

C++ design patterns

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Design patterns

A “design pattern” is
a common solution for a common problem

They became popular due to a book by
Erich Gamma, Richard Helm, Ralph Johnson
and John Vlissides, known as “the gang of four”,
who identified and described 23 classic patterns.

- A design pattern is not an algorithm.
- A design pattern is a repeatable solution or approach to a design problem.
- Design patterns can be classified in 3 main categories.

Pattern classification

Design patterns are classified depending on the design problem they address

- Creational patterns.
- Structural patterns.
- Behavioral patterns.

Creational patterns

Creational patterns deal with object creation

- Singleton
- (Abstract) Factory
- Builder
- Prototype

Singleton

A “Singleton” is a `class` that can be instantiated only once and whose instance is globally accessible.

- It's (ab)used for those objects containing very general information:
 - running directives and/or conditions,
 - data common properties,
 - common operations.
- This can be achieved by:
 - declaring the constructor `private`,
 - providing a `static` function creating only one instance of the `class` and returning the pointer to it.
- The object is actually created at its first use.
- It can be implemented in a `template`.

Singleton implementation

```
class ObjS {
public:
    static ObjS* instance();
    ...
private:
    ObjS();
    ~ObjS();
    ObjS(const ObjS& x);
    ObjS& operator=(const ObjS& x);
};
```

```
ObjS::ObjS() {...}
ObjS::~~ObjS() {...}
```

Special care must be taken to avoid:

- creating and using the object before proper initialization,
- using the object after its destruction.

Singleton creation and destruction

The singleton can be created as a `static` object:

- it can be used in other `static` objects constructors,
- it cannot be used in other `static` objects destructors.

```
ObjS* ObjS::instance() {  
    static ObjS obj;  
    return &obj;  
}
```

The singleton can be created dynamically keeping a `static` pointer to it:

- it can be used in other `static` objects destructors,
- the singleton own destructor is never run.

```
ObjP* ObjP::instance() {  
    static ObjP* obj=new ObjP;  
    return obj;  
}
```

A (rather dirty) trick: base and derived objects

An analogous pattern can be used with a base object pointer, where the function `instRef()` returns a reference-to-pointer, initially set at null, and the constructor sets that pointer to `this`:

- the client code can use only an interface,
- the actual object type can be chosen elsewhere.

```
class Base {
public:
    static Base* instance();
    ...
protected:
    Base();
    ...
private:
    static Base*& instRef();
    ...
};
```

Pointer saving

```
Base::Base() {  
    Base*& i=instRef();  
    if(i==nullptr)i=this;  
}
```

```
Base*& Base::instRef() {  
    static Base* obj=nullptr;  
    return obj;  
}
```

- The pointer `obj` is initially set at null.
- When an object, derived from `Base`, is created and `obj` is null, its pointer is stored in `obj`.
- `obj` points to the first object that has been created.
- Any following call to `instRef()` will return a pointer to the first object that has been created.

Current instance return

```
Base* Base::instance() {  
    static Base*& obj=instRef();  
    if(obj==nullptr) new Base;  
    return obj;  
}
```

- The first time the `instance()` function is called, the current pointer is checked.
- If no concrete object is found, a base object is created.

Derived object creation

```
class Derived: public Base {
public:
    Derived() {...}
    ...
};
static Derived d;
```

- When a `Derived` object is created, a `Base` object is also created.
- If a `Derived` object is created before any other object derived from `Base`, its pointer is saved.
- Any following call to `instance()` will return a pointer to a `Derived` object.
- A declaration and definition of one global `Derived` object make any call to `instance()` to return a pointer to it.

Factory

A “Factory” is a `class` that creates an instance of another `class` from a family of derived `classes` sharing a common base

- A “Factory” `class` has a (usually `static`) function returning a pointer to a `base class`.
- The actual object type depends on the arguments and/or other informations the function can obtain.
- The client does not depend on the derived `classes`.
- The client need not knowing all the informations needed to create the objects.

```
class ShapeFactory {  
public:  
    static Shape* create(...);  
    ...  
};
```

Abstract factory

An “Abstract Factory” is an interface to a concrete Factory, so that the objects actually created depend on the actual factory object

- The function to create objects is declared `virtual` .
- It is (re)implemented in all concrete factories.
- Example:
 - A generic `CarFactory` has `small` , `medium` and `large` functions to create `Cars`.
 - `Volkswagen` is a `CarFactory` , and implements its create functions to return `Polo` , `Golf` or `Passat` .
 - `Ford` is a `CarFactory` , and implements its create functions to return `Fiesta` , `Focus` or `Mondeo` .

Builder

A “Builder” is a `class` that creates complex objects step by step

- Used to encapsulate the operations needed to create a complex object.
- A Builder has functions to specify how the objects is to be built, and a function to actually create the result.
- A Builder usually specify only an interface, while a Concrete Builder actually performs the operations.
- The client can create different objects by using similar operations.

Builder operation

- Building directives can be given in different moments of the execution
- The builder collects all the information from various sources

```
Builder* b = ...;  
...  
b->setThis(...);  
...  
b->setThat(...);  
...  
b->setAnother(...);  
...  
Product* p = b->build();
```

Prototype

A “Prototype” is a `class` that creates new objects by cloning an initial object

- The object to clone can be obtained from a manager.
- As with Factory, the client need not knowing all the concrete object types.
- The Prototype manager can allow the registration of new objects at runtime.
- New objects can be registered at runtime, e.g. by loading new dynamic libraries with the `dlopen` function (`dlopen` usage is not limited to prototype pattern).

```
#include <dlfcn.h>
...
void* p=dlopen("libName.so", RTLD_LAZY);
...
```

Structural patterns

Structural patterns deal with object relations

- Proxy
- Flyweight
- ...and others

Proxy

A “Proxy” is an object to be used in place of another one

- The use of a proxy can be convenient when:
 - an object cannot be duplicated,
 - an object is too expensive to create or duplicate,
 - the object creation can/must be postponed until its really needed,
 - any operation can be done in the access to an object to make the access less expensive.
- A proxy provides a modified (usually simpler) interface to an (usually complex) object.
- A proxy contains a pointer or reference to the object it represents.

Flyweight

A “Flyweight” is a shared object that can be used in multiple contexts

- Several objects can exist, with:
 - large part of them being identical,
 - only a small part different.
- A save in memory (and sometimes computing time) can be obtained sharing the common parts.
- Fine granularity in object design.

Behavioral patterns

Behavioral patterns deal with object doing operations

- Observer
- Visitor
- Iterator
- ...and others

Observer

An “Observer” is an object doing an operation each time the state of some other object changes

- An observer is “updated” when the objects it depends on changes.
- Many objects may depend on the same object:
 - a standard way of subscribing to listening for events is needed,
 - a standard way of notifying dependent objects is needed,
 - an automatic subscribing can be implemented.
- Dispatcher/Observer `class` pairs can be implemented in `templates`.

Observer interface and implementation

```
class Object;  
class Observer {  
public:  
    Observer();  
    virtual ~Observer();  
    virtual void update(const Object& x)=0;  
};
```

```
...  
Observer::Observer() {  
    Dispatcher::subscribe(this);  
}  
Observer::~~Observer() {  
    Dispatcher::unsubscribe(this);  
}
```

The observer registers/unregisters itself in the constructor/destructor

Dispatcher interface

```
class Observer;
class Object;
class Dispatcher {
    friend class Observer;
public:
    static void notify(const Object& x);
private:
    Dispatcher() { };
    ~Dispatcher() { };
    static std::set<Observer*>* oL();
    static void subscribe(Observer* obs);
    static void unsubscribe(Observer* obs);
};
```

Dispatcher implementation

```
static std::set<Observer*>* Dispatcher::oL() {
    static std::set<Observer*>* ptr=
        new std::set<Observer*>;
    return ptr;
}
```

An observer can be created and registered at any time:

- the container must be created when needed first,
- a single instance can be provided by a `static` function.

```
void Dispatcher::subscribe(Observer* obs) {
    oL()->insert(obs);
}
```

```
void Dispatcher::unsubscribe(Observer* obs) {
    oL()->erase(obs);
}
```

Notification

```
void Dispatcher::notify(const Object& x) {
    std::set<Observer*>::iterator
        it=oL()->begin();
    std::set<Observer*>::iterator
        ie=oL()->end();
    while(it!=ie) (*it++)->update(x);
    return;
}
```

- The dispatcher notifies all the registered observers by calling their `update` function.
- Any concrete observer must override the `update` function.

Multiple dispatchers

In the shown implementation
only one dispatcher can exist at a time.

An implementation allowing for several dispatchers with different observers can be produced:

- the observer list cannot be stored in a (shared) `static set` because each dispatcher needs its own observer set,
- functions to subscribe-unsubscribe cannot be `static`, too, because the subscription-unsubscription must be done with a specific dispatcher.
- care is to be taken to handle notification of an observer by more than one dispatcher.

Operations “on demand”

An “Observer” can perform its operation:

- for each event (“active observer”), as previously described,
 - only if needed (“lazy observer”, not a classified pattern).
-
- A “lazy observer” when notified does not “update” itself:
 - it simply sets its state as “not updated”,
 - if requested to “check” its state it actually “updates”, if necessary,
 - it can cache any result and return it without recomputing, unless necessary.
 - Such a mechanism allows performing any operation only when needed:
 - an operation is not done if not needed,
 - operations are done at most once,
 - operations are automatically performed in the correct order.

Lazy Observer interface

```
class Object;
class LazyObserver {
public:
    LazyObserver();
    virtual ~LazyObserver();
    virtual void lazyUpdate(const Object& x);
protected:
    virtual void update(const Object& x)=0;
    virtual void check();
private:
    bool upToDate;
    bool updating;
    const Object* last;
};
```

Lazy Observer implementation

- The dispatcher actually calls the function `lazyUpdate`.
- The function `update` is called by the function `check`,

```
...  
LazyObserver::lazyUpdate(const Object& x) {  
    upToDate=updating=false;  
    last=&x;  
}  
LazyObserver::check() {  
    if(updating) return; // check for recursion  
    updating=true;  
    if(!upToDate) update(*last);  
    upToDate=true;  
    updating=false;  
    return;  
}
```

Active/lazy notification

```
void Dispatcher::notify(const Object& x) {
    std::set<LazyObserver*>::iterator
        lit=lOL()->begin();
    std::set<LazyObserver*>::iterator
        lie=lOL()->end();
    while(lit!=lie) (*lit++)->lazyUpdate(x);
    std::set<ActiveObserver*>::iterator
        ait=aOL()->begin();
    std::set<ActiveObserver*>::iterator
        aie=aOL()->end();
    while(ait!=aie) (*ait++)->update(x);
    return;
}
```

- The dispatcher notifies the lazy observers first.
- The active observers can use results from lazy ones.

Visitor

A “Visitor” is an object doing an operation on another object, where both the object and the operation belong to two families each sharing the same interface

- Example: several operations (area, perimeter...) can be performed on several geometric shapes (triangle, square...).
- The object used for the operation “accepts” the visitor.
- A generic visitor can be sent to a generic acceptor object, without knowing the exact derived types.
- The acceptor sends back a pointer to itself, making the visitor recognizing its type.
- In the whole process, two `virtual` function calls occur: the technique is called “double dispatch”.

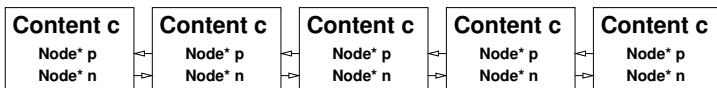
Iterator

An “Iterator” is an object able to navigate across the objects in a collection (e.g. an array)

- An iterator:
 - can be de-referenced as a pointer,
 - encapsulates the operations needed to navigate through the objects.
- A lot of implementations are available in the STL.

Linked list

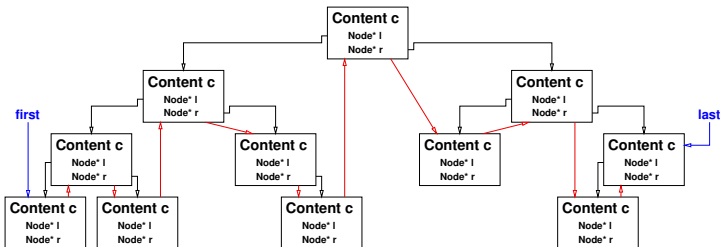
A “linked list” is a collection of objects contained in “nodes” where each node is linked to its neighbours through a pointer



- The navigation through the list requires the handling of the pointers.
- An “iterator” object can deal with that and let the client code to be simpler.

Recursive tree

A “recursive tree” is a collection of objects contained in “nodes” where each node can be linked to a left and a right node through a pointer



- All contents of “left branch” and “right branch” are less or greater, respectively, than the content of the parent node.
- The navigation can be a bit complicated.