Design Patterns

Index

Discussion of Creational Patterns

There are two common ways to parameterize a system by the classes of objects it creates. One way is to subclass the class that creates the objects; this corresponds to using the Factory Method (107) pattern. The main drawback of this approach is that it can require creating a new subclass just to change the class of the product. Such changes can cascade. For example, when the product creator is itself created by a factory method, then you have to override its creator as well.

The other way to parameterize a system relies more on object composition: Define an object that's responsible for knowing the class of the product objects, and make it a parameter of the system. This is a key aspect of the Abstract Factory (87), Builder (97), and Prototype (117) patterns. All three involve creating a new "factory object" whose responsibility is to create product objects. Abstract Factory has the factory object producing objects of several classes. Builder has the factory object building a complex product incrementally using a correspondingly complex protocol. Prototype has the factory object building a product by copying a prototype object. In this case, the factory object and the prototype are the same object, because the prototype is responsible for returning the product.

Consider the drawing editor framework described in the Prototype pattern. There are several ways to parameterize a GraphicTool by the class of product:

- By applying the Factory Method pattern, a subclass of GraphicTool will be created for each subclass of Graphic in the palette. GraphicTool will have a NewGraphic operation that each GraphicTool subclass will redefine.
- By applying the Abstract Factory pattern, there will be a class hierarchy of GraphicsFactories, one for each Graphic subclass. Each factory creates just one product in this case: CircleFactory will create Circles, LineFactory will create Lines, and so on. A GraphicTool will be parameterized with a factory for creating the appropriate kind of Graphics.
- By applying the Prototype pattern, each subclass of Graphics will implement the Clone operation, and a GraphicTool will be parameterized with a prototype of the Graphic it creates.

Which pattern is best depends on many factors. In our drawing editor framework, the Factory Method pattern is easiest to use at first. It's easy to define a new subclass of GraphicTool, and the instances of GraphicTool are created only when the palette is defined. The main disadvantage here is that GraphicTool subclasses proliferate, and none of them does very much.

Abstract Factory doesn't offer much of an improvement, because it requires an equally large GraphicsFactory class hierarchy. Abstract Factory would be preferable to Factory Method only if there were already a GraphicsFactory class hierarchy—either because the compiler provides it automatically (as in Smalltalk or Objective C) or because it's needed in another part of the system.

Overall, the Prototype pattern is probably the best for the drawing editor framework, because it only requires implementing a Clone operation on each Graphics class. That reduces the number of classes, and Clone can be used for purposes other than pure instantiation (e.g., a Duplicate menu operation).

Factory Method makes a design more customizable and only a little more complicated. Other design patterns require new classes, whereas Factory Method only requires a new operation. People often use Factory Method as the standard way to create objects, but it isn't necessary when the class that's instantiated never changes or when instantiation takes place in an operation that subclasses can easily override, such as an initialization operation.

Designs that use Abstract Factory, Prototype, or Builder are even more flexible than those that use Factory Method, but they're also more complex. Often, designs start out using Factory Method and evolve toward the other creational patterns as the designer discovers where more flexibility is needed. Knowing many design patterns gives you more choices when trading off one design criterion against another.

Abstract Factory

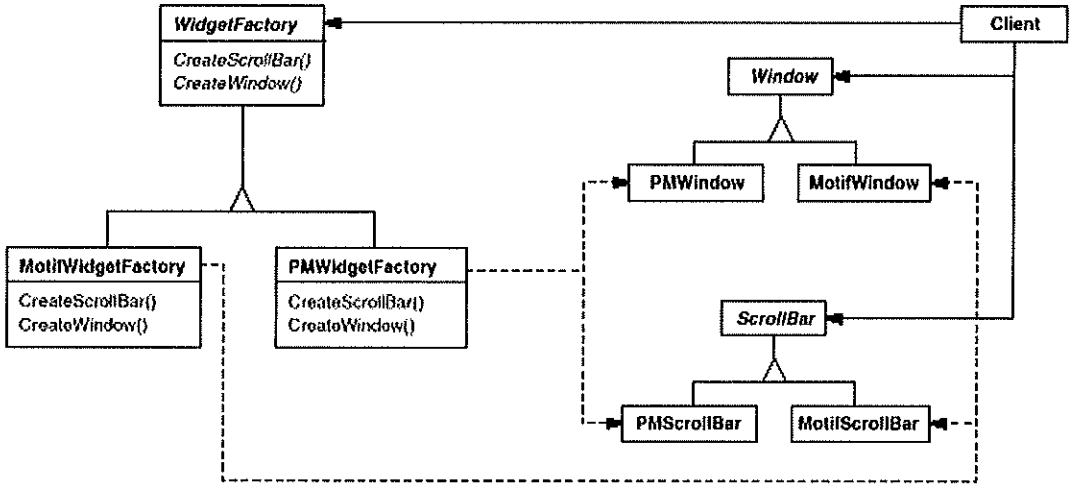
Intent

Provide an interface for creating families of related or dependent objects without specifying their concrete classes.

Motivation

Consider a user interface toolkit that supports multiple look-and-feel standards, such as Motif and Presentation Manager. Different look-and-feels define different appearances and behaviors for user interface "widgets" like scroll bars, windows, and buttons. To be portable across look-and-feel standards, an application should not hard-code its widgets for a particular look and feel. Instantiating look-and-feel-specific classes of widgets throughout the application makes it hard to change the look and feel later.

We can solve this problem by defining an abstract WidgetFactory class that declares an interface for creating each basic kind of widget. There's also an abstract class for each kind of widget, and concrete subclasses implement widgets for specific look-and-feel standards. WidgetFactory's interface has an operation that returns a new widget object for each abstract widget class. Clients call these operations to obtain widget instances, but clients aren't aware of the concrete classes they're using. Thus clients stay independent of the prevailing look and feel.



There is a concrete subclass of WidgetFactory for each look-and-feel standard. Each subclass implements the operations to create the appropriate widget for the look and feel. For example, the CreateScrollBar operation on the MotifWidgetFactory instantiates and returns a Motif scroll bar, while the corresponding operation on the PMWidgetFactory returns a scroll bar for Presentation Manager. Clients create widgets solely through the WidgetFactory interface and have no knowledge of the classes that implement widgets for a particular look and feel. In other words, clients only have to commit to an interface defined by an abstract class, not a particular concrete class.

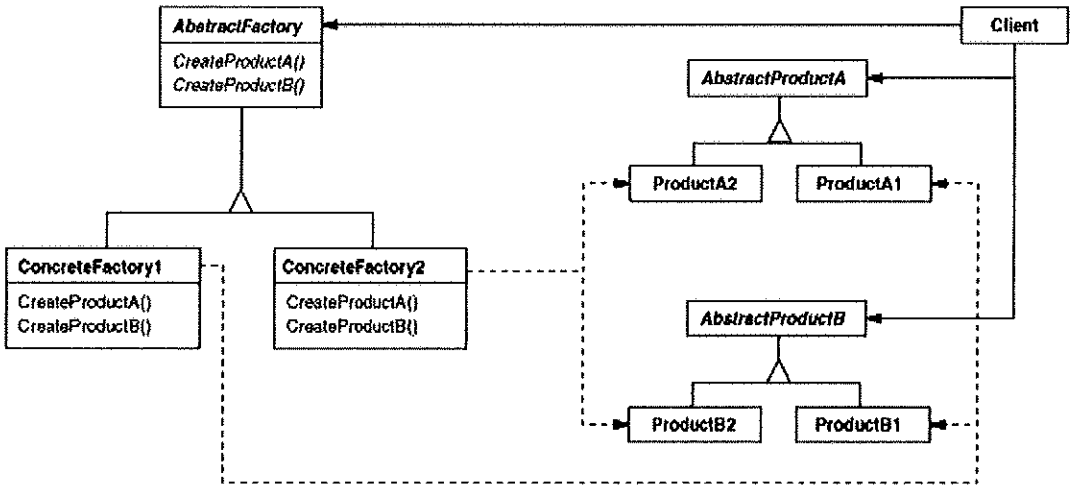
A WidgetFactory also enforces dependencies between the concrete widget classes. A Motif scroll bar should be used with a Motif button and a Motif text editor, and that constraint is enforced automatically as a consequence of using a MotifWidgetFactory.

Applicability

Use the Abstract Factory pattern when

- a system should be independent of how its products are created, composed, and represented.
- a system should be configured with one of multiple families of products.
- a family of related product objects is designed to be used together, and you need to enforce this constraint.
- you want to provide a class library of products, and you want to reveal just their interfaces, not their implementations.

Structure



Participants

- **AbstractFactory** (WidgetFactory)
  - declares an interface for operations that create abstract product objects.
- **ConcreteFactory** (MotifWidgetFactory, PMWidgetFactory)
  - implements the operations to create concrete product objects.
- **AbstractProduct** (Window, ScrollBar)
  - declares an interface for a type of product object.
- **ConcreteProduct** (MotifWindow, MotifScrollBar)
  - defines a product object to be created by the corresponding concrete factory.
  - implements the AbstractProduct interface.
- **Client**
  - uses only interfaces declared by AbstractFactory and AbstractProduct classes.

Collaborations

- Normally a single instance of a ConcreteFactory class is created at run-time. This concrete factory creates product objects having a particular implementation. To create different product objects, clients should use a different concrete factory.
- AbstractFactory defers creation of product objects to its ConcreteFactory subclass.

Consequences

The Abstract Factory pattern has the following benefits and liabilities:

1. *It isolates concrete classes.* The Abstract Factory pattern helps you control the classes of objects that an application creates. Because a factory encapsulates the responsibility and the process of creating product objects, it isolates clients from implementation classes. Clients manipulate instances through their abstract interfaces. Product class names are isolated in the implementation of the concrete factory; they do not appear in client code.
2. *It makes exchanging product families easy.* The class of a concrete factory appears only once in an application—that is, where it's instantiated. This makes it easy to change the concrete factory an application uses. It can use different product configurations simply by changing the concrete factory. Because an abstract factory creates a complete family of products, the whole product family changes at once. In our user interface example, we can switch from Motif widgets to Presentation Manager widgets simply by switching the corresponding factory objects and recreating the interface.
3. *It promotes consistency among products.* When product objects in a family are designed to work together, it's important that an application use objects from only one family at a time. AbstractFactory makes this easy to enforce.
4. *Supporting new kinds of products is difficult.* Extending abstract factories to produce new kinds of Products isn't easy. That's because the AbstractFactory interface fixes the set of products that can be created. Supporting new kinds of products requires extending the factory interface, which involves changing the AbstractFactory class and all of its subclasses. We discuss one solution to this problem in the Implementation section.

Builder

▼Intent

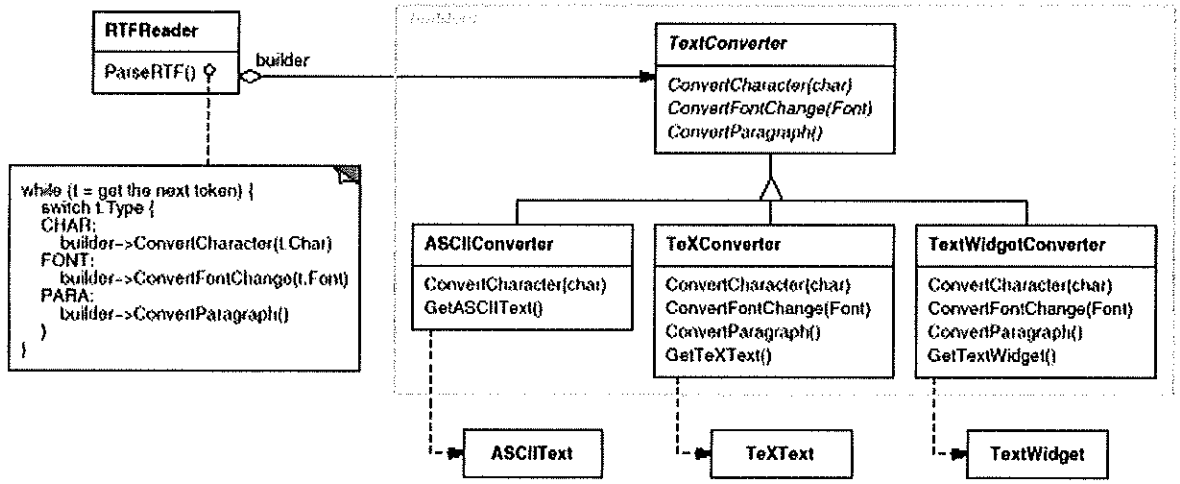
Separate the construction of a complex object from its representation so that the same construction process can create different representations.

▼Motivation

A reader for the RTF (Rich Text Format) document exchange format should be able to convert RTF to many text formats. The reader might convert RTF documents into plain ASCII text or into a text widget that can be edited interactively. The problem, however, is that the number of possible conversions is open-ended. So it should be easy to add a new conversion without modifying the reader.

A solution is to configure the RTFReader class with a TextConverter object that converts RTF to another textual representation. As the RTFReader parses the RTF document, it uses the TextConverter to perform the conversion. Whenever the RTFReader recognizes an RTF token (either plain text or an RTF control word), it issues a request to the TextConverter to convert the token. TextConverter objects are responsible both for performing the data conversion and for representing the token in a particular format.

Subclasses of TextConverter specialize in different conversions and formats. For example, an ASCIIConverter ignores requests to convert anything except plain text. A TeXConverter, on the other hand, will implement operations for all requests in order to produce a TeX representation that captures all the stylistic information in the text. A TextWidgetConverter will produce a complex user interface object that lets the user see and edit the text.



Each kind of converter class takes the mechanism for creating and assembling a complex object and puts it behind an abstract interface. The converter is separate from the reader, which is responsible for parsing an RTF document.

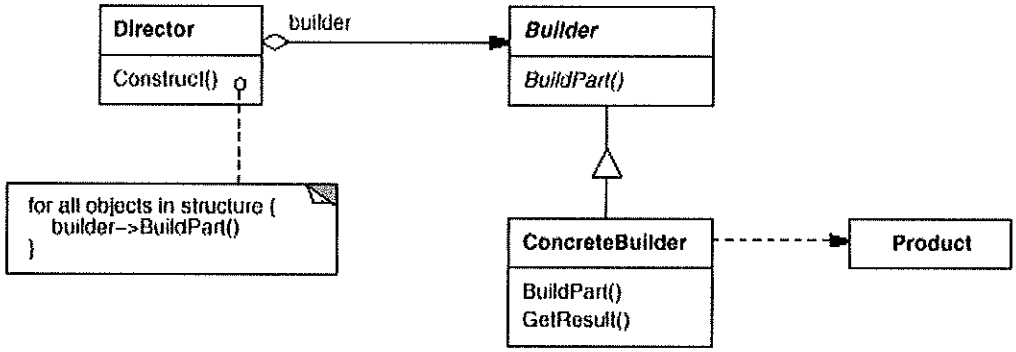
The Builder pattern captures all these relationships. Each converter class is called a **builder** in the pattern, and the reader is called the **director**. Applied to this example, the Builder pattern separates the algorithm for interpreting a textual format (that is, the parser for RTF documents) from how a converted format gets created and represented. This lets us reuse the RTFReader's parsing algorithm to create different text representations from RTF documents—just configure the RTFReader with different subclasses of TextConverter.

▼Applicability

Use the Builder pattern when

- the algorithm for creating a complex object should be independent of the parts that make up the object and how they're assembled.
- the construction process must allow different representations for the object that's constructed.

Structure



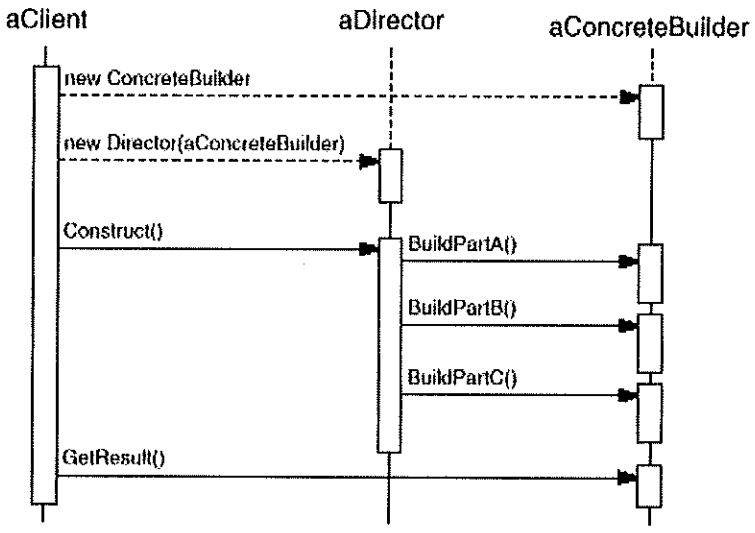
Participants

- **Builder** (TextConverter)
  - specifies an abstract interface for creating parts of a Product object.
- **ConcreteBuilder** (ASCIIConverter, TeXConverter, TextWidgetConverter)
  - constructs and assembles parts of the product by implementing the Builder interface.
  - defines and keeps track of the representation it creates.
  - provides an interface for retrieving the product (e.g., GetASCIIText, GetTextWidget).
- **Director** (RTFReader)
  - constructs an object using the Builder interface.
- **Product** (ASCIIText, TeXText, TextWidget)
  - represents the complex object under construction. ConcreteBuilder builds the product's internal representation and defines the process by which it's assembled.
  - includes classes that define the constituent parts, including interfaces for assembling the parts into the final result.

Collaborations

- The client creates the Director object and configures it with the desired Builder object.
- Director notifies the builder whenever a part of the product should be built.
- Builder handles requests from the director and adds parts to the product.
- The client retrieves the product from the builder.

The following interaction diagram illustrates how Builder and Director cooperate with a client.



▼ Consequences

Here are key consequences of the Builder pattern:

1. *It lets you vary a product's internal representation.* The Builder object provides the director with an abstract interface for constructing the product. The interface lets the builder hide the representation and internal structure of the product. It also hides how the product gets assembled. Because the product is constructed through an abstract interface, all you have to do to change the product's internal representation is define a new kind of builder.
2. *It isolates code for construction and representation.* The Builder pattern improves modularity by encapsulating the way a complex object is constructed and represented. Clients needn't know anything about the classes that define the product's internal structure; such classes don't appear in Builder's interface.

   Each ConcreteBuilder contains all the code to create and assemble a particular kind of product. The code is written once; then different Directors can reuse it to build Product variants from the same set of parts. In the earlier RTF example, we could define a reader for a format other than RTF, say, an SGMLReader, and use the same TextConverters to generate ASCIIText, TeXText, and TextWidget renditions of SGML documents.

3. *It gives you finer control over the construction process.* Unlike creational patterns that construct products in one shot, the Builder pattern constructs the product step by step under the director's control. Only when the product is finished does the director retrieve it from the builder. Hence the Builder interface reflects the process of constructing the product more than other creational patterns. This gives you finer control over the construction process and consequently the internal structure of the resulting product.

Factory Method

Intent

Define an interface for creating an object, but let subclasses decide which class to instantiate. Factory Method lets a class defer instantiation to subclasses.

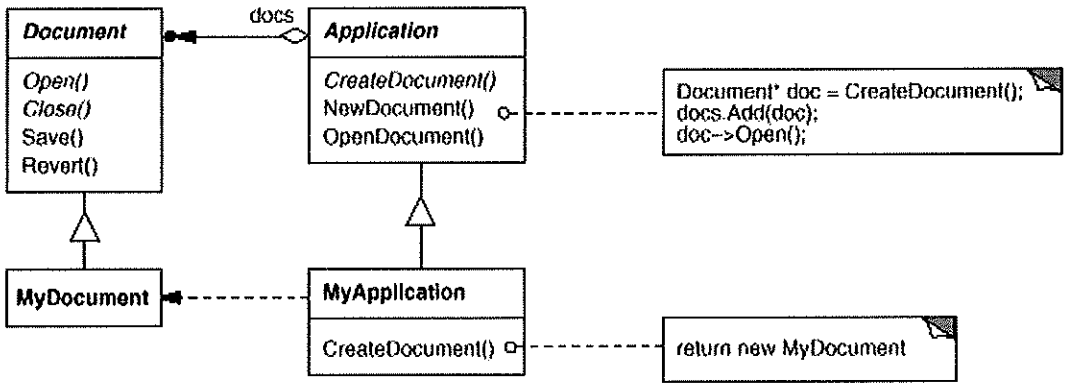
Motivation

Frameworks use abstract classes to define and maintain relationships between objects. A framework is often responsible for creating these objects as well.

Consider a framework for applications that can present multiple documents to the user. Two key abstractions in this framework are the classes Application and Document. Both classes are abstract, and clients have to subclass them to realize their application-specific implementations. To create a drawing application, for example, we define the classes DrawingApplication and DrawingDocument. The Application class is responsible for managing Documents and will create them as required—when the user selects Open or New from a menu, for example.

Because the particular Document subclass to instantiate is application-specific, the Application class can't predict the subclass of Document to instantiate—the Application class only knows *when* a new document should be created, not *what kind* of Document to create. This creates a dilemma: The framework must instantiate classes, but it only knows about abstract classes, which it cannot instantiate.

The Factory Method pattern offers a solution. It encapsulates the knowledge of which Document subclass to create and moves this knowledge out of the framework.



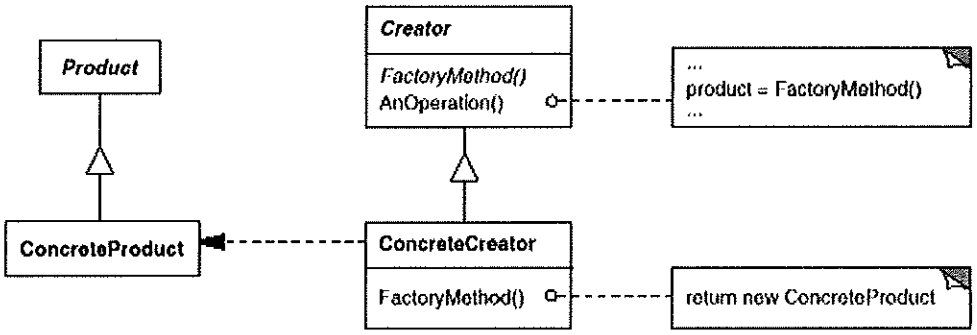
Application subclasses redefine an abstract CreateDocument operation on Application to return the appropriate Document subclass. Once an Application subclass is instantiated, it can then instantiate application-specific Documents without knowing their class. We call CreateDocument a **factory method** because it's responsible for "manufacturing" an object.

Applicability

Use the Factory Method pattern when

- a class can't anticipate the class of objects it must create.
- a class wants its subclasses to specify the objects it creates.
- classes delegate responsibility to one of several helper subclasses, and you want to localize the knowledge of which helper subclass is the delegate.

Structure



Participants

- **Product** (Document)
  - defines the interface of objects the factory method creates.
- **ConcreteProduct** (MyDocument)
  - implements the Product interface.
- **Creator** (Application)
  - declares the factory method, which returns an object of type Product. Creator may also define a default implementation of the factory method that returns a default ConcreteProduct object.
  - may call the factory method to create a Product object.
- **ConcreteCreator** (MyApplication)
  - overrides the factory method to return an instance of a ConcreteProduct.

Collaborations

- Creator relies on its subclasses to define the factory method so that it returns an instance of the appropriate ConcreteProduct.

Consequences

Factory methods eliminate the need to bind application-specific classes into your code. The code only deals with the Product interface; therefore it can work with any user-defined ConcreteProduct classes.

A potential disadvantage of factory methods is that clients might have to subclass the Creator class just to create a particular ConcreteProduct object. Subclassing is fine when the client has to subclass the Creator class anyway, but otherwise the client now must deal with another point of evolution.

Here are two additional consequences of the Factory Method pattern:

1. *Provides hooks for subclasses.* Creating objects inside a class with a factory method is always more flexible than creating an object directly. Factory Method gives subclasses a hook for providing an extended version of an object.

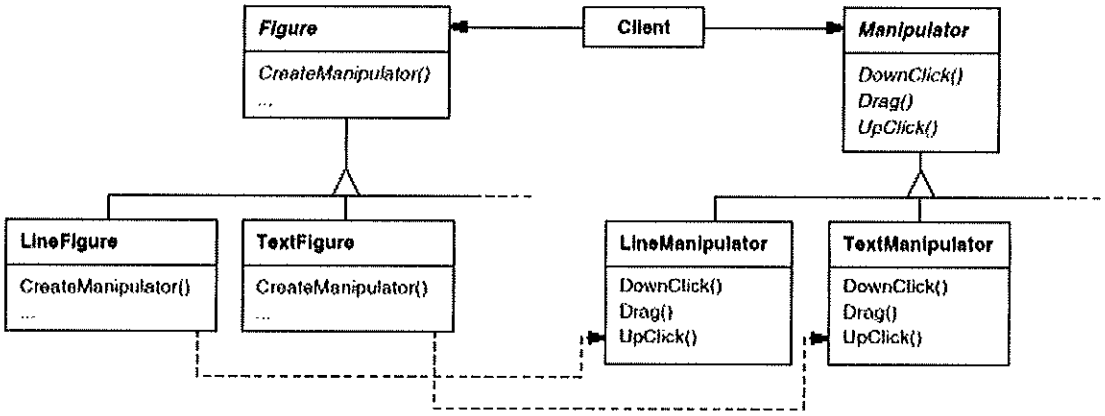
   In the Document example, the Document class could define a factory method called CreateFileDialog that creates a default file dialog object for opening an existing document. A Document subclass can define an application-specific file dialog by overriding this factory method. In this case the factory method is not abstract but provides a reasonable default implementation.

2. *Connects parallel class hierarchies.* In the examples we've considered so far, the factory method is only called by Creators. But this doesn't have to be the case; clients can find factory methods useful, especially in the case of parallel class hierarchies.

   Parallel class hierarchies result when a class delegates some of its responsibilities to a separate class. Consider graphical figures that can be manipulated interactively; that is, they can be stretched, moved, or rotated using the mouse. Implementing such interactions isn't always easy. It often requires storing and updating information that records the state of the manipulation at a given time. This state is needed only during manipulation; therefore it

needn't be kept in the figure object. Moreover, different figures behave differently when the user manipulates them. For example, stretching a line figure might have the effect of moving an endpoint, whereas stretching a text figure may change its line spacing.

With these constraints, it's better to use a separate Manipulator object that implements the interaction and keeps track of any manipulation-specific state that's needed. Different figures will use different Manipulator subclasses to handle particular interactions. The resulting Manipulator class hierarchy parallels (at least partially) the Figure class hierarchy:



The Figure class provides a CreateManipulator factory method that lets clients create a Figure's corresponding Manipulator. Figure subclasses override this method to return an instance of the Manipulator subclass that's right for them. Alternatively, the Figure class may implement CreateManipulator to return a default Manipulator instance, and Figure subclasses may simply inherit that default. The Figure classes that do so need no corresponding Manipulator subclass—hence the hierarchies are only partially parallel.

Notice how the factory method defines the connection between the two class hierarchies. It localizes knowledge of which classes belong together.

Prototype

▼Intent

Specify the kinds of objects to create using a prototypical instance, and create new objects by copying this prototype.

▼Motivation

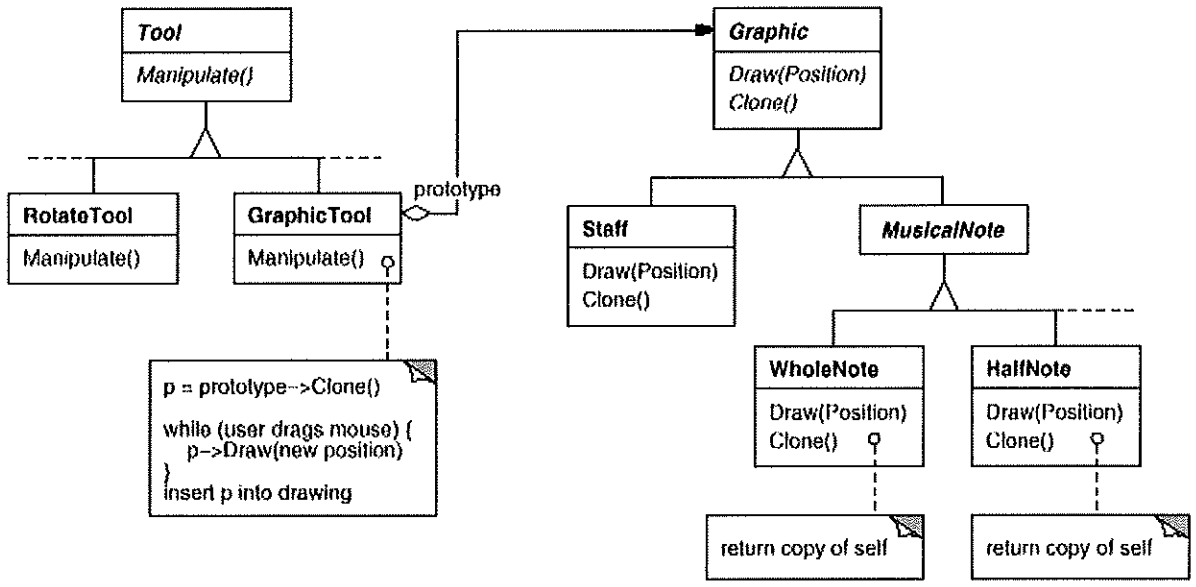
You could build an editor for music scores by customizing a general framework for graphical editors and adding new objects that represent notes, rests, and staves. The editor framework may have a palette of tools for adding these music objects to the score. The palette would also include tools for selecting, moving, and otherwise manipulating music objects. Users will click on the quarter-note tool and use it to add quarter notes to the score. Or they can use the move tool to move a note up or down on the staff, thereby changing its pitch.

Let's assume the framework provides an abstract Graphic class for graphical components, like notes and staves. Moreover, it'll provide an abstract Tool class for defining tools like those in the palette. The framework also predefines a GraphicTool subclass for tools that create instances of graphical objects and add them to the document.

But GraphicTool presents a problem to the framework designer. The classes for notes and staves are specific to our application, but the GraphicTool class belongs to the framework. GraphicTool doesn't know how to create instances of our music classes to add to the score. We could subclass GraphicTool for each kind of music object, but that would produce lots of subclasses that differ only in the kind of music object they instantiate. We know object composition is a flexible alternative to subclassing. The question is, how can the framework use it to parameterize instances of GraphicTool by the *class* of Graphic they're supposed to create?

The solution lies in making GraphicTool create a new Graphic by copying or "cloning" an instance of a Graphic subclass. We call this instance a **prototype**. GraphicTool is parameterized by the prototype it should clone and add to the document. If all Graphic subclasses support a Clone operation, then the GraphicTool can clone any kind of Graphic.

So in our music editor, each tool for creating a music object is an instance of GraphicTool that's initialized with a different prototype. Each GraphicTool instance will produce a music object by cloning its prototype and adding the clone to the score.



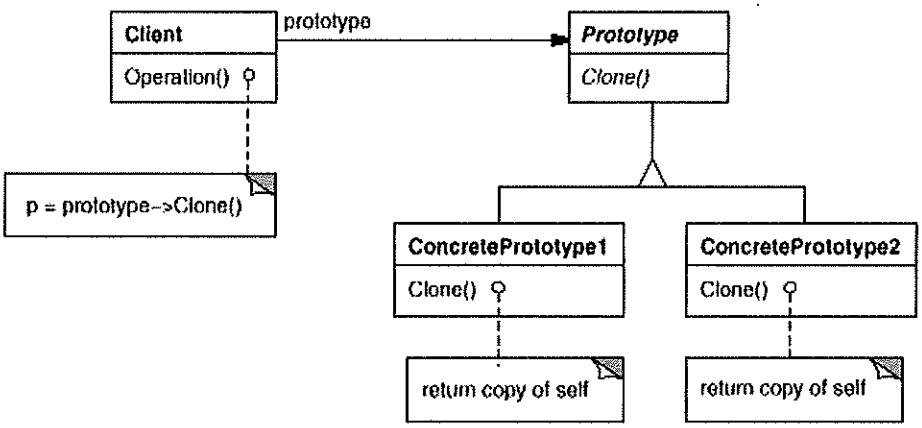
We can use the Prototype pattern to reduce the number of classes even further. We have separate classes for whole notes and half notes, but that's probably unnecessary. Instead they could be instances of the same class initialized with different bitmaps and durations. A tool for creating whole notes becomes just a GraphicTool whose prototype is a MusicalNote initialized to be a whole note. This can reduce the number of classes in the system dramatically. It also makes it easier to add a new kind of note to the music editor.

▼Applicability

Use the Prototype pattern when a system should be independent of how its products are created, composed, and represented; *and*

- when the classes to instantiate are specified at run-time, for example, by dynamic loading; *or*
- to avoid building a class hierarchy of factories that parallels the class hierarchy of products; *or*
- when instances of a class can have one of only a few different combinations of state. It may be more convenient to install a corresponding number of prototypes and clone them rather than instantiating the class manually, each time with the appropriate state.

▼Structure



▼Participants

- **Prototype** (Graphic)
  - declares an interface for cloning itself.
- **ConcretePrototype** (Staff, WholeNote, HalfNote)
  - implements an operation for cloning itself.
- **Client** (GraphicTool)
  - creates a new object by asking a prototype to clone itself.

▼Collaborations

- A client asks a prototype to clone itself.

▼Consequences

Prototype has many of the same consequences that Abstract Factory (87) and Builder (97) have: It hides the concrete product classes from the client, thereby reducing the number of names clients know about. Moreover, these patterns let a client work with application-specific classes without modification.

Additional benefits of the Prototype pattern are listed below.

1. *Adding and removing products at run-time.* Prototypes let you incorporate a new concrete product class into a system simply by registering a prototypical instance with the client. That's a bit more flexible than other creational patterns, because a client can install and remove prototypes at run-time.
2. *Specifying new objects by varying values.* Highly dynamic systems let you define new behavior through object composition—by specifying values for an object's variables, for example—and not by defining new classes. You effectively define new kinds of objects by instantiating existing classes and registering the instances as prototypes of client objects. A client can exhibit new behavior by delegating responsibility to the prototype.

This kind of design lets users define new "classes" without programming. In fact, cloning a prototype is similar to instantiating a class. The Prototype pattern can greatly reduce the number of classes a system needs. In our music editor, one GraphicTool class can create a limitless variety of music objects.

3. *Specifying new objects by varying structure.* Many applications build objects from parts and subparts. Editors for circuit design, for example, build circuits out of subcircuits.[1] For convenience, such applications often let you instantiate complex, user-defined structures, say, to use a specific subcircuit again and again.

   The Prototype pattern supports this as well. We simply add this subcircuit as a prototype to the palette of available circuit elements. As long as the composite circuit object implements Clone as a deep copy, circuits with different structures can be prototypes.

4. *Reduced subclassing.* Factory Method (107) often produces a hierarchy of Creator classes that parallels the product class hierarchy. The Prototype pattern lets you clone a prototype instead of asking a factory method to make a new object. Hence you don't need a Creator class hierarchy at all. This benefit applies primarily to languages like C++ that don't treat classes as first-class objects. Languages that do, like Smalltalk and Objective C, derive less benefit, since you can always use a class object as a creator. Class objects already act like prototypes in these languages.
5. *Configuring an application with classes dynamically.* Some run-time environments let you load classes into an application dynamically. The Prototype pattern is the key to exploiting such facilities in a language like C++.

   An application that wants to create instances of a dynamically loaded class won't be able to reference its constructor statically. Instead, the run-time environment creates an instance of each class automatically when it's loaded, and it registers the instance with a prototype manager (see the Implementation section). Then the application can ask the prototype manager for instances of newly loaded classes, classes that weren't linked with the program originally. The ET++ application framework [WGM88] has a run-time system that uses this scheme.

The main liability of the Prototype pattern is that each subclass of Prototype must implement the `Clone` operation, which may be difficult. For example, adding `Clone` is difficult when the classes under consideration already exist. Implementing `Clone` can be difficult when their internals include objects that don't support copying or have circular references.

Singleton

Intent

Ensure a class only has one instance, and provide a global point of access to it.

Motivation

It's important for some classes to have exactly one instance. Although there can be many printers in a system, there should be only one printer spooler. There should be only one file system and one window manager. A digital filter will have one A/D converter. An accounting system will be dedicated to serving one company.

How do we ensure that a class has only one instance and that the instance is easily accessible? A global variable makes an object accessible, but it doesn't keep you from instantiating multiple objects.

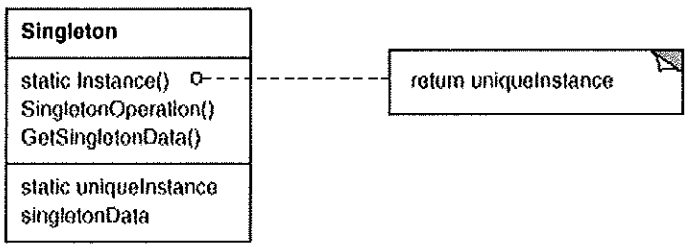
A better solution is to make the class itself responsible for keeping track of its sole instance. The class can ensure that no other instance can be created (by intercepting requests to create new objects), and it can provide a way to access the instance. This is the Singleton pattern.

Applicability

Use the Singleton pattern when

- there must be exactly one instance of a class, and it must be accessible to clients from a well-known access point.
- when the sole instance should be extensible by subclassing, and clients should be able to use an extended instance without modifying their code.

Structure



Participants

- **Singleton**
  - defines an Instance operation that lets clients access its unique instance. Instance is a class operation (that is, a class method in Smalltalk and a static member function in C++).
  - may be responsible for creating its own unique instance.

Collaborations

- Clients access a Singleton instance solely through Singleton's Instance operation.

Consequences

The Singleton pattern has several benefits:

1. *Controlled access to sole instance.* Because the Singleton class encapsulates its sole instance, it can have strict control over how and when clients access it.

2. *Reduced name space.* The Singleton pattern is an improvement over global variables. It avoids polluting the name space with global variables that store sole instances.
3. *Permits refinement of operations and representation.* The Singleton class may be subclassed, and it's easy to configure an application with an instance of this extended class. You can configure the application with an instance of the class you need at run-time.
4. *Permits a variable number of instances.* The pattern makes it easy to change your mind and allow more than one instance of the Singleton class. Moreover, you can use the same approach to control the number of instances that the application uses. Only the operation that grants access to the Singleton instance needs to change.
5. *More flexible than class operations.* Another way to package a singleton's functionality is to use class operations (that is, static member functions in C++ or class methods in Smalltalk). But both of these language techniques make it hard to change a design to allow more than one instance of a class. Moreover, static member functions in C++ are never virtual, so subclasses can't override them polymorphically.

Discussion of Structural Patterns

You may have noticed similarities between the structural patterns, especially in their participants and collaborations. This is so probably because structural patterns rely on the same small set of language mechanisms for structuring code and objects: single and multiple inheritance for class-based patterns, and object composition for object patterns. But the similarities belie the different intents among these patterns. In this section we compare and contrast groups of structural patterns to give you a feel for their relative merits.

▼Adapter versus Bridge

The Adapter (139) and Bridge (151) patterns have some common attributes. Both promote flexibility by providing a level of indirection to another object. Both involve forwarding requests 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 existing interfaces. It doesn't focus on how those interfaces are implemented, nor does it consider how they might evolve independently. It's a way of making two independently designed classes work together without reimplementing one or the other. Bridge, on the other hand, bridges an abstraction and its (potentially numerous) implementations. It provides a stable interface to clients even as it lets you vary the classes that implement it. It also accommodates new implementations as the system evolves.

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

You might think of a facade (see Facade (185)) as an adapter to a set of other objects. But that interpretation overlooks the fact that a facade defines a *new* interface, whereas an adapter reuses an old interface. Remember that an adapter makes two *existing* interfaces work together as opposed to defining an entirely new one.

▼Composite versus Decorator versus Proxy

Composite (163) and Decorator (175) have similar structure diagrams, reflecting the fact that both rely on recursive composition to organize an open-ended number of objects. This commonality might tempt you to think of a decorator object as a degenerate composite, but that misses the point of the Decorator pattern. The similarity ends at recursive composition, again because of differing intents.

Decorator is designed to let you add responsibilities to objects without subclassing. It avoids the explosion of subclasses that can arise from trying to cover every combination of responsibilities statically. Composite has a different intent. It focuses on structuring classes so that many related objects can be treated uniformly, and multiple objects can be treated as one. Its focus is not on embellishment but on representation.

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

Another pattern with a structure similar to Decorator's is Proxy (207). Both patterns describe how to provide a level of indirection to an object, and the implementations of both the proxy and decorator object 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 an identical interface to clients. Unlike Decorator, the Proxy pattern is not concerned with attaching or detaching properties dynamically, and it's not designed for recursive composition. Its intent is to provide a stand-in for a subject when it's inconvenient or undesirable to access the subject directly because, for example, it lives on a remote machine, has restricted access, or is persistent.

In the Proxy pattern, the subject defines the key functionality, and the proxy provides (or refuses) access to it. In Decorator, the component provides only part of the functionality, and one or more decorators furnish the rest. Decorator addresses the situation where an object's total functionality can't be determined at compile time, at least not conveniently. That open-endedness makes recursive composition an essential part of Decorator. That isn't the case in Proxy, because Proxy focuses on one relationship—between the proxy and its subject—and that relationship can be expressed statically.

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

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.

Motivation

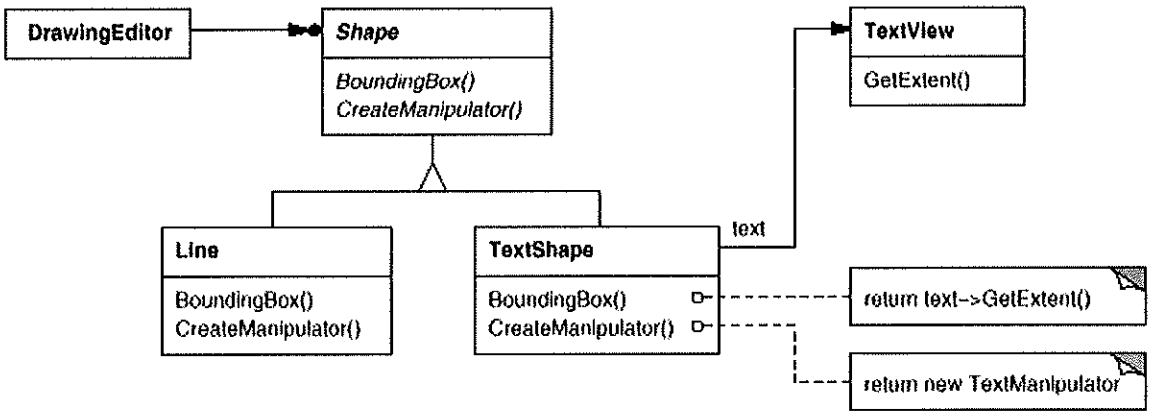
Sometimes a toolkit class that's designed for reuse isn't reusable only because its interface doesn't match the domain-specific interface an application requires.

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 LineShape class for lines, a PolygonShape class for polygons, and so forth.

Classes for elementary geometric shapes like LineShape and PolygonShape are rather easy to implement, because their drawing and editing capabilities are inherently limited. But a TextShape 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 TextView class for displaying and editing text. Ideally we'd like to reuse TextView to implement TextShape, but the toolkit wasn't designed with Shape classes in mind. So we can't use TextView and Shape objects interchangeably.

How can existing and unrelated classes like TextView work in an application that expects classes with a different and incompatible interface? We could change the TextView class so that it conforms to the Shape interface, but that isn't an option unless we have the toolkit's source code. Even if we did, it wouldn't make sense to change TextView; the toolkit shouldn't have to adopt domain-specific interfaces just to make one application work.

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 BoundingBox requests, declared in class Shape, are converted to GetExtent 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 CreateManipulator 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; TextManipulator, for example, is the corresponding subclass for TextShape. By returning a TextManipulator instance, TextShape adds the functionality that TextView lacks but Shape requires.

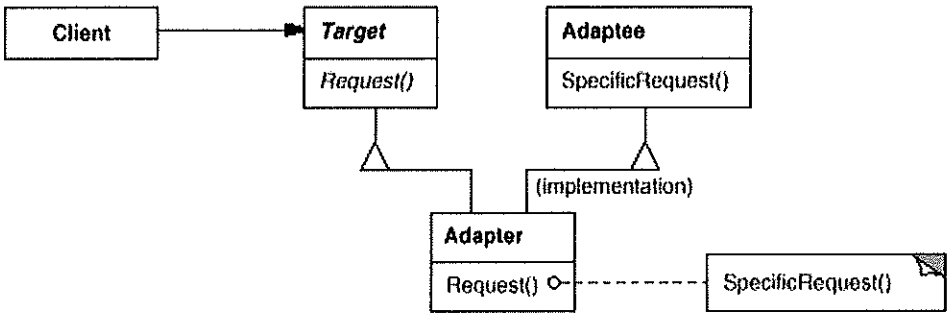
Applicability

Use the Adapter pattern when

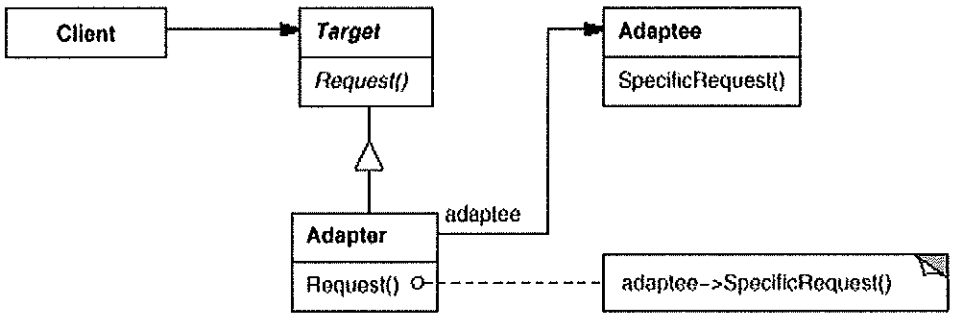
- you want to use an existing class, and its interface does not match the one you need.
- you want to create a reusable class that cooperates with unrelated or unforeseen classes, that is, classes that don't necessarily have compatible interfaces.
- *(object adapter only)* you need to use several existing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

Structure

A class adapter uses multiple inheritance 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** (DrawingEditor)
  - 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

- adapts Adaptee 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.
- lets 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

- lets 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 subclassing Adaptee and making Adapter refer to the subclass rather than the Adaptee itself.

Here are other issues to consider when using the Adapter pattern:

1. *How much adapting does Adapter do?* Adapters vary in the amount of work they do to adapt Adaptee to the Target interface. There is a spectrum of possible work, from simple interface conversion—for example, changing the names of operations—to supporting an entirely different set of operations. The amount of work Adapter does depends on how similar the Target interface is to Adaptee's.
2. *Pluggable adapters.* A class is more reusable when you minimize the assumptions other classes must make to use it. By building interface adaptation into a class, you eliminate the assumption that other classes see the same interface. Put another way, interface adaptation lets us incorporate our class into existing systems that might expect different interfaces to the class. ObjectWorks\Smalltalk [Par90] uses the term **pluggable adapter** to describe classes with built-in interface adaptation.

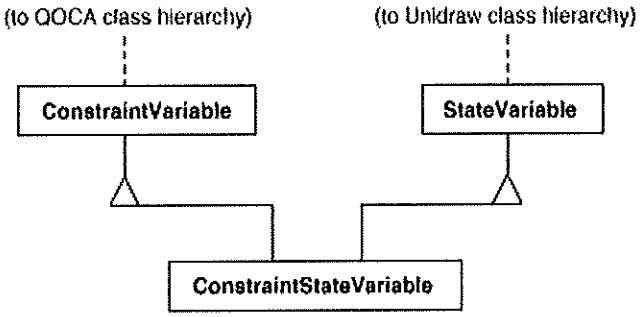
   Consider a TreeDisplay widget that can display tree structures graphically. If this were a special-purpose widget for use in just one application, then we might require the objects that it displays to have a specific interface; that is, all must descend from a Tree abstract class. But if we wanted to make TreeDisplay more reusable (say we wanted to make it part of a toolkit of useful widgets), then that requirement would be unreasonable. Applications will define their own classes for tree structures. They shouldn't be forced to use our Tree abstract class. Different tree structures will have different interfaces.

   In a directory hierarchy, for example, children might be accessed with a GetSubdirectories operation, whereas in an inheritance hierarchy, the corresponding operation might be called GetSubclasses. A reusable TreeDisplay widget must be able to display both kinds of hierarchies even if they use different interfaces. In other words, the TreeDisplay should have interface adaptation built into it.

   We'll look at different ways to build interface adaptation into classes in the Implementation section.

3. *Using two-way adapters to provide transparency.* A potential problem with adapters is that they aren't transparent to all clients. An adapted object no longer conforms to the Adaptee interface, so it can't be used as is wherever an Adaptee object can. **Two-way adapters** can provide such transparency. Specifically, they're useful when two different clients need to view an object differently.

   Consider the two-way adapter that integrates Unidraw, a graphical editor framework [VL90], and QOCA, a constraint-solving toolkit [HHMV92]. Both systems have classes that represent variables explicitly: Unidraw has StateVariable, and QOCA has ConstraintVariable. To make Unidraw work with QOCA, ConstraintVariable must be adapted to StateVariable; to let QOCA propagate solutions to Unidraw, StateVariable must be adapted to ConstraintVariable.



The solution involves a two-way class adapter ConstraintStateVariable, a subclass of both StateVariable and ConstraintVariable, that adapts the two interfaces to each other. Multiple inheritance is a viable solution in this case because the interfaces of the adapted classes are substantially different. The two-way class adapter conforms to both of the adapted classes and can work in either system.

Bridge

▼ Intent

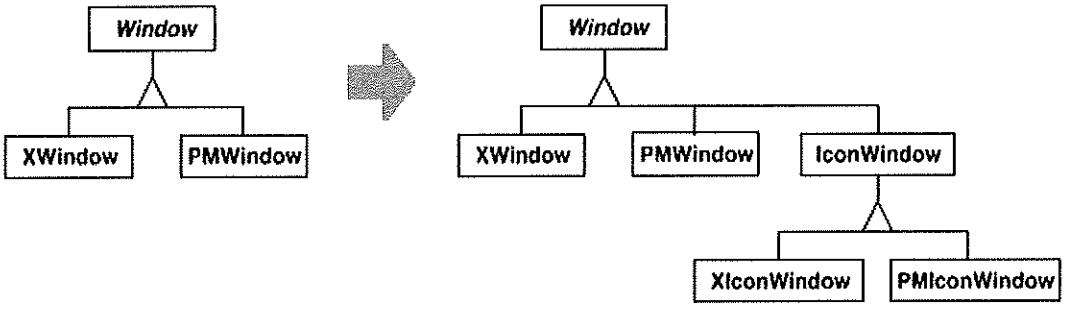
Decouple an abstraction from its implementation so that the two can vary independently.

▼ 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:

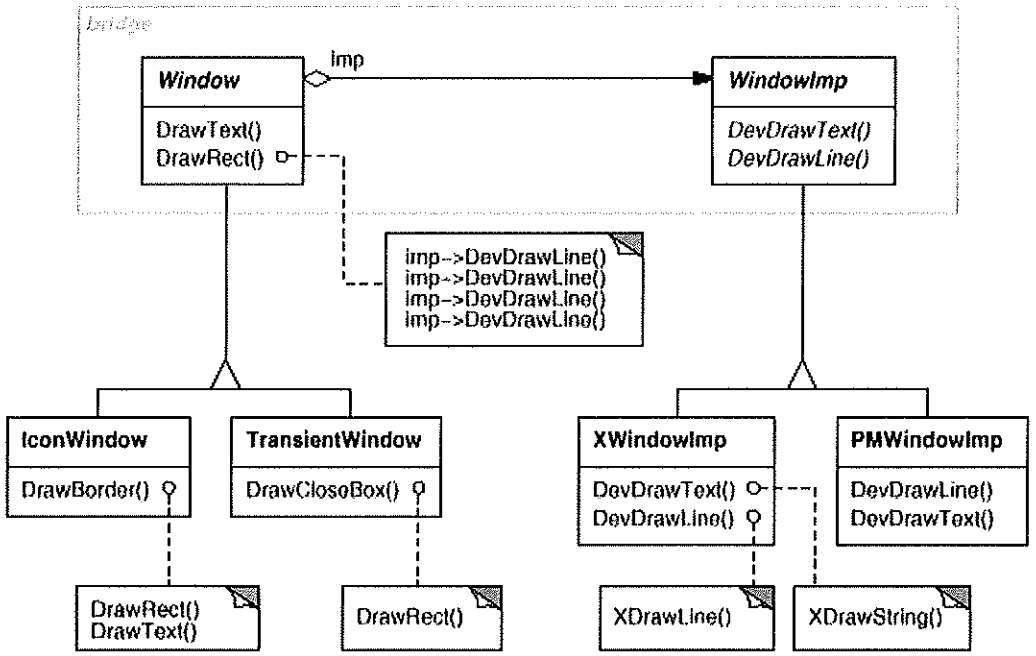
1. It's inconvenient to extend the Window abstraction to cover different kinds of windows or new platforms. Imagine an IconWindow subclass of Window that specializes the Window abstraction for icons. To support IconWindows for both platforms, we have to implement *two* new classes, XIconWindow and PMIconWindow. 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.

   Clients should be able to create a window without committing to a concrete implementation. Only the window implementation should depend on the platform on which the application runs. Therefore client code should instantiate windows without mentioning specific 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.



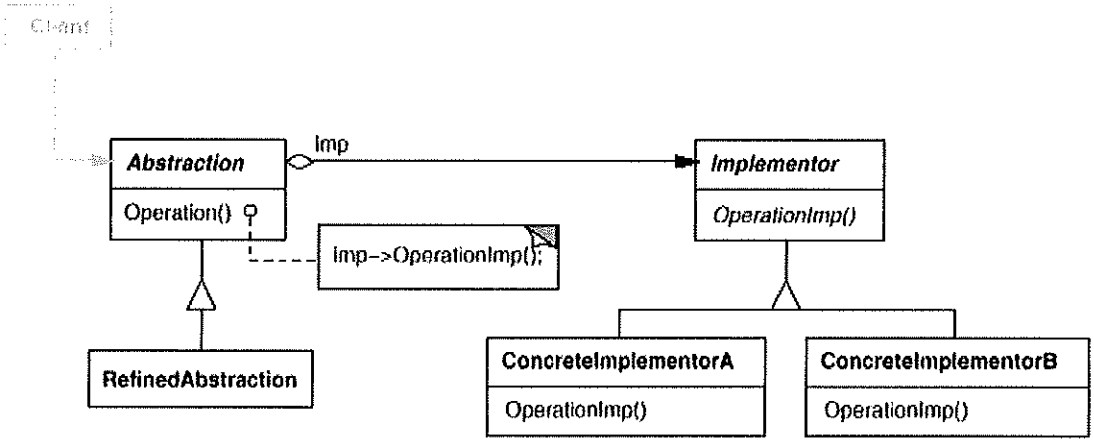
All operations on Window subclasses are implemented in terms of abstract operations from the WindowImp interface. This decouples the window abstractions from the various platform-specific implementations. We refer to the relationship between Window and WindowImp as a **bridge**, because it bridges the 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.
- both the abstractions and their implementations should be extensible by subclassing. In this case, the Bridge pattern lets you combine the different abstractions and implementations and extend them independently.
- 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 object into 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 bound permanently 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 Implementor.

2. *Improved extensibility.* You can extend the Abstraction and Implementor hierarchies independently.
3. *Hiding implementation details from clients.* You can shield clients from implementation details, like the sharing of implementor objects and the accompanying reference count mechanism (if any).

Composite

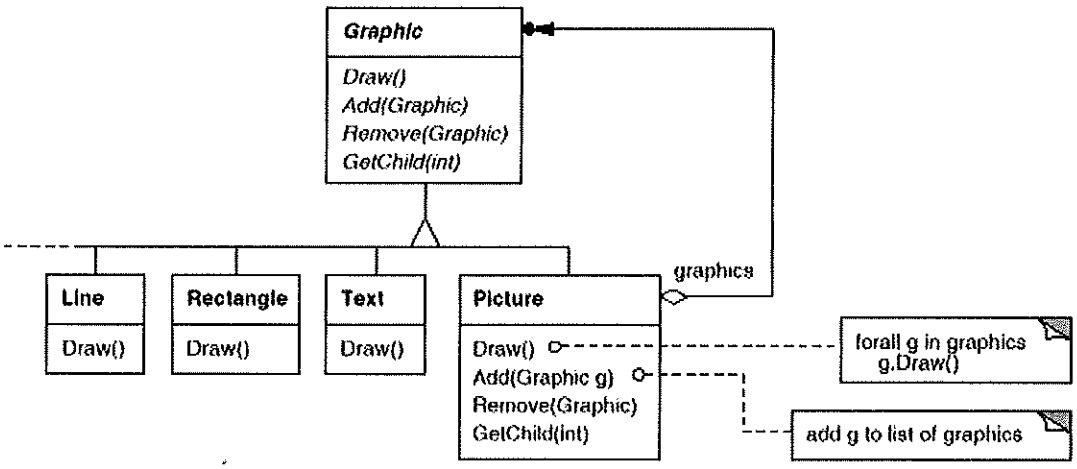
▼Intent

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.

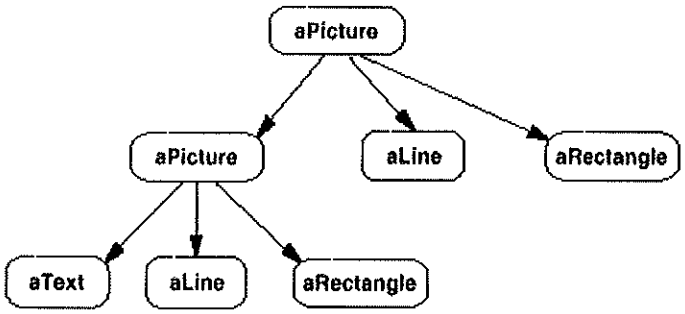


The key to the Composite pattern is an abstract class that represents *both* primitives and their containers. For the graphics system, this class is Graphic. Graphic declares operations like Draw that are specific to graphical objects. It also declares operations that all composite objects share, such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

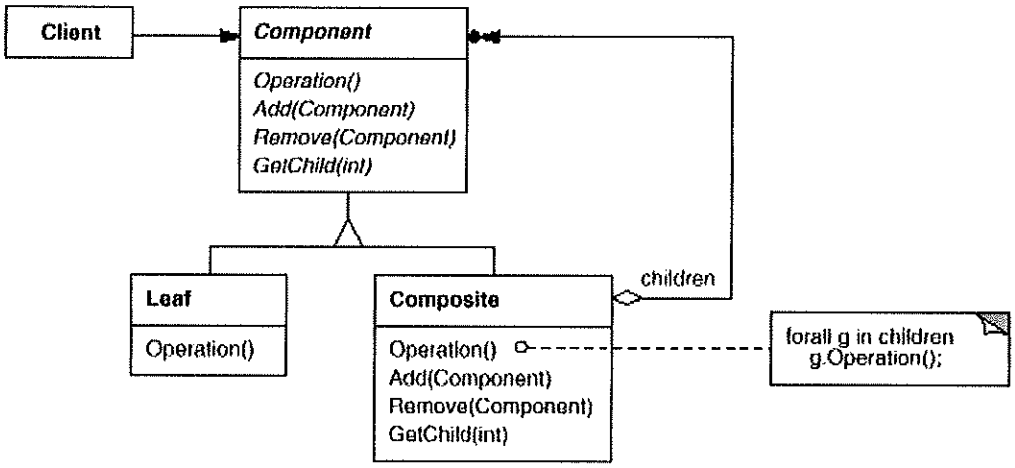


Applicability

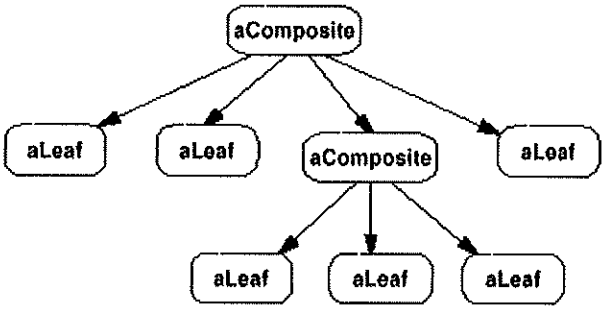
Use the Composite pattern when

- 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.
  - 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.

Decorator

Intent

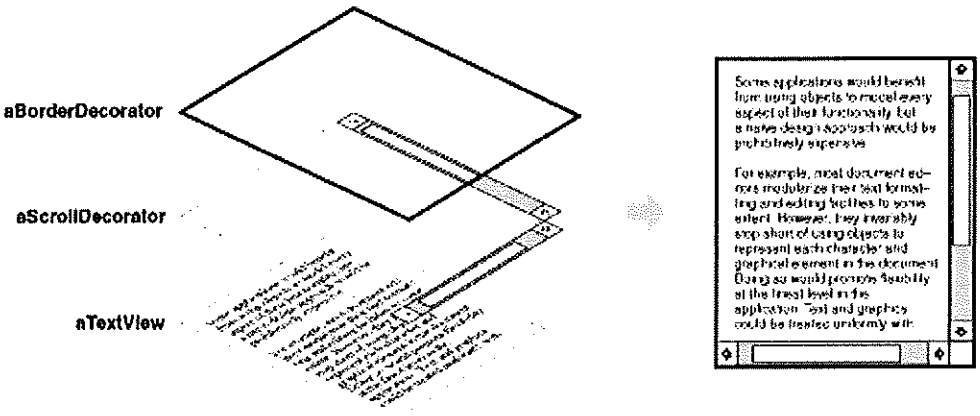
Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.

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.

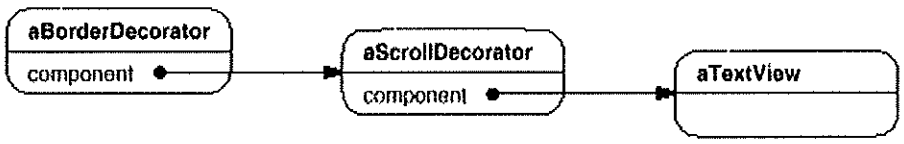
One way to add responsibilities is with inheritance. Inheriting a border from another class puts a border around every subclass instance. This is inflexible, however, because the choice of border is made statically. A client can't control how and when to decorate the component with a border.

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.

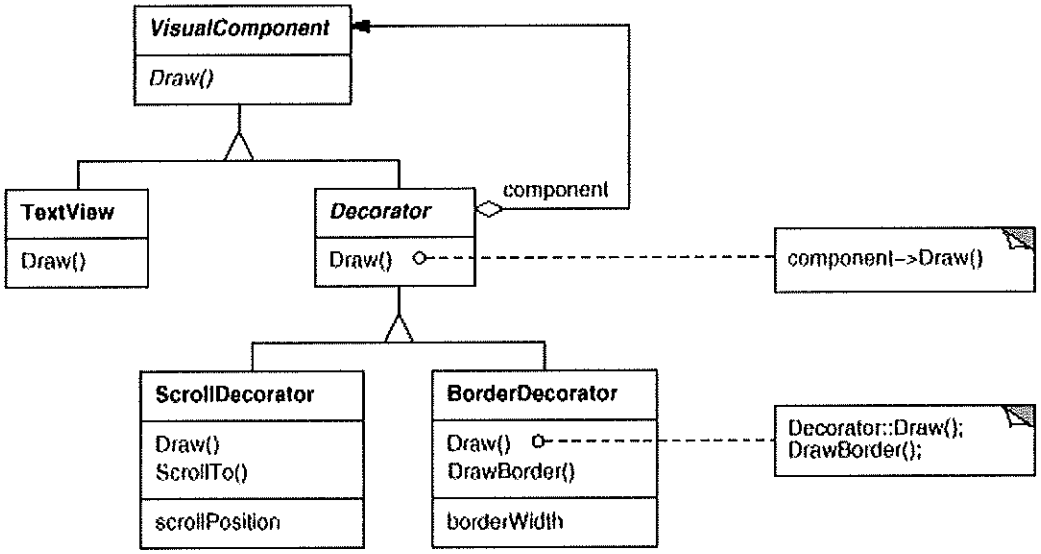


For example, suppose we have a TextView object that displays text in a window. TextView has no scroll bars by default, because we might not always need them. When we do, we can use a ScrollDecorator to add them. Suppose we also want to add a thick black border around the TextView. We can use a BorderDecorator 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.

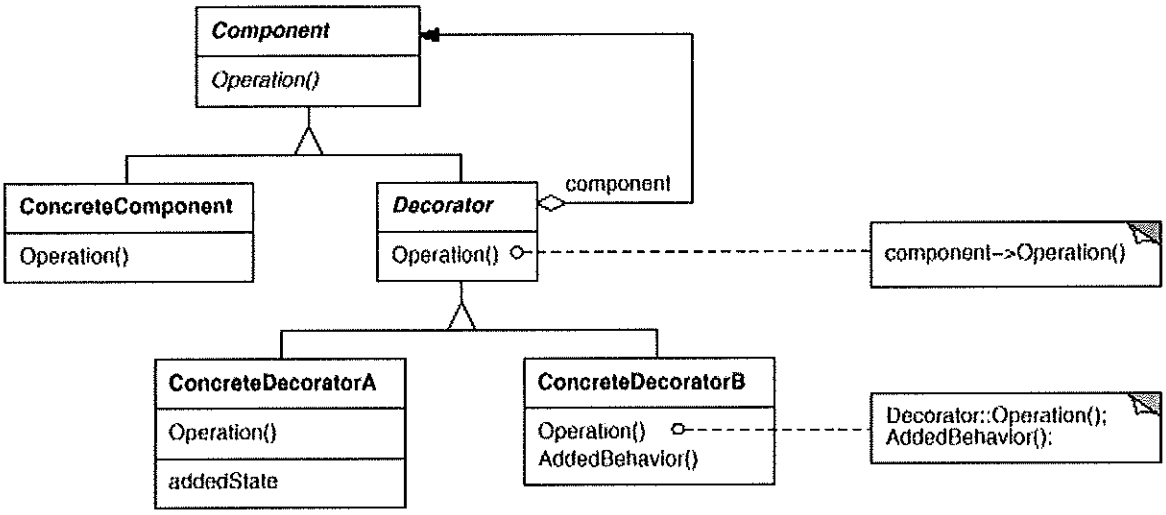
Decorator subclasses are free to add operations for specific functionality. For example, ScrollDecorator's ScrollTo operation lets other objects scroll the interface *if* they know there happens to be a ScrollDecorator object in the interface. The important aspect of this pattern is that it lets decorators 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)
  - defines the interface for objects that can have responsibilities added to them dynamically.
- **ConcreteComponent** (TextView)
  - defines an object to which additional responsibilities can be attached.
- **Decorator**
  - maintains a reference to a Component object and defines an interface that conforms to Component's interface.
- **ConcreteDecorator** (BorderDecorator, ScrollDecorator)
  - 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 provides a 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 offers a 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 a transparent 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 systems composed 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.

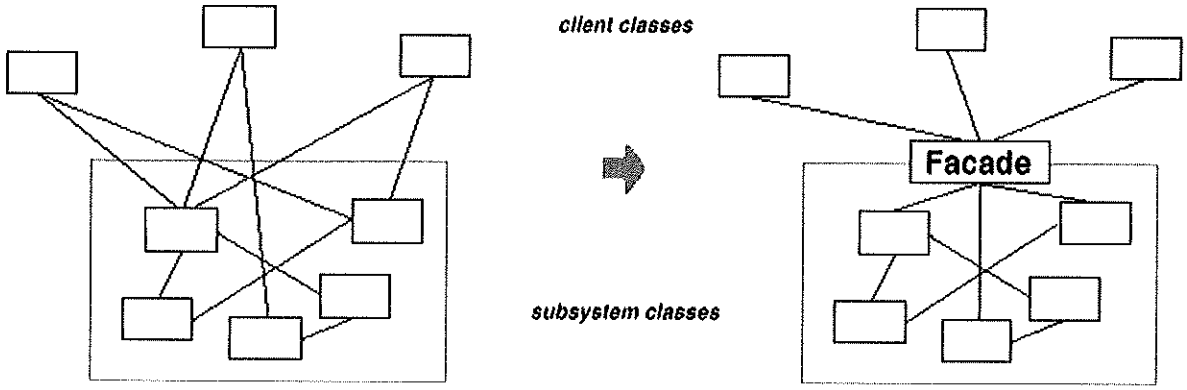
Facade

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.

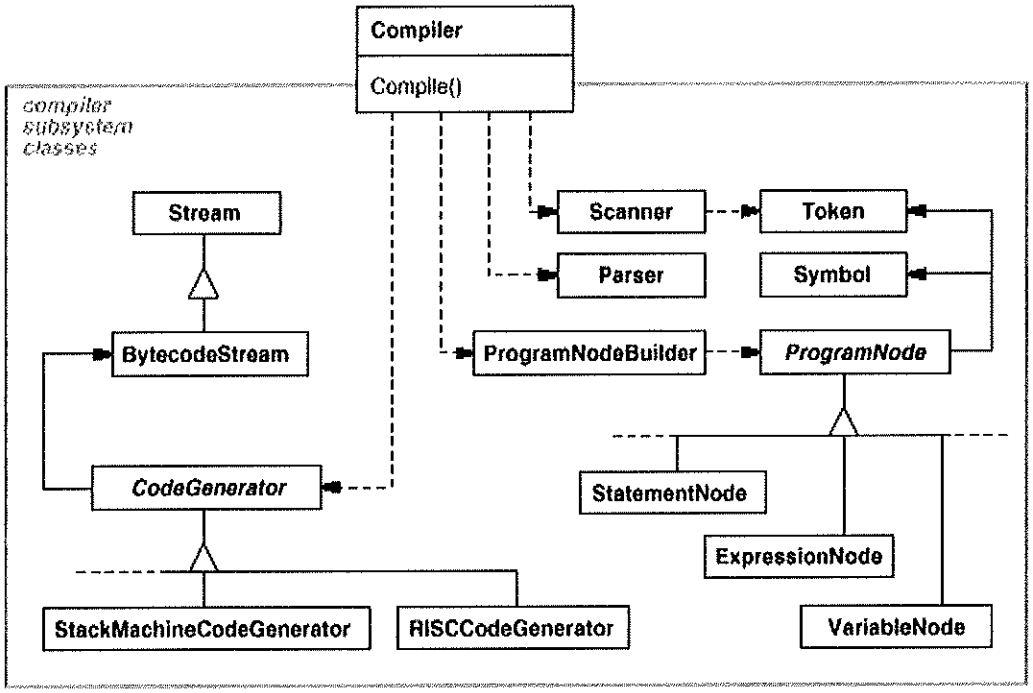
Motivation

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.

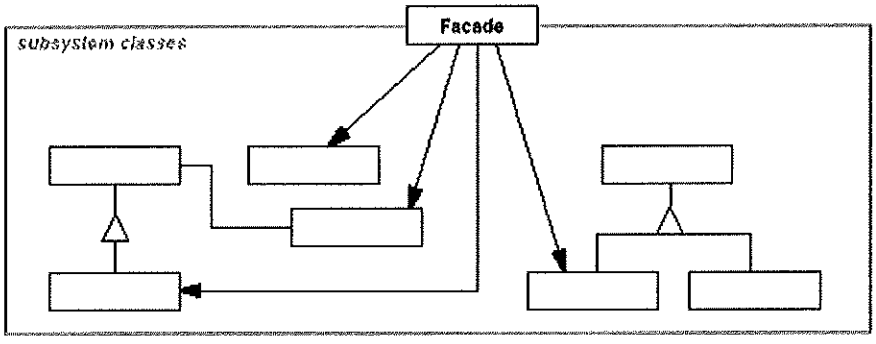


Applicability

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 help layer 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.

Proxy

Intent

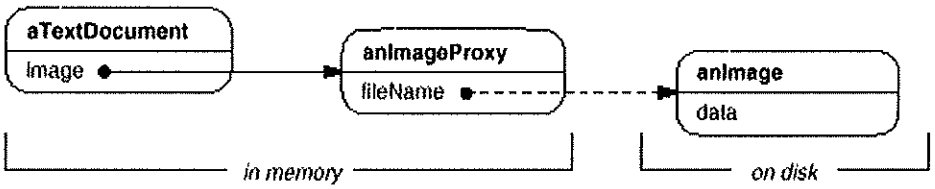
Provide a surrogate or placeholder for another object to control access to it.

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.

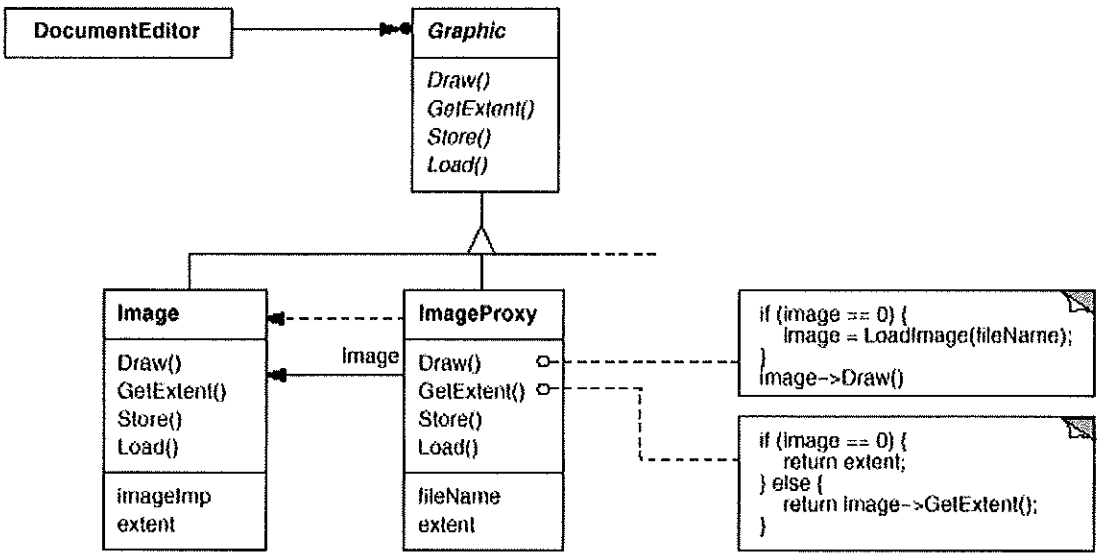
The solution is to use another object, an image **proxy**, that acts as a stand-in for the real image. The proxy acts just like the image and takes care of instantiating it when it's required.



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.

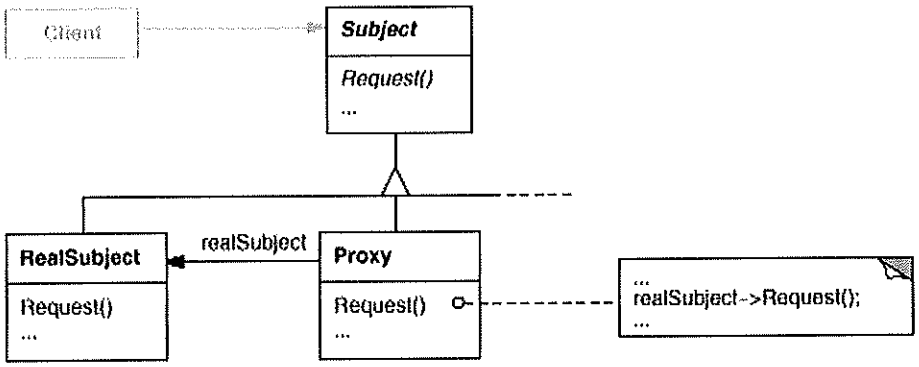
ImageProxy also stores the bounding box of the image and a reference to the real Image instance. This reference won't be valid until the proxy instantiates the real image. The Draw operation makes sure the image is instantiated before forwarding it the request. GetExtent forwards the request to the image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

Applicability

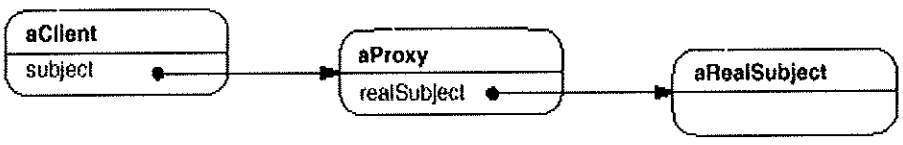
Proxy is applicable whenever there is a need for a more versatile or sophisticated reference to an object than a simple pointer. Here are several common situations in which the Proxy pattern is applicable:

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
   - counting the number of references to the real object so that it can be freed automatically when there are no more references (also called **smart pointers** [Ede92]).
   - loading a persistent object into memory when it's first referenced.
   - checking that the real object is locked before it's accessed to ensure that no other object can change it.

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 the RealSubject 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 proxies* are responsible for encoding a request and its arguments and for sending the encoded request to the real subject in a different address space.
        - *virtual proxies* may cache additional information about the real subject so that they can postpone accessing it. For example, the ImageProxy from the Motivation caches the real image's extent.
        - *protection proxies* check that the caller has the access permissions required to perform a request.
- **Subject** (Graphic)
    - defines the common interface for RealSubject and Proxy so that a Proxy can be used anywhere a RealSubject is expected.
- **RealSubject** (Image)
    - 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.

Discussion of Behavioral Patterns

▼ Encapsulating Variation

Encapsulating variation is a theme of many behavioral patterns. When an aspect of a program changes frequently, these patterns define an object that encapsulates that aspect. Then other parts of the program can collaborate with the object whenever they depend on that aspect. The patterns usually define an abstract class that describes the encapsulating object, and the pattern derives its name from that object.[12] For example,

- a Strategy object encapsulates an algorithm (Strategy (315)),
- a State object encapsulates a state-dependent behavior (State (305)),
- a Mediator object encapsulates the protocol between objects (Mediator (273)), and
- an Iterator object encapsulates the way you access and traverse the components of an aggregate object (Iterator (257)).

These patterns describe aspects of a program that are likely to change. Most patterns have two kinds of objects: the new object(s) that encapsulate the aspect, and the existing object(s) that use the new ones. Usually the functionality of new objects would be an integral part of the existing objects were it not for the pattern. For example, code for a Strategy would probably be wired into the strategy's Context, and code for a State would be implemented directly in the state's Context.

But not all object behavioral patterns partition functionality like this. For example, Chain of Responsibility (223) deals with an arbitrary number of objects (i.e., a chain), all of which may already exist in the system.

Chain of Responsibility illustrates another difference in behavioral patterns: Not all define static communication relationships between classes. Chain of Responsibility prescribes communication between an open-ended number of objects. Other patterns involve objects that are passed around as arguments.

▼ Objects as Arguments

Several patterns introduce an object that's *always* used as an argument. One of these is Visitor (331). A Visitor object is the argument to a polymorphic Accept operation on the objects it visits. The visitor is never considered a part of those objects, even though the conventional alternative to the pattern is to distribute Visitor code across the object structure classes.

Other patterns define objects that act as magic tokens to be passed around and invoked at a later time. Both Command (233) and Memento (283) fall into this category. In Command, the token represents a request; in Memento, it represents the internal state of an object at a particular time. In both cases, the token can have a complex internal representation, but the client is never aware of it. But even here there are differences. Polymorphism is important in the Command pattern, because executing the Command object is a polymorphic operation. In contrast, the Memento interface is so narrow that a memento can only be passed as a value. So it's likely to present no polymorphic operations at all to its clients.

▼ Should Communication be Encapsulated or Distributed?

Mediator (273) and Observer (293) are competing patterns. The difference between them is that Observer distributes communication by introducing Observer and Subject objects, whereas a Mediator object encapsulates the communication between other objects.

In the Observer pattern, there is no single object that encapsulates a constraint. Instead, the Observer and the Subject must cooperate to maintain the constraint. Communication patterns are determined by the way observers and subjects are interconnected: a single subject usually has many observers, and sometimes the observer of one subject is a subject of another observer. The Mediator pattern centralizes rather than distributes. It places the responsibility for maintaining a constraint squarely in the mediator.

We've found it easier to make reusable Observers and Subjects than to make reusable Mediators. The Observer pattern promotes partitioning and loose coupling between Observer and Subject, and that leads to finer-grained classes that are more apt to be reused.

On the other hand, it's easier to understand the flow of communication in Mediator than in Observer. Observers and subjects are usually connected shortly after they're created, and it's hard to see how they are connected later in the program. If you

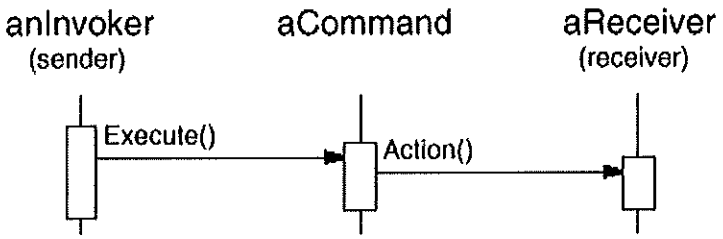
know the Observer pattern, then you understand that the way observers and subjects are connected is important, and you also know what connections to look for. However, the indirection that Observer introduces will still make a system harder to understand.

Observers in Smalltalk can be parameterized with messages to access the Subject state, and so they are even more reusable than they are in C++. This makes Observer more attractive than Mediator in Smalltalk. Thus a Smalltalk programmer will often use Observer where a C++ programmer would use Mediator.

▼ Decoupling Senders and Receivers

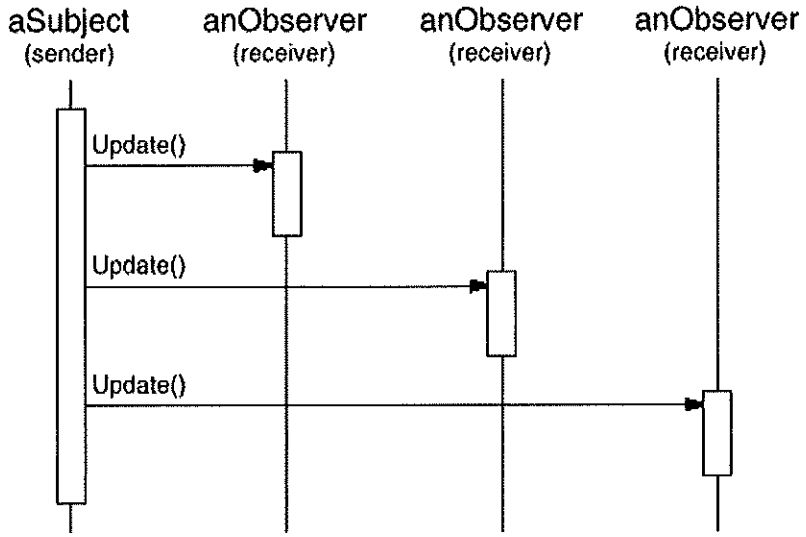
When collaborating objects refer to each other directly, they become dependent on each other, and that can have an adverse impact on the layering and reusability of a system. Command, Observer, Mediator, and Chain of Responsibility address how you can decouple senders and receivers, but with different trade-offs.

The Command pattern supports decoupling by using a Command object to define the binding between a sender and receiver:



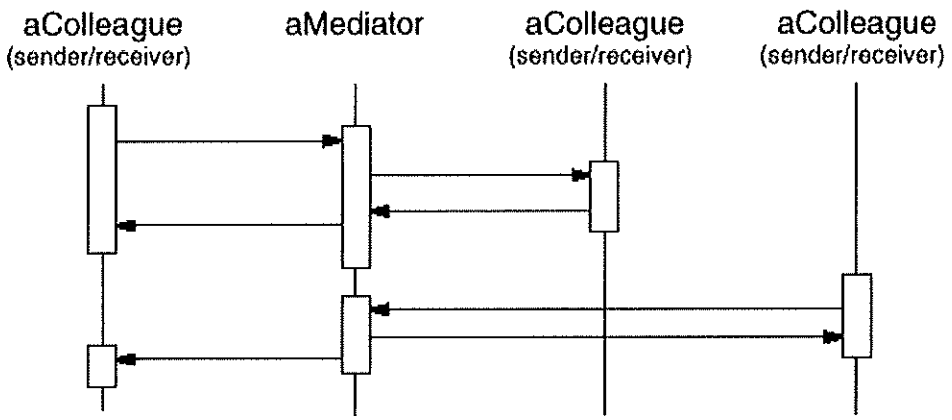
The Command object provides a simple interface for issuing the request (that is, the Execute operation). Defining the sender-receiver connection in a separate object lets the sender work with different receivers. It keeps the sender decoupled from the receivers, making senders easy to reuse. Moreover, you can reuse the Command object to parameterize a receiver with different senders. The Command pattern nominally requires a subclass for each sender-receiver connection, although the pattern describes implementation techniques that avoid subclassing.

The Observer pattern decouples senders (subjects) from receivers (observers) by defining an interface for signaling changes in subjects. Observer defines a looser sender-receiver binding than Command, since a subject may have multiple observers, and their number can vary at run-time.



The Subject and Observer interfaces in the Observer pattern are designed for communicating changes. Therefore the Observer pattern is best for decoupling objects when there are data dependencies between them.

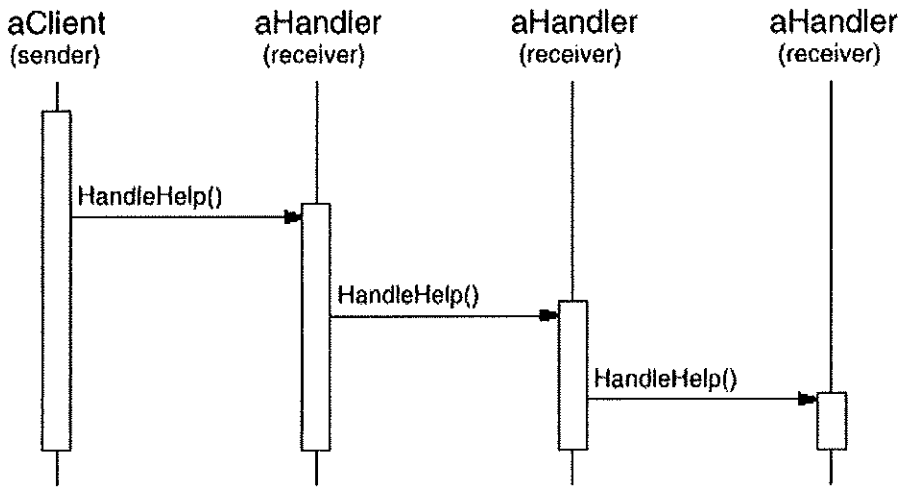
The Mediator pattern decouples objects by having them refer to each other indirectly through a Mediator object.



A Mediator object routes requests between Colleague objects and centralizes their communication. Consequently, colleagues can only talk to each other through the Mediator interface. Because this interface is fixed, the Mediator might have to implement its own dispatching scheme for added flexibility. Requests can be encoded and arguments packed in such a way that colleagues can request an open-ended set of operations.

The Mediator pattern can reduce subclassing in a system, because it centralizes communication behavior in one class instead of distributing it among subclasses. However, *ad hoc* dispatching schemes often decrease type safety.

Finally, the Chain of Responsibility pattern decouples the sender from the receiver by passing the request along a chain of potential receivers:



Since the interface between senders and receivers is fixed, Chain of Responsibility may also require a custom dispatching scheme. Hence it has the same type-safety drawbacks as Mediator. Chain of Responsibility is a good way to decouple the sender and the receiver if the chain is already part of the system's structure, and one of several objects may be in a position to handle the request. Moreover, the pattern offers added flexibility in that the chain can be changed or extended easily.

▼Summary

With few exceptions, behavioral design patterns complement and reinforce each other. A class in a chain of responsibility, for example, will probably include at least one application of Template Method (325). The template method can use primitive operations to determine whether the object should handle the request and to choose the object to forward to. The chain can use the Command pattern to represent requests as objects. Interpreter (243) can use the State pattern to define parsing contexts. An iterator can traverse an aggregate, and a visitor can apply an operation to each element in the aggregate.

Behavioral patterns work well with other patterns, too. For example, a system that uses the Composite (163) pattern might use a visitor to perform operations on components of the composition. It could use Chain of Responsibility to let components access global properties through their parent. It could also use Decorator (175) to override these properties on parts of the composition. It could use the Observer pattern to tie one object structure to another and the State pattern to let a component change its behavior as its state changes. The composition itself might be created using the approach in Builder (97), and it might be treated as a Prototype (117) by some other part of the system.

Well-designed object-oriented systems are just like this—they have multiple patterns embedded in them—but not because their designers necessarily thought in these terms. Composition at the *pattern* level rather than the class or object levels lets us achieve the same synergy with greater ease.

Command

Intent

Encapsulate a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations.

Motivation

Sometimes it's necessary to issue requests to objects without knowing anything about the operation being requested or the receiver of the request. For example, user interface toolkits include objects like buttons and menus that carry out a request in response to user input. But the toolkit can't implement the request explicitly in the button or menu, because only applications that use the toolkit know what should be done on which object. As toolkit designers we have no way of knowing the receiver of the request or the operations that will carry it out.

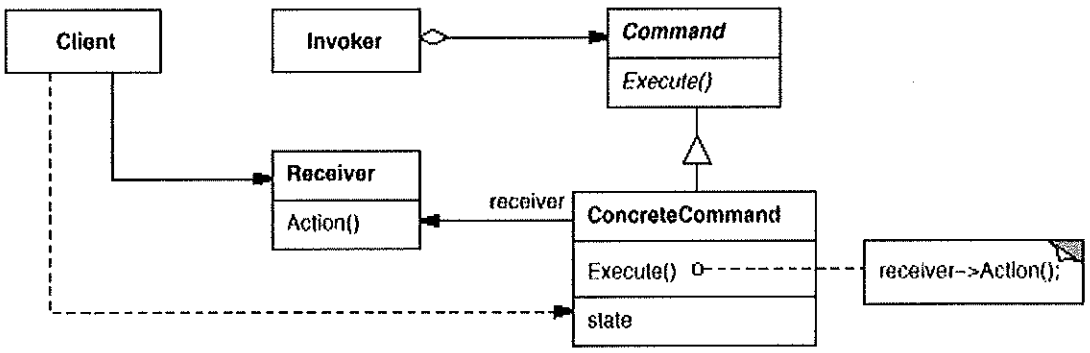
The Command pattern lets toolkit objects make requests of unspecified application objects by turning the request itself into an object. This object can be stored and passed around like other objects. The key to this pattern is an abstract Command class, which declares an interface for executing operations. In the simplest form this interface includes an abstract Execute operation. Concrete Command subclasses specify a receiver-action pair by storing the receiver as an instance variable and by implementing Execute to invoke the request. The receiver has the knowledge required to carry out the request.

Applicability

Use the Command pattern when you want to

- parameterize objects by an action to perform, as MenuItem objects did above. You can express such parameterization in a procedural language with a **callback** function, that is, a function that's registered somewhere to be called at a later point. Commands are an object-oriented replacement for callbacks.
- specify, queue, and execute requests at different times. A Command object can have a lifetime independent of the original request. If the receiver of a request can be represented in an address space-independent way, then you can transfer a command object for the request to a different process and fulfill the request there.
- support undo. The Command's Execute operation can store state for reversing its effects in the command itself. The Command interface must have an added Unexecute operation that reverses the effects of a previous call to Execute. Executed commands are stored in a history list. Unlimited-level undo and redo is achieved by traversing this list backwards and forwards calling Unexecute and Execute, respectively.
- support logging changes so that they can be reapplied in case of a system crash. By augmenting the Command interface with load and store operations, you can keep a persistent log of changes. Recovering from a crash involves reloading logged commands from disk and reexecuting them with the Execute operation.
- structure a system around high-level operations built on primitives operations. Such a structure is common in information systems that support **transactions**. A transaction encapsulates a set of changes to data. The Command pattern offers a way to model transactions. Commands have a common interface, letting you invoke all transactions the same way. The pattern also makes it easy to extend the system with new transactions.

Structure



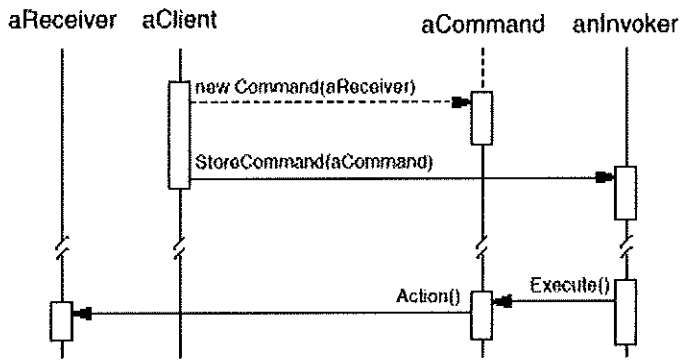
Participants

- **Command**
  - declares an interface for executing an operation.
- **ConcreteCommand** (PasteCommand, OpenCommand)
  - defines a binding between a Receiver object and an action.
  - implements Execute by invoking the corresponding operation(s) on Receiver.
- **Client** (Application)
  - creates a ConcreteCommand object and sets its receiver.
- **Invoker** (MenuItem)
  - asks the command to carry out the request.
- **Receiver** (Document, Application)
  - knows how to perform the operations associated with carrying out a request. Any class may serve as a Receiver.

Collaborations

- The client creates a ConcreteCommand object and specifies its receiver.
- An Invoker object stores the ConcreteCommand object.
- The invoker issues a request by calling Execute on the command. When commands are undoable, ConcreteCommand stores state for undoing the command prior to invoking Execute.
- The ConcreteCommand object invokes operations on its receiver to carry out the request.

The following diagram shows the interactions between these objects. It illustrates how Command decouples the invoker from the receiver (and the request it carries out).



Consequences

The Command pattern has the following consequences:

1. Command decouples the object that invokes the operation from the one that knows how to perform it.
2. Commands are first-class objects. They can be manipulated and extended like any other object.
3. You can assemble commands into a composite command. An example is the MacroCommand class described earlier. In general, composite commands are an instance of the Composite (163) pattern.
4. It's easy to add new Commands, because you don't have to change existing classes.

Chain of Responsibility

Intent

Avoid coupling the sender of a request to its receiver by giving more than one object a chance to handle the request. Chain the receiving objects and pass the request along the chain until an object handles it.

Motivation

Consider a context-sensitive help facility for a graphical user interface. The user can obtain help information on any part of the interface just by clicking on it. The help that's provided depends on the part of the interface that's selected and its context; for example, a button widget in a dialog box might have different help information than a similar button in the main window. If no specific help information exists for that part of the interface, then the help system should display a more general help message about the immediate context—the dialog box as a whole, for example.

Hence it's natural to organize help information according to its generality—from the most specific to the most general. Furthermore, it's clear that a help request is handled by one of several user interface objects; which one depends on the context and how specific the available help is.

The problem here is that the object that ultimately *provides* the help isn't known explicitly to the object (e.g., the button) that *initiates* the help request. What we need is a way to decouple the button that initiates the help request from the objects that might provide help information. The Chain of Responsibility pattern defines how that happens.

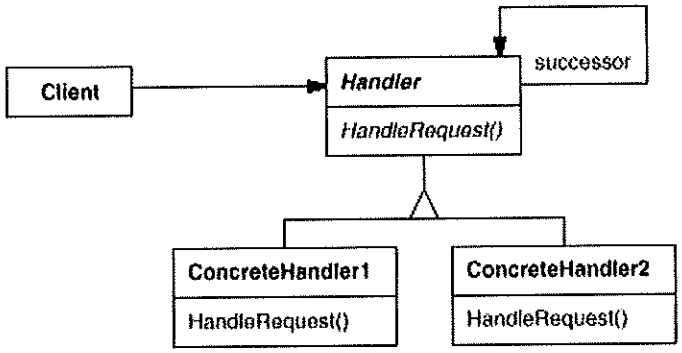
The idea of this pattern is to decouple senders and receivers by giving multiple objects a chance to handle a request. The request gets passed along a chain of objects until one of them handles it.

Applicability

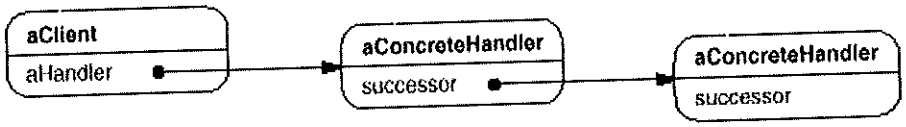
Use Chain of Responsibility when

- more than one object may handle a request, and the handler isn't known *a priori*. The handler should be ascertained automatically.
- you want to issue a request to one of several objects without specifying the receiver explicitly.
- the set of objects that can handle a request should be specified dynamically.

Structure



A typical object structure might look like this:



Participants

- **Handler** (HelpHandler)
  - defines an interface for handling requests.
  - (optional) implements the successor link.
- **ConcreteHandler** (PrintButton, PrintDialog)
  - handles requests it is responsible for.
  - can access its successor.
  - if the ConcreteHandler can handle the request, it does so; otherwise it forwards the request to its successor.
- **Client**
  - initiates the request to a ConcreteHandler object on the chain.

Collaborations

- When a client issues a request, the request propagates along the chain until a ConcreteHandler object takes responsibility for handling it.

Consequences

Chain of Responsibility has the following benefits and liabilities:

1. *Reduced coupling.* The pattern frees an object from knowing which other object handles a request. An object only has to know that a request will be handled "appropriately." Both the receiver and the sender have no explicit knowledge of each other, and an object in the chain doesn't have to know about the chain's structure.

   As a result, Chain of Responsibility can simplify object interconnections. Instead of objects maintaining references to all candidate receivers, they keep a single reference to their successor.

2. *Added flexibility in assigning responsibilities to objects.* Chain of Responsibility gives you added flexibility in distributing responsibilities among objects. You can add or change responsibilities for handling a request by adding to or otherwise changing the chain at run-time. You can combine this with subclassing to specialize handlers statically.
3. *Receipt isn't guaranteed.* Since a request has no explicit receiver, there's no *guarantee* it'll be handled—the request can fall off the end of the chain without ever being handled. A request can also go unhandled when the chain is not configured properly.

Iterator

Intent

Provide a way to access the elements of an aggregate object sequentially without exposing its underlying representation.

Motivation

An aggregate object such as a list should give you a way to access its elements without exposing its internal structure. Moreover, you might want to traverse the list in different ways, depending on what you want to accomplish. But you probably don't want to bloat the List interface with operations for different traversals, even if you could anticipate the ones you will need. You might also need to have more than one traversal pending on the same list.

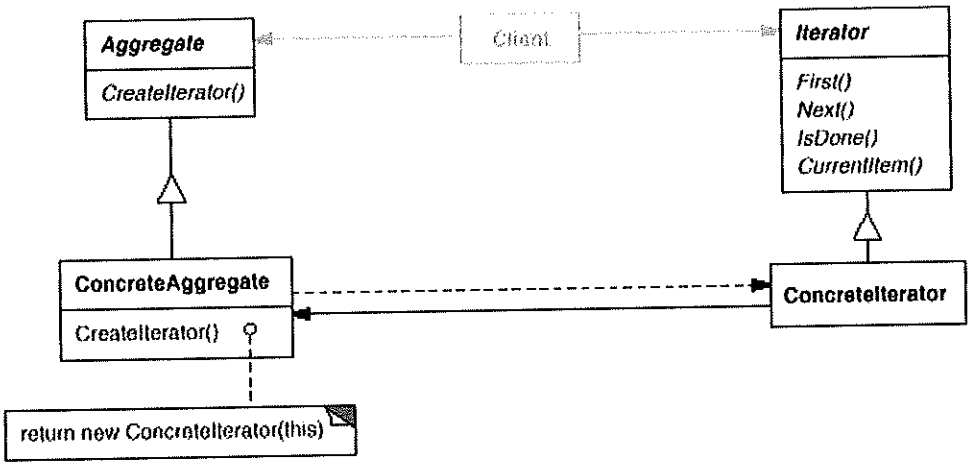
The Iterator pattern lets you do all this. The key idea in this pattern is to take the responsibility for access and traversal out of the list object and put it into an **iterator** object. The Iterator class defines an interface for accessing the list's elements. An iterator object is responsible for keeping track of the current element; that is, it knows which elements have been traversed already.

Applicability

Use the Iterator pattern

- to access an aggregate object's contents without exposing its internal representation.
- to support multiple traversals of aggregate objects.
- to provide a uniform interface for traversing different aggregate structures (that is, to support polymorphic iteration).

Structure



Participants

- **Iterator**
  - defines an interface for accessing and traversing elements.
- **ConcreteIterator**
  - implements the Iterator interface.
  - keeps track of the current position in the traversal of the aggregate.
- **Aggregate**
  - defines an interface for creating an Iterator object.
- **ConcreteAggregate**
  - implements the Iterator creation interface to return an instance of the proper ConcreteIterator.

Mediator

▼Intent

Define an object that encapsulates how a set of objects interact. Mediator promotes loose coupling by keeping objects from referring to each other explicitly, and it lets you vary their interaction independently.

▼Motivation

Object-oriented design encourages the distribution of behavior among objects. Such distribution can result in an object structure with many connections between objects; in the worst case, every object ends up knowing about every other.

Though partitioning a system into many objects generally enhances reusability, proliferating interconnections tend to reduce it again. Lots of interconnections make it less likely that an object can work without the support of others—the system acts as though it were monolithic. Moreover, it can be difficult to change the system's behavior in any significant way, since behavior is distributed among many objects. As a result, you may be forced to define many subclasses to customize the system's behavior.

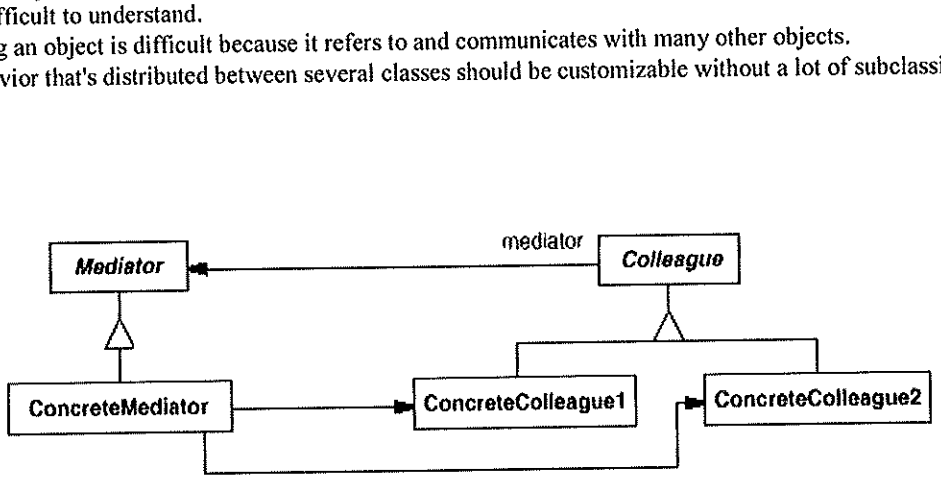
As an example, consider the implementation of dialog boxes in a graphical user interface. A dialog box uses a window to present a collection of widgets such as buttons, menus, and entry fields.

▼Applicability

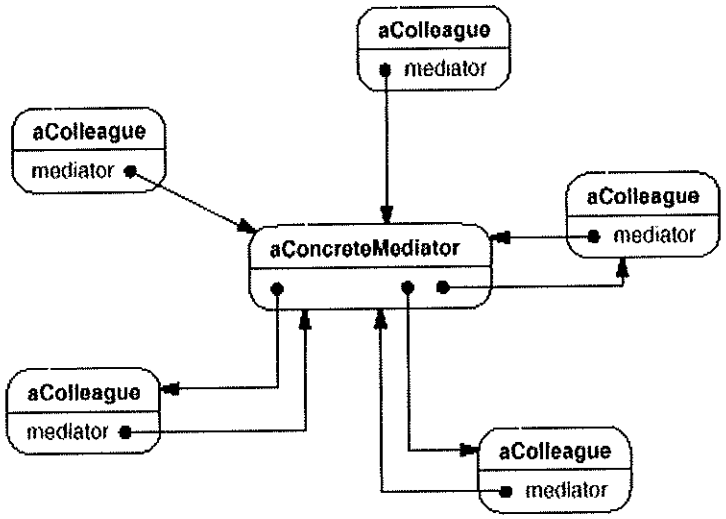
Use the Mediator pattern when

- a set of objects communicate in well-defined but complex ways. The resulting interdependencies are unstructured and difficult to understand.
- reusing an object is difficult because it refers to and communicates with many other objects.
- a behavior that's distributed between several classes should be customizable without a lot of subclassing.

▼Structure



A typical object structure might look like this:



Participants

- **Mediator** (DialogDirector)
  - defines an interface for communicating with Colleague objects.
- **ConcreteMediator** (FontDialogDirector)
  - implements cooperative behavior by coordinating Colleague objects.
  - knows and maintains its colleagues.
- **Colleague classes** (ListBox, EntryField)
  - each Colleague class knows its Mediator object.
  - each colleague communicates with its mediator whenever it would have otherwise communicated with another colleague.

Collaborations

- Colleagues send and receive requests from a Mediator object. The mediator implements the cooperative behavior by routing requests between the appropriate colleague(s).

Consequences

The Mediator pattern has the following benefits and drawbacks:

1. *It limits subclassing.* A mediator localizes behavior that otherwise would be distributed among several objects. Changing this behavior requires subclassing Mediator only; Colleague classes can be reused as is.
2. *It decouples colleagues.* A mediator promotes loose coupling between colleagues. You can vary and reuse Colleague and Mediator classes independently.
3. *It simplifies object protocols.* A mediator replaces many-to-many interactions with one-to-many interactions between the mediator and its colleagues. One-to-many relationships are easier to understand, maintain, and extend.
4. *It abstracts how objects cooperate.* Making mediation an independent concept and encapsulating it in an object lets you focus on how objects interact apart from their individual behavior. That can help clarify how objects interact in a system.
5. *It centralizes control.* The Mediator pattern trades complexity of interaction for complexity in the mediator. Because a mediator encapsulates protocols, it can become more complex than any individual colleague. This can make the mediator itself a monolith that's hard to maintain.

State

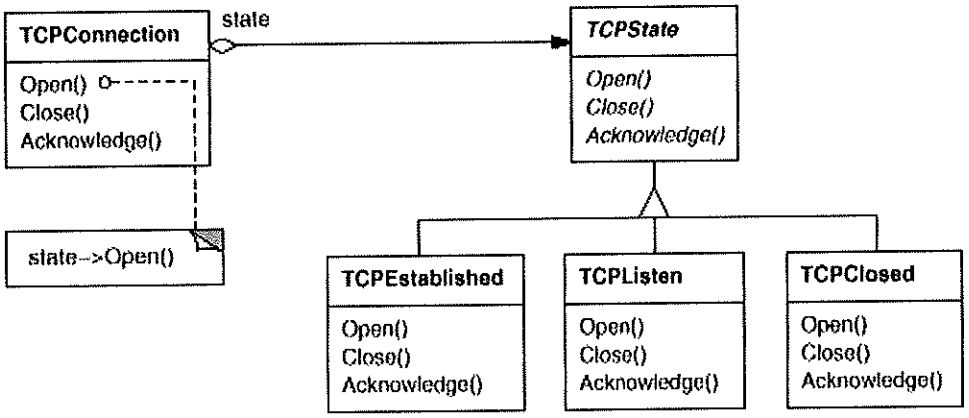
▼Intent

Allow an object to alter its behavior when its internal state changes. The object will appear to change its class.

▼Motivation

Consider a class TCPConnection that represents a network connection. A TCPConnection object can be in one of several different states: Established, Listening, Closed. When a TCPConnection object receives requests from other objects, it responds differently depending on its current state. For example, the effect of an Open request depends on whether the connection is in its Closed state or its Established state. The State pattern describes how TCPConnection can exhibit different behavior in each state.

The key idea in this pattern is to introduce an abstract class called TCPState to represent the states of the network connection. The TCPState class declares an interface common to all classes that represent different operational states. Subclasses of TCPState implement state-specific behavior. For example, the classes TCPEstablished and TCPClosed implement behavior particular to the Established and Closed states of TCPConnection.



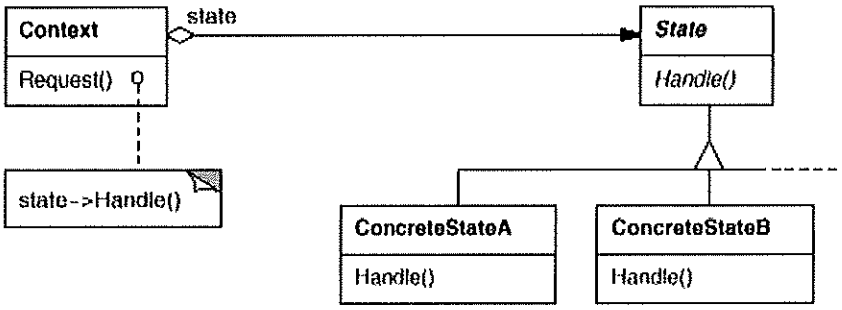
Whenever the connection changes state, the TCPConnection object changes the state object it uses. When the connection goes from established to closed, for example, TCPConnection will replace its TCPEstablished instance with a TCPClosed instance.

▼Applicability

Use the State pattern in either of the following cases:

- An object's behavior depends on its state, and it must change its behavior at run-time depending on that state.
- Operations have large, multipart conditional statements that depend on the object's state. This state is usually represented by one or more enumerated constants. Often, several operations will contain this same conditional structure. The State pattern puts each branch of the conditional in a separate class. This lets you treat the object's state as an object in its own right that can vary independently from other objects.

Structure



Participants

- **Context** (TCPConnection)
  - defines the interface of interest to clients.
  - maintains an instance of a ConcreteState subclass that defines the current state.
- **State** (TCPState)
  - defines an interface for encapsulating the behavior associated with a particular state of the Context.
- **ConcreteState subclasses** (TCPEstablished, TCPListen, TCPClosed)
  - each subclass implements a behavior associated with a state of the Context.

Collaborations

- Context delegates state-specific requests to the current ConcreteState object.
- A context may pass itself as an argument to the State object handling the request. This lets the State object access the context if necessary.
- Context is the primary interface for clients. Clients can configure a context with State objects. Once a context is configured, its clients don't have to deal with the State objects directly.
- Either Context or the ConcreteState subclasses can decide which state succeeds another and under what circumstances.

Consequences

The State pattern has the following consequences:

1. *It localizes state-specific behavior and partitions behavior for different states.* The State pattern puts all behavior associated with a particular state into one object. Because all state-specific code lives in a State subclass, new states and transitions can be added easily by defining new subclasses.

   An alternative is to use data values to define internal states and have Context operations check the data explicitly. But then we'd have look-alike conditional or case statements scattered throughout Context's implementation. Adding a new state could require changing several operations, which complicates maintenance.

   The State pattern avoids this problem but might introduce another, because the pattern distributes behavior for different states across several State subclasses. This increases the number of classes and is less compact than a single class. But such distribution is actually good if there are many states, which would otherwise necessitate large conditional statements.

   Like long procedures, large conditional statements are undesirable. They're monolithic and tend to make the code less explicit, which in turn makes them difficult to modify and extend. The State pattern offers a better way to structure state-specific code. The logic that determines the state transitions doesn't reside in monolithic `if` or `switch` statements but instead is partitioned between the State subclasses. Encapsulating each state transition and action in a class elevates the idea of an execution state to full object status. That imposes structure on the code and makes its intent clearer.

2. *It makes state transitions explicit.* When an object defines its current state solely in terms of internal data values, its state transitions have no explicit representation; they only show up as assignments to some variables. Introducing separate objects for different states makes the transitions more explicit. Also, State objects can protect the Context from inconsistent internal states, because state transitions are atomic from the Context's perspective—they happen by rebinding *one* variable (the Context's State object variable), not several [dCLF93].
3. *State objects can be shared.* If State objects have no instance variables—that is, the state they represent is encoded entirely in their type—then contexts can share a State object. When states are shared in this way, they are essentially flyweights (see Flyweight (195)) with no intrinsic state, only behavior.

Strategy

Intent

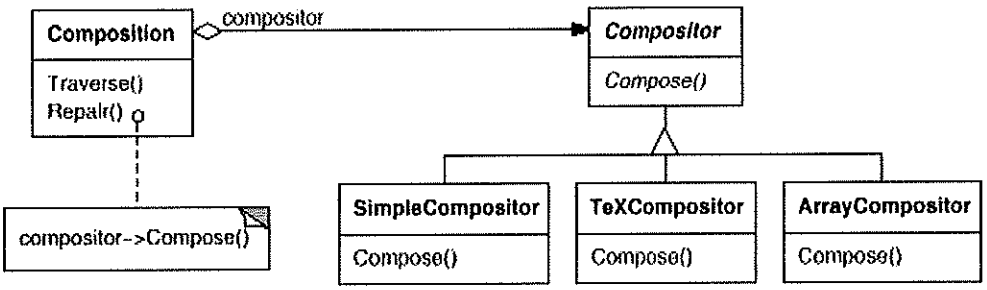
Define a family of algorithms, encapsulate each one, and make them interchangeable. Strategy lets the algorithm vary independently from clients that use it.

Motivation

Many algorithms exist for breaking a stream of text into lines. Hard-wiring all such algorithms into the classes that require them isn't desirable for several reasons:

- Clients that need linebreaking get more complex if they include the linebreaking code. That makes clients bigger and harder to maintain, especially if they support multiple linebreaking algorithms.
- Different algorithms will be appropriate at different times. We don't want to support multiple linebreaking algorithms if we don't use them all.
- It's difficult to add new algorithms and vary existing ones when linebreaking is an integral part of a client.

We can avoid these problems by defining classes that encapsulate different linebreaking algorithms. An algorithm that's encapsulated in this way is called a **strategy**.



Suppose a Composition class is responsible for maintaining and updating the linebreaks of text displayed in a text viewer. Linebreaking strategies aren't implemented by the class Composition. Instead, they are implemented separately by subclasses of the abstract Compositor class. Compositor subclasses implement different strategies:

Applicability

Use the Strategy pattern when

- many related classes differ only in their behavior. Strategies provide a way to configure a class with one of many behaviors.
- you need different variants of an algorithm. For example, you might define algorithms reflecting different space/time trade-offs. Strategies can be used when these variants are implemented as a class hierarchy of algorithms.
- an algorithm uses data that clients shouldn't know about. Use the Strategy pattern to avoid exposing complex, algorithm-specific data structures.
- a class defines many behaviors, and these appear as multiple conditional statements in its operations. Instead of many conditionals, move related conditional branches into their own Strategy class.

```
        case TeXStrategy:
            ComposeWithTeXCompositor();
            break;
        // ...
        }
        // merge results with existing composition, if necessary
    }
```

The Strategy pattern eliminates this case statement by delegating the linebreaking task to a Strategy object:

```
void Composition::Repair () {
    _compositor->Compose();
    // merge results with existing composition, if necessary
}
```

Code containing many conditional statements often indicates the need to apply the Strategy pattern.

4. *A choice of implementations.* Strategies can provide different implementations of the *same* behavior. The client can choose among strategies with different time and space trade-offs.
5. *Clients must be aware of different Strategies.* The pattern has a potential drawback in that a client must understand how Strategies differ before it can select the appropriate one. Clients might be exposed to implementation issues. Therefore you should use the Strategy pattern only when the variation in behavior is relevant to clients.
6. *Communication overhead between Strategy and Context.* The Strategy interface is shared by all ConcreteStrategy classes whether the algorithms they implement are trivial or complex. Hence it's likely that some ConcreteStrategies won't use all the information passed to them through this interface; simple ConcreteStrategies may use none of it! That means there will be times when the context creates and initializes parameters that never get used. If this is an issue, then you'll need tighter coupling between Strategy and Context.
7. *Increased number of objects.* Strategies increase the number of objects in an application. Sometimes you can reduce this overhead by implementing strategies as stateless objects that contexts can share. Any residual state is maintained by the context, which passes it in each request to the Strategy object. Shared strategies should not maintain state across invocations. The Flyweight (195) pattern describes this approach in more detail.

Template Method

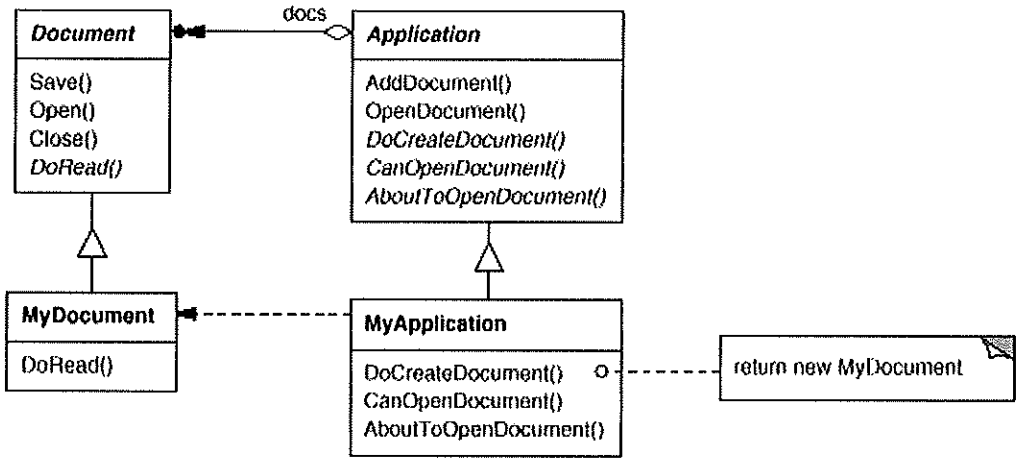
Intent

Define the skeleton of an algorithm in an operation, deferring some steps to subclasses. Template Method lets subclasses redefine certain steps of an algorithm without changing the algorithm's structure.

Motivation

Consider an application framework that provides Application and Document classes. The Application class is responsible for opening existing documents stored in an external format, such as a file. A Document object represents the information in a document once it's read from the file.

Applications built with the framework can subclass Application and Document to suit specific needs. For example, a drawing application defines DrawApplication and DrawDocument subclasses; a spreadsheet application defines SpreadsheetApplication and SpreadsheetDocument subclasses.



The abstract Application class defines the algorithm for opening and reading a document in its OpenDocument operation.

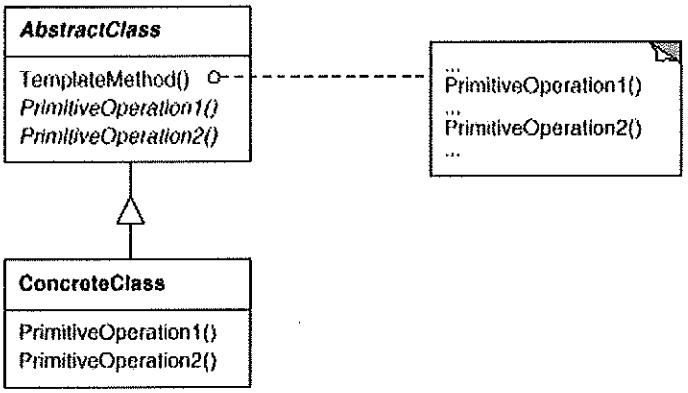
By defining some of the steps of an algorithm using abstract operations, the template method fixes their ordering, but it lets Application and Document subclasses vary those steps to suit their needs.

Applicability

The Template Method pattern should be used

- to implement the invariant parts of an algorithm once and leave it up to subclasses to implement the behavior that can vary.
- when common behavior among subclasses should be factored and localized in a common class to avoid code duplication. You first identify the differences in the existing code and then separate the differences into new operations. Finally, you replace the differing code with a template method that calls one of these new operations.
- to control subclasses extensions. You can define a template method that calls "hook" operations (see Consequences) at specific points, thereby permitting extensions only at those points.

Structure



Participants

- **AbstractClass** (Application)
  - defines abstract **primitive operations** that concrete subclasses define to implement steps of an algorithm.
  - implements a template method defining the skeleton of an algorithm. The template method calls primitive operations as well as operations defined in AbstractClass or those of other objects.
- **ConcreteClass** (MyApplication)
  - implements the primitive operations to carry out subclass-specific steps of the algorithm.

Collaborations

- ConcreteClass relies on AbstractClass to implement the invariant steps of the algorithm.

Consequences

Template methods are a fundamental technique for code reuse. They are particularly important in class libraries, because they are the means for factoring out common behavior in library classes.

Template methods lead to an inverted control structure that's sometimes referred to as "the Hollywood principle," that is, "Don't call us, we'll call you" [Swe85]. This refers to how a parent class calls the operations of a subclass and not the other way around.

Template methods call the following kinds of operations:

- concrete operations (either on the ConcreteClass or on client classes);
- concrete AbstractClass operations (i.e., operations that are generally useful to subclasses);
- primitive operations (i.e., abstract operations);
- factory methods (see Factory Method (107)); and
- **hook operations**, which provide default behavior that subclasses can extend if necessary. A hook operation often does nothing by default.

It's important for template methods to specify which operations are hooks (*may* be overridden) and which are abstract operations (*must* be overridden). To reuse an abstract class effectively, subclass writers must understand which operations are designed for overriding.

Visitor

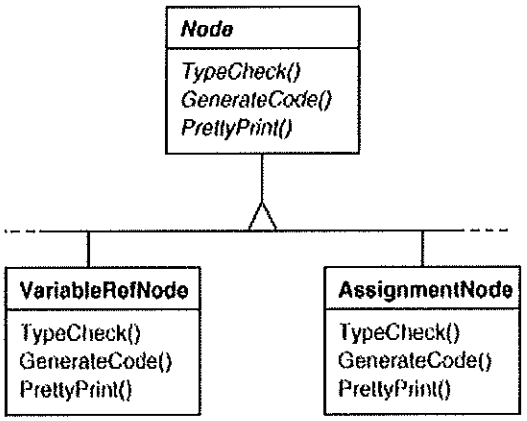
Intent

Represent an operation to be performed on the elements of an object structure. Visitor lets you define a new operation without changing the classes of the elements on which it operates.

Motivation

Consider a compiler that represents programs as abstract syntax trees. It will need to perform operations on abstract syntax trees for "static semantic" analyses like checking that all variables are defined. It will also need to generate code. So it might define operations for type-checking, code optimization, flow analysis, checking for variables being assigned values before they're used, and so on. Moreover, we could use the abstract syntax trees for pretty-printing, program restructuring, code instrumentation, and computing various metrics of a program.

Most of these operations will need to treat nodes that represent assignment statements differently from nodes that represent variables or arithmetic expressions. Hence there will be one class for assignment statements, another for variable accesses, another for arithmetic expressions, and so on. The set of node classes depends on the language being compiled, of course, but it doesn't change much for a given language.

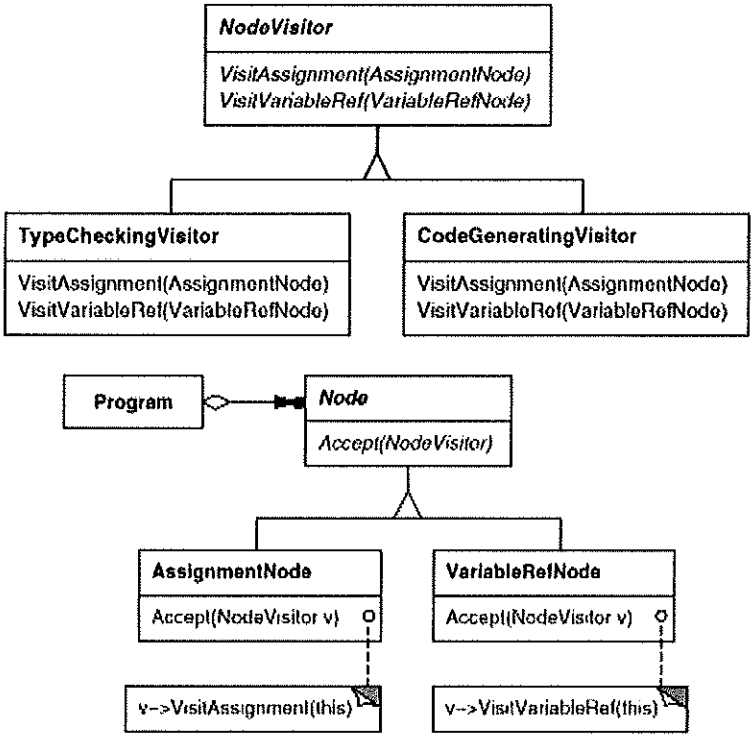


This diagram shows part of the Node class hierarchy. The problem here is that distributing all these operations across the various node classes leads to a system that's hard to understand, maintain, and change. It will be confusing to have type-checking code mixed with pretty-printing code or flow analysis code. Moreover, adding a new operation usually requires recompiling all of these classes. It would be better if each new operation could be added separately, and the node classes were independent of the operations that apply to them.

We can have both by packaging related operations from each class in a separate object, called a **visitor**, and passing it to elements of the abstract syntax tree as it's traversed. When an element "accepts" the visitor, it sends a request to the visitor that encodes the element's class. It also includes the element as an argument. The visitor will then execute the operation for that element—the operation that used to be in the class of the element.

For example, a compiler that didn't use visitors might type-check a procedure by calling the TypeCheck operation on its abstract syntax tree. Each of the nodes would implement TypeCheck by calling TypeCheck on its components (see the preceding class diagram). If the compiler type-checked a procedure using visitors, then it would create a TypeCheckingVisitor object and call the Accept operation on the abstract syntax tree with that object as an argument. Each of the nodes would implement Accept by calling back on the visitor: an assignment node calls VisitAssignment operation on the visitor, while a variable reference calls VisitVariableReference. What used to be the TypeCheck operation in class AssignmentNode is now the VisitAssignment operation on TypeCheckingVisitor.

To make visitors work for more than just type-checking, we need an abstract parent class NodeVisitor for all visitors of an abstract syntax tree. NodeVisitor must declare an operation for each node class. An application that needs to compute program metrics will define new subclasses of NodeVisitor and will no longer need to add application-specific code to the node classes. The Visitor pattern encapsulates the operations for each compilation phase in a Visitor associated with that phase.



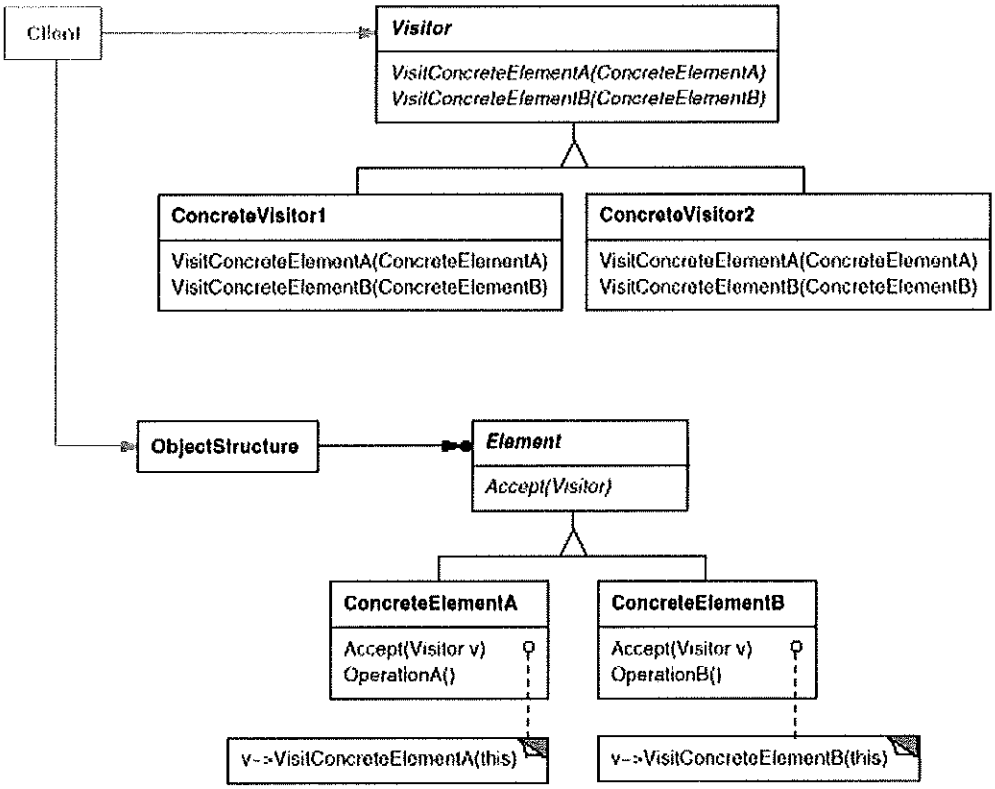
With the Visitor pattern, you define two class hierarchies: one for the elements being operated on (the Node hierarchy) and one for the visitors that define operations on the elements (the NodeVisitor hierarchy). You create a new operation by adding a new subclass to the visitor class hierarchy. As long as the grammar that the compiler accepts doesn't change (that is, we don't have to add new Node subclasses), we can add new functionality simply by defining new NodeVisitor subclasses.

Applicability

Use the Visitor pattern when

- an object structure contains many classes of objects with differing interfaces, and you want to perform operations on these objects that depend on their concrete classes.
- many distinct and unrelated operations need to be performed on objects in an object structure, and you want to avoid "polluting" their classes with these operations. Visitor lets you keep related operations together by defining them in one class. When the object structure is shared by many applications, use Visitor to put operations in just those applications that need them.
- the classes defining the object structure rarely change, but you often want to define new operations over the structure. Changing the object structure classes requires redefining the interface to all visitors, which is potentially costly. If the object structure classes change often, then it's probably better to define the operations in those classes.

Structure



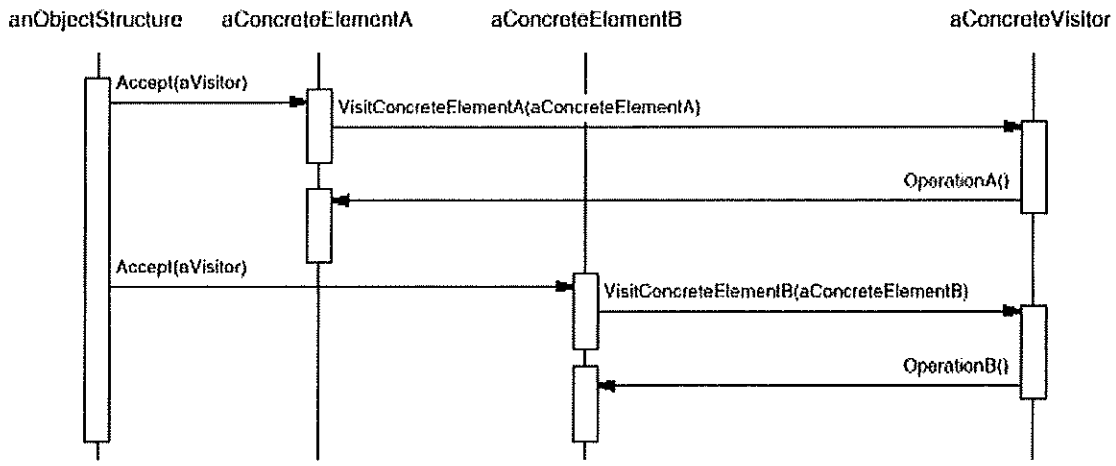
Participants

- **Visitor** (NodeVisitor)
  - declares a Visit operation for each class of ConcreteElement in the object structure. The operation's name and signature identifies the class that sends the Visit request to the visitor. That lets the visitor determine the concrete class of the element being visited. Then the visitor can access the element directly through its particular interface.
- **ConcreteVisitor** (TypeCheckingVisitor)
  - implements each operation declared by Visitor. Each operation implements a fragment of the algorithm defined for the corresponding class of object in the structure. ConcreteVisitor provides the context for the algorithm and stores its local state. This state often accumulates results during the traversal of the structure.
- **Element** (Node)
  - defines an Accept operation that takes a visitor as an argument.
- **ConcreteElement** (AssignmentNode,VariableRefNode)
  - implements an Accept operation that takes a visitor as an argument.
- **ObjectStructure** (Program)
  - can enumerate its elements.
  - may provide a high-level interface to allow the visitor to visit its elements.
  - may either be a composite (see Composite (163)) or a collection such as a list or a set.

Collaborations

- A client that uses the Visitor pattern must create a ConcreteVisitor object and then traverse the object structure, visiting each element with the visitor.
- When an element is visited, it calls the Visitor operation that corresponds to its class. The element supplies itself as an argument to this operation to let the visitor access its state, if necessary.

The following interaction diagram illustrates the collaborations between an object structure, a visitor, and two elements:



Consequences

Some of the benefits and liabilities of the Visitor pattern are as follows:

1. *Visitor makes adding new operations easy.* Visitors make it easy to add operations that depend on the components of complex objects. You can define a new operation over an object structure simply by adding a new visitor. In contrast, if you spread functionality over many classes, then you must change each class to define a new operation.
2. *A visitor gathers related operations and separates unrelated ones.* Related behavior isn't spread over the classes defining the object structure; it's localized in a visitor. Unrelated sets of behavior are partitioned in their own visitor subclasses. That simplifies both the classes defining the elements and the algorithms defined in the visitors. Any algorithm-specific data structures can be hidden in the visitor.
3. *Adding new ConcreteElement classes is hard.* The Visitor pattern makes it hard to add new subclasses of Element. Each new ConcreteElement gives rise to a new abstract operation on Visitor and a corresponding implementation in every ConcreteVisitor class. Sometimes a default implementation can be provided in Visitor that can be inherited by most of the ConcreteVisitors, but this is the exception rather than the rule.

   So the key consideration in applying the Visitor pattern is whether you are mostly likely to change the algorithm applied over an object structure or the classes of objects that make up the structure. The Visitor class hierarchy can be difficult to maintain when new ConcreteElement classes are added frequently. In such cases, it's probably easier just to define operations on the classes that make up the structure. If the Element class hierarchy is stable, but you are continually adding operations or changing algorithms, then the Visitor pattern will help you manage the changes.

4. *Visiting across class hierarchies.* An iterator (see Iterator (257)) can visit the objects in a structure as it traverses them by calling their operations. But an iterator can't work across object structures with different types of elements. For example, the Iterator interface defined on page 263 can access only objects of type `Item`:

```
template <class Item>
class Iterator {
    // ...
    Item CurrentItem() const;
};
```

   This implies that all elements the iterator can visit have a common parent class `Item`.

   Visitor does not have this restriction. It can visit objects that don't have a common parent class. You can add any type of object to a Visitor interface. For example, in

```
class Visitor {
public:
    // ...
    void VisitMyType(MyType*);
    void VisitYourType(YourType*);
};
```

   `MyType` and `YourType` do not have to be related through inheritance at all.

10. *Accumulating state.* Visitors can accumulate state as they visit each element in the object structure. Without a visitor, this state would be passed as extra arguments to the operations that perform the traversal, or they might appear as global variables.
11. *Breaking encapsulation.* Visitor's approach assumes that the ConcreteElement interface is powerful enough to let visitors do their job. As a result, the pattern often forces you to provide public operations that access an element's internal state, which may compromise its encapsulation.