

Design Patterns

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Acknowledgements

Materials based on a number of sources

- D. Levine and D. Schmidt
- R. Helm
- Gamma *et al*
- S. Konrad

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Motivation

- Developing software is hard
- Designing reusable software is more challenging
 - finding good objects and abstractions
 - flexibility, modularity, elegance → reuse
 - takes time for them to emerge, trial and error
- Successful designs do exist
 - exhibit recurring class and object structures

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Design Pattern

- Describes recurring design structure
 - names, abstracts from concrete designs
 - identifies classes, collaborations, responsibilities
 - applicability, trade-offs, consequences

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Becoming a Chess Master

- *First learn rules and physical requirements*
 - e.g., names of pieces, legal movements, chess board geometry and orientation, etc.
- *Then learn principles*
 - e.g., relative value of certain pieces, strategic value of center squares, power of a threat, etc.
- *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

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Becoming a Software Design Master

- *First learn rules*
 - e.g., algorithms, data structures, and languages of software.
- *Then learn principles*
 - e.g., structured programming, modular programming, object-oriented programming, etc.
- *To become a Master of SW 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

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Design Patterns

- Design patterns represent solutions to problems that arise when developing software within a particular context
 - “Patterns == problem/solution pairs in a context”
- Patterns capture the static and dynamic *structure* and *collaboration* among key participants in software designs
 - Especially good for describing how and why to resolve *non-functional issues*
- Patterns facilitate reuse of successful software architectures and designs.

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Design Patterns: Applications

- Wide variety of application domains:
 - drawing editors, banking, CAD, CAE, cellular network management, telecomm switches, program visualization
- Wide variety of technical areas:
 - user interface, communications, persistent objects, O/S kernels, distributed systems

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What Is a Design Pattern (1)

“Each pattern describes a problem which occurs over and over again in our environment and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it in the same way twice”

Christopher Alexander, A Pattern Language, 1977

Context: City Planning and Building architectures

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What Is a Design Pattern (2)

A pattern has 4 essential elements:

- Pattern name
- Problem
- Solution
- Consequences



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Pattern Name

- A handle used to describe:
 - a design problem,
 - its solutions and
 - its consequences
- Increases design vocabulary
- Makes it possible to design at a higher level of abstraction
- Enhances communication

But finding a good name is often difficult

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Problem

- Describes when to apply the pattern
- Explains the problem and its context
- Might describe specific design problems or class or object structures
- May contain a list of conditions
 - must be met
 - before it makes sense to apply the pattern

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Solution

- Describes the elements that make up the
 - design,
 - their relationships,
 - responsibilities and
 - collaborations
- ***Does not*** describe specific concrete implementation
- Abstract description of design problems and
 - how the pattern solves it

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Consequences

- Results and trade-offs of applying the pattern
- Critical for:
 - evaluate design alternatives and
 - understand costs and
 - understand benefits of applying the pattern
- Includes the impacts of a pattern on a system's:
 - flexibility,
 - extensibility
 - portability

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Design Patterns Are NOT

- Designs that can be encoded in classes and reused as is
 - (i.e. linked lists, hash tables)
- Complex domain-specific designs (for an entire application or subsystem)

They are:

“Descriptions of communicating objects and classes that are customized to solve a general design problem in a particular context.”

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Where Design Patterns Are Used

- **Object-Oriented Programming Languages:**
 - more amenable to implementing design patterns
- **Procedural languages:** need to define
 - *Inheritance*,
 - *Polymorphism* and
 - *Encapsulation*

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How to Describe Design Patterns

- Graphical notation is not sufficient
- In order to reuse design decisions,
 - alternatives and trade-offs that led to the decisions are important
- Concrete examples are also important

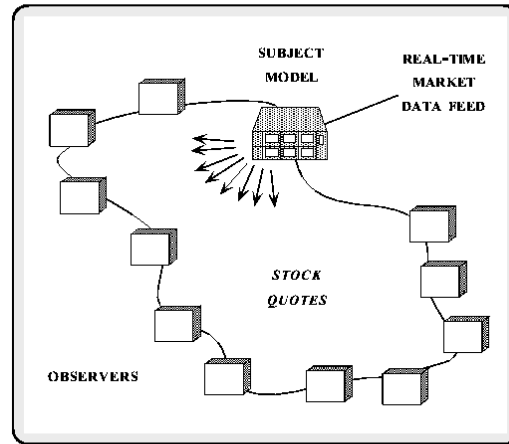
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A Design Pattern

- Describes a recurring design structure
 - names, abstracts from concrete designs
 - identifies classes, collaborations, responsibilities
 - applicability, trade-offs, consequences

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Example: Stock Quote Service



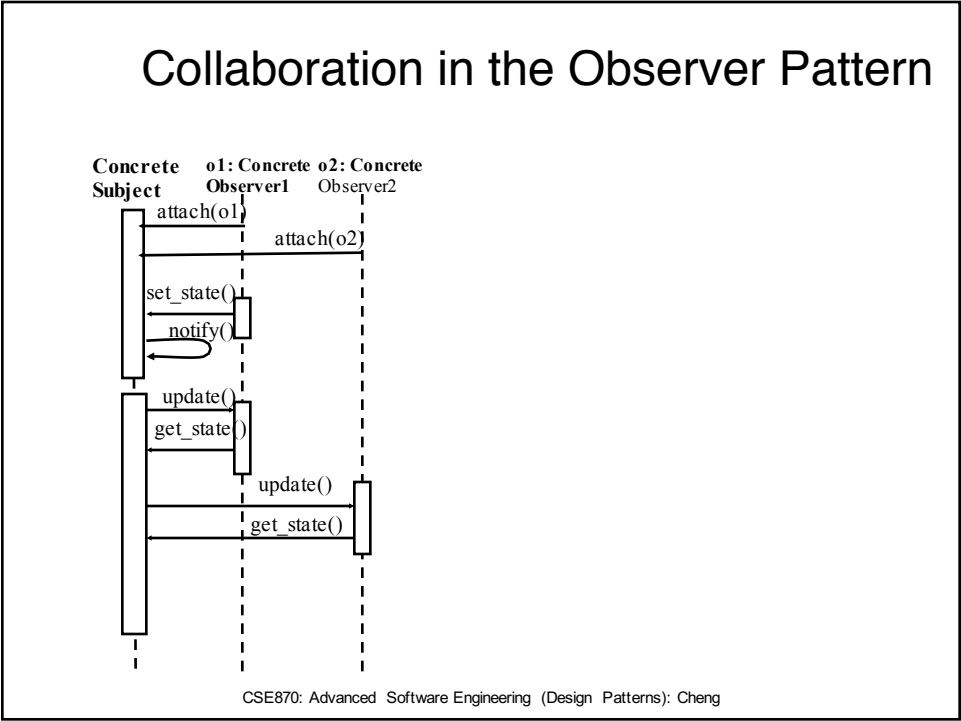
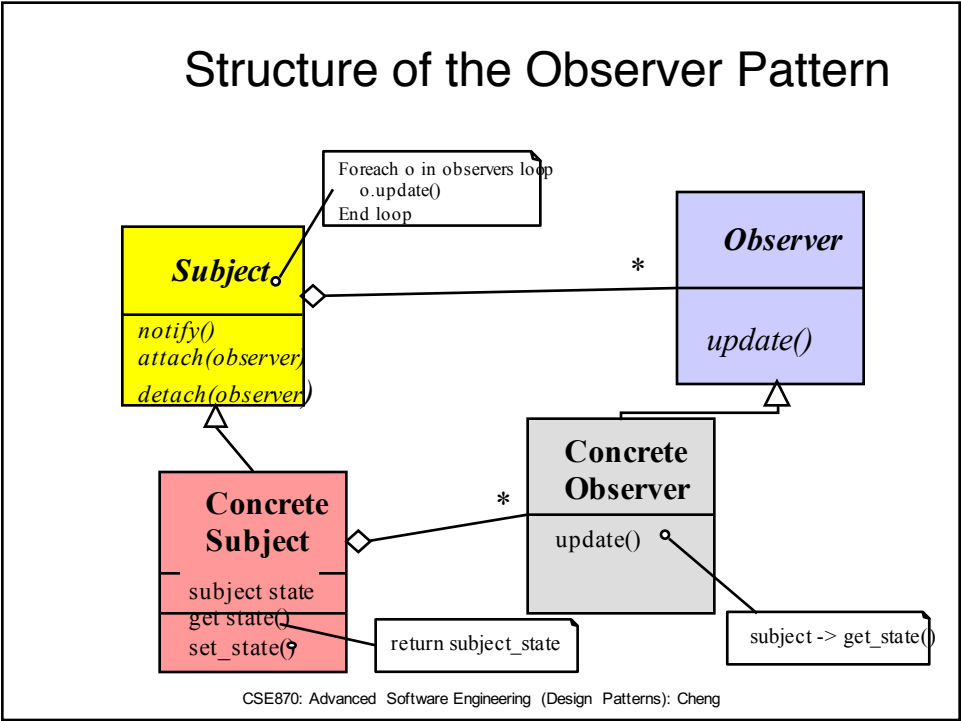
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Observer Pattern

- Intent:
 - Define a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically
- Key forces:
 - There may be many observers
 - Each observer may react differently to the same notification
 - The subject should be as decoupled as possible from the observers
 - allow observers to change independently of the subject

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Design Pattern Descriptions

- Main Parts:
 - Name and Classification (see table in two more slides)
 - Intent: Problem and Context
 - Also known as (other well-known names)
 - **Motivation: scenario illustrates a design problem**
 - Applicability: situations where pattern can be applied
 - **Structure: graphical representation of classes (class diagram, interaction diagram)**
 - Participants: objects/classes and their responsibilities
 - **Collaborations: how participants collaborate**
 - Consequences: trade-offs and results
 - Implementation: pitfalls, hints, techniques for coding; language-specific issues
 - Sample Code
 - Known Uses: examples of pattern in real systems
 - Related Patterns: closely related; what are diffs.
- Pattern descriptions are often independent of programming language or implementation details

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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
 - Composition of classes or objects
- **Behavioral patterns**:
 - Deal with dynamic interactions among societies of classes and objects
 - How they distribute responsibility

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Categorize Design Patterns

		Purpose		
		Creational	Structural	Behavioral
Scope	Class	Factory Method	Adapter (class)	Interpreter Template Method
	Object	Abstract Factory Builder Prototype Singleton	Adapter (object) Bridge Composite Decorator Flyweight Facade Proxy	Chain of Responsibility Command Iterator Mediator Memento Observer State Strategy Visitor

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Categorization Terms

- Scope: domain over which a pattern applies
 - Class Scope:
 - relationships between base classes and their subclasses
 - Static semantics
 - Object Scope:
 - relationships between peer objects
 - Can be changed at runtime
 - More dynamic

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Purpose of Patterns

- Creational:
 - Class: defer some part of object creation to subclasses
 - Object: Defer object creation to another object
- Structural:
 - Class: use inheritance to compose classes
 - Object: describe ways to assemble classes
- Behavioral:
 - Class: use inheritance to describe algs and flow of control
 - Object: describes how a group of objects cooperate to perform task that no single object can complete

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Terminology

- Signature: (*of an operation*)
 - operation name,
 - objects taken as parameters, and
 - operation's return value
- Interface: (*of an object*)
 - Set of all signatures defined by an object's operations
 - Characterizes the complete set of requests that can be sent to object.
 - Key to OO technology

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Creational Patterns

- Factory Method*:
 - method in a derived class creates associations
- 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

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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
- Facade:
 - simplifies the interface for a subsystem
- Flyweight:
 - many fine-grained objects shared efficiently.
- Proxy:
 - one object approximates another

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Behavioral Patterns

- Chain of Responsibility
 - request delegated to the responsible service provider
- Command:
 - request is first-class object
- Iterator:
 - Aggregate elements are accessed sequentially
- Interpreter*:
 - language interpreter for a small grammar
- Mediator:
 - coordinates interactions between its associates
- Memento:
 - snapshot captures and restores object states privately
- Observer:
 - dependents update automatically when subject changes
- State:
 - object whose behavior depends on its state

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Behavior Patterns (more)

- 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 a heterogeneous object structure

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When to Use Patterns

- Solutions to problems that recur with variations
 - No need for reuse if problem only arises in one context
- Solutions that require several steps:
 - Not all problems need all steps
 - Patterns can be overkill if solution is a simple linear set of instructions
- 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

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What Makes it a Pattern

A Pattern must:

- | | |
|--|---|
| – Solve a problem <ul style="list-style-type: none">• must be useful | – Teach <ul style="list-style-type: none">• provide sufficient understanding to tailor the solution |
| – Have a context <ul style="list-style-type: none">• describe where the solution can be used | – have a name <ul style="list-style-type: none">• referenced consistently |
| – Recur <ul style="list-style-type: none">• relevant in other situations | |

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PAUSE

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Class Scope

- **Class Creational: abstract how objects are instantiated**
 - hide specifics of creation process
 - may want to delay specifying a class name explicitly when instantiating an object
 - just want a specific protocol

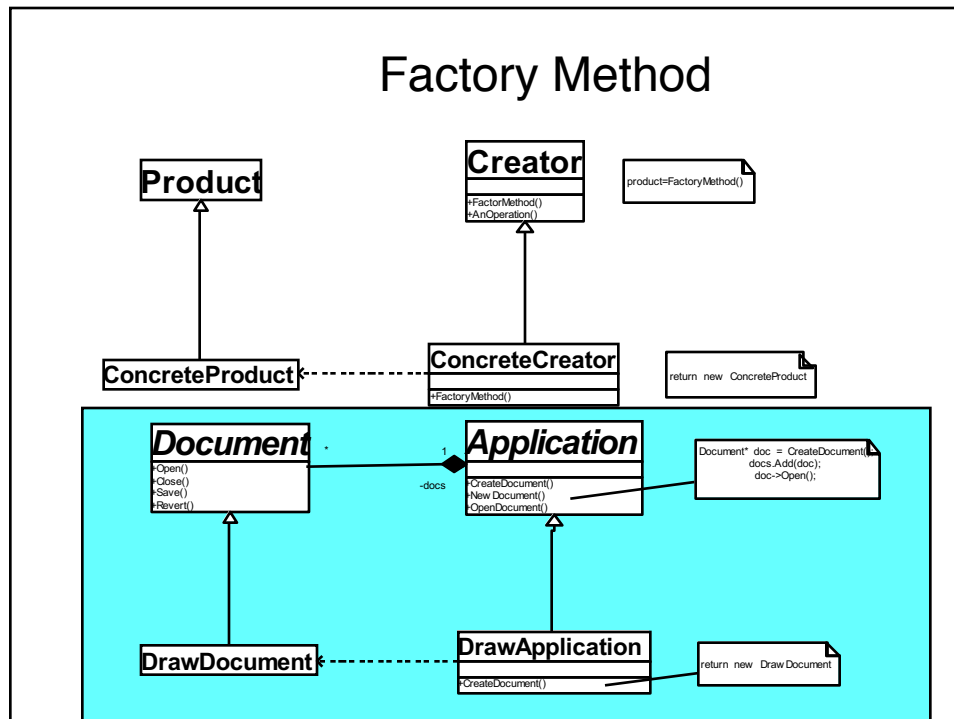
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Example Class Creational

- Use of *Factory Method*: instantiate members in base classes with objects created by subclasses.
- Abstract *Application* class: create application-specific documents conforming to particular *Document* type
- *Application* instantiates these *Document* objects by calling the factory method *CreateDocument*
- Method is overridden in classes derived from *Application*
- Subclass *DrawApplication* overrides *CreateDocument* to return a *DrawDocument* object

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Factory Method



Class Structural

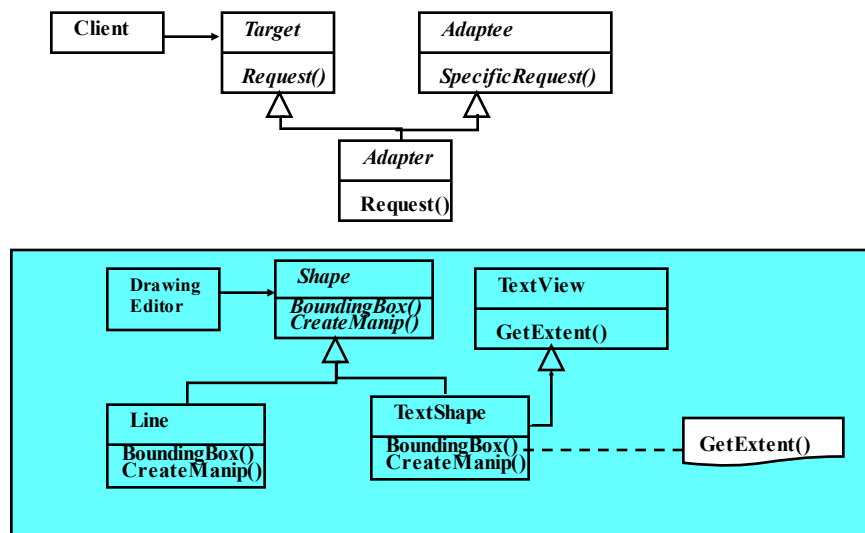
- **Class Structural:** use inheritance to compose protocols or code

- Example:

- Adapter Pattern: makes one interface (Adaptee's) conform to another --> uniform abstraction of different interfaces.
- Class Adapter inherits privately from an Adaptee class.
- Adapter then expresses its interface in terms of the Adaptee's.

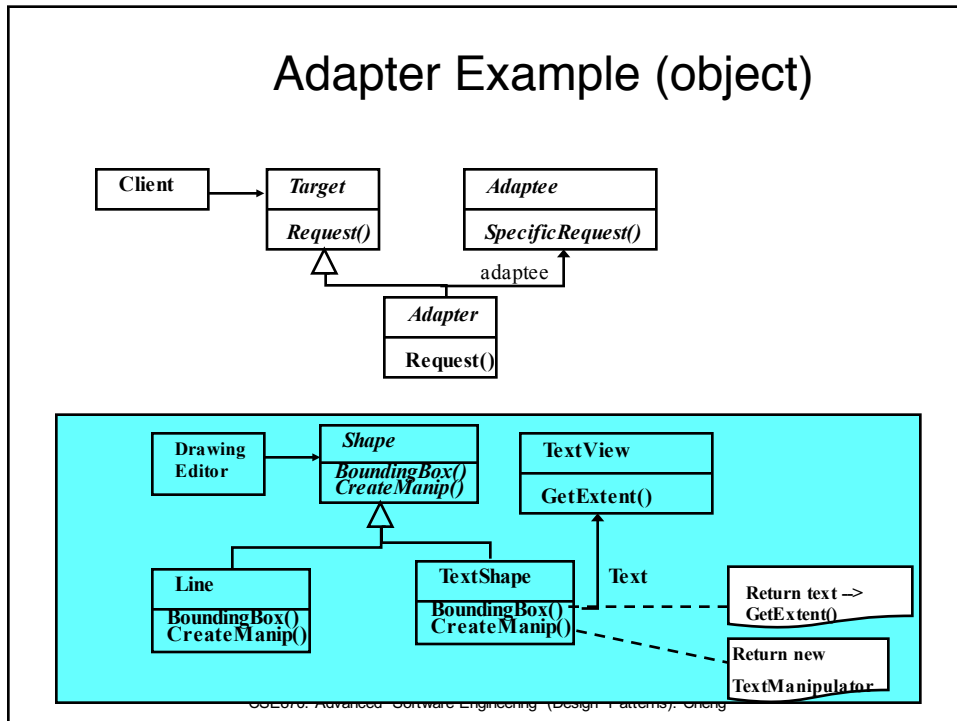
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Adapter Example (class)



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Adapter Example (object)



Class Behavioral

- **Class Behavioral**: capture how classes cooperate with their subclasses to satisfy semantics.
 - **Template Method**: defines algorithms step by step.
 - Each step can invoke an abstract method (that must be defined by the subclass) or a base method.
 - Subclass must implement specific behavior to provide required services

Object Scope

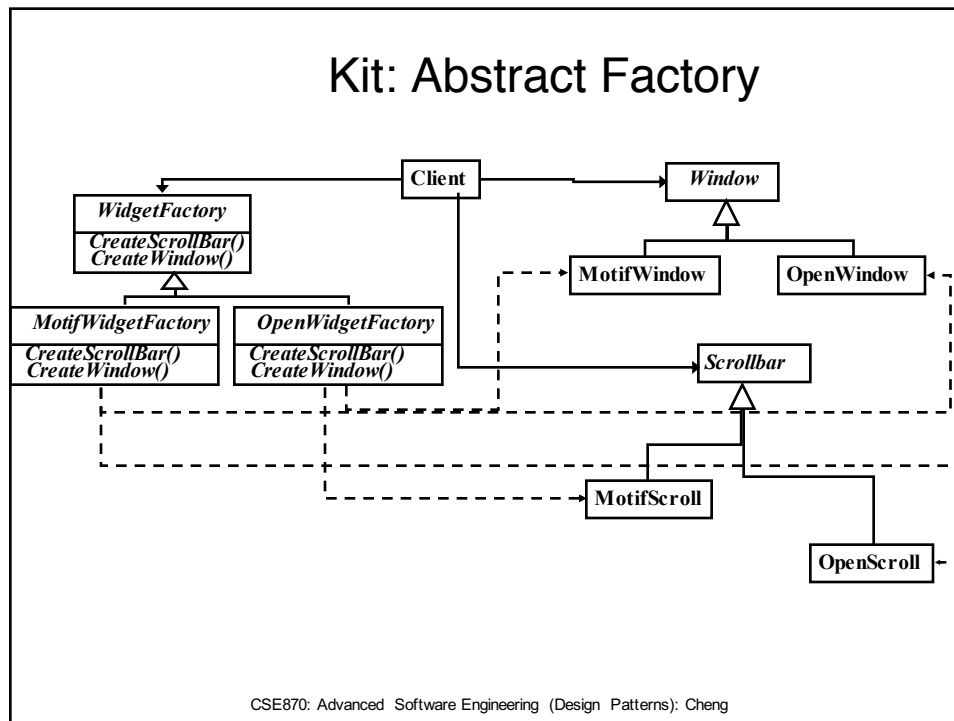
- Object Patterns all apply various forms of non-recursive object composition.
- Object Composition: most powerful form of reuse
- Reuse of a collection of objects is better achieved through variations of their composition, rather than through subclassing.

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Object Creational

- **Creational Object Patterns:** abstract how sets of objects are created
- Example:
 - Abstract Factory: create “product” objects through generic interface
 - Subclasses may manufacture specialized versions or compositions of objects as allowed by this generic interface
 - User Interface Toolkit: 2 types of scroll bars (Motif and Open Look)
 - Don’t want to hard-code specific one; an environment variable decides
 - Class **Kit**:
 - encapsulates scroll bar creation (and other UI entities);
 - an abstract factory that abstracts the specific type of scroll bar to instantiate
 - Subclasses of Kit refine operations in the protocol to return specialized types of scroll bars.
 - Subclasses **MotifKit** and **OpenLookKit** each have scroll bar operation.

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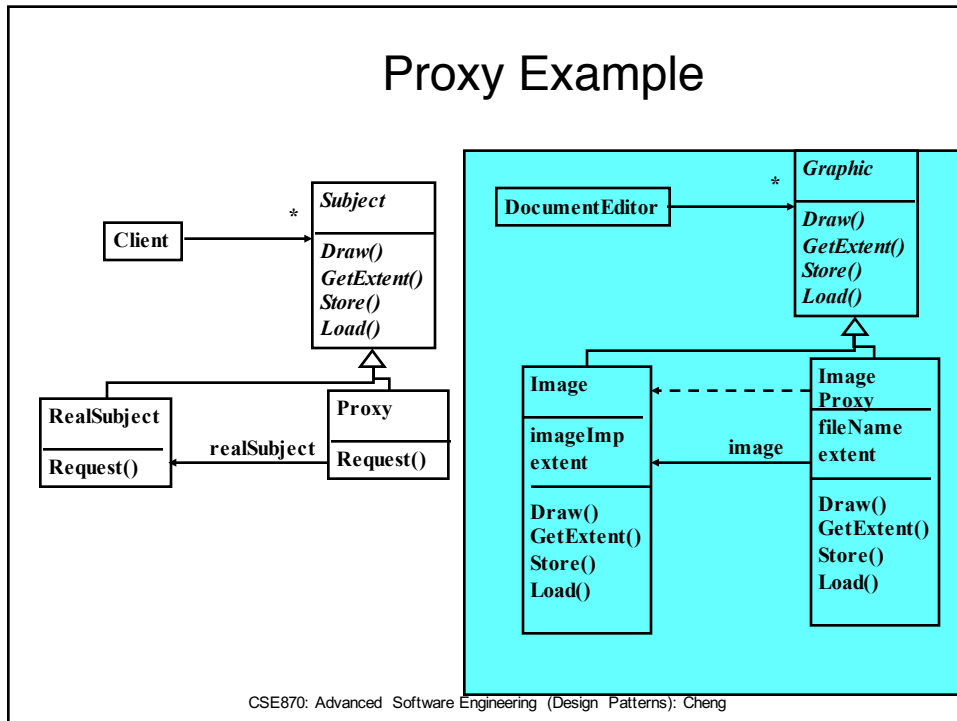


Object Structural

- Object Structural: Describe ways to assemble objects to realize new functionality
 - Added flexibility inherent in object composition due to ability to change composition at run-time
 - not possible with static class composition.
- Example:
 - Proxy: acts as convenient surrogate or placeholder for another object.
 - Remote Proxy: local representative for object in a different address space
 - Virtual Proxy: represent large object that should be loaded on demand
 - Protected Proxy: protect access to the original object

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Proxy Example



Object Behavioral

- Object Behavioral: Describe how a group of peer objects cooperate to perform a task that can be carried out by itself.
- Example:
 - Strategy Pattern: objectifies an algorithm
 - **Text Composition** Object: support different line breaking algorithms
 - Don't want to hard-code all algs into **text composition** class/subclasses
 - Objectify different algs and provide them as **Compositor** subclasses (contains criteria for line breaking strategies)
 - Interface for **Compositors** defined by Abstract Compositor Class
 - **Derived classes** provide different layout strategies (simple line breaks, left/right justification, etc.)
 - **Instances of Compositor subclasses** couple with text composition at run-time to provide text layout
 - Whenever **text composition** has to find line breaks, forwards the responsibility to its current **Compositor** object.

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Object Behavioral Example

- **Iterator Pattern**: Iteration over a recursive structure
- Traversal strategies for a given structure:
 - Extract and implement each traversal strategy in an **Iterator** class.
 - **Iterators** objectify traversal algs over recursive structures
 - Different **iterators** can implement pre-order, in-order, post-order traversals
 - Require nodes in structure to provide services to enumerate their sub-structures
 - Don't need to hard-code traversal algs throughout classes of objects in composite structure
 - **Iterators** may be replaced at run-time to provide alternate traversals.

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Object Structural Example

- **Facade Pattern (Wrapper)**: describes how to flexibly attach additional properties and services to an object
 - Can be nested recursively; compose more complex object structures
- **User Interface Example**:
 - A **Facade** containing a single UI component can add decorations such as border, shadows, scroll bars, or services (scrolling and zooming)
 - **Facade** must conform to interface of its wrapped component and forward messages to it
 - **Facade** can perform additional actions (e.g., drawing border around component) either before or after forwarding a message.

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Benefits of Design Patterns

- Design patterns enable large-scale reuse of software architectures
 - also help document systems
- Patterns explicitly capture expert knowledge and design tradeoffs
 - make it more widely available
- Patterns help improve developer communication
 - Pattern names form a vocabulary
- Patterns help ease the transition to OO technology

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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 SW development process is a human-intensive activity.

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Suggestions for Effective Pattern Use

- 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.

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