Idioms & Design Patterns Behavioral

Patterns and idioms can be grouped roughly into:

- Creational Patterns and idioms

  Singleton, Factory Method, Abstract Factory

  Named constructor

- Structural patterns and idioms

  Composite, Facade, Adapter

  Compiler Firewall

- Behavioral patterns and idioms

  Observer, MVC - more

  Double-dispatch

- Idioms are small-scale patterns, in this context
- Design patterns come in two basic flavors:

  Using one or more base classes to hide details from the client
  - One thing about most of the design patterns: presented in a very general form
    E.g. normally everything has an abstract base class that defines the working interfaces between the parts of the pattern
    But an actuall implementation might not need this - the abstract base can be collapsed into a single concrete class
  - E.g. Factory

  Other clever ideas using encapsulation, interfaces, class responsibilities to hide details from the client.
  - e.g. Singleton

Key concepts for using design patterns:

- Take the class relationships and the details seriously!

  You aren't taking advantage of the design pattern just by having some classes with the "buzzword" names organized kinda like the pattern. The exact way in which the classes relate to each other, and how key details are handled, is where the real power of the pattern is!

- The goal of many of the patterns is to achieve easy extensibility, at the expense of some verbosity and some run-time overhead.

  This means that a special case solution to a design problem will take less code, and maybe run faster, but it will be much harder to generalize when new features and capabilities get added to the code.

  The need to extend a program is very common, even if it wasn't planned for.

  Either use a design pattern from the beginning, to allow for future extensibility, or be ready to refactor the special case solution to make use of a design pattern so that future extensions will go more smoothly.

  So the goal of the patterns is not short code, or fast code, but easy-to-extend code.

Behavioral Patterns

Pattern: Observer

- Example usage: e.g. different windows that show different views of data for the same data set, stay up-to-date as data changes; add/remove window views at run time
- Purpose: Allow an arbitrary collection of objects to depend on another so that when it changes state, all of the dependent objects are notified and updated automatically. You need to notify a varying list of objects that an event has occurred.
- Solution: A Subject object keeps a list of Observer objects. Whenever the Subject changes state, it broadcasts an update event to all of its Observers. The list of Observers can change at run time.
- Advantage: Decouples Observers and Subjects

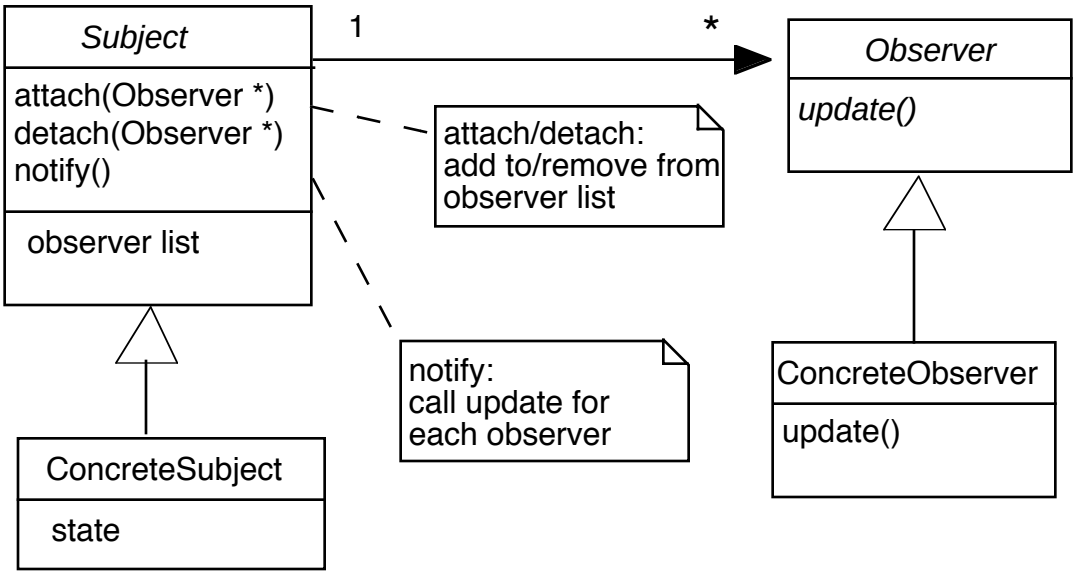
  The update and accessor interfaces define how they interact; - keeps e.g. display of data decoupled from generating the data

  Which observers are observing which subjects can be defined or changed at run time, which also means additional observer types can be added without changing the Subject code.
- Abstraction: Observers can be a base class so that different Observer classes can share the same interface and do different things. Likewise for Subject.

  Often, there is only one possible Subject, so the base class and the Concrete Subject are combined into a single concrete class.
- Basic Pattern principle: Figure out what could vary, and hide it - usually behind a base class.
- Also called publish/subscribe, closely related to Model-View-Controller
- Additional: Subject has attach/detach methods that are used to add or remove Observers. Information needed by the Observer can be provided in two ways:

  Push - Subject includes the relevant information as parameters of Observer update function.
  - Pro: Observer can be completely decoupled from Subject if parameter types permit.
  - Con: Observer interface more complicated - best with with specialized update functions.

  Pull - Observer has a way to get the relevant information from Subject.
  - Pro: Obsever interface can be very simple.
  - Con: Need access to Subject, and typically end up with some coupling to inteernals of Subject. - conflicts with major advantage of the pattern.
- UML picture


Subject
attach(Observer *)
detach(Observer *)
notify()
observer list
1
*
Observer
update()
attach/detach:
add to/remove from
observer list
notify:
call update for
each observer
ConcreteObserver
update()
ConcreteSubject
state

Pattern: Model-View-Controller

- Elaboration of Observer pattern for user interfaces
- A good approach to the problem of how to separate the functionality "engine" underlying an application from the User Interface code.

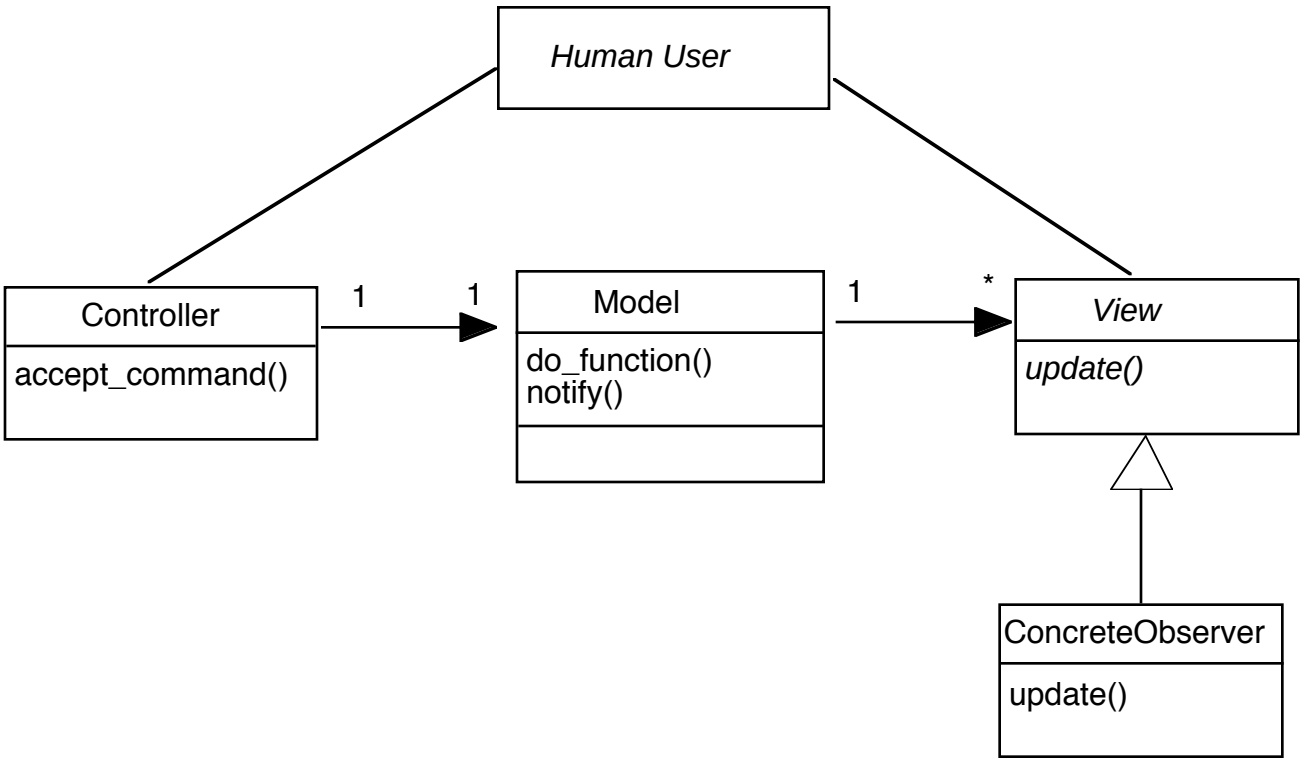
  Important because there is a tendency for the functionality code to get intertwined with the UI code, making it difficult to change either one - either for revisions/modifications, or to port to a different UI library or platform
- Based on Observer:

  The "Model" is the Subject - contains the application's data and the functionality engine.
  - Has interface to access and control state

  The "Views" are the different windows, etc, that function as "Observers" - dynamically changeable displays of the state of the application
  - are driven by update notifications from the model
  - either "pull" the data out of the model when they need to draw
  - or the model "pushes" the data into the View, which remembers the relevant data and draws it when told to draw - common GUI pattern

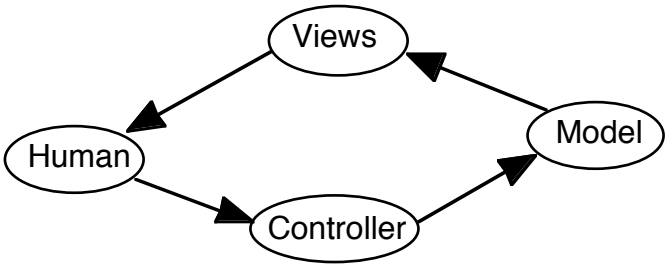
  The "Controller" is the module that the human user uses to control the application.
  - controls the Model
  - creates/destroys views, and attaches/detaches them from the model
  - in command-language interfaces, probably one one such object

  UML diagram

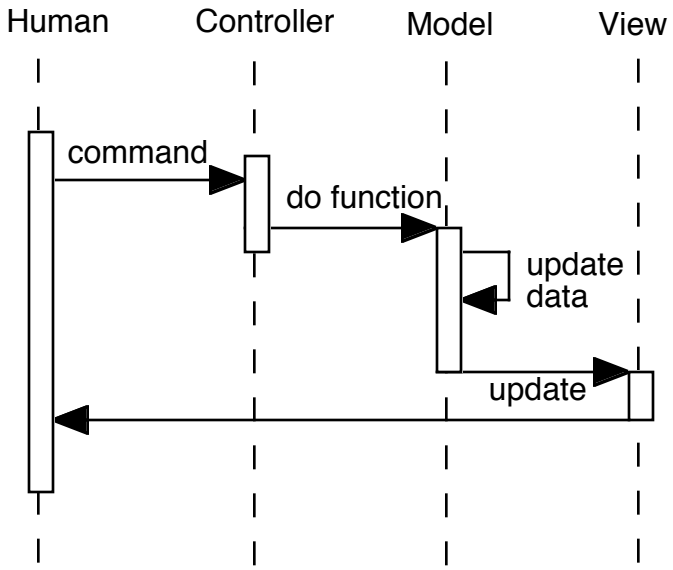


Flow of control:

- human user operates the Controller to tell the Model what to do. Model tells the Views what has changed. Human looks at the Views to decide what to do next.

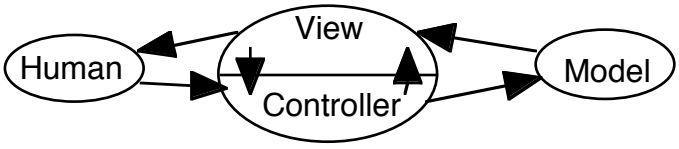


- UML sequence diagram



- In GUIs, common for the View and the Controller to be tightly coupled, Model-(ViewController)

  e.g. user tells Model what to do by using Controller functions tor selecting or manipulating objects on the View.



important distinction: two levels of MVC logic in a typical GUI

- GUI "widgets" - e.g. buttons, menus
  typically predefined customizable classes
- application window display - e.g. drag operations on application-specific contents
  typically completely application-specific

Typically each manipulatable object on the display is a distinct ViewController object
- so there are many possible ViewControllers

- Key to success is enforcing the strict flow of control and decoupling

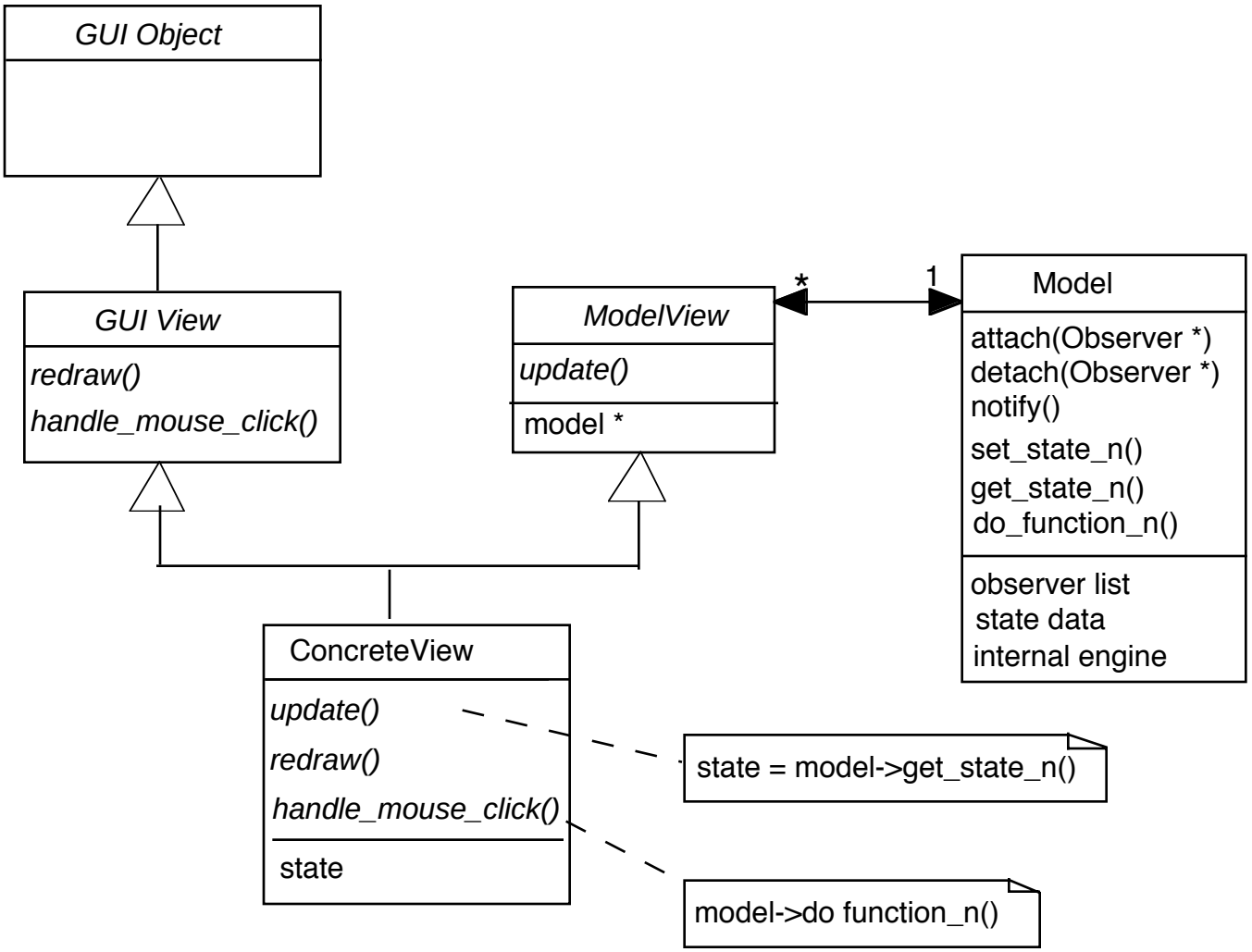
  Controller controls the model which updates the View
  - Mischief, difficulty happens when updating is not triggered by the Model

- in typical GUI library, there is a class hierarchy of GUI objects

  Do not want to couple Model views with the GUI views
  - Either have to modifiy GUI library, or else Model has to couple to specific GUI library

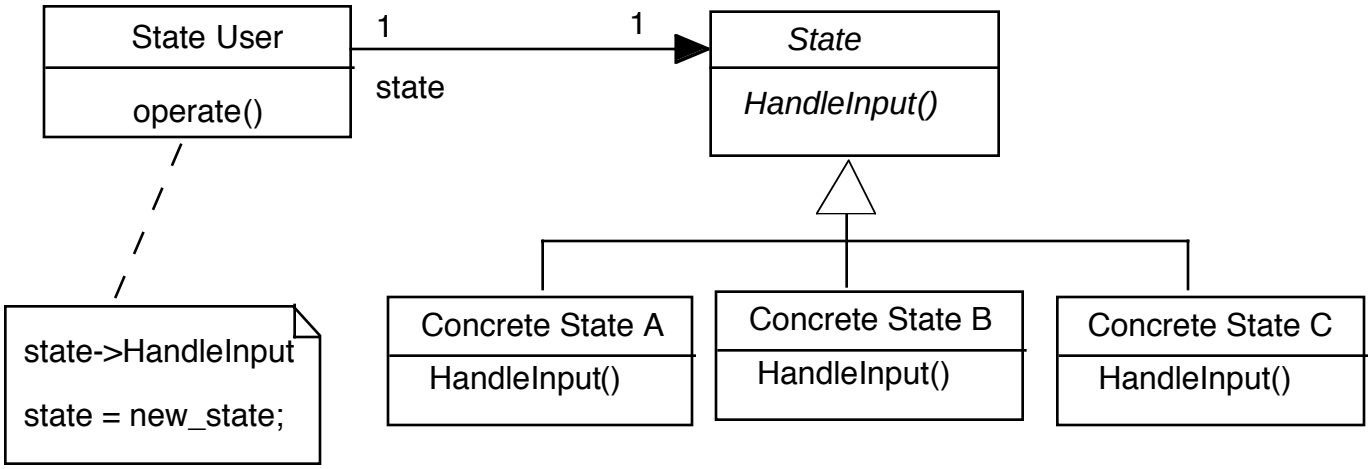
  Use adapter pattern to adapt Model View class to GUI Class hierarchy - a "class adapter" works especially well.

  Can use Multiple Inheritance to attach the Model View's interface to the appropriate class in the GUI library



State Pattern

- Problem: You have a system consisting of a bunch of functions that change their behavior depending on a relatively small set of state changes. Traditional solution is to have lots of tests or switches on the state in the functions.
- Instead, have a class for each state, whose functions behavie appropriately for that state. Use a base class to define the common interface for all of the functions. Change state by changing a pointer to point to an object of the appropriate type. Call the functions through this pointer.



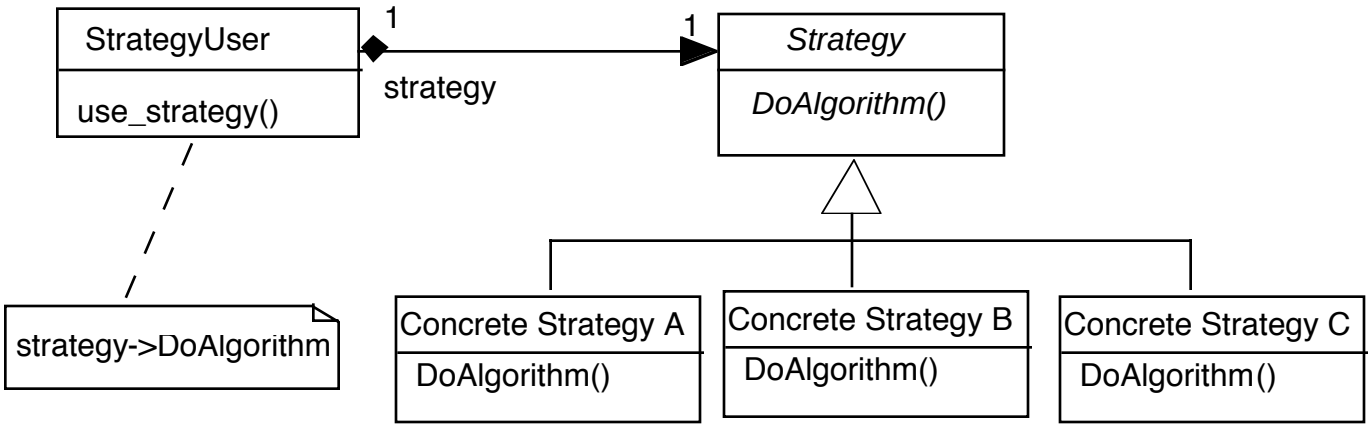
Note that you only need one object for each state.

Note that its fine if the state objects have no member variables.

- What varies: The system state. Hidden under a base class.

Strategy Pattern

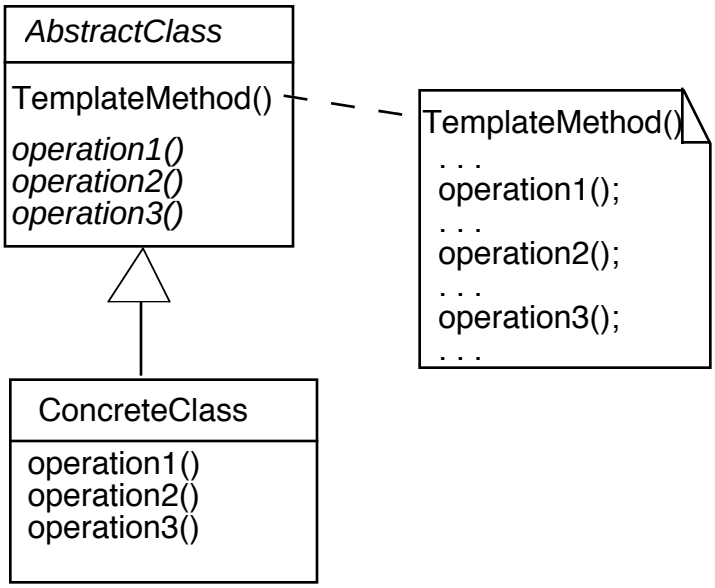
- Similar to state:
- Problem: Allow for changes in the algorithm or strategy used to do something, both for future extensions, and run time changes.
- Solution: Represent the common interface for all of the algorithms with a base class; instantiate the concrete class for the required strategy, and call it. The strategy can be changed at any time by using a different concrete class object.



- What can vary: The specific algorithm; Hidden under a base class.

"Template" Method Pattern

- Problem: You have a lot of different ways of doing a basic process, but some of the individual steps are different depending on which particular way you are using. But the basic process is always the same.
- Solution: A base class has a "template" method that represents the basic way the process is done - the "template" for the process (this is NOT a C++ template). The steps in the process are done by calling virtual member functions in the same class. Concrete derived classes override these virtual functions to represent the specific way the steps should be done.



Note that the base class method does virtual calls down to virtual functions overridden by the derived class. Unlike the usual pattern where a the most derived virtual function is called directly by the client, and then might call base class functions. This base-to-derived virtual calling sequence is the "Hollywood principle." - Don't call us, we'll call you.

- What varies: the exact content of each step; hidden behind virtual functions, while base class template method defines what stays constant

Non-virtual Interface Pattern

- Resembles Template Method Pattern
- Problem: You have a polymorphic class hierarchy, but need to separate the implementation provided by each derived class from the base class interface. For example, suppose you want all the virtual functions to share some behavior, differing only in specifics associated with derived classes. You forsee a need to change this sort of thing often.

  E.g. you want all of the functions to check preconditions, generate some logging information at beginning and end of execution.
- Note that conventional public virtual functions supply both interface and derived-class specific implementation.
- Solution: Make the base class public interface functions NON-VIRTUAL. This means they will always be called, not bypassed like virtual functions would be. They call the virtual functions to allow for different implementations. These virtual functions are protected, in the derived classes need access to them, or are private if not.

  Like a template method setup, except for removal of the virtual functions.from the public interface.

- Allows the public interface into the class hierarchy to be stable and always involved because it is non-virtual.
- Allows the implementation to be done in terms of virtual functions that are not in public interface.
- NVI version - zap() is the public interface; behaves as if virtual but with common behavior

```
#include <iostream>
using namespace std;

class Base {
public:
	void zap() {
		cout << "Start zapping!" << endl;
		defrangulate();
		degauss();
		transmogrify();
		cout << "Done zapping!" << endl;
		}
protected:
	virtual void degauss()
		{cout << "Base deguass" << endl;}
private:
	virtual void defrangulate()
		{cout << "Base defrangulate" << endl;}
	virtual void transmogrify()
		{cout << "Base transmogrify" << endl;}

};

class Derived0 : public Base {
private:
};

class Derived1 : public Base {
private:
	virtual void defrangulate()
		{cout << "Derived1 defrangulate" << endl;}
};

class Derived2 : public Base {
private:
	virtual void transmogrify()
		{cout << "Derived2 transmogrify" << endl;}
	virtual void degauss()
		{cout << "Derived2 deguass" << endl;
		Base::degauss();	// do Base's version also
		}
};


int main()
{
	Derived0 d0; Derived1 d1; Derived2 d2;

	(&d0)->zap();
	(&d1)->zap();
	(&d2)->zap();
}

/* Output
```

```
Start zapping!
Base defrangulate
Base deguass
Base transmogrify
Done zapping!
Start zapping!
Derived1 defrangulate
Base deguass
Base transmogrify
Done zapping!
Start zapping!
Base defrangulate
Derived2 deguass
Base deguass
Derived2 transmogrify
Done zapping!
*/
```

- For comparison, the conventional virtual public interface version

Memento Pattern

- Problem: One component needs to save and restore the state of another component, whenever it wants, and without having to know anything about the internals of the component.
- Solution: The controlling component asks the component whose state is being saved/restored (the Originator) to create a Memento object whose contents are private for all other components. The Originator gives the Memento object to the controlling component (the Caretaker). When the Caretaker wants the Originator to return to a previous state, it gives the corresponding Memento object to the Originator, who then uses the information in the Memento to restore itself.

  In C++, Memento should have all members private, but declare Originator as a friend; This encapsulates all of the state information.

- Sketch example:

```
class Memento {
private:
        friend Originator;
        int i;
        int j;
        Memento();
};

class Originator {
public:
        Memento * create_memento() {
                Memento * m = new Memento;
                m->i = i;
                m->j = j;
                return m;
                }
        void use_memento(Memento * m) {
                i = m->i;
                j = m->j;
                }
private:
        int i;
        int j;
};

in Caretaker:
Originator originator;
vector<Memento *> saved_states;

// save the state
        Memento * m = originator.create_memento();
        saved_states.push_back(m);

// restore state n
        Memento * m = saved_states[n];
        originator.use_memento(m);
        // originator is now in state
```

  multiple states stored, and a chosen one restored

- What varies:

  details about what might be part of the saved state - hidden inside the object;

what the caretaker might do with it - not part of originator's responsibility

Chain of Responsibility

- a series of class objects in a chain

  first object in chain is given a request

  each object either handles it or passes it to the next object

  decouples originator of request from handler of request

- often used in GUIs -

  if a derived class object can't handle the user command, hand it to the base class object to handle, and so on up to the top level of the application.

  enables each object to respond to the commands it is interested in

Command

- put all the information for an action in an object, using abstract interface for them, e.g. virtual void execute();

  class AbstractCommand {
  - public:
  - virtual void execute() = 0;
  - virtual void undo();
  - };

  class ConcreteCommand1 : public AbstractCommand {
  - public:
  - virtual void execute();
  - virtual void undo();
  - private:
  - // member variables
  - };

  client has e.g. perform(AbstractCommand *), e.g. queue<AbstractCommand *>, etc.

- objects can be kept in a queue, passed from one place to another, created by different parts of the program

  e.g. command line, menu item, button could all create the same "save" command object, with its data (e.g. file name).

- when it is time to do the action, call its execute method - does whatever needs to be done.

  necessary information is stored internally

- To undo the action, call its undo() method - the object has all of the necessary information stored internally, and the method knows how to reverse the operation.

An example

- my action processor - a combination of template method and command objects

  the action processor has a template method
  - each action is first prepared, then executed, then finish step done.
  - can be processing an action in each stage, but each one can be entered only if previous action has completed it.

  action objects have a common prepare, execute, finish abstract base class
  - each specific action class overrides these functions according to the kind of action it implements.

  elsewhere in the system, a series of action objects are created and then sent to an action processor

Technique: Double dispatch, multimethods - function called depends on the type of more than one object

- In C++, run-time polymorphism depends on the type of one object

  if f is a virtual function defined in a base class, and p is Base *, then p->f() will call the version of f that is defined for whatever type of object p is actually pointed to.

- But what if we want to execute a function that depends on the run-time type of more than one object?

  trivial at compile time and if object types are known - just use function overloading: f(Derived1 *, Derived2 *)

  But at run time, we normally have base type pointers:

  Base * p1 = new Derived1;

  Base * p2 = new Derived2;

  call a function with p1 and p2 involved, run the version of it that corresponds to Derived1 and Derived1, Derived1 and Derived2, etc.

- Some examples:

  Symmetrical cases
  - Collisions in a space game
    torpedo, spaceship, spacestation
  - Intersecting shapes
    circle, rectangle, ellipse

  Assymmetrical cases - more common
  - GUI
    window types - different widgets
    kinds of input events
    top level of code is a loop around handling events
    get an event - e.g. left mouse button down
    determine which widget it is happening in - e.g. window
    execute a piece of code that depends on the kind of widget and the kind of event
  - Event-driven simulators
    events happen in simulated time
    processors do things in response to the events
    what happens depends on the kind of processor and the kind of event

- In general, dispatching code based on two types is pretty common and important - double dispatch - in general, multiple dispatch, multimethods

  C++ doesn't directly support it at all!!

  Other languages do - e.g. CLOS
  - defmethod foo(Derived1 o1, Derived1 o2)
    {code for this combination}
  - defmethod foo(Derived1 o1, Derived2 o2)
    {code for this combination}
  - defmethod foo(Derived1 o1, Derived3 o2)
    {code for this combination}

- So how do you get the same result in C++? Relatively awkward because the compiler doesn't do very much of the work for you.

  Might-have been -
  - intersect (virtual Shape * s1, virtual Shape * s2);

- Three general ways to get it - all with problems.

  Combination of virtual functions and overloaded functions - asymmetrical case
  - Hierarchy of Processor, Event base classes
  - Top level

    ```
    Event * eptr = // next event to process
    Processor * pptr = // next relevant processor
    eptr->send_self(pptr);  // execute the function for the combination of event and processor
    ```
  - class Event

    ```
    virtual void send_self(Processor * p) {}
    ```
  - class A_event : public Event

    ```
    virtual void send_self(Processor * p)
        {p->handle_event(this);}
    ```
  - class B_event : public Event

    ```
    virtual void send_self(Processor * p)
        {p->handle_event(this);}
    ```
  - class Processor

    ```
    virtual void handle_event(A_event *  e) {}
    virtual void handle_event(B_event * e) {}
    ```
  - class Processor1 : public Processor

    ```
    virtual void handle_event(A_event * e) {//  code for P1 A }
    virtual void handle_event(B_event * e) {// code for P1 B }
    ```
  - class Processor2 : public Processor

    ```
    virtual void handle_event(A_event * e) {// code for P2 A}
    virtual void handle_event(B_event  * e) {// code for P2 B}
    ```
  - Pros

    Slick, extremely fast, correctness enforced at compile/link time
  - Cons

    Adding a new event or processor type requires modifications in base class

    Unsuitable for a library that the user is not supposed to have to modify

Combination of virtual functions and overloaded functions - symmetrical case

- Hierarchy of Shapes, compute intersections of them
- top level

```
Shape * s1 = new Rectangle, * s2 = new Circle;
result = s1->intersect(s2);
```

- class Shape {

```
virtual bool intersect(Shape *) = 0;
virtual bool intersect(Rectangle *) = 0;
virtual bool intersect(Circle *) = 0;
}
```

- class Rectangle : public Shape {

```
virtual bool intersect(Shape * s)
    {return s->intersect(this);}
virtual bool intersect(Rectangle *) {//compute Rectangle/Rectangle}
virtual bool intersect(Circle *) {//compute Rectangle/Circle}
}
```

- class Circle : public Shape {

```
virtual bool intersect(Shape * s)
    {return s->intersect(this);}
virtual bool intersect(Rectangle *) {//compute Circle/Rectangle}
virtual bool intersect(Circle *) {//compute Circle/Circle}
}
```

- result = s1->intersect(s2);

```
s1->goes to rectangle::Intersect(Shape * s)
    s-> goes to Circle::intersect(Rectangle) {// compute Circle/Rectange
```

- Pros

```
very fast, compiler enforces correctness
```

- Cons

```
if you add another Shape type, base and all sibling classes have to be modified
unsuitable for a library that the user is not supposed to have to modify
```

Another interpretation and application of this concept

- If an object from a class in a hierarchy wants to know what kind of object it has a pointer to from a different class hierarchy, can use double-dispatch to have that other object "tell" the first one what it is by what function it calls in the first object:
- Can eliminate need to interrogate type of other object by RTTI
- A::do_something(Base * b) {

```
b->call_back_to_me(this);
}
```

- A::do_something1() {here if b is a D1}
- A::do_something2() {here if b is a D2}
- class Base {

```
virtual void call_back_to_me(A *) {}
};
```

- class D1 : public Base {

```
virtual void call_back_to_me(A * a)
    {a->do_something1();}
};
```

- class D2 : public Base {

```
virtual void call_back_to_me(A * a)
    {a->do_something2();}
};
```

- If do_something1 and do_something2 are also virtual functions for a class hierarchy, you have the full double dispatch

Combination of virtual functions and switch on type

- Crude version - commonly seen in GUI frameworks
- user generates a stream of events - mouse moves, clicks, keys, etc.
  events have different types - e.g. an enum Event_type.
  example: mouse button is pressed down - what function should be run?
  depends on where the mouse is pointing.
- Widget class has a function
  virtual void handle_event(Event_type e).
- each widget (window, button, menu item, etc) on the screen is associated with a region of the screen.
  base class is Widget
  bool point_is_in_me(Mouse_point p);
  figure out which widget the mouse is pointing to, save as Widget * widget_ptr.
- call widget_ptr->handle_event(event_type);
  automagically calls the event handler for the kind of widget -e.g. a button.
- Button::handle_event(Event_type e)

```
switch(e) {
    case BUTTON_DOWN:
        /* button has been pressed - do button pressed stuff */
    case BUTTON_RELEASED:
        /* button has been released - do button released stuff */
    etc
    default:
        /* can't handle this event - ignore it  or call base classes handle_event to
        deal with it*/
        }
```

- Pros
  traditional, simple
- Cons
  tedious code - GUI framework + "wizards" can automate a lot of this;
  Clever ways also to delegate events so that the switch in a widget only has to switch on the cases it is interested in - using the Chain of Responsibility pattern
  Can be serious maintenance problem - but not so bad if event types are relatively few and pretty stable
  Which they tend to be in GUI frameworks - only a few kinds of basic user actions - determined by the standard hardware on the machine.
  move the mouse, press/release buttons, hit a key on the keyboard
  But tends to get complicated as the event handling concept is so flexible, used for more than just user-generated events, so opens maintenance problems.

Slicker version - use a map from typeid to function pointers to replace switch on type

- if symmetrical can double this up

Fast table look up - see Alexandrescu

- Alexandrescu, Andrei, Modern C++ Design: Generic Programming and Design Patterns Applied. Addison-Wesley, 2001.
- use a 2D vector (of vectors) of function pointers - fill up at beginning, then access at run time
- write a registry function that gives each class a unique ID number, store those function pointers at those (i, j) cells
- to dispatch a function call, get Id number for each type, execute the function in that i, j cell

Some others

- Iterator

- Visitor