Design Patterns

Martin Kellogg

Reading Quiz: Design Patterns

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Announcements

- Thanks to those of you who filled out the first team survey
- I have not forgotten that I promised to offer some way to make up poor IP1 grades
  - I'll announce something soon™
- Signups for preliminary demo slots (with me) are open
  - This is mandatory
  - See Discord for the link
- Wizard-of-Oz demo feedback from me coming soon, hopefully tomorrow

Design Patterns

Today’s agenda:

- **Finish Architecture slides**
- Strategies for good design
- Examples of design patterns
  - Structural patterns
  - Creational patterns
  - Behavioural patterns

Architecture vs. reality

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    - selected **deviations** can be explained more concisely and with clearer reasoning

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- When looking at an architecture, small details do matter a lot at the **interface** between components
  - e.g., NASA lost a $125 million Mars orbiter because one engineering team used metric units while another used Imperial units
- Architecture should warn about **incompatibility between components**, which can be caused by (among other things):
  - mismatched interfaces
  - mismatched operating assumptions (e.g., one component assumes Windows, the other assumes Linux)

Architecture: styles: other examples

Examples of architectural styles:

- pipe-and-filter
- client-server
- model-view-controller
- microservices

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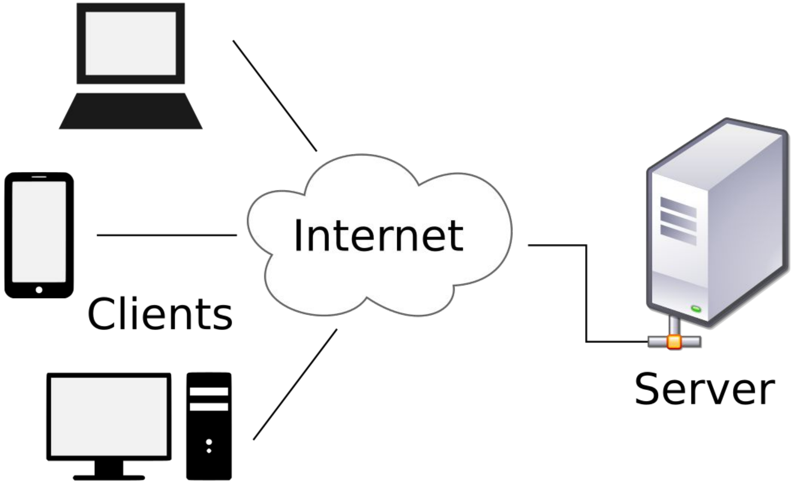

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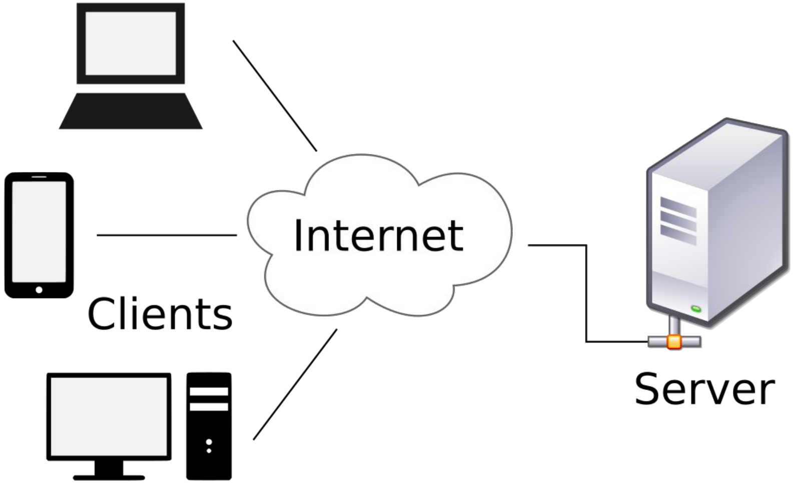

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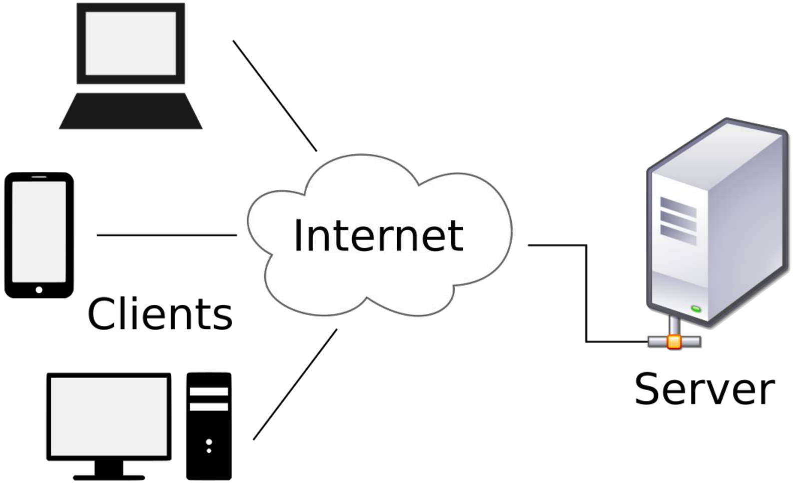
- example of decomposition: server has its own architecture internally, but we don't see it



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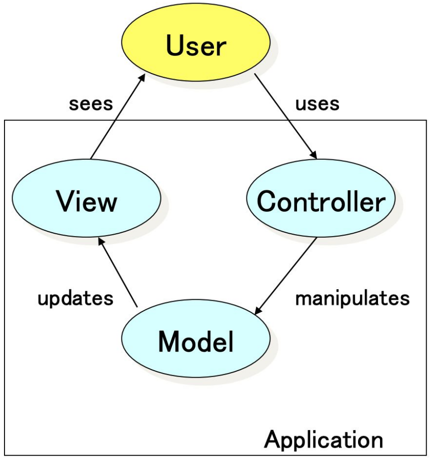

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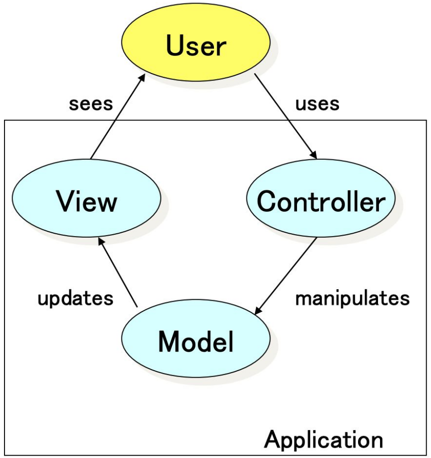

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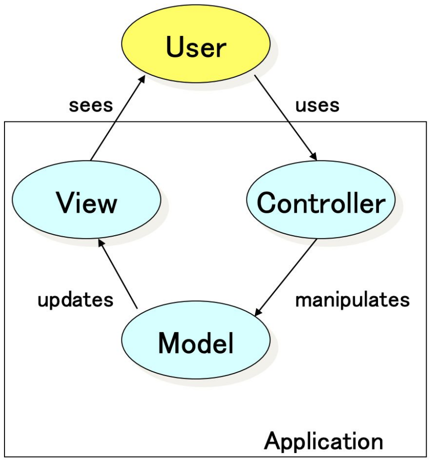

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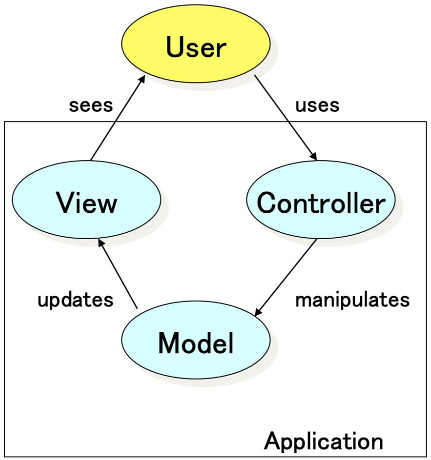
- one or more ***controllers***, which accept input and convert it to commands for the model or view



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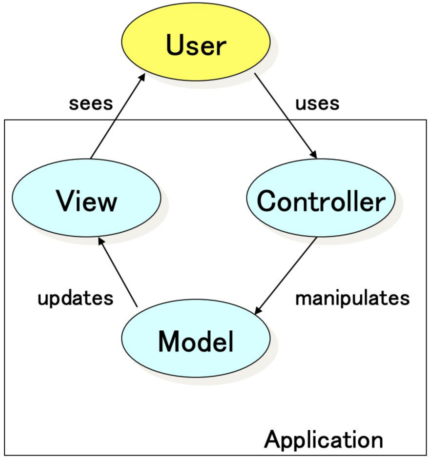

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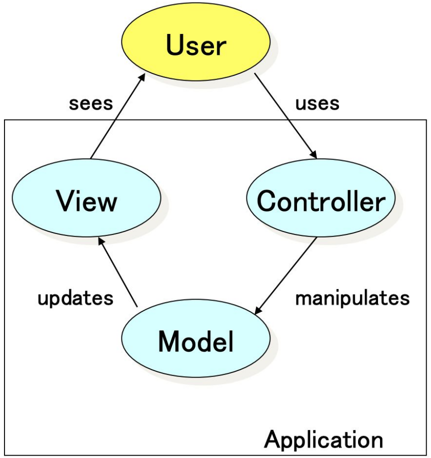
Key advantage of MVC: **separates** data representation (Model), visualization/user interface (View), and client interaction (Controller)



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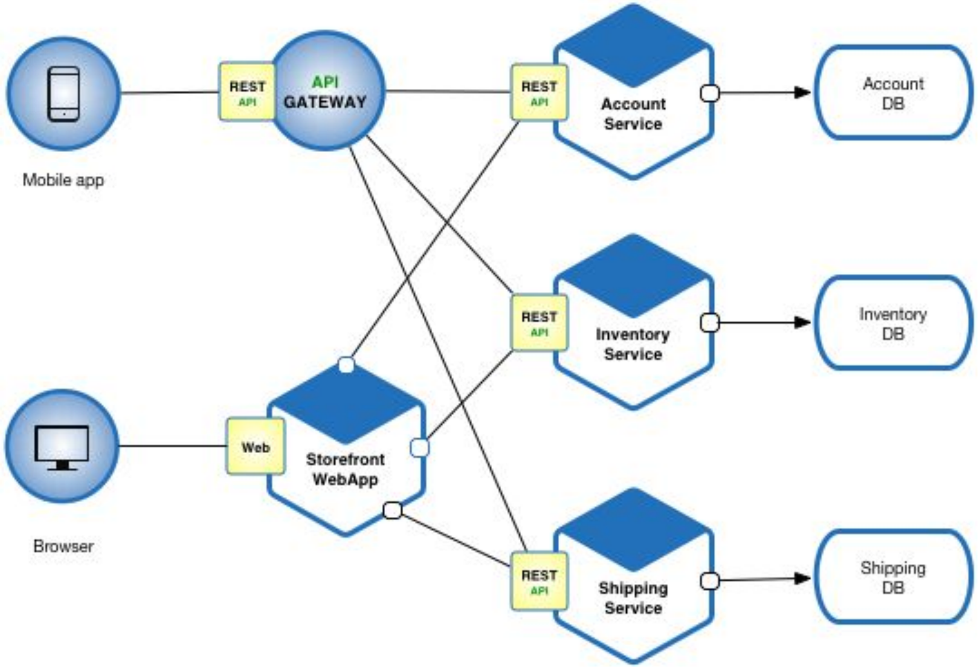

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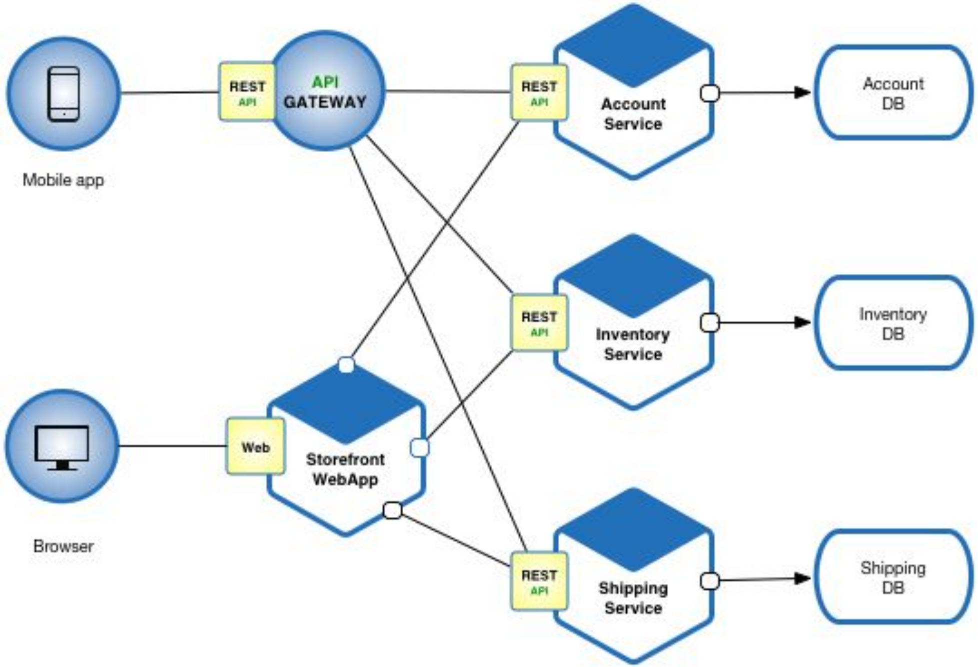

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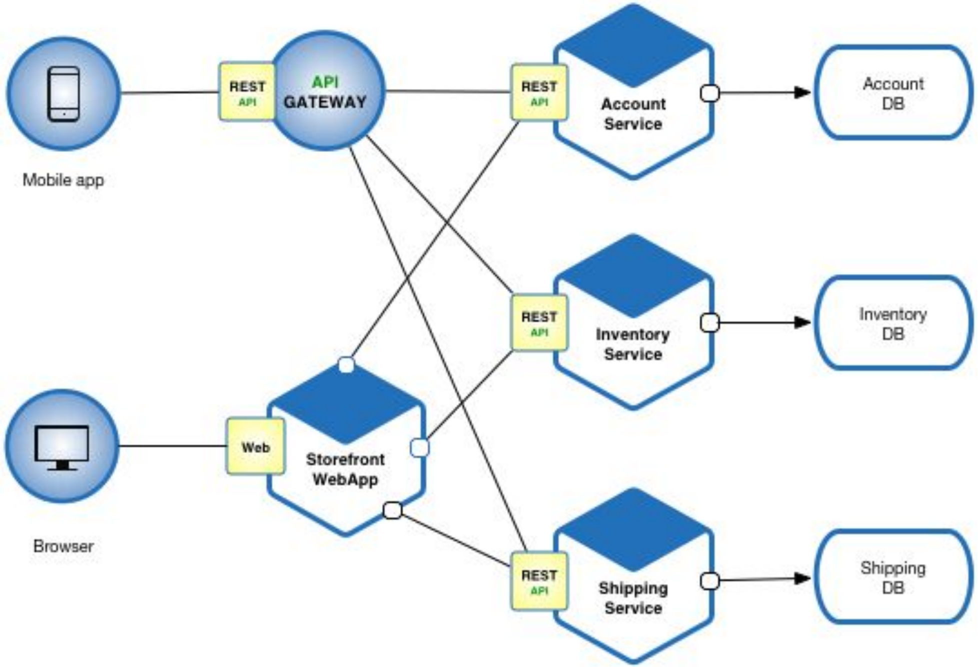

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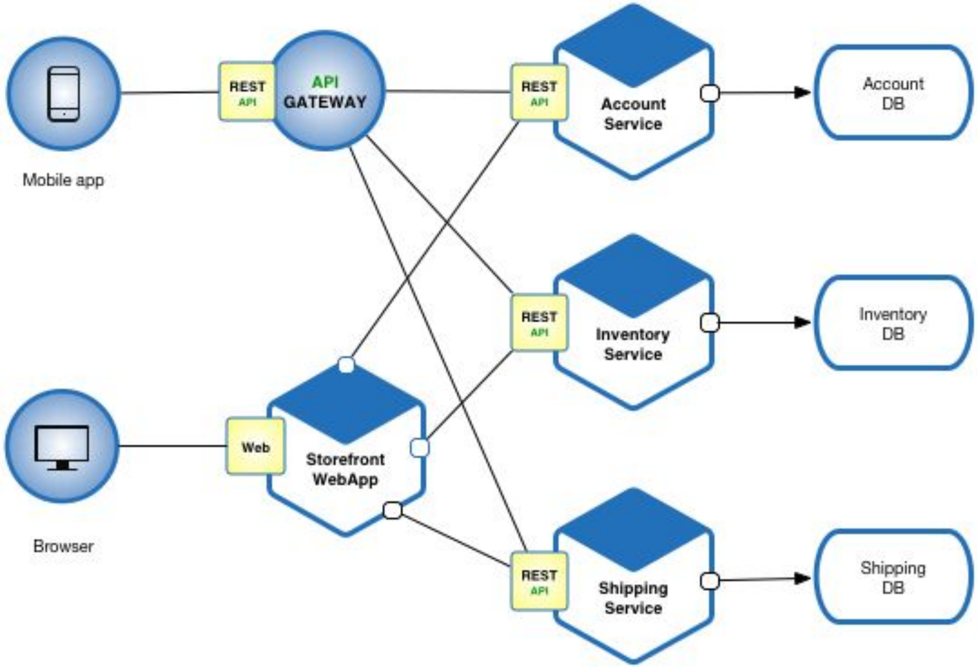

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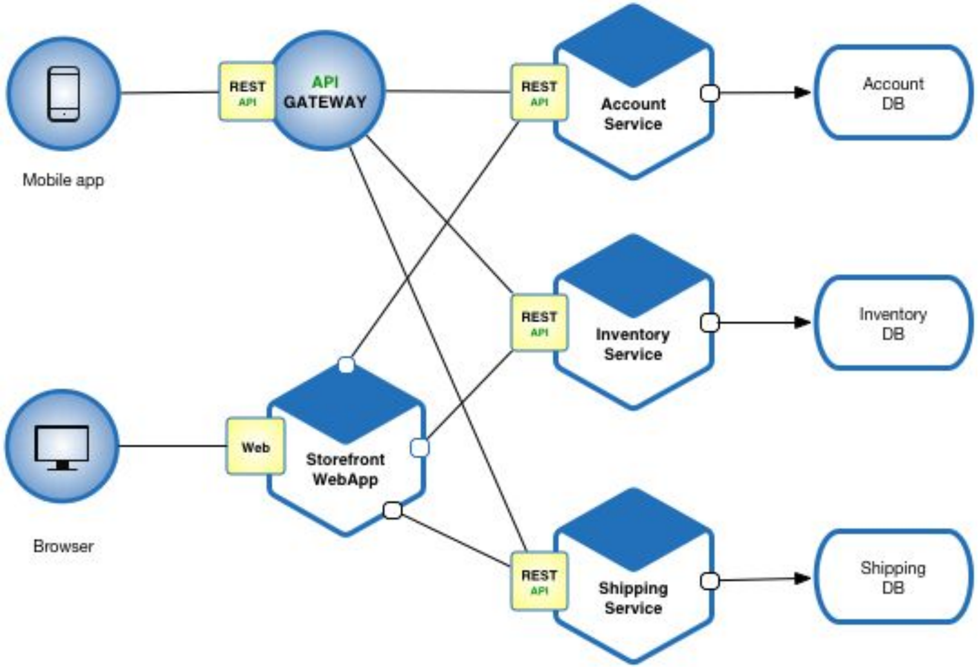

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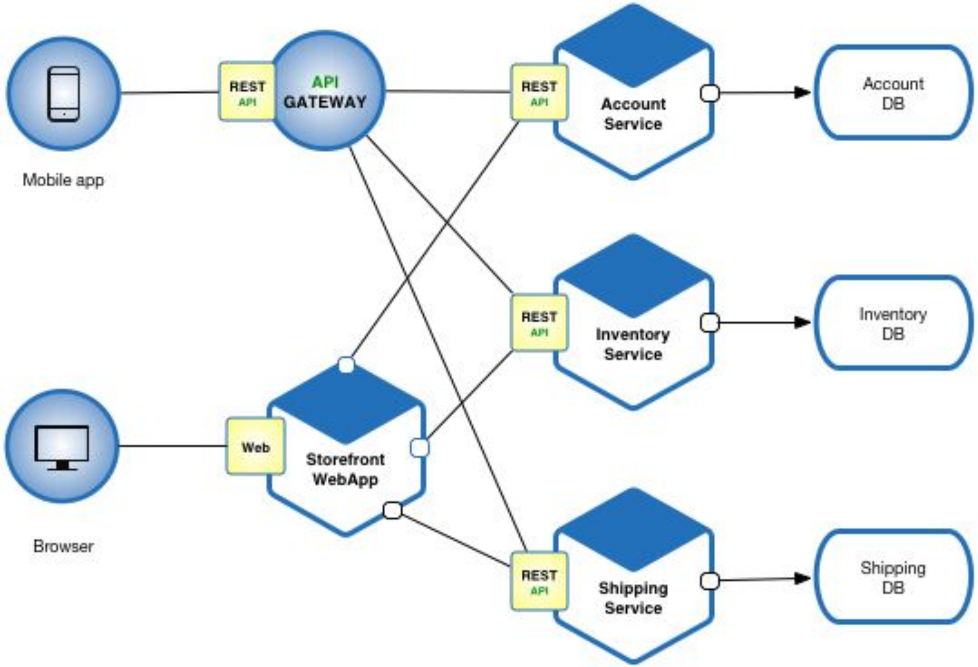

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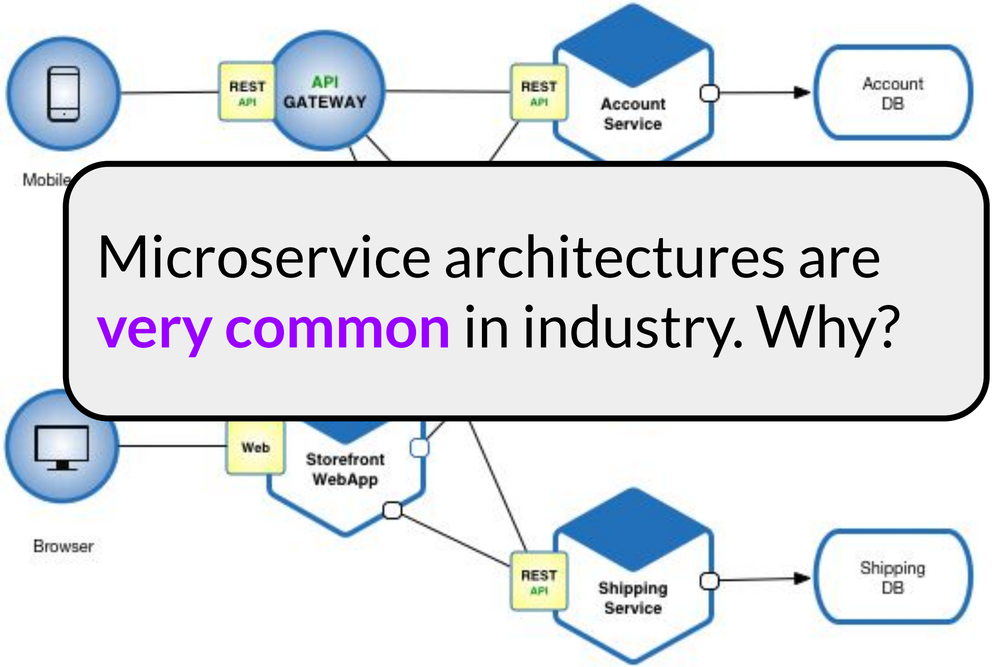

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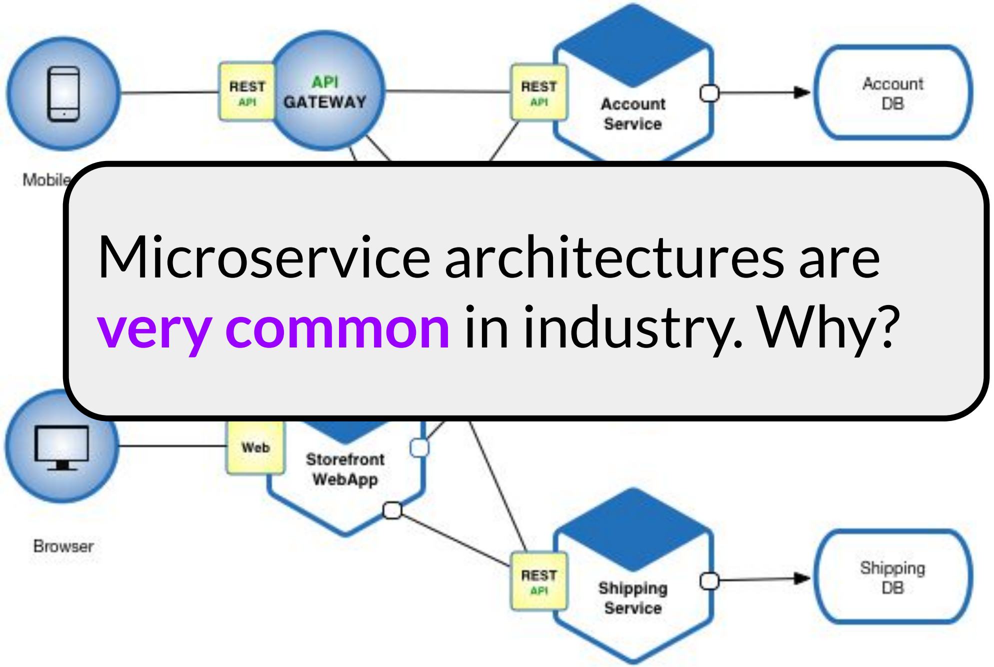

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  - does communicate how components are related
  - does not communicate internal structure of components
    - definitely does not tell you how to implement them!

Takeaways: architecture

- An architecture is a high-level view of a software system
- Good architectures communicate how the pieces of the system (the components) fit together
- Many architectural styles exist, and you should have a passing familiarity with several
    - common interview question: “on the whiteboard, design a [insert architectural style here] system to do X”
- Architectural styles are a guide, but are not prescriptive
    - real systems usually deviate from their “whiteboard architecture”, but deviations can be explained

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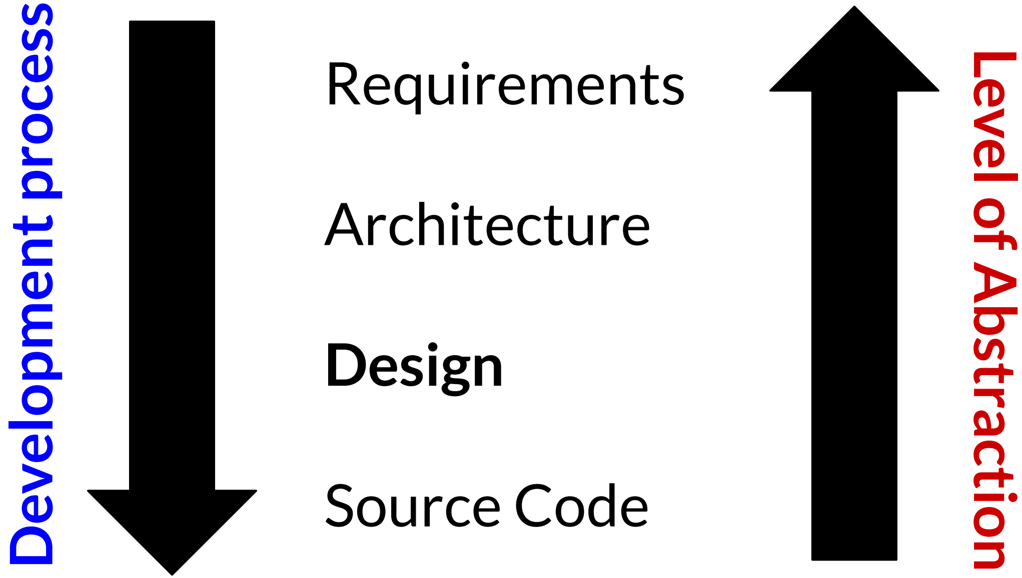
Design

"Architecture" vs "Design"



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

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Key goal: design for **change** and **reuse**

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- 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!

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- 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

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  - 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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Our key goal for today: learn about some of the **strategies** that companies like Amazon.com use to manage this complexity

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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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Design to Admit Testing

- Consider a ***library-oriented architecture***, a variation of **modular programming** or **microservice architecture** with a focus on separation of concerns and **interface design**
    - “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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  - This is one of the motivations behind **unit testing**
- Solution: design with **more entry points** for self-contained functionality (cf. AVL tree, priority queue, etc.)

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    - "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?"

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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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- 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

Designing for coverage-based testing

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- Code coverage has many flaws
  - At a high level, simple coverage metrics **do not align** with covering requirements (cf. traceability)

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- Code coverage has many flaws
  - At a high level, simple coverage metrics **do not align** with covering requirements (cf. traceability)
- Solutions:

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

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- Muddies meaning of coverage (100% not desired)

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These are examples of ***metamorphic testing***, which is a generalization of differential testing. Ask me more in OH!

Design Patterns

Today’s agenda:

- Finish Architecture slides
- Strategies for good design
- **Examples of design patterns**
  - Structural patterns
  - Creational patterns
  - Behavioural patterns

Design patterns

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- patterns apply in almost all OO languages
- 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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  - although people often blame themselves when objects appear to malfunction, it is not the fault of the user but rather the lack of intuitive guidance that should be present in the design

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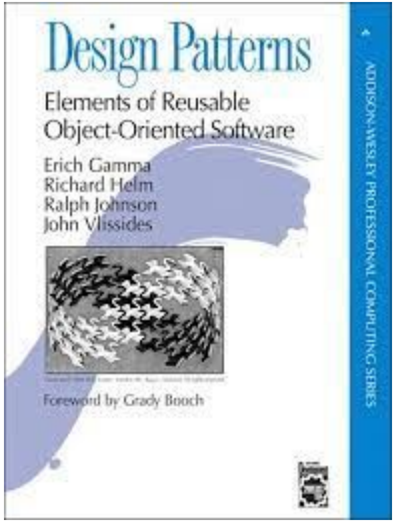
  communication between object and user
  - although people often blame themselves when objects appear to malfunction, it is not the fault of the user but rather the lack of intuitive guidance that should be present in the design

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**
  - Use patterns that fit your current or anticipated needs.
- Consider **multiple designs**
  - Diagram your designs before writing code.

Design patterns: categories

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  - Provide cleaner or more specialized interfaces

Design patterns: structural: adapter

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- Examples:
  - Implementing a Stack interface using a LinkedList interface
  - Early implementations of fstream in C++
    - … were simply adapters around the C FILE macro

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- The **composite design pattern** allows clients to treat individual objects and groups of objects uniformly
  - e.g., selecting and moving objects in PowerPoint
- 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

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

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Creational patterns: named constructor

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```
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;
};
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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.

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  - this is a specific variant of the named constructor pattern

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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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public:
 static Payment* make_credit_payment(string name){
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 }
 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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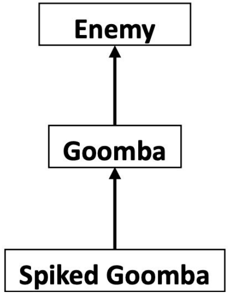

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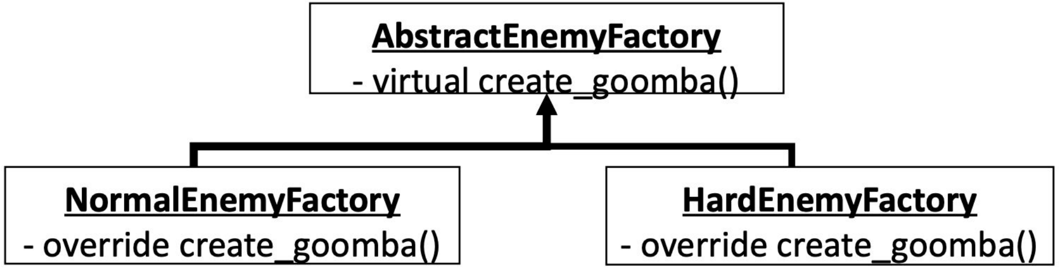

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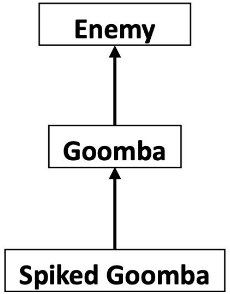

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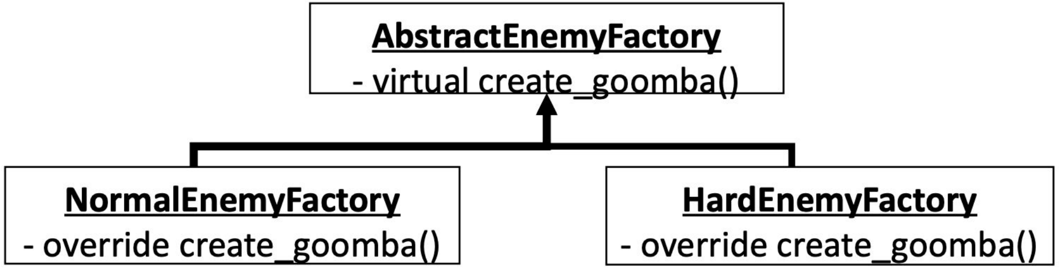


```
// Only have to do this once!
AbstractEnemyFactory* factory = nullptr;
if (difficulty == “normal”)
  factory = new NormalEnemyFactory();
else if (difficulty == “hard”)
  factory = new HardEnemyFactory();
Enemy* goomba = factory->create_goomba();
```

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- 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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    - 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.

<u>Singleton</u>
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

lazy initializaton of single object

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   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

```
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;
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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();
   System.out.println(bills);
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}
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Output:

```
Singleton DB created
0
1
```

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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- Is this a good idea or not?

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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**.)

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

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- 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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- The ***iterator pattern*** is a common behavioral design pattern. It provides a uniform interface for traversing containers regardless of how they are implemented.
    - 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

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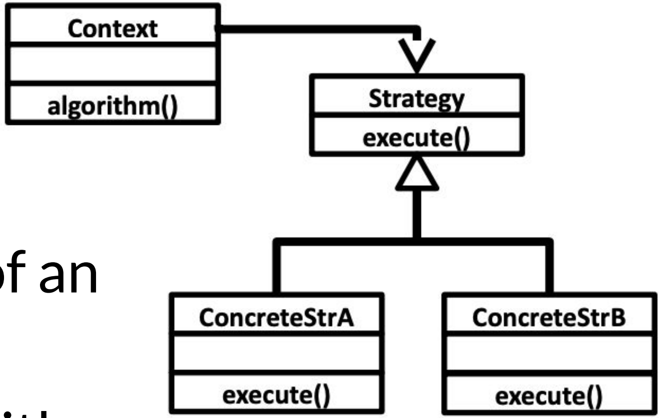
Strategy Design Pattern



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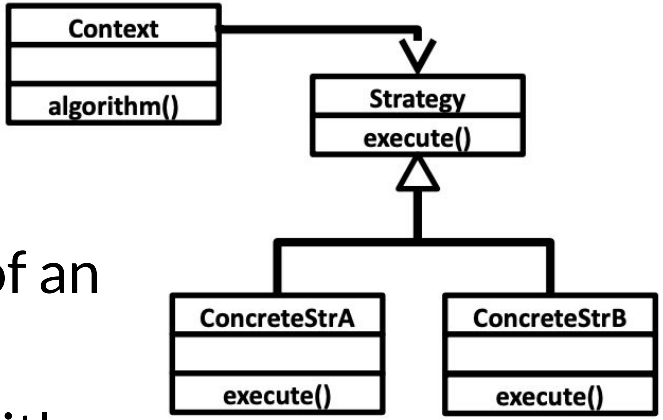

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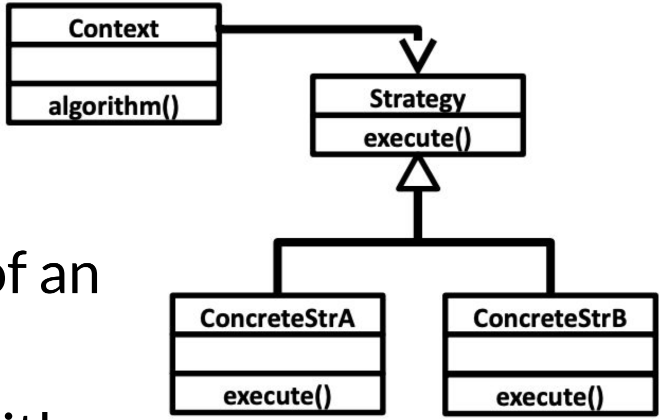

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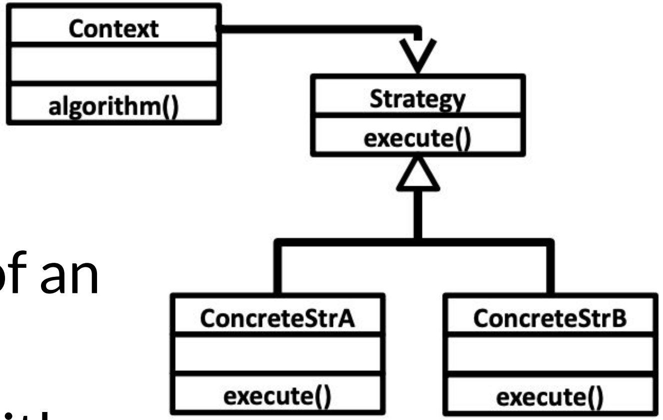

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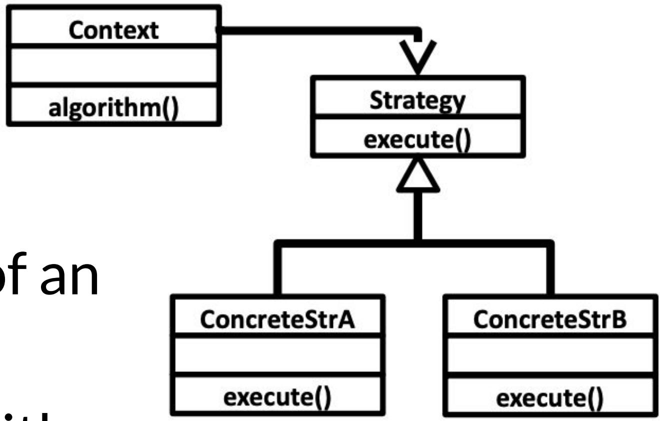

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    - Introduces extra interfaces and classes: code can be harder to understand; adds overhead if the strategies are simple

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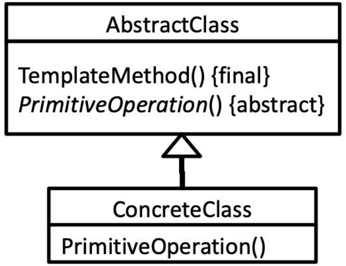

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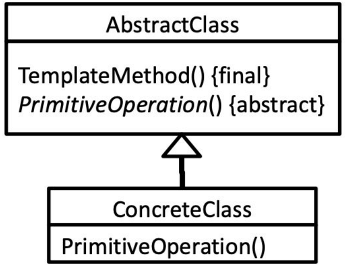

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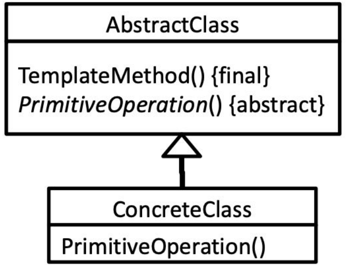

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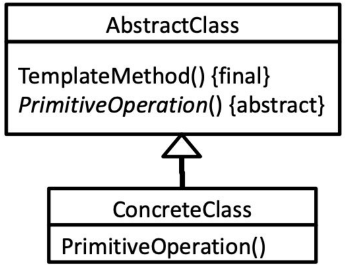

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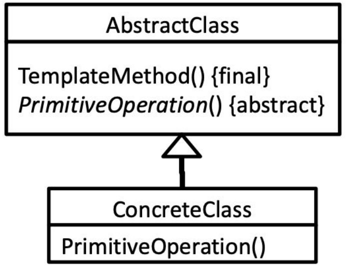

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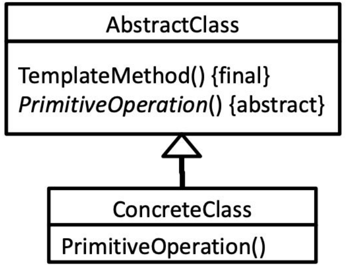

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    - Code reuse for the invariant parts of algorithm
    - Customization is restricted to the primitive operations
    - Inverted ("Hollywood-style") control for customization: "don't call us, we'll call you" (cf. comparison function in sorting)
    - 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.

Scenario: binge-watching

- Idea: when the last video is watched, call release_binge_watch() on the user.

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class User {
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   if (c == binge_channel) {
     binge_channel = null;
   }
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```
class Channel {
 // Called when the last video is shown
 public void on_last_video_shown() {
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- What are some problems with this approach?

Scenario: binge-watching: anti-patterns

- With this design, User and Channel are **tightly coupled**
  - Changing one likely requires a change to the other

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- 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

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What can we do instead?

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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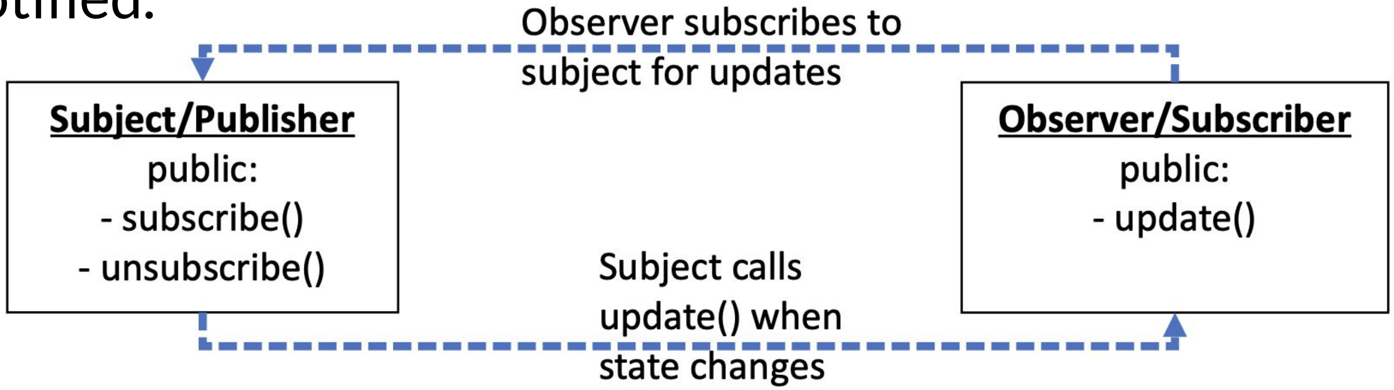

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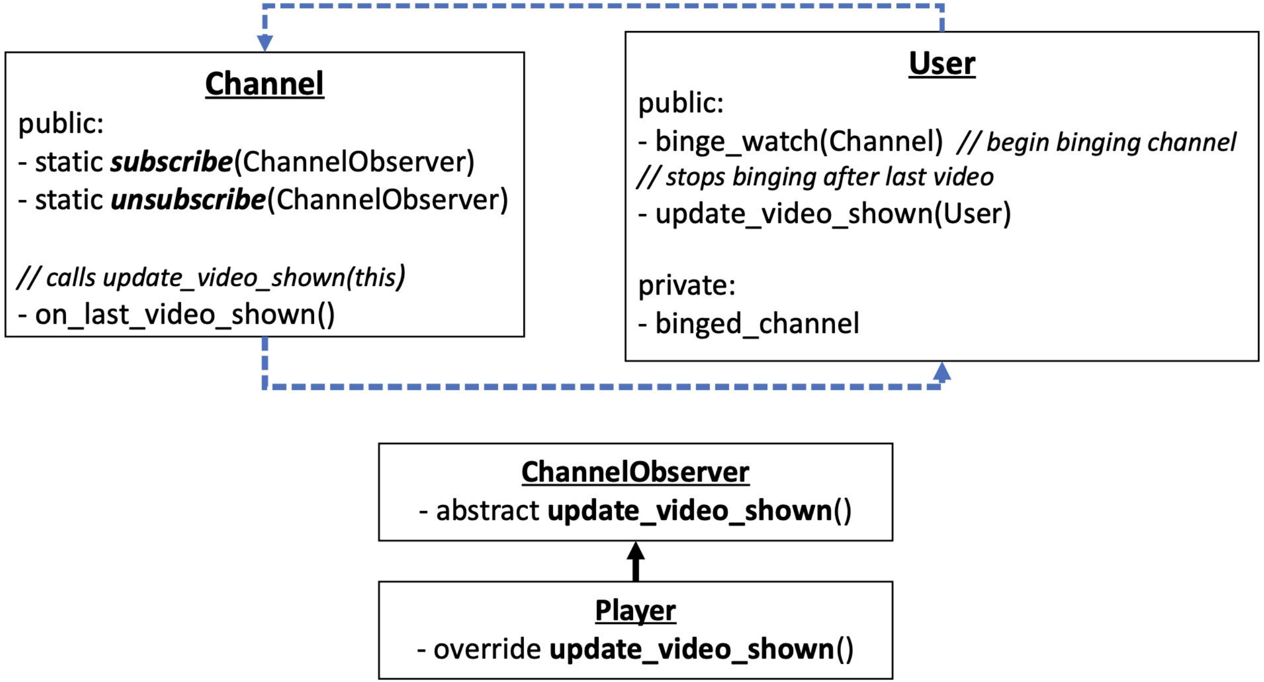

Observer Pattern: bing-watch scenario

```
class Channel {
 public static void subscribe(ChannelObserver obs) {
   subscribers.Add(obs);
 }
 public static void unsubscribe(ChannelObserver obs) {
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 }
 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

wn()

wn()

Observer Pattern: bing-watch scenario

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interface ChannelObserver {
 void update_video_shown(Channel channel);
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- 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**)

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