Should Decorators Preserve the Component Interface?

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Abstract

Decorator design pattern is a well known pattern that allows dynamical attachment of additional functionality to an object. Decorators have been proposed as flexible alternative to subclassing for extending functionality. Still, the Decorator pattern has certain limitations, especially related to the fact that in its classical form it is constrained to a single interface, which is implicitly defined by the type of the concrete components that we intend to decorate. Another problem associated to the Decorator pattern is related to the linear composition of the decorations, which could lead to problems in accessing the newly added responsibilities.

In this context, the paper presents variants of the Decorator pattern: MixDecorator and D2Decorator, and a variant specific only to C++ language based on templates – HybridDecorator. MixDecorator could be considered a new enhanced version of the Decorator pattern that eliminates some constraints of the Decorator pattern, but also it could be used as a base of a general extension mechanism. The main advantage of using MixDecorator is that it allows direct access to all newly added responsibilities, and so, we may combine different interface-responsibilities (newly added public methods) and operate with them directly and in any order, hiding the linear composition of the decorations. D2Decorator is a variant based on a double-dispatch mechanism, which is used for connecting the actual decorator that has to receive a certain message call. The C++ metaprogramming mechanism based on templates allows an interesting hybrid variant of the Decorator – HybridDecorator, which mixes on-demand defined inheritance with composition.

Using these variants of the Decorator pattern we are not longer limited to one single interface; the set of the messages that could be sent to an object could be enlarged, and so, we may consider that using them, we can dynamically change the type of objects.

Keywords: OOP design patterns, Decorator, interface responsibility, extensibility

1 Introduction

The authors of Gang of Four Design Patterns book [Gamma et al., 1994] argue in favour of object composition over class inheritance, and Decorator pattern is one of the patterns that well expresses this issue. The classical Decorator pattern offers extensions of objects functionality in order to modify their behaviour. The properties of the designs based on Decorator are similar to those of the corresponding designs based on inheritance, but the variations are in this case even more modularized; we obtain fine-grained modularization. Decorator-based designs define variations that are reusable with any class in the basic component hierarchy, and also the variations could be applied in different combinations and dynamically.
The usual agreement is that decorators and the original component class share a common set of operations (interface), but this requirement is mostly due to the classical solution proposed for the problem. Transparent enclosure condition imposes only the fact that a decorated component should be able to receive any message from the component interface.

It may be considered that each method that belongs to an object interface (i.e. the set of all methods that could be invoked for that object) corresponds to a responsibility of that object, and we will refer to these methods that characterize an object behaviour as interface-responsibilities. We argue that the Decorator pattern should allow defining decorations that add new interface-responsibilities, not just changing the behaviour of an existing one. This would be natural if we analyse the pattern intent and applicability.

In order to overcome this limitation to one interface, the paper introduces and discusses new enhanced Decorator variants: MixDecorator, D2Decorator, and a C++ meta-programming approach based on templates.

MixDecorator is an enhanced version of Decorator pattern that does not just eliminate some constraints of the classical pattern (e.g. limitation to one interface), but it introduces significant flexibility and abstraction, allowing the definition of a general extension mechanism. It relies on recursive dispatcher methods for finding the invoked methods.

A double-dispatch mechanism could be also used in order to pass over the linear composition constraints; this led to another variant which we choose to call D2Decorator. This variant imposes building a new class (a dispatcher) for each newly added interface-responsibility, but allows dynamic extensibility in a structured way.

C++ templates represents a powerful static mechanism, that allows behaviour infusion or dependency injection – as in the case of C++ policies. They can be used for creating a hybrid Decorator variant that combines static and dynamic applications.

The paper is structured as follows: next section succinctly describes the classical version of the Decorator pattern and emphasizes the constraints and limitations imposed by it. Section 4 describes the general definition of the MixDecorator pattern. At the implementation phase the pattern could be simplified, but there are different simplifications that are language dependent. Section 4.3 presents these possibilities for Java and C#, C++, and some details about the Python implementation. The D2Decorator is presented in Section 5 with its advantages and disadvantages, and the Hybrid Decorator is discussed in section 6. The analysis of these variants and the conclusions are presented in section 7.

2 Decorator pattern

The Decorator pattern is a structural design pattern used to extend or alter the functionality of objects by wrapping them into instances of selected decorator classes. The variation of the functionality is very well modularized – only one class is defined per each variation (Gamma et al. 1994, Shalloway and Trott 2004). Essentially, this allows decoration based on linear composition of some independent decorations.

The intent of this pattern is to attach additional responsibilities to an object dynamically, and to provide a flexible alternative to subclassing for extending functionality; its applicability is:

- to add responsibilities to individual objects dynamically and transparently, that is, without affecting other objects;
- for responsibilities that can be withdrawn;
Figure 1: The class diagram of the standard Decorator pattern.

- when extension by subclassing is impractical because:
  - an explosion of subclasses is needed to support every combination, or
  - a class definition may be hidden or otherwise unavailable for subclassing.

All these do not suggest that we need to impose that the decorators should conform to the interface of the component it decorates. This is only imposed by the proposed solution.

Figure 1 shows the corresponding class diagram of the classical solution.

An instance of the ConcreteComponent class could be ‘decorated’ with an instance of Decorator1, or Decorator2, and the result could be decorated again with another decorator instance. A forwarding semantic is associated to decorators (Büchi and Weck [2000]) that could redefine the base method operation, but each redefinition of the method operation inside the decorators should invoke the operation on the aggregated object (base). As the component class and the class of each decorator share the same base class, multiple decorators can be applied to the object in order to incrementally modify behaviour. This means that the modifications could be done also at the run-time not only at the design time. This allows changes to be applied to objects in response to specific conditions such as user-selected options or business rules.

The solution of the pattern is based on a combination between inheritance and composition: Decorated is derived from IComponent but in the same time wraps an IComponent. So, theoretically, the associated semantic would be that a Decorator “is-a” but also “has-a” IComponent; still in this case composition and inheritance are used only as implementation mechanisms.

2.1 Limitations of the Classical Decorator Pattern

A Decorator based design could encounter some problems such as:

- lack of object identity (a decorator and its component are not identical);

- no late binding – since a decorator and its component interact via forward semantics, which does not ensure late binding (Büchi and Weck [2000]);

- fragile base-class problem – when the component interface is changed (Kniesel et al. [2004], Sabane et al. [2016], Bloch [2017]); and
the limitation of the decorators to the component interface.

We will discuss here in more details the last limitation and how it could be overcome.

As a possible usage scenario, we may consider that we have \( n \) new interface-responsibilities intended to be defined as decorations for a base class of \texttt{IComponent} type. These responsibilities are defined as methods – \( f_1, f_2, \ldots, f_n \). As the pattern specifies, \( n \) decorator classes will be defined (\texttt{Decorator1, Decorator2 \ldots Decoratorn}), each defining the corresponding method, and they are all derived from the decoration class \texttt{Decorator}. Theoretically, we may obtain any combination of decorations, but we only have the base class interface available (\texttt{ICompoment}).

So, if there are some responsibilities that are really new interface-responsibilities (that change the object interface) and they are not used just to alter the behaviour of the operations defined in the base class, they will be accessible only if the last added decoration is the one that defines them. More specifically, if the responsibility \( f_1 \) is a new interface-responsibility and it is defined in the class \texttt{Decorator1}, then the corresponding message could only be sent to an object that has the \texttt{Decorator1} decoration, and if it is used through a reference of \texttt{Decorator1} type. The following Java code snippet emphasizes this situation (Listing 1).

The code in Listing 1 suggests a possible solution, but this is an improper solution since it has obviously several drawbacks:

- we have to invoke an additional operation that allows decoration removal – \texttt{getBase()}; in case we don’t have it, there is no solution;
- if \texttt{Decorator2} is removed, its added functionality is lost;
- if there are several decorations that should be removed then several additional operations are necessary, and all corresponding added behaviour is lost;
- if we don’t know the exact position (order) of the searched decoration, the code becomes very complex (some sort of reflection has to be used).

In fact, removing decorations in order to reveal interface-responsibilities is not a real solution since it breaks the way in which decorated objects are supposed to be used. Also, it is an ad-hoc workaround that is based on knowing the order in which decorations were added.

### 2.2 New Forces for Decorator

Based on the previous analysis we enlarge the \texttt{Decorator} pattern ‘forces’ to overcome the analysed limitation:

```java
IComponent o = new Decorator1(new Decorator2(new ConcreteComponent()));
(()(Decorator1)o).f1();
IComponent oo = new Decorator2(new Decorator1(new ConcreteComponent()));
// ((Decorator1).oo).f1(); ERROR
((Decorator1)oo.getBase()).f1(); // an improper solution
```
1. Adding new capabilities (including interface-responsibilities) should be possible to clients.
2. The different capabilities should be decoupled and reusable.
3. Easy to change, e.g. withdraw or add capabilities.
4. All newly added responsibilities should be directly accessible to the client.
5. Assure good efficiency and extendability.

3 Applications and examples

Many situations where decorations imply adding new interface-responsibilities could be encountered. The applications that were initially designed based on the classical Decorator, and which define new interface-responsibilities for the decorated objects need to be more carefully treated and adjusted.

Two examples are discussed next.

Example [Java IO streams]. The definition of Java IO streams is a classical example of Decorator usage. We may consider the InputStream hierarchy from Java IO streams package – Figure 2. In this case, FilterInputStream corresponds to the Decorator, and it is derived from InputStream that corresponds to IComponent. As it can be noticed FilterInputStream preserves the interface of InputStream. There are several decoration classes derived from FilterInputStream such as PushBackInputStream that defines three unread methods, which are not defined in the FilterInputStream interface; BufferedInputStream that just alters the behaviour of the standard InputStream interface; or CheckedInputStream that maintains a checksum of the data being read and allows using it using the method getChecksum.
In a practical usage, we may combine them and decorate a certain stream – e.g. FileInputStream, first with the PushBackInputStream decorator, and then with the BufferedInputStream or/and with the CheckedInputStream. If we would like to use the unread() method, this is not longer directly available.

```java
InputStream pi = new BufferedInputStream(new CheckedInputStream(
    new PushbackInputStream(new FileInputStream("input")), new CRC32()));
// pi.unread(); ERROR
```

Listing 2: Java InputStream example

Since, the class FilterInputStream does not provide an operation as getBase(), not even the simplistic solution presented before in the previous section is possible. (The class FilterInputStream has a field in but it is protected and so inaccessible; a solution could be to specialize all the classes derived from FilterInputStream and define for them a getBase() method that returns in, but this is obviously improper.) If a method of type getBase() would be provided for FilterInputStream, then one of the enhanced variants of the Decorator that we propose here could be used, and so we could eliminate the constraints of the current implementation.

**Example [ReaderDecorator].** We consider an application that defines text analyzer decorations which decorate a Reader (an object that could retrieve from a stream, a single character, an entire line, or a specified number of characters). There are examples of such readers in Java and also in C# - (Java: the Reader class; C# - the StreamReader class). In order to offer a Decorator infrastructure for such a class we need to define a ReaderDecorator class (that corresponds to Decorator) that wraps inside a Reader object.

We may first define a decoration that is able to count the number of already read characters, and next we may add another decoration oriented to words that provides methods such as readWord() (able to read the next word), and getNoWords() (that returns the number of words already read). For these, there are new interface-responsibilities that should be used: getNoChars(), readWord(), getNoWords(). These new responsabilities imply also overwriting the readChar() method in order to update the no_of_chars and no_of_words attributes defined by the new decorators.

In a further step of the development, a sentence oriented decorator could be added; it defines methods such as readSentence() and getNoSentences(). They also imply a new attribute definition no_of_sentences that should be updated by readChar().

The use of decorations is appropriate since if we do not need to read or count sentences we don’t have to add the SentenceDecorator, and similarly for WordDecorator, or CharCounterDecorator. The three decorators could be added in any order, and also could be retrieved if they are no longer necessary (to assure efficiency).

Further developments are possible, by adding other different kinds of decorators oriented on text reading. Examples could be decorators able to read a special kind of text files (xml, html, or others).

## 4 MixDecorator

In order to overcome the unique interface limitation of the Decorator pattern, an enhanced variant named MixDecorator is proposed. Its first proposal has been done by Niculescu [2015], and here is presented an adapted improved version of that.
4.1 The MixDecorator Solution:

The structure of the MixDecorator is inspired by the Decorator pattern and it is very similar to it, but there are several important differences that allow achieving the enhanced ‘forces’.

The structure of this solution is presented in Figure 3. The Decorator class has almost the same definition as the corresponding class from the classical Decorator pattern – the difference consists of the additional method getBase() that returns the wrapped object. This method allows the fulfillment of the force no. 3 that allows decorations to be dynamically removed. In addition, there is an abstract class DecoComponent that defines methods that correspond to the newly added interface-responsibilities. These methods have the role of dispatcher methods, meaning that they allow finding and calling the real implementations of the homonymous (methods with the same name) methods in the concrete decorators.

The definition of the Decorator corresponds to a ForwardingDecorator that has been proved to deal well with the fragile-base class problem ([Bloch 2017]), and also allows undecorated components to be used through DecoComponent references (i.e. a ConcreteComponent is just wrapped with a Decorator).

In order to better explain the pattern, we will give some implementation details in Java. The Decorator class is defined similarly to the classical pattern, but it extends DecoComponent (indirectly also IComponent) and defines the method getBase() – Listing 3.

As it can be seen from Fig. 3, the concrete decorator classes Decorator1, Decorator2, Decorator3 are derived from Decorator and implicitly from DecoComponent. For a particular application/framework, after the new interface-responsibilities are inventoried, then the class DecoComponent could be defined.

Very important is the fact that we must allow the possibility to extend the set of the methods defined inside DecoComponent, and this is analysed and discussed in section 4.2.

Since a method corresponding to a new interface-responsibility (as f1()) could be defined into a decoration which is present somewhere in the chain of the decorations, we need a searching mechanism for calling this concrete method. The role of the methods of DecoComponent is to define
public classDecorator implements DecoComponent {
    protected IComponent base;
    publicDecorator(IComponent base) {
        this.base = base;
    }
    public void operation() {
        base.operation();
    }
    public IComponent getBase() {
        return base;
    }
} // end of class Decorator

public interface DecoComponent extends IComponent {
    default public void f1() throws UnsupportedFunctionalityException {
        IComponent base = getBase();
        // if base is a decorated object
        if (base instanceof DecoComponent) {
            ((DecoComponent)base).f1();
        }
        // if base is not a decorated object
        else throw new UnsupportedFunctionalityException("f1");
    }
    ...
} // end of interface DecoComponent

Listing 3: MixDecorator – Decorator class.

Listing 4: MixDecorator – DecoComponent in the context of MixDecorator

this recursive searching mechanism.

For Java implementation, we can define DecoComponent as an interface with default methods. A default method is a virtual method that specifies a concrete implementation within an interface: if any class implementing the interface will override the method, the more specific implementation will be executed (Oracle [2018]).

The code snippet that corresponds to the DecoComponent implementation in Java could be defined as it is shown in the Listing 1 where the implementation for the f1() method is given. The code hides a recursion that tries to call the method f1(), and if this is not available for the top decoration, it goes further to the previous decoration, by using getBase(). The recursion stops either when the concrete method is found or when it arrives to an undecorated component. The call of ((DecoComponent)base).f1() could either lead to the invocation of the concrete implementation of f1() – iff the base is exactly the decorator that defines f1(), or to another invocation of the f1() method defined into DecoComponent.

The following code snippet is an example that emphasizes the forces fulfillment; the execution throws no exception, and it can be noticed that, for example, f3() and f2() could be called even if
Listing 5: Testing different methods calls when the set of operations is extended

```java
// Listing 5: Testing different methods calls when the set of operations is extended

IComponent c = new ConcreteComponent();
DecoComponent dc = new Decorator(c);
dc.operation(); // Decorator just forward the call to ConcreteComponent
DecoComponent d = new Decorator1(new Decorator2(new Decorator3(c)));
d.operation();
d.f1(); d.f2(); d.f3();
```

Listing 6: `MixDecorator` – Testing different methods calls when the set of operations is extended

```java
// Listing 6: MixDecorator – Testing different methods calls when the set of operations is extended

IComponent c = new ConcreteComponent();
DecoComponent d1 = new Decorator1(c);
DecoComponent_Extended d41 = new Decorator4(d1);
d41.f1(); d41.f4(); // correct
DecoComponent d341 = new Decorator3(d41);
d341.f4(); // incorrect -- error
```

neither `Decorator3` nor `Decorator2` are the last added decoration.

When the object `d` invokes the method `f1()`, since `Decorator1` overrides the method `f1()`, the concrete implementation defined in `Decorator1` is called. When method `f2()` is called, first its implementation from `DecoComponent` is called, but then the call is sent forward to the base, which is the object obtained through “new Decorator2(new Decorator3(c))”; this call will invoke the definition of the method from `Decorator2`. Similar mechanism is used when `f3()` is called.

**Remark:**
- In this general solution the `DecoComponent` is defined as a separate class in order to specify the newly added responsibilities, and how are they treated. A much simpler solution is to combine it with the `Decorator` class itself.

### 4.2 Extensions with Other Responsibilities

The design may imply a dynamic development, and so new useful decorations could be discovered in time, and these new decorations could define new interface-responsibilities, too. To solve this problem it wouldn’t be enough just to extend the `DecoComponent` class to a class `DecoComponent_Extended` and define the new decorators by extending this class, because in this way we do not achieve fully compatibility between all the decorators. For example, if we considered `Decorator4` such a decorator that defines the new method `f4()` and we define in the class `DecoComponent_Extended` the method `f4()` (similarly to `f1()` from `DecoComponent`), then the following code produces the correct execution for `d41` but incorrect for `d341`.

For allowing extensions with new decorations that define interface-responsibilities, we need to be able to add new methods to the `DecoComponent` interface/class and to provide a basic implementation for them, too. Many modern languages offer the possibility to define extension methods – as C# ([Microsoft 2020](https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/properties)), or Kotlin ([Kotlin 2020](https://kotlinlang.org/docs/extensions-in-the-standard-library.html)), or some other similar mechanisms – as default interface methods in Java ([Oracle 2018](https://docs.oracle.com/javase/tutorial/java/IandI/defaultmethods.html)).
4.3 Implementation Analysis and Possible Simplifications

The general solution of MixDecorator with the structure emphasized in Figure 3 could be implemented in any object-oriented language, but it is imperative to allow also extensibility and this comes with a special requirement:

- **General requirement for MixDecorator:** The language should provide the possibility of adding new methods to an interface/class, and also to provide a basic implementation for them.

By using specific language constructs, the pattern could be simplified and also improved. We will analyse this for several languages.

4.3.1 Java Implementation

As could been seen in the previous code snippets, the Java solution is based on using interface with default methods. The primary intent of introducing default methods in Java was to allow interfaces to be extended over time preserving backward compatibility. They are also associated to traits mechanisms as was proved by Bono et al. [2014].

Based on this mechanism included in Java 8, we may update the implementation of the interface DecoComponent by adding new methods that correspond to the newly added responsibilities (Listing 7). The initial decorators classes do not have to be recompiled, and no adaptation is needed. Still, we need to have access to the DecoComponent interface in order to replace its implementation, or at least to be able to specify the path where this is defined. Considering this, the implementation of the method $f_4()$ could be added to DecoComponent as emphasized in Listing 7. In this way, any decorators’ combination is possible – the newly added decorators could be "covered" by the previously defined ones, and vice-versa.

4.3.2 C# Implementation

Using extension methods in C# we are able to add new methods to a class after the complete definition of the class (Microsoft [2015]). They allow the extension of an existing type with new functionality, without having to sub-class or recompile the old type.
public static class Decorator_Extensions {
    public static void f4(DecoComponent cdb) {
        Decorator4 cdb4 = cdb as Decorator4;
        if (cdb4 != null) cdb4.f4();
        else {
            DecoComponent cdb_base = cdb.getBase() as DecoComponent;
            if (cdb_base != null) cdb_base.f4();
            else throw new UnsupportedFunctionalityException("f4");
        }
    }
}

//~ end of class Decorator_Extension

Listing 8: MixDecorator – C# definition of the extension methods for the Decorator class

But, this mechanism allows only static binding and so the methods that could be added to a class cannot be declared virtual. In fact, an extension method is a static method defined in a non-generic static class, but which can be invoked using an instance method syntax.

The C# solution for extensibility requires the definition of a new static class that defines the extension methods for the DecoComponent class (or directly to the Decorator class). The extension methods define the recursive search mechanisms for the new methods. What is different in the C# solution is that being based on static methods, the base case should be also treated inside the extension method. The base case is represented by the situation when the invoked responsibility is defined by a method of the last added decorator.

For each new interface-responsibility or for a set of interface-responsibilities, a new static class could be defined – this class defines extension methods that specify the recursive search mechanisms.

More concretely, we may add a static class Decorator_Extension where the method f4() is defined as extension method. The class Decorator_Extension provides extension for DecoComponent:

In Java, the base case of the recursive search is implicitly done based on polymorphic call, but when C# extension methods are used, this case should be explicitly defined.

In C# the simplification could be done by defining extension methods directly to the Decorator class, and by excluding DecoComponent.

4.3.3 C++ Implementation

In a language like C++, we don’t have extension methods, but we still have to respect the constraint of allowing the definitions of new interface-responsibilities. To overcome this, we may use template classes with policies in order to postpone the specification of the parent class for decorators. C++ Policies could be considered a very interesting and useful meta-programming mechanism that allows behavior infusion in a class through templates and inheritance as was analysed by [Alexandrescu 2001, Abrahams and Gurtovoy 2003]. On the other hand, Smaragdakis and Batory 2000 show that in C++, mixins could be defined using templates, and we may consider that C++ mixins could be implemented using policies.

The solution is to force the Decorator class to extend the most recently defined DecoComponent class. So, the Decorator class is defined as a template class, and the template parameter will also be used as a parent class for the Decorator class – Listing 9. This is necessary because, in this way,
we may postpone the specification of the base class, and allow this base to be either `DecoComponent` or another class that extends `DecoComponent` (e.g. `DecoComponent_Extended`).

The concrete decorators are also defined as template classes, since they are derived from the `Decorator` class. `DecoComponent` would still be used as a parent class for the `Decorator` class, but this relation will be defined through the template parameter. The `DecoComponent` class defines the corresponding search methods for the newly defined methods in the concrete decorators (Listing 10).

The class `DecoComponent` could be extended (e.g. `DecoComponent_Extended`) with classes that define new methods that correspond to the new responsibilities added into additional decorators (Listing 11).

When the decorators are used, we need to specify their parent class that could be either `DecoComponent` or `DecoComponent_Extended`. In this way, all the new responsibilities are correctly found.

The example presented in Listing 12 shows first a decoration with `Decorator1` (for which we have the correspondent class `DecoComponent`), and then we have an object decorated with `Decorator1`, which is added over `Decorator4`; in this case we have to specify `DecoComponent_Extended` as a superclass (template parameter). Since `DecoComponent_Extended` class extends `DecoComponent` the function `f4()` could be called even after `Decorator1` was added, and `f1()` is also accessible.

**Remarks:**

- This solution used for C++, emphasized also an interesting mechanism that allows creating a new class from different base classes, and so adjust the type that we need using the inheritance mechanism. It could be seen also as a mixin mechanism ([Bracha and Cook][1990]).

- Since in C++ the template instantiation leads to the creation of a new class it is a statical approach, but only for the supertype specification.

### 4.3.4 Python Implementation

In Python a classical decorator pattern approach could be used, together with a searching mechanism method, which could be easily specified using `.getattr()` method – as it is emphasized by the
class DecoComponent : public IComponent {
    public:
        virtual IComponent* getBase() = 0;
        virtual void f1();
        virtual void f2();
        virtual void f3();
    }
}

void DecoComponent::f1() {
    IComponent* base = getBase();
    DecoComponent* decor = static_cast<DecoComponent*>(base);
    if (decor) { // if is decorated
        decor->f1();
    } else
        throw new UnsupportedFunctionalityException("f1");
}

// similar definitions for f2 and f3

Listing 10: MixDecorator – C++ implementation of DecoComponent and its method f1

class DecoComponent_Extended: public DecoComponent {
    public:
        virtual void f4();
    }

void DecoComponent_Extended::f4() {
    IComponent* base = getBase();
    DecoComponent_Extended* decor = static_cast<DecoComponent_Extended*>(base);
    if (decor) { // if is decorated
        decor->f4();
    } else
        throw new UnsupportedFunctionalityException("f4");
}

Listing 11: MixDecorator – C++ implementation of DecoComponent_Extended and its method f4

IComponent* c = new ConcreteComponent();
Decorator<DecoComponent>* dc = new Decorator1<DecoComponent>(c);
Decorator<DecoComponent_Extended>* dc14 =
    new Decorator1<DecoComponent_Extended>(
        new Decorator4<DecoComponent_Extended>(c));
dc->f1();
dc14->f4();
dc14->f1();
dc14->operation();

Listing 12: MixDecorator – Testing different methods’ calls in C++ implementation
Listing 13: MixDecorator – Python implementation of the components and decorators

code presented in Listing 13.

If one needs a new decorator Decorator4 that defines a new method (f4), a new class could be directly derived from the Decorator class. Using this approach all the methods could be used in any order, as emphasised in the Listing 14.

The __getattr__() method is implicitly used to lookup for the class attributes, being used to define the recursive search.

4.3.5 Comparison of the implementation solutions

We may notice that the solutions are simpler if the language provides mechanisms that allow some kind of type extensions, such as mixins or traits.

Probably the simplest solution is the one that Python offers, but this is due to the fact that Python is a dynamical typed language.

At a glance, C# provides also a very simple and nice solution, but still there are situations when it could become very complex because it is based on a static mechanism. The solution of C# implementation based on extension methods could avoid the definition of the class DecoComponent since all the extensions could be done on the same interface IComponent (but semantically this is maybe not the best solution). A definition of a new decorator that defines a new interface-responsibility, even in a further step of development, does not imply more operations for a decorator that has been defined at the first step of the development.

The C# extensions methods are static methods that are called as they are instance methods.
class Decorator4 (Decorator):
    def __init__(self, decoratee):
        self._decoratee = decoratee
    def f4(self):
        print("original f4")

c = ConcretComponent()
d = Decorator1(Decorator4(Decorator3(c)))
d.f()
d.f1()
d.f4()

Listing 14: MixDecorator – Python decorators that define new methods, and their testing

public static class DecoComponent_Extended4 {
    public static void f4(this DecoComponent cdb) {
        Decorator4 cdb4 = cdb as Decorator4_prime;
        if (cdb4 != null) cdb4.f4();
        else {
            cdb4 = cdb as Decorator4;
            if (cdb4 != null) cdb4.f4();
            else {
                DecoComponent cdb_base = cdb.getBase() as DecoComponent;
                if (cdb_base != null) cdb_base.f4();
                else throw new UnsupportedFunctionalityException("f4");
            }
        }
    }
} //~ end of class DecoComponent_Extended4

Listing 15: MixDecorator – C# extension methods that correspond to an operation defined in two decorators

In principle, this static character does not affect the solution, because, in this case, these static methods provide just a search mechanism for the instance methods with the same name. This search mechanism does not have to be changed dynamically. Still, if there are more decorations that define new responsibilities but with the same name (for example there is also a Decorator4_prime that extends Decorator4 and overrides the method f4()), the C# solution should verify in chain all the possibilities starting from the most specialized class (i.e. calling f4 from Decorator4_prime or from Decorator4). The code snippet in Listing 15 emphasizes such a situation.

Since the Java solution is based on polymorphic calls, this problem doesn’t appear in the Java implementation.

Based on these, we may conclude that apparently the implementation of MixDecorator pattern is simpler and easier with C# extension methods. But based on the previous analysis, it would be recommended to use default methods in C#, too; they were just added in C# 8.0 [Microsoft [2020]]. The implementation based on default methods is more object-oriented rigorous and more efficient since some actions are done implicitly based on polymorphic call of the invoked methods.

The C++ also provides a good solution for MixDecorator implementation; this is based on
templates, which represents static mechanisms, too. Even though, the C++ solution does not have the C# problems since the methods \((f_1(), f_2(), \ldots)\) are defined as virtual functions.

### 4.4 MixDecorator Consequences

The solution offered by the \(\text{MixDecorator}\) pattern preserves the general advantages of \(\text{Decorator}\), but presents several new advantages:

- The linear combination of the decorations is hidden. The final object could be seen as an object with a set of additional responsibilities.
- It is easy to add any combination of capabilities. The same capability can even be added twice.
- Added behaviour could be used in any combination, without any additional operation, such as withdrawing decorations.
- Clients have to refer to \(\text{DecoComponent}\) interface through which concrete or decorated components can be used.
- The definition of \(\text{DecoComponent}\) implies a specification of all new interface-responsibilities that are defined through decorations; even if initially just a small set is defined, it could be extended with an adaptation that is language dependent.

### 5 \(\text{D2Decorator} – \) A Variant Based on Double-Dispatch

The \(\text{MixDecorator}\) solution presented in section 4 collects together the methods corresponding to different interface-responsibilities and provides for each a recursive search mechanism inside the interface/class \(\text{DecoComponent}\). When new decorators are defined, \(\text{DecoComponent}\) should be extended with new methods. Another way of solving the messages calls is to use a double-dispatching mechanism.

#### 5.1 \(\text{D2Decorator} \) Solution

Instead of defining an all-operations interface, we may define for each newly added decorator, which defines a new interface-responsibility, a specialized dispatcher that could be used in the search mechanism. The dispatchers are objects that have the responsibility of executing their corresponding methods. The recursive search algorithm is extracted in only one method that is parameterised with an argument of dispatcher type.

The structure of \(\text{D2Decorator}\) pattern is shown in Fig. 4. The solution includes the structure of the classical \(\text{Decorator}\), but needs to use also special dispatcher classes. The interface \(\text{IDecoratorDispatcher}\) defines one method, \(\text{dispatch}\), which will be implemented by the special classes – the dispatchers – that have the role to execute the newly added interface-responsibilities. It can be seen as a functional interface.

The search mechanism is again recursive, and relies on type casting and extracting the wrapped object – \(\text{base}\). The link with the method that should be called is done through the dispatcher associated to that method. The class \(\text{Decorator}\) provides a general execution operation \(\text{apply}\) that receives an argument of type \(\text{IDecoratorDispatcher}\). The method asks first the received dispatcher
Figure 4: The class diagram for the D2Decorator pattern.

```
public class Decorator extends IComponent {
    protected IComponent base;
    // ...;
    public void apply(IDecoratorDispatcher d) throws UnsupportedFunctionalityException {
        try {
            d.dispatch(this); // base case
        } catch (UnsupportedFunctionalityException e) {
            if (base instanceof Decorator)
                ((Decorator) base).apply(d); // the recursive call
            else throw e;
        }
    } // end
```

Listing 16: D2Decorator – the method apply() from Decorator class
public class F1Operation implements IDecoratorDispatcher {
    public void dispatch ( IComponent c) throws UnsupportedFunctionalityException {
        if (c instanceof Decorator1)
            ((Decorator1)c).f1();
        else throw new UnsupportedFunctionalityException("f1");
    }
} //~ end of class F1Operation

Listing 17: D2Decorator – The method dispatch inside a concrete implementation of IDecoratorDispatcher interface: F1Operation

Decorator d12 = new Decorator1(new Decorator2(new ConcreteComponent()));
d12.operation();
d12.apply(F1Operation.getInstance());
d12.apply(F2Operation.getInstance());

Listing 18: D2Decorator – Testing different methods calls.

to try to execute the desired operation through the dispatch method, and if it does not succeed then, if the base is also a decorator, the apply method is recursively invoked for the base – Listing 16. The dispatch method invoked by the dispatcher argument will call the associated operation defined in the corresponding Decorator.

For Decorator1 that defines the method f1() a dispatcher F1Operation should be defined as the code in Listing 17 emphasizes:

*Remark:* Since, for an operation it is enough to have only one instance of the corresponding dispatcher, the Singleton pattern could be used for the dispatchers.

All the operations could be called, regardless the order in which the decorators were added. The following code snippet emphasizes the call of operation f1() followed by the call of operation f2():

It can be noticed that the calls of the methods that do not belong to the IComponent interface, are done through the method apply, and the differentiation is specified by the type of parameter received. Each dispatcher type is connected to one method that represents an interface-responsibility.

5.2 D2Decorator Implementation

The given examples do not show the case when the new methods also have arguments. If the new methods don’t have arguments then any object-oriented language could be used for the implementation.

In order to allow arguments for the newly added responsibilities, we must define the function apply having beside the dispatcher argument, a variable list of arguments; this list has to be then sent to the dispatch method, which in turn will use it for calling the actual method.

From this we deduce that the most important requirement for a general D2Decorator implementation is related to the need of having methods with variable lists of arguments.

- **General requirement for D2Decorator:** The requirement of a language to support the
D2Decorator implementation is the need to define variable lists of arguments and the possibility to transfer this list to another function call.

5.3 D2Decorator Consequences

As MixDecorator, the D2Decorator pattern preserves the benefits of the Decorator pattern, but additionally comes with some advantages and disadvantages.

Advantages:

- We may mix together new and old decorators that define new interface-responsibilities, in any order, and all methods that define interface-responsibilities are accessible.
- In contrast with MixDecorator, the recursion for finding the invoked method is defined only once in the method apply(). This solution factorizes the invocation process by separating the recursive search definition by the actual function call.

Disadvantages:

- An important disadvantage is given by the fact that in order to call the new interface-responsibilities, we have to use the method apply() instead of a simple invocation of the corresponding method by its name.
- For each newly added interface-responsibility, a new dispatcher class should be defined; each decorator that defines new interface-responsibilities has to come together with corresponding dispatchers for each such an interface-responsibility. This could lead to a lot of fine-grain classes.
- The D2Decorator works well and it is also simple iff the new methods don’t have arguments. When the method that should be called has arguments, these should be taken from the argument list of the apply method. These arguments are taken from the apply method and sent through the dispatch() method to the actual method. Depending on the implementation language this could become a difficult task.

6 Static versus Dynamic solution - HybridDecorator

For the MixDecorator C++ implementation, we have shown how the template mixins (policies) could be used as a mean for enlarging the interfaces. Template policies could also be used for defining another alternative, a hybrid solutions of the Decorator pattern.

Templates are metaprogramming mechanisms that allow macro-definitions from which new classes are created at the compilation phase; so they are static mechanisms. The decorators are defined as mechanisms that allow dynamic adaptation of the objects – they allow adding responsibilities dynamically and transparently, and withdrawing these responsibilities when they are not longer necessary.

We propose a variant for which the combinations of the added responsibilities are defined statically, but they could be added and removed dynamically to/from an object.

The presented solution – HybridDecorator – is based on C++ policies that are implicitly based on inheritance; but the idea that inheritance should be avoided was in the context of using inheritance for creating all possible combinations of decorations – and this is not the case for this solution. The
recursion implicitly involved by the templates policies fits very well to the recursion implied by the Decorator definition. (This variant was first proposed by Niculescu \[2020\].)

6.1 **HybridDecorator solution**

The hybrid solution is both static and dynamic, and also uses both inheritance and composition. This preserves the basic object wrapping, but the decorations will be defined as a single class obtained through a chain of inheritance derivations. In order to assure this, we need to define a class `Decorator` that provides the support for composition, but at the same time, intermediates the decorations inheritance.

The class is defined for the following two cases:

- the basic case with the template parameter equal to `IComponent`,
- the general case with a general template parameter(`T`).

These two cases are different, and this difference is mainly related to the call of the overridden method `operation()`:

- for the general case the call is sent up to the superclass – `T` – Listing \[19\]
- for the basic case the call is sent to the wrapped object (base) – Listing \[20\]
template <typename T>
class Decorator: public T {
protected:
   IComponent* base;
public:
   Decorator(IComponent* r): T(r) {
      this->base = r;
   }
   void operation() {
      T::operation();
   }
   IComponent* getBase() {
      return T::getBase();
   }
};

Listing 19: HybridDecorator – The definition of the class Decorator for the general template parameter

template <>
class Decorator<IComponent>: public IComponent {
protected:
   IComponent* base;
public:
   Decorator(IComponent* r) {
      this->base = r;
   }
   void operation() {
      base->operation();
   }
   IComponent* getBase() {
      return base;
   }
};

Listing 20: HybridDecorator – The definition of the class Decorator for the implicit template parameter IComponent
```cpp
template <typename T=IComponent>
class Decorator1: public Decorator<T> {
public:
    Decorator1(IComponent* r): Decorator<T>(r) {
        base = r;
    }
    void f1() {
        std::cout << "call f1 in Decorator1" << std::endl;
    }
};
```

Listing 21: *HybridDecorator* – The definition of *Decorator1* class.

The associated UML diagram for this hybrid implementation is shown in Fig. 5. The solution preserves the classical solution of using both inheritance and composition: *Decorator* class “has-a” *IComponent* (the attribute *base*), but it is also derived from *IComponent*. Still, as the diagram emphasizes, there are two definitions of the class *Decorator*: one for the implicit type parameter *IComponent*, and the other for the general case, when the template parameter could be any decorator specialization. The class *Decorator* is derived from the template parameter, too. This is not visible in the UML diagram but it is important for the recursive definition of the decorators. Also, the method *getBase()* is necessary for this variant.

The concrete decorators – as *Decorator1* and *Decorator2* – are derived from the class *Decorator*, and so these are also template classes. For them it is not necessary to give special definition for the implicit type case (*IComponent*), since this is solved in the *Decorator* class. The definition of the *Decorator1* class is given in Listing 21.

An usage example based on this solution is given in the Listing 22. It can be noticed that the usage looks very similar to the classical *Decorator* implementation, but the composition is replaced with the template parameter specification.

Through the definition *Decorator3<Decorator1<Decorator2<IComponent>>>*, a new class is created, and this class is obtained by deriving *Decorator2* from *IComponent*, *Decorator1* from *Decorator2*, and *Decorator3* from *Decorator1*. This class has an attribute – *base* – of type *IComponent*. This specific inheritance is created only for this particular example; other variations are created when they are needed.

### 6.2 *HybridDecorator* Consequence

*HybridDecorator* presents several advantages and disadvantages:

**Advantages:**

- Only the classes for the needed combinations are created.
- All new defined methods in different decorators are accessible.
- The combination of the functionalities could be changed – the basic object is retrieved (through the method *getBase()*), and then it could be passed to another combination of functionalities.
- For all the specializations of *IComponent* only one particular class that corresponds to a particular functionality combination could be used;
In order to add a new decoration (or combination), a new object wrapping (similar to the classical `Decorator`) could be done – the wrapping will specify a new class with the desired decoration.

- static class creation assures efficiency,

- in comparison to the solutions of the `MixDecorator` or `D2Decorator`, `HybridDecorator` implicitly assures full accessibility of all new interface-responsibilities, without being necessary to define another special class/es or methods to intermediate this.

Disadvantages:

- The decorations could not be individually retrieved;

- There is no supertype for all possible decorators’ combinations to be used as a general reference type.

- It could be used by adding successively the decorators without using template policies, and in this case, the constraints related to accessibility are the same as for the classical `Decorator`.

The hybrid aspect of this solution is very important: we have an object wrapped into a decoration object (composition), but this decoration object is defined as a combination of fine grain decorators that are built through inheritance defined using the C++ template mechanism. If only inheritance would be used (as it is emphasized by the code in the Listing [23]), then we wouldn’t satisfy the `Decorator` forces that impose decorations to be dynamically added and withdrawn.
1 Decorator1< Decorator2< Decorator3<ConcreteComponent>>>*d123c =
2     new Decorator1<Decorator2<Decorator3<ConcreteComponent>>>();
3 d123c->f1(); d123c->f2(); d123c->f3(); d123c->operation();

Listing 23: A variant based only on inheritance – usage example

**Remark** Even if this variant is specific only to the C++ language, this brings an interesting insight about the possibility to define the Decorator pattern using metaprogramming mechanisms.

### 7 Analysis and Conclusions

The paper presents a new modern view over a classical and very used pattern – *Decorator*. An important restriction of the *Decorator* classical solution is the limitation to the component interface. This could be overcome by using pattern adaptations, which are being based on new developments of the object-oriented languages (default methods in interfaces, extension methods, template mixins, variable argument list), or on metaprogramming.

The presented variants: *MixDecorator*, *D2Decorator*, and *HybridDecorator* represent variants of the *Decorator* pattern since they allow modularized functionality specialization, but also, in addition, they facilitate the addition of new interface-responsibilities. In this way, the set of messages that could be sent to an object is enlarged. We may consider that using them, we *dynamically modify the type of an object*. Different combinations of these messages could be used, and all the responsibilities are directly accessible.

For the *MixDecorator*, the implementation constraint for extensibility is related to the fact that we have to be able to add a set of operations to an interface (or a class), and also to provide a basic implementation for the corresponding methods. This could be achieved by using language specific mechanisms, such as that provided by the Java extended interfaces, or the C# and Kotlin extension methods. In C++ we may use an implementation variant based on mixin templates.

If we deeply analyze the *MixDecorator* solution, we may notice that the structure of the search algorithm for the concrete implementation of an interface-responsibility is the same for all of them. So, it would be useful if we can generate the dispatcher methods based on some metaprogramming mechanisms, since they are particularized only by the decorator type that define the new method, and the method’s name and arguments.

The variant based on double-dispatch – *D2Decorator* – factorizes the definitions of the dispatcher methods in different classes (the dispatchers), but the recursion has to be defined only in the *Decorator* class. This variant could be applied in any object-oriented language, that allows variable list arguments, offering the advantage of mixing together new and old decorators in any order, without adaptation or modification. Still, its main disadvantage is that the methods should be called, not directly, but through a general method, `apply(IDecoratorDispatcher d)` (and this also implies that for each interface-responsibility a new dispatcher class should be defined).

In a pattern oriented analysis, comparing with *Factory Method* and *Abstract Factory*, we may consider that we have defined and used *Dispatcher Method* and *Abstract Dispatcher* patterns.

*HybridDecorator* is specific only to C++, but it emphasizes an interesting solution of the problem for which the *Decorator* was initially proposed. The inheritance is used for creating the combination
of decorators, but this is done through the meta-programming mechanism brought by the C++ templates; in this way the desired decoration combination is created only when it is needed.

**Mixins and traits oriented analysis.** Traits and mixins are both related – they allow the injection of some code into a class. Both constructs exploit composition instead of inheritance as a mechanism for software reuse and they are alternatives to multiple inheritance. Since the applicability of the discussed Decorator variants is related to the possibility of adding new functionalities, a comparison with them it’s worth to be done.

Mixin programming is a style of software development where units of functionality are created in a class and then mixed in with other classes (Bracha and Cook [1990]). A mixin class could be considered as a parent class that is inherited from – but this is not done in order to obtain a specialization. Typically, the mixin will export services to a child class, but no semantics will be implied about the child “being a kind of” the parent. The main differences between the Decorator pattern and mixins are based on the fact that with decorators we want to add functionality to objects, not to create new classes that contain a combination of methods from other classes. With decorators we may extend functionality (change behaviour and add new responsibilities) of an object, and this new functionality could be added and removed dynamically. This could bring advantages for implementations in languages where there are no specific mixins mechanisms. On the other hand, because for the MixDecorator we have to be able to add methods to the DecoComponent (or directly to the Decorator class), we may consider that the MixDecorator implementation could be based on mixins, if they are available in the implementation language (as it is the case of the C++ implementation).

Traits also allow the programmer to create components that are designed for reuse, rather than for instantiation (Scharli et al. [2002]). Being stateless, they are more lightweight entities that serve as the primitive units of code reuse. Java 8 extended interfaces that allow default method definitions may be considered a kind of trait mechanism – Java Traits, as was analysed by Bono et al. [2014]. We have used them in order to define the DecoComponent interface for the Java MixDecorator implementation. In Scala it is possible to add a trait to an object instance when the object is created, and not only to an entire class; but this is possible because in Scala we work with singleton objects (Scala [2015]). Adding functionality to an object is what we do using decorators.

As the examples with the Input/OutputStream and ReaderDecorator show, the applicability of these enhanced variants of the Decorator pattern is clearly defined and brings important advantages over the classical one. The fact that through the Decorator pattern only linear combinations of features are allowed, could be seen as a disadvantage, but using these new variants, this is hidden: all the new features become visible. Other, classical examples (e.g. graphical windows) or more complex examples (e.g. features based collection definitions) could be given.

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