# Design Patterns in C++

## Behavioural Patterns

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# What are Behavioural Patterns

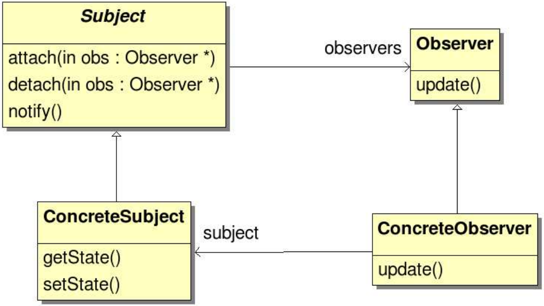
- Behavioural patterns describe patterns of message communications between objects
- Therefore, they are concerned with *algorithms*, rather than with *structures*
  - Of course, behavioural patterns are strictly related to structural patterns
- Key observation: how the objects know about each other?
- Main goal: *decouple* objects from each other to allow a dynamic and flexible configurations of algorithms and methods

# Outline

# Motivation

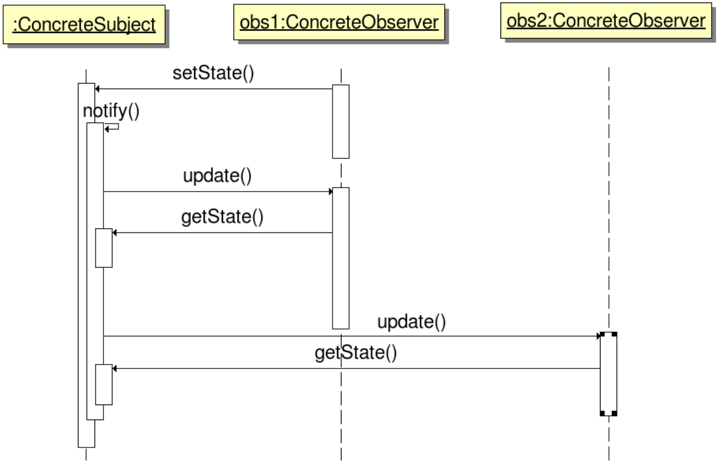
- We need to maintain consistency among (weakly-)related object
    - When something happens to an object, other objects must be informed
- Typical example in GUIs
    - The Document object must be informed when a button “Print” is clicked, so that the print() operation can be invoked
    - The ViewPort object must be informed when the window is resized(), so that it can adjust the visualization of the objects
    - We have already presented an example when presenting the Adapter pattern: an object can “listen” to other objects changes
- Participants:
    - An object changes its state (subject)
    - Another object wants to be informed (observer)

# UML Diagram




- Subject is the interface for something to to be observed
- Observer is thing that observes

# Message sequence chart



# Example

- The user resizes a window:
  - every component of the window needs to be informed of a resize operation (viewport, scrollbars, toolbars, etc.)
  - in this way, every object can synchronize its state with the new window size
- Solution:
  - The window can install *observers*
  - All components (viewport, scrollbar, etc.) can attach an observer to the main window that is informed when a resize operation is under way
  - The observer asks for the current size of the window, and invoke methods on the objects to adjust their state (size)

## Consequences

- **Abstract coupling** between subject and observer
  - all that a subject knows is that there is a list of observers, but it does not know anything about the observers themselves
  - the observer instead must know the subjects
- **Broadcast communication**
  - There can be many independent observers, with different purposes and hierarchies
  - *Example*: resizing a window can affect the viewports inside the window, the scrollbars, etc.

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- **Broadcast communication**
  - There can be many independent observers, with different purposes and hierarchies
  - *Example*: resizing a window can affect the viewports inside the window, the scrollbars, etc.
- **Unexpected updates**
  - A seemingly innocuous operation on the subject may cause a cascade of updates on the observers and their dependent objects, many of them may not care about any update
  - This simple protocol does not tell the observer *what* change happened to the subject (a resize? a move?)

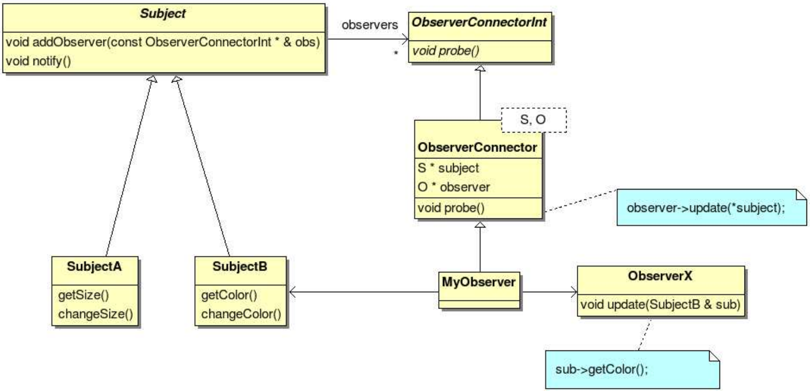
# Update problems

- **Pull model**
  - the subject sends nothing
  - the observer askes for details about the changes
  - equivalent to what we have already seen
- **Push model**
  - the subject sends the observer detailed information about the change (whether it wants it or not)
  - the observer can understand if he is interested in the change by analysing this additional parameter
- **Specifying events**
  - By complicating the protocol, it is possible to register to specific aspects
    - onResize()
    - onMove(),
    - ...
  - more efficient, but more complex interface

# Extensions

- It is possible to efficiently and effectively use templates for extending as much as possible to usage of the observer pattern
- the first extension we consider is to have an observer that wants to observe different subjects
  - however, in the standard patterns, only one subject is possible
  - we could have different pointers inside the ConcreteObserver class, however the update takes no parameter
  - to understand which subject has changed, we need to pass a parameter to the update
  - we could pass a simple integer, 0 meaning the first subject, 1 the second subject, and so on
  - however, the subject must know its number for the specific observer; and the observer has to implement a switch case
  - not very scalable
- My solution is to use one more class, that *connects* subject with observer

# UML diagram




- See the code in observer example

# Outline

# Motivation

- Consider a context-sensitive “help” for a GUI
  - the user can click on any part of the interface and obtain help on it
- The help that is actually provided depends on
  - which part of the interface (button, menu, etc.)
  - the context (where the button is)
- Example:
  - a button in a dialog box
  - a button in the main window
- If no help can be found for that part, a more general help page is shown

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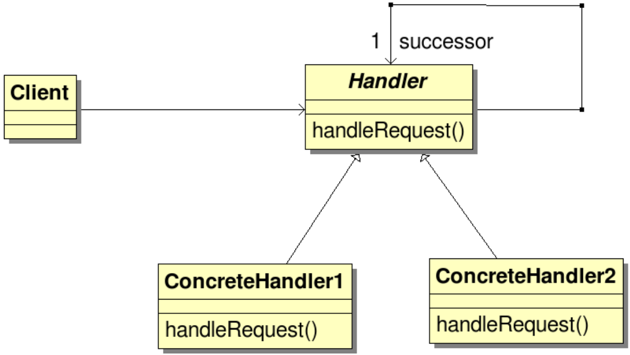
- Example:
  - a button in a dialog box
  - a button in the main window
- If no help can be found for that part, a more general help page is shown
- The help should be organized hierarchically
  - From more general to more specific
- The object that provides the help is not known to the object that initiates the request for help
  - the button does not know which help object will handle the request, as this depends on the context

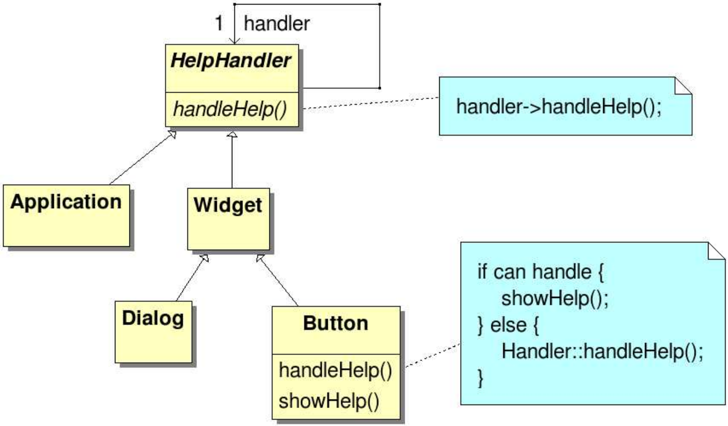
# Goals and requirements

- Decouple senders and receivers
- Gives multiple objects a chance to handle the request
- Chain:
  - build a list of receivers
  - pass the request to the first receiver
  - if the request cannot be handled, pass it to the next receiver in the chain
- Consequences
  - *Reduced coupling*: the sender does not care which object handles the request
  - *Added flexibility in assigning responsibility*: different responsibility can be distributed to different objects
  - *Receipt is not guaranteed*: there is not guarantee that eventually some object will handle the request

# UML diagram


1
successor
Client
Handler
handleRequest()
ConcreteHandler1
handleRequest()
ConcreteHandler2
handleRequest()

# Example Instance



# Notes

- Applicability
  - More than one object can handle a request, and the handler is not known a priori
  - 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
- Implementation
  - *Connecting successors*: the `Handler` class itself usually maintains a link to the successor. Also, it automatically forwards allow requests by default if there is a successor.
  - *Representing requests*: usually represented in the method call itself (i.e. `handleHelp()`). However, we could think of one or more parameters to encode the specific request.
  - to simplify the passage of parameters, we could also encode them into an object that is passed along the chain

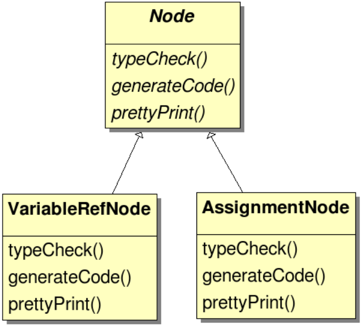
# Outline

# Motivation

- Consider a compiler that internally represents a program as an abstract syntax tree
  - the compiler will take as input a text file containing the program
  - the *parser* component will read the file and build the syntax tree
  - then it performs syntax checking on the tree
    - for example, it checks that all used variables have actually been defined, and that the type corresponds
  - it will also need to generate code
  - optionally, it can need to print the program in a nice formatted way
- In general, on a complex structure, you may need to define several distinct operations
- The structure may consists of different types of nodes (see the `Composite` pattern)

# Naive approach

- Let's define a method for each operation in the node itself



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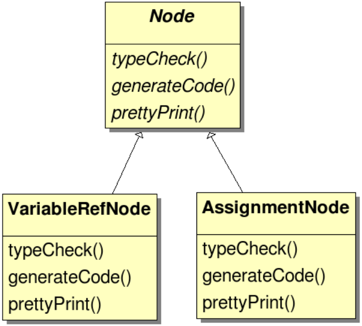
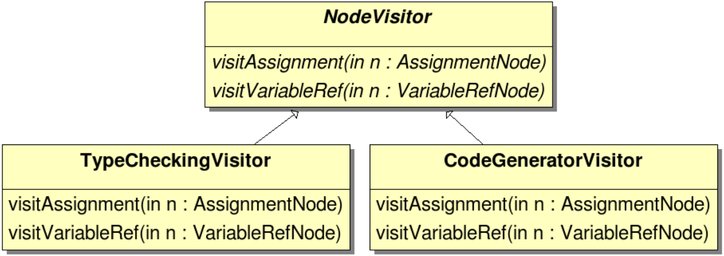



- Not correct. Why?

# The problem

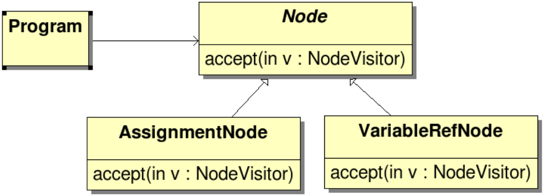
- Does not scale: what if we want to implement one more operation to visit the node?
  - We need to change all the `Node` classes
- Also, we are doing many things to do in a single class
  - The `Node` class should care about the structure, and to provide a generic interface to all types of nodes
  - `Node` typically implements a **Composite** pattern
- What we need to do
  - Decouple visiting from Nodes.
  - Solution: use a different class to encapsulate the various visiting operations

# The Visitors



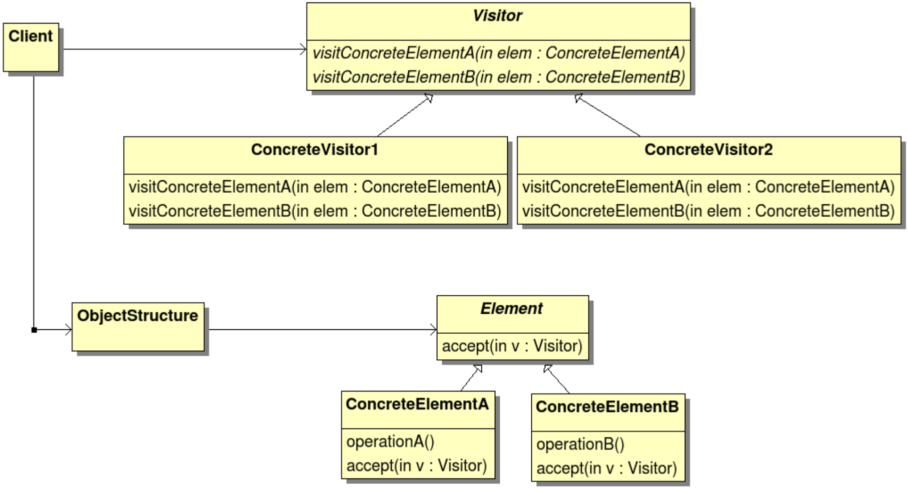

- These classes take care of visiting the Nodes, and doing the appropriate operations
- each concrete visitor implements a different kind of visit

# The Nodes to be visited

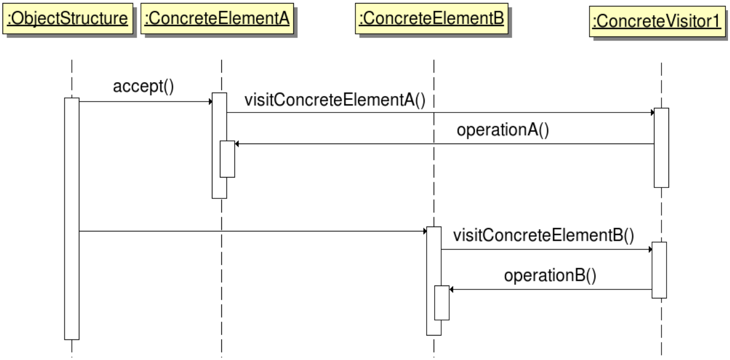



- Now the `Node` class is much simples
- it only need to provide a *hook* for allowing visitors to visit it

# Generic UML diagram



# Message Sequence Chart



# Applicability

- Use the Visitor pattern when
  - an object structure contains many classes of objects with different interfaces, and you want to perform operations on the elements of the structure
  - many different operations needs to be performed on objects in a structure, and you want to avoid putting such operations on the objects (decoupling)
  - the classes defining the object structure rarely or never change

# Consequences

- *Visitor makes adding new operations easier*
- *Adding a new `ConcreteElement` is hard*
- similar to an `Iterator`, however the Iterator visits elements of the same type, while visitor traverses structure of objects of different types
- *Accumulating State*: since the visitor is an object, while visiting it can accumulate state, or cross-check the structure

# Implementation techniques

- The visitor is able to understand the type of the element it is visiting using the technique called **double dispatch**.
- Single dispatch:
  - the operation to be invoked depends on the type of the object (or of the pointer), and on the parameter list
  - in object oriented slang, we say that it depends on the message type (the method) and on the receiver (the object) type
- Double Dispatch:
  - The operation that is invoked depends on the message type (the method) and on *two* receivers
  - *accept()* is a double-dispatch operation, because the final method that is called depends both on the visitor type and the element type
  - the technique used for the template observer is quite similar: which operation is invoked depends on the message type (update), on the receiver (the observer) and on the subject (parameter of the update)

# Who performs the visit?

- Different techniques
  - The object structure
  - the Visitor
  - A separate object (an Iterator)

# Outline

# Motivation

*Given a language, define a representation for its grammar along with an interpreter that uses the representation to interpret sentences in the language*

- In many cases it is useful to define a small language to define things that need to be expressed easily
- Examples where a simple language may be useful
  - Configuration files for creating objects
  - List of complex parameters
  - Rules to configure filters, etc.
- If the language is complex (for example, a scripting or programming language), it is better to use classical tools like parser generators
- However, when we want to implement a simple thing, then it may be useful to do it by hand in C
- In the following example, we will assume to build a simple interpreter for regular expressions

# Example

- Grammar rules

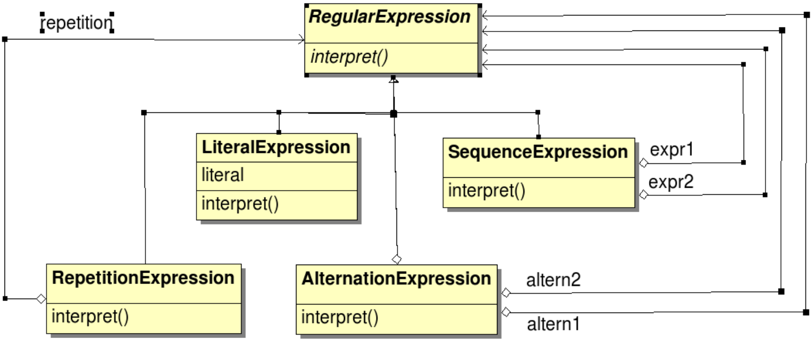
```
expression ::= literal | alternation | sequence | repetition |
    '(' expression ')'
alternation ::= expression '|' expression
sequence ::= expression '&' expression
repetition ::= expression '*'
literal :: = 'a' | 'b' | 'c' | ... {'a' | 'b' | 'c' | ... }*
```

- Expression is the starting rule
- Literal is a *terminal* symbol

# Abstract Syntax Tree

- To implement the previous grammar, we prepare a class for each rule
- each class derives from an abstract class
- at the end of the parsing we must obtain an *abstract syntax tree* that will represent the expression

# UML representation

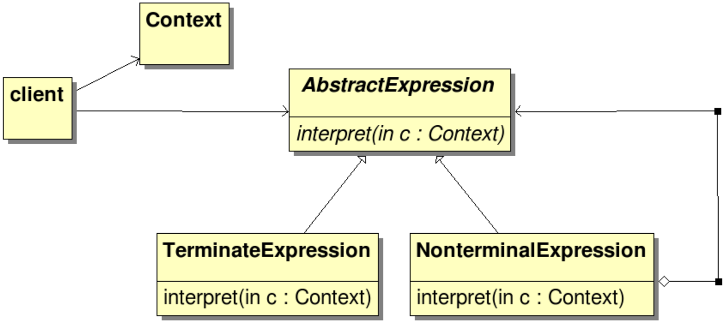


# How the interpret works

- The abstract syntax tree must be built by a parser (not part of this pattern)
- once the tree is built, we can use it in our program.
  - For example, we could pass the interpret a sequence of characters, and it will tell us it the sequence respects the regular expression
  - we would also pretty-print the expression, or transform it into another representation (for example a finite state machine)

# UML representation

- A general UML representation is the following



# Participants

- **AbstractExpression** (RegularExpression)
  - it represents the abstract interface for the node in the tree
- **TerminalExpression** (LiteralExpression)
  - Represents the leaf of the tree, cannot be further expanded
- **NonTerminalExpression** (SequenceExpression, AlternationExpression, etc.)
  - this class represents a rule in the grammar
  - it is also an intermediate node in the tree, can contain children
- **Context**
  - Contains global information useful for the interpret
- **Client**
  - builds the abstract syntax tree via a parser
  - calls the interpreter operation to carry on the interpretation of the language

# Consequences

- *It's easy to change and extend the grammar*
  - appropriate classes can be written, existing classes appropriately modified
- *Easy to implement the grammar*
  - Classes are easy to write and often their generation can be automated by a parser generator
- *Complex grammars are hard to maintain*
  - When the number of rules is large, you need a lot of classes
  - also, not very efficient to execute
- Adding new ways to interpret expressions
  - Since you have the tree, you can do many things with it
  - by using a Visitor pattern, you can easily add new operations without modifying the classes

# Example of parser

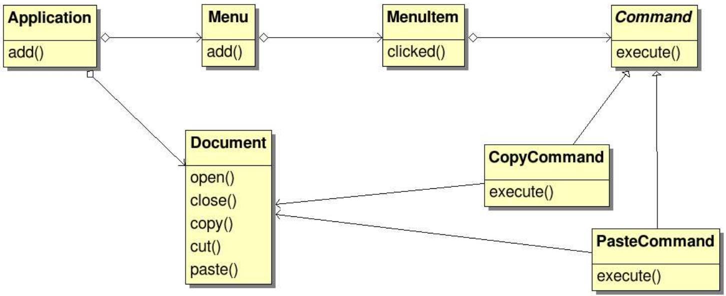
- In the code

# Outline

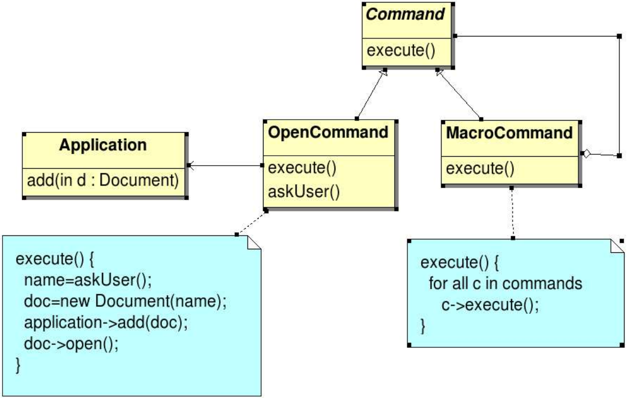
# Motivation

- Sometimes it is necessary to issue requests to objects without knowing anything about the operation being requested, or the receiver of the request
  - Example: when pressing a button, something happens that is not related or implemented to the Button class
  - In many cases, exactly the same operation can be performed by a menu item, or by a button in a toolbar
- We want to encapsulate commands into *objects*
- This patterns is the OO equivalent of C *callbacks*
- Other uses
  - Undo/redo of commands
  - Composing commands (macros)

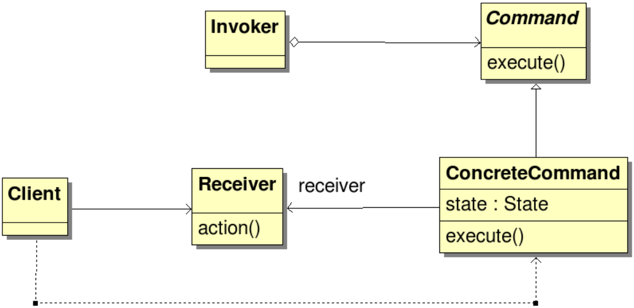
# UML example


Application
add()
Menu
add()
MenuItem
clicked()
Command
execute()
Document
open()
close()
copy()
cut()
paste()
CopyCommand
execute()
PasteCommand
execute()

# Implementing macros



# General UML structure



# Undo/Redo

- It is not always possible
  - The operation should be reversible
  - Need to add and undo() operation in the Command abstract class
  - The command may need to carry additional state of the receiver inside
  - We need an history list (how far should we go with the history?)
- Using prototype
  - We could use a Prototype pattern to create copies of commands, customize with the internal state of the receiver, and then save the copy on the history

# Differences with callbacks

- Commands are objects, not just functions
  - They can carry state information on the receivers
  - They can carry information on the history itself
- The Invoker only needs to know the general interface of the command (execute()), not the specific internal information (i.e. parameters, etc.) which are decided at creation time

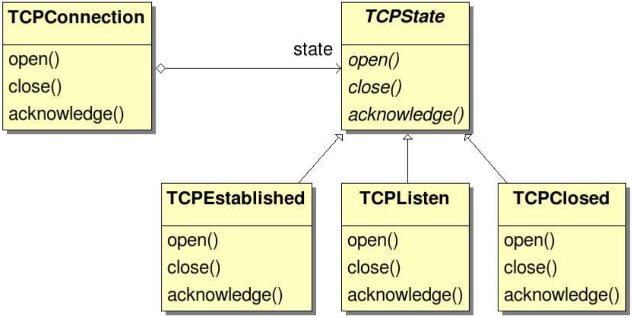
# Outline

# The State pattern

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

- This pattern is useful to implement simple state machines
- The idea is to implement each state with a different class, and each event with a different method
- Consider a library to implement the TCP protocol
  - A TCPConnection can be in one of several different states
  - For example, the connection can be void, established, closing, etc.
  - the response to a request of open depends on the current state of the connection: only if the connection is not yet established we can open it
- this behaviour can be implemented as follows:
  - An abstract class TCPState that implements a method for each possible request
  - the derived classes represent the possible states
  - only some of them will respond to a certain request

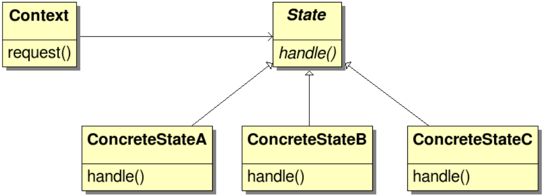
# Example


TCPConnection
open()
close()
acknowledge()
state
TCPState
open()
close()
acknowledge()
TCPEstablished
open()
close()
acknowledge()
TCPListen
open()
close()
acknowledge()
TCPClosed
open()
close()
acknowledge()

# Applicability

- Use the State pattern in one of the following cases
  - an object behaviour depends on its state, that will change at run-time
  - operations have large, multi-part, conditional statements that depend on the object state. This state is usually represented by one or more enumerated constants

# UML diagram



Context
request()
State
handle()
ConcreteStateA
handle()
ConcreteStateB
handle()
ConcreteStateC
handle()

# Participants

- **Context** (TCPConnection)
  - defines the interface of interest to clients
  - maintains an instance of a ConcreteState subclass that defines the current state through a pointer to the abstract State class
- **State** (TCPState)
  - defines and interface for encapsulating the behaviour associated with a particular state of the Context
- **ConcreteState** subclasses
  - each subclass implements a behaviour associated with a state of the Context

# Consequences

- *Localizes state-specific behaviour and partitions behaviour for different states*.
  - All behaviour associate with a particular state is concentrate into a single class (ConcreteState).
  - new states and transitions can be easily added
  - the pattern then avoid large if/then/else conditional instructions
  - however, distributing information in state classes may not be appropriate for complex behaviour, because it increases the amount of interaction and dependencies between classes
- *it makes state transitions explicit*.
  - a transition is a change in the state object, therefore is quite visible

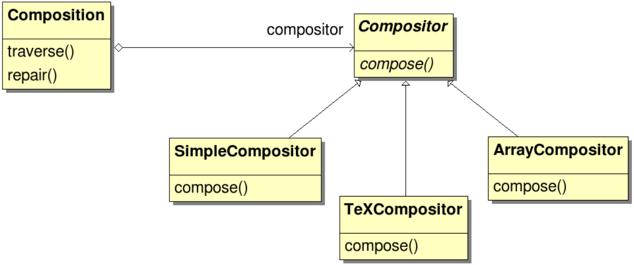
# Outline

# Strategy

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

- In general, it is useful to delegate an algorithm to a function, instead of embedding it into the normal code
  - we make the algorithm general and reusable
  - we can easily change the algorithm by substituting the function
- In object oriented programming, objects can be used instead of functions
- An example:
  - many algorithms exist for breaking a stream of text into lines
  - hard-wiring them into the class that uses them is undesirable, because it goes against the single-responsibility principle
  - therefore, we could define an hierarchy of “function objects” that behave like functions

# UML diagram


Composition
traverse()
repair()
compositor
Compositor
compose()
SimpleCompositor
compose()
TeXCompositor
compose()
ArrayCompositor
compose()

# Structure

- **SimpleCompositor** implements a simple strategy that determines linebreaks one at a time
- **TeXCompositor** implements the TeX algorithm for finding linebreaks. This strategy tries to optimize linebreaks globally, that is one paragraph at a time
- **ArrayCompositor** implements a strategy that selects breaks so that each row has a fixed number of items. It's useful for breaking a collection of icons into rows, for example

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- A Composition maintains a reference to a Compositor object
- we can change strategy both at compile time and at run-time
- Why using classes instead of functions?
    - Objects can carry state, while functions can't

# In C++

- In C++ you can define a method without name, through the `operator()`

```
class MyFunctor {
    ...
public:
    MyFunctor();
    double operator() {...}
    ...
};

MyFunctor a;
...
double result = a();
// equivalent to
// result = a.operator();
```

- You can also pass parameters to the operator, and overload it

# Strategy as template parameters

- Using this technique, a class can be easily parametrised through a template instead than by inheritance

```
template <class Functor>
class Context {
    Functor f;
public:
    ...
    void operation() {
        f();
    }
};
```