Introduction to Patterns and Frameworks

Douglas C. Schmidt

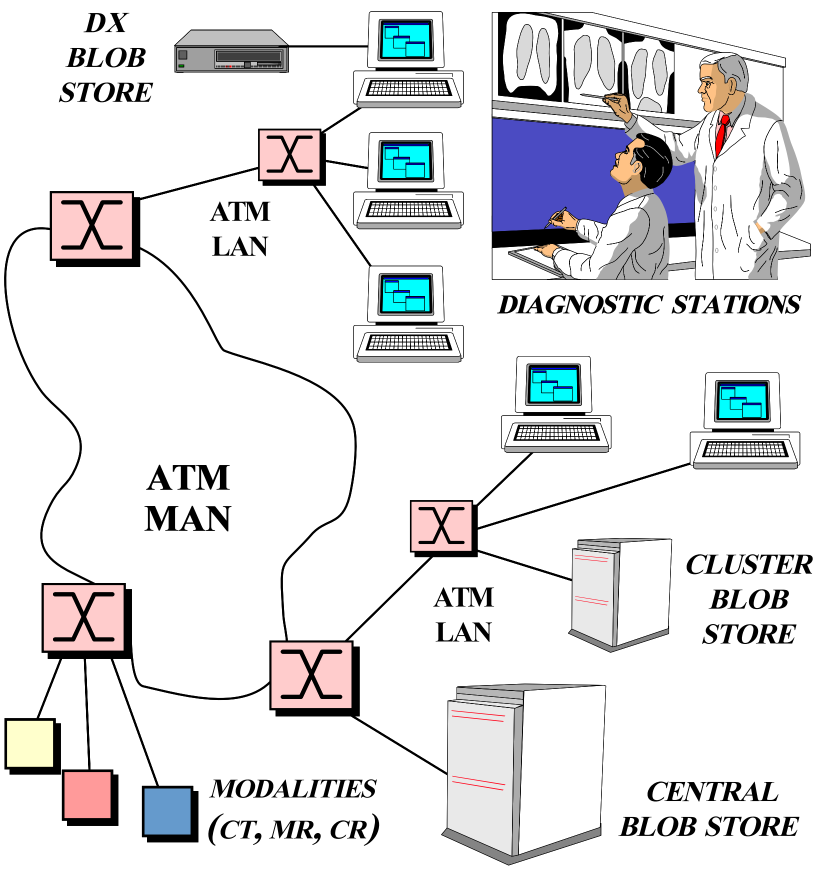
Professor
d.schmidt@vanderbilt.edu
www.cs.wustl.edu/∼schmidt/

Department of EECS
Vanderbilt University
(615) 343-8197

Patterns and Frameworks

- Motivation for Patterns and Frameworks
- What is a Pattern? A Framework?
- Pattern Categories
- Pattern Examples

Motivation for Patterns and Frameworks



- Developing software is hard
- Developing reusable software is even harder
- Proven solutions include *patterns* and *frameworks*
- www.cs.wustl.edu/∼schmidt/patterns.html

Overview of Patterns and Frameworks

- Patterns support reuse of software *architecture* and *design*
  - *Patterns capture the static and dynamic structures and collaborations of successful solutions to problems that arise when building applications in a particular domain*
- Frameworks support reuse of *detailed design* and *code*
  - *A framework is an integrated set of components that collaborate to provide a reusable architecture for a family of related applications*
- Together, *design patterns* and *frameworks* help to improve software quality and reduce development time
  - *e.g.*, reuse, extensibility, modularity, performance

Patterns of Learning

- Successful solutions to many areas of human endeavor are deeply rooted in patterns
  - In fact, an important goal of education is transmitting *patterns of learning* from generation to generation
- In a moment, we'll explore how patterns are used to learn chess
- Learning to develop good software is similar to learning to play good chess
  - Though the consequences of failure are often far less dramatic!

Becoming a Chess Master

- ***First learn the rules***
  - *e.g.*, names of pieces, legal movements, chess board geometry and orientation, *etc.*
- ***Then learn the principles***
  - *e.g.*, relative value of certain pieces, strategic value of center squares, power of a threat, *etc.*
- ***However, to become a master of chess, one must study the games of other masters***
  - These games contain *patterns* that must be understood, memorized, and applied repeatedly
- ***There are hundreds of these patterns***

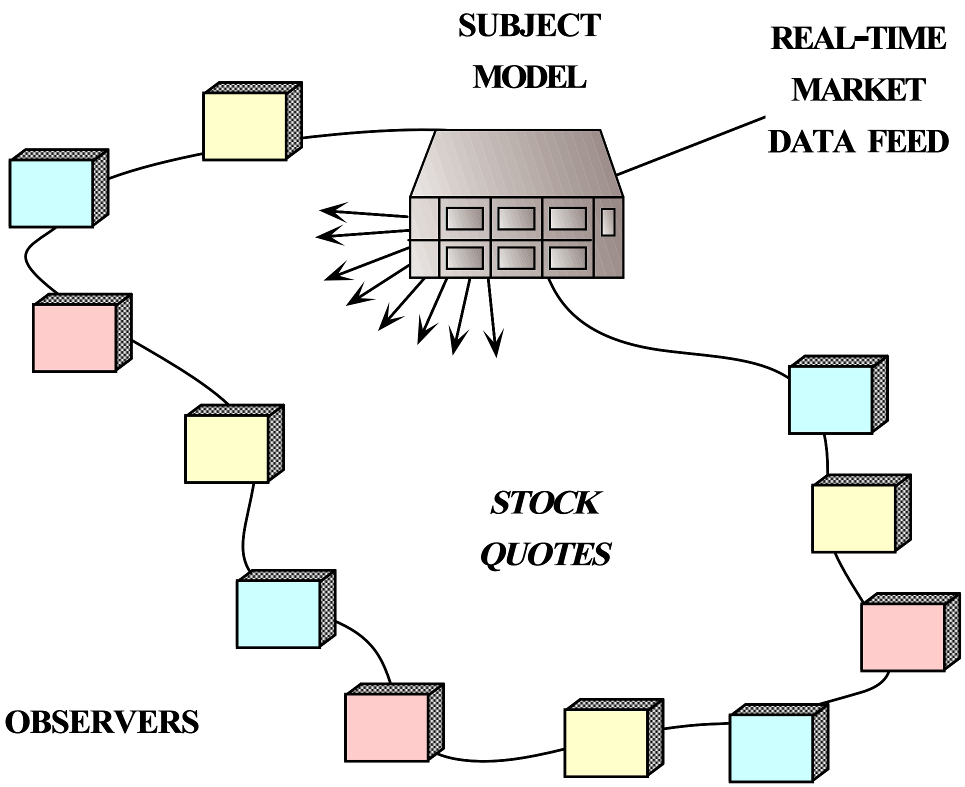
Becoming a Software Design Master

- ***First learn the rules***
  - *e.g.*, the algorithms, data structures and languages of software
- ***Then learn the principles***
  - *e.g.*, structured programming, modular programming, object oriented programming, generic programming, *etc.*
- ***However, to become a master of software design, one must study the designs of other masters***
  - These designs contain *patterns* that must be understood, memorized, and applied repeatedly
- ***There are hundreds of these patterns***

Design Patterns

- Design patterns represent *solutions* to *problems* that arise when developing software within a particular *context*
  - *i.e.*, “Pattern == problem/solution pair in a context”
- Patterns capture the static and dynamic *structure* and *collaboration* among key *participants* in software designs
  - They are particularly useful for articulating how and why to resolve *non-functional forces*
- Patterns facilitate reuse of successful *software architectures* and *designs*

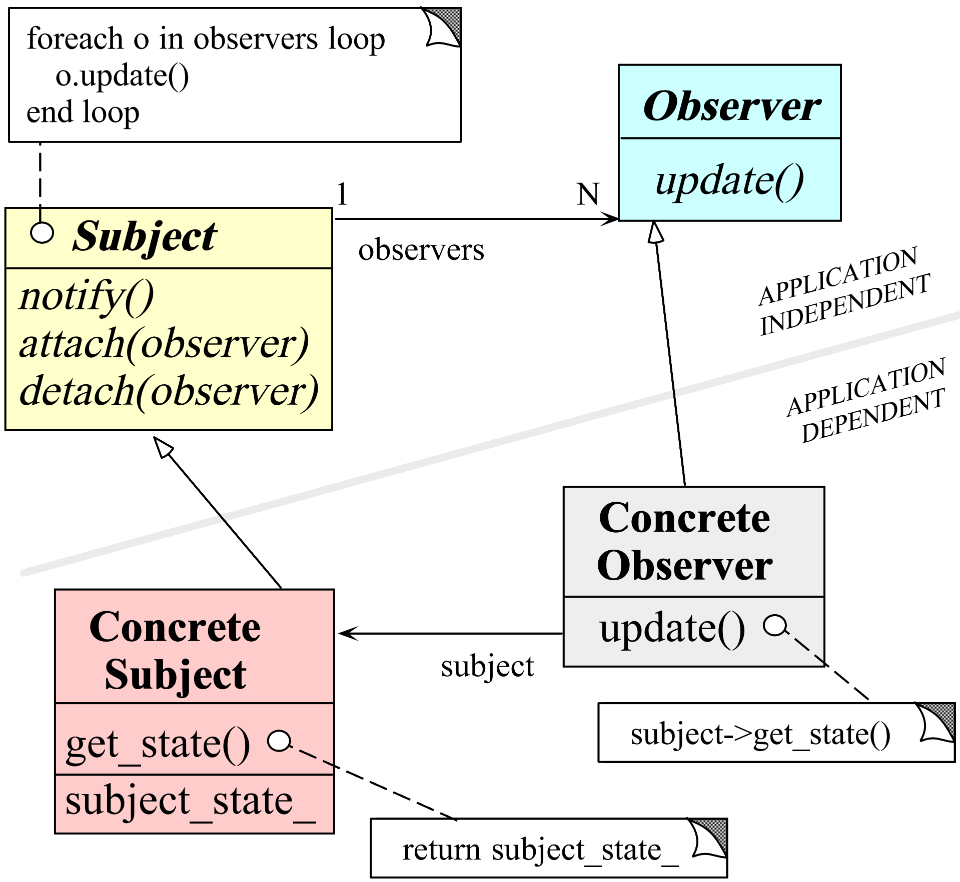
Example: Stock Quote Service



Key Forces

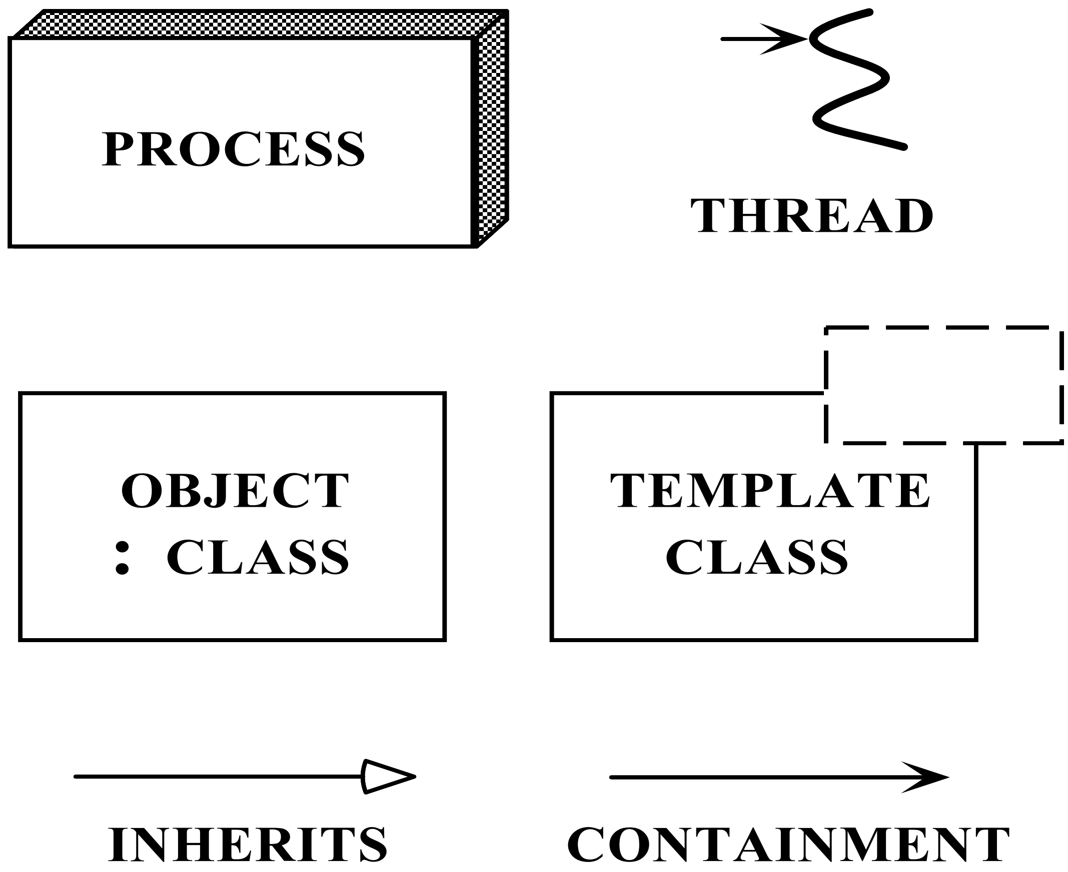
1. There may be many observers
2. Each observer may react differently to the same notification
3. The subject should be as decoupled as possible from the observers
   - *i.e.*, allow observers to change independently of the subject

Structure of the Observer Pattern

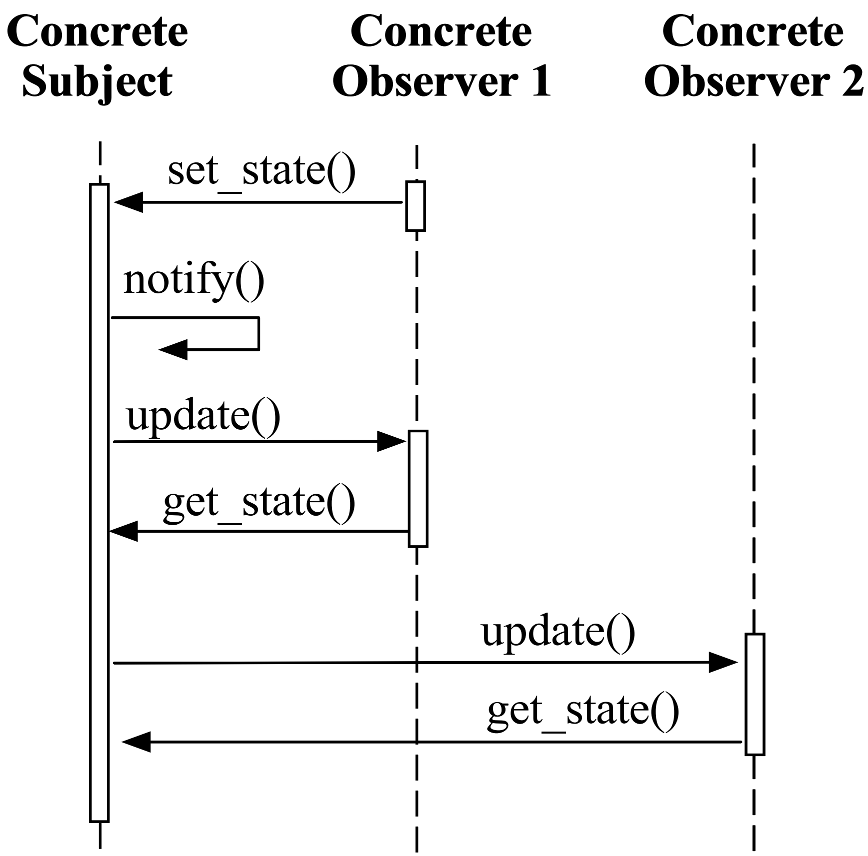


- **Intent**
  - *Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.*

Graphical Notation



Collaboration in the Observer Pattern



Variations

- “Push” architectures combine control flow and data flow
- “Pull” architectures separate control flow from data flow

Design Pattern Descriptions

Main parts

1. *Name and intent*
2. *Problem and context*
3. *Force(s) addressed*
4. *Abstract description of structure and collaborations in solution*
5. *Positive and negative consequence(s) of use*
6. *Implementation guidelines and sample code*
7. *Known uses and related patterns*

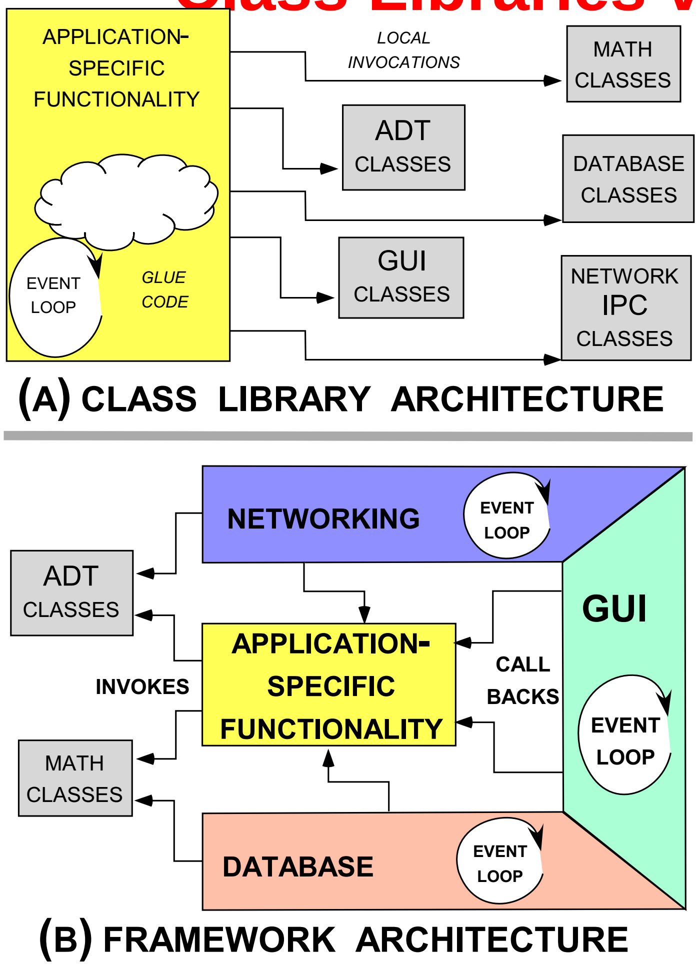
Pattern descriptions are often independent of programming language or implementation details

- Contrast with frameworks

Frameworks

1. ***Frameworks are semi-complete applications***
   - Complete applications are developed by *inheriting* from, and *instantiating* parameterized framework components
2. ***Frameworks provide domain-specific functionality***
   - *e.g.*, business applications, telecommunication applications, window systems, databases, distributed applications, OS kernels
3. ***Frameworks exhibit inversion of control at run-time***
   - *i.e.*, the framework determines which objects and methods to invoke in response to events

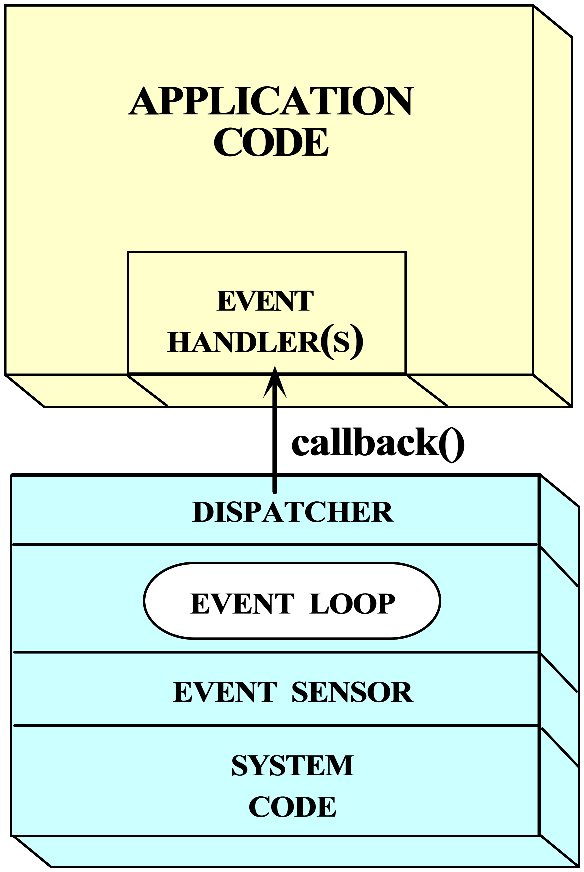
Class Libraries vs. Frameworks vs. Patterns



Definition

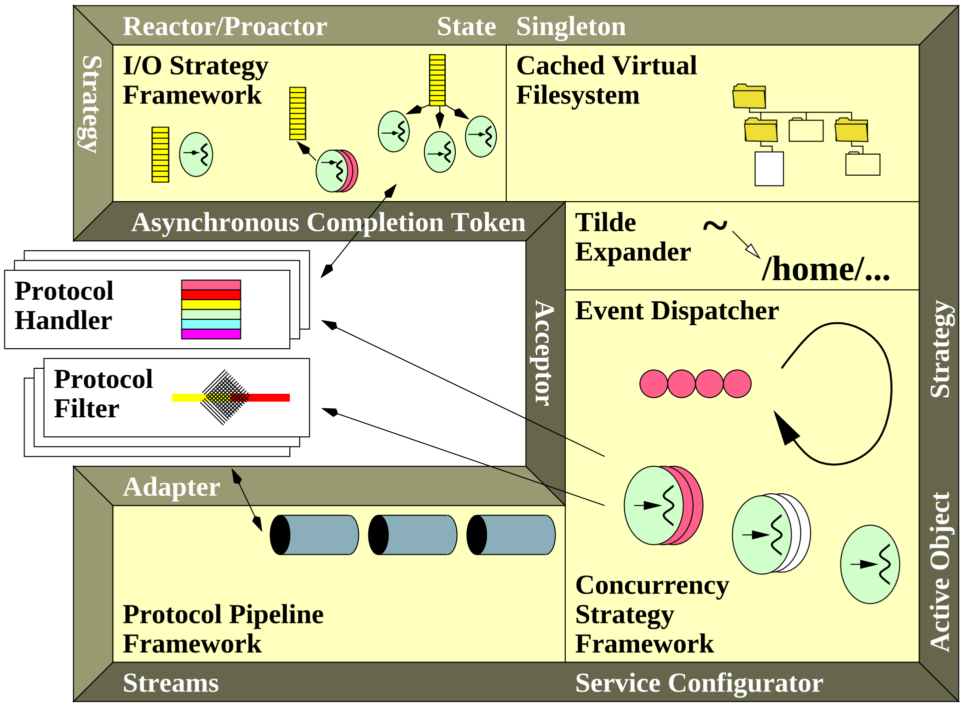
- *Class libraries*
  - Self-contained, “pluggable” ADTs
- *Frameworks*
  - Reusable, “semi-complete” applications
- *Patterns*
  - Problem, solution, context

Component Integration in Frameworks



- Framework components are loosely coupled via *callbacks*
- Callbacks allow independently developed software components to be connected together
- Callbacks provide a connection-point where generic framework objects can communicate with application objects
  - The framework provides the common *template methods* and the application provides the variant *hook methods*

Comparing Patterns and Frameworks



- Patterns and frameworks are highly synergistic
  - *i.e.*, neither is subordinate
- Patterns can be characterized as more abstract descriptions of frameworks, which are implemented in a particular language

In general, sophisticated frameworks embody dozens of patterns and patterns are often used to document frameworks

Design Pattern Space

- *Creational patterns*
  - Deal with initializing and configuring classes and objects
- *Structural patterns*
  - Deal with decoupling interface and implementation of classes and objects
- *Behavioral patterns*
  - Deal with dynamic interactions among societies of classes and objects

Creational Patterns

- *Factory Method*
  - Method in a derived class creates associates
- *Abstract Factory*
  - Factory for building related objects
- *Builder*
  - Factory for building complex objects incrementally
- *Prototype*
  - Factory for cloning new instances from a prototype
- *Singleton*
  - Factory for a singular (sole) instance

Structural Patterns

- *Adapter*
  - Translator adapts a server interface for a client
- *Bridge*
  - Abstraction for binding one of many implementations
- *Composite*
  - Structure for building recursive aggregations
- *Decorator*
  - Decorator extends an object transparently

Structural Patterns (cont'd)

- *Facade*
  - Facade simplifies the interface for a subsystem
- *Flyweight*
  - Many fine-grained objects shared efficiently
- *Proxy*
  - One object approximates another

Behavioral Patterns

- *Chain of Responsibility*
  - Request delegated to the responsible service provider
- *Command*
  - Request as first-class object
- *Interpreter*
  - Language interpreter for a small grammar
- *Iterator*
  - Aggregate elements are accessed sequentially

Behavioral Patterns (cont'd)

- *Mediator*
  - Mediator coordinates interactions between its associates
- *Memento*
  - Snapshot captures and restores object states privately
- *Observer*
  - Dependents update automatically when a subject changes
- *State*
  - Object whose behavior depends on its state

Behavioral Patterns (cont'd)

- *Strategy*
  - Abstraction for selecting one of many algorithms
- *Template Method*
  - Algorithm with some steps supplied by a derived class
- *Visitor*
  - Operations applied to elements of an heterogeneous object structure

When to Use Patterns

1. *Solutions to problems that recur with variations*
   - No need for reuse if the problem only arises in one context
2. *Solutions that require several steps*
   - Not all problems need all steps
   - Patterns can be overkill if solution is simple linear set of instructions
3. *Solutions where the solver is more interested in the existence of the solution than its complete derivation*
   - Patterns leave out too much to be useful to someone who really wants to understand
     – They can be a temporary bridge, however

What Makes a Pattern a Pattern?

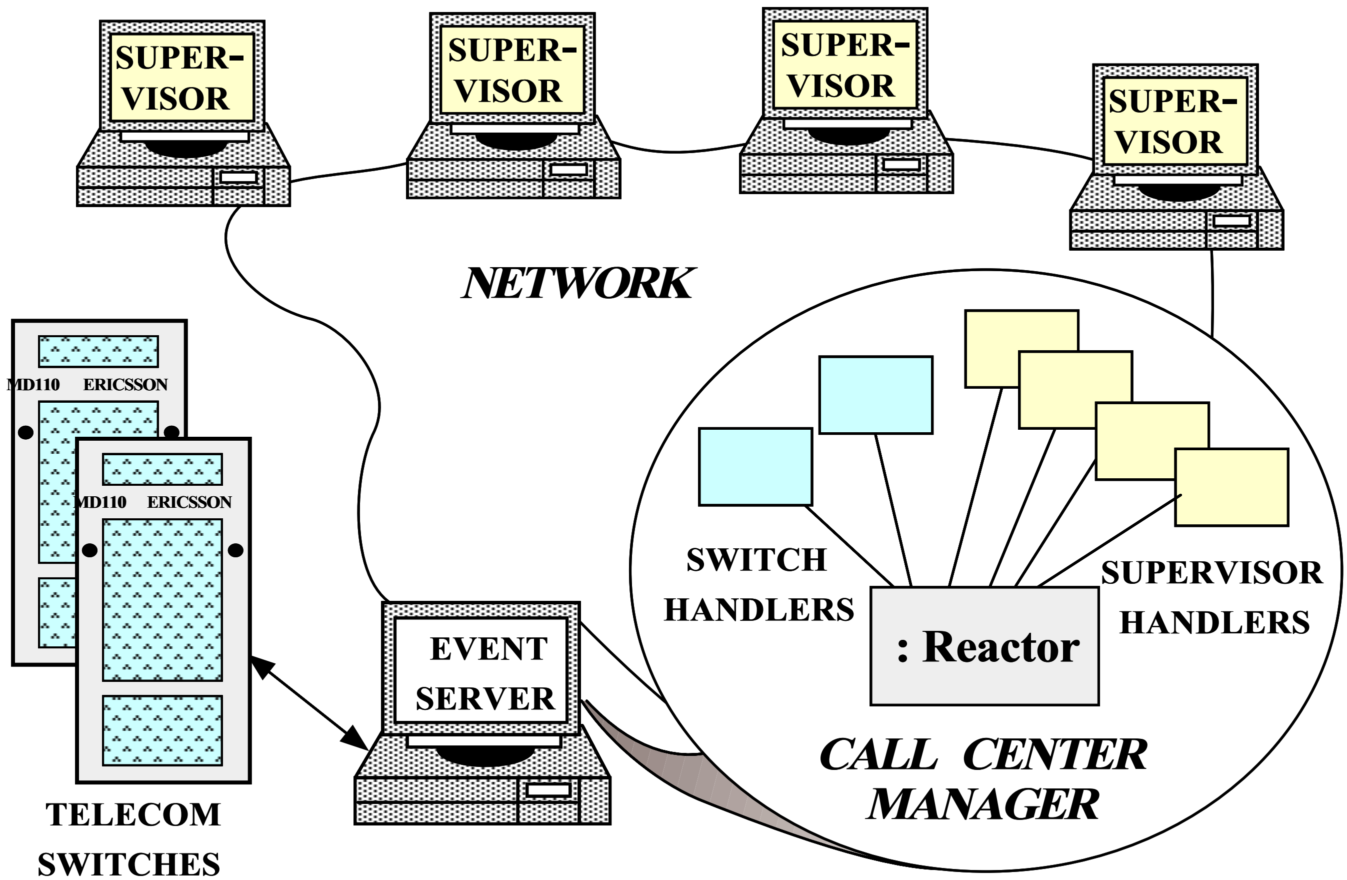
A *pattern* must:

- ***Solve a problem***,
  - *i.e.*, it must be useful!
- ***Have a context***,
  - It must describe where the solution can be used
- ***Recur***,
  - It must be relevant in other situations
- ***Teach***
  - It must provide sufficient understanding to tailor the solution
- ***Have a name***
  - It must be referred to consistently

Case Study: A Reusable Object-Oriented Communication Software Framework

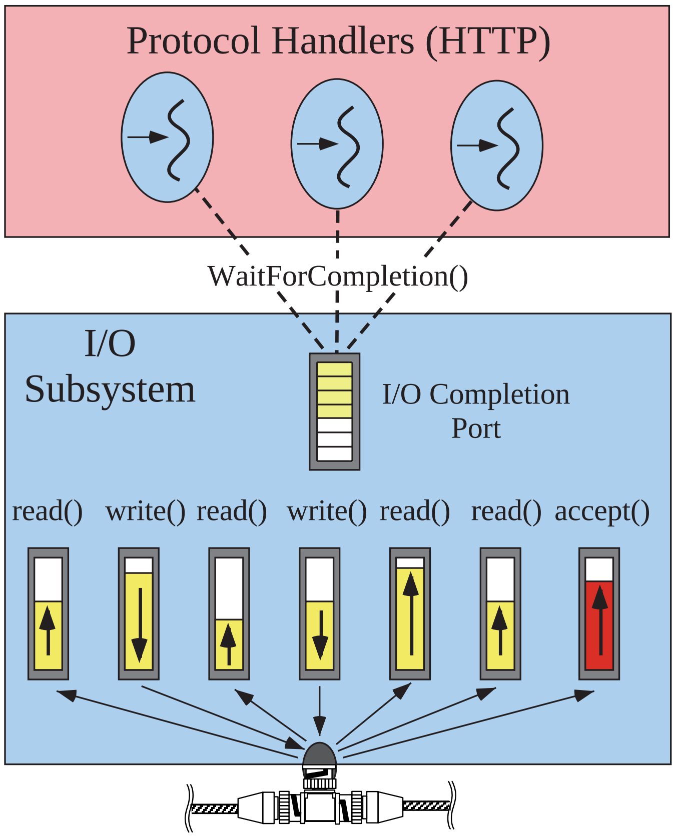
- Developing portable, reusable, and efficient communication software is hard
- OS platforms are often fundamentally incompatible
  - *e.g.*, different concurrency and I/O models
- Thus, it may be impractical to directly reuse:
  - *Algorithms*
  - *Detailed designs*
  - *Interfaces*
  - *Implementations*

System Overview



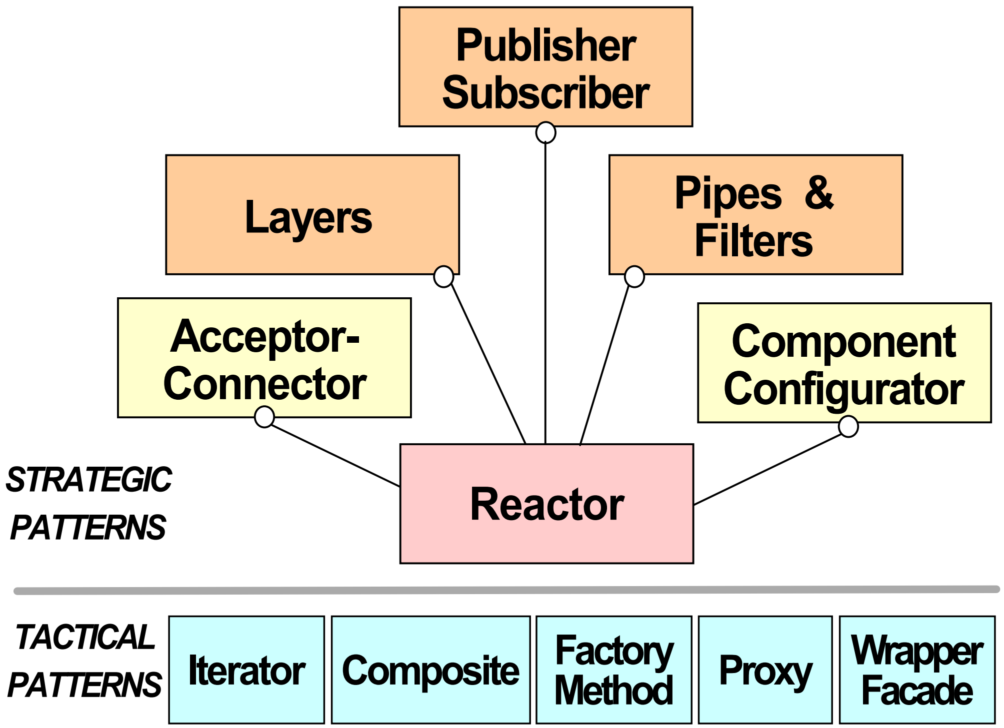
- OO framework for Call Center Management
- www.cs.wustl.edu/∼schmidt/PDF/ECOOP-95.pdf
- www.cs.wustl.edu/∼schmidt/PDF/DSEJ-94.pdf

Problem: Cross-platform Reuse



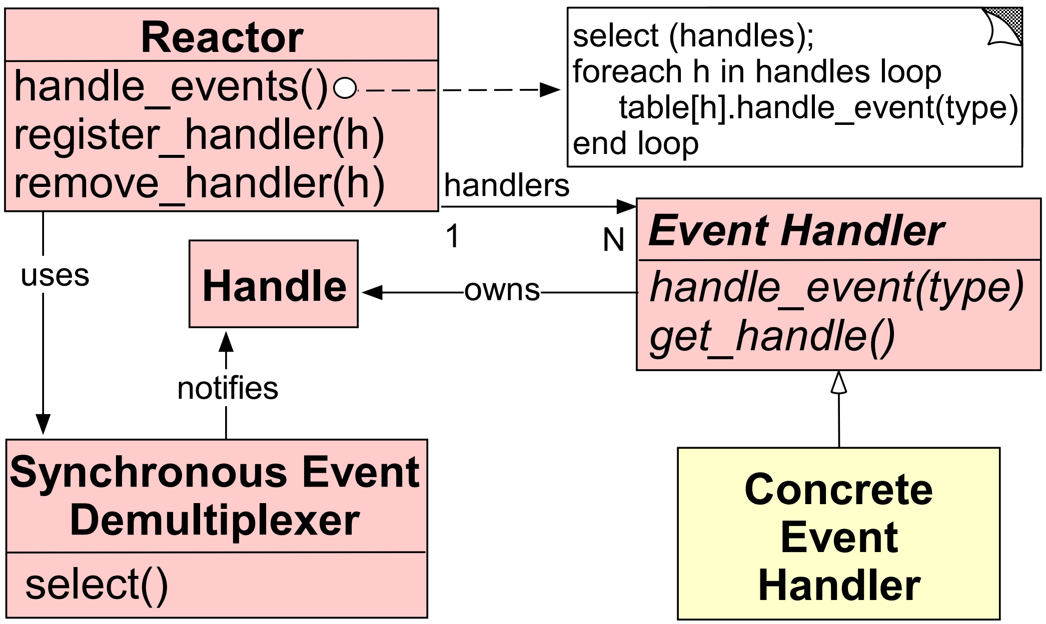
- OO framework was first developed on UNIX and later ported to Windows NT 3.51 in 1993
- UNIX and Windows NT have fundamentally different I/O models
  - *i.e.*, synchronous vs. asynchronous
- Thus, direct reuse of original framework was infeasible
  - Later solved by ACE and Windows NT 4.0

Solution: Reuse Design Patterns



- Patterns support reuse of *software architecture*
- Patterns embody successful *solutions* to *problems* that arise when developing software in a particular *context*
- Patterns reduced project risk by leveraging proven design expertise

The Reactor Pattern



www.cs.wustl.edu/∼schmidt/POSA/

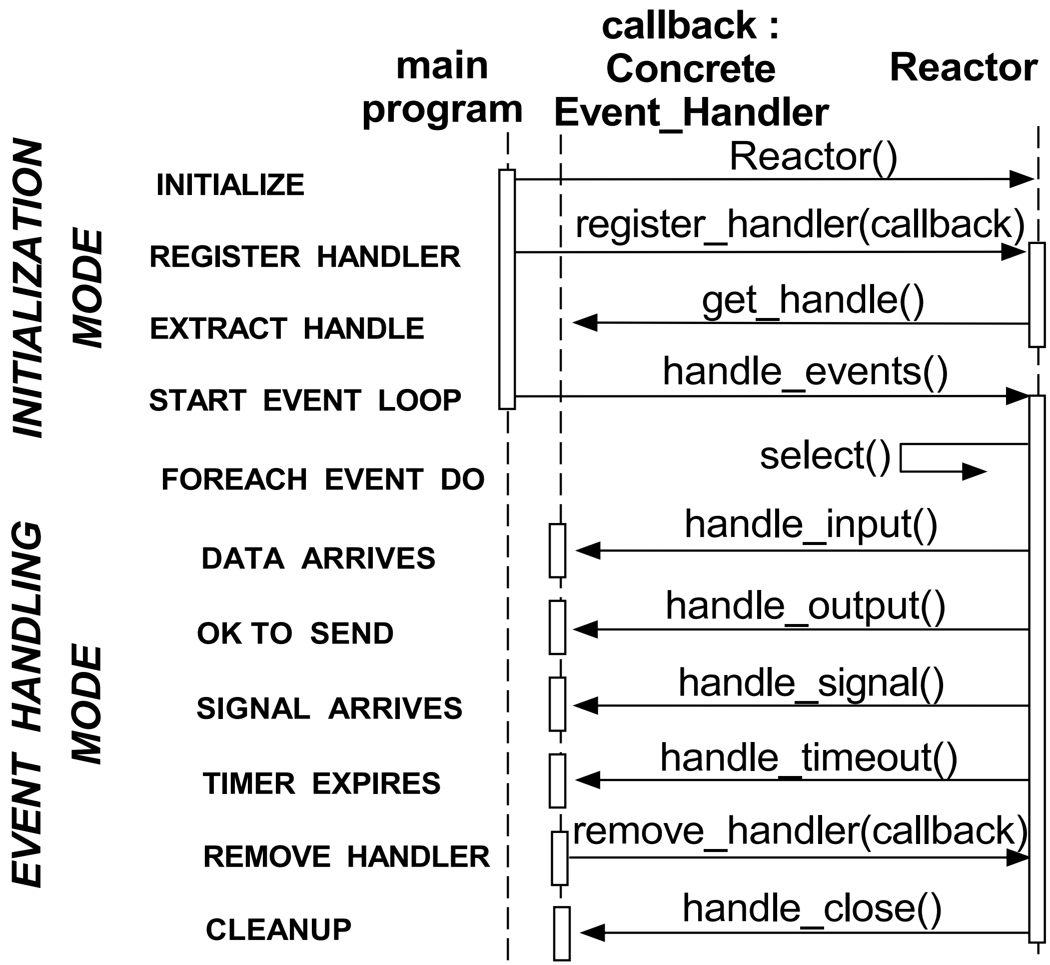
Intent

- *Decouples synchronous event demuxing & dispatching from event handling*

Forces Resolved

- Efficiently demux events *synchronously* within one thread
- Extending applications without changing demux infrastructure

Collaboration in the Reactor Pattern



- Note *inversion of control*
- Also note how long-running event handler callbacks can degrade quality of service

Using ACE's Reactor Pattern Implementation

```
#include "ace/Reactor.h"
class My_Event_Handler : public ACE_Event_Handler {
public:
  virtual int handle_input (ACE_HANDLE h) {
    cout << "input on handle " << h << endl;
    return 0; }
  virtual int handle_signal (int signum,
                             siginfo_t *,
                             ucontext_t *) {
    cout << "signal " << signum << endl;
    return 0; }
  virtual ACE_HANDLE get_handle (void) const {
    return ACE_STDIN; }
};
```

Using ACE's Reactor Pattern Implementation (cont'd)

```
int main (int argc, char *argv[])
{
  My_Event_Handler eh;
  ACE_Reactor reactor;

  reactor.register_handler
    (&eh, ACE_Event_Handler::READ_MASK);

  reactor.register_handler
    (SIGINT, &eh);

  for (;;)
    reactor.handle_events ();

  /* NOTREACHED */
  return 0;
}
```

Differences Between UNIX and Windows NT

- *Reactive* vs. *Proactive* I/O
  - Reactive I/O is synchronous
  - Proactive I/O is asynchronous
    - Requires additional interfaces to "arm" the I/O mechanism
  - See *Proactor* pattern
    - www.cs.wustl.edu/~schmidt/POSA/
- Other differences include
  - *Resource limitations*
    - *e.g.*, Windows **`WaitForMultipleObjects()`** limits HANDLEs per-thread to 64
  - *Demultiplexing fairness*
    - *e.g.*, **`WaitForMultipleObjects`** always returns the lowest active HANDLE

Lessons Learned from Case Study

- Real-world constraints of OS platforms can preclude direct reuse of communication software
  - *e.g.*, must often use non-portable features for performance
- Reuse of design patterns may be the only viable means to leverage previous development expertise
- Design patterns are useful, but are no panacea
  - Managing expectations is crucial
  - Deep knowledge of platforms, systems, and protocols is also very important

Key Principles

- Successful patterns and frameworks can be boiled down to a few key principles:

  1. Separate interface from implementation
  2. Determine what is *common* and what is *variable* with an interface and an implementation
     - Common == stable
  3. Allow substitution of *variable* implementations via a *common* interface

- Dividing *commonality* from *variability* should be goal-oriented rather than exhaustive

Planning for Change

- Often, aspects of a design “seem” constant until they are examined in the light of the dependency structure of an application
  - At this point, it becomes necessary to refactor the framework or pattern to account for the variation
- Frameworks often represent the distinction between commonality and variability via *template methods* and *hook methods,* respectively

The Open/Closed Principle

- Determining common vs. variable components is important
  - Insufficient variation makes it hard for users to customize framework components
  - Conversely, insufficient commonality makes it hard for users to comprehend and depend upon the framework's behavior
- In general, dependency should always be in the direction of stability
  - *i.e.*, a software component should not depend on any component that is less stable than itself
- The "Open/Closed" principle
  - This principle allows the most stable component to be extensible

The Open/Closed Principle (cont'd)

- Components should be:
  - open for extension
  - closed for modification
- Impacts
  - Abstraction is good
  - Inheritance and polymorphism are good
  - Public data members and global data are bad
  - Run-time type identification can be bad

Violation of Open/Closed Principle

```
struct Shape { enum Type { CIRCLE, SQUARE }
                   shape_type;
               /* . . . */ };
void draw_square (const Square &);
void draw_circle (const Circle &);

void draw_shape (const Shape &shape) {
  switch (shape.shape_type) {
    case SQUARE:
      draw_square ((const Square &) shape);
      break;
    case CIRCLE:
      draw_circle ((const Circle &) shape);
      break;
    // etc.
```

Application of Open/Closed Principle

```
class Shape {
public:
  virtual void draw () const = 0;
};

class Square : public Shape { /* . . . */ };
class Circle : public Shape { /* . . . */ };

typedef vector<Shape> Shape_Vector;

void draw_all (const Shape_Vector &shapes) {
  for (Shape_Vector::iterator i = shapes.begin();
       i != shapes.end ();
       i++)
    (*iterator).draw ();
}
```

Benefits of Design Patterns

- ***Design patterns enable large-scale reuse of software architectures***
  - They also help document systems to enhance understanding
- ***Patterns explicitly capture expert knowledge and design tradeoffs, and make this expertise more widely available***
- ***Patterns help improve developer communication***
  - Pattern names form a vocabulary
- ***Patterns help ease the transition to object-oriented technology***

Drawbacks to Design Patterns

- ***Patterns do not lead to direct code reuse***
- ***Patterns are deceptively simple***
- ***Teams may suffer from pattern overload***
- ***Patterns are validated by experience and discussion rather than by automated testing***
- ***Integrating patterns into a software development process is a human-intensive activity***

Tips for Using Patterns Effectively

- ***Do not recast everything as a pattern.***
  - Instead, develop strategic domain patterns and reuse existing tactical patterns
- ***Institutionalize rewards for developing patterns***
- ***Directly involve pattern authors with application developers and domain experts***
- ***Clearly document when patterns apply and do not apply***
- ***Manage expectations carefully***

Lessons Learned using OO Frameworks

- ***Benefits of frameworks***
  - Enable direct reuse of code
  - Facilitate larger amounts of reuse than stand-alone functions or individual classes
- ***Drawbacks of frameworks***
  - High initial learning curve
    - Many classes, many levels of abstraction
  - The flow of control for reactive dispatching is non-intuitive
  - Verification and validation of generic components is hard

Patterns and Framework Literature

- **Books**
  - Gamma et al., *Design Patterns: Elements of Reusable Object-Oriented Software* AW, '94
  - *Pattern Languages of Program Design* series by AW, '95-'99.
  - Siemens & Schmidt, *Pattern-Oriented Software Architecture*, Wiley, volumes '96 & '00 (`www.posa.uci.edu`)
  - Schmidt & Huston, *C++ Network Programming: Mastering Complexity with ACE and Patterns*, AW, '02 (`www.cs.wustl.edu/~schmidt/ACE/book1/`)
  - Schmidt & Huston, *C++ Network Programming: Systematic Reuse with ACE and Frameworks*, AW, '03 (`www.cs.wustl.edu/~schmidt/ACE/book2/`)

Conferences and Workshops on Patterns

- Pattern Language of Programs Conferences
  - September 8-12, 2003, Monticello, Illinois, USA
  - http://hillside.net/conferences/plop.htm
- The European Pattern Languages of Programming conference
  - June 25-29, 2003, Kloster Irsee, Germany
  - http://hillside.net/conferences/europlop.htm
- Middleware 2003
  - June 16-20, 2003, Rio, Brazil
  - www.cs.wustl.edu/ schmidt/activities-chair.html

Summary

- Mature engineering disciplines have handbooks that describe successful solutions to known problems
  - *e.g.*, automobile designers don't design cars using the laws of physics, they adapt adequate solutions from the handbook known to work well enough
  - The extra few percent of performance available by starting from scratch typically isn't worth the cost
- Patterns can form the basis for the handbook of software engineering
  - If software is to become an engineering discipline, successful practices must be systematically documented and widely disseminated