Design Patterns in C++

Structural Patterns

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Introduction to Structural Patterns

- Structural patterns are concerned with how classes and objects are composed to for larger structures.
- Two kinds of “composition”:
  - static composition though inheritance
    - A class functionality is extended by deriving a new class and overloading polymorphic methods, or by adding new methods
    - A class can mix the functionality of two classes through multiple inheritance
    - A class can implement multiple interfaces through interface inheritance
  - dynamic composition through associations
    - an object holds a pointer to another object
    - an object *delegates* part of its functionality to another object
    - an object can be composed by several smaller objects in many different ways

Outline

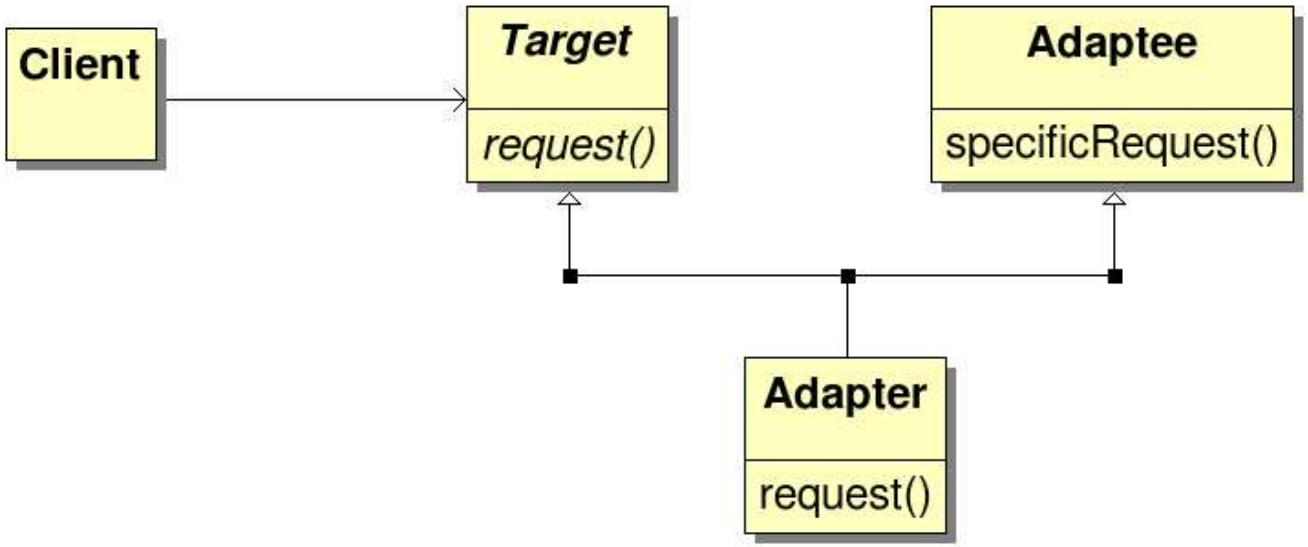
Motivation

- We have implemented a toolkit to draw graphics objects
  - the base class is *Graphic*, then we have `CompositeGraphic`,and *Line*, *Polygon*, etc.
  - (see the `Composite` example)
- We would like to add a `TextBox`, but it is difficult to implement
- So we decide to buy an off-the-shel library that implements `TextBox`
- However, `TextBox` does not derive from `Graphic`.
  - and we don't have their source code
- How to include it in our framework?

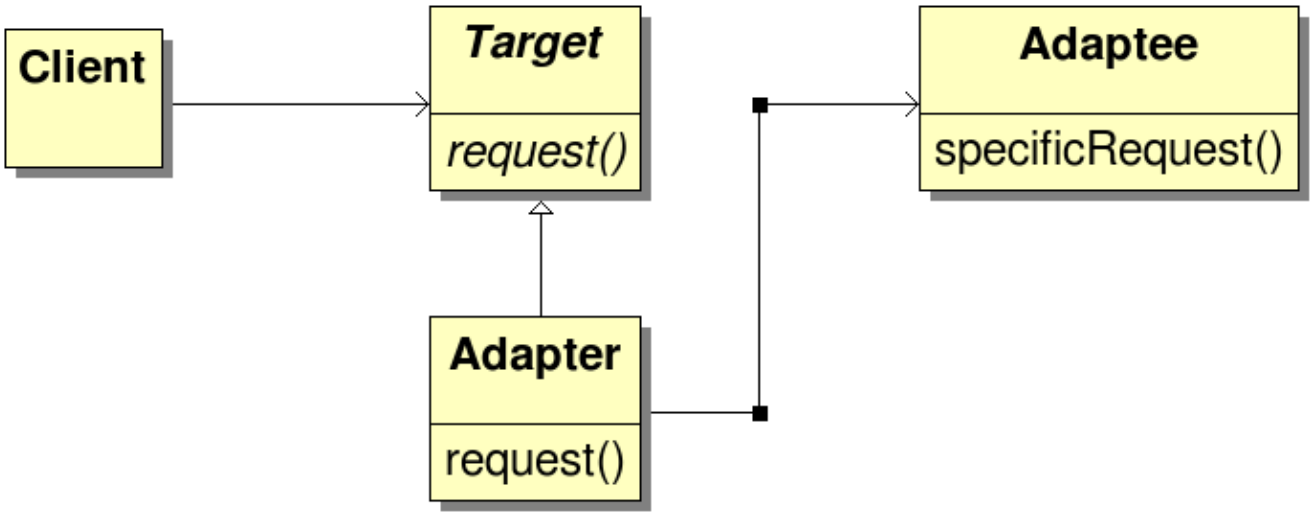
Options

- We have two options
  - Implement a `TextShape` class that derives from `Graphic` and from `TextBox`, reimplementing part of the interface
  - Implement a `TextShape` class that derives from `Graphic`, and holds an object of type `TextBox` inside
- These two represent the two options for the *Adapter* pattern

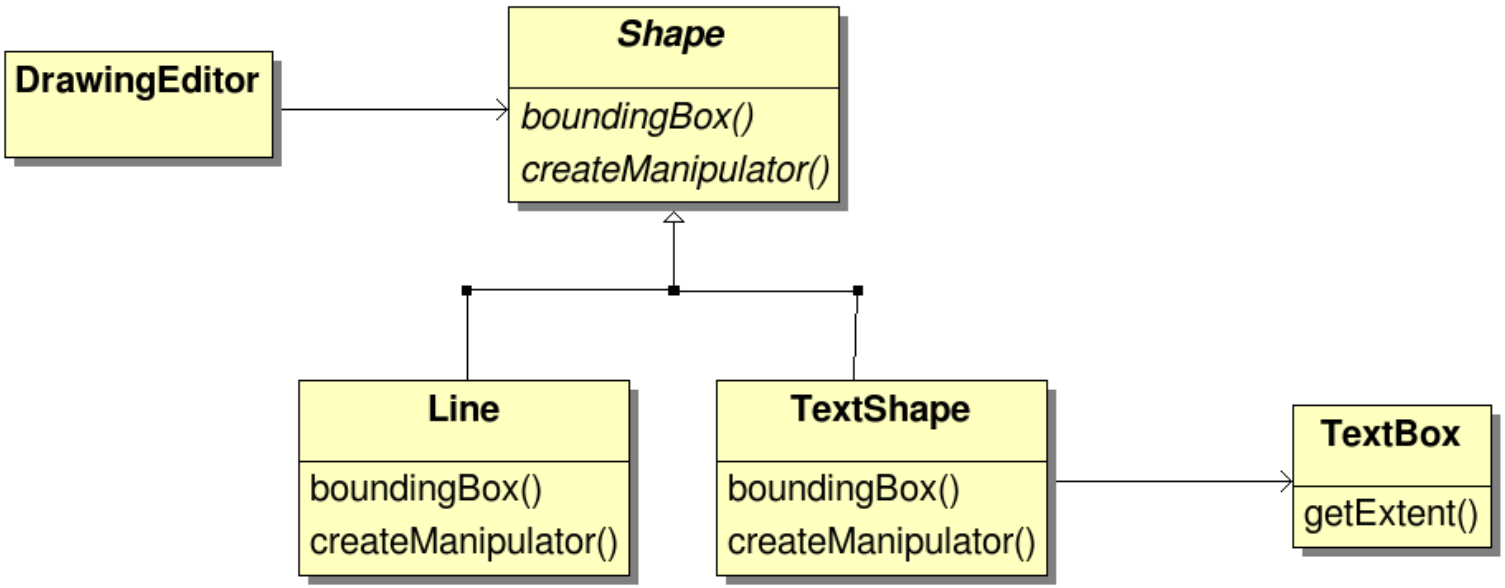
Multiple Inheritance option



Composition Option



Example


DrawingEditor
Shape
boundingBox()
createManipulator()
Line
boundingBox()
createManipulator()
TextShape
boundingBox()
createManipulator()
TextBox
getExtent()

Another example

- Suppose we are given the class:

```
class DocManager {
public:
    ...
    void printDocument();
    void saveDocument();
    ...
};
```

- which is responsible for opening, closing, saving, and printing text documents

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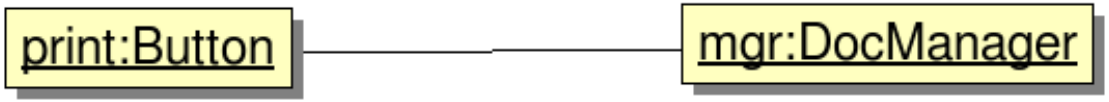
```

- which is responsible for opening, closing, saving, and printing text documents
- Now suppose we want to build a word-processing application:
  - Graphical user interface that allows, among other things, users to save the file by clicking a `Save` button and to print the file by clicking a `Print` button.
  - Details of saving and printing are handled by the class DocManager
- **Key problem:** How to design class `Button` so that its instances can collaborate with instances of class `DocManager`

Example – cont.



- Observe: Two instances and one link:
  - “print button” object of class `Button`
  - “document manager” object of class `DocManager`
  - `Button` press should invoke `printDocument()` operation
- **Question:** How might one design classes `Button` and `DocManager` to support this link?

Bad design

```
class Button {
protected:
    DocManager* target;
    void monitorMouse() {
        ...
        if (/* mouse click */) {
            target->printDocument();
        }
        ...
    }
    ...
};
```

- Why this is a bad design?

Comments

- Observe: To invoke `printDocument()` operation, `Button` needed to know the class (`DocManager`) of the target object.
- However:
  - Button should not care that target is a `DocManager`
  - Not requesting information from target
  - More like sending a message to say: “Hey, I’ve been pressed!. Go do something!”
- **Question:** How can we design Button to send messages to objects of arbitrary classes?;

Use interface class

```
class ButtonListener {
public:
    virtual void buttonPressed(const string&) = 0;
};
```

- This interface declares the messages that an object must be able to handle in order to collaborate with a `Button`

A better design

```
class Button {
public:
    Button(const string& lab) :
        label(lab), target(0) {}

    void setListener(ButtonListener* blis) {
        target=blis;
    }

protected:
    string label;
    ButtonListener* target;

    void monitorMouse() {
        ...
        if(/* mouse click */) {
            if (target)
                target->buttonPressed(label);
        }
        ...
    }
};
```

Collaborator

- *Collaborator*: any object that implements the `ButtonListener` interface
- Collaborator must register interest in press events
- What if `DocManager` is already written and tested and does not implements interface `ButtonListener`?
- Use the adapter interface

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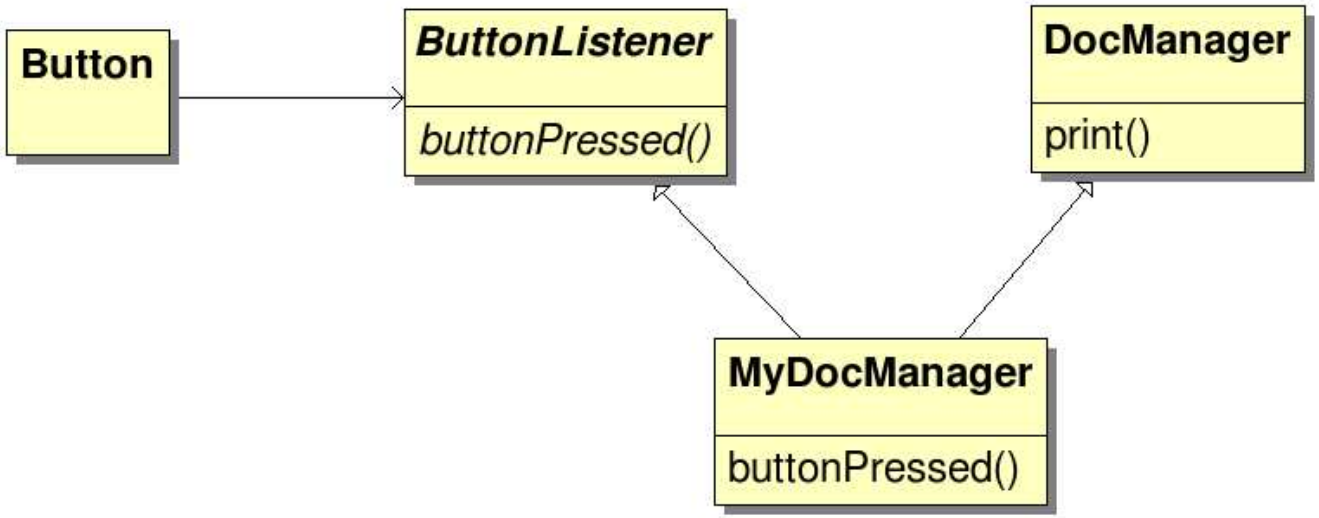


Advantages

- Class `Button` very reusable
- We can understand the `Button`–`ButtonListener` collaboration with little knowledge of Button and no knowledge of `DocManager`
  - Example of *separation of concerns*
- Clear mechanism for adapting arbitrary class to implement the `ButtonListener` interface
- Rather than thinking of a program as a sequence of steps that compute a function We think of a program as comprising two parts: initialization and then interaction
  - Initialization involves the allocation of objects and the assembly of objects into collaborations;
  - Interaction involves the interaction of objects with other objects by sending messages back and forth

Which structure to use?

- Multiple inheritance:
  - Expose interfaces of the adaptee to clients
  - Allow the adapter to be used in places where an adaptee is expected
- Composition
  - Does not expose interfaces of the adaptee to clients (safer)
  - In places that an adaptee is expected, the adapter needs to provide a function `getAdaptee()` to return the pointer to the adaptee object.

Outline

Motivation

- Suppose that a general concept can have more than one alternative implementation
  - The window example, where there are different types of windows (icon, dialogue, framed, etc.), and they can be implemented in different windows managers
  - A communication channel can be implemented on top of several protocols
- The natural way to handle this situation is by using inheritance
- However, it may sometimes happen that the same abstraction must be extended across two or more orthogonal directions
  - In the case of the window manager, suppose that you can have several OS platforms, and on each platform, several different window classes
  - In the case of a communication system, two orthogonal concepts are again the OS and the protocol
- Using only inheritance leads to a multiplication of different classes

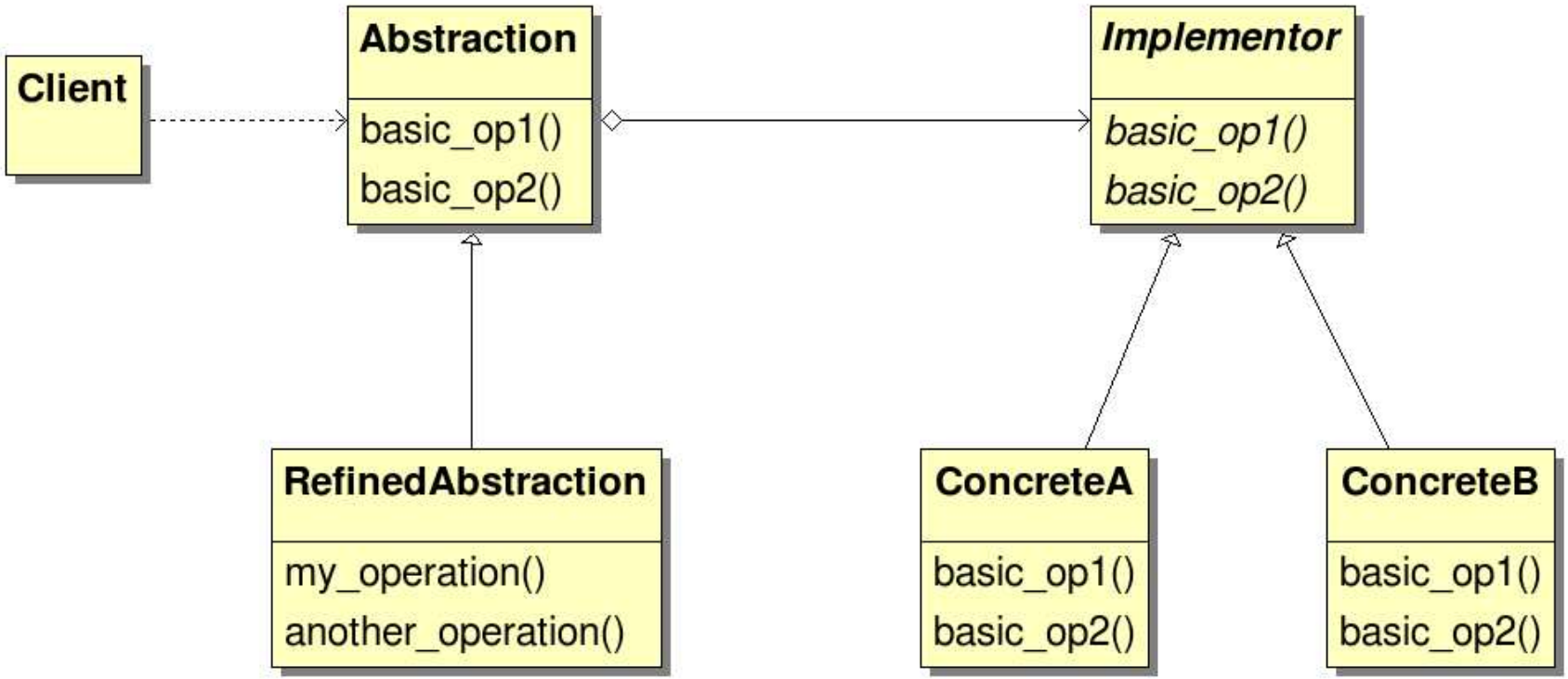
Separation of concerns

- Inheritance is static:
  - The client will depend upon a specific platform
  - Whenever a client creates a window, it must select the correct class depending on the platform (similar problem of the abstract factory)
- Adding a new look-and-feel requires adding many different classes

Bridge pattern

- Still use inheritance, but use a different class hierarchy for each orthogonal extension
  - One class hierarchy for each different window type
  - One class hierarchy for each window manager
- All operations on windows must be implemented in terms of “basic” operations
- These basic operations can have several different implementations on the different window managers

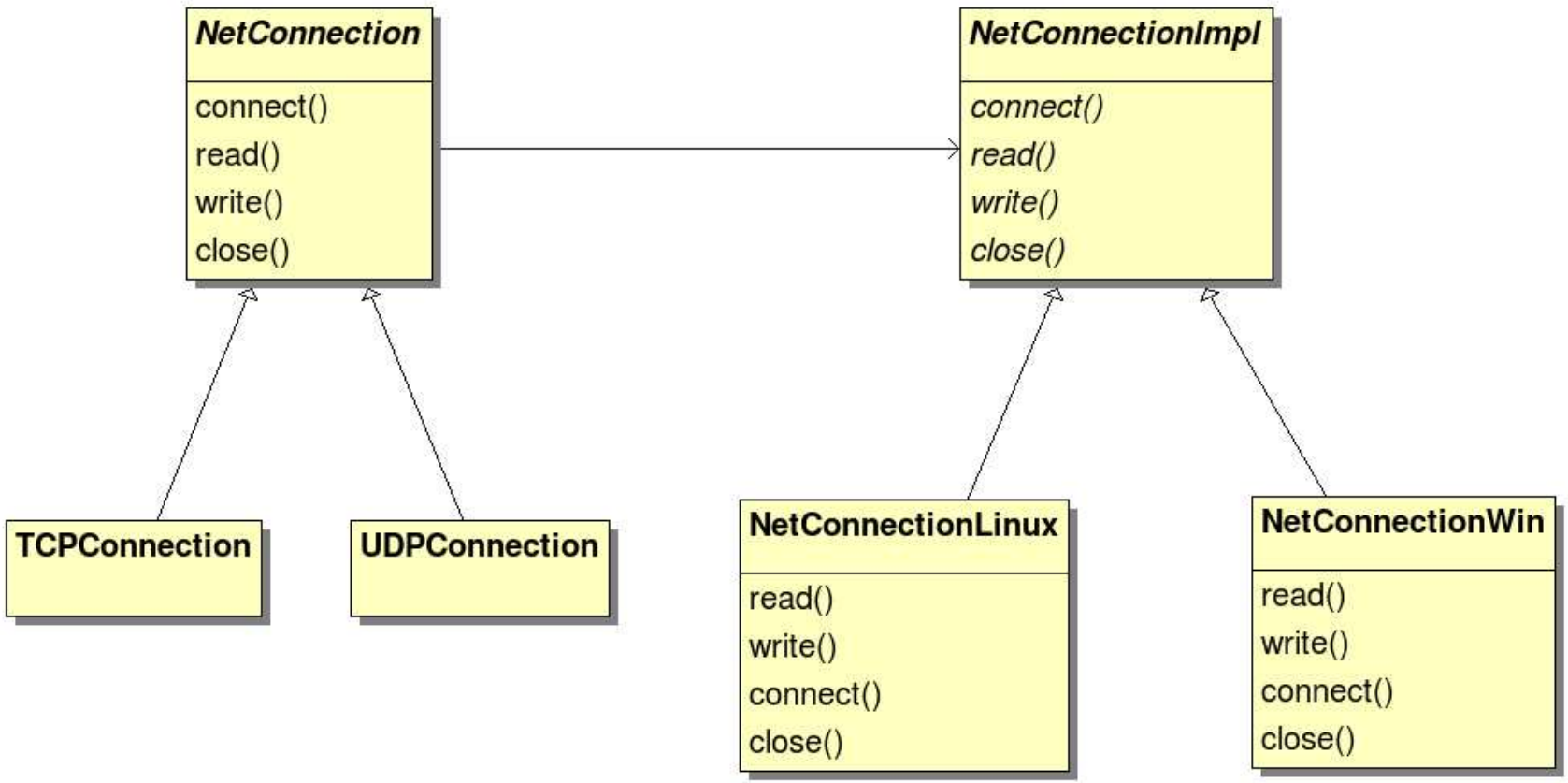
UML Structure



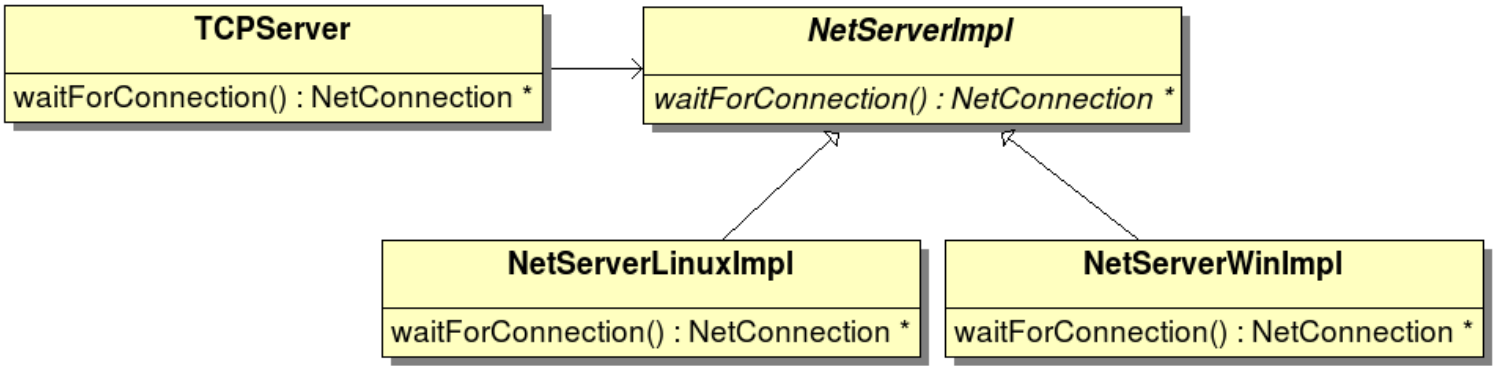
An example

- In this example, we show how to use the bridge to generalize the type of connection, independently of the OS and of the protocol (TCP or UDP)
- The application has (soft) real-time constraints, and we would also like to have error correction and retransmission when possible
- Initially the application will run on a local network, later it may be possible to transmit on a wide area network
- The idea is that the user should be able to easily change from a TCP to a UDP and vice versa
- Also, the application must be portable across several OS and RTOS

Net connections



Server


TCPServer
waitForConnection() : NetConnection *
NetServerImpl
waitForConnection() : NetConnection *
NetServerLinuxImpl
waitForConnection() : NetConnection *
NetServerWinImpl
waitForConnection() : NetConnection *

Extensions

- The client is not totally independent from the protocol
- TCP needs a “Server” on a passive socket, which returns a NetConnection
- while UDP can just wait for a message on a certain port of a regular NetConnection
- There are other ways to abstract from the OS
  - For example, the **Facade** pattern, which consists of an interface to centralize all OS abstractions (threads, semaphores, etc.)
  - In such a case, the Bridge Pattern is simplified, but still useful, because it decouples the protocol

Consequences

- *Decoupling interface and implementation*
  - An implementation is not bound permanently to an interface
  - No compile-time dependencies, because changing an implementation does not require to re-compile the abstractions and its clients
- *Improved extensibility*
  - Abstractions and implementers can be extended independently
- *Hiding implementation details*
- How to create, and who creates the right implementer object?
  - Use a factory object, that knows all implementation details of the platform, so that the clients and the abstraction are completely independent of the implementation

Outline

Composite pattern

- We must write a complex program that has to treat several object in a hierarchical way
  - Objects are composed together to create more complex objects
  - For example, a painting program treats shapes, that can be composed of more simple shapes (lines, squares, triangles, etc.)
  - Composite objects must be treated like simple ones
  - Another example: a word processor, which allows the user to compose a page consisting of letters, figures, and compositions of more elementary objects

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  - Another example: a word processor, which allows the user to compose a page consisting of letters, figures, and compositions of more elementary objects
- Requirements:
  - Treat simple and complex objects uniformly in code – move, erase, rotate and set color work on all
  - Some composite objects are defined statically (wheels), while others dynamically (user selection)
  - Composite objects can be made of other composite objects

Solution

- All simple objects inherit from a common interface, say Graphic:

```
class Graphic {
public:
    virtual void move(int x, int y) = 0;
    virtual void setColor(Color c) = 0;
    virtual void rotate(double angle) = 0;
};
```

- The classes Line, Circle and others inherit Graphic and add specific features (radius, length, etc.)

```
class CompositeGraphic
  : public Graphic,
    public list<Graphic>
{
    void rotate(double angle) {
        for (int i=0; i<count(); i++)
            item(i)->rotate();
    }
}
```

The solution – II

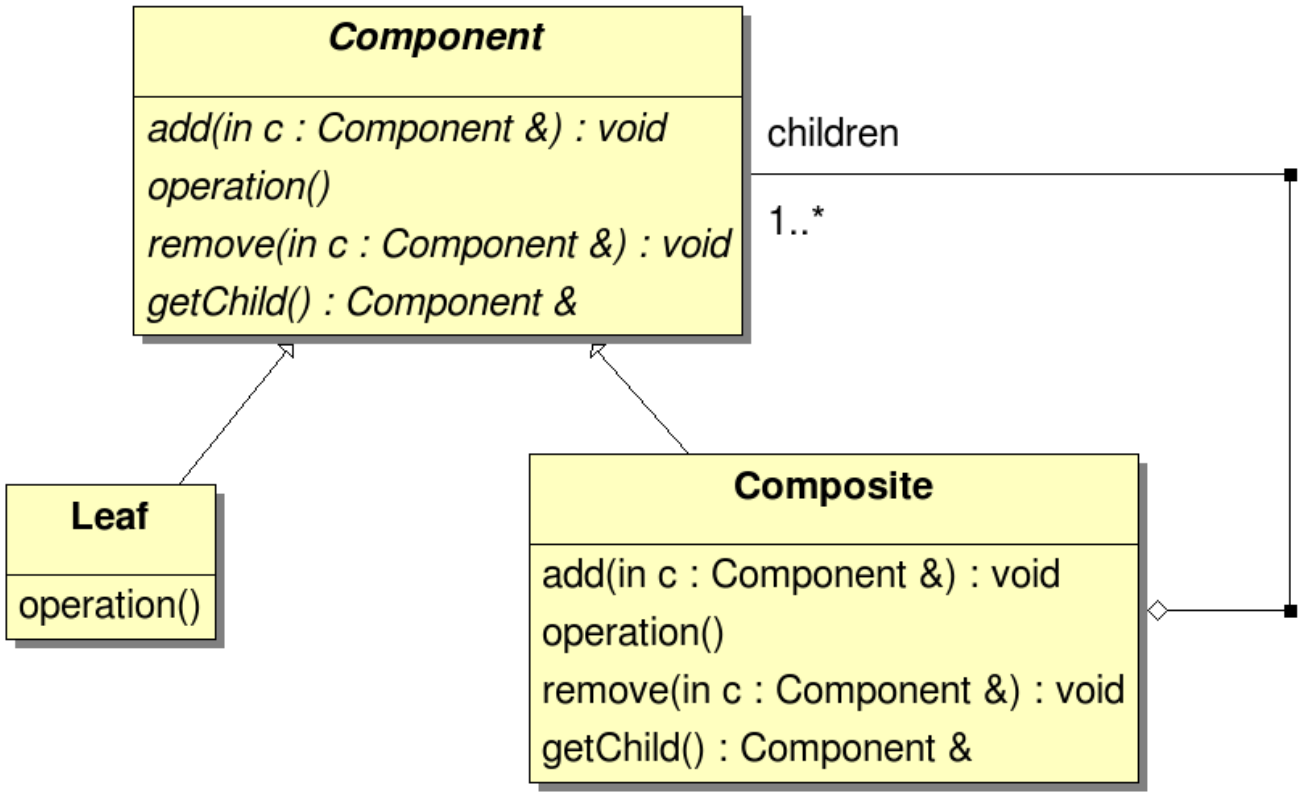
- Since a `CompositeGraphic` is a `list`, it had `add()`, `remove()` and `count()` methods
- Since it is also a `Graphic`, it has `rotate()`, `move()` and `setColor()` too
- Such operations on a composite object work using a “forall” loop
- Works even when a composite holds other composites – results in a tree-like data structure

The solution – III

- Example of creating a composite

```
CompositeGraphic *cg;
cg = new CompositeGraphic();
cg->add(new Line(0,0,100,100));
cg->add(new Circle(50,50,100));
cg->add(t); // dynamic text graphic
cg->remove(2);
```

UML representation



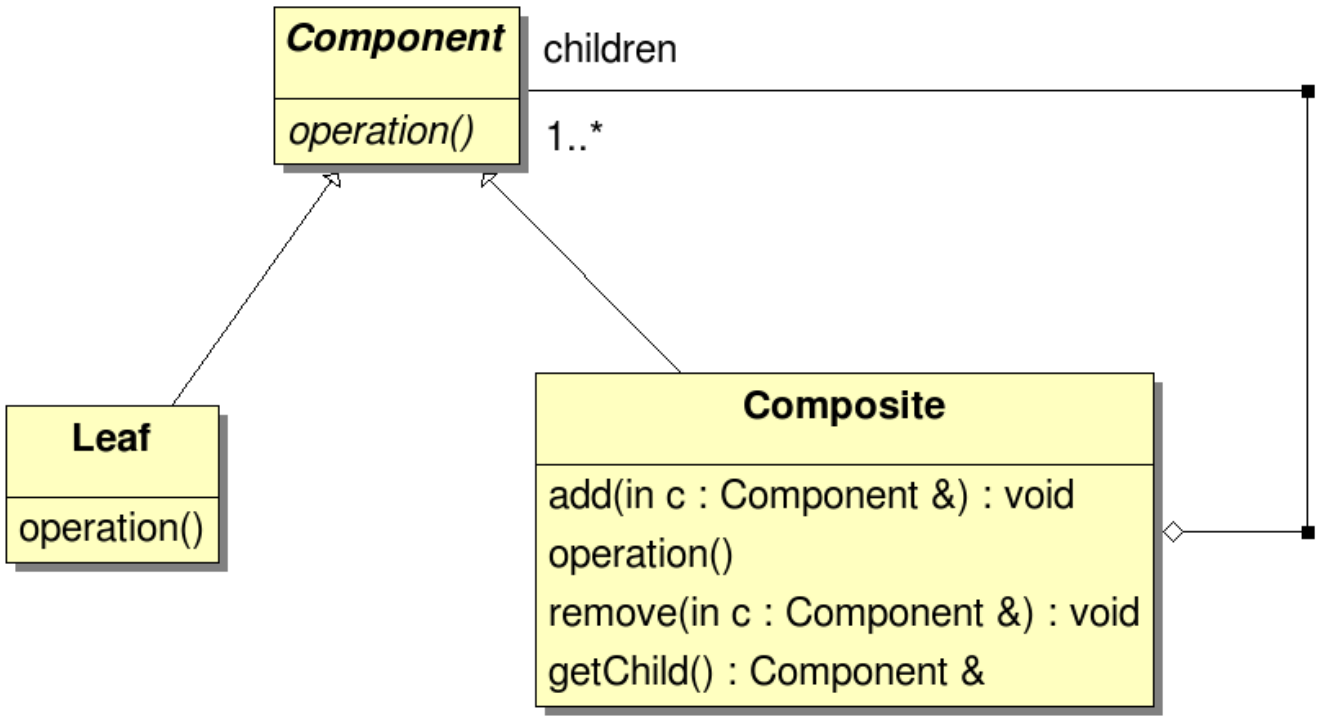
Participants

- Component (Graphic)
  - declares the interface for objects in the composition
  - implements default behaviour for the interface common to all classes, as appropriate
  - declares an interface for accessing and managing its child components
  - (optional) defines an interface for accessing a component's parent in the recursive structure, and implements it if that's appropriate
- Leaf (Rectangle, Line, Text, etc.)
  - represents leaf objects in the composition. A leaf has no children
  - defines behaviour for primitive objects in the composition
- Composite (Picture)
  - defines behaviour for components having children
  - stores child components
  - implements child-related operations in the Component interface
- Client
  - manipulates objects in the composition through the Component interface

Trade-off between transparency and safety

- Although the Composite class implements the Add and Remove operations for managing children, an important issue in the Composite pattern is which classes declare these operations in the Composite class hierarchy
- For transparency, define child management code at the root of the hierarchy. Thus, you can treat all components uniformly. It costs you safety, however, because clients may try to do meaningless things like add and remove objects from leaves
- For safety, define child management in the Composite class. Thus, any attempt to add or remove objects from leaves will be caught at compile-time. But you lose transparency, because leaves and composites have different interfaces

Composite for safety



Known uses

- Document editing programs
- GUI (a form is a composite widget)
- Compiler parse trees (a function is composed of simpler statements or function calls, same for modules)
- Financial assets can be simple (stocks, options) or a composite portfolio

Outline

Motivation

- Sometimes we need to add responsibilities to individual objects (rather than to entire classes)
  - For example, in a GUI, add borders, or additional behaviours like scrollbar, to a widget
- *Inheritance approach*
  - We could let the class `Widget` inherit from a `Border` class
  - Not flexible, because for any additional responsibility, we must add additional inheritance
  - Not flexible because is static: the client cannot control dynamically whether to add or not add the border
- *Composition approach*
  - Enclose the component into another object which additionally implements the new responsibility (i.e. draws the border)
  - More flexible, can be done dynamically
  - The enclosing object is called **decorator** (or wrapper)

Example

- A `TextView` object which displays text in a window
- `TextView` class has no scrollbars by default
- we add a `ScrollDecorator` to attach scrollbars to a `TextView` object
- What if we also want a border?
- Well, let's use a `BorderDecorator`!

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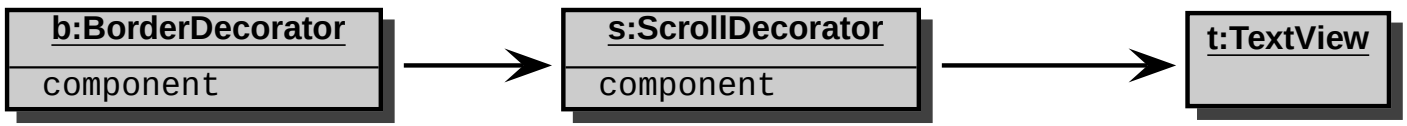
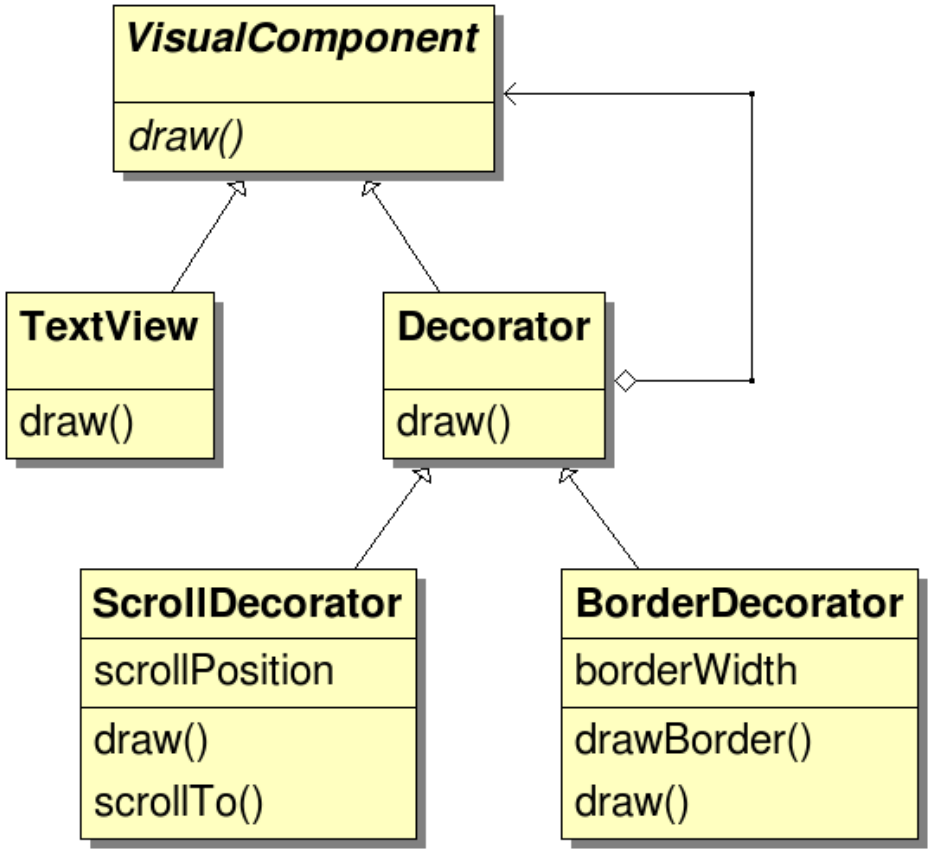


UML structure for Decorator



Description

- `VisualComponent` is the the abstract class all components must comply to
- From it, many different component classes derive with specific behaviours
- One of these classes is the `Decorator` which does nothing but *wrapping* another component and forwarding all requests to it
  - In the previous example, the `Decorator` class must forward all requests of `draw()` to its component:

```
void Decorator::draw() {
    component->draw();
}
```

Decorators internals

- All *decorators* classes must derive from `Decorator`, implementing the additional interface (`scrollTo()`, `drawBorder()`, etc.)
- The `draw()` function is overridden to add the additional behavior

```
void BorderDecorator::draw() {
    Decorator::draw();
    drawBorder();
}
```

- what the client will see will be the interface of the `VisualComponent`, plus the interface of the most external decorator
- The key property is the any decorator implements the same interface of any other component
- therefore, from the client point of view, it does not matter if an object is decorated or not

Notes

- When to use
  - To add responsibilities to individual object dynamically and transparently
  - When extension by sub-classing is impractical
- Don’t use it the component class has large interface
  - Implementation becomes too heavy (all methods must be re-implemented by forwarding to the internal component
- When there are many “decoration options” you may end up with a lot of small classes
  - The library may become more complex to understand and to use due to the large number of classes
- Where it is used
  - In the Java IO library, the most basic classes perform raw input/output
  - more sophisticated I/O though decorators (i.e. `BufferedInputStream`, `LineNumberInputStream`, are all decorators of `InputStream`)

Outline

Proxy

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

- Some times it is impossible, or too expensive, to directly access an object
  - Maybe the object is physically on another PC (in distributed systems)
  - In other cases, the object is too expensive to create, so it may be created on demand
- In such cases, we could use a placeholder for the object, that is called *Proxy*

Example

- Suppose that a text document can embed images
- Some of these can be very large, and so expensive to create and visualize
- on the other hand the user wants to load the document as soon as possible

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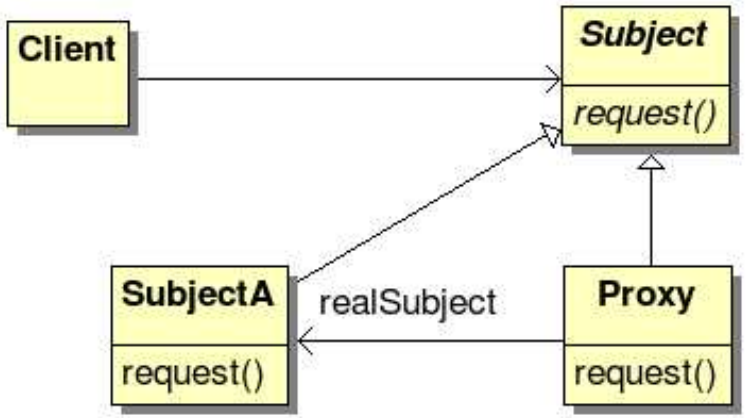
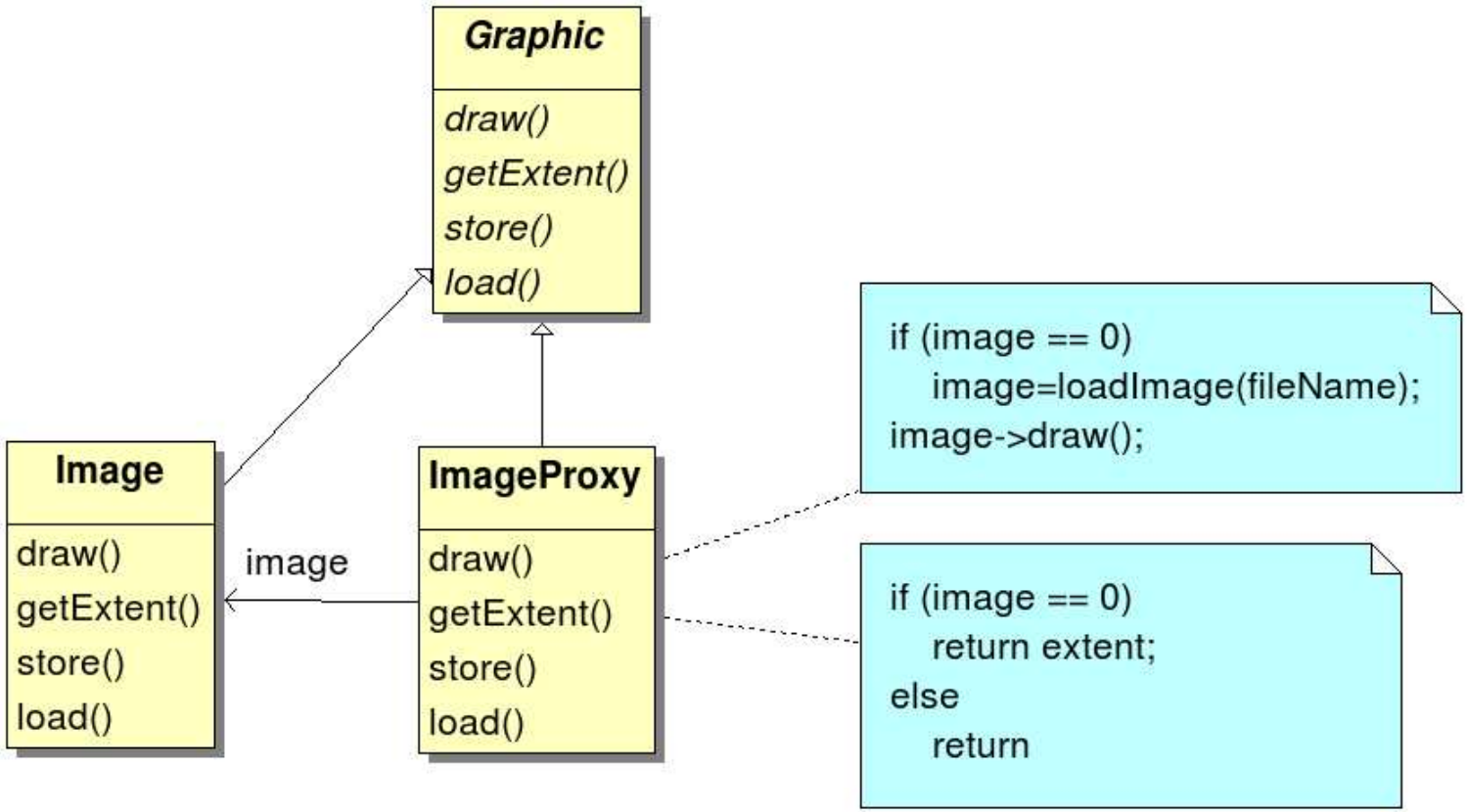
- Suppose that a text document can embed images
- Some of these can be very large, and so expensive to create and visualize
- on the other hand the user wants to load the document as soon as possible
- the solution could be to use a “similar object” that has the same methods as the original image objects
- the object will start loading and visualizing the image only when necessary (for example, on request for `draw()`), and in the meanwhile could draw a simple white box in its placeholder
- it can also return the size of the image (height and width) that it is what is needed to format the rest of the document

The structure



Generalization



Participants

- **Proxy** (ImageProxy)
  - maintains a reference that lets the proxy access the real subject. Its interface must be the same as the one of the `RealSubject`.
  - provides an interface identical to Subject's so that a proxy can be substituted for the real subject
  - controls access to the real subject and may be responsible for creating and deleting it
  - other responsibilities depends on the kind of proxy
- **Subject** (Graphic)
  - defines the common interface for *RealSubject* and *Proxy* so that a proxy can be used anywhere a *RealSubject* is expected
- **RealSubject** (Image)
  - defines the real object that the proxy represents

Applicability

- Proxy is applicable whenever there is the need for a more sophisticated reference to an object that a simple pointer
  - A **remote proxy** provides a local representative for an object in a different address space
  - a **virtual proxy** creates an expensive object on demand (like in the example)
  - a **protection proxy** controls access to the original object. Protection proxies are useful when objects should have different access rights
  - A **smart reference** is a replacement for a bare pointer (see *share_ptr* or `auto_ptr`)
  - implement **copy-on-write** behaviour when copying large objects

Outline

Comparison of structural patterns

- Many of the patterns we have seen have very similar class diagrams
  - Therefore, the structure is quite similar
  - the basic idea is to favour composition for extending functionality, and use inheritance to make interfaces uniform, and this is why they look similar
  - however, the intent of these patterns is different

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  - Both promote flexibility by providing a level of indirection to another object
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- **Adapter** versus **Bridge**
  - Both promote flexibility by providing a level of indirection to another object
  - both involve forwarding requests to this object from an interface other than its own
  - the different is on their *intent*
  - **Adapter** tries to adapt an existing interface to work with other classes; it is used *after* the class is available
  - **Bridge** provides a bridge to a potentially large number of implementations; it is used *before* the classes are available

Composite / Decorator / Proxy

- **Composite** and **Decorator** have similar recursive structure
  - Composite is used to group objects and treat them as one single object
  - Decorator is used to add functionality to classes without using inheritance
  - These intents are complementary
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  - These intents are complementary
  - therefore, these patterns are sometimes used in concert
- **Decorator** and **Proxy** are also similar
  - They both provide the same interface as the original object
  - However, Decorator is used to add functionalities; Decorators can be wrapped one inside the other
  - **Proxy** is used to control access