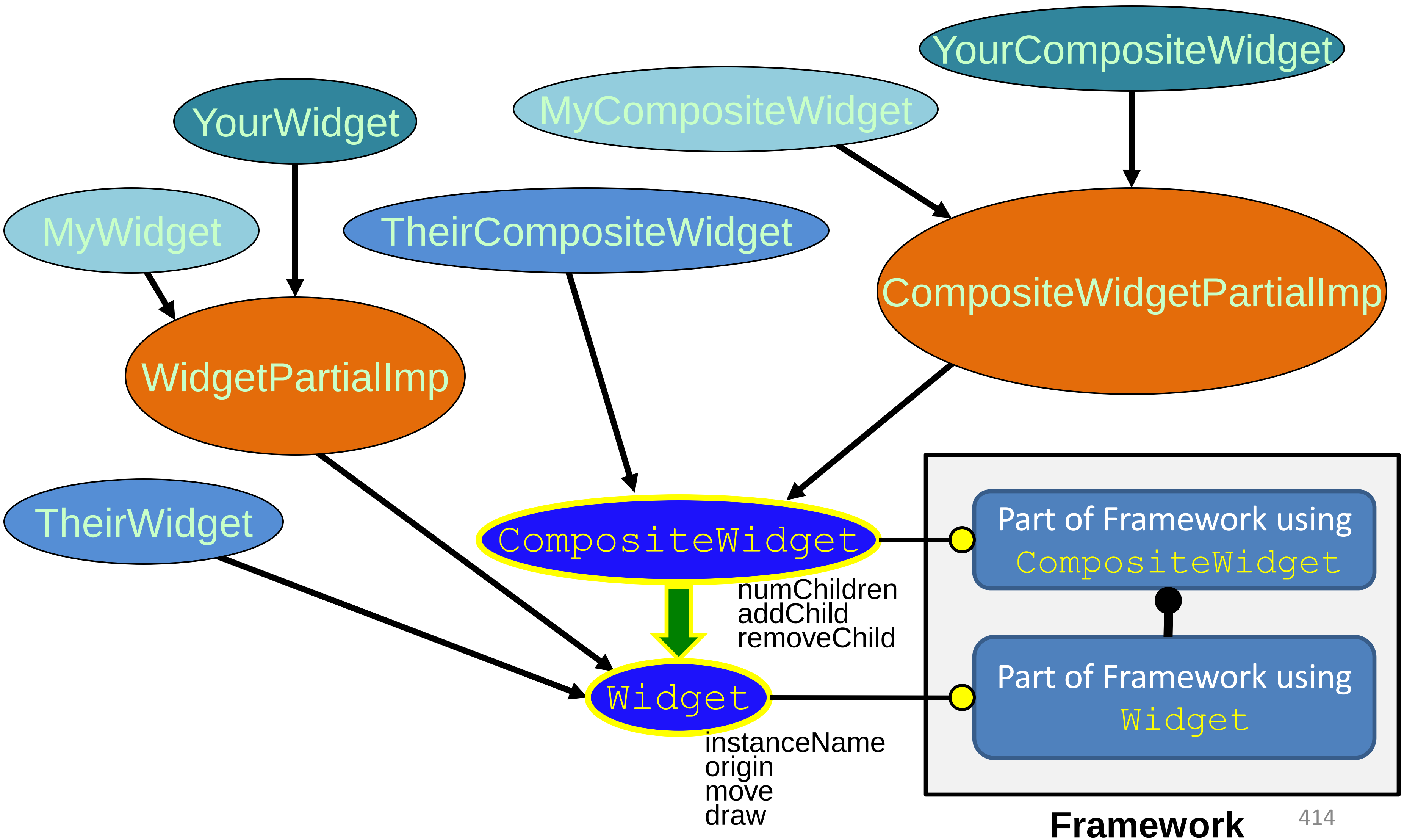


4. Proper Inheritance

Using Implementation Inheritance Effectively



Combining Kinds of Inheritance

Combining Kinds of Inheritance

- Structural & Interface

Combining Kinds of Inheritance

- Structural & Interface
  - Typically for Efficiency and Syntactic Sugar.

Combining Kinds of Inheritance

- Structural & Interface
  - Typically for Efficiency and Syntactic Sugar.
- Interface & Implementation

Combining Kinds of Inheritance

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- Interface & Implementation
  - Interface inheritance (widening) first; then implementation inheritance (no widening) .

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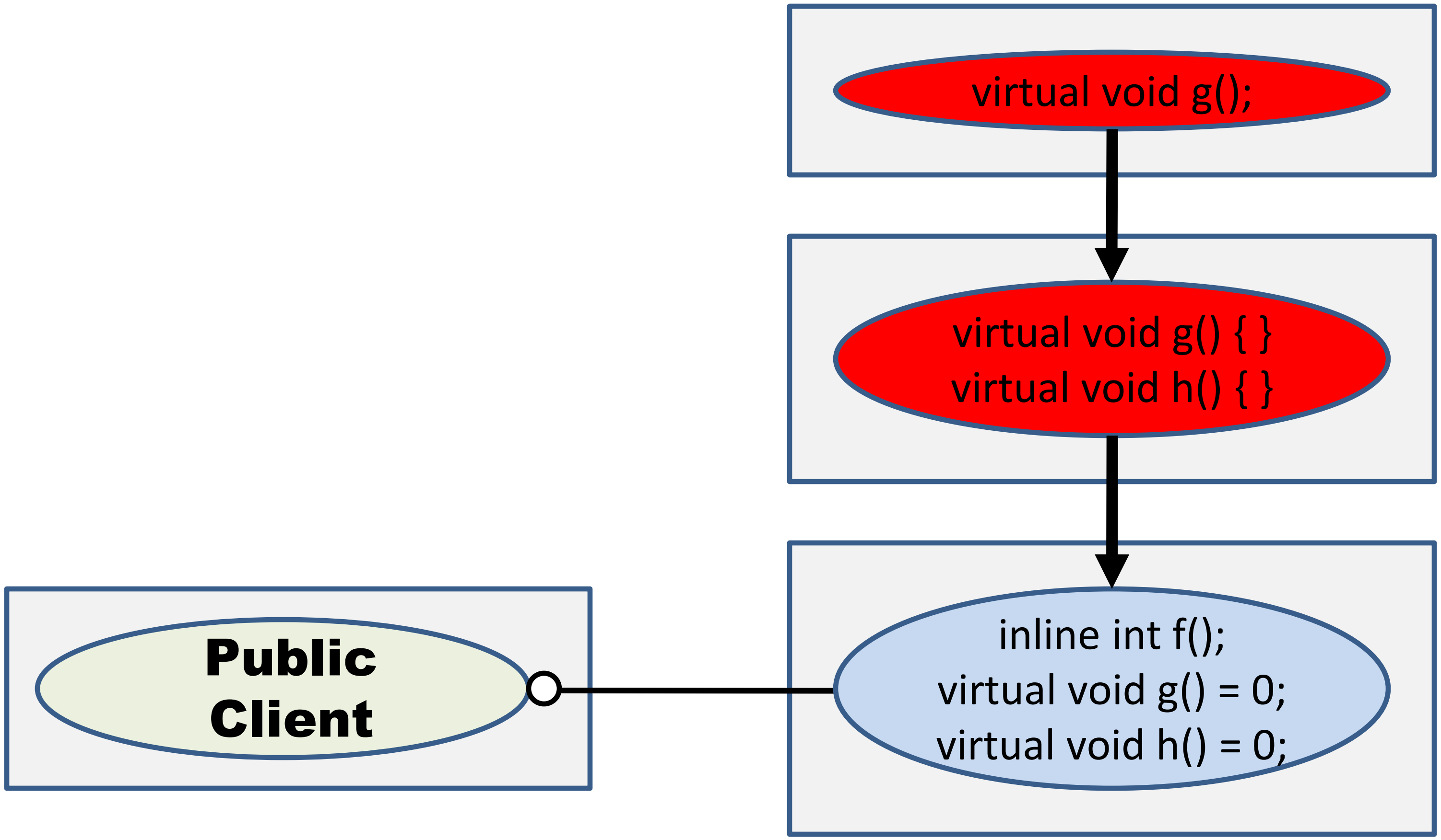
- Implementation & Structural

Combining Kinds of Inheritance

- Structural & Interface
  - Typically for Efficiency and Syntactic Sugar.
- Interface & Implementation
  - Interface inheritance (widening) first; then implementation inheritance (no widening) .
- Implementation & Structural
  - Bad Idea: Unnecessarily addresses the needs of derived class authors and public clients in the same physical component.

Combining Kinds of Inheritance



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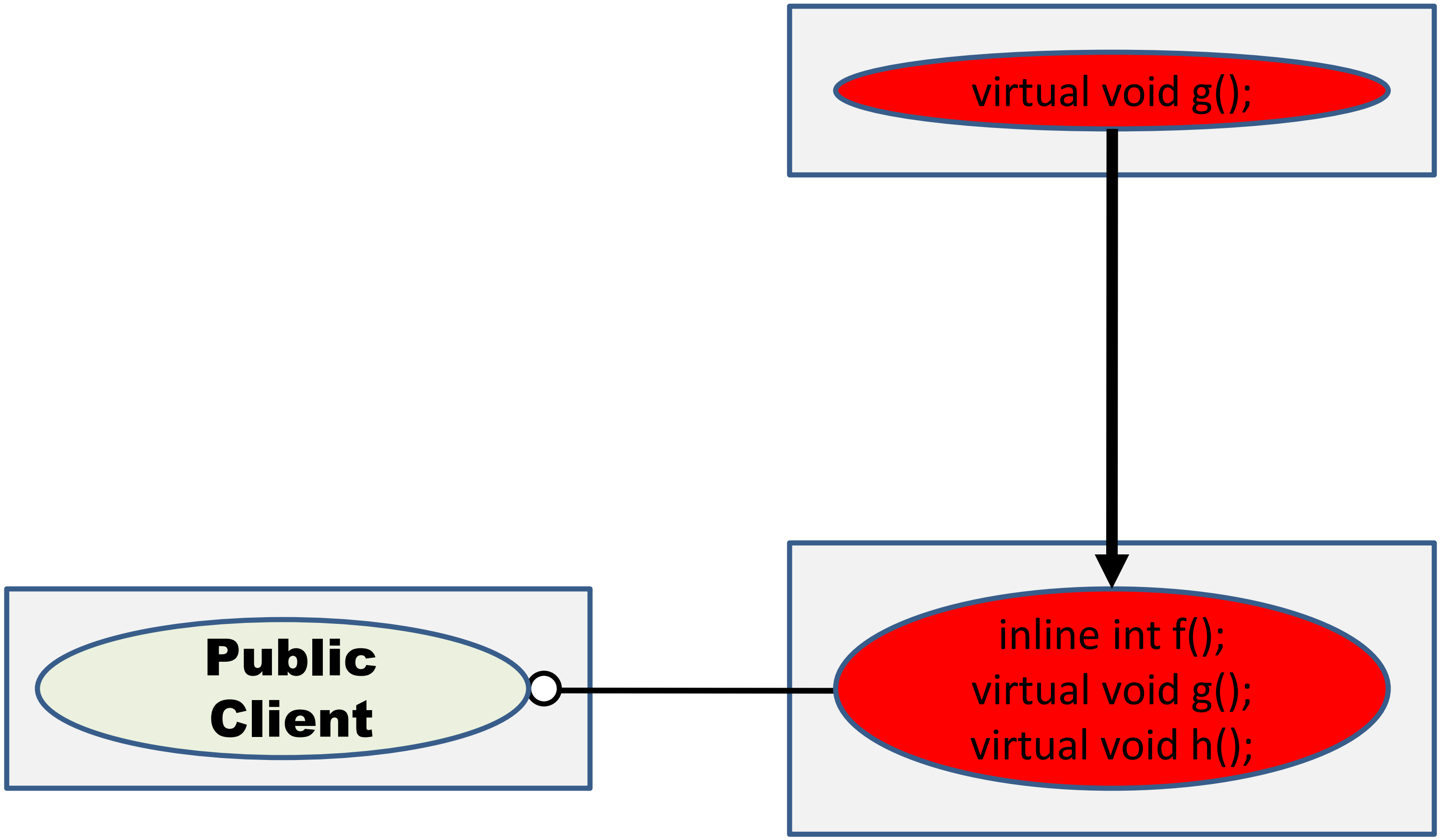

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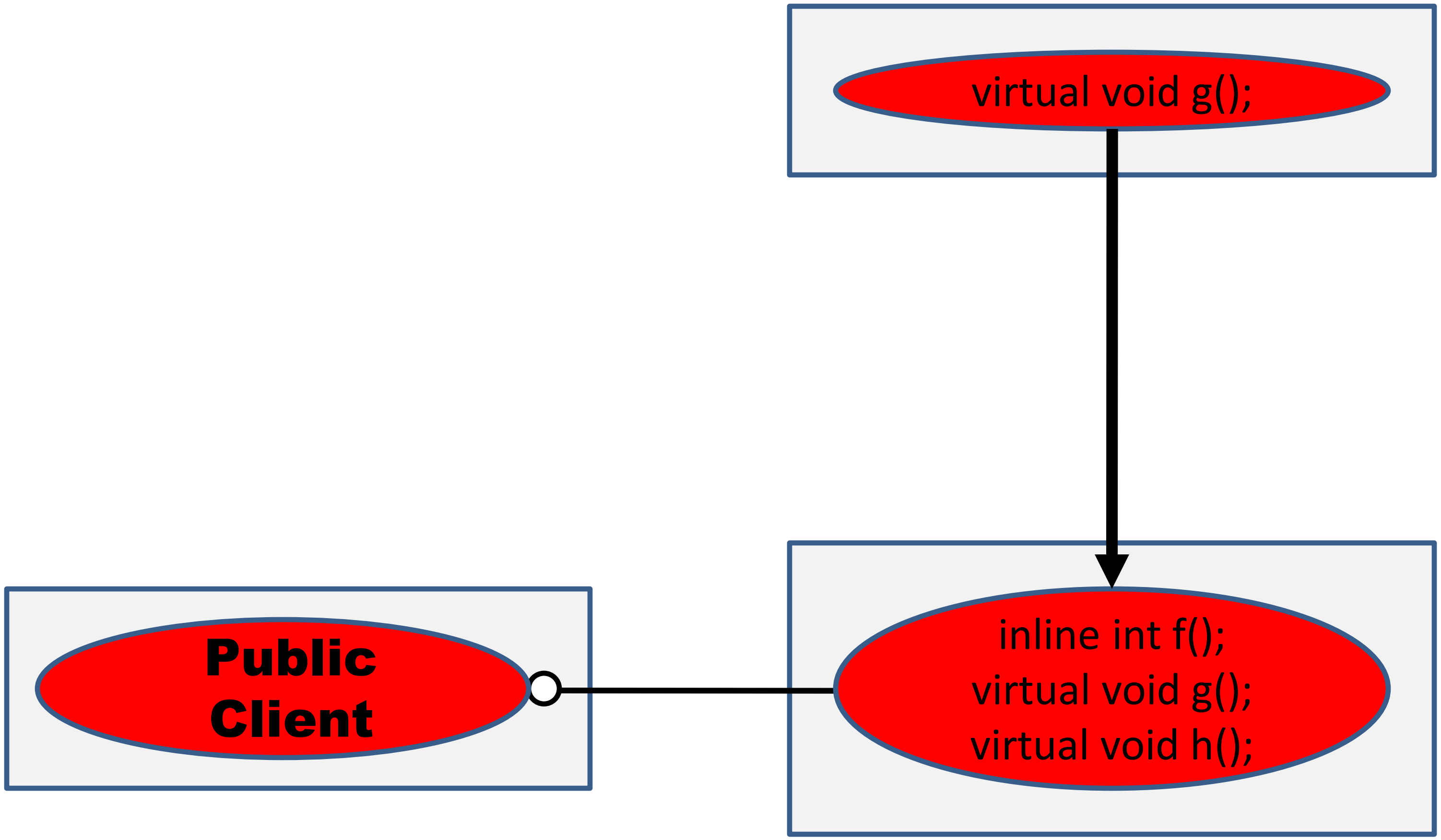
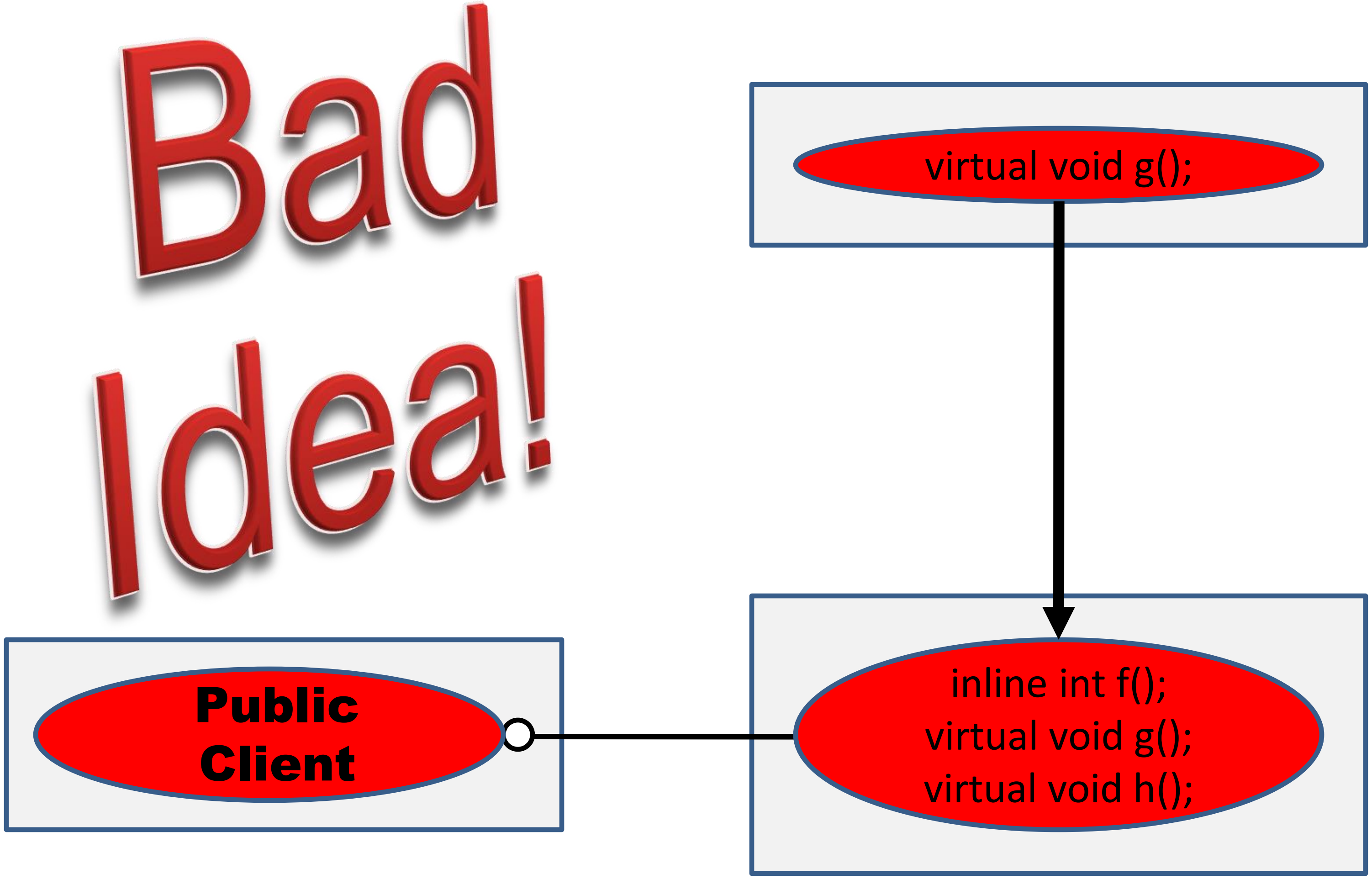
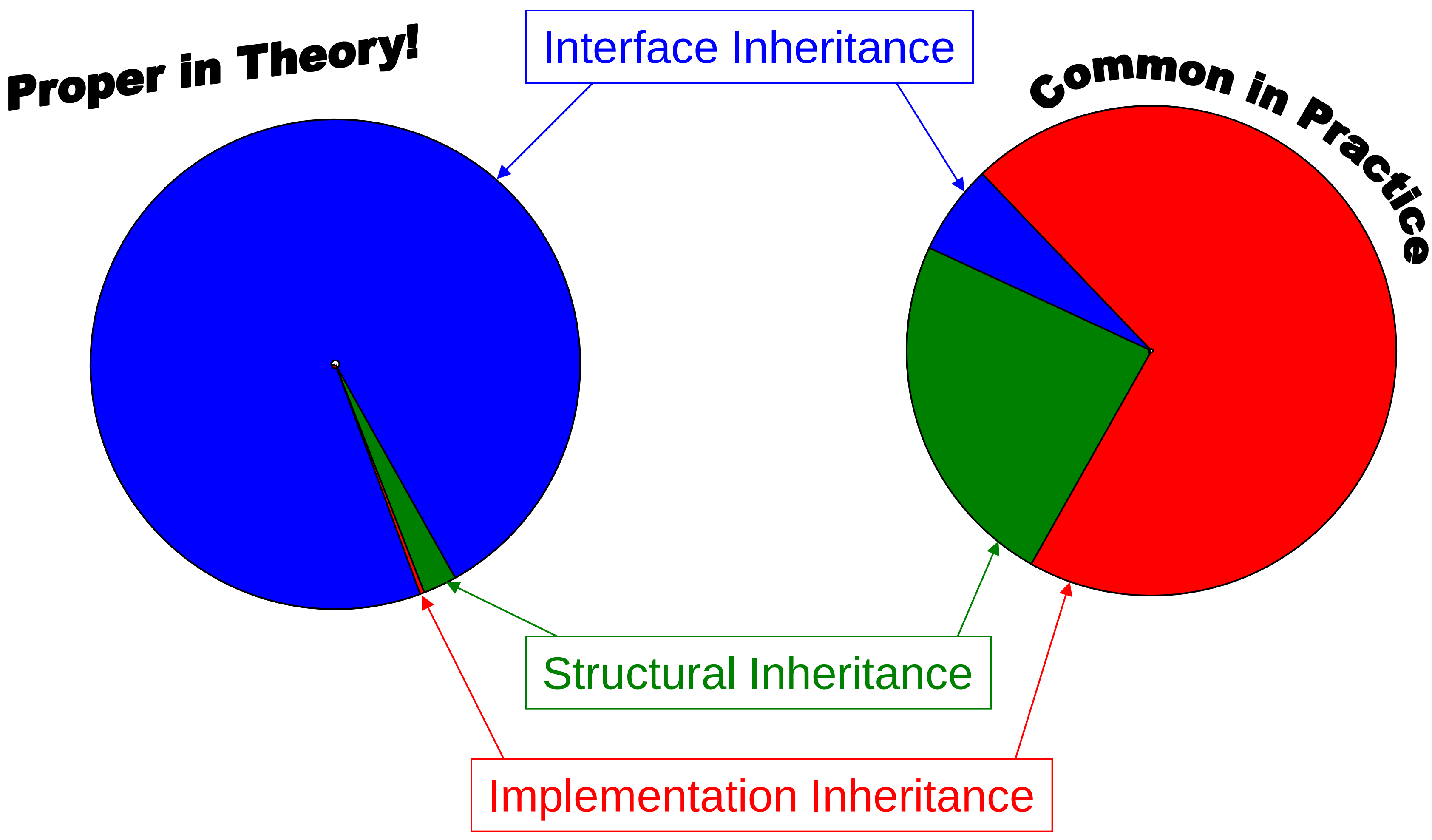


Combining Kinds of Inheritance



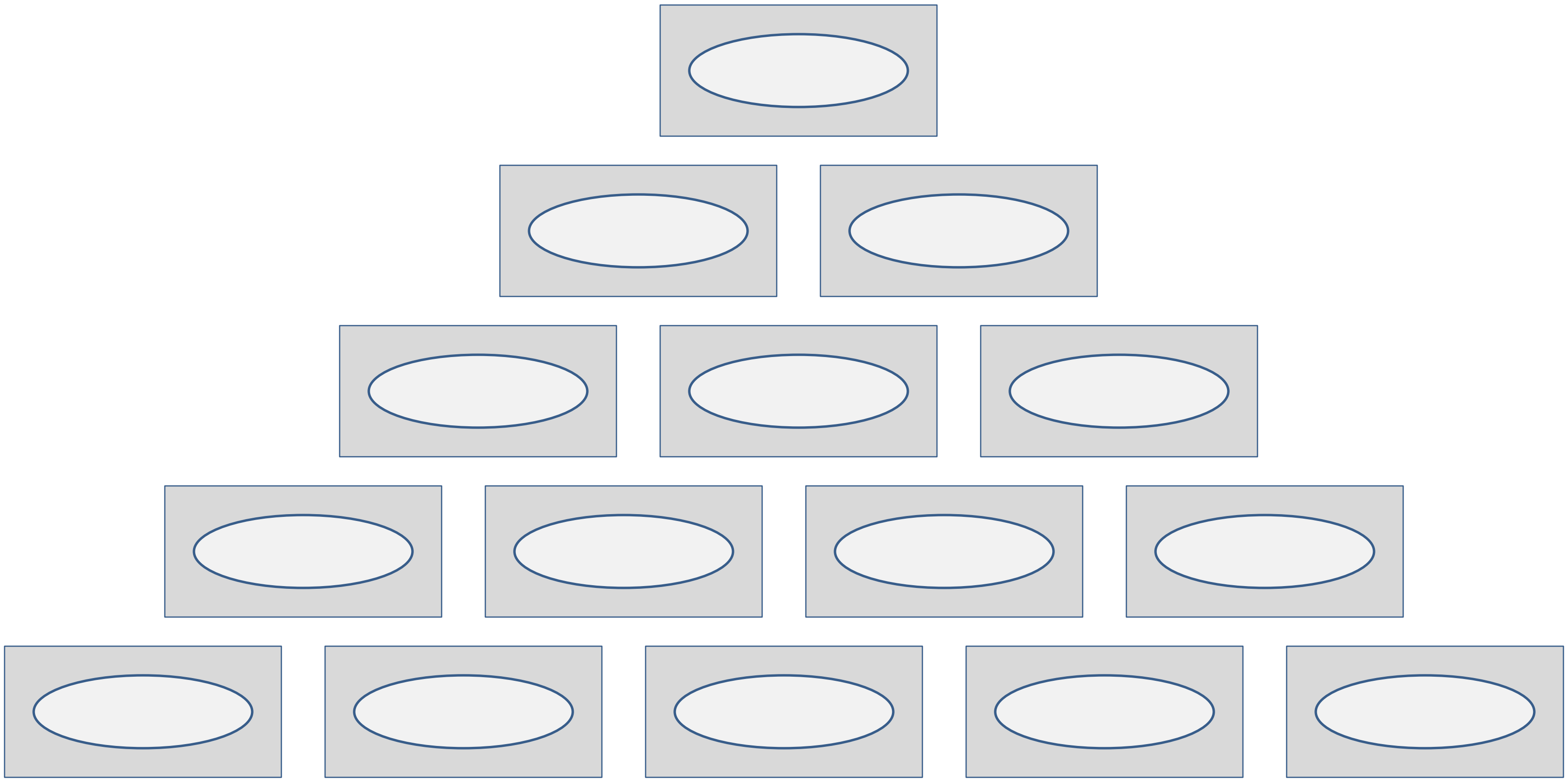
4. Proper Inheritance

Relative Utility

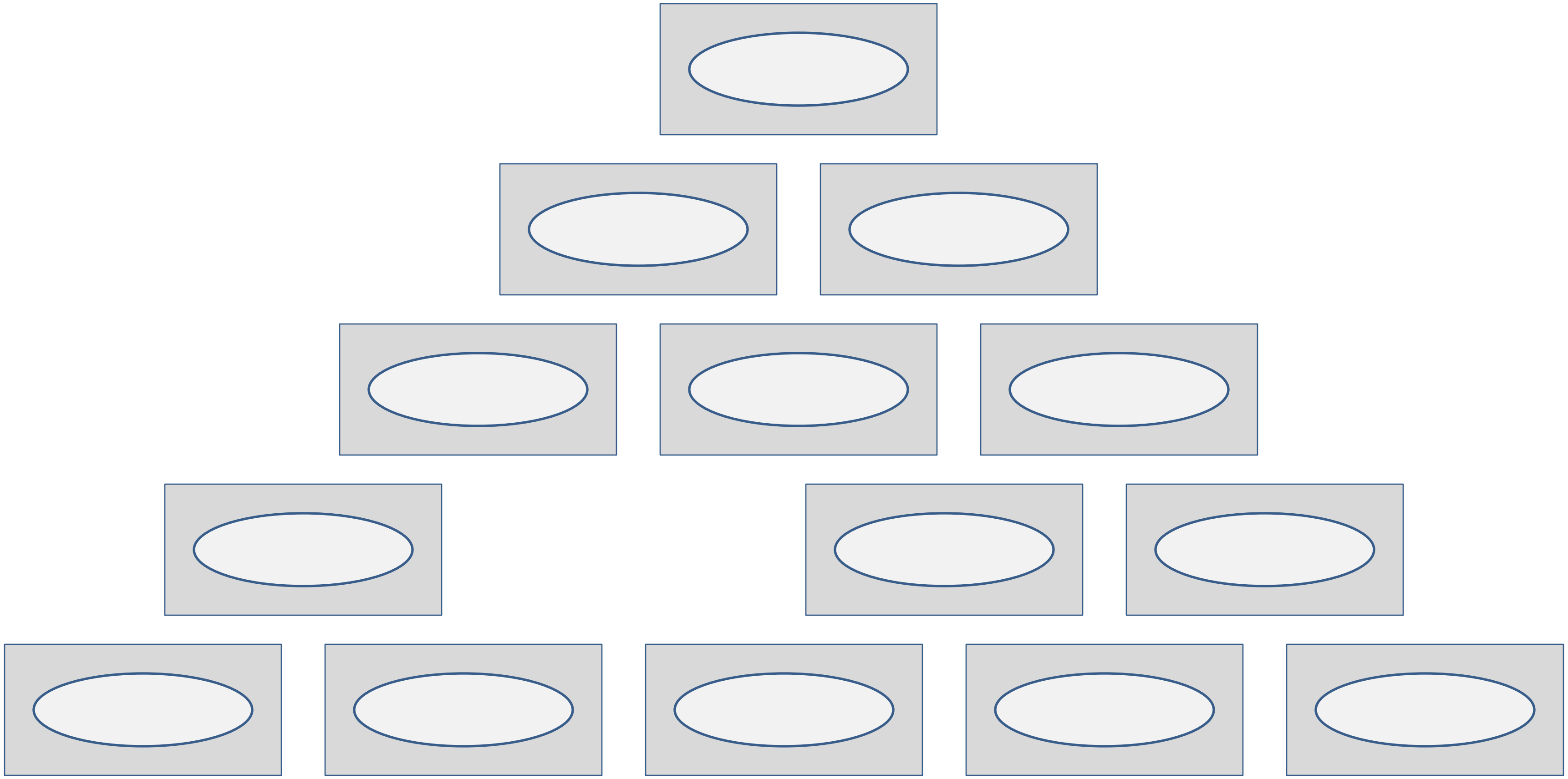


4. Proper Inheritance

Physical Substitutability



Physical Substitutability



4. Proper Inheritance

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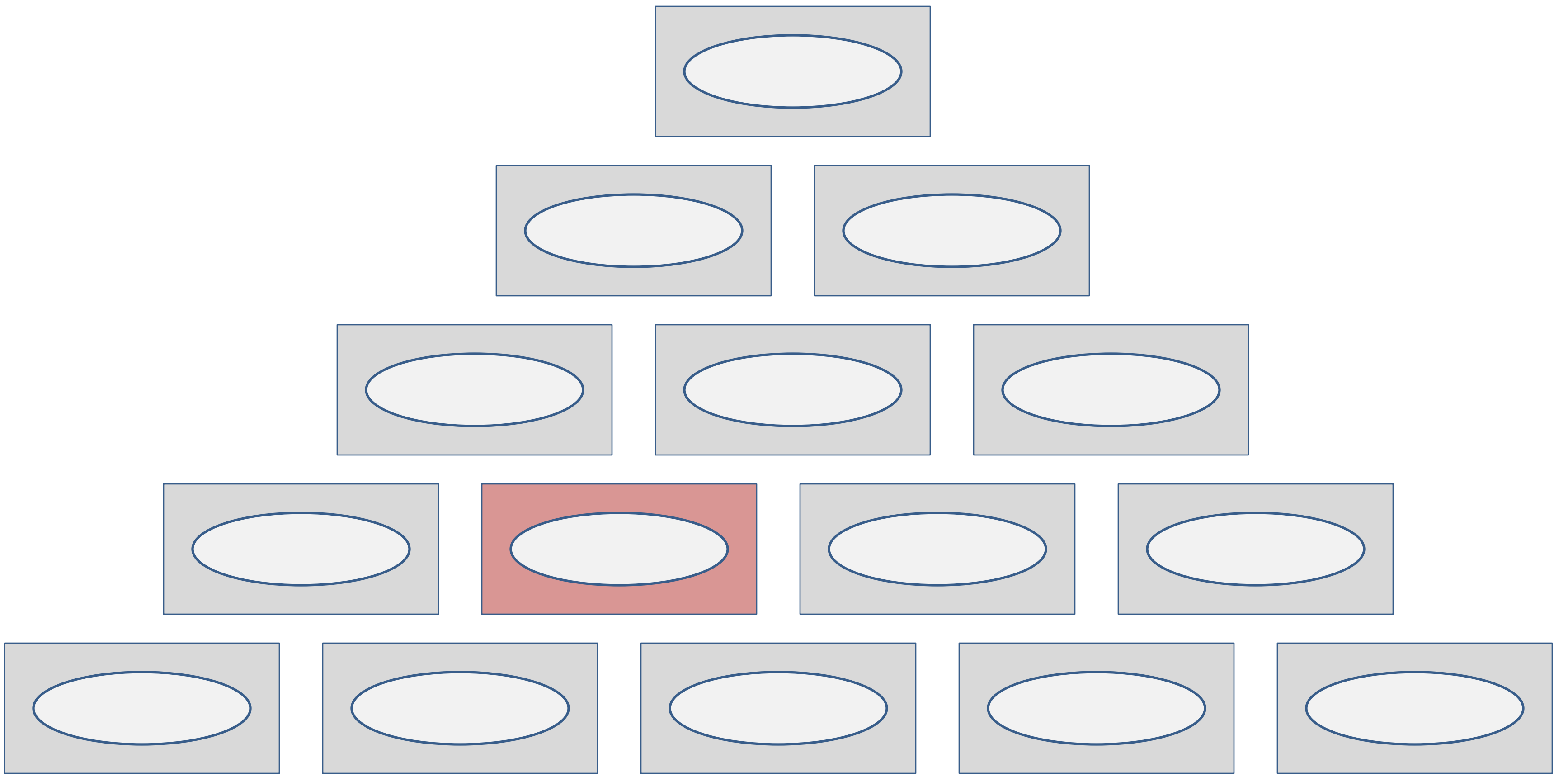
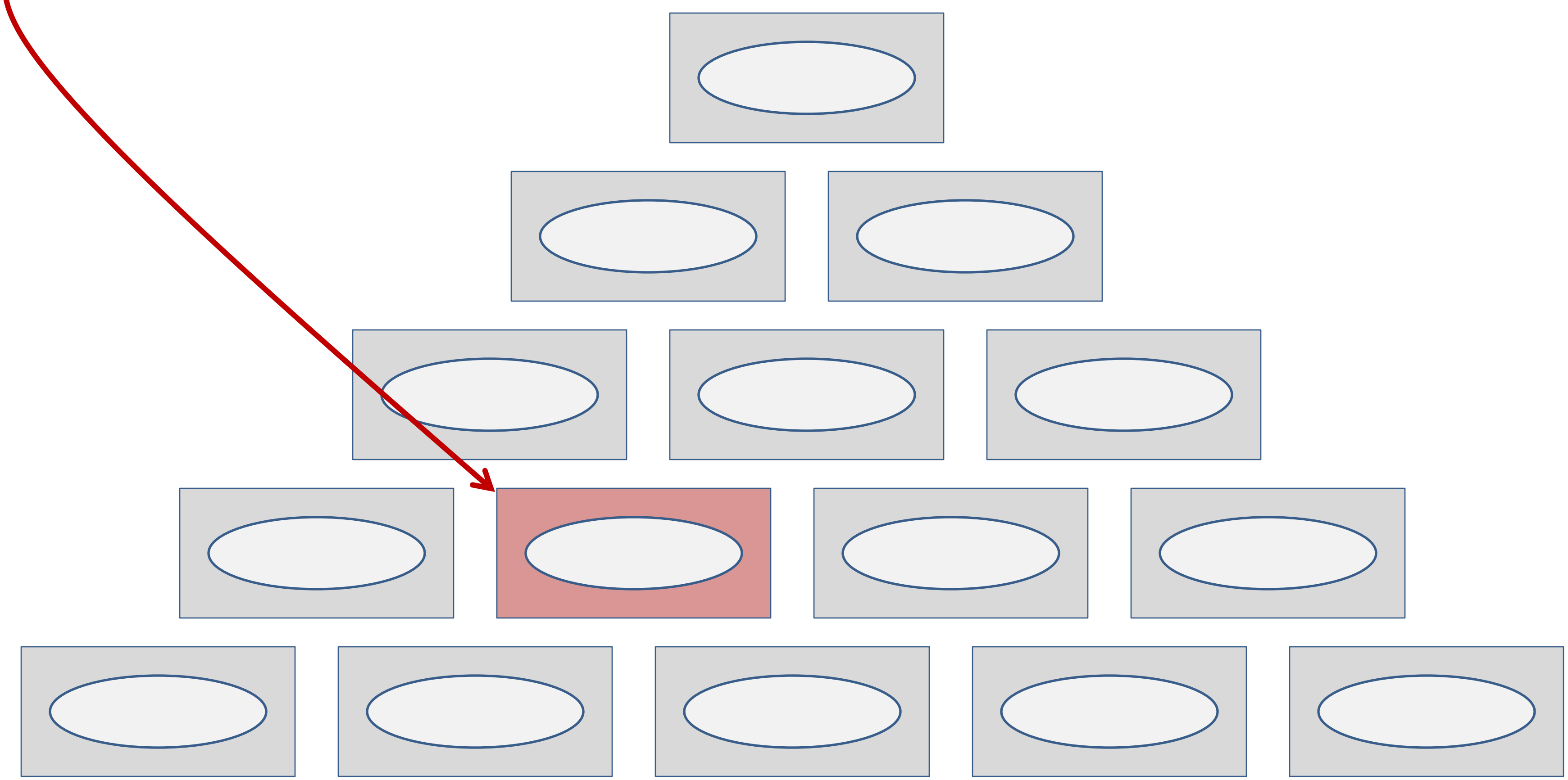


Physical Substitutability

What Criteria Must Be Satisfied?



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4. Proper Inheritance

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- New behaviors may be defined, and essential ones extended, so long as the component is backward compatible with pre-existing clients.

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- Runtime must not be increased significantly for important (relevant) use-cases.

4. Proper Inheritance

End of Section

Questions?

What Questions are we Answering?

- What distinguishes *Interface*, *Structural*, and *Implementation* inheritance?
- What do we mean by the *Is-A* relationship, & how does *proper inheritance* vary from one form to the next.
  - What does ***LSP*** *(Liskov Substitution Principle) have to do with it?*
- How are each of the three inheritances used effectively?
  - Who is the principal client of each kind of inheritance?
  - How are interface and implementation inheritance *ordered*?
  - Does it make sense to combine two (or all three) inheritances?
  - What is the relative utility of the three forms of inheritance?
- How are *structural inheritance*, (logical) *substitutability*, & *backward compatibility* of (physical) components related?

Outline

1. Components (review)

   Modularity, Logical/Physical Dependencies, & Level numbers

2. Interfaces and Contracts (review)

   Syntax versus Semantics & *Essential Behavior*

3. Narrow versus Wide Contracts (review)

   The Significance of *Undefined Behavior*

4. Proper Inheritance

   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

Conclusion

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- **<u>No</u>** *cyclic* dependencies**/***long-distance* friendships!

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   Syntax versus Semantics & *Essential Behavior*

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- *Assertions* in *destructors* help verify ***invariants***.

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  - Enable practical/effective *Defensive Programming*
- *Defensive programming* means ***<u>fault intolerance</u>***!

Conclusion

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   Is-A for *Interface*, *Structural*, & *Implementation* Inheritance

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- *Backward **compatibility*** for components is a whole lot like ***proper*** *structural inheritance*.

Conclusion

The End