UNIT-3 Structural Patterns

Structural patterns are concerned with how classes and objects are composed to form larger structures. Structural *class* patterns use inheritance to compose interfaces or implementations. As a simple example, consider how multiple inheritances mix two or more classes into one. The result is a class that combines the properties of its parent classes. This pattern is particularly useful for making independently developed class libraries work together.

Rather than composing interfaces or implementations, structural *object* patterns describe ways to compose objects to realize new functionality. The added flexibility of object composition comes from the ability to change the composition at run-time, which is impossible with static class composition.

The following are Structural design patterns

- Adapter(Class & Object)
- Bridge
- Composite
- Decorator
- Façade
- Flyweight
- Proxy

Adapter

Intent

Convert the interface of a class into another interface clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces.

Also Known As

Wrapper

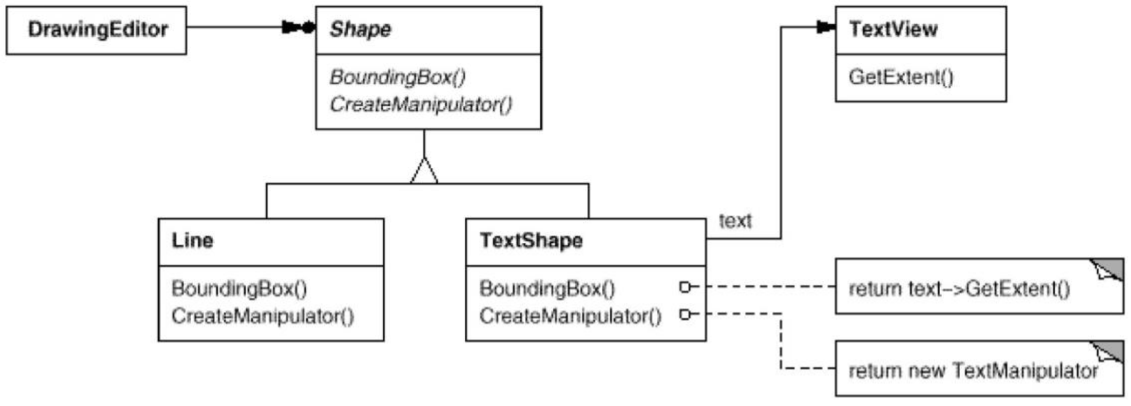
Motivation

Sometimes a toolkit class that's designed for reuse isn't reusable only because its interface doesn't match the domain-specific interface an application requires.

Consider for example a drawing editor that lets users draw and arrange graphical elements (lines, polygons, text, etc.) into pictures and diagrams. The drawing editor's key abstraction is the graphical object, which has an editable shape and can draw itself. The interface for graphical objects is defined by an abstract class called Shape. The editor defines a subclass of Shape for each kind of graphical object: a Line Shape class for lines, a Polygon Shape class for polygons, and so forth.

Classes for elementary geometric shapes like Line Shape and Polygon Shape are rather easy to implement, because their drawing and editing capabilities are inherently limited. But a Text Shape subclass that can display and edit text is considerably more difficult to implement, since even basic text editing involves complicated screen update and buffer management. Meanwhile, an off-the-shelf user interface toolkit might already provide a sophisticated Text View class for displaying and editing text. Ideally we'd like to reuse Text View to implement Text Shape, but the toolkit wasn't designed with Shape classes in mind. So we can't use Text View and Shape objects interchangeably.

Instead, we could define TextShape so that it *adapts* the TextView interface to Shape's. We can do this in one of two ways: (1) by inheriting Shape's interface and TextView's implementation or (2) by composing a TextView instance within a TextShape and implementing TextShape in terms of TextView's interface. These two approaches correspond to the class and object versions of the Adapter pattern. We call TextShape an adapter.



This diagram illustrates the object adapter case. It shows how Bounding Box requests, declared in class Shape, are converted to Get Extent requests defined in TextView. Since TextShape adapts TextView to the Shape interface, the drawing editor can reuse the otherwise incompatible TextView class.

Often the adapter is responsible for functionality the adapted class doesn't provide. The diagram shows how an adapter can fulfill such responsibilities. The user should be able to "drag" every Shape object to a new location interactively, but TextView isn't designed to do that. TextShape can add this missing functionality by implementing Shape's Create Manipulator operation, which returns an instance of the appropriate Manipulator subclass.

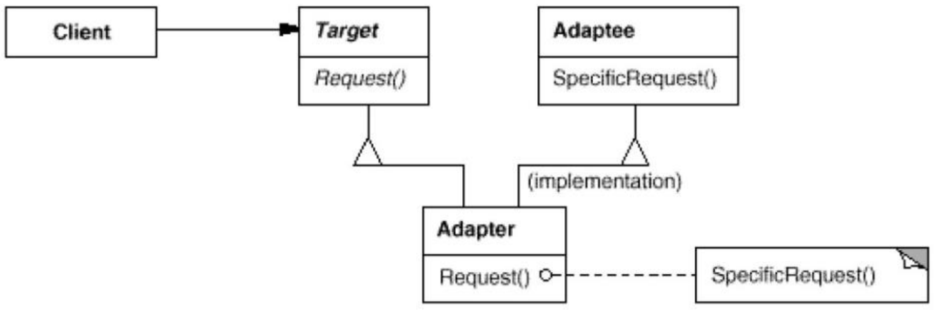
Manipulator is an abstract class for objects that know how to animate a Shape in response to user input, like dragging the shape to a new location. There are subclasses of Manipulator for different shapes; Text Manipulator, for example, is the corresponding subclass for TextShape. By returning a Text Manipulator instance, TextShape adds the functionality that TextView lacks but Shape requires.

Applicability

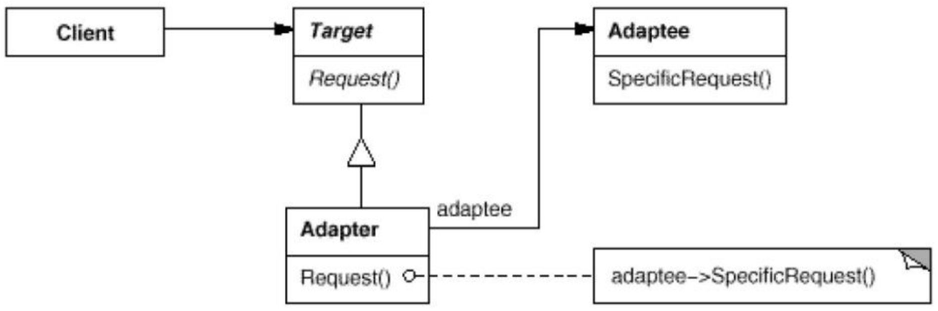
Use the Adapter pattern when
You want to use an existing class, and its interface does not match the one you need.
You want to create a reusable class that cooperates with unrelated or unforeseen classes, that is, classes that don't necessarily have compatible interfaces.
(object adapter only) you need to use several existing subclasses, but it'simpractical to adapt their interface by sub classing every one. An object adapter can adapt the interface of its parent class.

Structure

A class adapter uses multiple inheritances to adapt one interface to another:



An object adapter relies on object composition:



Participants

Target (Shape)

Defines the domain-specific interface that Client uses.

Client (Drawing Editor)

Collaborates with objects conforming to the Target interface.

Adaptee (TextView)

Defines an existing interface that needs adapting.

Adapter (TextShape)

Adapts the interface of Adaptee to the Target interface.

Collaborations

· Clients call operations on an Adapter instance. In turn, the adapter calls Adaptee operations that carry out the request.

Consequences

Class and object adapters have different trade-offs. A class adapter

· AdaptsAdaptee to Target by committing to a concrete Adapter class. As a consequence, a class adapter won't work when we want to adapt a class *and* all its subclasses.

· let’s Adapter override some of Adaptee's behavior, since Adapter is a subclass of Adaptee.

· introduces only one object, and no additional pointer indirection is needed to get to the adaptee.

An object adapter

· Let’s a single Adapter work with many Adaptees that is, the Adaptee itself and all of its subclasses (if any). The Adapter can also add functionality to all Adaptees at once.

· Makes it harder to override Adaptee behavior. It will require subclassingAdaptee and making Adapter refer to the subclass rather than the Adaptee itself.

Implementation

Although the implementation of Adapter is usually straightforward, here are some issues to keep in mind:

1. *Implementing class adapters in C++*. In a C++ implementation of a classadapter, Adapter would inherit publicly from Target and privately from Adaptee. Thus Adapter would be a subtype of Target but not of Adaptee.
2. *Pluggable adapters*. Let's look at three ways to implement pluggable adaptersfor the Tree Display widget described earlier, which can lay out and display a hierarchical structure automatically.

The first step, which is common to all three of the implementations discussed here, is to find a "narrow" interface for Adaptee, that is, the smallest subset of operations that lets us do the adaptation. A narrow interface consisting of only a couple of operations is easier to adapt than an interface with dozens of operations. For TreeDisplay, the adaptee is any hierarchical structure. A minimalist interface might include two operations, one that defines how to present a node in the hierarchical structure graphically, and another that retrieves the node's children.

Sample Code

We'll give a brief sketch of the implementation of class and object adapters for the Motivation example beginning with the classes Shape and TextView.

```
class Shape { public:
Shape();
virtual void BoundingBox(
Point&bottomLeft, Point&topRight )const;
virtual Manipulator* CreateManipulator() const;
};
```

```
classTextView { public:
TextView();
voidGetOrigin(Coord& x, Coord& y) const;
voidGetExtent(Coord&  width,  Coord&  height)  const;  virtual  bool
IsEmpty() const;
};
```

Shape assumes a bounding box defined by its opposing corners. In contrast, TextView is defined by an origin, height, and width. Shape also defines a CreateManipulator operation for creating a Manipulator object, which knows how to animate a shape when the user manipulates it.[1]TextView has no equivalent operation. The class TextShape is an adapter between these different interfaces.

A class adapter uses multiple inheritance to adapt interfaces. The key to class adapters is to use one inheritance branch to inherit the interface and another branch to inherit the implementation. The usual way to make this distinction in C++ is to inherit the interface publicly and inherit the implementation privately. We'll use this convention to define the TextShape adapter.

```
classTextShape : public Shape, private TextView { public:
TextShape();

virtual void BoundingBox(
Point&bottomLeft, Point&topRight )const;
virtual bool IsEmpty() const;
virtual Manipulator* CreateManipulator() const;
};
voidTextShape::BoundingBox (
Point&bottomLeft, Point&topRight )const {
Coord bottom, left, width, height;

GetOrigin(bottom, left);
GetExtent(width, height);

bottomLeft = Point(bottom, left);
topRight = Point(bottom + height, left + width);
}
```

The IsEmpty operation demonstrates the direct forwarding of requests common in adapter implementations:

```
boolTextShape::IsEmpty () const {
returnTextView::IsEmpty();
}
```

Known Uses

The Motivation example comes from ET++Draw, a drawing application based on ET++. ET++Draw reuses the ET++ classes for text editing by using a TextShape adapter class.

Related Patterns

Bridge has a structure similar to an object adapter, but Bridge has a different intent: It is meant to separate an interface from its implementation so that they can be varied easily and independently. An adapter is meant to change the interface of an *existing* object.

Decoratorenhances another object without changing its interface. A decorator is thus more transparent to the application than an adapter is. As a consequence, Decorator supports recursive composition, which isn't possible with pure adapters.

Proxy defines a representative or surrogate for another object and does not change its interface.

Bridge

▼Intent

Decouple an abstraction from its implementation so that the two can vary independently.

▼Also Known As

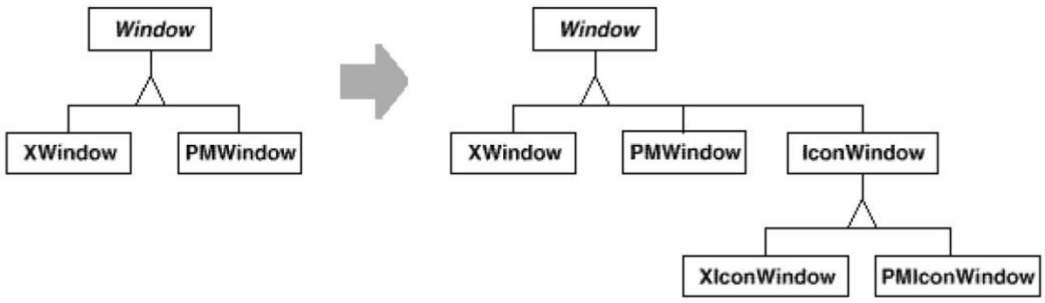
Handle/Body

▼Motivation

When an abstraction can have one of several possible implementations, the usual way to accommodate them is to use inheritance. An abstract class defines the interface to the abstraction, and concrete subclasses implement it in different ways. But this approach isn't always flexible enough. Inheritance binds an implementation to the abstraction permanently, which makes it difficult to modify, extend, and reuse abstractions and implementations independently.

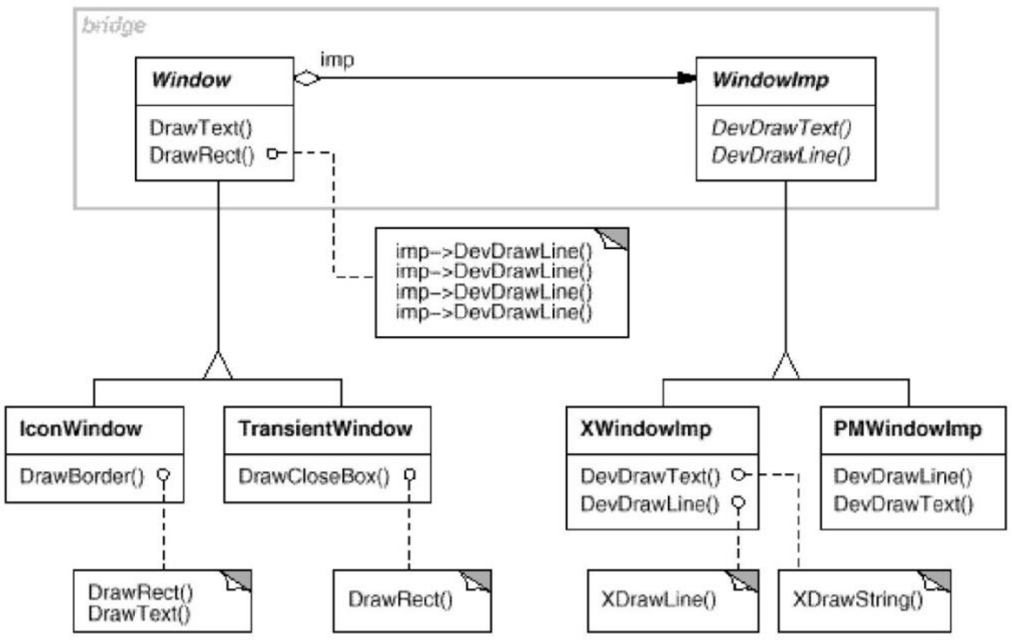
Consider the implementation of a portable Window abstraction in a user interface toolkit. This abstraction should enable us to write applications that work on both the X Window System and IBM's Presentation Manager (PM), for example. Using inheritance, we could define an abstract class Window and subclasses XWindow and PMWindow that implement the Window interface for the different platforms. But this approach has two drawbacks:

1. It's inconvenient to extend the Window abstraction to cover different kinds of windows or new platforms. Imagine an IconWindow subclass of Window that specializes the Window abstraction for icons. To support IconWindows for both platforms, we have to implement *two* new classes, XIconWindow and PMIconWindow. Worse, we'll have to define two classes for *every* kind of window. Supporting a third platform requires yet another new Window subclass for every kind of window.



2. It makes client code platform-dependent. Whenever a client creates a window, it instantiates a concrete class that has a specific implementation. For example, creating an XWindow object binds the Window abstraction to the X Window implementation, which makes the client code dependent on the X Window implementation. This, in turn, makes it harder to port the client code to other platforms.

The Bridge pattern addresses these problems by putting the Window abstraction and its implementation in separate class hierarchies. There is one class hierarchy for window interfaces (Window, IconWindow, TransientWindow) and a separate hierarchy for platform-specific window implementations, with WindowImp as its root. The XWindowImp subclass, for example, provides an implementation based on the X Window System.



All operations on Window subclasses are implemented in terms of abstract operations from the WindowImp interface. This decouples the window abstractions from the various platform-specific implementations. We refer to the relationship between Window and WindowImp as a bridge, because it bridges the abstraction and its implementation, letting them vary independently.

▾Applicability

Use the Bridge pattern when

· you want to avoid a permanent binding between an abstraction and its implementation. This might be the case, for example, when the implementation must be selected or switched at run-time.

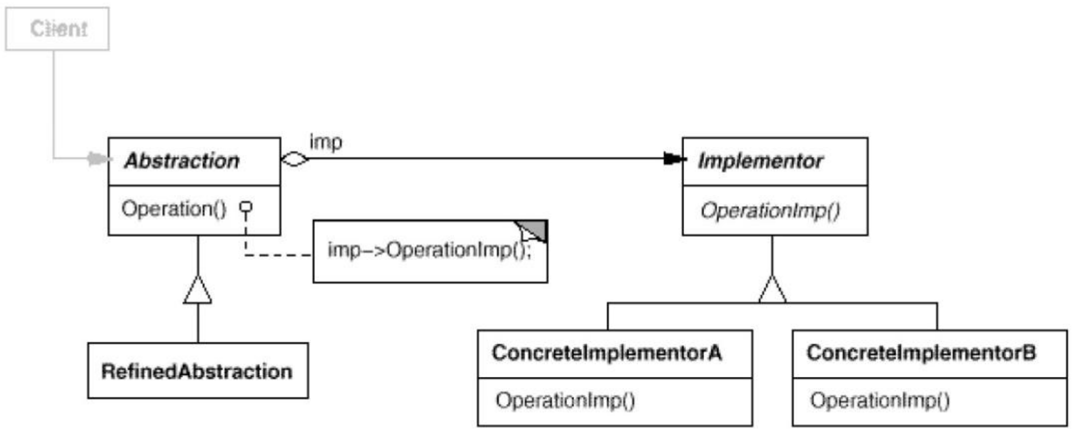
· changes in the implementation of an abstraction should have no impact on clients; that is, their code should not have to be recompiled.

· (C++) you want to hide the implementation of an abstraction completely from clients. In C++ the representation of a class is visible in the class interface.

· you have a proliferation of classes as shown earlier in the first Motivation diagram. Such a class hierarchy indicates the need for splitting an objectinto two parts. Rumbaugh uses the term "nested generalizations" [RBP+91] to refer to such class hierarchies.

· you want to share an implementation among multiple objects (perhaps using reference counting), and this fact should be hidden from the client. A simple example is Coplien's String class [Cop92], in which multiple objects can share the same string representation (StringRep).

▾Structure



▾Participants

· Abstraction (Window)

defines the abstraction's interface.

maintains a reference to an object of type Implementor.

· RefinedAbstraction (IconWindow)

Extends the interface defined by Abstraction.

· Implementor (WindowImp)

defines the interface for implementation classes. This interface doesn't have to correspond exactly to Abstraction's interface; in fact the two interfaces can be quite different. Typically the Implementor interface provides only primitive operations, and Abstraction defines higher-level operations based on these primitives.

· ConcreteImplementor (XWindowImp, PMWindowImp)

implements the Implementor interface and defines its concrete implementation.

Collaborations

· Abstraction forwards client requests to its Implementor object.

Consequences

The Bridge pattern has the following consequences:

1. *Decoupling interface and implementation.* An implementation is not boundpermanently to an interface. The implementation of an abstraction can be configured at run-time. It's even possible for an object to change its implementation at run-time.

Decoupling Abstraction and Implementor also eliminates compile-time dependencies on the implementation. Changing an implementation class doesn't require recompiling the Abstraction class and its clients. This property is essential when you must ensure binary compatibility between different versions of a class library.

Furthermore, this decoupling encourages layering that can lead to a better-structured system. The high-level part of a system only has to know about Abstraction and Implementer.

2. *Improved extensibility.* You can extend the Abstraction and Implementorhierarchies

independently.

3. *Hiding implementation details from clients.* You can shield clients fromimplementation details, like the sharing of implementor objects and the accompanying reference count mechanism (if any).

▾Implementation

Consider the following implementation issues when applying the Bridge pattern:

1. *Only one Implementor.* In situations where there's only one implementation,creating an abstract Implementor class isn't necessary. This is a degenerate case of the Bridge pattern; there's a one-to-one relationship between Abstraction and Implementor. Nevertheless, this separation is still useful when a change in the implementation of a class must not affect its existing clients that is, they shouldn't have to be recompiled, just relinked.

Carolanuses the term "Cheshire Cat" to describe this separation. In C++, the class interface of the Implementor class can be defined in aprivate header file that isn't provided to clients. This lets you hide an implementation of a class completely from its clients.

2. *Creating the right Implementor object.* How, when, and where do you decidewhich

Implementor class to instantiate when there's more than one?

If Abstraction knows about all ConcreteImplementor classes, then it can instantiate one of them in its constructor; it can decide between them based on parameters passed to its constructor. If, for example, a collection class supports multiple implementations, the decision can be based on the size of the collection. A linked list implementation can be used for small collections and a hash table for larger ones.

▾Sample Code

The following C++ code implements the Window/WindowImp example from the Motivation section. The Window class defines the window abstraction for client applications:

```
class Window { public:
```

```
Window(View* contents);

// requests handled by window virtual void

DrawContents();

virtual void Open(); virtual void Close(); virtual

void Iconify(); virtual void Deiconify();

// requests forwarded to implementation virtual void
SetOrigin(const Point& at); virtual void SetExtent(const Point&
extent); virtual void Raise();
virtual void Lower();

virtual void DrawLine(const Point&, const Point&); virtual void

DrawRect(const Point&, const Point&); virtual void

DrawPolygon(const Point[], int n); virtual void DrawText(const char*,

const Point&);
```

Known Uses

The Window example above comes from ET++. In ET++, WindowImp is called "WindowPort" and has subclasses such as XWindowPort and SunWindowPort. The Window object creates its corresponding Implementor object by requesting it from an abstract factory called "WindowSystem." WindowSystem provides an interface for creating platform-specific objects such as fonts, cursors, bitmaps, and so forth.

Related Patterns

An Abstract Factory can create and configure a particular Bridge.

The Adapter pattern is geared toward making unrelated classes work together. It is usually applied to systems after they're designed. Bridge, on the other hand, is used up-front in a design to let abstractions and implementations vary independently.

Composite

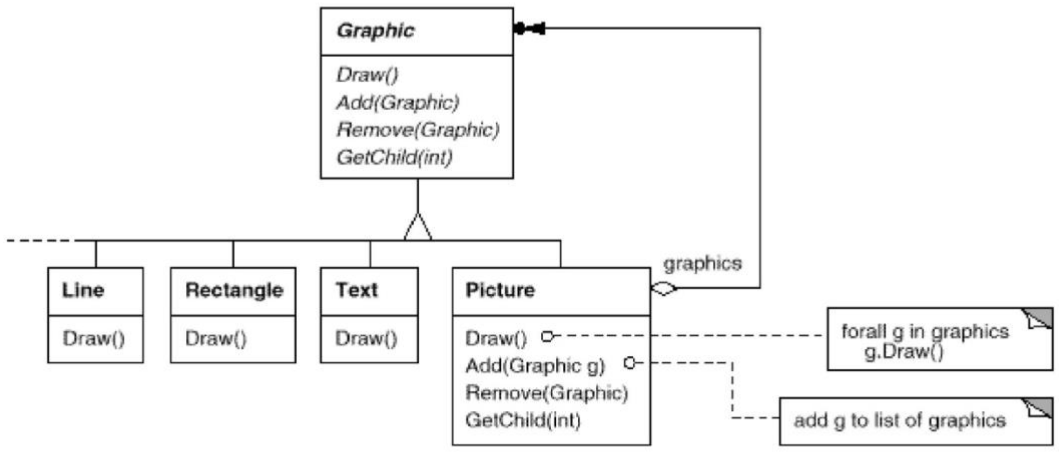
▾Intent

Compose objects into tree structures to represent part-whole hierarchies. Composite lets clients treat individual objects and compositions of objects uniformly.

▾Motivation

Graphics applications like drawing editors and schematic capture systems let users build complex diagrams out of simple components. The user can group components to form larger components, which in turn can be grouped to form still larger components. A simple implementation could define classes for graphical primitives such as Text and Lines plus other classes that act as containers for these primitives.

But there's a problem with this approach: Code that uses these classes must treat primitive and container objects differently, even if most of the time the user treats them identically. Having to distinguish these objects makes the application more complex. The Composite pattern describes how to use recursive composition so that clients don't have to make this distinction.



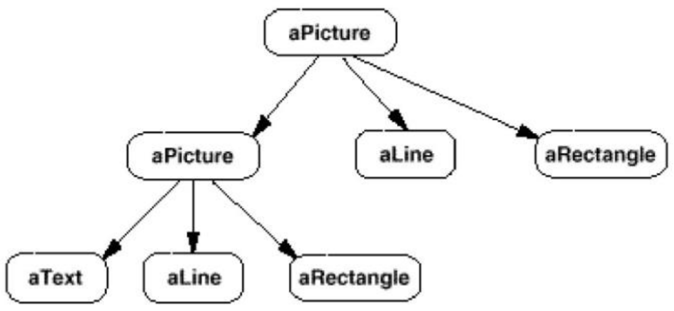
The key to the Composite pattern is an abstract class that represents *both* primitives and their containers. For the graphics system, this class is Graphic. Graphic declares operations like Draw that are specific to graphical objects.

It also declares operations that all composite objects share, such as operations for accessing and managing its children.

The subclasses Line, Rectangle, and Text (see preceding class diagram) define primitive graphical objects. These classes implement Draw to draw lines, rectangles, and text, respectively. Since primitive graphics have no child graphics, none of these subclasses implements child-related operations.

The Picture class defines an aggregate of Graphic objects. Picture implements Draw to call Draw on its children, and it implements child-related operations accordingly. Because the Picture interface conforms to the Graphic interface, Picture objects can compose other Pictures recursively.

The following diagram shows a typical composite object structure of recursively composed Graphic objects:



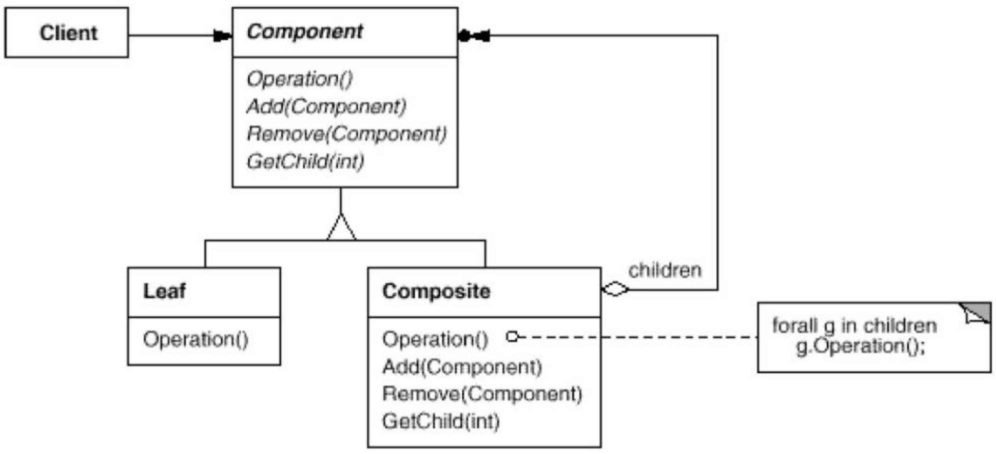
▾ Applicability

Use the Composite pattern when

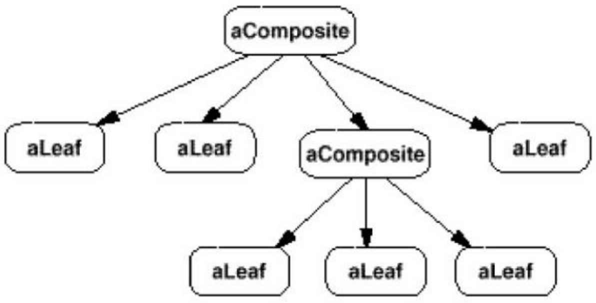
· you want to represent part-whole hierarchies of objects.

· you want clients to be able to ignore the difference between compositions of objects and individual objects. Clients will treat all objects in the composite structure uniformly.

▾Structure



A typical Composite object structure might look like this:



▾Participants

Component (Graphic)

declares the interface for objects in the composition.

implements default behavior for the interface common to all classes, as appropriate.

declares an interface for accessing and managing its child components.

(optional) defines an interface for accessing a component's parent in the recursive structure, and implements it if that's appropriate.

· Leaf (Rectangle, Line, Text, etc.)

represents leaf objects in the composition. A leaf has no children.

defines behavior for primitive objects in the composition.

· Composite (Picture)

defines behavior for components having children. o stores child components.

implements child-related operations in the Component interface.

· Client

manipulates objects in the composition through the Component interface.

Collaborations

· Clients use the Component class interface to interact with objects in the composite structure. If the recipient is a Leaf, then the request is handled directly. If the recipient is a Composite, then it usually forwards requests to its child components, possibly performing additional operations before and/or after forwarding.

Consequences

The Composite pattern

· defines class hierarchies consisting of primitive objects and composite objects. Primitive objects can be composed into more complex objects, which in turn can be composed, and so on recursively. Wherever client code expects a primitive object, it can also take a composite object.

· makes the client simple. Clients can treat composite structures and individual objects uniformly. Clients normally don't know (and shouldn't care) whether they're dealing with a leaf or a composite component. This simplifies client code, because it avoids having to write tag-and-case-statement-style functions over the classes that define the composition.

· makes it easier to add new kinds of components. Newly defined Composite or Leaf subclasses work automatically with existing structures and client code. Clients don't have to be changed for new Component classes.

· can make your design overly general. The disadvantage of making it easy to add new components is that it makes it harder to restrict the components of a composite. Sometimes you want a composite to have only certain components. With Composite, you can't rely on the type system to enforce those constraints for you. You'll have to use run-time checks instead.

Implementation

There are many issues to consider when implementing the Composite pattern:

1. *Explicit parent references.* Maintaining references from child componentsto their parent can simplify the traversal and management of a composite structure. The parent reference simplifies moving up the structure and deleting a component. Parent references also help support the Chain of Responsibility pattern.

The usual place to define the parent reference is in the Component class. Leaf and Composite classes can inherit the reference and the operations that manage it.

With parent references, it's essential to maintain the invariant that all children of a composite have as their parent the composite that in turn has them as children. The easiest way to ensure this is to change a component's parent *only* when it's being added or removed from a composite. If this can be implemented once in the Add and Remove operations of the Composite class, then it can be inherited by all the subclasses, and the invariant will be maintained automatically.

2. *Sharing components.* It's often useful to share components, for example,to reduce storage requirements. But when a component can have no more than one parent, sharing components becomes difficult.

A possible solution is for children to store multiple parents. But that can lead to ambiguities as a request propagates up the structure. The Flyweight (218) pattern shows how to rework a design to avoid storing parents altogether. It works in cases where children can avoid sending parent requests by externalizing some or all of their state.

3. *Maximizing the Component interface.* One of the goals of the Compositepattern is to make clients unaware of the specific Leaf or Composite classes they're using. To attain this goal, the Component class should define as many common operations for Composite and Leaf classes as possible. The Component class usually provides default implementations for these operations, and Leaf and Composite subclasses will override them.

Sample Code

Equipment such as computers and stereo components are often organized into part-whole or containment hierarchies. For example, a chassis can contain drives and planar boards, a bus can contain cards, and a cabinet can contain chassis, buses, and so forth. Such structures can be modeled naturally with the Composite pattern.

Equipment class defines an interface for all equipment in the part-whole hierarchy.

```
class Equipment { public:
virtual ~Equipment();

const char* Name() { return _name; }

virtual Watt Power(); virtual Currency
NetPrice();
virtual Currency DiscountPrice();

virtual void Add(Equipment*); virtual void
Remove(Equipment*); virtual Iterator*
CreateIterator();
protected:
Equipment(const char*); private:
const char* _name;
};
```

Known Uses

Examples of the Composite pattern can be found in almost all object-oriented systems. The original View class of Smalltalk Model/View/Controller was a Composite, and nearly every user interface toolkit or framework has followed in its steps, including ET++ (with its VObjects) and InterViews (Styles, Graphics, and Glyphs). It's interesting to note that the original View of Model/View/Controller had a set of subviews; in other words, View was both the Component class and the Composite class. Release 4.0 of Smalltalk-80 revised Model/View/Controller with a VisualComponent class that has subclasses View and CompositeView.

The RTL Smalltalk compiler framework uses the Composite pattern extensively. RTLExpression is a Component class for parse trees. It has subclasses, such as BinaryExpression, that contain child RTLExpression objects. These classes define a composite structure for parse trees. RegisterTransfer is the Component class for a program's intermediate Single Static Assignment (SSA) form. Leaf subclasses of RegisterTransfer define different static assignments such as

- primitive assignments that perform an operation on two registers and assign the result to a third;
- an assignment with a source register but no destination register, which indicates that the register is used after a routine returns; and
- an assignment with a destination register but no source, which indicates that the register is assigned before the routine starts.

Another subclass, RegisterTransferSet, is a Composite class for representing assignments that change several registers at once.

Another example of this pattern occurs in the financial domain, where a portfolio aggregates individual assets. You can support complex aggregations of assets by implementing a portfolio as a Composite that conforms to the interface of an individual asset [BE93].

The Command (263) pattern describes how Command objects can be composed and sequenced with a MacroCommand Composite class.

▼Related Patterns

Often the component-parent link is used for a Chain of Responsibility .

Decorator is often used with Composite. When decorators and composites are used together, they will usually have a common parent class. So decorators will have to support the Component interface with operations like Add, Remove, and GetChild.

Flyweight lets you share components, but they can no longer refer to their parents.

Iterator can be used to traverse composites.

Decorator

▼Intent

Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.

Also Known As

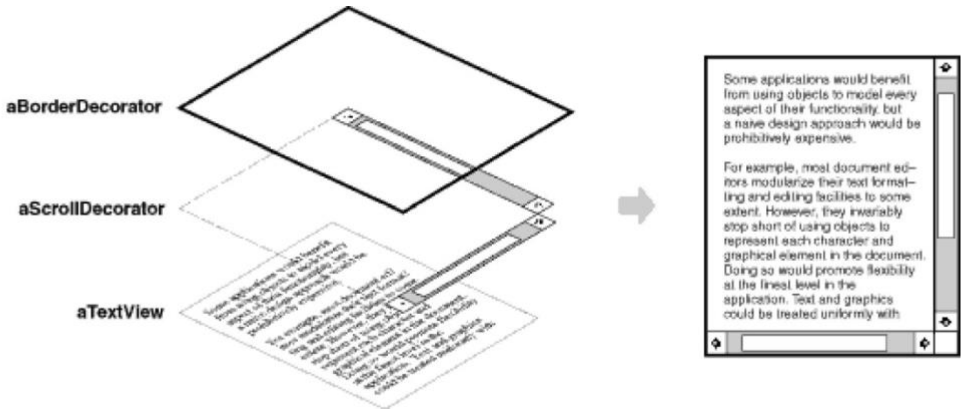
Wrapper

Motivation

Sometimes we want to add responsibilities to individual objects, not to an entire class. A graphical user interface toolkit, for example, should let you add properties like borders or behaviors like scrolling to any user interface component.

One way to add responsibilities is with inheritance. Inheriting a border from another class puts a border around every subclass instance. This is inflexible, however, because the choice of border is made statically. A client can't control how and when to decorate the component with a border.

A more flexible approach is to enclose the component in another object that adds the border. The enclosing object is called a decorator. The decorator conforms to the interface of the component it decorates so that its presence is transparent to the component's clients. The decorator forwards requests to the component and may perform additional actions (such as drawing a border) before or after forwarding. Transparency lets you nest decorators recursively, thereby allowing an unlimited number of added responsibilities.



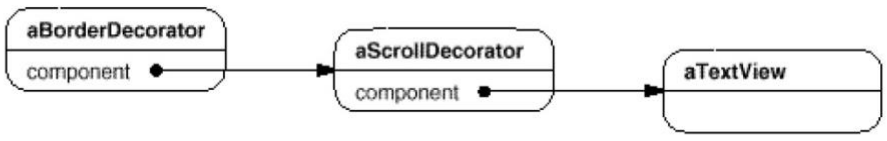
Some applications would benefit from using objects to model every aspect of their functionality, but a naive design approach would be prohibitively expensive.

For example, most document ed– itors modularize their text format– ting and editing facilities to some extent. However, they invariably stop short of using objects to represent each character and graphical element in the document. Doing so would promote flexibility at the finest level in the application. Text and graphics could be treated uniformly with

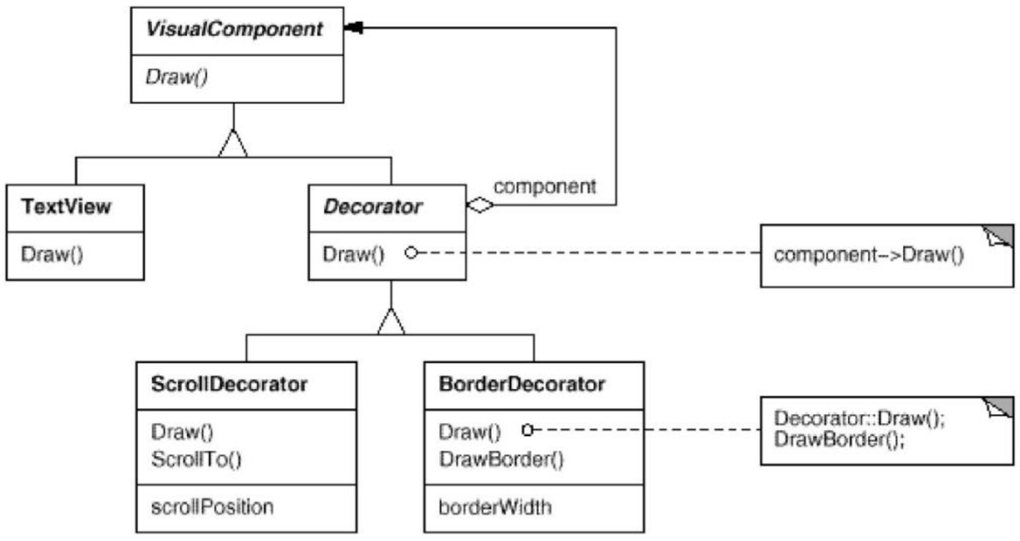
For example, suppose we have a TextView object that displays text in a window. TextView has no scroll bars by default, because we might not always need them. When we do, we can use a

ScrollDecorator to add them. Suppose we also want to add a thick black border around the TextView. We can use a BorderDecorator to add this as well. We simply compose the decorators with the TextView to produce the desired result.

The following object diagram shows how to compose a TextView object with BorderDecorator and ScrollDecorator objects to produce a bordered, scrollable text view:



The ScrollDecorator and BorderDecorator classes are subclasses of Decorator, an abstract class for visual components that decorate other visual components.



VisualComponent is the abstract class for visual objects. It defines their drawing and event handling interface. Note how the Decorator class simply forwards draw requests to its component, and how Decorator subclasses can extend this operation.

Decorator subclasses are free to add operations for specific functionality. For example, ScrollDecorator'sScrollTo operation lets other objects scroll the interface *if* they know there happens to be a ScrollDecorator object in the interface. The important aspect of this pattern is that it lets decorators appear anywhere a VisualComponent can. That way clients generally can't tell the difference between a decorated component and an undecorated one, and so they don't depend at all on the decoration.

Applicability

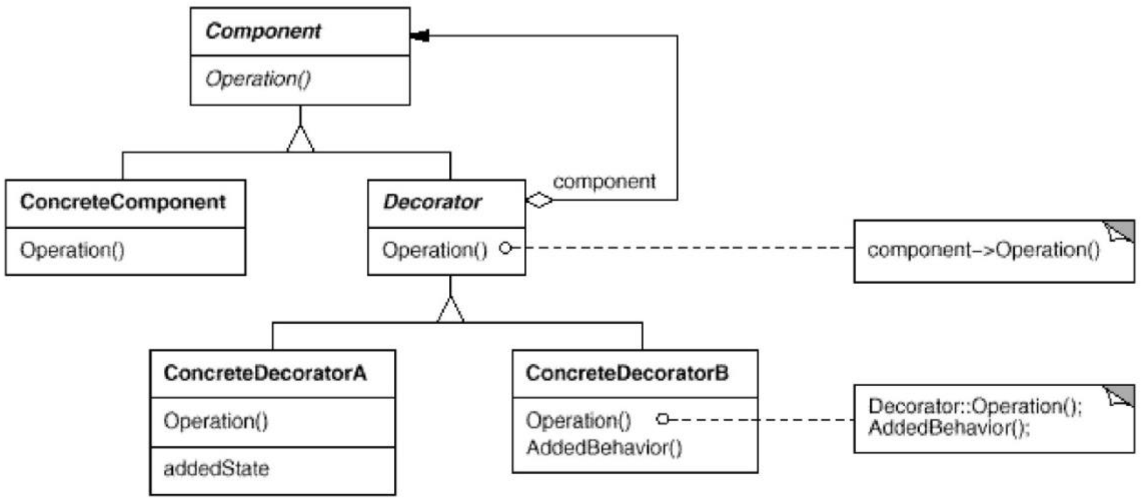
Use Decorator

· to add responsibilities to individual objects dynamically and transparently, that is, without affecting other objects.

· for responsibilities that can be withdrawn.

· when extension by subclassing is impractical. Sometimes a large number of independent extensions are possible and would produce an explosion of subclasses to support every combination. Or a class definition may be hidden or otherwise unavailable for subclassing.

Structure



Participants

· Component (VisualComponent)

o defines the interface for objects that can have responsibilities added to them dynamically.

· ConcreteComponent (TextView)

o defines an object to which additional responsibilities can be attached.

· Decorator

o maintains a reference to a Component object and defines an interface that conforms to Component's interface.

· ConcreteDecorator (BorderDecorator, ScrollDecorator)

o adds responsibilities to the component.

Collaborations

· Decorator forwards requests to its Component object. It may optionally perform additional operations before and after forwarding the request.

Consequences

The Decorator pattern has at least two key benefits and two liabilities:

1. *More flexibility than static inheritance.* The Decorator pattern providesa more flexible way to add responsibilities to objects than can be had with static (multiple) inheritance. With decorators, responsibilities can be added and removed at run-time simply by attaching and detaching them. In contrast, inheritance requires creating a new class for each additional responsibility (e.g., BorderedScrollableTextView, BorderedTextView).
This gives rise to many classes and increases the complexity of a system. Furthermore, providing different Decorator classes for a specific Component class lets you mix and match responsibilities. Decorators also make it easy to add a property twice. For example, to give a TextView a double border, simply attach two BorderDecorators. Inheriting from a Border class twice is error-prone at best.

2. *Avoids feature-laden classes high up in the hierarchy.* Decorator offersa pay-as-you-go approach to adding responsibilities. Instead of trying to support all foreseeable features in a complex, customizable class, you can define a simple class and add functionality incrementally with Decorator objects. Functionality can be composed from simple pieces. As a result, an application needn't pay for features it doesn't use. It's also easy to define new kinds of Decorators independently from the classes of objects they extend, even for unforeseen extensions. Extending a complex class tends to expose details unrelated to the responsibilities you're adding.

3. *A decorator and its component aren't identical.* A decorator acts as atransparent enclosure. But from an object identity point of view, a decorated component is not identical to the component itself. Hence you shouldn't rely on object identity when you use decorators.

4. *Lots of little objects.* A design that uses Decorator often results in systemscomposed of lots of little objects that all look alike. The objects differ only in the way they are interconnected, not in their class or in the value of their variables. Although these systems are easy to customize by those who understand them, they can be hard to learn and debug.

Implementation

Several issues should be considered when applying the Decorator pattern:

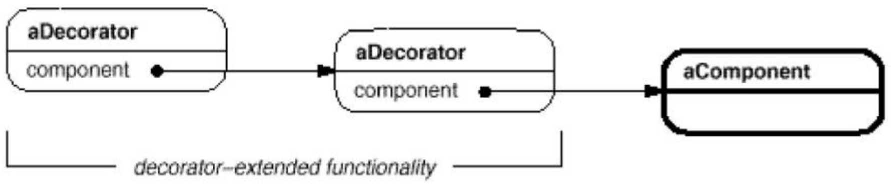
1. *Interface conformance.* A decorator object's interface must conform to theinterface of the component it decorates. ConcreteDecorator classes must therefore inherit from a common class (at least in C++).
2. *Omitting the abstract Decorator class.* There's no need to define an abstractDecorator class when you only need to add one responsibility. That's often the case when you're dealing with an existing class hierarchy rather thandesigning a new one. In that case, you can merge Decorator's responsibility for forwarding requests to the component into the ConcreteDecorator.
3. *Keeping Component classes lightweight.* To ensure a conforming interface,components and decorators must descend from a common Component class. It's important to keep this common class lightweight; that is, it should focus on defining an interface, not on storing data. The definition of the data representation should be deferred to subclasses; otherwise the complexity of the Component class might make the decorators too heavyweight to use in quantity. Putting a lot of functionality into Component also increases the probability that concrete subclasses will pay for features they don't need.
4. *Changing the skin of an object versus changing its guts.* We can think ofa decorator as a skin over an object that changes its behavior. An alternative is to change the object's guts. The Strategy pattern is a good example of a pattern for changing the guts.

Strategies are a better choice in situations where the Component class is intrinsically heavyweight, thereby making the Decorator pattern too costly to apply. In the Strategy pattern, the component forwards some of its behavior to a separate strategy object. The Strategy pattern lets us alter or extend the component's functionality by replacing the strategy object.

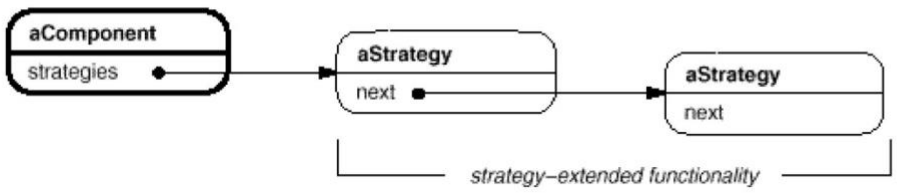
For example, we can support different border styles by having the component defer border-drawing to a separate Border object. The Border object is a Strategy object that encapsulates a border-drawing strategy. By extending the number of strategies from just one to an open-ended list, we achieve the same effect as nesting decorators recursively.

In MacApp 3.0 [App89] and Bedrock [Sym93a], for example, graphical components (called "views") maintain a list of "adorner" objects that can attach additional adornments like borders to a view component. If a view has any adorners attached, then it gives them a chance to draw additional embellishments. MacApp and Bedrock must use this approach because the View class is heavyweight. It would be too expensive to use a full-fledged View just to add a border.

Since the Decorator pattern only changes a component from the outside, the component doesn't have to know anything about its decorators; that is, the decorators are transparent to the component:



With strategies, the component itself knows about possible extensions. So it has to reference and maintain the corresponding strategies:



The Strategy-based approach might require modifying the component to accommodate new extensions. On the other hand, a strategy can have its own specialized interface, whereas a decorator's interface must conform to the component's. A strategy for rendering a border, for example, need only define the interface for rendering a border (DrawBorder, GetWidth, etc.), which means that the strategy can be lightweight even if the Component class is heavyweight.

MacApp and Bedrock use this approach for more than just adorning views. They also use it to augment the event-handling behavior of objects. In both systems, a view maintains a list of "behavior" objects that can modify and intercept events. The view gives each of the registered behavior objects a chance to handle the event before nonregistered behaviors, effectively overriding them. You can decorate a view with special keyboard-handling support, for example, by registering a behavior object that intercepts and handles key events.

Sample Code

The following code shows how to implement user interface decorators in C++. We'll assume there's a Component class called VisualComponent.

```
classVisualComponent {
public:
VisualComponent();
virtual void Draw();
virtual void Resize();
// ...
};
```

We define a subclass of VisualComponent called Decorator, which we'll subclass to obtain different decorations.

```
class Decorator : public VisualComponent { public:
Decorator(VisualComponent*);

virtual void Draw(); virtual void Resize(); //
private:
VisualComponent* _component;
};
```

Decorator decorates the VisualComponent referenced by the _component instance variable, which is initialized in the constructor. For each operation in VisualComponent's interface, Decorator defines a default implementation that passes the request on to _component:

```
void Decorator::Draw () { _component-
>Draw();
}

void Decorator::Resize () { _component-
>Resize();
}
```

Known Uses

Many object-oriented user interface toolkits use decorators to add graphical embellishments to widgets. Examples include InterViews [LVC98, LCI+92], ET++ [WGM88], and the ObjectWorks\Smalltalk class library [Par90]. More exotic applications of Decorator are the DebuggingGlyph from InterViews and the PassivityWrapper from ParcPlace Smalltalk. A DebuggingGlyph prints out debugging information before and after it forwards a layout request to its component. This trace information can be used to analyze and debug the layout behavior of objects in a complex composition. The PassivityWrapper can enable or disable user interactions with the component.

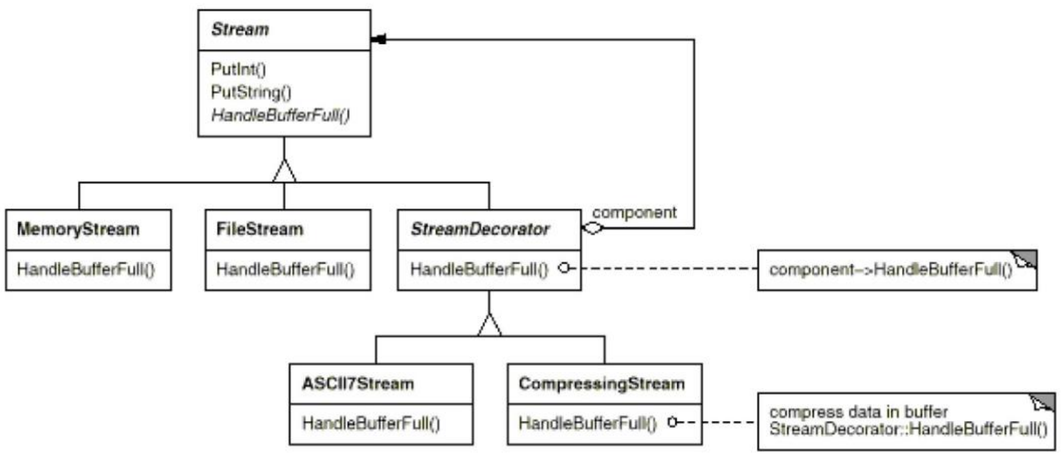
But the Decorator pattern is by no means limited to graphical user interfaces, as the following example (based on the ET++ streaming classes [WGM88]) illustrates.

Streams are a fundamental abstraction in most I/O facilities. A stream can provide an interface for converting objects into a sequence of bytes or characters. That lets us transcribe an object to a file or to a string in memory for retrieval later. A straightforward way to do this is to define an abstract Stream class with subclasses MemoryStream and FileStream. But suppose we also want to be able to do the following:

· Compress the stream data using different compression algorithms (run-length encoding, Lempel-Ziv, etc.).

· Reduce the stream data to 7-bit ASCII characters so that it can be transmitted over an ASCII communication channel.

The Decorator pattern gives us an elegant way to add these responsibilities to streams. The diagram below shows one solution to the problem:



The Stream abstract class maintains an internal buffer and provides operations for storing data onto the stream (PutInt, PutString). Whenever the buffer is full, Stream calls the abstract operation HandleBufferFull, which does the actual data transfer. The FileStream version of this operation overrides this operation to transfer the buffer to a file.

The key class here is StreamDecorator, which maintains a reference to a component stream and forwards requests to it. StreamDecorator subclasses override HandleBufferFull and perform additional actions before calling StreamDecorator'sHandleBufferFull operation.

For example, the CompressingStream subclass compresses the data, and the ASCII7Stream converts the data into 7-bit ASCII. Now, to create a FileStream that compresses its data *and* converts the compressed binary data to 7-bit ASCII, we decorate a FileStream with a CompressingStream and an ASCII7Stream:

Related Patterns

Adapter: A decorator is different from an adapter in that a decorator only changes an object's responsibilities, not its interface; an adapter will give an object a completely new interface.

Composite: A decorator can be viewed as a degenerate composite with only one component.

However, a decorator adds additional responsibilities it isn't intended for object aggregation.

Strategy: A decorator lets you change the skin of an object; a strategy lets you change the guts. These are two alternative ways of changing an object.

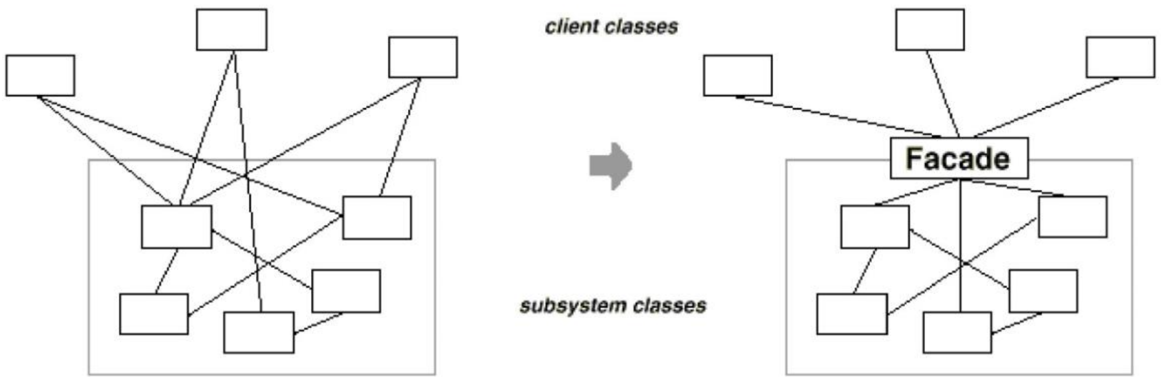
Facade:

Intent

Provide a unified interface to a set of interfaces in a subsystem. Facade defines a higher-level interface that makes the subsystem easier to use.

Motivation

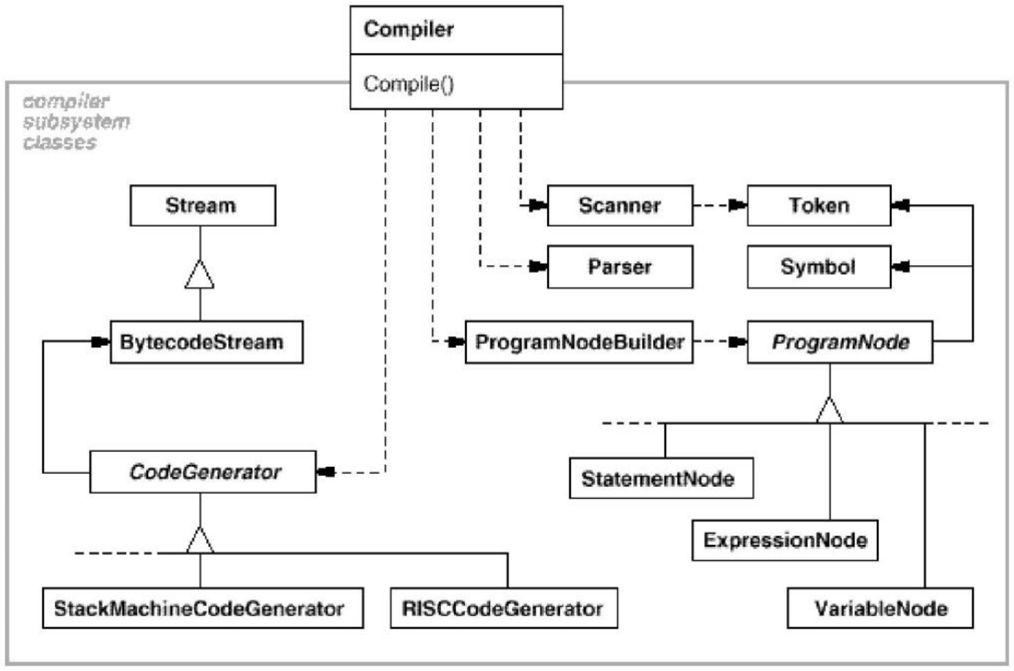
Structuring a system into subsystems helps reduce complexity. A common design goal is to minimize the communication and dependencies between subsystems. One way to achieve this goal is to introduce a facade object that provides a single, simplified interface to the more general facilities of a subsystem.



Consider for example a programming environment that gives applications access to its compiler subsystem. This subsystem contains classes such as Scanner, Parser, ProgramNode, BytecodeStream, and ProgramNodeBuilder that implement the compiler.

Some specialized applications might need to access these classes directly. But most clients of a compiler generally don't care about details like parsing and code generation; they merely want to compile some code. For them, the powerful but low-level interfaces in the compiler subsystem only complicate their task.

To provide a higher-level interface that can shield clients from these classes, the compiler subsystem also includes a Compiler class. This class defines a unified interface to the compiler's functionality. The Compiler class acts as a facade: It offers clients a single, simple interface to the compiler subsystem. It glues together the classes that implement compiler functionality without hiding them completely. The compiler facade makes life easier for most programmers without hiding the lower-level functionality from the few that need it.



▾Applicability

Use the Facade pattern when

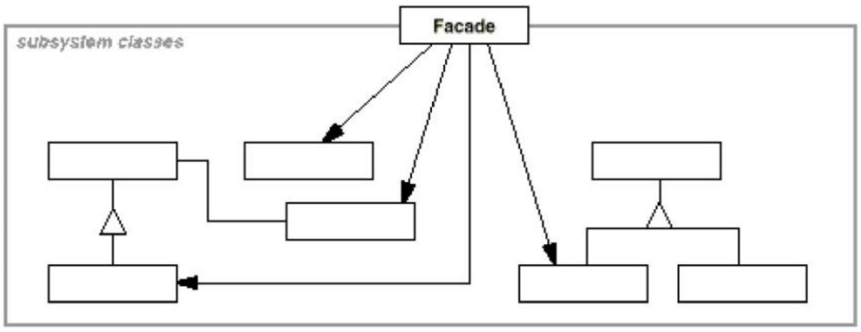
· you want to provide a simple interface to a complex subsystem. Subsystems often get more complex as they evolve. Most patterns, when applied, result in more and smaller classes. This makes the subsystem more reusable and easier to customize, but it also becomes harder to use for clients that don't need to customize it.

· A facade can provide a simple default view of the subsystem that is good enough for most clients. Only clients needing more customizability will need to look beyond the facade.

· There are many dependencies between clients and the implementation classes of an abstraction. Introduce a facade to decouple the subsystem from clients and other subsystems, thereby promoting subsystem independence and portability.

· you want to layer your subsystems. Use a facade to define an entry point to each subsystem level. If subsystems are dependent, then you can simplify the dependencies between them by making them communicate with each other solely through their facades.

▾Structure



▾Participants

· Facade (Compiler)

knows which subsystem classes are responsible for a request.

delegates client requests to appropriate subsystem objects.

· subsystem classes (Scanner, Parser, ProgramNode, etc.)

implement subsystem functionality.

handle work assigned by the Facade object.

have no knowledge of the facade; that is, they keep no references to it.

▾Collaborations

· Clients communicate with the subsystem by sending requests to Facade, which forwards them to the appropriate subsystem object(s). Although the subsystem objects perform the actual work, the facade may have to do work of its own to translate its interface to subsystem interfaces.

· Clients that use the facade don't have to access its subsystem objects directly.

▾Consequences

The Facade pattern offers the following benefits:

1. It shields clients from subsystem components, thereby reducing the number of objects that clients deal with and making the subsystem easier to use.
2. It promotes weak coupling between the subsystem and its clients. Often the

components in a subsystem are strongly coupled. Weak coupling lets you vary the components of the subsystem without affecting its clients. Facades helplayer a system and the dependencies between objects. They can eliminate complex or circular dependencies. This can be an important consequence when the client and the subsystem are implemented independently.

Reducing compilation dependencies is vital in large software systems. You want to save time by minimizing recompilation when subsystem classes change. Reducing compilation dependencies with facades can limit the recompilation needed for a small change in an important subsystem. A facade can also simplify porting systems to other platforms, because it's less likely that building one subsystem requires building all others.

3. It doesn't prevent applications from using subsystem classes if they need to. Thus you can choose between ease of use and generality.

▼Implementation

Consider the following issues when implementing a facade:

1. *Reducing client-subsystem coupling.* The coupling between clients and thesubsystem can be reduced even further by making Facade an abstract class with concrete subclasses for different implementations of a subsystem. Then clients can communicate with the subsystem through the interface of the abstract Facade class. This abstract coupling keeps clients from knowing which implementation of a subsystem is used.

An alternative to subclassing is to configure a Facade object with different subsystem objects. To customize the facade, simply replace one or more of its subsystem objects.

2. *Public versus private subsystem classes.* A subsystem is analogous to a classin that both have interfaces, and both encapsulate something a class encapsulates state and operations, while a subsystem encapsulates classes. And just as it's useful to think of the public and private interface of a class, we can think of the public and private interface of a subsystem.

The public interface to a subsystem consists of classes that all clients can access; the private interface is just for subsystem extenders. The Facade class is part of the public interface, of course, but it's not the only part. Other subsystem classes are usually public as well. For example, the classes Parser and Scanner in the compiler subsystem are part of the public interface.

Making subsystem classes private would be useful, but few object-oriented languages support it. Both C++ and Smalltalk traditionally have had a globalname space for classes. Recently, however, the C++ standardization committee added name spaces to the language [Str94], which will let you expose just the public subsystem classes.

Sample Code

Let's take a closer look at how to put a facade on a compiler subsystem.

The compiler subsystem defines a {BytecodeStream} class that implements a stream of Bytecode objects. A Bytecode object encapsulates a bytecode, which can specify machine instructions. The subsystem also defines a Token class for objects that encapsulate tokens in the programming language.

The Scanner class takes a stream of characters and produces a stream of tokens, one token at a time.

```
class Scanner { public:
Scanner(istream&); virtual ~Scanner();

virtual Token& Scan(); private:
istream& _inputStream;
};
```

The class Parser uses a ProgramNodeBuilder to construct a parse tree from a Scanner's tokens.

```
class Parser { public:
Parser();
virtual ~Parser();
virtual void Parse(Scanner&, ProgramNodeBuilder&);
};
```

Parser calls back on ProgramNodeBuilder to build the parse tree incrementally. These classes interact according to the Builder pattern.

```
classProgramNodeBuilder {

public:
ProgramNodeBuilder();
virtualProgramNode*    NewVariable(    const    char*

variableName

) const;

virtualProgramNode* NewAssignment(
ProgramNode* variable, ProgramNode* expression )const;

virtualProgramNode*  NewReturnStatement(  ProgramNode*

value

) const;

virtualProgramNode*   NewCondition(   ProgramNode*

condition,

ProgramNode* truePart, ProgramNode* falsePart )const;
// ...

ProgramNode* GetRootNode(); private:
ProgramNode* _node;
};
```

The parse tree is made up of instances of ProgramNode subclasses such as StatementNode, ExpressionNode, and so forth. The ProgramNode hierarchy is an example of the Composite pattern. ProgramNode defines an interface for manipulating the program node and its children, if any.

```
classProgramNode { public:
// program node manipulation
virtual void GetSourcePosition(int& line, int& index);
//                  ...

//                  child manipulation
virtual    void    Add(ProgramNode*);    virtual    void

Remove(ProgramNode*); // ...

virtual void Traverse(CodeGenerator&);
protected:
ProgramNode();
};
```

▼Known Uses

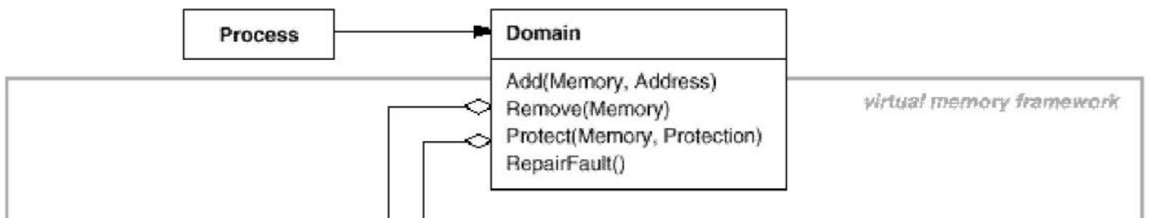
The compiler example in the Sample Code section was inspired by the

ObjectWorks\Smalltalk compiler system [Par90].

In the ET++ application framework [WGM88], an application can have built-in browsing tools for inspecting its objects at run-time. These browsing tools are implemented in a separate subsystem that includes a Facade class called "ProgrammingEnvironment." This facade defines operations such as InspectObject and InspectClass for accessing the browsers.

An ET++ application can also forgo built-in browsing support. In that case, ProgrammingEnvironment implements these requests as null operations; that is, they do nothing. Only the ETProgrammingEnvironment subclass implements these requests with operations that display the corresponding browsers. The application has no knowledge of whether a browsing environment is available or not; there's abstract coupling between the application and the browsing subsystem.

The Choices operating system [CIRM93] uses facades to compose many frameworks into one. The key abstractions in Choices are processes, storage, and address spaces. For each of these abstractions there is a corresponding subsystem, implemented as a framework, that supports porting Choices to a variety of different hardware platforms. Two of these subsystems have a "representative" (i.e., facade). These representatives are FileSystemInterface (storage) and Domain (address spaces).



For example, the virtual memory framework has Domain as its facade. A Domain represents an address space. It provides a mapping between virtual addresses and offsets into memory objects, files, or backing store. The main operations on Domain support adding a memory object at a particular address, removing a memory object, and handling a page fault.

▼Related Patterns

Abstract Factory can be used with Facade to provide an interface for creating subsystem objects in a subsystem-independent way. Abstract Factory can also be used as an alternative to Facade to hide platform-specific classes.

Mediator is similar to Facade in that it abstracts functionality of existing classes. However, Mediator's purpose is to abstract arbitrary communication between colleague objects, often centralizing functionality that doesn't belong in any one of them. A mediator's colleagues are aware of and communicate with the mediator instead of communicating with each other directly.

Flyweight

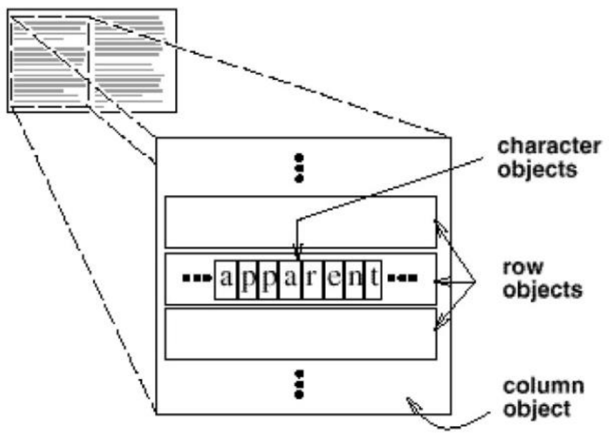
▼Intent

Use sharing to support large numbers of fine-grained objects efficiently.

▼Motivation

Some applications could benefit from using objects throughout their design, but a naive implementation would be prohibitively expensive.

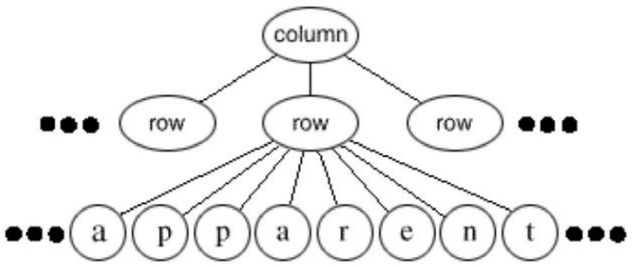
For example, most document editor implementations have text formatting and editing facilities that are modularized to some extent. Object-oriented document editors typically use objects to represent embedded elements like tables and figures. However, they usually stop short of using an object for each character in the document, even though doing so would promote flexibility at the finest levels in the application. Characters and embedded elements could then be treated uniformly with respect to how they are drawn and formatted. The application could be extended to support new character sets without disturbing other functionality. The application's object structure could mimic the document's physical structure. The following diagram shows how a document editor can use objects to represent characters.



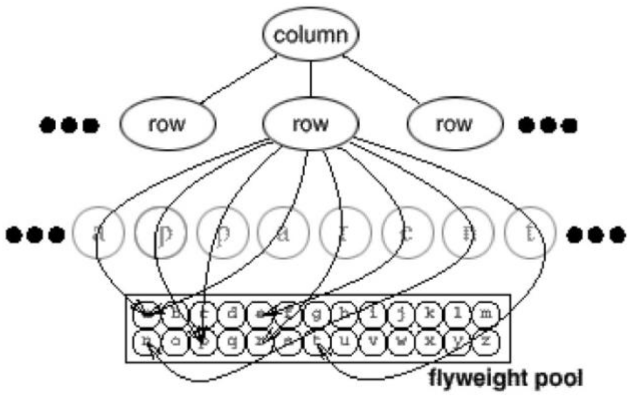
The drawback of such a design is its cost. Even moderate-sized documents may require hundreds of thousands of character objects, which will consume lots of memory and may incur unacceptable run-time overhead. The Flyweight pattern describes how to share objects to allow their use at fine granularities without prohibitive cost.

A flyweight is a shared object that can be used in multiple contexts simultaneously. The flyweight acts as an independent object in each context it's indistinguishable from an instance of the object that's not shared. Flyweights cannot make assumptions about the context in which they operate. The key concept here is the distinction between intrinsic and extrinsic state. Intrinsic state is stored in the flyweight; it consists of information that's independent of the flyweight's context, thereby making it sharable.

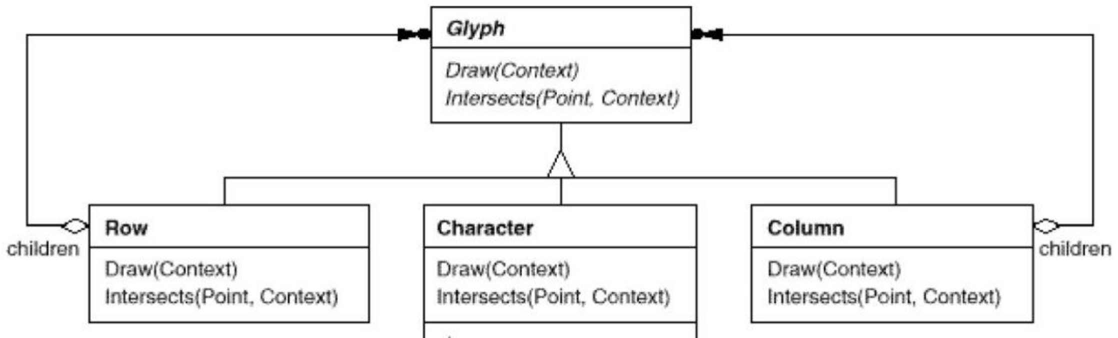
Flyweights model concepts or entities that are normally too plentiful to represent with objects. For example, a document editor can create a flyweight for each letter of the alphabet. Each flyweight stores a character code, but its coordinate position in the document and its typographic style can be determined from the text layout algorithms and formatting commands in effect wherever the character appears. The character code is intrinsic state, while the other information is extrinsic. Logically there is an object for every occurrence of a given character in the document:



Physically, however, there is one shared flyweight object per character, and it appears in different contexts in the document structure. Each occurrence of a particular character object refers to the same instance in the shared pool of flyweight objects:



The class structure for these objects is shown next. Glyph is the abstract class for graphical objects, some of which may be flyweights. Operations that may depend on extrinsic state have it passed to them as a parameter. For example, Draw and Intersects must know which context the glyph is in before they can do their job.


Glyph
Draw(Context)
Intersects(Point, Context)
children
Row
Draw(Context)
Intersects(Point, Context)
Character
Draw(Context)
Intersects(Point, Context)
Column
Draw(Context)
Intersects(Point, Context)
children

A flyweight representing the letter "a" only stores the corresponding character code; it doesn't need to store its location or font. Clients supply the context-dependent information that the flyweight needs to draw itself. For example, a Row glyph knows where its children should draw themselves so that they are tiled horizontally. Thus it can pass each child its location in the draw request.

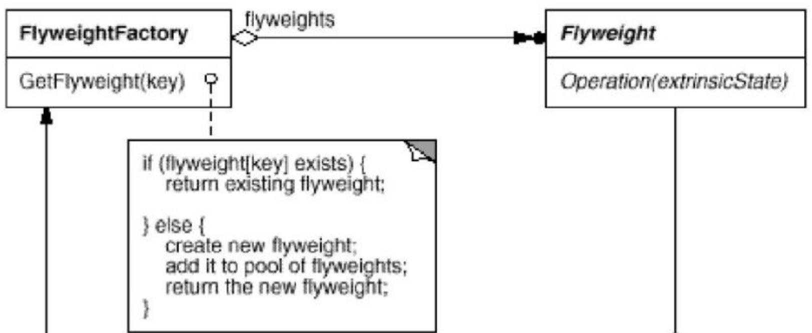
Because the number of different character objects is far less than the number of characters in the document, the total number of objects is substantially less than what a naive implementation would use. A document in which all characters appear in the same font and color will allocate on the order of 100 character objects (roughly the size of the ASCII character set) regardless of the document's length. And since most documents use no more than 10 different font-color combinations, this number won't grow appreciably in practice. An object abstraction thus becomes practical for individual characters.

Applicability

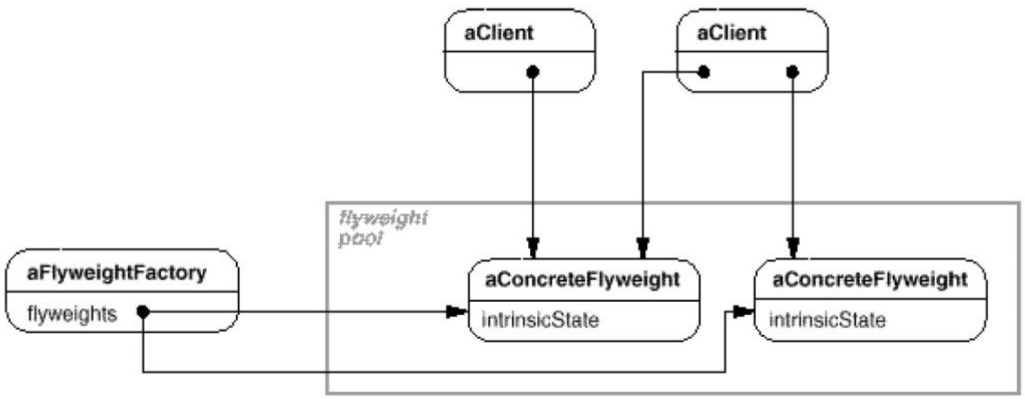
The Flyweight pattern's effectiveness depends heavily on how and where it's used. Apply the Flyweight pattern when *all* of the following are true:

· An application uses a large number of objects.
· Storage costs are high because of the sheer quantity of objects.
· Most object state can be made extrinsic.
· Many groups of objects may be replaced by relatively few shared objects once extrinsic state is removed.
· The application doesn't depend on object identity. Since flyweight objects may be shared, identity tests will return true for conceptually distinct objects.

Structure


FlyweightFactory
GetFlyweight(key)
flyweights
Flyweight
Operation(extrinsicState)
if (flyweight[key] exists) {
return existing flyweight;
} else {
create new flyweight;
add it to pool of flyweights;
return the new flyweight;
}

The following object diagram shows how flyweights are shared:



Participants

- Flyweight

declares an interface through which flyweights can receive and act on extrinsic state.

- ConcreteFlyweight (Character)

implements the Flyweight interface and adds storage for intrinsic state, if any. A ConcreteFlyweight object must be sharable. Any state it stores must be intrinsic; that is, it must be independent of the ConcreteFlyweight object's context.

- UnsharedConcreteFlyweight (Row, Column)

not all Flyweight subclasses need to be shared. The Flyweight interface *enables* sharing; it doesn't enforce it. It's common for UnsharedConcreteFlyweight objects to have ConcreteFlyweight objects as children at some level in the flyweight object structure (as the Row and Column classes have).

· FlyweightFactory

creates and manages flyweight objects.

ensures that flyweights are shared properly. When a client requests a flyweight, the FlyweightFactory object supplies an existing instance or creates one, if none exists.

Client

maintains a reference to flyweight(s).

computes or stores the extrinsic state of flyweight(s).

Collaborations

· State that a flyweight needs to function must be characterized as either intrinsic or extrinsic. Intrinsic state is stored in the ConcreteFlyweightobject; extrinsic state is stored or computed by Client objects. Clients pass this state to the flyweight when they invoke its operations.

· Clients should not instantiate ConcreteFlyweights directly. Clients must obtain ConcreteFlyweight objects exclusively from the FlyweightFactory object to ensure they are shared properly.

Consequences

Flyweights may introduce run-time costs associated with transferring, finding, and/or computing extrinsic state, especially if it was formerly stored as intrinsic state. However, such costs are offset by space savings, which increase as more flyweights are shared.

Storage savings are a function of several factors:

· the reduction in the total number of instances that comes from sharing
· the amount of intrinsic state per object
· whether extrinsic state is computed or stored.

The more flyweights are shared, the greater the storage savings. The savings increase with the amount of shared state. The greatest savings occur when the objects use substantial quantities of both intrinsic and extrinsic state, and the extrinsic state can be computed rather than stored. Then you save on storage in two ways: Sharing reduces the cost of intrinsic state, and you trade extrinsic state for computation time.

The Flyweight pattern is often combined with the Composite pattern to represent a hierarchical structure as a graph with shared leaf nodes. A consequence of sharing is that flyweight leaf nodes cannot store a pointer to their parent. Rather, the parent pointer is passed to the flyweight as part of its extrinsic state. This has a major impact on how the objects in the hierarchy communicate with each other.

Implementation

Consider the following issues when implementing the Flyweight pattern:

1. *Removing extrinsic state.* The pattern's applicability is determinedlargely by how easy it is to identify extrinsic state and remove it from shared objects. Removing extrinsic state won't help reduce storage costs if there are as many different kinds of extrinsic state as there are objects before sharing. Ideally, extrinsic state can be computed from a separate object structure, one with far smaller storage requirements.
In our document editor, for example, we can store a map of typographic information in a separate structure rather than store the font and type style with each character object. The map keeps track of runs of characters with the same typographic attributes. When a character draws itself, it receives its typographic attributes as a side-effect of the draw traversal. Because documents normally use just a few different fonts and styles, storing this information externally to each character object is far more efficient than storing it internally.

2. *Managing shared objects.* Because objects are shared, clients shouldn'tinstantiate them directly. FlyweightFactory lets clients locate a particular flyweight. FlyweightFactory objects often use an associative store to let clients look up flyweights of interest. For example, the flyweight factory in the document editor example can keep a table of flyweights indexed by character codes. The manager returns the proper flyweight given its code, creating the flyweight if it does not already exist.

Sharability also implies some form of reference counting or garbage collection to reclaim a flyweight's storage when it's no longer needed. However, neither is necessary if the number of flyweights is fixed and small (e.g., flyweights for the ASCII character set). In that case, the flyweights are worth keeping around permanently.

Sample Code

Returning to our document formatter example, we can define a Glyph base class for flyweight graphical objects. Logically, glyphs are Composites that have graphical attributes and can draw themselves. Here we focus on just the font attribute, but the same approach can be used for any other graphical attributes a glyph might have.

```
class Glyph { public:
virtual ~Glyph();
virtual void Draw(Window*, GlyphContext&);
virtual void SetFont(Font*, GlyphContext&); virtual Font*

GetFont(GlyphContext&);

virtual void First(GlyphContext&);
virtual void Next(GlyphContext&); virtual bool IsDone(GlyphContext&); virtual Glyph*
Current(GlyphContext&);
virtual void Insert(Glyph*, GlyphContext&); virtual void
Remove(GlyphContext&);
protected:
Glyph();
};
```

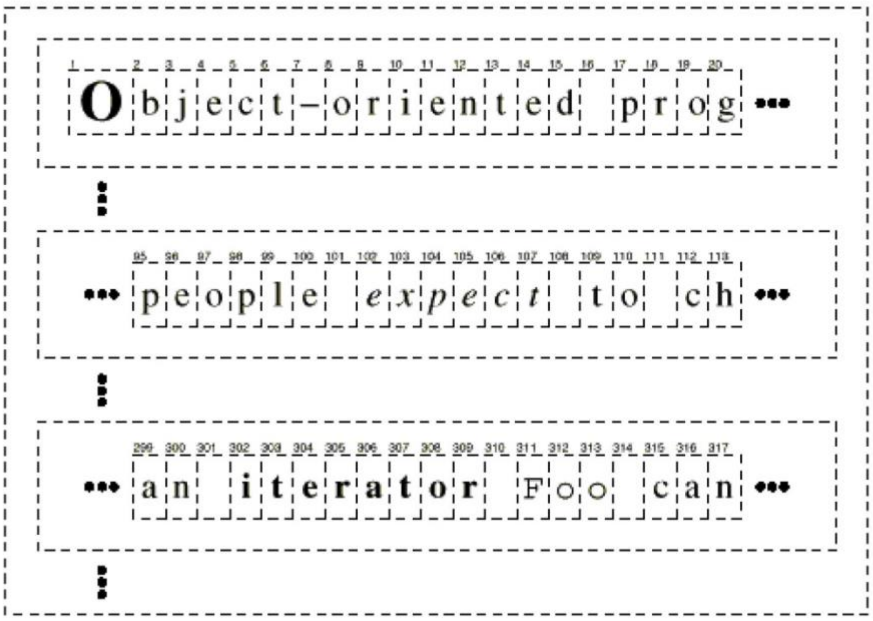
The Character subclass just stores a character code:

```
class Character : public Glyph { public:
Character(char);

virtual void Draw(Window*, GlyphContext&); private:
char _charcode;
};
```

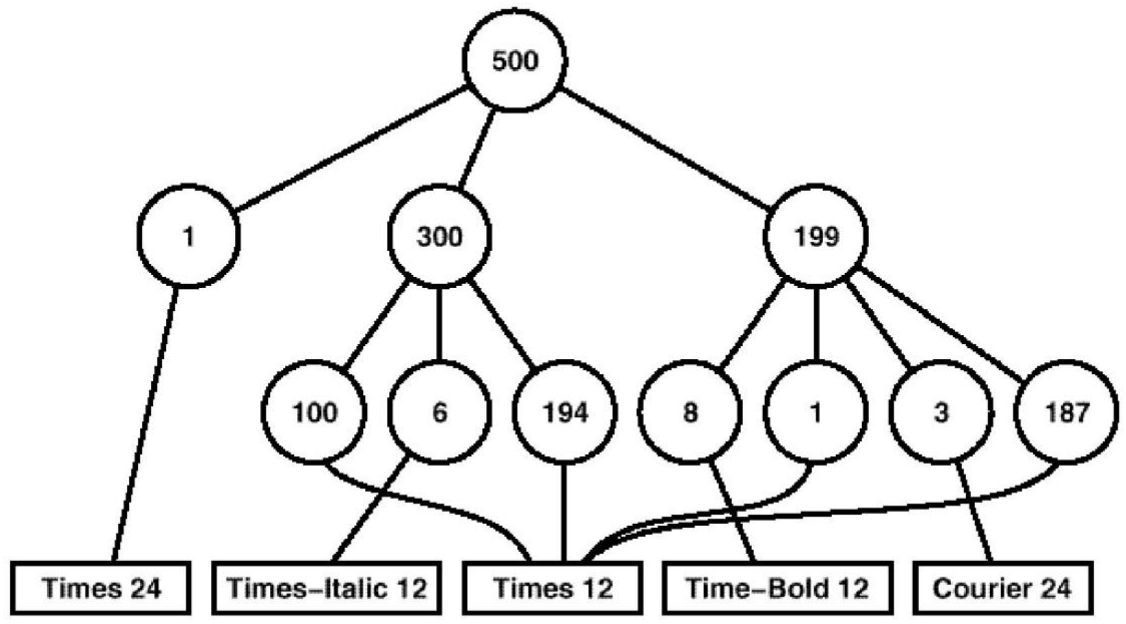
To keep from allocating space for a font attribute in every glyph, we'll store the attribute extrinsically in a GlyphContext object. GlyphContext acts as a repository of extrinsic state. It maintains a compact mapping between a glyph and its font (and any other graphical attributes it might have) in different contexts. Any operation that needs to know the glyph's font in a given context will have a GlyphContext instance passed to it as a parameter. The operation can then query the GlyphContext for the font in that context. The context depends on the glyph's location in the glyph structure. Therefore Glyph's child iteration and manipulation operations must update the GlyphContext whenever they're used.

```
classGlyphContext { public:
GlyphContext();
virtual ~GlyphContext();

virtual  void  Next(int  step  =  1);  virtual  void  Insert(int

quantity = 1);

virtual Font* GetFont();
virtual void SetFont(Font*, int span = 1); private:
int _index;
BTree* _fonts;
};
```

Consider the following excerpt from a glyph composition:



The BTree structure for font information might look like



Interior nodes define ranges of glyph indices. BTree is updated in response to font changes and whenever glyphs are added to or removed from the glyph structure. For example, assuming we're at index 102 in the traversal, the following code sets the font of each character in the word "expect" to that of the surrounding text (that is, times12, an instance of Font for 12-point Times Roman):

▾Known Uses

The concept of flyweight objects was first described and explored as a design technique in InterViews 3.0 [CL90]. Its developers built a powerful document editor called Doc as a proof of concept [CL92]. Doc uses glyph objects to represent each character in the document. The editor builds one Glyph instance for each character in a particular style (which defines its graphical attributes); hence a character's intrinsic state consists of the character code and its style information (an index into a style table).[4]That means only position is extrinsic, making Doc fast. Documents are represented by a class Document, which also acts as the FlyweightFactory. Measurements on Doc have shown that sharing flyweight characters is quite effective. In a typical case, a document containing 180,000 characters required allocation of only 480 character objects.

ET++ [WGM88] uses flyweights to support look-and-feel independence.[5] The look-and-feel standard affects the layout of user interface elements (e.g., scroll bars, buttons, menus known collectively as "widgets") and their decorations (e.g., shadows, beveling). A widget delegates all its layout and drawing behavior to a separate Layout object. Changing the Layout object changes the look and feel, even at run-time.

For each widget class there is a corresponding Layout class (e.g., ScrollbarLayout, MenubarLayout, etc.). An obvious problem with this approach is that using separate layout objects doubles the number of user interface objects: For each user interface object there is an additional Layout object. To avoid this overhead, Layout objects are implemented as flyweights. They make good flyweights because they deal mostly with defining behavior, and it's easy to pass them what little extrinsic state they need to lay out or draw an object.

The Layout objects are created and managed by Look objects. The Look class is an Abstract Factory (99) that retrieves a specific Layout object with operations like GetButtonLayout, GetMenuBarLayout, and so forth. For each look-and-feel standard there is a corresponding Look subclass (e.g., MotifLook, OpenLook) that supplies the appropriate Layout objects.

By the way, Layout objects are essentially strategies. They are an example of a strategy object implemented as a flyweight.

Related Patterns

The Flyweight pattern is often combined with the Composite pattern to implement a logically hierarchical structure in terms of a directed-acyclic graph with shared leaf nodes.
It's often best to implement State and Strategy objects as flyweights.
Look-up time in this scheme is proportional to the font change frequency. Worst-case performance occurs when a font change occurs on every character, but that's unusual in practice.

In the Sample Code given earlier, style information is made extrinsic, leaving the character code as the only intrinsic state.

See Abstract Factory for another approach to look-and-feel independence.

Proxy

Intent

Provide a surrogate or placeholder for another object to control access to it.

Also Known As

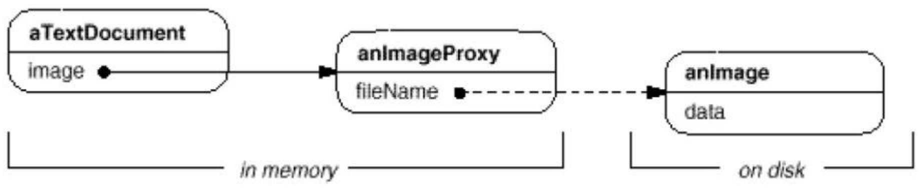
Surrogate

Motivation

One reason for controlling access to an object is to defer the full cost of its creation and initialization until we actually need to use it. Consider a document editor that can embed graphical objects in a document. Some graphical objects, like large raster images, can be expensive to create. But opening a document should be fast, so we should avoid creating all the expensive objects at once when the document is opened. This isn't necessary anyway, because not all of these objects will be visible in the document at the same time.

These constraints would suggest creating each expensive object *on demand*, which in this case occurs when an image becomes visible. But what do we put in the document in place of the image? And how can we hide the fact that the image is created on demand so that we don't complicate the editor's implementation? This optimization shouldn't impact the rendering and formatting code, for example.

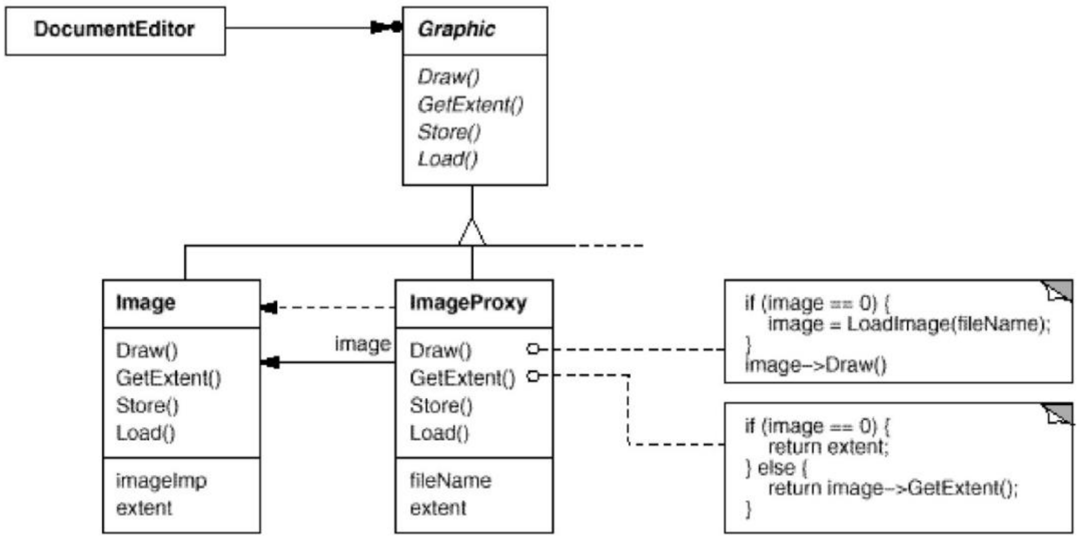
The solution is to use another object, an image proxy, that acts as a stand-in for the real image. The proxy acts just like the image and takes care of instantiating it when it's required.



The image proxy creates the real image only when the document editor asks it to display itself by invoking its Draw operation. The proxy forwards subsequent requests directly to the image. It must therefore keep a reference to the image after creating it.
Let's assume that images are stored in separate files. In this case we can use the file name as the reference to the real object. The proxy also stores its extent, that is, its width and height. The extent

lets the proxy respond to requests for its size from the formatter without actually instantiating the image.

The following class diagram illustrates this example in more detail.



The document editor accesses embedded images through the interface defined by the abstract Graphic class. ImageProxy is a class for images that are created on demand. ImageProxy maintains the file name as a reference to the image on disk. The file name is passed as an argument to the ImageProxy constructor.

ImageProxy also stores the bounding box of the image and a reference to the real Image instance. This reference won't be valid until the proxy instantiates the real image. The Draw operation makes sure the image is instantiated before forwarding it the request.

▼Applicability

Proxy is applicable whenever there is a need for a more versatile or sophisticated reference to an object than a simple pointer. Here are several common situations in which the Proxy pattern is applicable:

1. A remote proxy provides a local representative for an object in a different address space. NEXTSTEP [Add94] uses the class NXProxy for this purpose. Coplien [Cop92] calls this kind of proxy an "Ambassador."

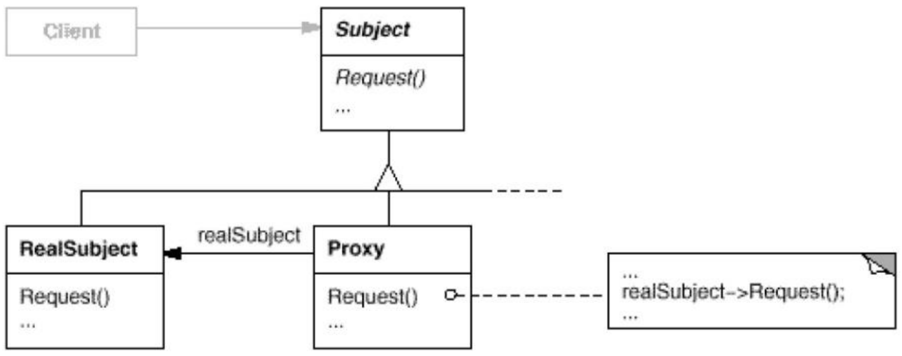
2. A virtual proxy creates expensive objects on demand. The ImageProxy described

in the Motivation is an example of such a proxy.

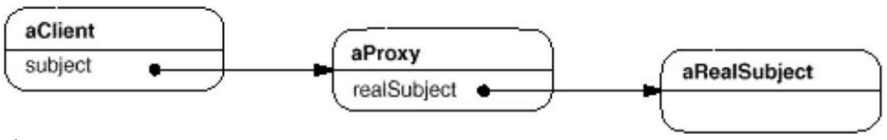
3. A protection proxy controls access to the original object. Protection proxies are useful when objects should have different access rights. For example, KernelProxies in the Choices operating system [CIRM93] provide protected access to operating system objects.

4. A smart reference is a replacement for a bare pointer that performs additional actions when an object is accessed. Typical uses include

Structure



Here's a possible object diagram of a proxy structure at run-time:



Participants

Proxy (ImageProxy)

maintains a reference that lets the proxy access the real subject. Proxy may refer to a Subject if theRealSubject and Subject interfaces are the same.

provides an interface identical to Subject's so that a proxy can by substituted for the real subject.

controls access to the real subject and may be responsible for creating and deleting it.

other responsibilities depend on the kind of proxy:

Remote Proxiesare responsible for encoding a request andits arguments and for sending the encoded request to the real subject in a different address space.

Virtual Proxiesmay cache additional information about thereal subject so that they can postpone accessing it. For example, the ImageProxy from the Motivation caches the real image's extent.

Protection Proxiescheck that the caller has the accesspermissions required to perform a request.

· Subject (Graphic)

o defines the common interface for RealSubject and Proxy so that a Proxy can be used anywhere a RealSubject is expected.

· RealSubject (Image)

o defines the real object that the proxy represents.

Collaborations

· Proxy forwards requests to RealSubject when appropriate, depending on the kind of proxy.

Consequences

The Proxy pattern introduces a level of indirection when accessing an object.
The additional indirection has many uses, depending on the kind of proxy:

1. A remote proxy can hide the fact that an object resides in a different address space.
2. A virtual proxy can perform optimizations such as creating an object on demand.
3. Both protection proxies and smart references allow additional housekeeping tasks when an object is accessed.

There's another optimization that the Proxy pattern can hide from the client. It's called copy-on-write, and it's related to creation on demand. Copying a large and complicated object can be an expensive operation. If the copy is never modified, then there's no need to incur this cost. By using a proxy to postpone the copying process, we ensure that we pay the price of copying the object only if it's modified.

To make copy-on-write work, the subject must be reference counted. Copying the proxy will do nothing more than increment this reference count. Only when the client requests an operation that modifies the subject does the proxy actually copy it. In that case the proxy must also decrement the subject's reference count. When the reference count goes to zero, the subject gets deleted.

Copy-on-write can reduce the cost of copying heavyweight subjects significantly.

Implementation

The Proxy pattern can exploit the following language features:

1. *Overloading the member access operator in C++*. C++ supports overloadingoperator->, the member access operator. Overloading this operator lets you perform additional work whenever an object is dereferenced. This can be helpful for implementing some kinds of proxy; the proxy behaves just like a pointer.

The following example illustrates how to use this technique to implement a virtual proxy called ImagePtr.

```
class Image;
extern  Image*  LoadAnImageFile(const  char*);  //  external

function

classImagePtr { public:
ImagePtr(const char* imageFile); virtual ~ImagePtr();

virtual        Image*        operator->();        virtual
Image&operator*();
private:
Image* LoadImage(); private:
Image* _image;
const char* _imageFile;
};

ImagePtr::ImagePtr (const char* theImageFile) { _imageFile =
theImageFile;
_image = 0;
}
Image* ImagePtr::LoadImage () {
if (_image == 0) {
_image = LoadAnImageFile(_imageFile);
}
return _image;
}
```

The overloaded -> and * operators use LoadImage to return _image to callers (loading it if necessary).

```
Image* ImagePtr::operator-> () {
returnLoadImage();
}

Image&ImagePtr::operator* () {
return *LoadImage();
}
```

▼Sample Code

The following code implements two kinds of proxy: the virtual proxy described in the Motivation section, and a proxy implemented with doesNotUnderstand:.[7]

1. *A virtual proxy.* The Graphic class defines the interface for graphicalobjects:

```
class Graphic { public:
virtual ~Graphic();

virtual   void   Draw(const   Point&   at)   =   0;   virtual   void

HandleMouse(Event& event) = 0;

virtualconst Point&GetExtent() = 0;

virtual   void   Load(istream&   from)   =   0;   virtual   void

Save(ostream& to) = 0;
protected:
Graphic();
};
```

The Image class implements the Graphic interface to display image files.
Image overrides HandleMouse to let users resize the image interactively.

```
class Image : public Graphic { public:
```

```
Image(const char* file); // loads image from a file virtual ~Image();

virtual void Draw(const Point& at); virtual void

HandleMouse(Event& event);

virtualconst Point&GetExtent();

virtual void Load(istream& from); virtual void

Save(ostream& to);

private:
// ...
};
```

ImageProxy has the same interface as Image:

```
classImageProxy : public Graphic { public:

ImageProxy(const char* imageFile); virtual

~ImageProxy();

virtual void Draw(const Point& at); virtual void

HandleMouse(Event& event);

virtualconst Point&GetExtent();
virtual void Load(istream& from); virtual void

Save(ostream& to);

protected:
Image* GetImage(); private:

Image* _image;

Point _extent; char* _fileName;

};
```

The constructor saves a local copy of the name of the file that stores the image, and it initializes

_extent and _image:

```
ImageProxy::ImageProxy (const char* fileName) { _fileName =
strdup(fileName);
_extent = Point::Zero; // don't know extent yet _image = 0;
}

Image* ImageProxy::GetImage() {
if (_image == 0) {
_image = new Image(_fileName);
}
return _image;
}
```

Known Uses

The virtual proxy example in the Motivation section is from the ET++ text building block classes.

NEXTSTEP [Add94] uses proxies (instances of class NXProxy) as local representatives for objects that may be distributed. A server creates proxies for remote objects when clients request them. On receiving a message, the proxy encodes it along with its arguments and then forwards the encoded message to the remote subject. Similarly, the subject encodes any return results and sends them back to the NXProxy object.

McCullough [McC87] discusses using proxies in Smalltalk to access remote objects. Pascoe [Pas86] describes how to provide side-effects on method calls and access control with "Encapsulators."

Related Patterns

Adapter: An adapter provides a different interface to the object it adapts. In contrast, a proxy provides the same interface as its subject. However, a proxy used for access protection might refuse to perform an operation that the subject will perform, so its interface may be effectively a subset of the subject's.

Decorator: Although decorators can have similar implementations as proxies, decorators have a different purpose. A decorator adds one or more responsibilities to an object, whereas a proxy controls access to an object.

Proxies vary in the degree to which they are implemented like a decorator. A protection proxy might be implemented exactly like a decorator. On the other hand, a remote proxy will not contain a direct reference to its real subject but only an indirect reference, such as "host ID and local address on host." A virtual proxy will start off with an indirect reference such as a file name but will eventually obtain and use a direct reference.

Discussion of Structural Patterns

You may have noticed similarities between the structural patterns,especially in their participants and collaborations. This is soprobably because structural patterns rely on the same small set oflanguage mechanisms for structuring code and objects: single andmultiple inheritance for class-based patterns, and object compositionfor object patterns. But the similarities belie the different intentsamong these patterns. In this section we compare and contrast groupsof structural patterns to give you a feel for their relative merits.

▼Adapter versus Bridge

The Adapter and Bridge patternshave some common attributes. Both promote flexibility by providing alevel of indirection to another object. Both involve forwardingrequests to this object from an interface other than its own.

The key difference between these patterns lies in their intents.Adapter focuses on resolving incompatibilities between two existinginterfaces. It doesn't focus on how those interfaces are implemented,nor does it consider how they might evolve independently. It's a wayof making two independently designed classes work together withoutreimplementing one or the other. Bridge, on the other hand, bridges anabstraction and its (potentially numerous) implementations. Itprovides a stable interface to clients even as it lets you vary theclasses that implement it. It also accommodates new implementations asthe system evolves.

As a result of these differences, Adapter and Bridge are often used atdifferent points in the software lifecycle. An adapter often becomesnecessary when you discover that two incompatible classesshould work together, generally to avoid replicating code. Thecoupling is unforeseen. In contrast, the user of a bridge understandsup-front that an abstraction must have several implementations, andboth may evolve independently. The Adapter pattern makes things work*after* they're designed; Bridge makes them work *before*theyare. That doesn't mean Adapter is somehow inferior to Bridge; eachpattern merely addresses a different problem.

You might think of a facade as anadapter to a set of other objects. But that interpretation overlooksthe fact that a facade defines a *new* interface, whereas an adapterreuses an old interface. Remember that an adapter makes two *existing* interfaces work together as opposed to defining an entirelynew one.

▼Composite versus Decorator versus Proxy

Composite and Decorator have similar structure diagrams, reflecting the fact that both rely onrecursive composition to organize an open-ended number of objects.This commonality might tempt you to think of a decorator object as adegenerate composite, but that misses the point of the Decoratorpattern. The similarity ends at recursive composition, again becauseof differing intents.

Decorator is designed to let you add responsibilities to objectswithoutsubclassing. It avoids the explosion of subclasses that canarise from trying to cover every combination of responsibilitiesstatically. Composite has a different intent. It focuses onstructuring classes so that many related objects can be treateduniformly, and multiple objects can be treated as one. Its focus isnot on embellishment but on representation.

These intents are distinct but complementary. Consequently, theComposite and Decorator patterns are often used in concert. Both leadto the kind of design in which you can build applications just byplugging objects together without defining any new classes. There willbe an abstract class with some subclasses that are composites, somethat are decorators, and some that implement the fundamental buildingblocks of the system. In this case, both composites and decoratorswill have a common interface. From the point of view of the Decoratorpattern, a composite is a ConcreteComponent. From the point of view ofthe Composite pattern, a decorator is a Leaf. Of course, they don't*have* to be used together and, as we have seen, their intentsare quite different.

Another pattern with a structure similar to Decorator's is Proxy.Both patterns describe how to provide a level of indirection to anobject, and the implementations of both the proxy and decoratorobject keep a reference to another object to which they forward requests. Once again, however, they are intended for different purposes.

Like Decorator, the Proxy pattern composes an object and provides anidentical interface to clients. Unlike Decorator, the Proxy pattern isnot concerned with attaching or detaching properties dynamically, andit's not designed for recursive composition. Its intent is to providea stand-in for a subject when it's inconvenient or undesirable toaccess the subject directly because, for example, it lives on a remotemachine, has restricted access, or is persistent.

In the Proxy pattern, the subject defines the key functionality, andthe proxy provides (or refuses) access to it. In Decorator, thecomponent provides only part of the functionality, and one or moredecorators furnish the rest. Decorator addresses the situation wherean object's total functionality can't be determined at compile time,at least not conveniently. That open-endedness makes recursivecomposition an essential part of Decorator.

These differences are significant because they capture solutions tospecific recurring problems in object-oriented design. But thatdoesn'tmean these patterns can't be combined. You might envision aproxy-decorator that adds functionality to a proxy, or adecorator-proxy that embellishes a remote object. Although such hybrids*might* be useful (we don't have real examples handy), they aredivisible into patterns that *are* useful.