A view uses an instance of a Controller subclass to implement a particular response strategy; to implement a different strategy, simply replace the instance with a different kind of controller. It's even possible to change a view's controller at run-time to let the view change the way it responds to user input. For example, a view can be disabled so that it doesn't accept input simply by giving it a controller that ignores input events.

The View-Controller relationship is an example of the Strategy (315) design pattern. A Strategy is an object that represents an algorithm. It's useful when you want to replace the algorithm either statically or dynamically, when you have a lot of variants of the algorithm, or when the algorithm has complex data structures that you want to encapsulate.

MVC uses other design patterns, such as Factory Method (107) to specify the default controller class for a view and Decorator (175) to add scrolling to a view. But the main relationships in MVC are given by the Observer, Composite, and Strategy design patterns.

1.3 Describing Design Patterns

How do we describe design patterns? Graphical notations, while important and useful, aren't sufficient. They simply capture the end product of the design process as relationships between classes and objects. To reuse the design, we must also record the decisions, alternatives, and trade-offs that led to it. Concrete examples are important too, because they help you see the design in action.

We describe design patterns using a consistent format. Each pattern is divided into sections according to the following template. The template lends a uniform structure to the information, making design patterns easier to learn, compare, and use.

Pattern Name and Classification

The pattern's name conveys the essence of the pattern succinctly. A good name is vital, because it will become part of your design vocabulary. The pattern's classification reflects the scheme we introduce in Section 1.5.

Intent

A short statement that answers the following questions: What does the design pattern do? What is its rationale and intent? What particular design issue or problem does it address?

Also Known As

Other well-known names for the pattern, if any.

Motivation

A scenario that illustrates a design problem and how the class and object structures in the pattern solve the problem. The scenario will help you understand the more abstract description of the pattern that follows.

Applicability

What are the situations in which the design pattern can be applied? What are examples of poor designs that the pattern can address? How can you recognize these situations?

Structure

A graphical representation of the classes in the pattern using a notation based on the Object Modeling Technique (OMT) [RBP+91]. We also use interaction diagrams [JCJO92, Boo94] to illustrate sequences of requests and collaborations between objects. Appendix B describes these notations in detail.

Participants

The classes and/or objects participating in the design pattern and their responsibilities.

Collaborations

How the participants collaborate to carry out their responsibilities.

Consequences

How does the pattern support its objectives? What are the trade-offs and results of using the pattern? What aspect of system structure does it let you vary independently?

Implementation

What pitfalls, hints, or techniques should you be aware of when implementing the pattern? Are there language-specific issues?

Sample Code

Code fragments that illustrate how you might implement the pattern in C++ or Smalltalk.

Known Uses

Examples of the pattern found in real systems. We include at least two examples from different domains.

Related Patterns

What design patterns are closely related to this one? What are the important differences? With which other patterns should this one be used?

The appendices provide background information that will help you understand the patterns and the discussions surrounding them. Appendix A is a glossary of terminology

we use. We've already mentioned Appendix B, which presents the various notations. We'll also describe aspects of the notations as we introduce them in the upcoming discussions. Finally, Appendix C contains source code for the foundation classes we use in code samples.

1.4 The Catalog of Design Patterns

The catalog beginning on page 79 contains 23 design patterns. Their names and intents are listed next to give you an overview. The number in parentheses after each pattern name gives the page number for the pattern (a convention we follow throughout the book).

Abstract Factory (87) Provide an interface for creating families of related or dependent objects without specifying their concrete classes.

Adapter (139) Convert the interface of a class into another interface clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces.

Bridge (151) Decouple an abstraction from its implementation so that the two can vary independently.

Builder (97) Separate the construction of a complex object from its representation so that the same construction process can create different representations.

Chain of Responsibility (223) 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.

Command (233) Encapsulate a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations.

Composite (163) Compose objects into tree structures to represent part-whole hierarchies. Composite lets clients treat individual objects and compositions of objects uniformly.

Decorator (175) Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.

Facade (185) 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.

Factory Method (107) Define an interface for creating an object, but let subclasses decide which class to instantiate. Factory Method lets a class defer instantiation to subclasses.

Flyweight (195) Use sharing to support large numbers of fine-grained objects efficiently.

Interpreter (243) Given a language, define a represention for its grammar along with an interpreter that uses the representation to interpret sentences in the language.

Iterator (257) Provide a way to access the elements of an aggregate object sequentially without exposing its underlying representation.

Mediator (273) 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.

Memento (283) Without violating encapsulation, capture and externalize an object's internal state so that the object can be restored to this state later.

Observer (293) Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.

Prototype (117) Specify the kinds of objects to create using a prototypical instance, and create new objects by copying this prototype.

Proxy (207) Provide a surrogate or placeholder for another object to control access to it.

Singleton (127) Ensure a class only has one instance, and provide a global point of access to it.

State (305) Allow an object to alter its behavior when its internal state changes. The object will appear to change its class.

Strategy (315) Define a family of algorithms, encapsulate each one, and make them interchangeable. Strategy lets the algorithm vary independently from clients that use it.

Template Method (325) 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.

Visitor (331) 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.

1.5 Organizing the Catalog

Design patterns vary in their granularity and level of abstraction. Because there are many design patterns, we need a way to organize them. This section classifies design patterns so that we can refer to families of related patterns. The classification helps you

Creational Patterns

Abstract Factory (87) Provide an interface for creating families of related or dependent objects without specifying their concrete classes.

Builder (97) Separate the construction of a complex object from its representation so that the same construction process can create different representations.

Factory Method (107) Define an interface for creating an object, but let subclasses decide which class to instantiate. Factory Method lets a class defer instantiation to subclasses.

Prototype (117) Specify the kinds of objects to create using a prototypical instance, and create new objects by copying this prototype.

Singleton (127) Ensure a class only has one instance, and provide a global point of access to it.

Structural Patterns

Adapter (139) Convert the interface of a class into another interface clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces.

Bridge (151) Decouple an abstraction from its implementation so that the two can vary independently.

Composite (163) Compose objects into tree structures to represent part-whole hierarchies. Composite lets clients treat individual objects and compositions of objects uniformly.

Decorator (175) Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.

Facade (185) 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.

Flyweight (195) Use sharing to support large numbers of fine-grained objects efficiently.

Proxy (207) Provide a surrogate or placeholder for another object to control access to it.

Behavioral Patterns

Chain of Responsibility (223) 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.

Command (233) Encapsulate a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations.

Interpreter (243) Given a language, define a represention for its grammar along with an interpreter that uses the representation to interpret sentences in the language.

Iterator (257) Provide a way to access the elements of an aggregate object sequentially without exposing its underlying representation.

Mediator (273) 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.

Memento (283) Without violating encapsulation, capture and externalize an object's internal state so that the object can be restored to this state later.

Observer (293) Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.

State (305) Allow an object to alter its behavior when its internal state changes. The object will appear to change its class.

Strategy (315) Define a family of algorithms, encapsulate each one, and make them interchangeable. Strategy lets the algorithm vary independently from clients that use it.

Template Method (325) 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.

Visitor (331) 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.

OBSERVER

Object Behavioral

Intent

Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.

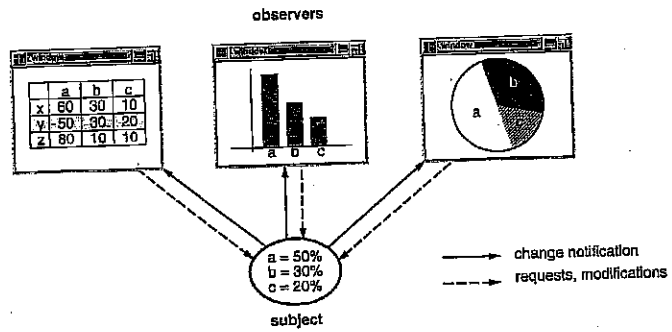
Also Known As

Dependants, Publish-Subscribe

Motivation

A common side-effect of partitioning a system into a collection of cooperating classes is the need to maintain consistency between related objects. You don't want to achieve consistency by making the classes tightly coupled, because that reduces their reusability.

For example, many graphical user interface toolkits separate the presentational aspects of the user interface from the underlying application data [KP88, LVC89, P+88, WGM88]. Classes defining application data and presentations can be reused independently. They can work together, too. Both a spreadsheet object and bar chart object can depict information in the same application data object using different presentations. The spreadsheet and the bar chart don't know about each other, thereby letting you reuse only the one you need. But they *behave* as though they do. When the user changes the information in the spreadsheet, the bar chart reflects the changes immediately, and vice versa.



This behavior implies that the spreadsheet and bar chart are dependent on the data object and therefore should be notified of any change in its state. And there's no reason to limit the number of dependent objects to two; there may be any number of different user interfaces to the same data.

The Observer pattern describes how to establish these relationships. The key objects in this pattern are **subject** and **observer**. A subject may have any number of dependent observers. All observers are notified whenever the subject undergoes a change in state. In response, each observer will query the subject to synchronize its state with the subject's state.

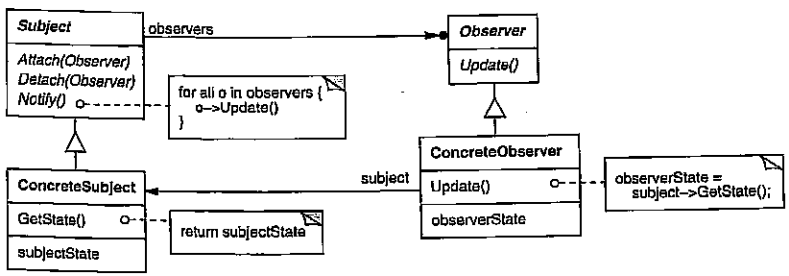
This kind of interaction is also known as **publish-subscribe**. The subject is the publisher of notifications. It sends out these notifications without having to know who its observers are. Any number of observers can subscribe to receive notifications.

pplicability

Use the Observer pattern in any of the following situations:

- When an abstraction has two aspects, one dependent on the other. Encapsulating these aspects in separate objects lets you vary and reuse them independently.
- When a change to one object requires changing others, and you don't know how many objects need to be changed.
- When an object should be able to notify other objects without making assumptions about who these objects are. In other words, you don't want these objects tightly coupled.

:ructure



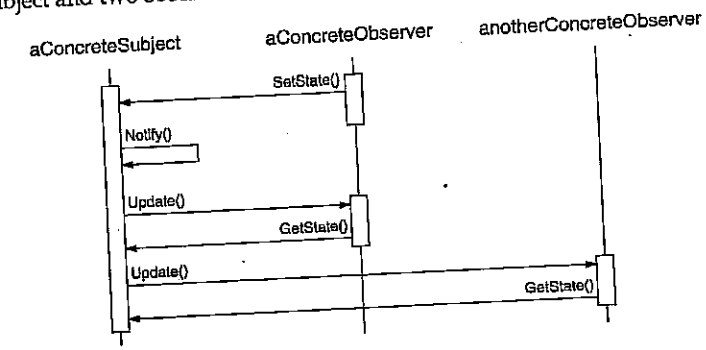
Participants

- **Subject**
  - knows its observers. Any number of Observer objects may observe a subject.
  - provides an interface for attaching and detaching Observer objects.
- **Observer**
  - defines an updating interface for objects that should be notified of changes in a subject.
- **ConcreteSubject**
  - stores state of interest to ConcreteObserver objects.
  - sends a notification to its observers when its state changes.
- **ConcreteObserver**
  - maintains a reference to a ConcreteSubject object.
  - stores state that should stay consistent with the subject's.
  - implements the Observer updating interface to keep its state consistent with the subject's.

Collaborations

- ConcreteSubject notifies its observers whenever a change occurs that could make its observers' state inconsistent with its own.
- After being informed of a change in the concrete subject, a ConcreteObserver object may query the subject for information. ConcreteObserver uses this information to reconcile its state with that of the subject.

The following interaction diagram illustrates the collaborations between a subject and two observers:



Note how the Observer object that initiates the change request postpones its update until it gets a notification from the subject. Notify is not always performed by an observer. It can be performed by the subject or by some other object entirely. The Implementation section discusses some common variations.

nsequences

The Observer pattern lets you vary subjects and observers independently. You can reuse subjects without reusing their observers, and vice versa. It lets you add observers without modifying the subject or other observers.

Further benefits and liabilities of the Observer pattern include the following:

1. *Abstract coupling between Subject and Observer.* All a subject knows is that it has a list of observers, each conforming to the simple interface of the abstract Observer class. The subject doesn't know the concrete class of any observer. Thus the coupling between subjects and observers is abstract and minimal.

   Because Subject and Observer aren't tightly coupled, they can belong to different layers of abstraction in a system. A lower-level subject can communicate and inform a higher-level observer, thereby keeping the system's layering intact. If Subject and Observer are lumped together, then the resulting object must either span two layers (and violate the layering), or it must be forced to live in one layer or the other (which might compromise the layering abstraction).

2. *Support for broadcast communication.* Unlike an ordinary request, the notification that a subject sends needn't specify its receiver. The notification is broadcast automatically to all interested objects that subscribed to it. The subject doesn't care how many interested objects exist; its only responsibility is to notify its observers. This gives you the freedom to add and remove observers at any time. It's up to the observer to handle or ignore a notification.

3. *Unexpected updates.* Because observers have no knowledge of each other's presence, they can be blind to the ultimate cost of changing the subject. A seemingly innocuous operation on the subject may cause a cascade of updates to observers and their dependent objects. Moreover, dependency criteria that aren't well-defined or maintained usually lead to spurious updates, which can be hard to track down.

   This problem is aggravated by the fact that the simple update protocol provides no details on *what* changed in the subject. Without additional protocol to help observers discover what changed, they may be forced to work hard to deduce the changes.

nplementation

Several issues related to the implementation of the dependency mechanism are discussed in this section.

1. *Mapping subjects to their observers.* The simplest way for a subject to keep track of the observers it should notify is to store references to them explicitly in the subject. However, such storage may be too expensive when there are many subjects and few observers. One solution is to trade space for time by using an associative look-up (e.g., a hash table) to maintain the subject-to-observer mapping. Thus a subject with no observers does not incur storage overhead. On the other hand, this approach increases the cost of accessing the observers.

2. *Observing more than one subject.* It might make sense in some situations for an observer to depend on more than one subject. For example, a spreadsheet may depend on more than one data source. It's necessary to extend the Update interface in such cases to let the observer know *which* observer is sending the notification. The subject can simply pass itself as a parameter in the Update operation, thereby letting the observer know which subject to examine.

3. *Who triggers the update?* The subject and its observers rely on the notification mechanism to stay consistent. But what object actually calls Notify to trigger the update? Here are two options:

   (a) Have state-setting operations on Subject call Notify after they change the subject's state. The advantage of this approach is that clients don't have to remember to call Notify on the subject. The disadvantage is that several consecutive operations will cause several consecutive updates, which may be inefficient.

   (b) Make clients responsible for calling Notify at the right time. The advantage here is that the client can wait to trigger the update until after a series of state changes has been made, thereby avoiding needless intermediate updates. The disadvantage is that clients have an added responsibility to trigger the update. That makes errors more likely, since clients might forget to call Notify.

4. *Dangling references to deleted subjects.* Deleting a subject should not produce dangling references in its observers. One way to avoid dangling references is to make the subject notify its observers as it is deleted so that they can reset their reference to it. In general, simply deleting the observers is not an option, because other objects may reference them, or they may be observing other subjects as well.

5. *Making sure Subject state is self-consistent before notification.* It's important to make sure Subject state is self-consistent before calling Notify, because observers query the subject for its current state in the course of updating their own state.

   This self-consistency rule is easy to violate unintentionally when Subject subclass operations call inherited operations. For example, the notification in

the following code sequence is trigged when the subject is in an inconsistent state:

```
void MySubject::Operation (int newValue) {
    BaseClassSubject::Operation(newValue);
        // trigger notification

    _myInstVar += newValue;
        // update subclass state (too late!)
}
```

You can avoid this pitfall by sending notifications from template methods (Template Method (325)) in abstract Subject classes. Define primitive operation for subclasses to override, and make Notify the last operation in the template method, which will ensure that the object is self-consistent when subclasses override Subject operations.

```
void Text::Cut (TextRange r) {
     ReplaceRange(r);        // redefined in subclasses
     Notify();
}
```

By the way, it's always a good idea to document which Subject operations trigger notifications.

6. *Avoiding observer-specific update protocols: the push and pull models.* Implementations of the Observer pattern often have the subject broadcast additional information about the change. The subject passes this information as an argument to Update. The amount of information may vary widely.

   At one extreme, which we call the **push model**, the subject sends observers detailed information about the change, whether they want it or not. At the other extreme is the **pull model**; the subject sends nothing but the most minimal notification, and observers ask for details explicitly thereafter.

   The pull model emphasizes the subject's ignorance of its observers, whereas the push model assumes subjects know something about their observers' needs. The push model might make observers less reusable, because Subject classes make assumptions about Observer classes that might not always be true. On the other hand, the pull model may be inefficient, because Observer classes must ascertain what changed without help from the Subject.

7. *Specifying modifications of interest explicitly.* You can improve update efficiency by extending the subject's registration interface to allow registering observers only for specific events of interest. When such an event occurs, the subject informs only those observers that have registered interest in that event. Digitalk Smalltalk supports this with the notion of **aspects** for Model (i.e., Subject) objects. To register interest in particular events, View objects (i.e., observers) send an

```
add: self interestIn: anAspect
```


message to their models, where `anAspect` specifies the event of interest. At notification time, the subject supplies the changed aspect to its observers as a parameter to the Update operation. For example:

```
observer update: theChangedAspect
```

8. *Encapsulating complex update semantics.* When the dependency relationship between subjects and observers is particularly complex, an object that maintains these relationships might be required. We call such an object a **ChangeManager**. Its purpose is to minimize the work required to make observers reflect a change in their subject. For example, if an operation involves changes to several interdependent subjects, you might have to ensure that their observers are notified only after *all* the subjects have been modified to avoid notifying observers more than once.

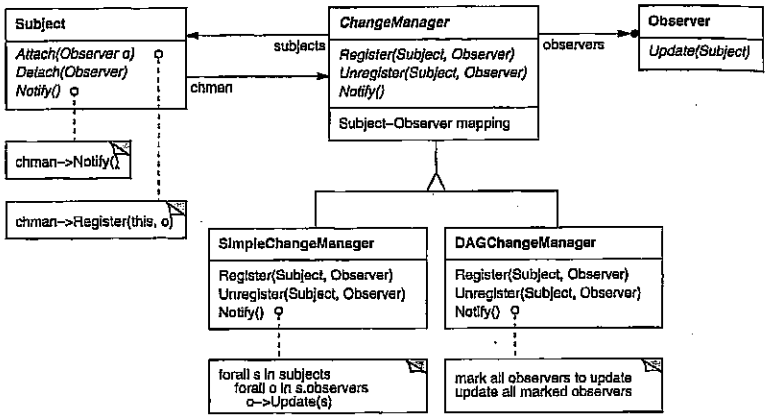
   ChangeManager has three responsibilities:

   (a) It maps a subject to its observers and provides an interface to maintain this mapping. This eliminates the need for subjects to maintain references to their observers and vice versa.

   (b) It defines a particular update strategy.

   (c) It updates all dependent observers at the request of a subject.

   The following diagram depicts a simple ChangeManager-based implementation of the Observer pattern. There are two specialized ChangeManagers. SimpleChangeManager is naive in that it always updates all observers of each subject. In contrast, DAGChangeManager handles directed-acyclic graphs of dependencies between subjects and their observers. A DAGChangeManager is preferable to a SimpleChangeManager when an observer observes more than one subject. In that case, a change in two or more subjects might cause redundant updates. The DAGChangeManager ensures the observer receives just one update. SimpleChangeManager is fine when multiple updates aren't an issue.



ChangeManager is an instance of the Mediator (273) pattern. In general there is only one ChangeManager, and it is known globally. The Singleton pattern (127) would be useful here.

9. *Combining the Subject and Observer classes.* Class libraries written in languages that lack multiple inheritance (like Smalltalk) generally don't define separate Subject and Observer classes but combine their interfaces in one class. That lets you define an object that acts as both a subject and an observer without multiple inheritance. In Smalltalk, for example, the Subject and Observer interfaces are defined in the root class Object, making them available to all classes.

mple Code

An abstract class defines the Observer interface:

```
class Subject;

class Observer {
public:
    virtual ~Observer();
    virtual void Update(Subject* theChangedSubject) = 0;
protected:
    Observer();
};
```

This implementation supports multiple subjects for each observer. The subject passed to the `Update` operation lets the observer determine which subject changed when it observes more than one.

Similarly, an abstract class defines the Subject interface:


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

    virtual void Attach(Observer*);
    virtual void Detach(Observer*);
    virtual void Notify();
protected:
    Subject();
private:
    List<Observer*> *_observers;
};

void Subject::Attach (Observer* o) {
    _observers->Append(o);
}

void Subject::Detach (Observer* o) {
    _observers->Remove(o);
}

void Subject::Notify () {
    ListIterator<Observer*> i(_observers);

    for (i.First(); !i.IsDone(); i.Next()) {
        i.CurrentItem()->Update(this);
    }
}
```

`ClockTimer` is a concrete subject for storing and maintaining the time of day. It notifies its observers every second. `ClockTimer` provides the interface for retrieving individual time units such as the hour, minute, and second.

```
class ClockTimer : public Subject {
public:
    ClockTimer();

    virtual int GetHour();
    virtual int GetMinute();
    virtual int GetSecond();

    void Tick();
};
```

The `Tick` operation gets called by an internal timer at regular intervals to provide an accurate time base. `Tick` updates the `ClockTimer`'s internal state and calls `Notify` to inform observers of the change:

```
void ClockTimer::Tick () {
    // update internal time-keeping state
    // ...
    Notify();
}
```

Now we can define a class `DigitalClock` that displays the time. It inherits its graphical functionality from a `Widget` class provided by a user interface toolkit. The Observer interface is mixed into the `DigitalClock` interface by inheriting from `Observer`.

```
class DigitalClock: public Widget, public Observer {
public:
    DigitalClock(ClockTimer*);
    virtual ~DigitalClock();

    virtual void Update(Subject*);
        // overrides Observer operation

    virtual void Draw();
        // overrides Widget operation;
        // defines how to draw the digital clock
private:
    ClockTimer* _subject;
};

DigitalClock::DigitalClock (ClockTimer* s) {
    _subject = s;
    _subject->Attach(this);
}

DigitalClock::~DigitalClock () {
    _subject->Detach(this);
}
```

Before the `Update` operation draws the clock face, it checks to make sure the notifying subject is the clock's subject:

```
void DigitalClock::Update (Subject* theChangedSubject) {
    if (theChangedSubject == _subject) {
        Draw();
    }
}

void DigitalClock::Draw () {
    // get the new values from the subject

    int hour = _subject->GetHour();
    int minute = _subject->GetMinute();
    // etc.

    // draw the digital clock
}
```

An `AnalogClock` class can be defined in the same way.


```
class AnalogClock : public Widget, public Observer {
public:
    AnalogClock(ClockTimer*);
    virtual void Update(Subject*);
    virtual void Draw();
    // ...
};
```

The following code creates an `AnalogClock` and a `DigitalClock` that always show the same time:

```
ClockTimer* timer = new ClockTimer;
AnalogClock* analogClock = new AnalogClock(timer);
DigitalClock* digitalClock = new DigitalClock(timer);
```

Whenever the `timer` ticks, the two clocks will be updated and will redisplay themselves appropriately.

Known Uses

The first and perhaps best-known example of the Observer pattern appears in Smalltalk Model/View/Controller (MVC), the user interface framework in the Smalltalk environment [KP88]. MVC's Model class plays the role of Subject, while View is the base class for observers. Smalltalk, ET++ [WGM88], and the THINK class library [Sym93b] provide a general dependency mechanism by putting Subject and Observer interfaces in the parent class for all other classes in the system.

Other user interface toolkits that employ this pattern are InterViews [LVC89], the Andrew Toolkit [P+88], and Unidraw [VL90]. InterViews defines Observer and Observable (for subjects) classes explicitly. Andrew calls them "view" and "data object," respectively. Unidraw splits graphical editor objects into View (for observers) and Subject parts.

Related Patterns

Mediator (273): By encapsulating complex update semantics, the ChangeManager acts as mediator between subjects and observers.

Singleton (127): The ChangeManager may use the Singleton pattern to make it unique and globally accessible.

MEDIATOR

Object Behavioral

Intent

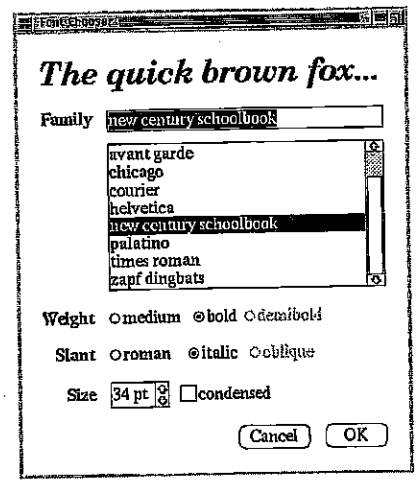
Define an object that encapsulates how a set of objects interact. Mediator promotes loose coupling by keeping objects from referring to each other explicitly, and it lets you vary their interaction independently.

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, as shown here:

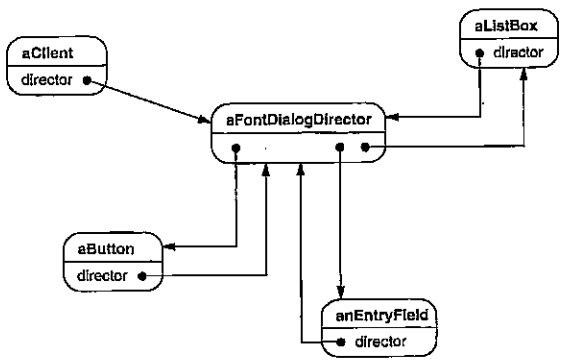


Often there are dependencies between the widgets in the dialog. For example, a button gets disabled when a certain entry field is empty. Selecting an entry in a list of choices called a **list box** might change the contents of an entry field. Conversely, typing text into the entry field might automatically select one or more corresponding entries in the list box. Once text appears in the entry field, other buttons may become enabled that let the user do something with the text, such as changing or deleting the thing to which it refers.

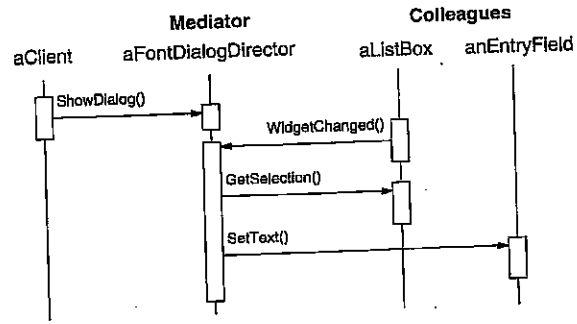
Different dialog boxes will have different dependencies between widgets. So even though dialogs display the same kinds of widgets, they can't simply reuse stock widget classes; they have to be customized to reflect dialog-specific dependencies. Customizing them individually by subclassing will be tedious, since many classes are involved.

You can avoid these problems by encapsulating collective behavior in a separate **mediator** object. A mediator is responsible for controlling and coordinating the interactions of a group of objects. The mediator serves as an intermediary that keeps objects in the group from referring to each other explicitly. The objects only know the mediator, thereby reducing the number of interconnections.

For example, **FontDialogDirector** can be the mediator between the widgets in a dialog box. A FontDialogDirector object knows the widgets in a dialog and coordinates their interaction. It acts as a hub of communication for widgets:



The following interaction diagram illustrates how the objects cooperate to handle a change in a list box's selection:

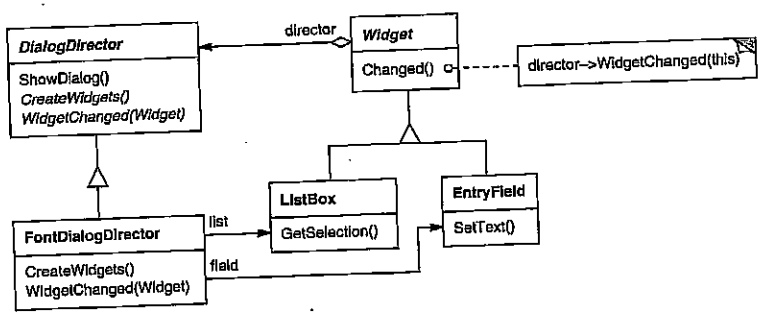


Here's the succession of events by which a list box's selection passes to an entry field:

1. The list box tells its director that it's changed.
2. The director gets the selection from the list box.
3. The director passes the selection to the entry field.
4. Now that the entry field contains some text, the director enables button(s) for initiating an action (e.g., "demibold," "oblique").

Note how the director mediates between the list box and the entry field. Widgets communicate with each other only indirectly, through the director. They don't have to know about each other; all they know is the director. Furthermore, because the behavior is localized in one class, it can be changed or replaced by extending or replacing that class.

Here's how the FontDialogDirector abstraction can be integrated into a class library:



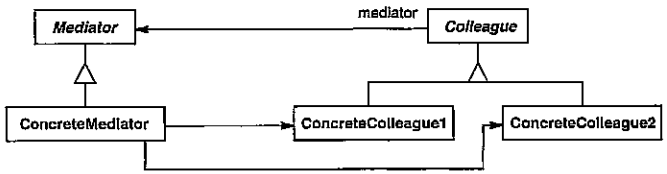
DialogDirector is an abstract class that defines the overall behavior of a dialog. Clients call the ShowDialog operation to display the dialog on the screen. CreateWidgets is an abstract operation for creating the widgets of a dialog. WidgetChanged is another abstract operation; widgets call it to inform their director that they have changed. DialogDirector subclasses override CreateWidgets to create the proper widgets, and they override WidgetChanged to handle the changes.

ɔplicability

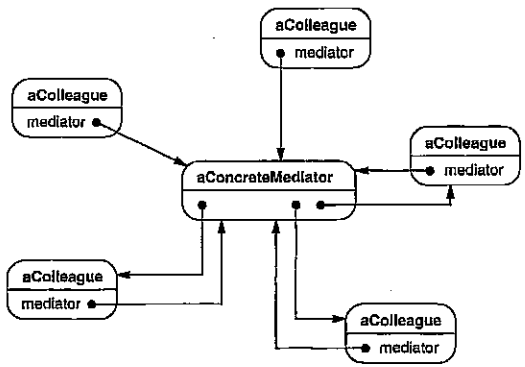
Use the Mediator pattern when

- 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.

ɪucture



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.

nplementation

The following implementation issues are relevant to the Mediator pattern:

1. *Omitting the abstract Mediator class.* There's no need to define an abstract Mediator class when colleagues work with only one mediator. The abstract coupling that the Mediator class provides lets colleagues work with different Mediator subclasses, and vice versa.
2. *Colleague-Mediator communication.* Colleagues have to communicate with their mediator when an event of interest occurs. One approach is to implement the Mediator as an Observer using the Observer (293) pattern. Colleague classes act as Subjects, sending notifications to the mediator whenever they change state. The mediator responds by propagating the effects of the change to other colleagues.

   Another approach defines a specialized notification interface in Mediator that lets colleagues be more direct in their communication. Smalltalk/V for Windows uses a form of delegation: When communicating with the mediator, a colleague passes itself as an argument, allowing the mediator to identify the sender. The Sample Code uses this approach, and the Smalltalk/V implementation is discussed further in the Known Uses.

mple Code

We'll use a DialogDirector to implement the font dialog box shown in the Motivation. The abstract class `DialogDirector` defines the interface for directors.

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

    virtual void ShowDialog();
    virtual void WidgetChanged(Widget*) = 0;

protected:
    DialogDirector();
    virtual void CreateWidgets() = 0;
};
```

`Widget` is the abstract base class for widgets. A widget knows its director.

```
class Widget {
public:
    Widget(DialogDirector*);
    virtual void Changed();

    virtual void HandleMouse(MouseEvent& event);
    // ...
private:
    DialogDirector* _director;
};
```


`Changed` calls the director's `WidgetChanged` operation. Widgets call `WidgetChanged` on their director to inform it of a significant event.

```
void Widget::Changed () {
    _director->WidgetChanged(this);
}
```

Subclasses of `DialogDirector` override `WidgetChanged` to affect the appropriate widgets. The widget passes a reference to itself as an argument to `WidgetChanged` to let the director identify the widget that changed. `DialogDirector` subclasses redefine the `CreateWidgets` pure virtual to construct the widgets in the dialog.

The `ListBox`, `EntryField`, and `Button` are subclasses of `Widget` for specialized user interface elements. `ListBox` provides a `GetSelection` operation to get the current selection, and `EntryField`'s `SetText` operation puts new text into the field.

```
class ListBox : public Widget {
public:
    ListBox(DialogDirector*);

    virtual const char* GetSelection();
    virtual void SetList(List<char*>* listItems);
    virtual void HandleMouse(MouseEvent& event);
    // ...
};

class EntryField : public Widget {
public:
    EntryField(DialogDirector*);

    virtual void SetText(const char* text);
    virtual const char* GetText();
    virtual void HandleMouse(MouseEvent& event);
    // ...
};
```

`Button` is a simple widget that calls `Changed` whenever it's pressed. This gets done in its implementation of `HandleMouse`:

```
class Button : public Widget {
public:
    Button(DialogDirector*);

    virtual void SetText(const char* text);
    virtual void HandleMouse(MouseEvent& event);
    // ...
};
```

```
void Button::HandleMouse (MouseEvent& event) {
    // ...
    Changed();
}
```

The `FontDialogDirector` class mediates between widgets in the dialog box. `FontDialogDirector` is a subclass of `DialogDirector`:

```
class FontDialogDirector : public DialogDirector {
public:
    FontDialogDirector();
    virtual ~FontDialogDirector();
    virtual void WidgetChanged(Widget*);

protected:
    virtual void CreateWidgets();

private:
    Button* _ok;
    Button* _cancel;
    ListBox* _fontList;
    EntryField* _fontName;
};
```

`FontDialogDirector` keeps track of the widgets it displays. It redefines `CreateWidgets` to create the widgets and initialize its references to them:

```
void FontDialogDirector::CreateWidgets () {
    _ok = new Button(this);
    _cancel = new Button(this);
    _fontList = new ListBox(this);
    _fontName = new EntryField(this);

    // fill the listBox with the available font names

    // assemble the widgets in the dialog
}
```

`WidgetChanged` ensures that the widgets work together properly:

```
void FontDialogDirector::WidgetChanged (
    Widget* theChangedWidget
) {
    if (theChangedWidget == _fontList) {
        _fontName->SetText(_fontList->GetSelection());

    } else if (theChangedWidget == _ok) {
        // apply font change and dismiss dialog
        // ...
    } else if (theChangedWidget == _cancel) {
        // dismiss dialog
    }
}
```

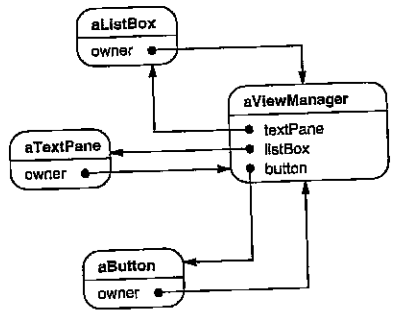

The complexity of `WidgetChanged` increases proportionally with the complexity of the dialog. Large dialogs are undesirable for other reasons, of course, but mediator complexity might mitigate the pattern's benefits in other applications.

Known Uses

Both ET++ [WGM88] and the THINK C class library [Sym93b] use director-like objects in dialogs as mediators between widgets.

The application architecture of Smalltalk/V for Windows is based on a mediator structure [LaL94]. In that environment, an application consists of a Window containing a set of panes. The library contains several predefined Pane objects; examples include TextPane, ListBox, Button, and so on. These panes can be used without subclassing. An application developer only subclasses from ViewManager, a class that's responsible for doing inter-pane coordination. ViewManager is the Mediator, and each pane only knows its view manager, which is considered the "owner" of the pane. Panes don't refer to each other directly.

The following object diagram shows a snapshot of an application at run-time:



Smalltalk/V uses an event mechanism for Pane-ViewManager communication. A pane generates an event when it wants to get information from the mediator or when it wants to inform the mediator that something significant happened. An event defines a symbol (e.g., `#select`) that identifies the event. To handle the event, the view manager registers a method selector with the pane. This selector is the event's handler; it will be invoked whenever the event occurs.

The following code excerpt shows how a ListPane object gets created inside a ViewManager subclass and how ViewManager registers an event handler for the `#select` event:

```
self addSubpane: (ListPane new
    paneName: 'myListPane';
    owner: self;
    when: #select perform: #listSelect:).
```

Another application of the Mediator pattern is in coordinating complex updates. An example is the ChangeManager class mentioned in Observer (293). ChangeManager mediates between subjects and observers to avoid redundant updates. When an object changes, it notifies the ChangeManager, which in turn coordinates the update by notifying the object's dependents.

A similar application appears in the Unidraw drawing framework [VL90] and uses a class called CSolver to enforce connectivity constraints between "connectors." Objects in graphical editors can appear to stick to one another in different ways. Connectors are useful in applications that maintain connectivity automatically, like diagram editors and circuit design systems. CSolver is a mediator between connectors. It solves the connectivity constraints and updates the connectors' positions to reflect them.

Related Patterns

Facade (185) differs from Mediator in that it abstracts a subsystem of objects to provide a more convenient interface. Its protocol is unidirectional; that is, Facade objects make requests of the subsystem classes but not vice versa. In contrast, Mediator enables cooperative behavior that colleague objects don't or can't provide, and the protocol is multidirectional.

Colleagues can communicate with the mediator using the Observer (293) pattern.

VISITOR

Object Behavioral

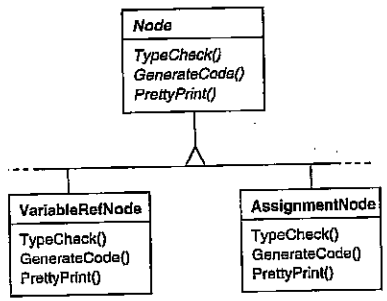
Intent

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.



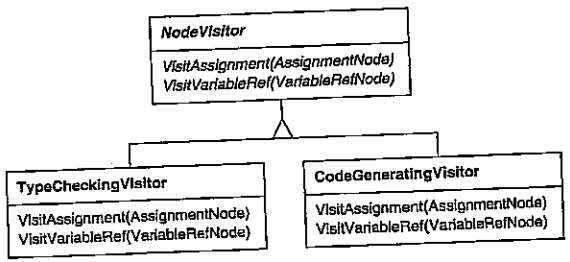
This diagram shows part of the Node class hierarchy. The problem here is that distributing all these operations across the various node classes leads to a system that's hard to understand, maintain, and change. It will be confusing to have type-checking code mixed with pretty-printing code or flow analysis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

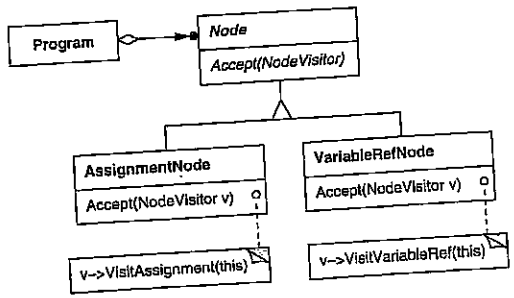
be better if each new operation could be added separately, and the node classes were independent of the operations that apply to them.

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.





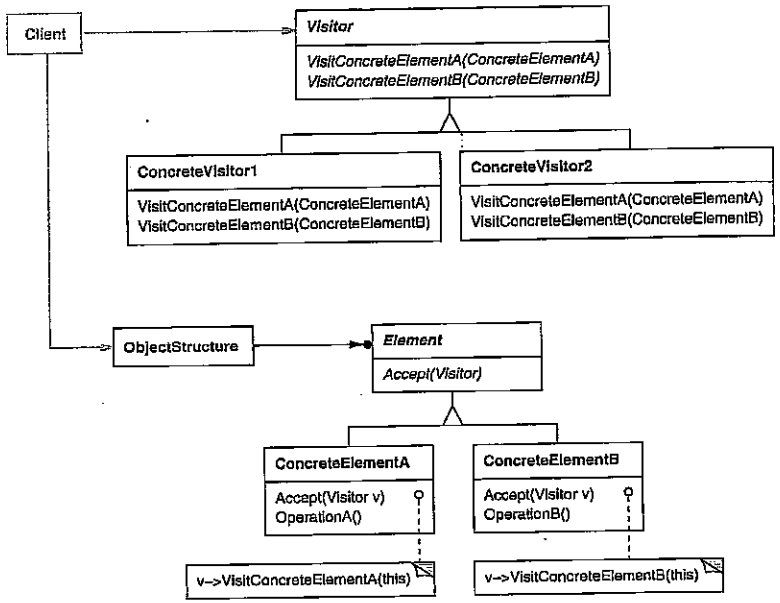
With the Visitor pattern, you define two class hierarchies: one for the elements being operated on (the Node hierarchy) and one for the visitors that define operations on the elements (the NodeVisitor hierarchy). You create a new operation by adding a new subclass in the visitors class hierarchy. As 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.

ructure



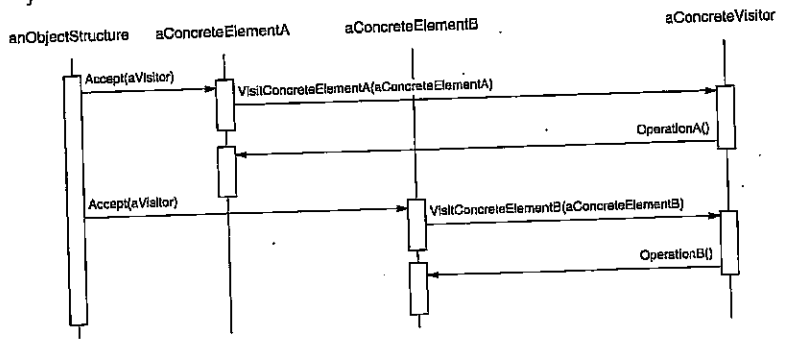
ırticipants

- **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.

5. *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.

6. *Breaking encapsulation.* Visitor's approach assumes that the Element 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.

Implementation

Each object structure will have an associated Visitor class. This abstract visitor class declares a VisitConcreteElement operation for each class of ConcreteElement defining the object structure. Each Visit operation on the Visitor declares its argument to be a particular ConcreteElement, allowing the Visitor to access the interface of the ConcreteElement directly. ConcreteVisitor classes override each Visit operation to implement visitor-specific behavior for the corresponding ConcreteElement class.

The Visitor class would be declared like this in C++:

```
class Visitor {
public:
    virtual void VisitElementA(ElementA*);
    virtual void VisitElementB(ElementB*);

    // and so on for other concrete elements
protected:
    Visitor();
};
```

Each class of ConcreteElement implements an `Accept` operation that calls the matching `Visit...` operation on the visitor for that ConcreteElement. Thus the operation that ends up getting called depends on both the class of the element and the class of the visitor.[10]

The concrete elements are declared as

```
class Element {
public:
    virtual ~Element();
    virtual void Accept(Visitor&) = 0;
protected:
    Element();
};
```

[10] We could use function overloading to give these operations the same simple name, like `Visit`, since the operations are already differentiated by the parameter they're passed. There are pros and cons to such overloading. On the one hand, it reinforces the fact that each operation involves the same analysis, albeit on a different argument. On the other hand, that might make what's going on at the call site less obvious to someone reading the code. It really boils down to whether you believe function overloading is good or not.

```
class ElementA : public Element {
public:
    ElementA();
    virtual void Accept(Visitor& v) { v.VisitElementA(this); }
};

class ElementB : public Element {
public:
    ElementB();
    virtual void Accept(Visitor& v) { v.VisitElementB(this); }
};
```

A `CompositeElement` class might implement `Accept` like this:

```
class CompositeElement : public Element {
public:
    virtual void Accept(Visitor&);
private:
    List<Element*>* _children;
};

void CompositeElement::Accept (Visitor& v) {
    ListIterator<Element*> i(_children);

    for (i.First(); !i.IsDone(); i.Next()) {
        i.CurrentItem()->Accept(v);
    }
    v.VisitCompositeElement(this);
}
```

Here are two other implementation issues that arise when you apply the Visitor pattern:

1. *Double dispatch.* Effectively, the Visitor pattern lets you add operations to classes without changing them. Visitor achieves this by using a technique called **double-dispatch**. It's a well-known technique. In fact, some programming languages support it directly (CLOS, for example). Languages like C++ and Smalltalk support **single-dispatch**.

   In single-dispatch languages, two criteria determine which operation will fulfill a request: the name of the request and the type of receiver. For example, the operation that a GenerateCode request will call depends on the type of node object you ask. In C++, calling `GenerateCode` on an instance of `VariableRefNode` will call `VariableRefNode::GenerateCode` (which generates code for a variable reference). Calling `GenerateCode` on a `AssignmentNode` will call `AssignmentNode::GenerateCode` (which will generate code for an assignment). The operation that gets executed depends both on the kind of request and the type of the receiver.

   "Double-dispatch" simply means the operation that gets executed depends on the kind of request and the types of *two* receivers. `Accept` is a double-dispatch operation. Its meaning depends on two types: the Visitor's and the Element's. Double-dispatching lets visitors request different operations on each class of element.[11]

   This is the key to the Visitor pattern: The operation that gets executed depends on both the type of Visitor and the type of Element it visits. Instead of binding operations statically into the Element interface, you can consolidate the operations in a Visitor and use `Accept` to do the binding at run-time. Extending the Element interface amounts to defining one new Visitor subclass rather many new Element subclass classes.

2. *Who is responsible for traversing the object structure?* A visitor must visit each element of the object structure. The question is, how does it get there? We can put responsibility for traversal in any of three places: in the object structure, in the visitor, or in a separate iterator object (see Iterator (257)).

   Often the object structure is responsible for iteration. A collection will simply iterate over its elements, calling the Accept operation on each. A composite will commonly traverse itself by having each Accept operation traverse the element's children and call Accept on each of them recursively.

   Another solution is to use an iterator to visit the elements. In C++, you could use either an internal or external iterator, depending on what is available and what is most efficient. In Smalltalk, you usually use an internal iterator using `do:` and a block. Since internal iterators are implemented by the object structure, using an internal iterator is a lot like making the object structure responsible for iteration. The main difference is that an internal iterator will not cause double-dispatching—it will call an operation on the *visitor* with an *element* as an argument as opposed to calling an operation on the *element* with the *visitor* as an argument. But it's easy to use the Visitor pattern with an internal iterator if the operation on the visitor simply calls the operation on the element without recursing.

   You could even put the traversal algorithm in the visitor, although you'll end up duplicating the traversal code in each ConcreteVisitor for each aggregate ConcreteElement. The main reason to put the traversal strategy in the visitor is to implement a particularly complex traversal, one that depends on the results of the operations on the object structure. We'll give an example of such a case in the Sample Code.

Sample Code

Because visitors are usually associated with composites, we'll use the `Equipment` classes defined in the Sample Code of Composite (163) to illustrate the Visitor pattern. We will use Visitor to define operations for computing the inventory of materials and the total cost for a piece of equipment. The `Equipment` classes are

[11] If we can have *double*-dispatch, then why not *triple* or *quadruple*, or any other number? Actually, double-dispatch is just a special case of **multiple dispatch**, in which the operation is chosen based on any number of types. (CLOS actually supports multiple dispatch.) Languages that support double- or multiple dispatch lessen the need for the Visitor pattern.

so simple that using Visitor isn't really necessary, but they make it easy to see what's involved in implementing the pattern.

Here again is the `Equipment` class from Composite (163). We've augmented it with an `Accept` operation to let it work with a visitor.

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

    const char* Name() { return _name; }

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

    virtual void Accept(EquipmentVisitor&);
protected:
    Equipment(const char*);
private:
    const char* _name;
};
```

The `Equipment` operations return the attributes of a piece of equipment, such as its power consumption and cost. Subclasses redefine these operations appropriately for specific types of equipment (e.g., a chassis, drives, and planar boards).

The abstract class for all visitors of equipment has a virtual function for each subclass of equipment, as shown next. All of the virtual functions do nothing by default.

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

    virtual void VisitFloppyDisk(FloppyDisk*);
    virtual void VisitCard(Card*);
    virtual void VisitChassis(Chassis*);
    virtual void VisitBus(Bus*);

    // and so on for other concrete subclasses of Equipment
protected:
    EquipmentVisitor();
};
```

`Equipment` subclasses define `Accept` in basically the same way: It calls the `EquipmentVisitor` operation that corresponds to the class that received the `Accept` request, like this:

```
void FloppyDisk::Accept (EquipmentVisitor& visitor) {
   visitor.VisitFloppyDisk(this);
}
```


Equipment that contains other equipment (in particular, subclasses of `CompositeEquipment` in the Composite pattern) implements `Accept` by iterating over their children and calling `Accept` on each of them. They then call the `Visit` operation on themselves. For example, `Chassis::Accept` could traverse all the parts in the chassis as follows:

```
void Chassis::Accept (EquipmentVisitor& visitor) {
    for (
        ListIterator<Equipment*> i(_parts);
        !i.IsDone();
        i.Next()
    ) {
        i.CurrentItem()->Accept(visitor);
    }
    visitor.VisitChassis(this);
}
```

Subclasses of `EquipmentVisitor` define particular algorithms over the equipment structure. The `PricingVisitor` computes the cost of the equipment structure. It computes the net price of all simple equipment (e.g., floppies) and the discount price of all composite equipment (e.g., chassis and buses).

```
class PricingVisitor : public EquipmentVisitor {
public:
    PricingVisitor();

    Currency& GetTotalPrice();

    virtual void VisitFloppyDisk(FloppyDisk*);
    virtual void VisitCard(Card*);
    virtual void VisitChassis(Chassis*);
    virtual void VisitBus(Bus*);
    // ...
private:
    Currency _total;
};

void PricingVisitor::VisitFloppyDisk (FloppyDisk* e) {
    _total += e->NetPrice();
}

void PricingVisitor::VisitChassis (Chassis* e) {
    _total += e->DiscountPrice();
}
```

`PricingVisitor` will compute the total cost of all nodes in the equipment structure. Note that `PricingVisitor` chooses the appropriate pricing policy for a class of equipment by dispatching to the corresponding member function. What's more, we can change the pricing policy of an equipment structure just by changing the `PricingVisitor` class.

We can define a visitor for computing inventory like this:

```
class InventoryVisitor : public EquipmentVisitor {
public:
    InventoryVisitor();

    Inventory& GetInventory();

    virtual void VisitFloppyDisk(FloppyDisk*);
    virtual void VisitCard(Card*);
    virtual void VisitChassis(Chassis*);
    virtual void VisitBus(Bus*);
    // ...

private:
    Inventory _inventory;
};
```

The `InventoryVisitor` accumulates the totals for each type of equipment in the object structure. `InventoryVisitor` uses an `Inventory` class that defines an interface for adding equipment (which we won't bother defining here).

```
void InventoryVisitor::VisitFloppyDisk (FloppyDisk* e) {
    _inventory.Accumulate(e);
}

void InventoryVisitor::VisitChassis (Chassis* e) {
    _inventory.Accumulate(e);
}
```

Here's how we can use an `InventoryVisitor` on an equipment structure:

```
Equipment* component;
InventoryVisitor visitor;

component->Accept(visitor);
cout << "Inventory "
     << component->Name()
     << visitor.GetInventory();
```

Now we'll show how to implement the Smalltalk example from the Interpreter pattern (see page 248) with the Visitor pattern. Like the previous example, this one is so small that Visitor probably won't buy us much, but it provides a good illustration of how to use the pattern. Further, it illustrates a situation in which iteration is the visitor's responsibility.

The object structure (regular expressions) is made of four classes, and all of them have an `accept:` method that takes the visitor as an argument. In class `SequenceExpression`, the `accept:` method is


```
accept: aVisitor
    ^ aVisitor visitSequence: self
```

In class `RepeatExpression`, the `accept:` method sends the `visitRepeat:` message. In class `AlternationExpression`, it sends the `visitAlternation:` message. In class `LiteralExpression`, it sends the `visitLiteral:` message.

The four classes also must have accessing functions that the visitor can use. For `SequenceExpression` these are `expression1` and `expression2`; for `AlternationExpression` these are `alternative1` and `alternative2`; for `RepeatExpression` it is `repetition`; and for `LiteralExpression` these are `components`.

The ConcreteVisitor class is `REMatchingVisitor`. It is responsible for the traversal because its traversal algorithm is irregular. The biggest irregularity is that a `RepeatExpression` will repeatedly traverse its component. The class `REMatchingVisitor` has an instance variable `inputState`. Its methods are essentially the same as the `match:` methods of the expression classes in the Interpreter pattern except they replace the argument named `inputState` with the expression node being matched. However, they still return the set of streams that the expression would match to identify the current state.

```
visitSequence: sequenceExp
    inputState := sequenceExp expression1 accept: self.
    ^ sequenceExp expression2 accept: self.

visitRepeat: repeatExp
    | finalState |
    finalState := inputState copy.
    [inputState isEmpty]
        whileFalse:
            [inputState := repeatExp repetition accept: self.
            finalState addAll: inputState].
    ^ finalState

visitAlternation: alternateExp
    | finalState originalState |
    originalState := inputState.
    finalState := alternateExp alternative1 accept: self.
    inputState := originalState.
    finalState addAll: (alternateExp alternative2 accept: self).
    ^ finalState
```

```
visitLiteral: literalExp
    | finalState tStream |
    finalState := Set new.
    inputState
        do:
            [:stream | tStream := stream copy.
                (tStream nextAvailable:
                    literalExp components size
                ) = literalExp components
                    ifTrue: [finalState add: tStream]
            ].
    ^ finalState
```

Known Uses

The Smalltalk-80 compiler has a Visitor class called ProgramNodeEnumerator. It's used primarily for algorithms that analyze source code. It isn't used for code generation or pretty-printing, although it could be.

IRIS Inventor [Str93] is a toolkit for developing 3-D graphics applications. Inventor represents a three-dimensional scene as a hierarchy of nodes, each representing either a geometric object or an attribute of one. Operations like rendering a scene or mapping an input event require traversing this hierarchy in different ways. Inventor does this using visitors called "actions." There are different visitors for rendering, event handling, searching, filing, and determining bounding boxes.

To make adding new nodes easier, Inventor implements a double-dispatch scheme for C++. The scheme relies on run-time type information and a two-dimensional table in which rows represent visitors and columns represent node classes. The cells store a pointer to the function bound to the visitor and node class.

Mark Linton coined the term "Visitor" in the X Consortium's Fresco Application Toolkit specification [LP93].

Related Patterns

Composite (163): Visitors can be used to apply an operation over an object structure defined by the Composite pattern.

Interpreter (243): Visitor may be applied to do the interpretation.