Software Architecture (2/2)

Martin Kellogg

Software Architecture (Part 2 of 2)

Today's agenda:

- **Strategies for good design**
- Design patterns
  - Structural patterns
  - Creational patterns
  - Behavioural patterns

Design

"Architecture" vs "Design"

Development process ↓

Requirements

Architecture

Design

Source Code

Level of Abstraction ↑

Definition: *software design* is the structure or organization of a particular component of your system

Design

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- In class, many programs are written once, to a fixed specification, and then **thrown away**
- In industry, many programs are written once and then **modified** as requirements, customers, and developers change
- Many fundamental tenets of object-oriented design facilitate **subsequent change**
  - You may have seen these before, but now you are in a position to really appreciate the motivation!

Design: desiderata

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- Internal details of other classes do not need to be understood, **contract** is sufficient
- Class implementations and their contracts can be tested separately (**unit testing**)

Design for reuse

Design for reuse: delegation

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- Reduce "cut and paste" code and defects

Design for change: motivation

- Amazon.com processes millions of orders each year, selling in 75 countries, all 50 states, and thousands of cities worldwide.
  - These countries, states, and cities have hundreds of distinct sales tax policies
  - For any order and destination, Amazon.com must be able to compute the correct sales tax for the order and destination.

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  > This is called the *Liskov Substitution Principle*: "any subclass object should be safe to use in place of a superclass object at run time"

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- Then we should design our software so that **testing** is effective:
  - Design to admit testing
  - Design to admit fault injection
  - Design to admit coverage
  - Recognize "free test" opportunities

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  - "Package logical components of your application independently - literally as separate gems, eggs, RPMs, or whatever - and maintain them as internal open-source projects … This approach combats the tightly-coupled spaghetti so often lurking in big codebases by giving everything the Right Place in which to exist."

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- Solution: design with **more entry points** for self-contained functionality (cf. AVL tree, priority queue, etc.)

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  - e.g., have an **interface** where abstract commands can be queued up: one way to get them is from the UI, but another is programmatic
  - "If I create a world with blocks X, Y and Z and then we launch bird A at angle B, does C occur within five timesteps?"

Example: fault injection

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- Problem for both: Hardware, OS and Networking errors can occur **infrequently**, but you still want to test them
  - Must design for it! But how…?

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- Don't have your code call fopen() or cout or whatever directly
- Instead, add a very thin **level of indirection** where you call my_fopen which then calls fopen
- Later add "if coin_flip() then fail else ..." to that indirection layer to **inject faults** while testing
  - let the compiler optimize it away for your production code

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  - Design and write the code so that high code coverage **correlates** with high requirements coverage!

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  - Add in "get the time", "do X", "get the time", "subtract", "if t2 – t1 < Y then …"

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  - Structural patterns
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- all patterns have **tradeoffs**. In OO languages, design patterns often trade **verbosity or efficiency** for **extensibility**
- we'll consider **structural**, **creational** and **behavioral** design patterns

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Same ideas apply to software:
- design GUIs that people
  intuitively know how to use
- design code that other
  developers **intuitively** know
  how to read

Design patterns: "gang of four"

- The book popularizing software design patterns is often called the "**Gang of Four**" book after its four authors
- I don't care if you remember this, but it'll be handy to know about (e.g., for interviews)
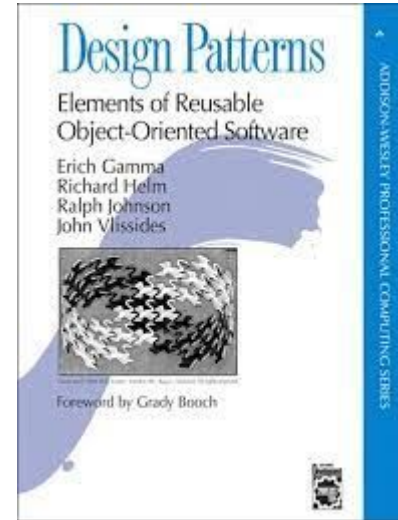
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- Consider your **requirements and their changes**
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- Consider **multiple designs**
  - Diagram your designs before writing code.

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  - Hide implementation details
  - Provide cleaner or more specialized interfaces

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  - Early implementations of fstream in C++
    - … were simply adapters around the C FILE macro

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- The **proxy design pattern** provides a surrogate or placeholder for another object to control access to it
  - e.g., std::vector exposes std::vector::reference as a method of accessing individual bits. In particular, objects of this class are returned by operator[] by value. (https://en.cppreference.com/w/cpp/container/vector_bool)

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- A plain constructor **may not allow** you to:
  - Control how and when an object is used
  - Overcome language limitations (e.g., no default arguments)
  - Hide polymorphic types
  - Specify different combinations of optional arguments

Design patterns: creational patterns

- ***Creational design patterns*** avoid complexity by controlling object creation so that objects ar̲e̲ ̲t̲h̲e̲ ̲r̲i̲g̲h̲t̲ ̲o̲n̲e̲ ̲f̲o̲r̲ ̲t̲h̲e̲ situation. They make a sys̲t̲e̲m̲ ̲i̲n̲d̲e̲p̲e̲n̲d̲e̲n̲t̲ ̲o̲f̲ ̲h̲o̲w̲ ̲o̲b̲j̲e̲c̲t̲s̲ **are created**.

> Different creational patterns allow you to overcome these limitations of simple constructors

- A plain constructor **may not allow** you to:
  - Control how and when an object is used
  - Overcome language limitations (e.g., no default arguments)
  - Hide polymorphic types
  - Specify different combinations of optional arguments

Creational patterns: named constructor

- In the ***Named Constructor Pattern***, you declare the class's normal constructors to be private or protected and make a public static creation method.

Creational patterns: named constructor

- In the *Named Constructor Pattern*, you declare the class's normal constructors to be private or protected and make a public static creation method.

```
class Llama {
public:
 static Llama* create_llama(string name) {
 return new Llama(name);
 }
private: // Making ctor private
 Llama(string name_in): name(name_in) {}
 string name;
};
```

Creational patterns: named constructor

- In the ***Named Constructor Patter*** constructors to be private or pr[...] creation method.

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private: // Making ctor private
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  string name;
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```

Why might you do this?
- might want to change to Llama subclass later
- want to validate arguments from clients, but make construction fast internally
- etc.

Creational patterns: factories

- Suppose we need to create and use polymorphic objects **without exposing their types** to the client

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Creational patterns: factories

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  - this is a specific variant of the named constructor pattern

Creational patterns: factories

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```
Payment * payment_factory(string name, string type) {
 if (type == "credit_card")
   return new CreditCardPayment(name);
 else if (type == "bitcoin")
   return new BitcoinPayment(name);
 … }

Payment * webapp_session_payment =
 payment_factory(customer_name, "credit_card");
```

Creational patterns: factories

- The ***factory method pattern*** (or design pattern that uses facto without having the return type

> Note how the implementation details are hidden from the client, and they can only treat the result as a **generic** payment

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Creational patterns: factories

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Creational patterns: factories

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```
class PaymentFactory {
public:
 static Payment* make_credit_payment(string name){
   return new CreditCardPayment(name);
 }
 static Payment* make_bc_payment(string name){
   return new BitcoinPayment(name);
 }};
Payment * webapp_session_payment =
PaymentFactory::make_credit_payment(customer_name);
```

Creational patterns: example

- Suppose we're implementing a computer game with a **polymorphic Enemy class hierarchy**, and we want to spawn **different versions** of enemies based on the difficulty level.

- e.g., normal difficulty = regular Goomba

- hard difficulty = spiked Goomba

Creational patterns: example: anti-patterns

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Enemy* goomba = nullptr;
if (difficulty == "normal")
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Creational patterns: example: anti-patterns

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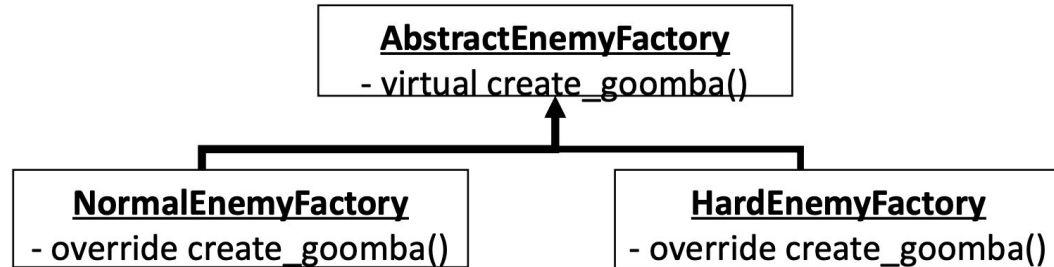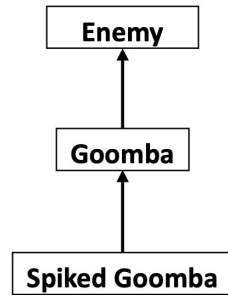
Why is this bad?

Creational patterns: example: anti-patterns

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Enemy* goomba = nullptr;
if (difficulty == "normal")
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```

Why is this bad?
- code duplication
- consider how you'd add a new difficulty level…

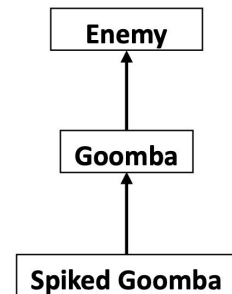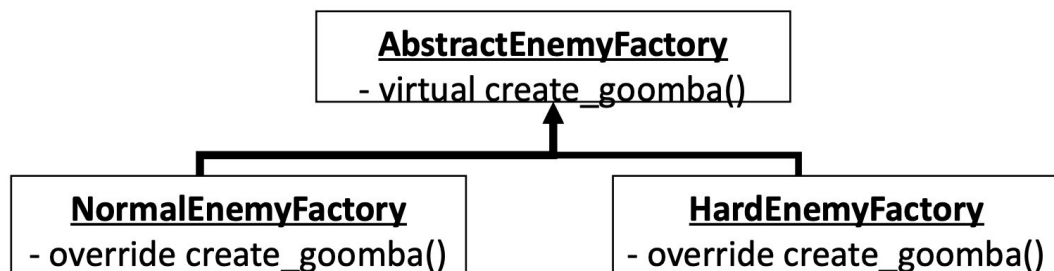# Creational patterns: abstract factories

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Creational patterns: abstract factories

Enemy

Goomba

Spiked Goomba

- The ***abstract factory pattern*** encapsulates a group of factories that have a common theme without specifying their concrete classes.

AbstractEnemyFactory
- virtual create_goomba()

NormalEnemyFactory
- override create_goomba()

HardEnemyFactory
- override create_goomba()

Creational patterns: abstract factories

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Goomba

Spiked Goomba

- The ***abstract factory pattern*** encapsulates a group of factories that have a common theme without specifying their concrete classes.

AbstractEnemyFactory
- virtual create_goomba()

NormalEnemyFactory
- override create_goomba()

HardEnemyFactory
- override create_goomba()

```
// Only have to do this once!
AbstractEnemyFactory* factory = nullptr;
if (difficulty == "normal")
  factory = new NormalEnemyFactory();
else if (difficulty == "hard")
  factory = new HardEnemyFactory();
Enemy* goomba = factory->create_goomba();
```

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- Suppose we have some application **state that needs to be globally accessible**. However, we need to control how that data is accessed and updated.
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  - fails to control access or updates!

Scenario: global application state

- Suppose we have some application **state that needs to be globally accessible**. However, we need to control how that data is accessed and updated.
- The anti-pattern (**bad**) solution is to have an **unprotected global variable** (e.g., a public static field).
  - fails to control access or updates!
- A "less bad" solution is to put all of the state in one class and have a **global instance** of that class.

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Scenario: global application state

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  - If you **must** access some state everywhere, passing it as a parameter to every function clutters the code (readability vs. …)
    - This is not an argument for using global variables to avoid passing a few parameters.
  - Or if you need to access state stored outside your program (e.g., database, web API)
  - Then global variables **may** be acceptable

Singleton design pattern

- The ***singleton pattern*** restricts the instantiation of a class to **exactly one** logical instance. It ensures that a class has only one logical instance at runtime and provides a global point of access to it.

Singleton
public:
- static ***get_instance***() *// named ctor*

private:
- static ***instance*** *// the one instance*
- Singleton() *// ctor*

Singleton design pattern: example

```
class Singleton {
 // public way to get "the one logical instance"
 public static Singleton get_instance() {
    if (Singleton.instance == null) Singleton.instance = new Singleton();
    return Singleton.instance;
 }
 private static Singleton instance = null;
 private Singleton() { // only runs once
    billing_database = 0;
    System.out.println("Singleton DB created");
 }
 // Our global state
 private int billing_database;
 public int get_billing_count() { return billing_database; }
 public void increment_billing_count() { billing_database += 1; }
}
```

Singleton design pattern: example

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class Singleton {
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}
```

**lazy initializaton
of single object**

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```

this constructor can't be called any other way

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```

**all clients share
this global state**

Singleton design pattern: example

What is the output of this code?

Singleton
public:
- static ***get_instance***() // *named ctor*
- get_billing_count()
- increment_billing_count() // *adds 1*

private:
- static ***instance*** // *the one instance*
- Singleton() // *ctor, prints message*
- billing_database

```
class Main {
 public static void main(String[] args) {
    int bills = Singleton.get_instance().get_billing_count();
    System.out.println(bills);

    Singleton.get_instance().increment_billing_count();
    bills = Singleton.get_instance().get_billing_count();
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Singleton design pattern: example

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Output:
```
Singleton DB created
0
1
```

Singleton design pattern: another example

- Suppose we are implementing a computer version of the card game Euchre. In addition to a few abstract datatypes, we have a Game class that stores the state needed for a game of Euchre. When started, our application prototype plays one game of Euchre and then exits.

- Design question: **should we make Game a singleton**?

Singleton design pattern: another example

- Making Game a Singleton is **tempting**
  - There is only one Game instance in our application

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- However, there only **happens** to be one instance of Game. There's **no requirement** that we only have one instance.
- We should only use the Singleton pattern when current or future **requirements** dictate that only one instance should exist.
  - Singleton is **not** a license to make everything global.

Behavioural Design Patterns

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    - e.g., same underlying algorithm, different interfaces or same interface, different underlying algorithms
  - Examples: strategy pattern, template method pattern, iterator pattern, observer pattern, etc.

Iterator Pattern

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  - e.g., Java's List interface doesn't care whether it's backed by an array or a linked list
- Similar patterns exist for other kinds of data structures
  - e.g., *visitor pattern* for tree-like structures
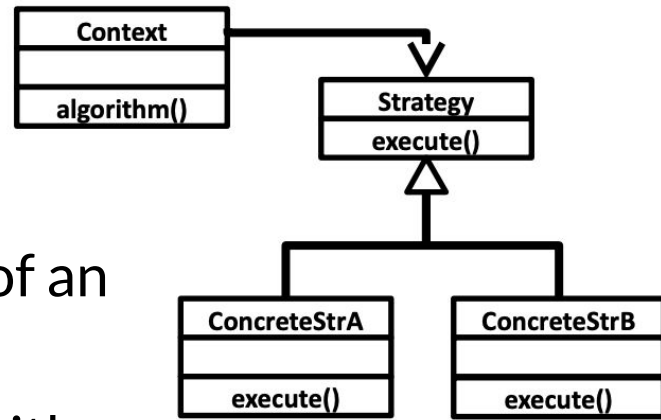
Strategy Design Pattern

Strategy Design Pattern

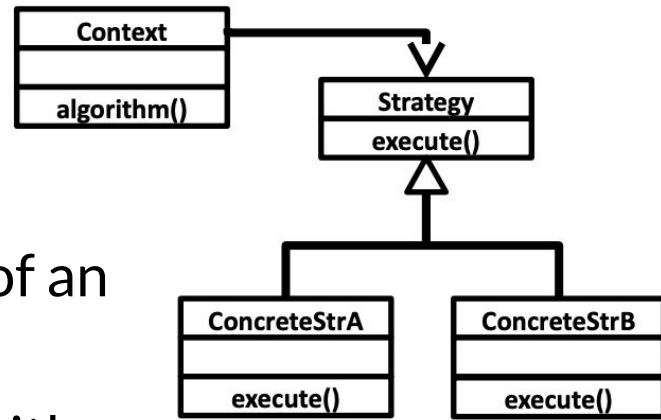- Problem: Clients need different **variants** of an algorithm

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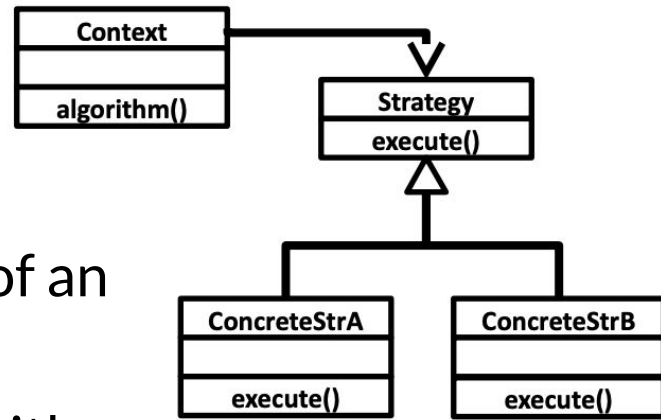
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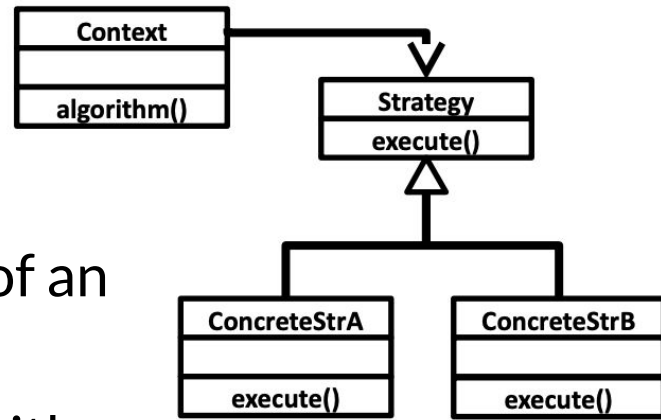
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  - Separates algorithm from client context
  - Introduces extra interfaces and classes: code can be harder to understand; adds overhead if the strategies are simple
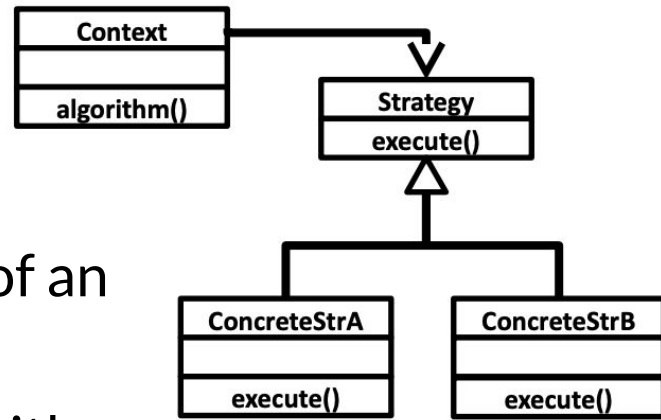
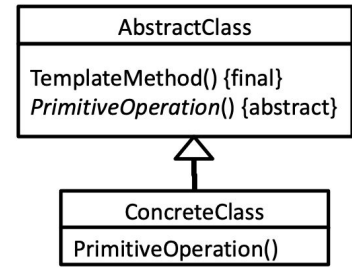# Template Method Design Pattern

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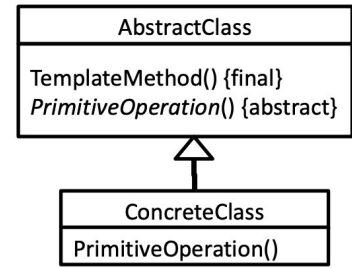
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Template Method Design Pattern

AbstractClass
TemplateMethod() {final}
PrimitiveOperation() {abstract}

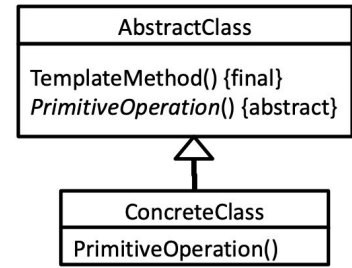ConcreteClass
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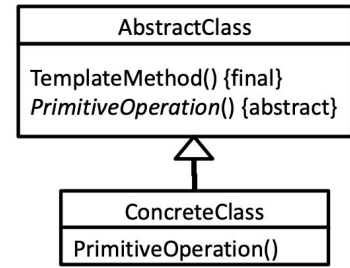
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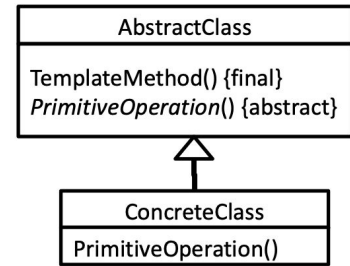
△

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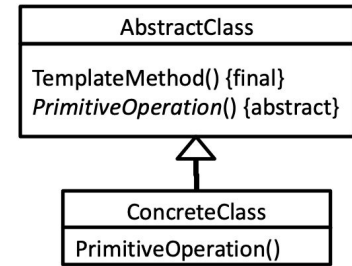ConcreteClass
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  - Customization is restricted to the primitive operations
  - Inverted ("Hollywood-style") control for customization: "don't call us, we'll call you" (cf. comparison function in sorting)
  - Invariant parts of the algorithm are not changed by subclasses

Template vs. Strategy Design Pattern

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Template vs. Strategy Design Pattern

- Both support variation in a larger context
- **Template method** uses inheritance + an overridable method
- **Strategy** uses an interface and polymorphism (via composition)
  - Strategy objects are reusable across multiple classes
  - Multiple strategy objects are possible per class

Scenario: binge-watching

- Suppose we're implementing a video streaming website in which users can "binge-watch" (or "lock on") to one channel. The user will then see that channel's videos in sequence. When the last such video is watched, the user should stop binge-watching that channel.

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```
class User {
 public void release_binge_watch(Channel c) {
   if (c == binge_channel) {
     binge_channel = null;
   }
 }
 private Channel binge_channel;
}
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```

```
class Channel {
 // Called when the last video is shown
 public void on_last_video_shown() {
    // Global accessor for the user
    get_user().release_binge_watch(this);
 }
}
```

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```

- What are some problems with this approach?

Scenario: binge-watching: anti-patterns

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  What can we do instead?

- Whenever requirements change and we want to do something else when a video finishes (e.g., update advertising) we **must update the Channel class** and couple it to the new feature

Observer Pattern

- The *observer pattern* (also called "*publish-subscribe*") allows dependent objects to be notified automatically when the state of a subject changes. It defines a one-to-many dependency between objects so that when one object changes state, all of it dependents are notified.
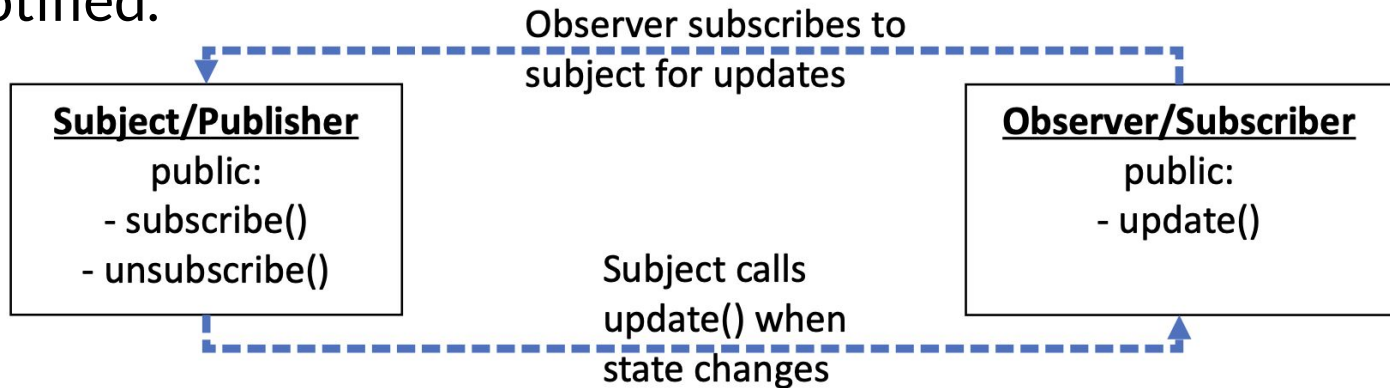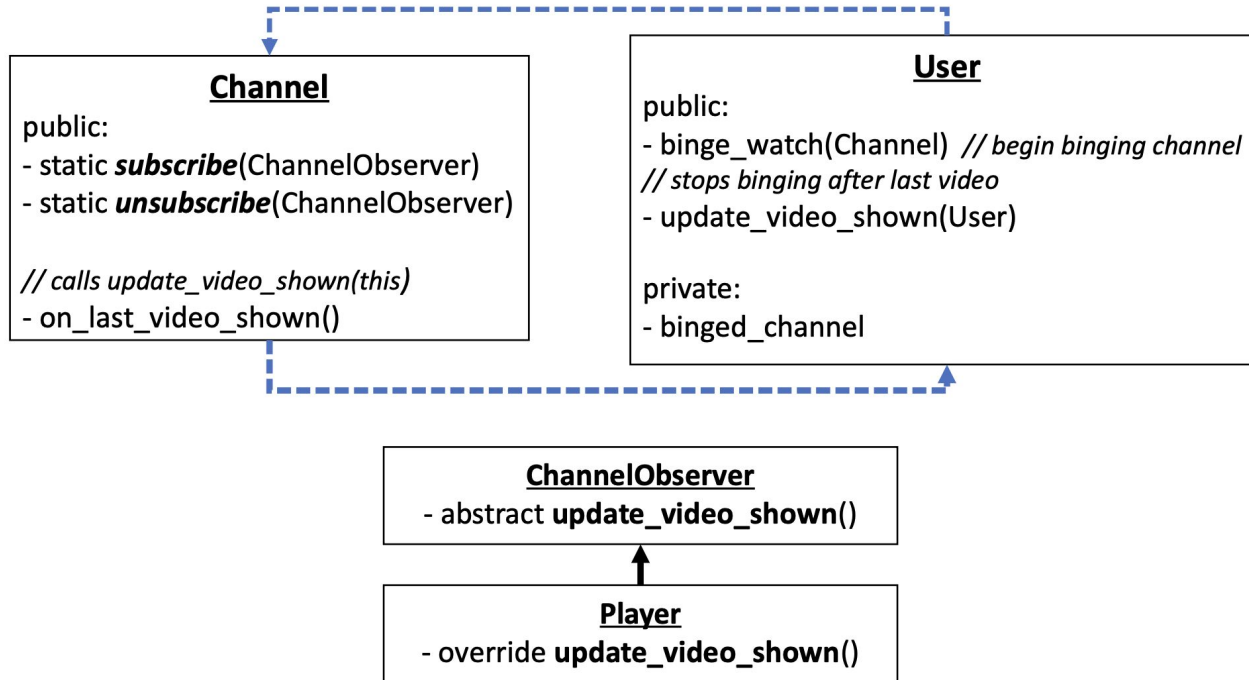
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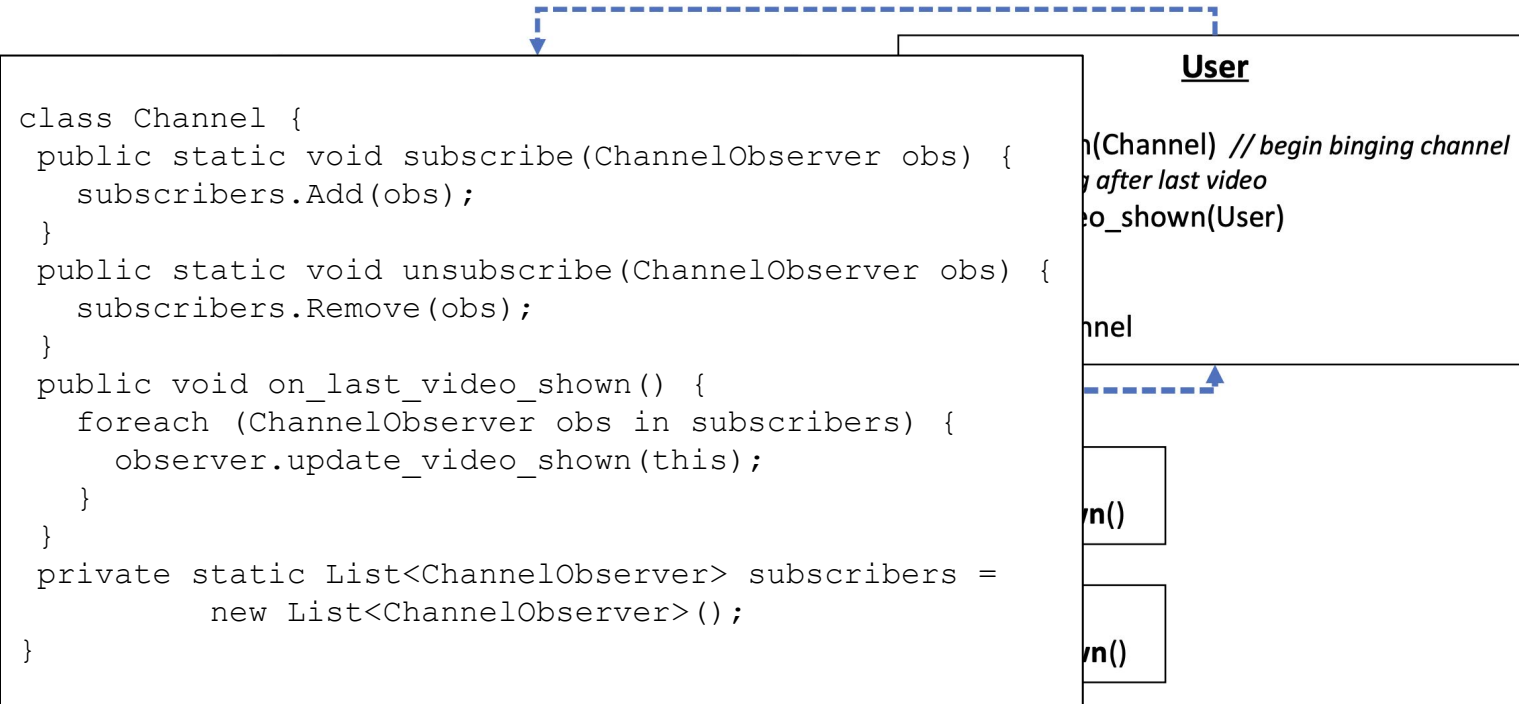
Observer subscribes to
subject for updates

Subject/Publisher
public:
- subscribe()
- unsubscribe()

Observer/Subscriber
public:
- update()

Subject calls
update() when
state changes

Observer Pattern: bing-watch scenario

Channel

public:
- static *subscribe*(ChannelObserver)
- static *unsubscribe*(ChannelObserver)

// calls update_video_shown(this)
- on_last_video_shown()

User

public:
- binge_watch(Channel) *// begin binging channel*
// stops binging after last video
- update_video_shown(User)

private:
- binged_channel

ChannelObserver
- abstract **update_video_shown()**

Player
- override **update_video_shown()**

Observer Pattern: bing-watch scenario

```
class Channel {
 public static void subscribe(ChannelObserver obs) {
    subscribers.Add(obs);
 }
 public static void unsubscribe(ChannelObserver obs) {
    subscribers.Remove(obs);
 }
 public void on_last_video_shown() {
    foreach (ChannelObserver obs in subscribers) {
      observer.update_video_shown(this);
    }
 }
 private static List<ChannelObserver> subscribers =
          new List<ChannelObserver>();
}
```

User

n(Channel) *// begin binging channel*
g after last video
eo_shown(User)

nnel

yn()

yn()

Observer Pattern: bing-watch scenario

```
interface ChannelObserver {
  void update_video_shown(Channel channel);
}
```

```
class Channel {
 public static void subscribe(ChannelObserver obs) {
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 }
 public static void unsubscribe(ChannelObserver obs) {
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 private static List<ChannelObserver> subscribers =
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```

n(Channel) // begin binging channel
g after last video
o_shown(User)

nel

```
class User: ChannelObserver {
 public void update_video_shown(Channel c) {
    if (c == binged_channel)
      binged_channel = null;
 }
 public void binge_watch(Channel c) {
    binged_channel = c;
 }
 private Channel binged_channel;
}
```

Observer Pattern: update functions

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Observer Pattern: update functions

- Having multiple "update_" functions, one for each type of state change, keeps messages **granular**
  - Observers that do not care about a particular type of update can ignore it (via an empty implementation of the update function)
- Generally it is better to pass the newly-updated data as a parameter to the update function (**push**) as opposed to making observers fetch it each time (**pull**)

Reading Quiz: Architecture 2

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Q1: The author claims that:
A. patterns try to describe more general concepts; recipes are specific to a particular language or framework
B. patterns are descriptions of existing systems; recipes are instructions for how to build new systems
C. "patterns are for knitting; recipes are for cooking"

Q2: **TRUE** or **FALSE**: the authors define libraries as "out-of-process components who communicate via a mechanism like a web request or remote procedure call"; and services as "components that are linked into a program and called using in-memory function calls"

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Design patterns: takeaways

- Thinking about design before you start coding is usually worthwhile for large projects
  - Design around the most expensive parts of the software engineering process (usually maintainence!)
- Design patterns are re-usable solutions to common problems
- Be familiar with them enough to recognize when they're being used
  - and to know when to use them yourself
  - you can look up details of a pattern if you remember its name!
- Be mindful of and avoid common anti-patterns

Cut slides (not enough time!)

Singleton design pattern: get_instance()

● Could we avoid typing Single.get_instance() so many times by doing this at all of the points in our program that use the singleton?

```
Single s = Singleton.get_instance();
System.out.println(s.get_billing_count());
… // later
System.out.println(s.get_billing_count());
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Singleton design pattern: get_instance()

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```
Single s = Singleton.get_inst
System.out.println(s.get_bill
… // later
System.out.println(s.get_bill
```

- Is this a good idea or not?

This is a **bad idea**. There is **no guarantee** that get_instance() will return the same pointer (same object) every time it is called. (It may return different **concrete copies** of the **same logical item**.)