7

- Design patterns
  - Definition
  - Example
- Design Patterns in Distributed systems
  - Observer
  - Command
  - Memento

Design patterns

- Definition
  - A **design pattern** is a tried & tested **solution** to a common **design problem**
- Compare with problem frames:
  - A problem frame is a common form of **a problem**
  - A design pattern is a common form of **a solution**
    - … in the **design** space – there are also patterns in the implementation, e.g. standard bits of code
- As for all patterns, it's an idea, not a rule
  - Amenable to adaptation

Design patterns

- A design pattern is characterized by
  - A **name**
  - A description of the **problem** it aims to solve
  - A description of the **solution**
    - Elements of the design
    - Relationships among them
      - Interactions, responsabilities, collaboration
  - A discussion of the **consequences** of applying the pattern
    - Design trade-offs

An example: MVC

- One of the most famous patterns: **Model-View-Controller**
- Originally introduced in the Smalltalk-80 base library
- **Problem**: a good general way to handle user interface components
- **Solution**: use three different objects, with well-defined interfaces but arbitrary implementations
  - Model, View, Controller

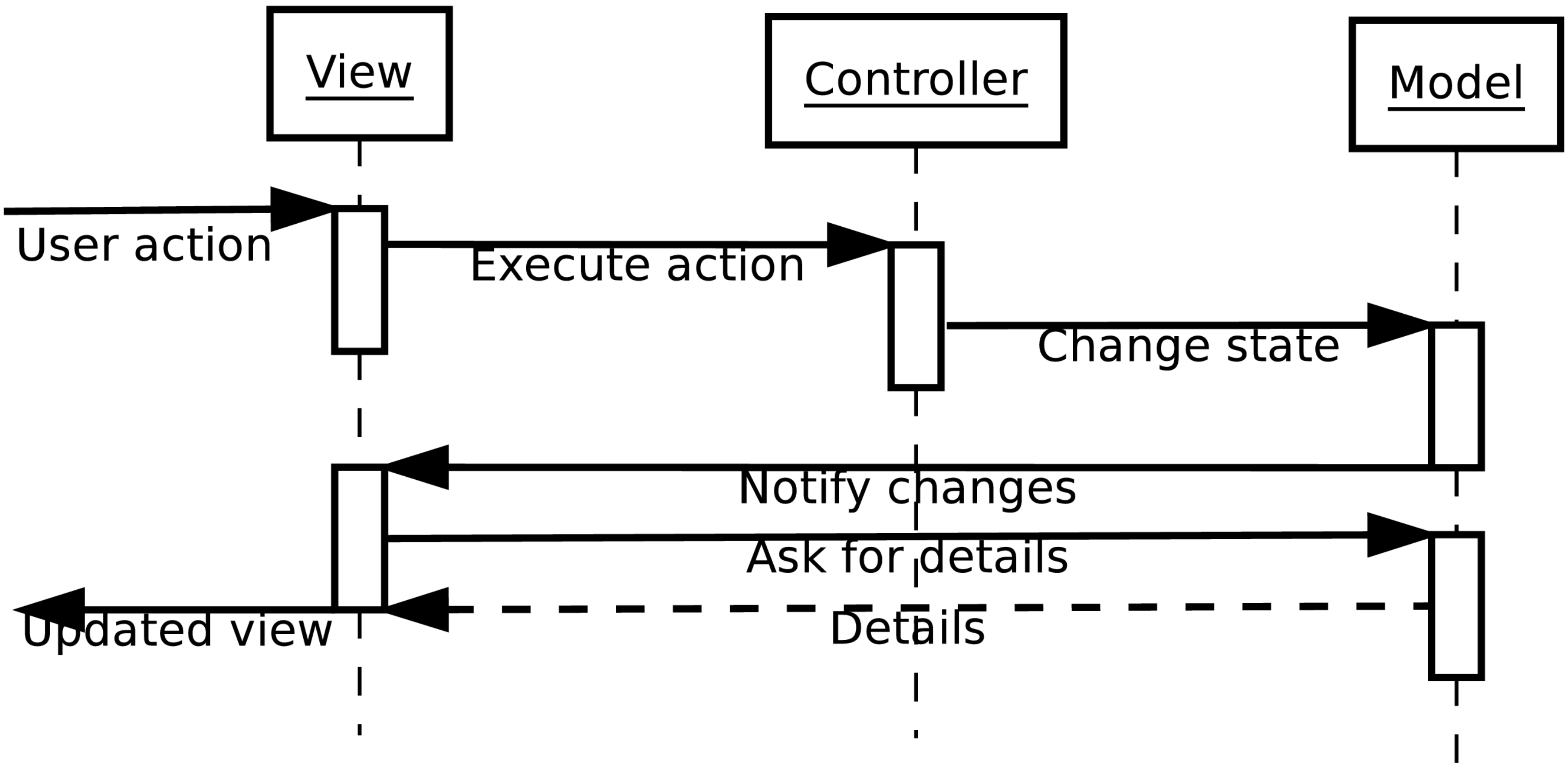
An example: MVC

- **Model**: an object that provides a purely abstract description of the “thing” that is to be represented by the UI control
- **View**: an object that, given the data in the Model, can render it on-screen in some form
- **Controller**: an object that, given some user input (e.g., a mouse click or keypress), alters the Model (or possibly the View) according to user's intentions

An example: MVC

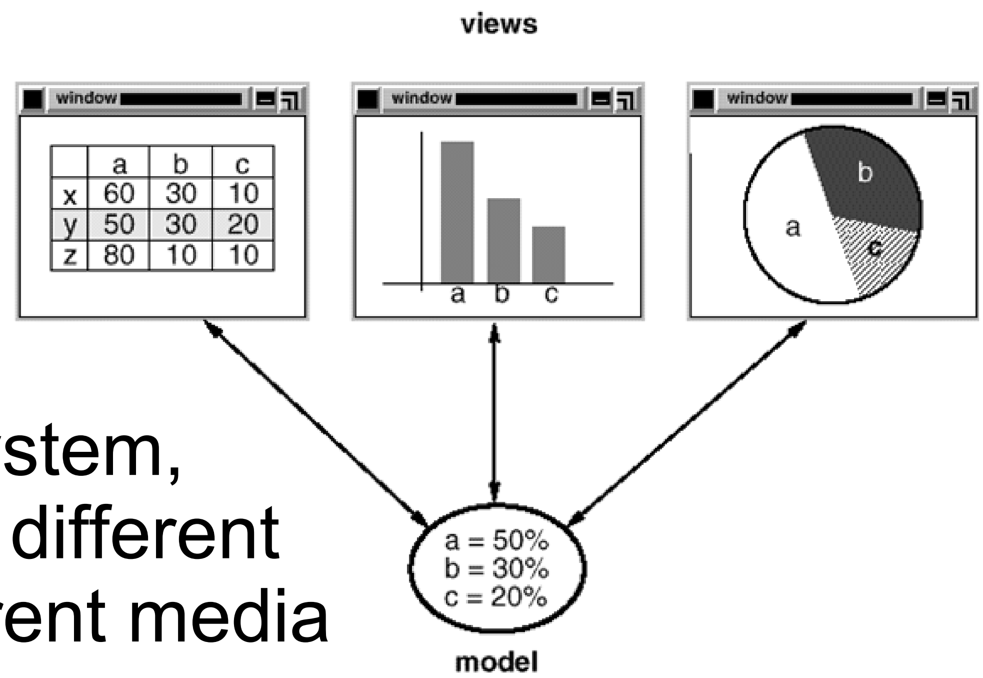
- The relationship between Model, View and Controller is **dynamic**
  - It can be set-up and changed at runtime
    - e.g., need to disable a GUI element to prevent issuing of invalid commands? Change its Controller to a dummy one that ignores all user input
- Each object has precise **responsabilities**
  - Described in terms of the **interfaces** it must offer to other objects
    - e.g., all Controllers must implement the same interface, regardless of their actual class

An example: MVC



An example: MVC

- The basic MVC pattern uses 1:1 relationships between Model, View, Controller
- With further massaging, these can become *n*:*m* relationships
- Most often seen as multiple views for the same model
  - Hint: in a distributed system, each view can be on a different machine and use different media



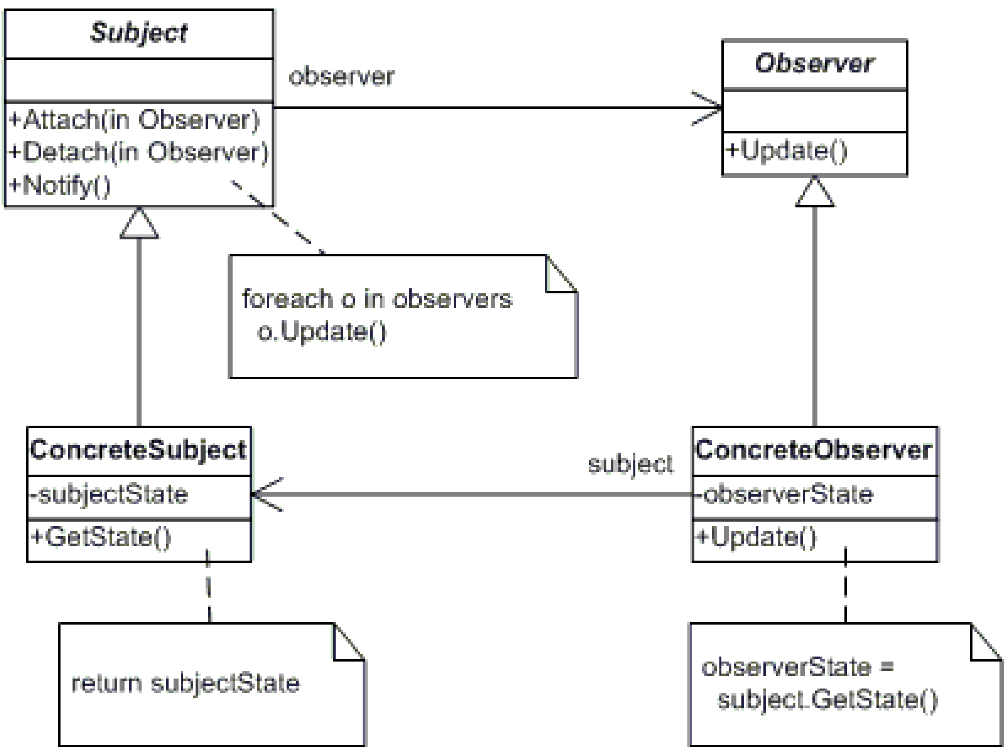
Design patterns in distributed systems

- Most design patterns assume that...
  - Objects have a private state
  - Objects can communicate by invoking operations
  - Objects can exchange arbitrary data as parameters attached to such operations
  - Objects have their own control flow
    - Either their own thread, or hijacking the control flow of the caller
- All these properties can be scaled up to units of a distributed systems
  - Computation + memory + message-passing

The Observer pattern

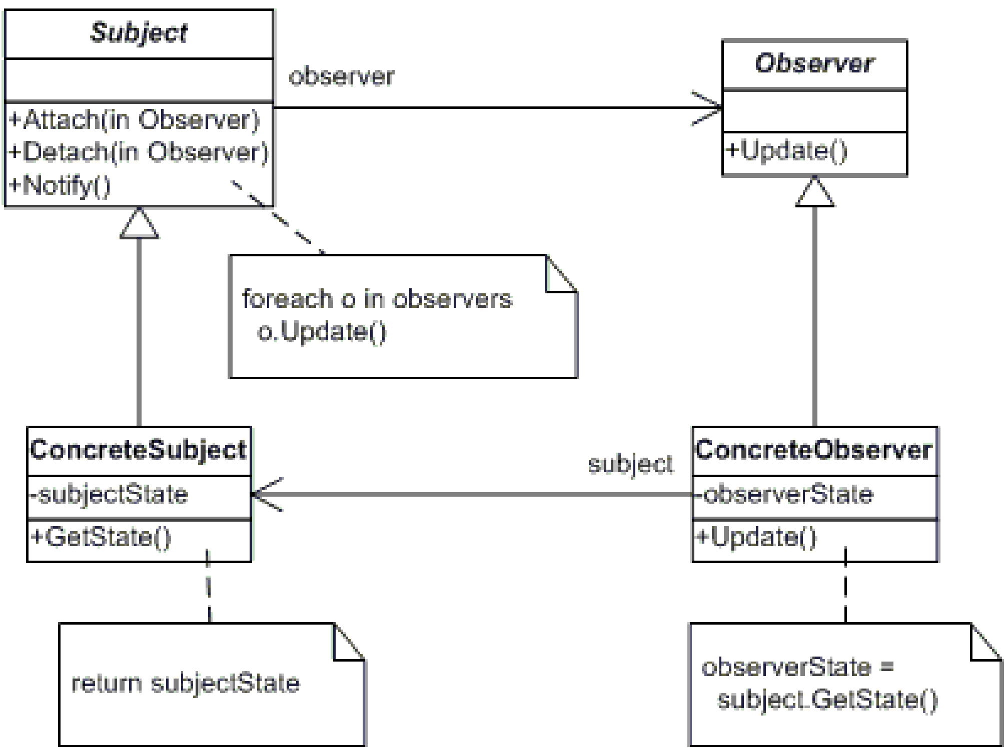
- "Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically"
- This allows to keep a single copy of the data, and have multiple other objects depend on them
  - Used e.g. in multi-view MVC
  - Can be used for asymmetric replication and notification in distributed systems

The Observer pattern



- Subject (interface)
  - The thing to be observed
  - Maintains a set of observers
- ConcreteSubject (object)
  - Has the actual state
  - Provides operations to retrieve and alter the state

The Observer pattern



(note: applicable to parts of state)

- Observer (interface)
  - The thing to be notified
- ConcreteObserver (object)
  - Has a local copy of the remote ConcreteSubject state
  - Goal is to keep the copy up-to-date

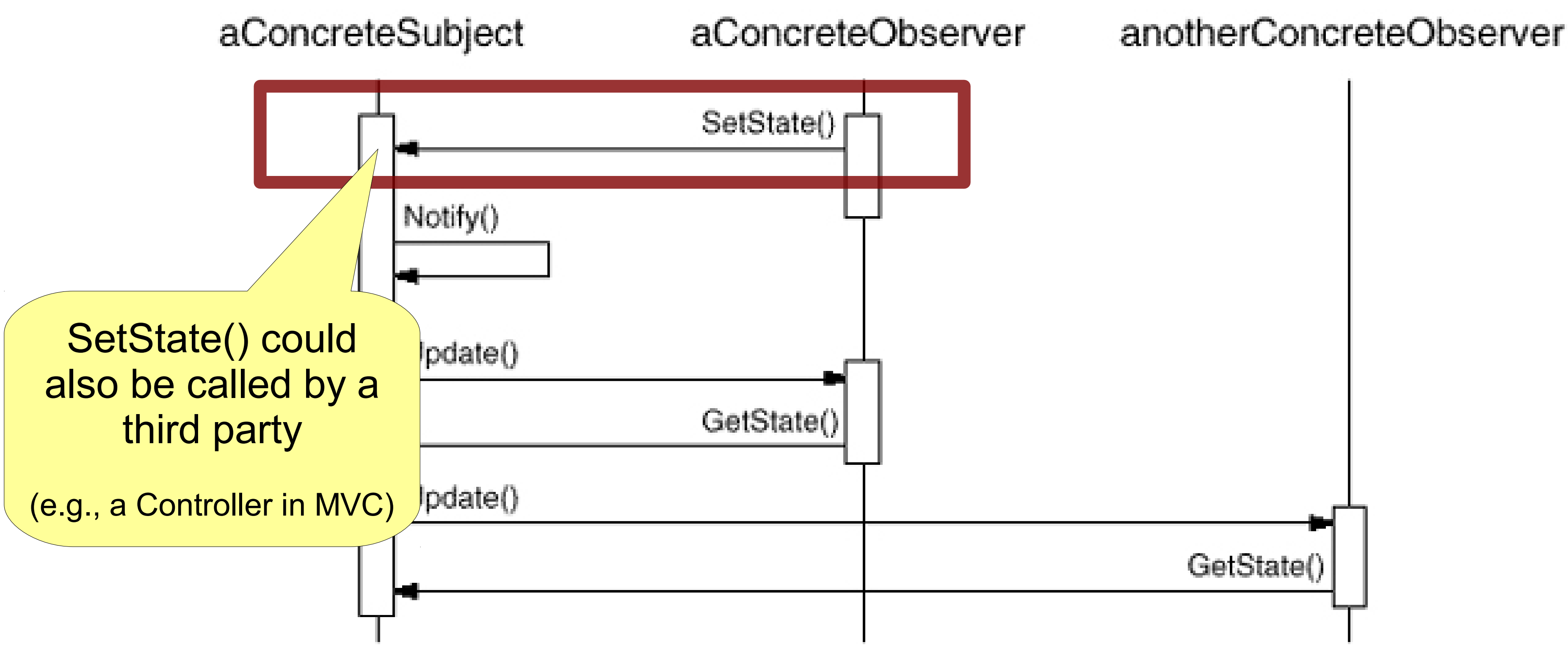
The Observer pattern

- Registration
  - a.k.a., *Subscribe*
- An observer calls subect.attach(self)
- The subject adds the observer to the set of current observers

- De-registration
  - a.k.a., *Unsubscribe*
- An observer calls subject.detach(self)
- The subject removes the observer from the set of current observers

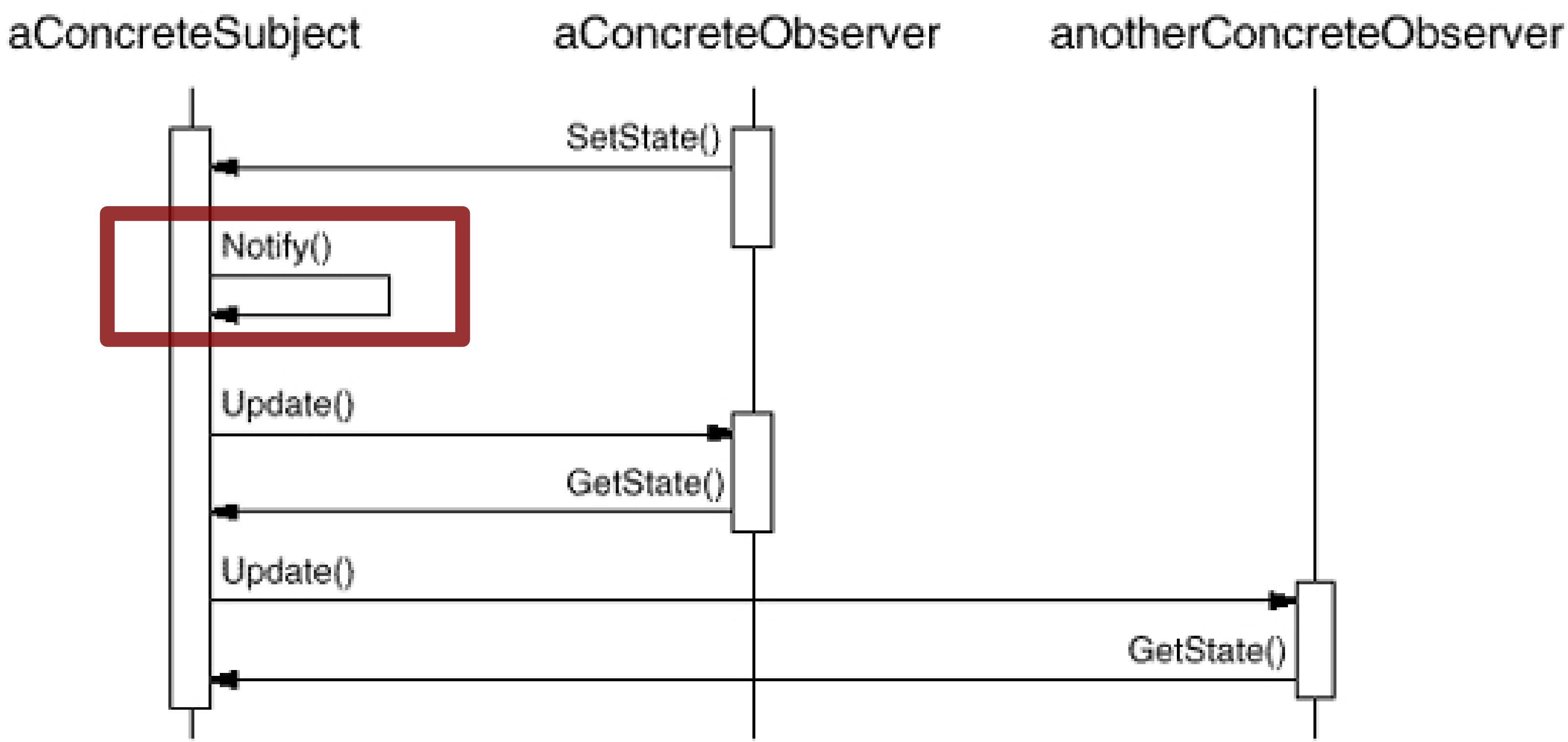
The Observer pattern

- The state of ConcreteSubject changes
  - Due to a call to a setState() method or due to some autonomous event



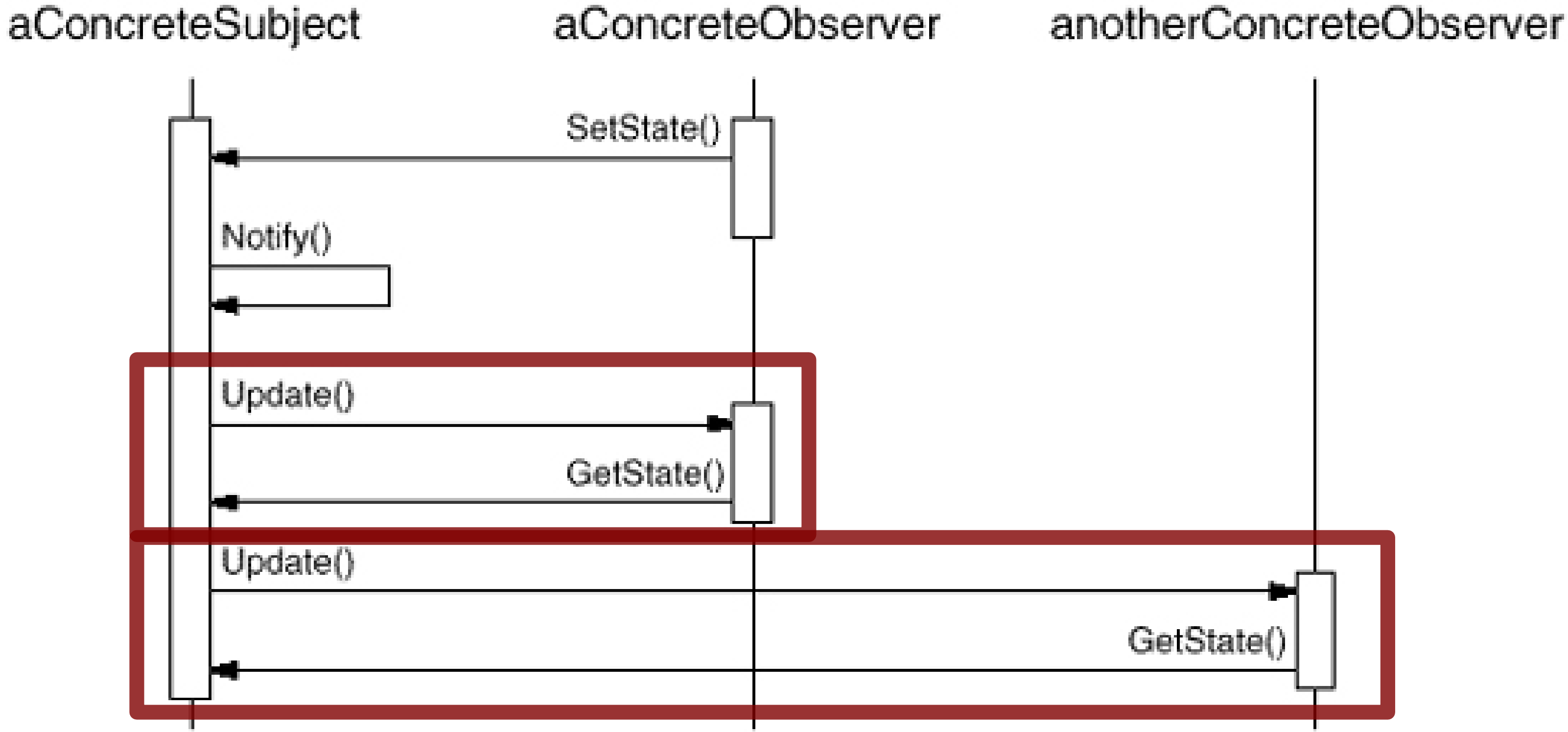
The Observer pattern

- ConcreteSubject calls notify() of Subject
  - Most often, Subject is an abstract class implementing notify() — could also be an interface



The Observer pattern

- Notify() loops over all registered observers
  - Calling update() on each
  - Each observer calls getState() on the subject



Observer vs. Publish & Subscribe

- The Observer pattern is a variation of a more general protocol known as **Publish & Subscribe**
- The Subscribe part is identical to registration and de-registration via attach() and detach()
- The Publish part is more general
  - In Observer, the only cause for broadcast are changes in the state
  - In P&S, any event can be published
    - Details of the event are often sent as parameters of update(), not retrieved via separate getState()s

Implementation of Observer

```
public class Subject {
  List<Observer> obs = new ArrayList<Observer>();

   public Observable() {  super();  }
   public void attach(Observer o) { obs.add(o); }
   public void detach(Observer o) { obs.remove(o); }
   public void notify(Object data) {
      for (Observer o: obs) o.update(this, data);
   }
 }
```

Adapted (and simplified) from java.util.Observable

Implementation of Observer

```
public interface Observer {
    public void update(Subject s, Object data);
}
```

Adapted (and simplified) from java.util.Observer

Implementation of Observer

```
public class concreteSubject extends Subject {
    declarations for concrete state
    constructors etc.
    public void setState(args) {
        updates state based on arguments
        this.notify(object describing change)
    }
    public State getState(args) {
        return state based on arguments
    }
}
```

Implementation of Observer

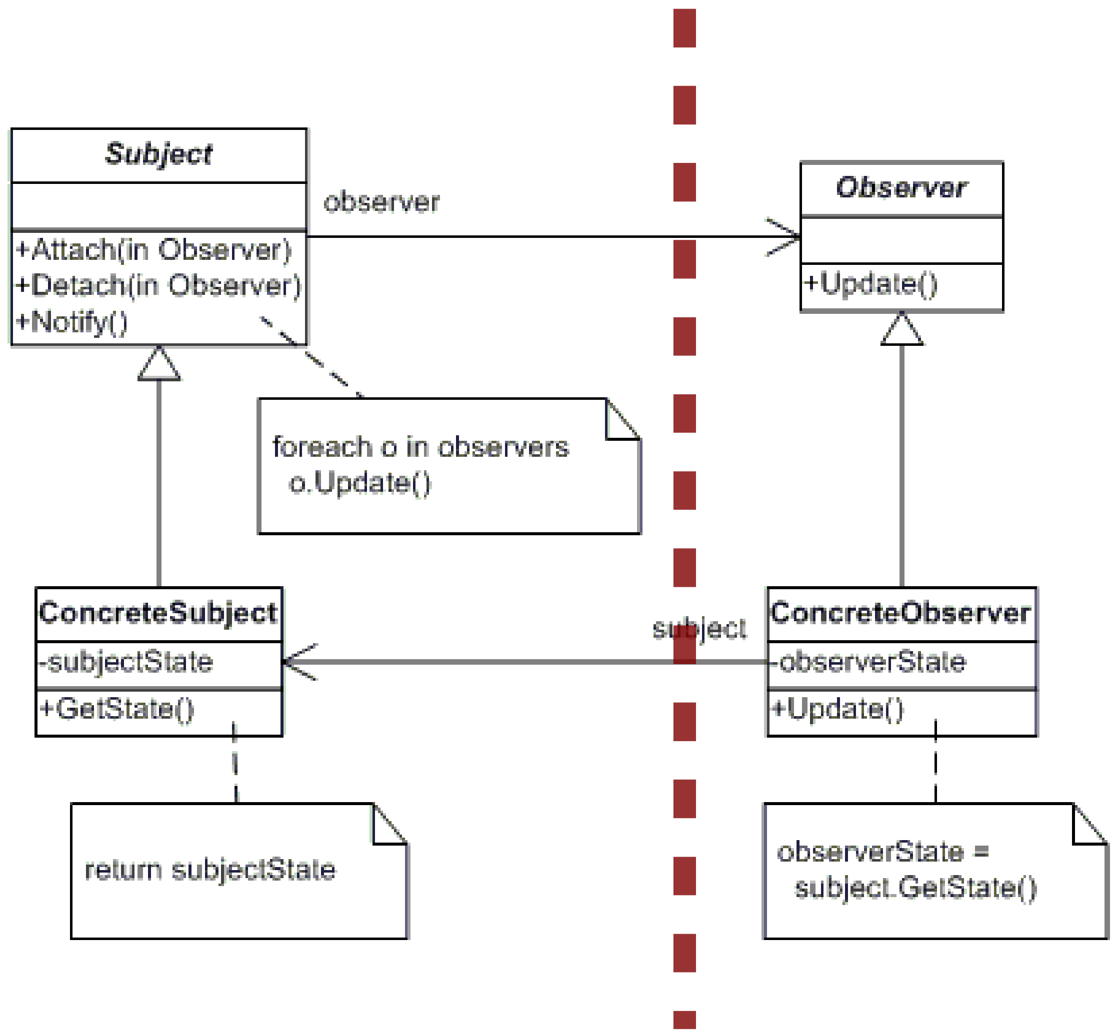
```
public class concreteObserver implements Observer {
   ...
   public void update(Subject s, Object data) {
      ObservedState = s.getState(args);
      Reacts to changes – for example, by
      updating a local copy of the Subject's state,
      or by redrawing a View, etc.
   }
   ...
}
```

<u>Note</u>: we have omitted for clarity

- Error checking
- Synchronization
- Optimization

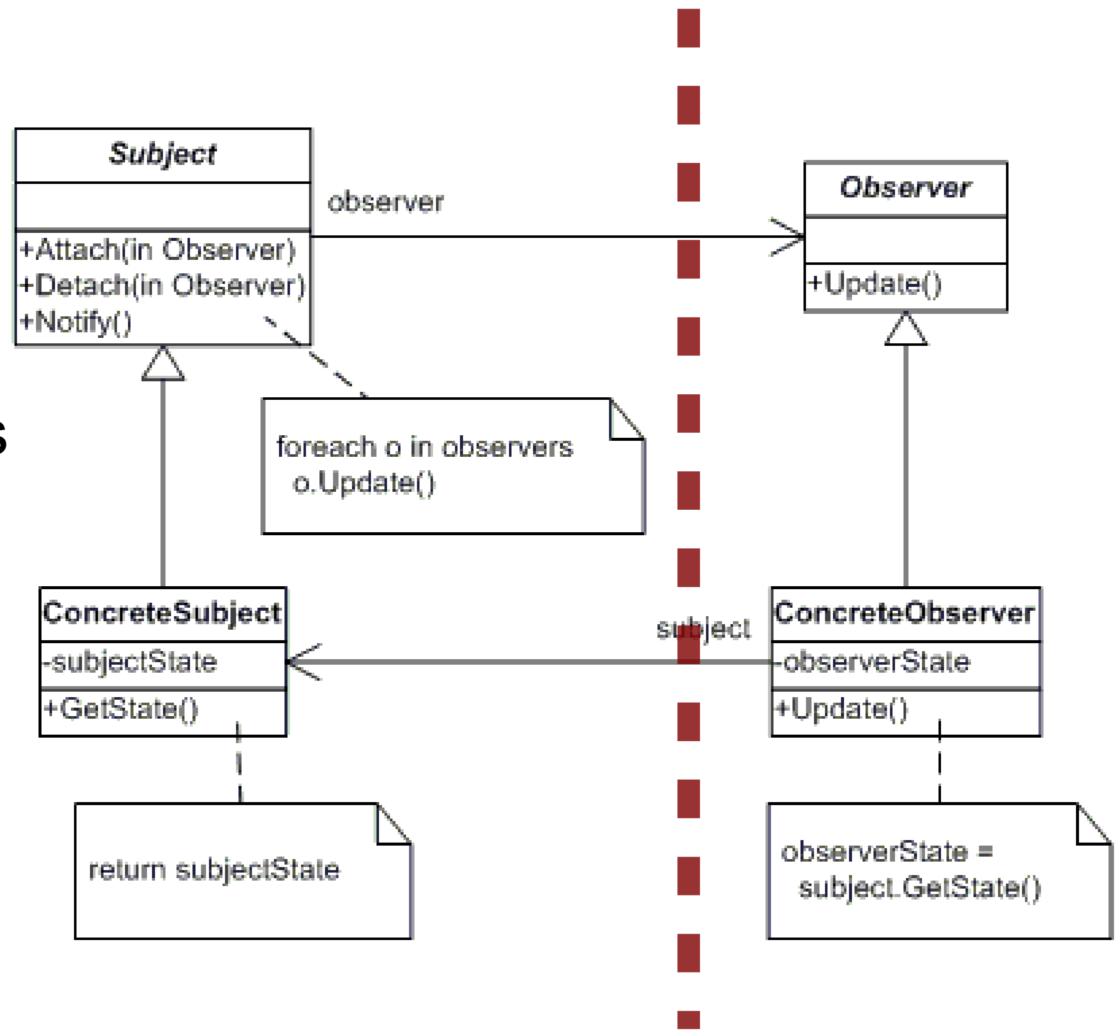
Observer in a distributed system

- When applied in a distributed application
  - Subject and Observer often reside on different nodes
  - Communications among the two can be
    - Slow
    - Costly
    - Unreliable
    - Limited capacity



Observer in a distributed system

- Invoking operations across different nodes
  - Several options
    - Use CORBA, RMI, or other RPC mechanisms
    - Send a message encoding the request according to some agreed-upon protocol
    - Use ad-hoc signaling
      - e.g., on receipt of an SMS with text “update” the machine will...



Observer in a distributed system

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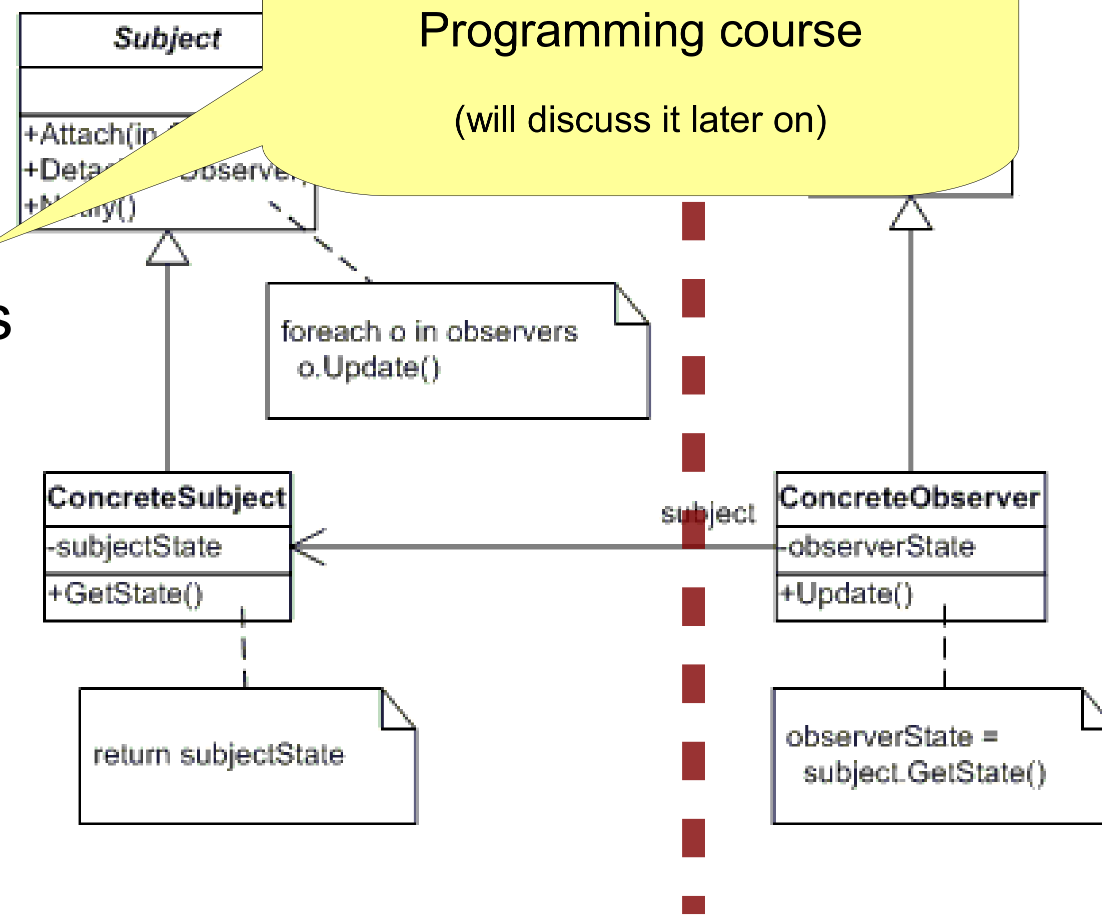
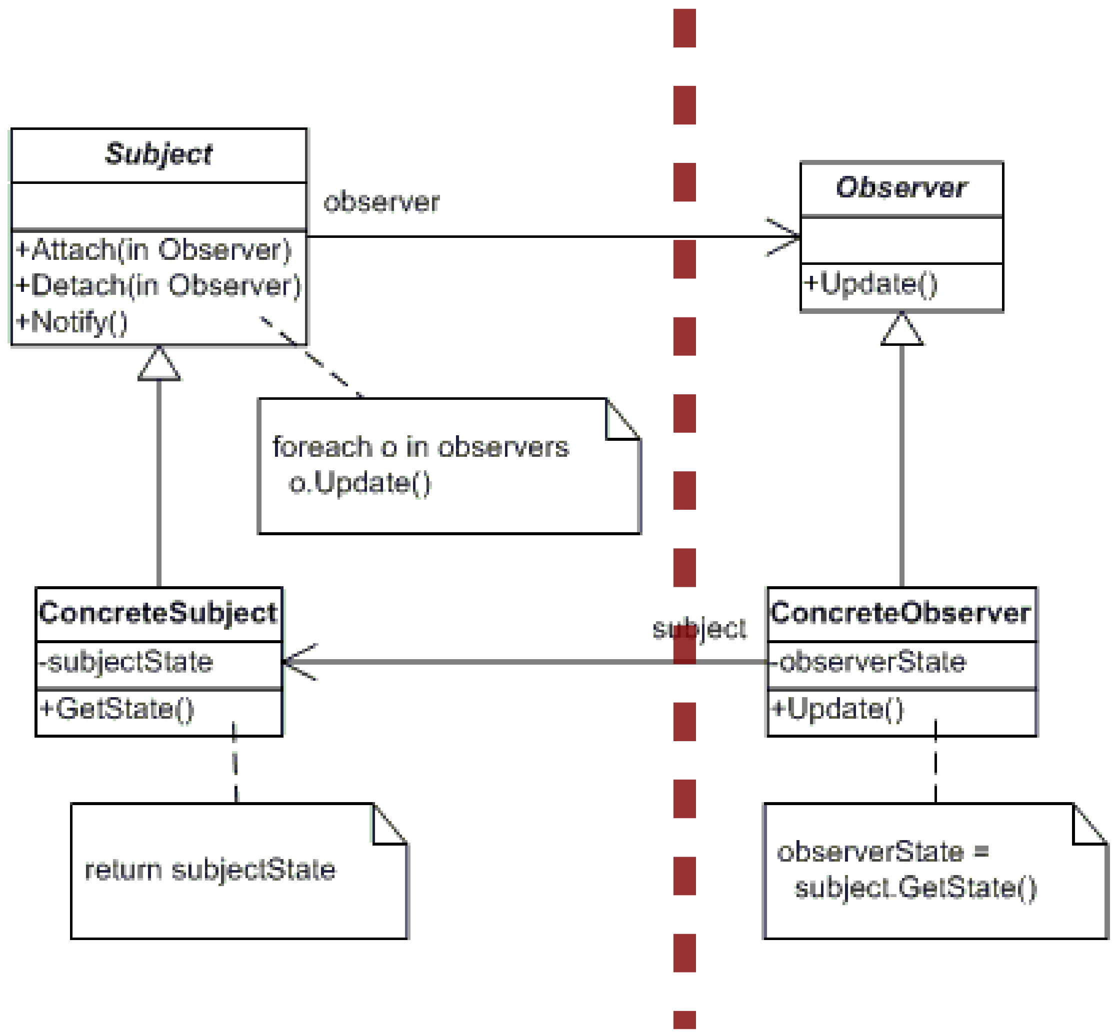
A theme for a Network Programming course

(will discuss it later on)



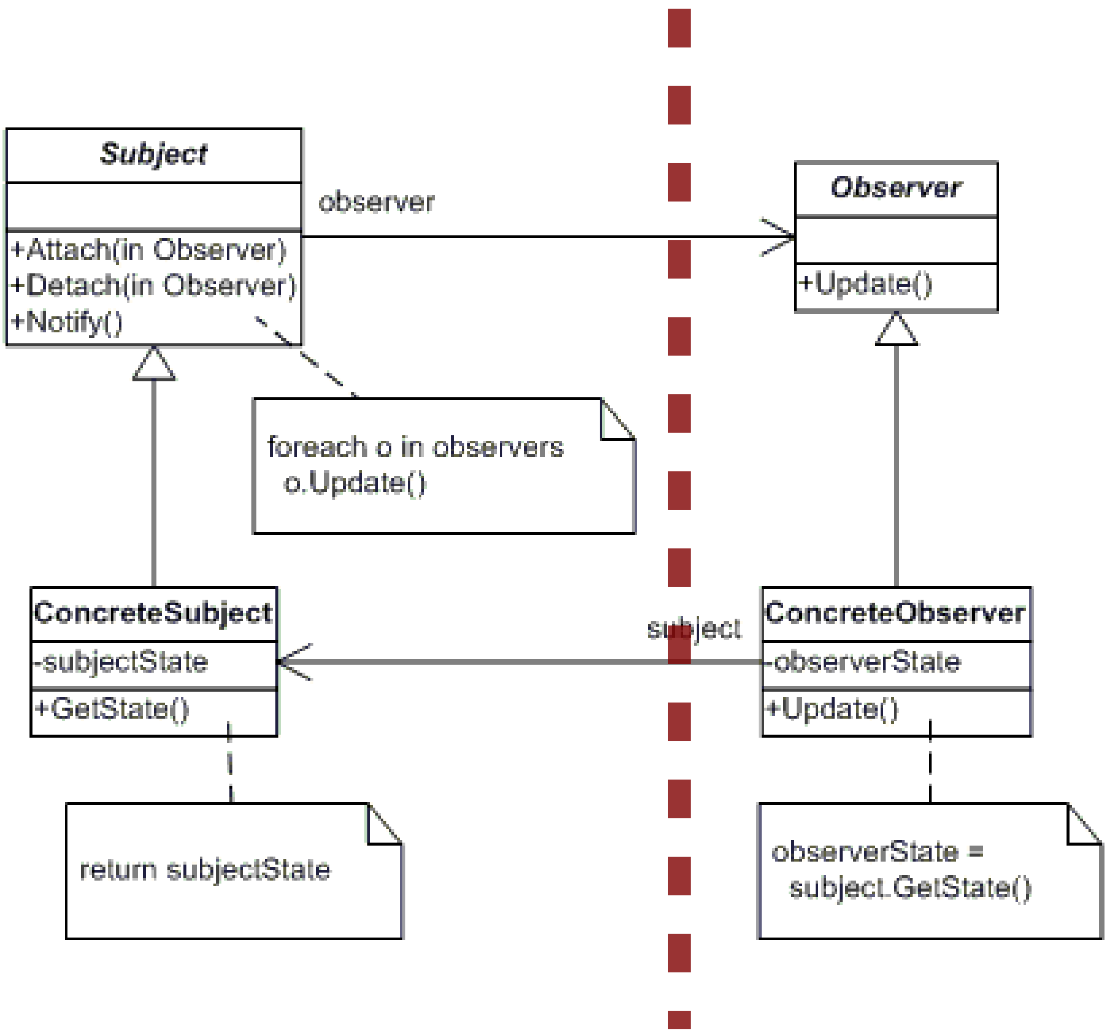
Observer in a distributed system

- Establishing identity across different nodes
  - attach() and detach() are easy with local objects
    - Storing a pointer to the observer suffices
  - More complex in a distributed system
    - Need some sort of unique ID



Observer in a distributed system

- Concurrent execution of updates
  - Each node can perform whatever its own update() requires in parallel with others
  - No need for a call to update() to be blocking
    - Same holds locally, proper synchronization
    - Use **broadcast** for update()



Building a cost model for Observer

- Cost for attach() and detach()
  - One call + passing of ID for each
  - (possible hidden cost for accessing a network ID)
- Cost for each update()
  - One call [for update()] + passing of ID + passing of data
  - One call [for getState()] + passing of state
- Cost for each notify()
  - *K* updates(), with *K* = number of registered observers

Building a cost model for Observer

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  - ...()] ...ssing of ID + passing
  - ...e()] + passing of state
  - ...)
  - ... = number of registered

These are typically infrequent operations

In most systems, only performed at boot-up or shutdown

In some system, performed when a node joins/leaves the distributed system

Rarely, hugely dynamic

Building a cost model for Observer

This part is paid **at each state change**

Cost proportional to (serialized) size of the state and to the number of observers

Can become **HUGE!**

- Cost for attach() an
  - One call + passi
  - (possible hidden cost for accessing a network ID)
- Cost for each update()
  - One call [for update()] + passing of ID + passing of data
  - One call [for getState()] + passing of state
- Cost for each notify()
  - *K* updates(), with *K* = number of registered observers

Optimizing the distributed Observer

- We need strategies to reduce the cost of Observer in a distributed application
- Main venues:
  - Reduce the number of updates
  - Reduce the size of each update
  - Reduce the number of observers
- The particular **problem** will often dictate what is possible and what is not
- Strike a balance between code complexity ($\rightarrow$ robustness) and performance ($\rightarrow$ efficiency)

Reducing the # of updates

- Coalescing
  - At times, it is not sensible to send out many little updates: it's better to **coalesce** many setState() calls, then send out a single cumulative notify()
  - Add two operations to Subject
    - hold() - suspends all updates
    - release() - resumes sending out updates
      - Also, sends out a first notify() if there was any change w.r.t. the previous hold()
  - Risk: hold() without release()!
  - Increases code complexity (e.g., multiple calls)

Reducing the # of updates

- **Partitioning**
  - Upon registration, express interest in some subset of the state
  - Only send out updates to Observers that have expressed interest in the changed partition
  - Equivalent to having many smaller Subjects
- Implementation
  - Add a parameter *interest* to attach() (often, a bitmask), or

    Add an operation setInterest(o,i) to express that observer *o* is interested in facet *i* of the state

Reducing the # of updates

- **Flow control**
  - Stop sending further updates until the Observer has finished processing the previous set
  - Also helps with the overrun concern
  - Needs an additional cost to signal completion
- Implementation
  - In notify(), use an asynch invocation for update()
  - Put every notified Observer in a “suspended” set
  - Add an operation done() to resume an observer
  - In the implementation of notify(), call done() once finished

Reducing the # of updates

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Might miss intermediate states

Applicable when the “most recent state” counts, and older states are of little interest (real-time applications)

Not applicable when all updates are significant (e.g., financial transactions)

Reducing the # of updates

- **Shifting responsibility to clients**
  - Instead of triggering an update at each setState(), allow clients to call notify() when they think that observers need to be notified
  - Only applicable if clients of the Subject have an idea about the needs of Observers
  - Reduces decoupling, makes systems more tangled
  - Increases chances of missing an update
    - i.e., client “forgets” to call notify()

Reducing the size of each update

- **Using small getters**
  - In our scheme, update() has a negligible payload
  - getState() is where the largest amount of data is transferred
  - Replace getState() with finer-grain getters
    - Each get...() pays the cost of 1 call + the cost for transferring the data
    - Balancing: too many getters to call, and you end up paying more than a single call to transfer the whole state

Reducing the size of each update

- **Put the payload in update()**
  - Instead of having update() cause a call to getState(), pass the state change as parameter
  - Opposite to coalescing, friendly to partition
- Implementation

```
public void setX(T x) {
   T oldValue = x;
   this.x = x;
   notify("x", oldValue, x); → update
}
```

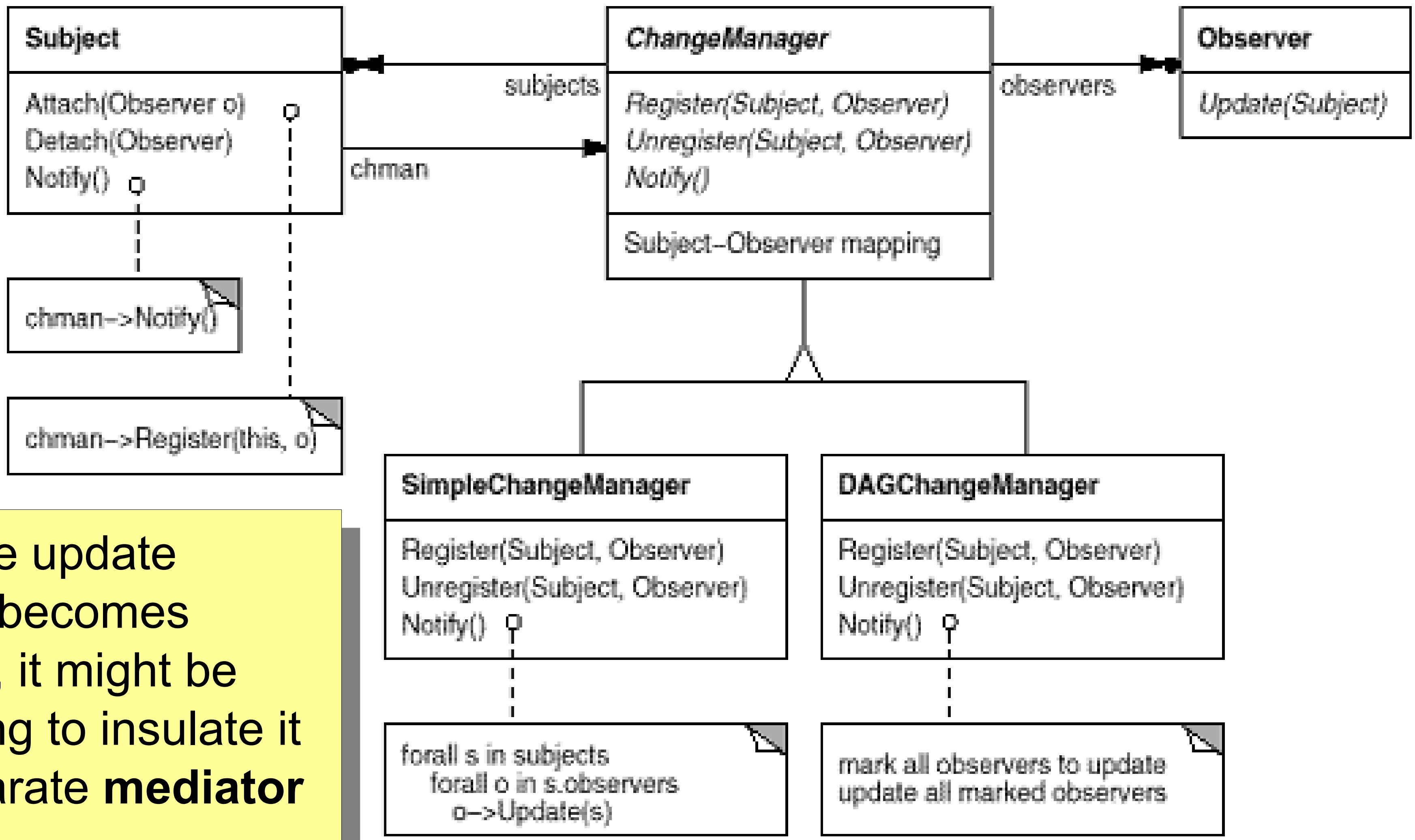
Reducing the size of each update

- **Push model**
  - Each setX() sends full notification for that particular update
  - Observer has it all
- **Pull model**
  - Each setX() sends just a notify(void)
  - Observer decides if, what, when to get...()
- **Intermediate models**
  - Some of the information about a change is sent with update()
  - Some is retrieved by the Observer upon need

Reducing the # of observers

- Rarely we have the luxury of deciding how many observers we will have
  - e.g.: web browsers on a page from our server
- At times, it can be decided at design time
- It might be possible to keep the number of observers low by dynamic attach()/detach()
  - Balancing the cost for those with the cost for updates
- We can set a hard limit
  - the (K+1)th attach() will fail
  - QoS to already registered observers wins

Complex update strategies

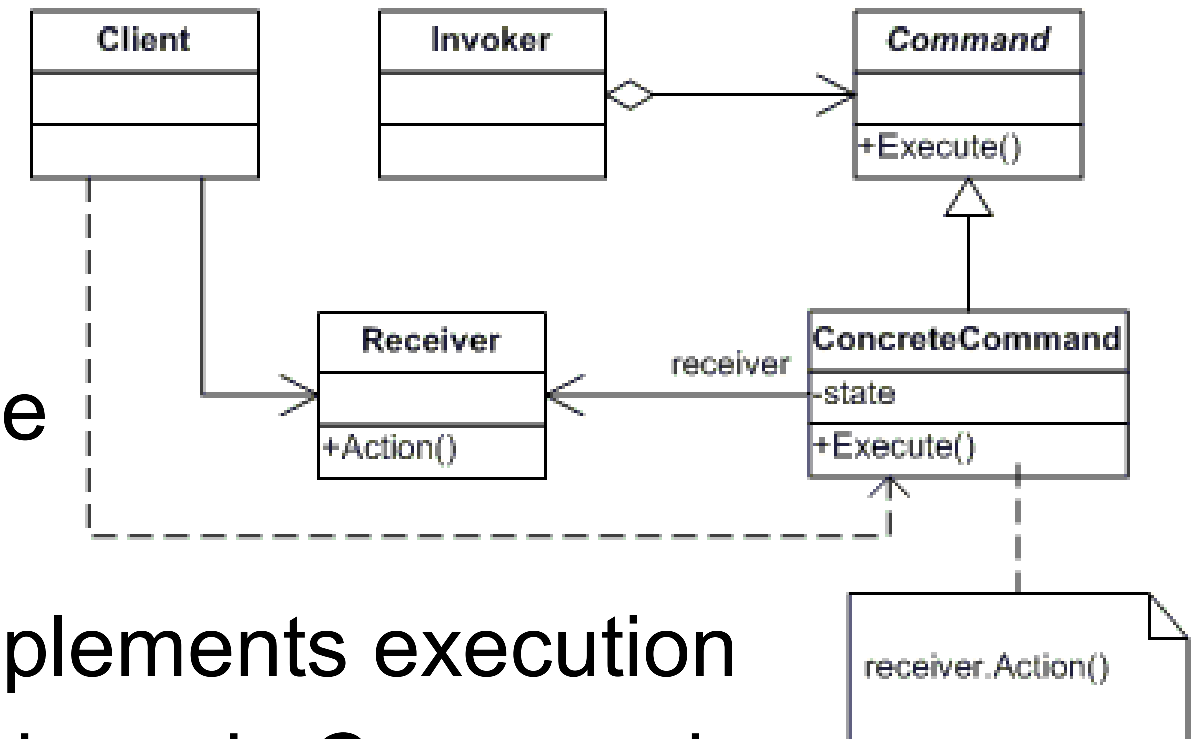


When the update strategy becomes complex, it might be interesting to insulate it in a separate **mediator** object

The Command pattern

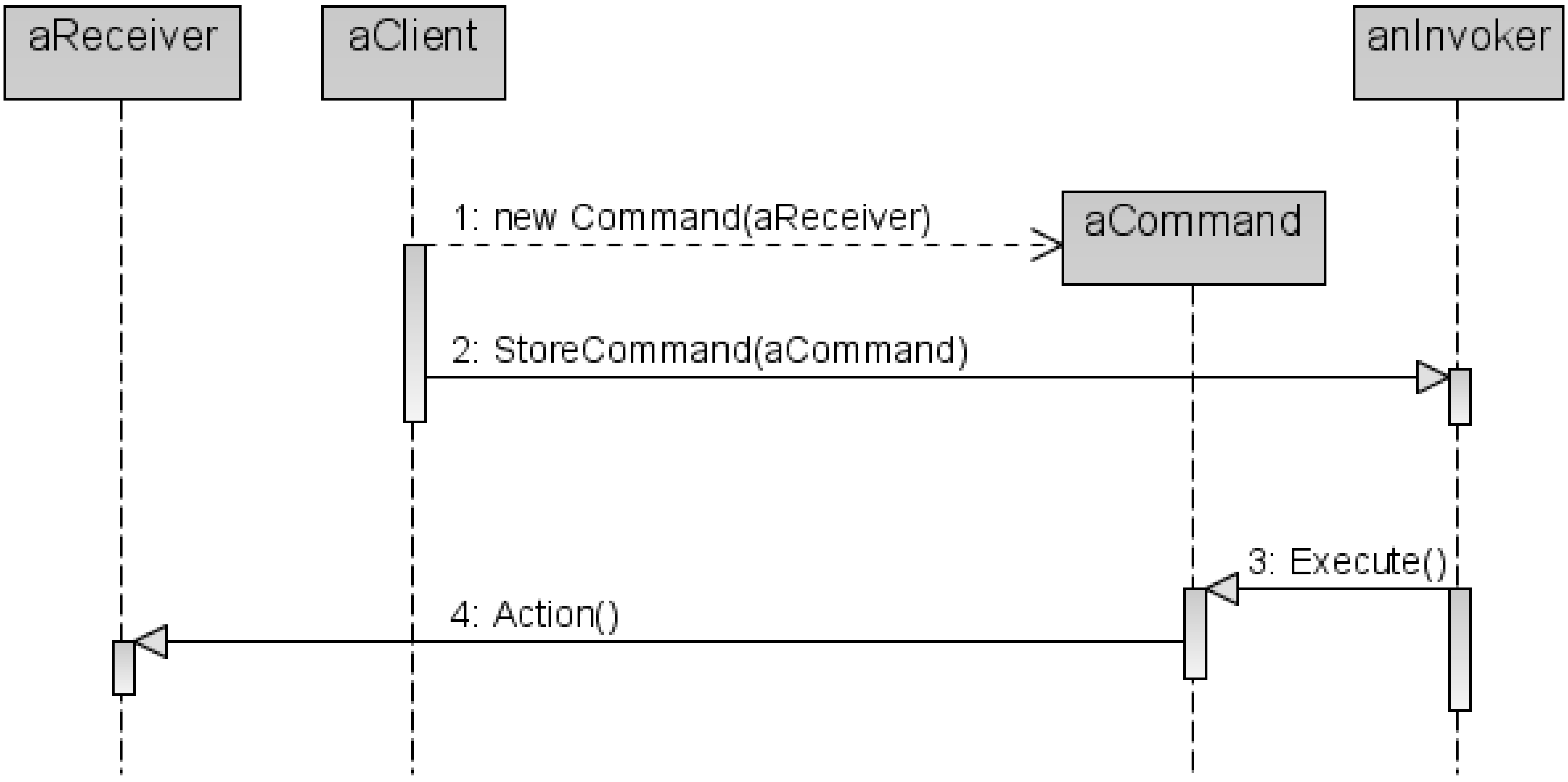
- “Encapsulate a request as an object, thereby letting you parametrize clients with different requests, queue or log requests, and support undoable operations”
- Normally operations are requested by invoking a method
- With Command, operations are requested by passing an object
  - The object can carry an implementation with it
  - BUT, only few communication channels can carry code

The Command pattern



- **Command**: an interface to execute
- an operation
- **ConcreteCmd**: implements execution
- **Client**: creates and sends Commands
- **Invoker**: causes the execution of a Command
- **Receiver**: knows how to manage Commands

The Command pattern



The Command pattern

- execute() vs. action()
  - The Invoker calls execute() on the Command
  - execute() in turns calls one or more operations (action())on the receiver to produce the desired effect
- Leeway about how much processing should be done in execute(), and how much in action()
  - The Command could be very autonomous and do all the state changing itself
  - The Command could be just a **delegate** and simply call an operation of the receiver

Implementing Command

```
public interface Command {
    public abstract void execute();
}
public class Genesis implements Command {
    public void execute() { universe.start(); }
}
public class Armageddon implements Command {
    public void execute() { universe.stop(); }
}
public class MinorMiracle implements Command {
    public void execute() { universe.setState(...); }
}
```

Implementing Command

```
public interface Command {
    public abstract void execut…
}
public class Genesis implements …mmand {
    public void execute() { universe.start(); }
}
public class …s Command {
    public vo… …se.stop(); }
}
public class …nts Command {
    public void execute() { universe.setState(...); }
}
```

Receiver, here accessed statically.

Could be a parameter set in the constructor of Command.

action() of the Receiver.

Could also be a complex set of changes, or include significant business logic

Implementing Command

```
public interface Invoker {
   public void storeCommand(Command c);
}

public class PermissionInvoker {
   public void storeCommand(Command c) {
      if (requiresPermission(c))
         askUser(c);  ← exception if "No!"
      c.execute();
}
```

Immediate execution.
Double-checks priviledged Commands.

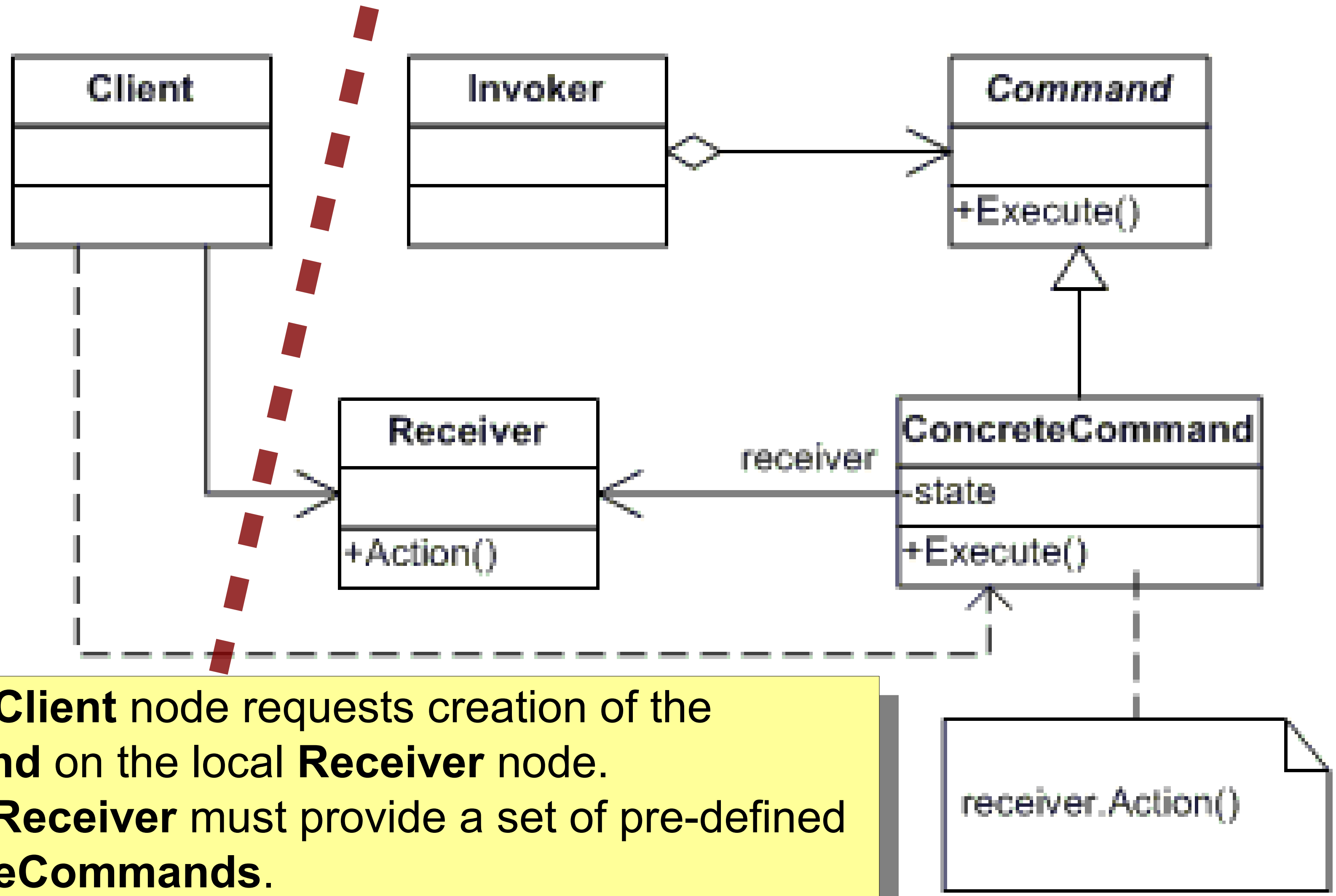
Implementing Command

```
public class UndoInvoker implements Invoker {
   Stack<State> undoStack = new Stack<State>();

   public void storeCommand(Command c) {
      undoStack.push(universe.getState());
      c.execute();
   }
   public void undo() {
      Universe.setState(undoStack.pop());
   }
}
```

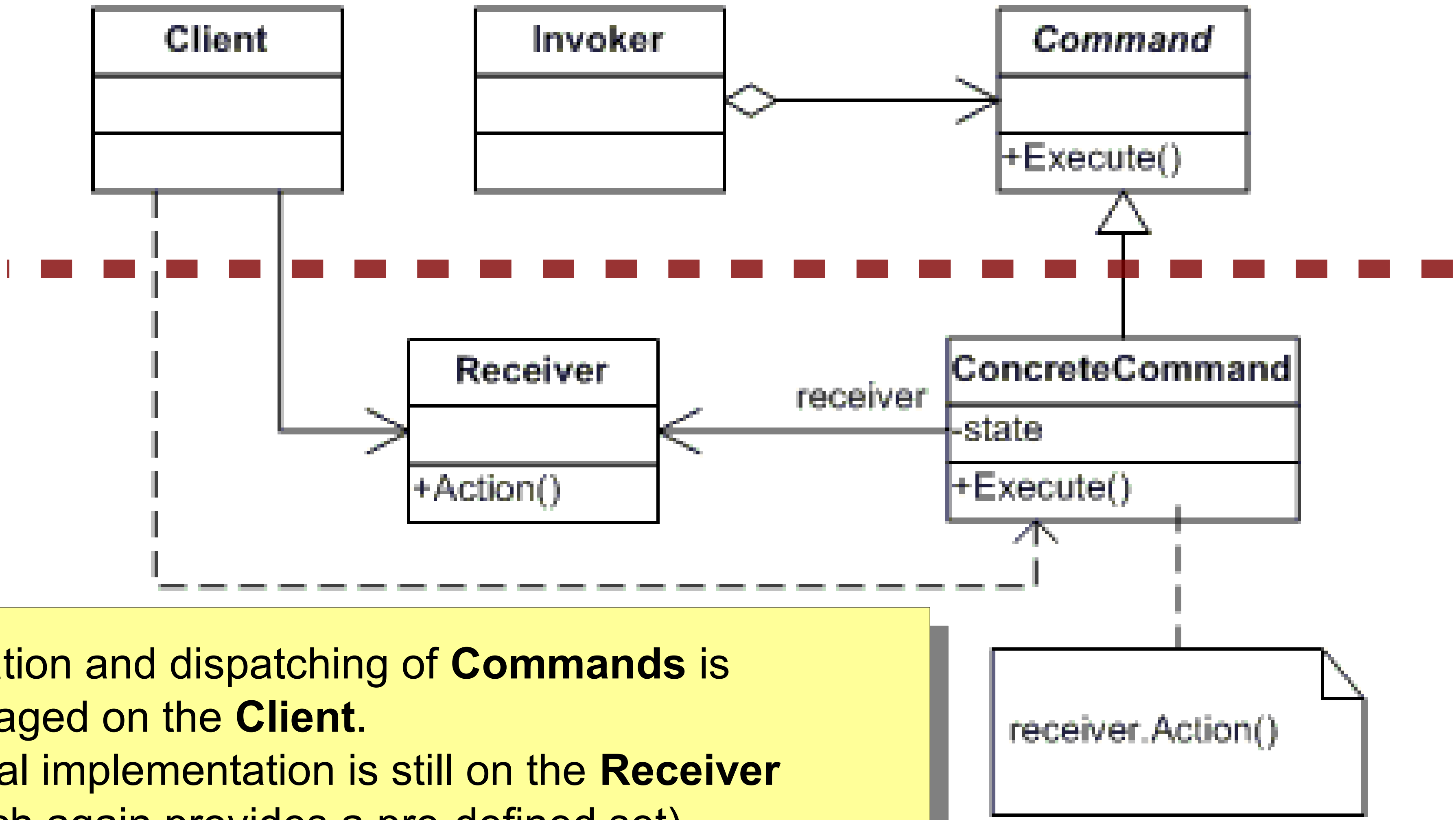
Immediate execution.
Supports undo.

Distributing Command



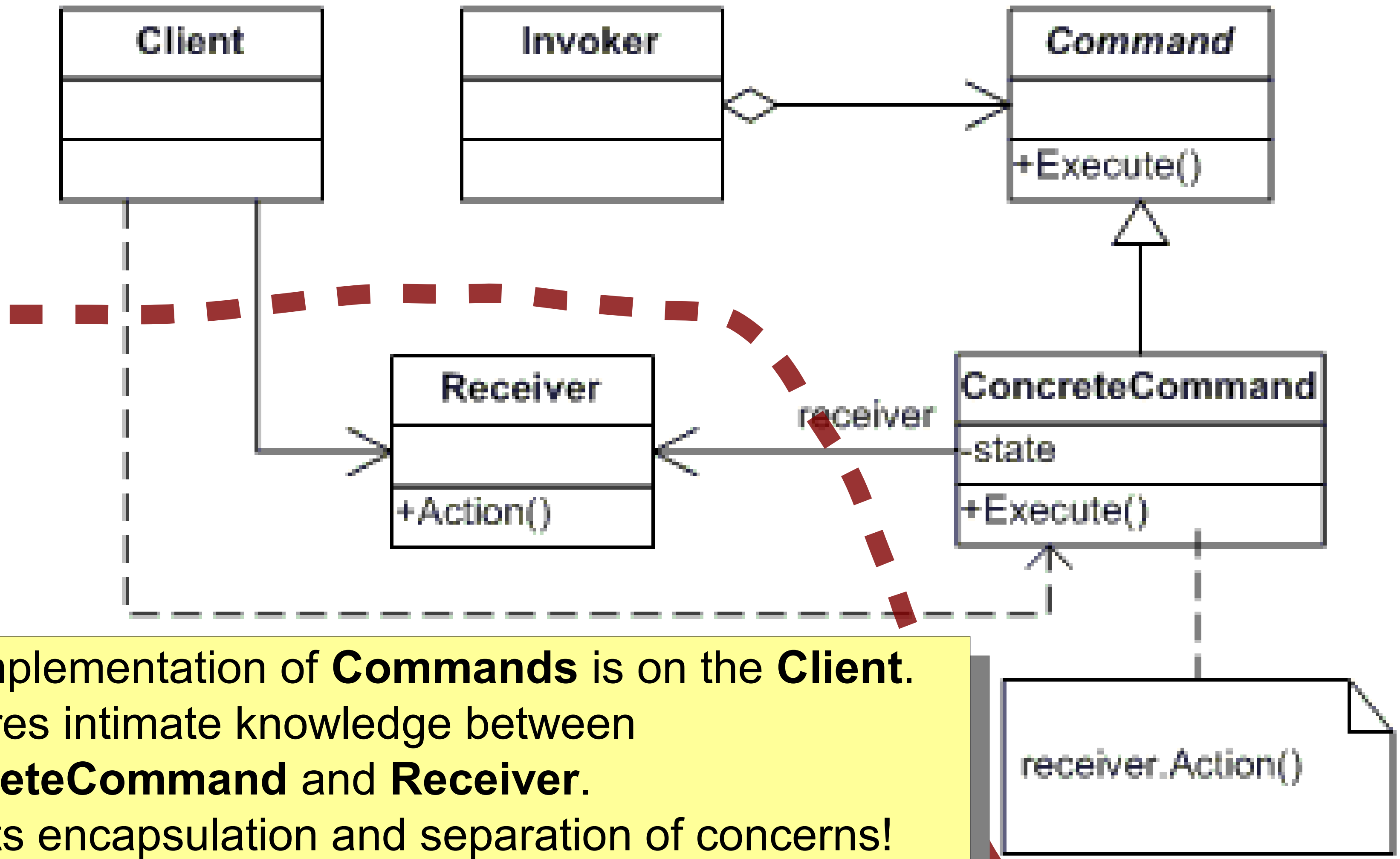
Remote **Client** node requests creation of the **Command** on the local **Receiver** node.
Doable, **Receiver** must provide a set of pre-defined **ConcreteCommands**.
Only creation request needs to be transmitted

Distributing Command



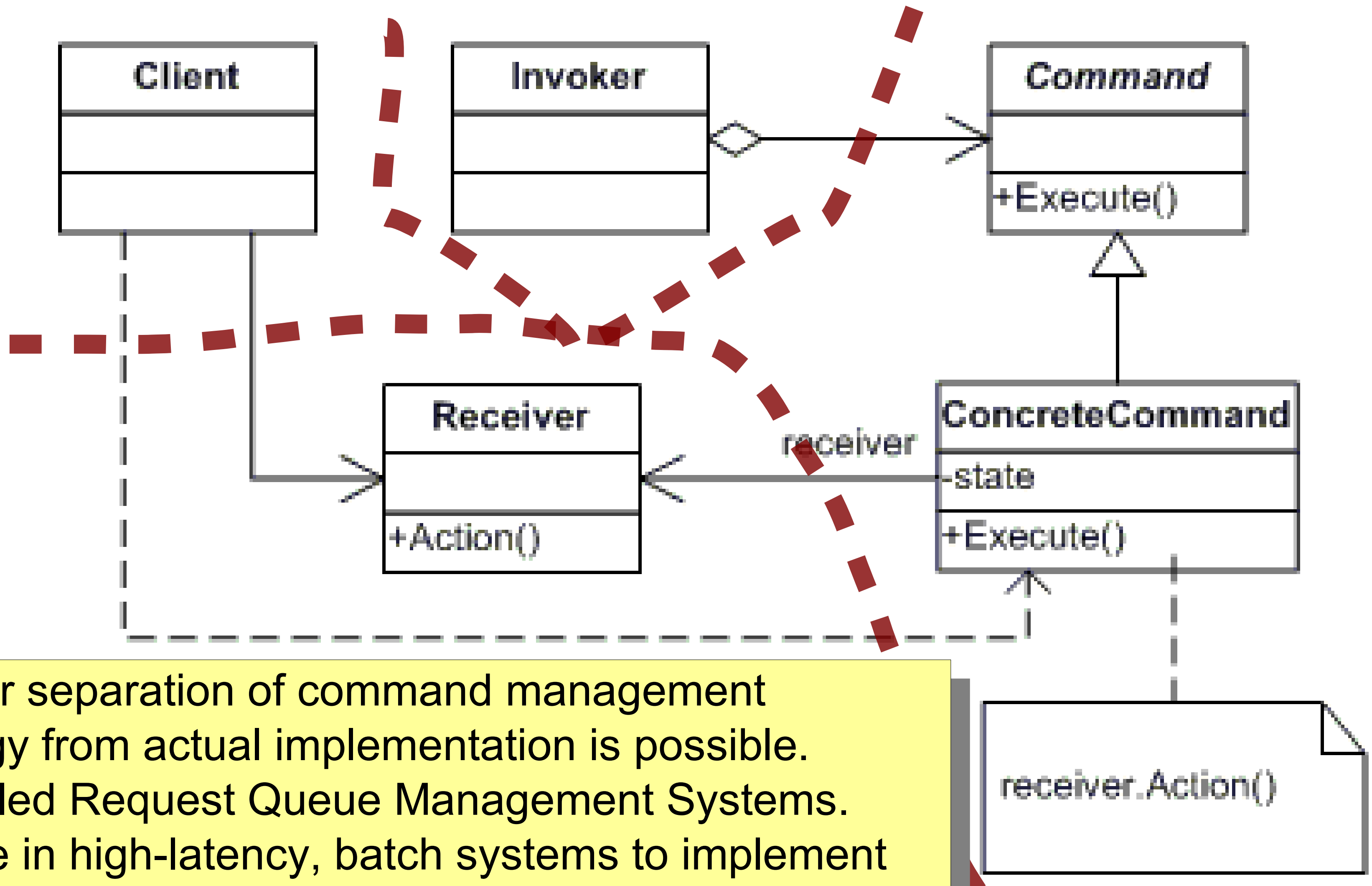
Creation and dispatching of **Commands** is managed on the **Client**.
Actual implementation is still on the **Receiver** (which again provides a pre-defined set).

Distributing Command



The implementation of **Commands** is on the **Client**.
Requires intimate knowledge between **ConcreteCommand** and **Receiver**.
Defeats encapsulation and separation of concerns!
Might require code migration.

Distributing Command



Further separation of command management strategy from actual implementation is possible. So-called Request Queue Management Systems. Usable in high-latency, batch systems to implement logging, journaling, etc.

Goals for Command

- Implement delayed execution
  - Commands can be queued and executed later
- Implement logging/journaling/stat collection
  - A record is kept of who issued which commands to whom, execution times, etc.
- Implement undo/redo/repeat
  - Whenever a command is executed, add it to a list of undoable operations
  - Command can have undo() and redo()
  - Alternatively, can use a stack of states

Goals for Command

- Implement Command queue inspection techniques
  - Buffering and coalescing commands
    - "only last valid command counts"
  - Accumulation
    - Transform move(dx1, dy1); move(dx2, dy2) to move(dx1+dx2, dy1+dy2)
- Implement preemptible Commands
  - Allows changing your mind
    - Send! — then, you can press Cancel sending in the next 5 seconds

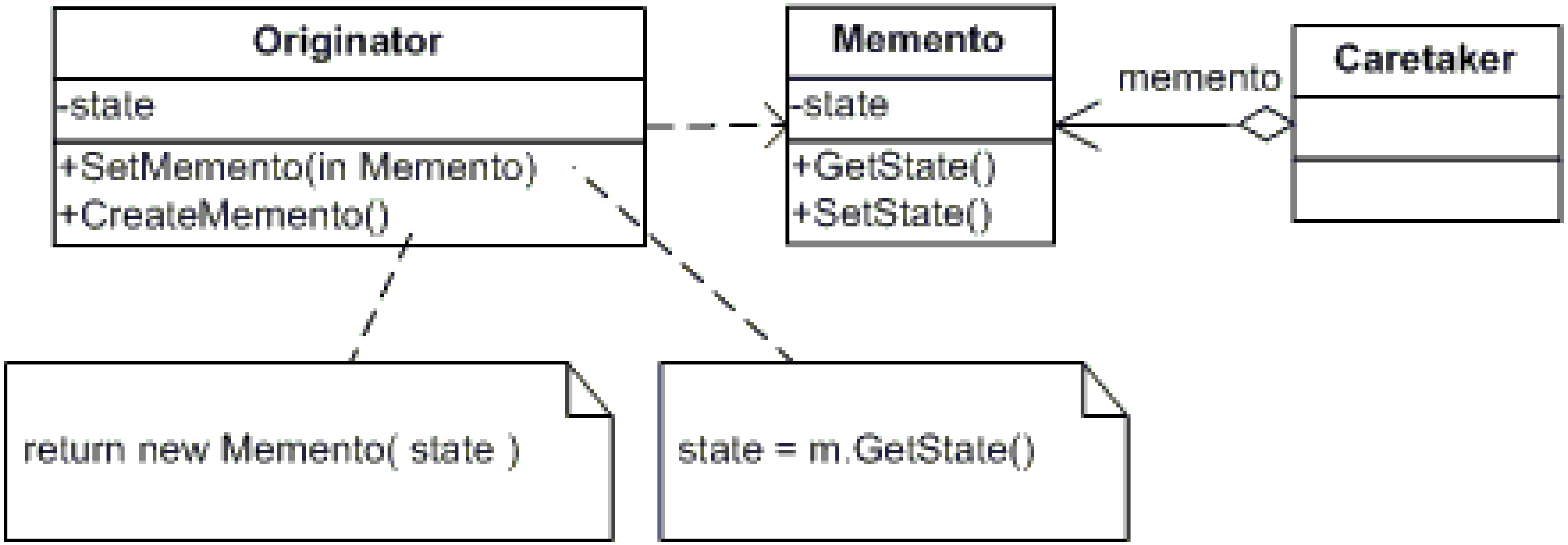
Goals for Command

- Allows multiple sources for the same Command
  - An icon in the tool bar
  - A menu entry
  - A keyboard shortcut
  - A scripting interface
- Allows multiple destinations for the same Command
  - “Cut” can be sent to a text, to a picture, to a sound sample...

The Memento pattern

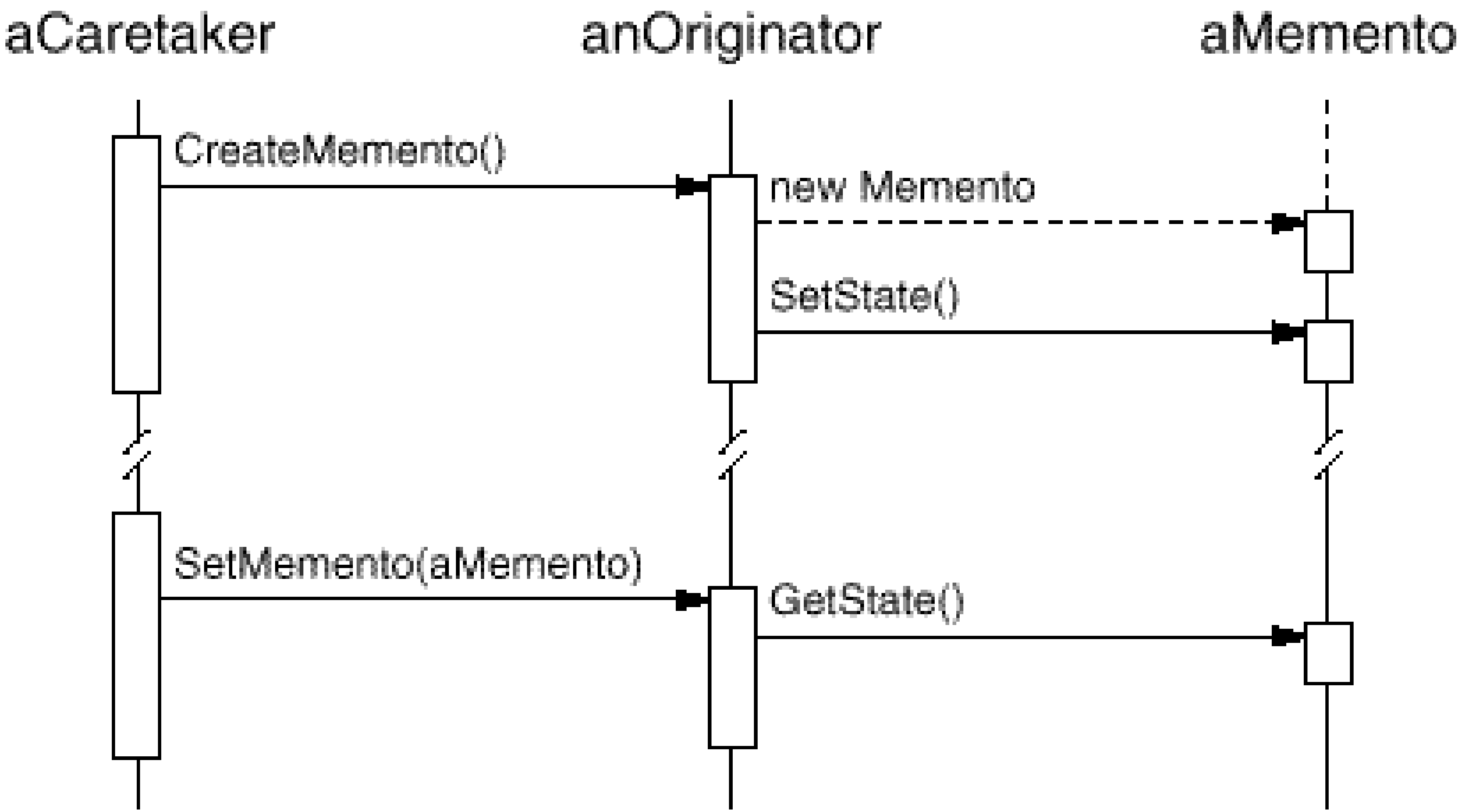
- “Without violating encapsulation, capture and externalize an object's internal state so that the object can be resotred to this state later”
- In practice, we want an opaque container for the private state of some object
  - The owner can “lend” the state to someone else
  - Only the owner can recover the internal state
  - Still, the opaque state can be stored, transmitted etc.

The Memento pattern

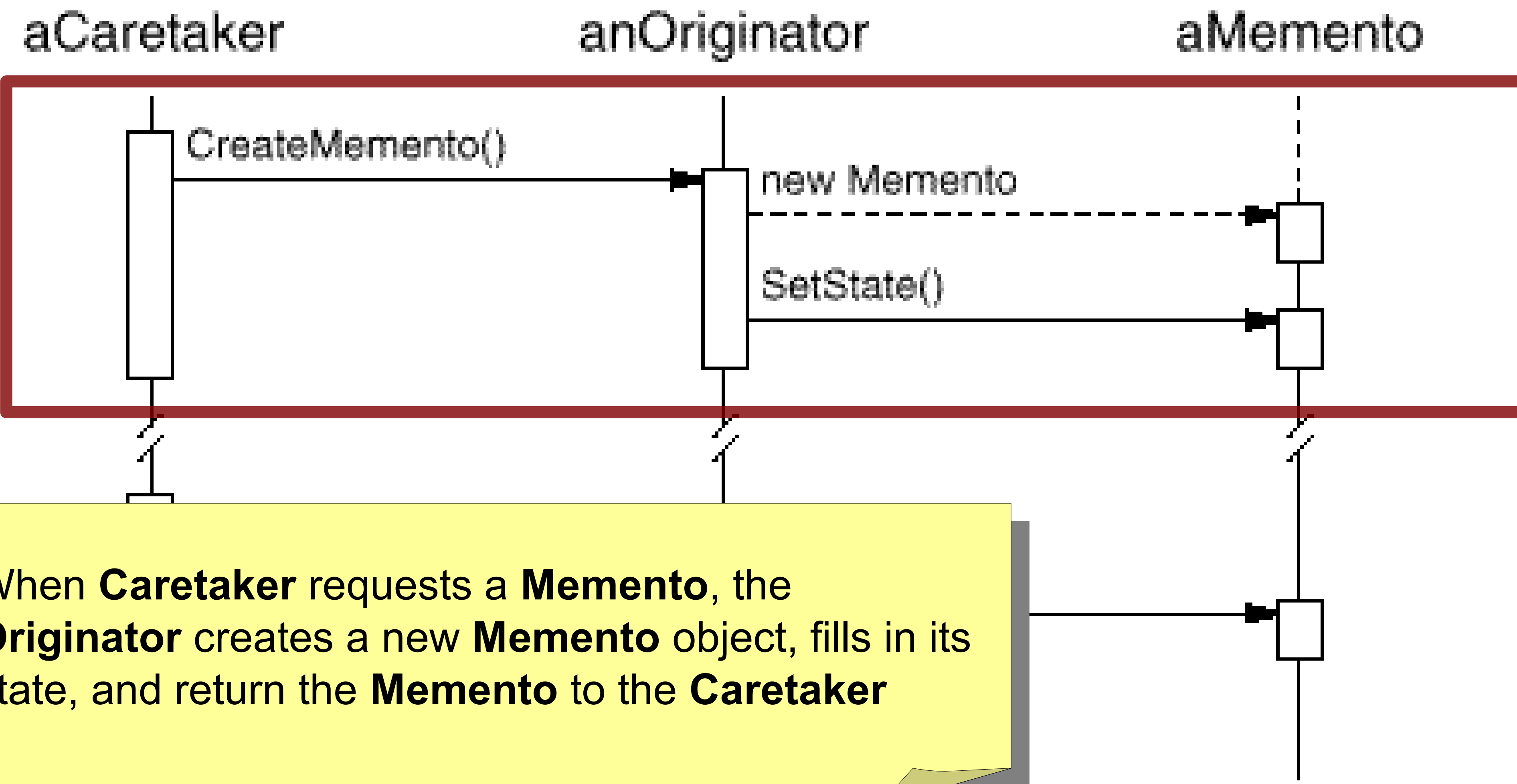


- **Originator** has the state, can create **Memento**s
- **Memento** holds the state in the opaque form
- **Caretaker** can only store/retrieve/pass **Memento**s

The Memento pattern

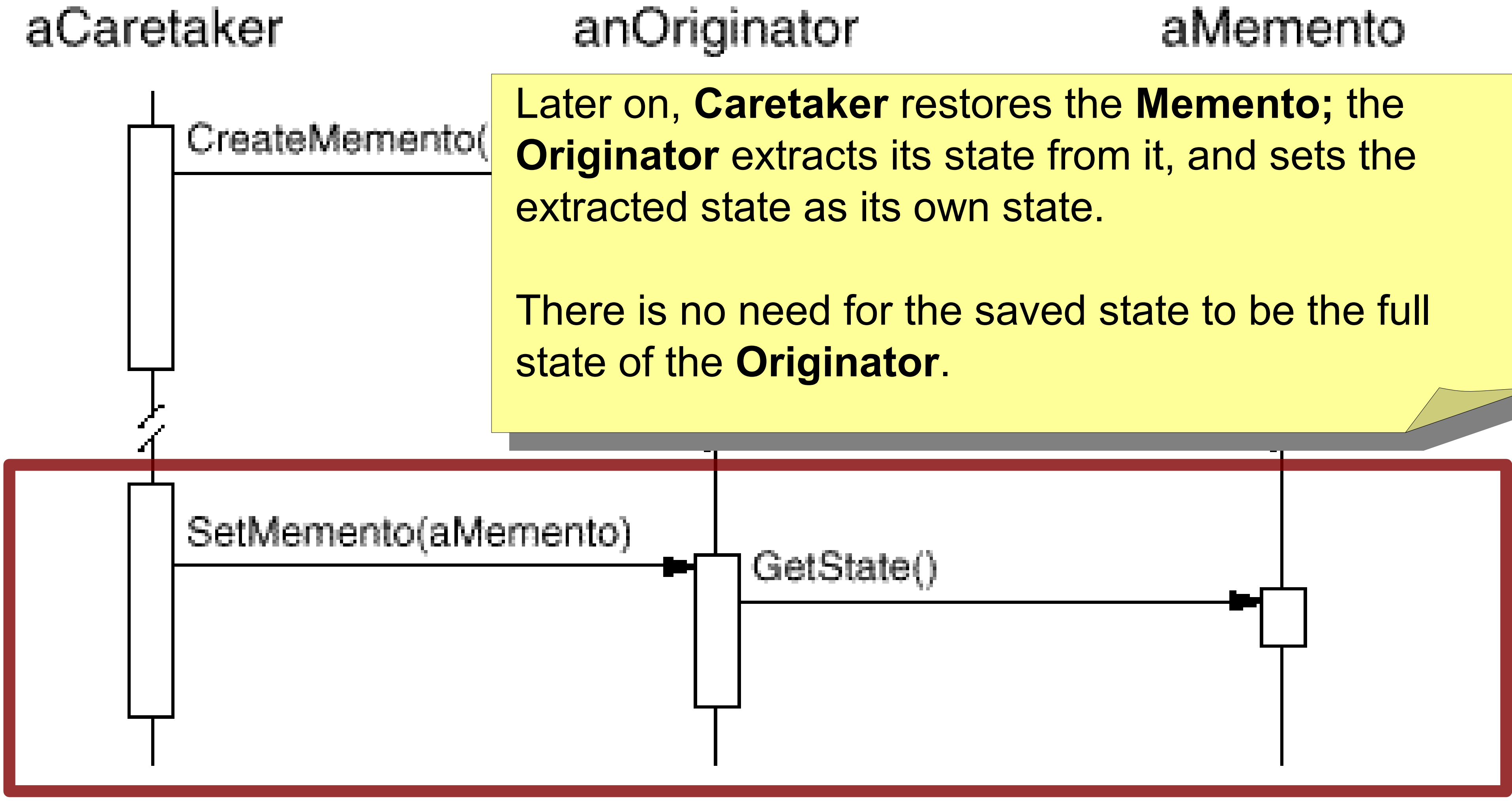


The Memento pattern



When **Caretaker** requests a **Memento**, the **Originator** creates a new **Memento** object, fills in its state, and return the **Memento** to the **Caretaker**

The Memento pattern



Later on, **Caretaker** restores the **Memento;** the **Originator** extracts its state from it, and sets the extracted state as its own state.

There is no need for the saved state to be the full state of the **Originator**.

Distributing Memento

Memento spans both nodes