Week 9: Detailed Design and Implementation

YZM2021 - Software Engineering Principles

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Date: 25.11.2025

Where Are We?

What We've Covered:

- **Week 1-2:** Software Engineering & Principles (SOLID, DRY, KISS)
- **Week 3:** Process Models (Waterfall, RUP, Incremental)
- **Week 4:** Agile Methodologies (Scrum, XP, Kanban)
- **Week 5:** Requirements Engineering (Functional/Non-Functional, Elicitation)
- **Week 6:** System Modeling & UML (Use Case, Class, Sequence Diagrams)
- **Week 7:** Software Architecture (Patterns, Views, Components, Deployment)
- **Week 8:** 📝 **Midterm 1**

Today:

- **Week 9: Detailed Design and Implementation**

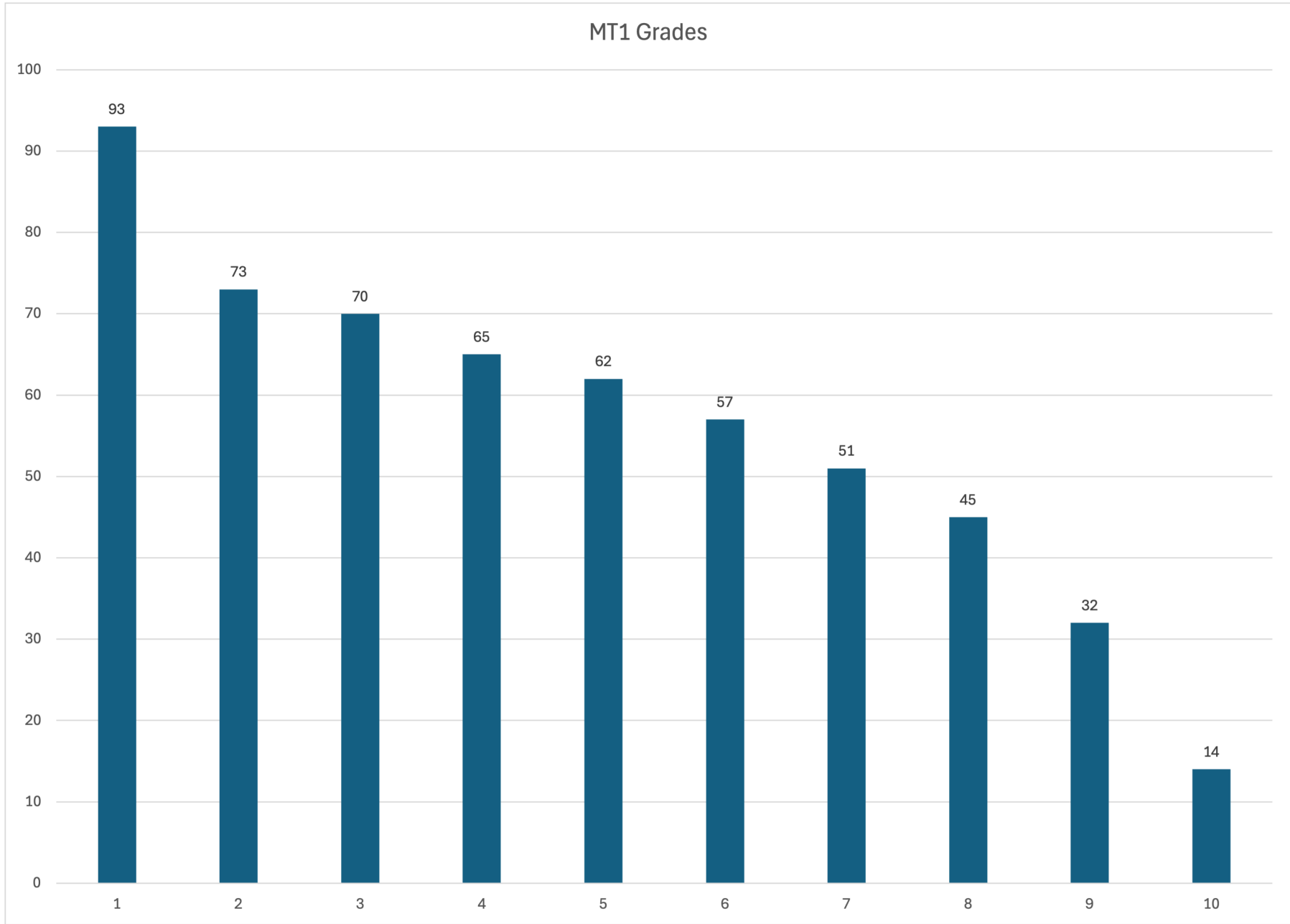
Midterm 1 Grades Are Out

Average: 56,2

Maximum: 93

Average Points per Question

- Q1: 2.7 / 5
- Q2: 4.3 / 5
- Q3: 3.1 / 5
- Q4: 9.7 / 15
- Q5: 6.7 / 15
- Q6: 5.1 / 15
- Q7: 24.5 / 40


MT1 Grades
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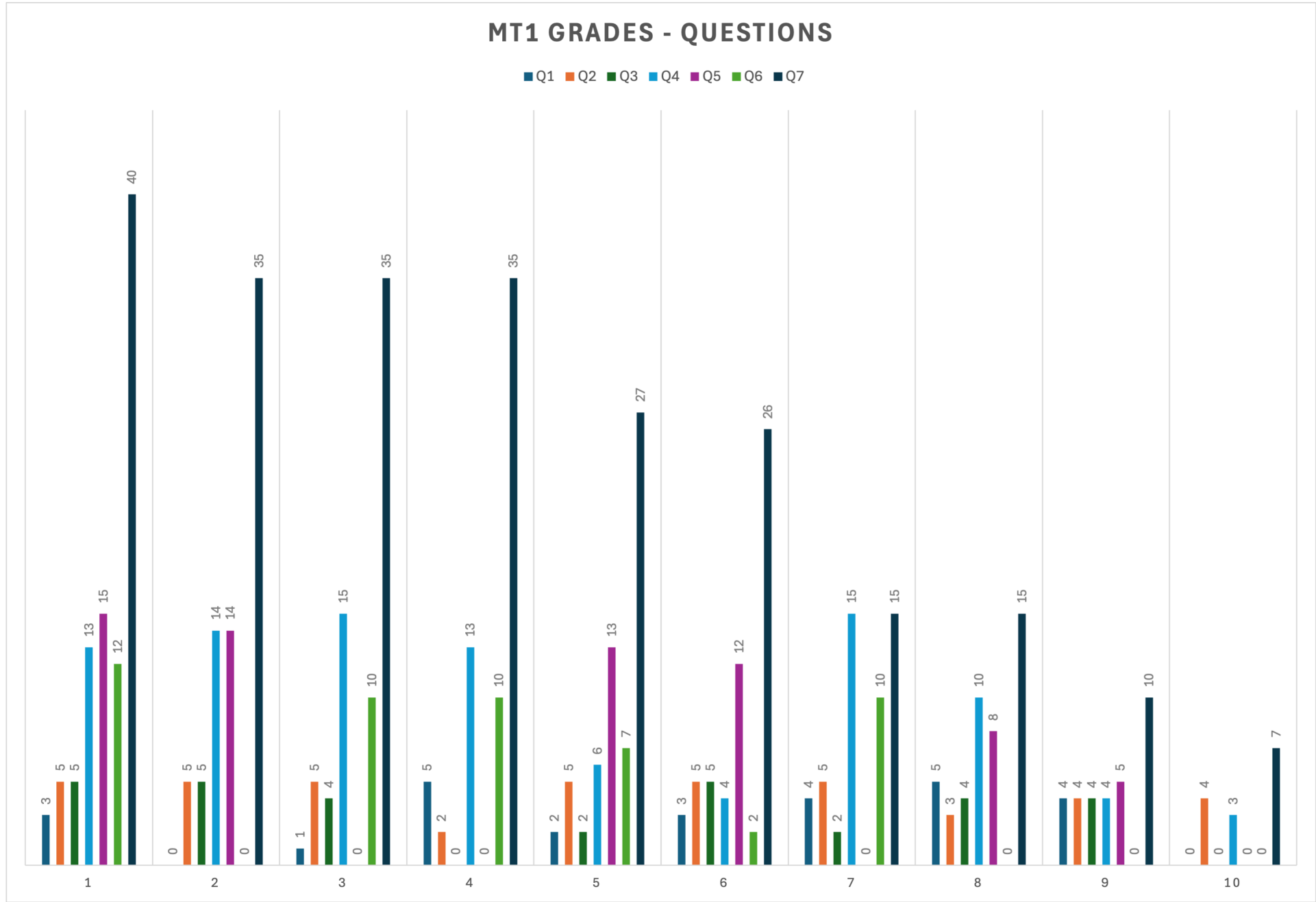
MT1 GRADES - QUESTIONS
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Today's Learning Outcomes

By the end of this lecture, you will be able to:

1. **Distinguish** between architectural design and detailed design
2. **Identify** and **apply** the most common design patterns from the Gang of Four catalog
3. **Recognize** when a specific pattern solves a design problem
4. **Implement** design patterns in code (JavaScript/TypeScript, Python)
5. **Combine** multiple patterns to solve complex design challenges
6. **Evaluate** trade-offs and avoid over-engineering with patterns
7. **Refactor** existing code to use appropriate design patterns
8. **Document** pattern usage in Software Design Document

Architecture vs Detailed Design

Architectural Design

Focus: System structure and high-level organization

Questions:

- What are the major components?
- How do components communicate?
- Where does the system run? (deployment)
- What patterns organize the system?
- How do we achieve NFRs? (scalability, security)

Artifacts:

- Component diagrams
- Deployment diagrams
- Architecture decision records

Scope: Entire system

Detailed Design

Focus: Internal structure of individual components

Questions:

- How are classes organized within a component?
- What design patterns solve specific problems?
- How do objects collaborate?
- What are the responsibilities of each class?
- How do we make code flexible and maintainable?

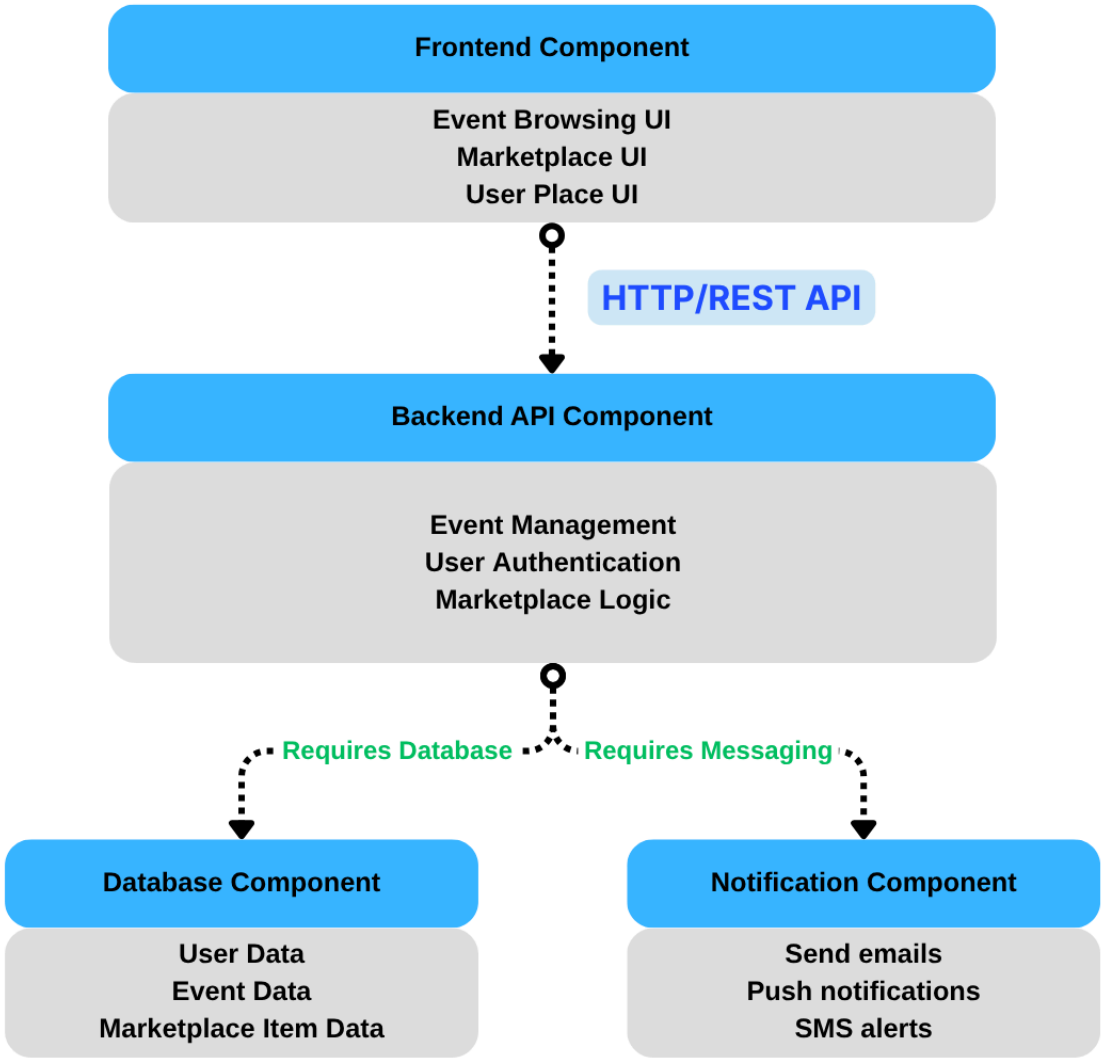
Artifacts:

- Detailed class diagrams
- Design pattern documentation
- Interface specifications

Scope: Individual components, classes, modules

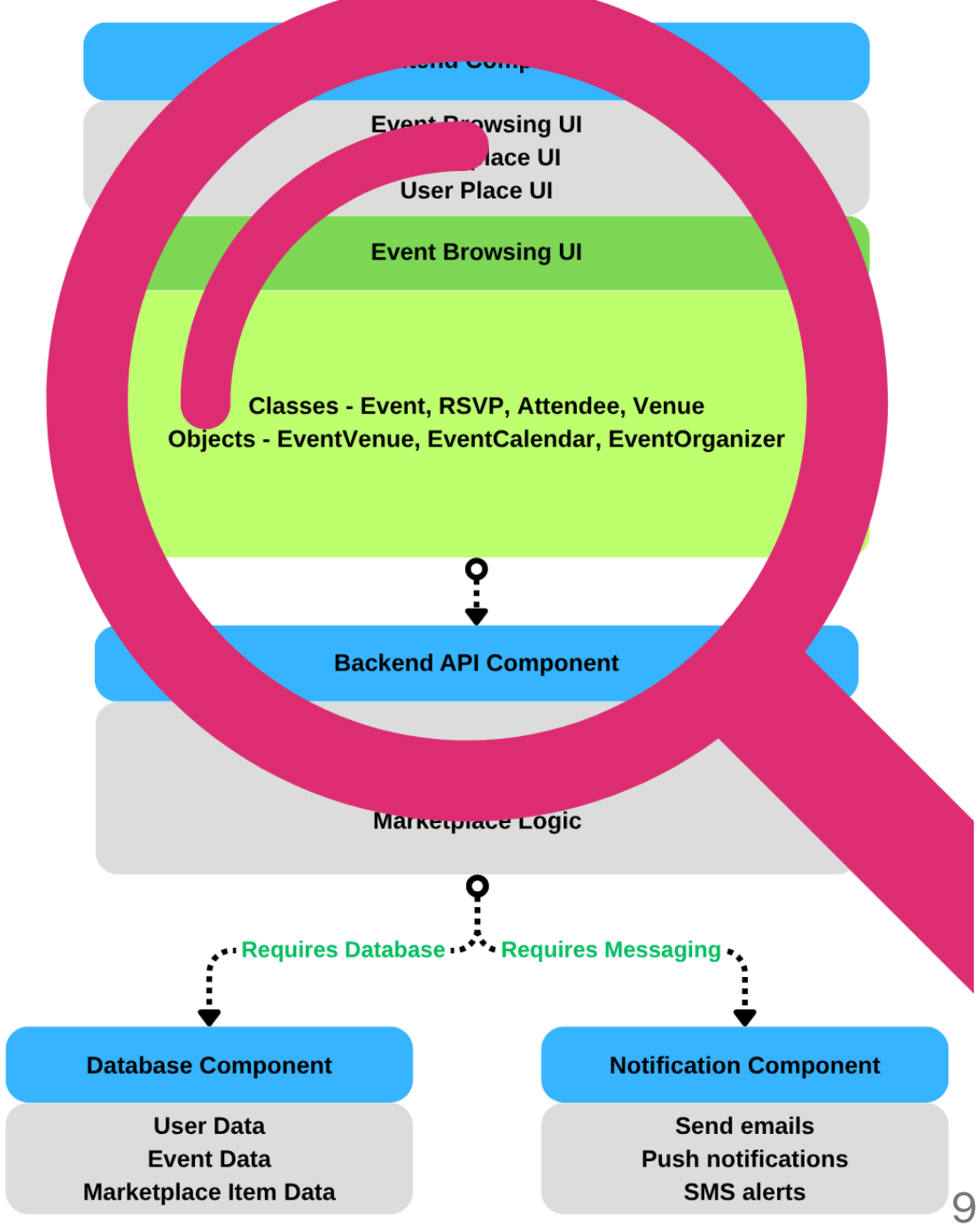
Architecture vs Detailed Design

Architecture decides **what** components exist and **how** they interact.
Detailed Design decides how each component is implemented internally.



Architecture vs Detailed Design

Architecture decides what components exist and how they interact.
Detailed Design decides **how** each component is implemented internally.



Object-Oriented Design using the UML

An **object-oriented system** is made up of interacting objects that maintain their own **local state** and provide **operations** on that state.

- The representation of the state is **private** and cannot be accessed directly from outside the object.
- **Object-oriented design processes** involve designing object classes and the relationships between these classes.
- These classes define the objects in the system and their interactions.
- When the design is realized as an executing program, the objects are created dynamically from these class definitions.

Why Object-Oriented Design?

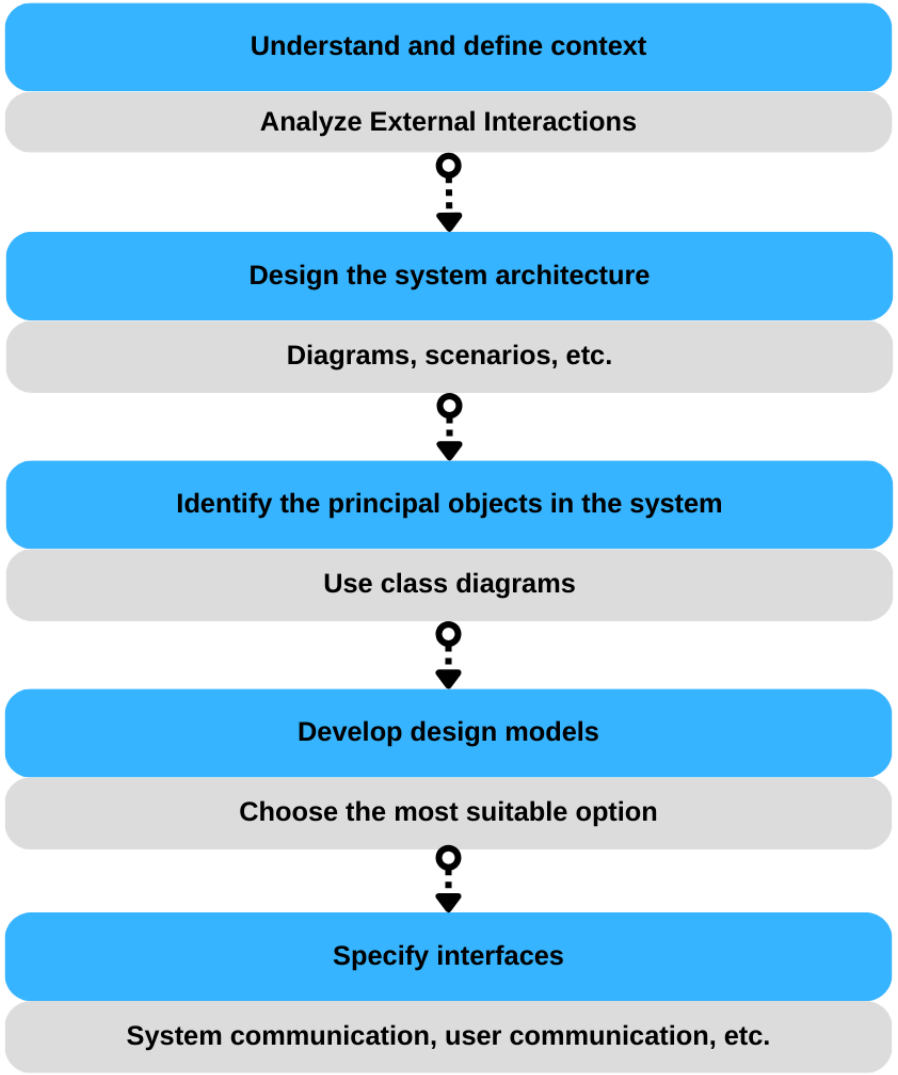
Object-oriented systems are easier to change than systems developed using functional approaches.

- Objects include both data and operations to manipulate that data (stand-alone entities).
- Changing the implementation of an object or adding services should not affect other system objects.
- **Clear mapping** between real-world entities (such as hardware components) and their controlling objects.
- This improves the **understandability**, and hence the **maintainability**, of the design.

The Object-Oriented Design Process

To develop a system design from concept to detailed, object-oriented design:

1. **Understand and define the context** and the external interactions with the system.
2. **Design the system architecture**.
3. **Identify the principal objects** in the system.
4. **Develop design models**.
5. **Specify interfaces**.



The Object-Oriented Design Process

Design is **not** a clear-cut, sequential process.

- You develop a design by getting ideas, proposing solutions, and refining these solutions as information becomes available
- You inevitably have to **backtrack and retry** when problems arise
- Sometimes you explore options in detail; at other times you ignore details until late in the process
- All of the design activities are **interleaved** and influence each other

Example: CampusPal Event Management

We will illustrate the need for detailed design using our class project, **CampusPal**.

- **CampusPal** is a campus community platform.
- It handles **Events**, **Marketplace**, and **Social Feeds**.
- Let's focus on the **Event Management** module.

The Challenge: How do we design the internal software objects to handle event creation, registration, and notifications reliably and flexibly?

Step 1: System Context and Interactions

Understanding the Boundaries

Goal: Understand relationships between the software and its external environment.

Why it's important:

- Decides how to provide required functionality.
- Structures communication with the environment.
- Establishes system boundaries (what's IN vs. what's OUT).

Outcome:

- **System Context Diagram:** Shows the system as a whole and its external interfaces.

CampusPal Context:

- **Users:** Students, Faculty, Admins
- **External Systems:** Google Maps API, Payment Gateway, University Auth System

Step 2: Architectural Design

Structuring the System

Goal: Design the system architecture based on interactions and architectural principles.

Process:

- Use context interactions as a basis.
- Apply architectural patterns (e.g., Layered, MVC).
- Incorporate domain knowledge.

Outcome:

- **Component Diagram:** Shows main modules.
- **Deployment Diagram:** Shows physical hardware/nodes.

CampusPal Architecture:

- **Web/Mobile App:** Presentation Layer
- **API Server:** Business Logic Layer
- **Database:** Data Persistence Layer

Step 3: Object Class Identification

Finding the Objects

Goal: Identify essential objects/classes from requirements and use cases.

Approaches:

- **Grammatical Analysis:** Look for nouns (objects) and verbs (operations) in requirements.
- **Tangible Things:** Events, Venues, Users.
- **Events/Interactions:** Registration, Notification.

Outcome:

- **Use Case Diagram:** Identifies actors and major functions.
- **Initial Class List:** Nouns extracted from stories.

CampusPal Objects:

- `Event` (The core entity)
- `User` (Student/Faculty)
- `Registration` (Link between User and Event)
- `Venue` (Location)

Step 4: Design Models

The Bridge to Implementation

Goal: Show objects/classes and their relationships in detail.

Types of Models:

- **Structural:** Class diagrams (static relationships).
- **Dynamic:** Sequence/State diagrams (interactions/states).

Outcome:

- **Detailed Class Diagram:** Attributes, methods, relationships.
- **Sequence Diagram:** Time-ordered interactions.
- **State Diagram:** Lifecycle of objects.

CampusPal Design Model:

- **Structural:** `Event` has a One-to-Many relationship with `Registration`.
- **Dynamic:** Sequence of `User` -> `EventController.register()` -> `RegistrationService`.

Step 5: Interface Specification

Defining Contracts

Goal: Specify interfaces between components to allow parallel development.

Why specify interfaces?

- Objects/Subsystems can be designed independently.
- Hides implementation details.
- Developers can code against the interface contract.

CampusPal Example:

`INotificationService` interface:

```
interface INotificationService {
  send(userId: string, msg: string): Promise<void>;
}
```

Team A builds the Event Logic using this interface.
Team B implements `EmailNotificationService` later.

From Concept to Code

We will apply **Design Patterns** to solve specific design challenges within **CampusPal**

Why Design Patterns?

When moving from Architecture (High Level) to Detailed Design (Low Level), we encounter recurring problems:

- *"How do I create different types of events?"*
- *"How do I notify the UI when data changes?"*
- *"How do I support multiple payment methods?"*

Design Patterns provide the standard answers to these questions.

Design Patterns

What Are Design Patterns?

> **A design pattern is a reusable solution to a commonly occurring problem in software design.**

Design patterns are **templates** - not finished code, but proven approaches you can adapt to your specific situation.

Key Characteristics:

- **Proven:** Battle-tested in real-world projects
- **Reusable:** Apply to many different contexts
- **Language-independent:** Concepts work in any OOP language
- **Named:** Common vocabulary (e.g., "use Observer pattern")
- **Documented:** Structure, participants, consequences

What Patterns Are NOT:

Not libraries or frameworks you import
Not finished code you copy-paste
Not algorithms (sorting, searching)
Not always the best solution

A Brief History - The Gang of Four

The Book That Started It All

"Design Patterns: Elements of Reusable Object-Oriented Software"

Authors / Gang of Four:

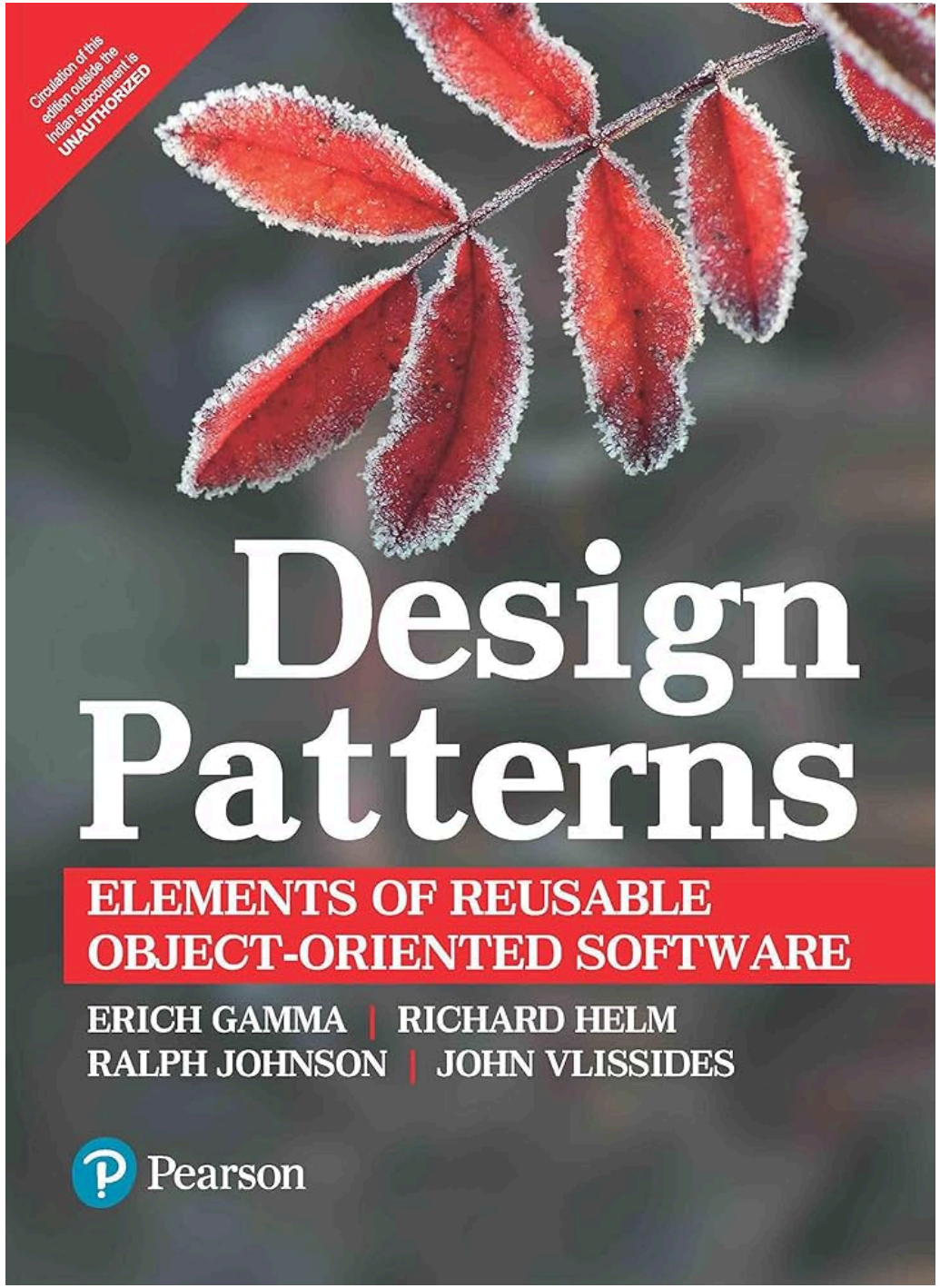
- Erich Gamma
- Richard Helm
- Ralph Johnson
- John Vlissides

Published: 1994

Created a common language for software designers

Defined **23 classic patterns** and organized into three categories:

- **Creational** (5 patterns)
- **Structural** (7 patterns)
- **Behavioral** (11 patterns)



Why Patterns Matter

1. Common Communication

- Better than explaining the entire approach

2. Proven Solutions

- Patterns solve real problems

3. Best Practices

- Patterns embody good OO design principles

4. Flexibility

- Patterns make code easier to change

5. Career Skill

- Industry standard knowledge

The Three Categories of Patterns

Creational Patterns

Problem: How do we create objects?

Focus: Object instantiation mechanisms

Patterns We'll Cover:

1. **Singleton**
2. **Factory Method**
3. **Abstract Factory**
4. **Builder**
5. **Prototype**

Goal: Make object creation flexible and decoupled

Structural Patterns

Problem: How do we compose objects?

Focus: Relationships between entities

Patterns We'll Cover:

1. **Adapter**
2. **Decorator**
3. **Facade**
4. **Proxy**

Goal: Ensure flexibility in how objects work together

Behavioral Patterns

Problem: How do objects communicate?

Focus: Responsibilities and interactions

Patterns We'll Cover:

1. **Observer**
2. **Strategy**
3. **Template Method**
4. **Command**
5. **State**
6. **Iterator**
7. **Chain of Responsibility**

Goal: Make communication between objects flexible and maintainable

Three Categories of Patterns: 1. Creational

Creation Mechanisms

Problem: Direct object creation (using `new`) creates tight coupling between the creator and the created class.

Focus: How objects are instantiated.

Goal: Decouple the system from how its objects are created, composed, and represented.

Core Idea:
Encapsulate knowledge about which concrete classes the system uses.

Patterns We'll Cover:

1. **Singleton:** Ensure single instance
2. **Factory Method:** Subclasses decide instantiation
3. **Abstract Factory:** Families of related objects
4. **Builder:** Step-by-step construction
5. **Prototype:** Cloning existing objects

Part 1: Creational Patterns

How Do We Create Objects Flexibly?

The Problem:

- Using `new` directly creates tight coupling
- Hard to change which concrete class is instantiated
- Difficult to control object creation logic
- Can't easily swap implementations

The Solution: Creational Patterns

Control object creation to make systems more flexible and decoupled.

1. Singleton Pattern

Ensure a class has only one instance and provide a global point of access to it

The Problem:

Some objects should exist only once:

- Database connection pool
- Configuration manager
- Logger
- Application state/cache

What happens if we have multiple?

- Resource conflicts
- Inconsistent state
- Wasted memory
- Race conditions

The Solution:

Make the class responsible for ensuring only one instance exists.

Structure:

1. **Private Constructor**: Prevents direct instantiation with `new`
2. **Static Instance**: Holds the single instance
3. **Static Accessor**: `getInstance()` creates if needed, returns existing
4. Lazy or eager initialization

Singleton Pattern

Singleton - CampusPal Example

AuthService Implementation

```
class AuthService {
  private static instance: AuthService;
  private currentUser: User | null = null;
  private token: string | null = null;

  public static getInstance(): AuthService {
    if (!AuthService.instance) {
      AuthService.instance = new AuthService();
    }
    return AuthService.instance;
  }

  public async login(email: string, password: string) {
    // Login logic
    const user = await api.login(email, password);
    this.currentUser = user;
    this.token = user.token;
  }

  public isAuthenticated(): boolean {
    return this.token !== null;
  }
}
```

Using the Singleton

```
// Anywhere in the app:
const auth = AuthService.getInstance();

if (auth.isAuthenticated()) {
  // Show user dashboard
  console.log("User is logged in");
} else {
  // Redirect to login
  window.location.href = '/login';
}
```

2. Factory Method Pattern

Define an interface for creating an object, but let subclasses decide which class to instantiate

The Problem:

You need to create objects but don't know the exact type until runtime:

- Different types of notifications (email, SMS, push)
- Different payment methods (credit card, PayPal, crypto)
- Different document formats (PDF, Word, HTML)

Direct instantiation:

```
// ❌ Tight coupling
if (type === 'email') {
  notification = new EmailNotification();
} else if (type === 'sms') {
  notification = new SMSNotification();
}
```

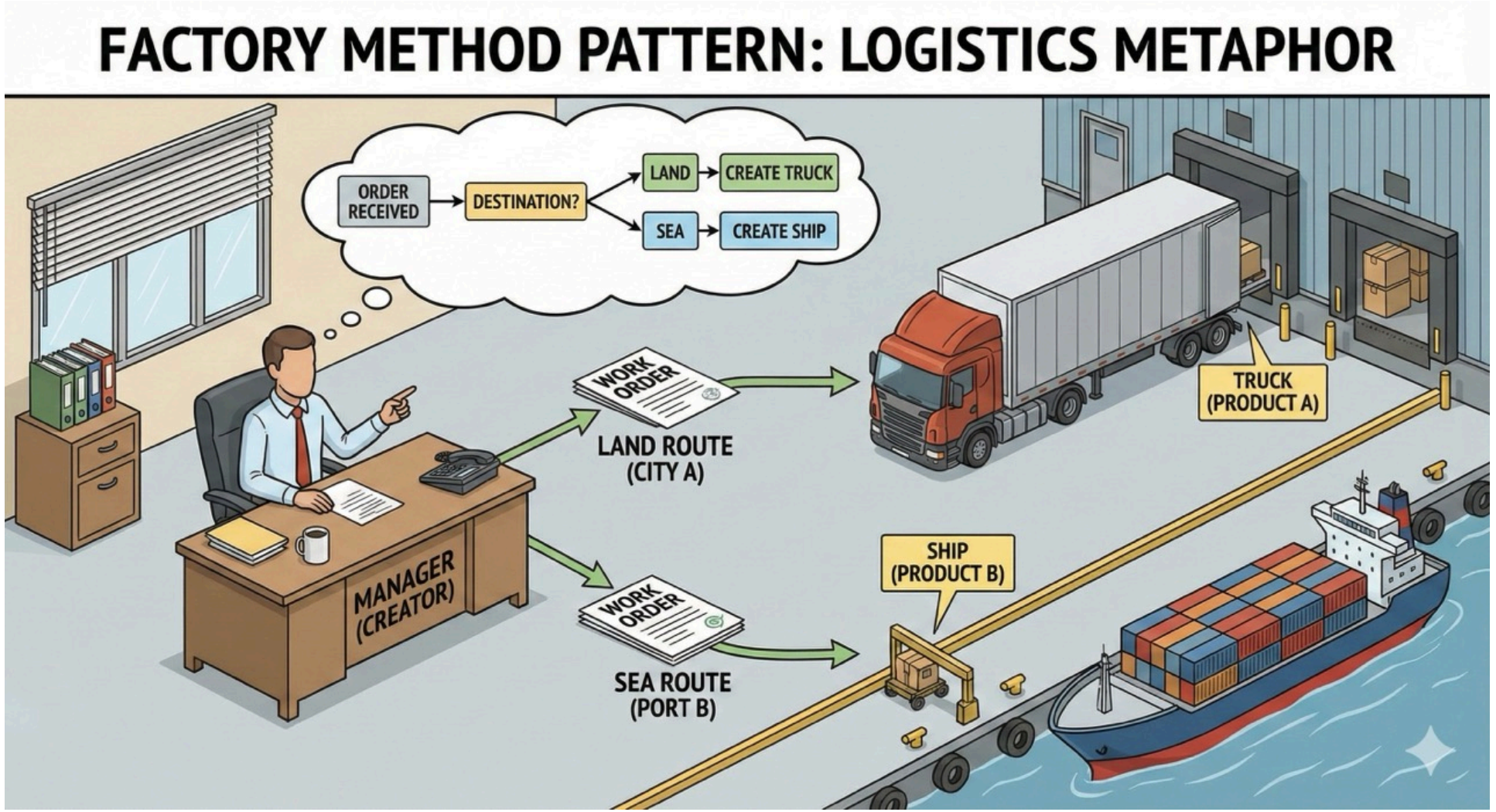
The Solution:

Let a factory method create the object:

1. Method gets the payload
2. It decides which type to generate/call
3. Others call Factory, not the sub methods

Open/Closed: Add new types without modifying existing code!

Factory Pattern



Factory Method - CampusPal Example

Notification System

The Scenario:

CampusPal sends notifications when:

- Event registration confirmed
- Event reminder (10 mins before)
- New marketplace item matching interests
- Someone comments on your post

Different users prefer different channels:

- Email (default)
- SMS
- Push notifications (mobile app)
- In-app notifications

Factory Code

```
// Factory creates the right notification
class NotificationFactory {
  static createForUser(user: User): Notification {
    if (user.hasApp && user.preferences.push) {
      return new PushNotification(user.deviceToken);
    } else if (user.isPremium && user.preferences.sms) {
      return new SMSNotification(user.phone);
    } else {
      return new EmailNotification(user.email);
    }
  }
}

// Usage in event registration
async function registerForEvent(user: User, event: Event) {
  // Register user
  await db.registrations.create({ userId: user.id, eventId: event.id });

  // Send notification (don't care which type!)
  const notification = NotificationFactory.createForUser(user);
  notification.send(`You're registered for ${event.title}!`);
}
```

3. Abstract Factory Pattern

Provide an interface for creating families of related or dependent objects without specifying their concrete classes.

The Problem:

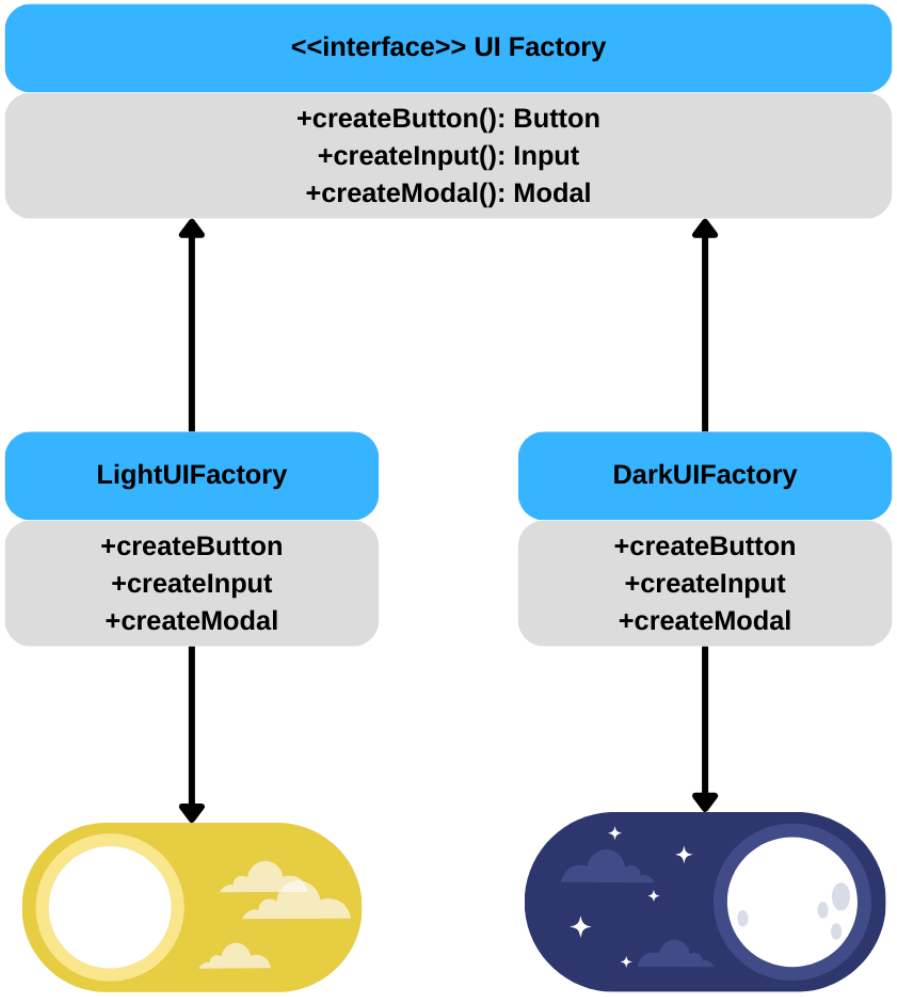
You need to create **sets of related objects** that work together:

- UI components for different platforms (iOS, Android, Web)
- Database drivers (MySQL, PostgreSQL, MongoDB)
- Theme systems (Light theme, Dark theme)

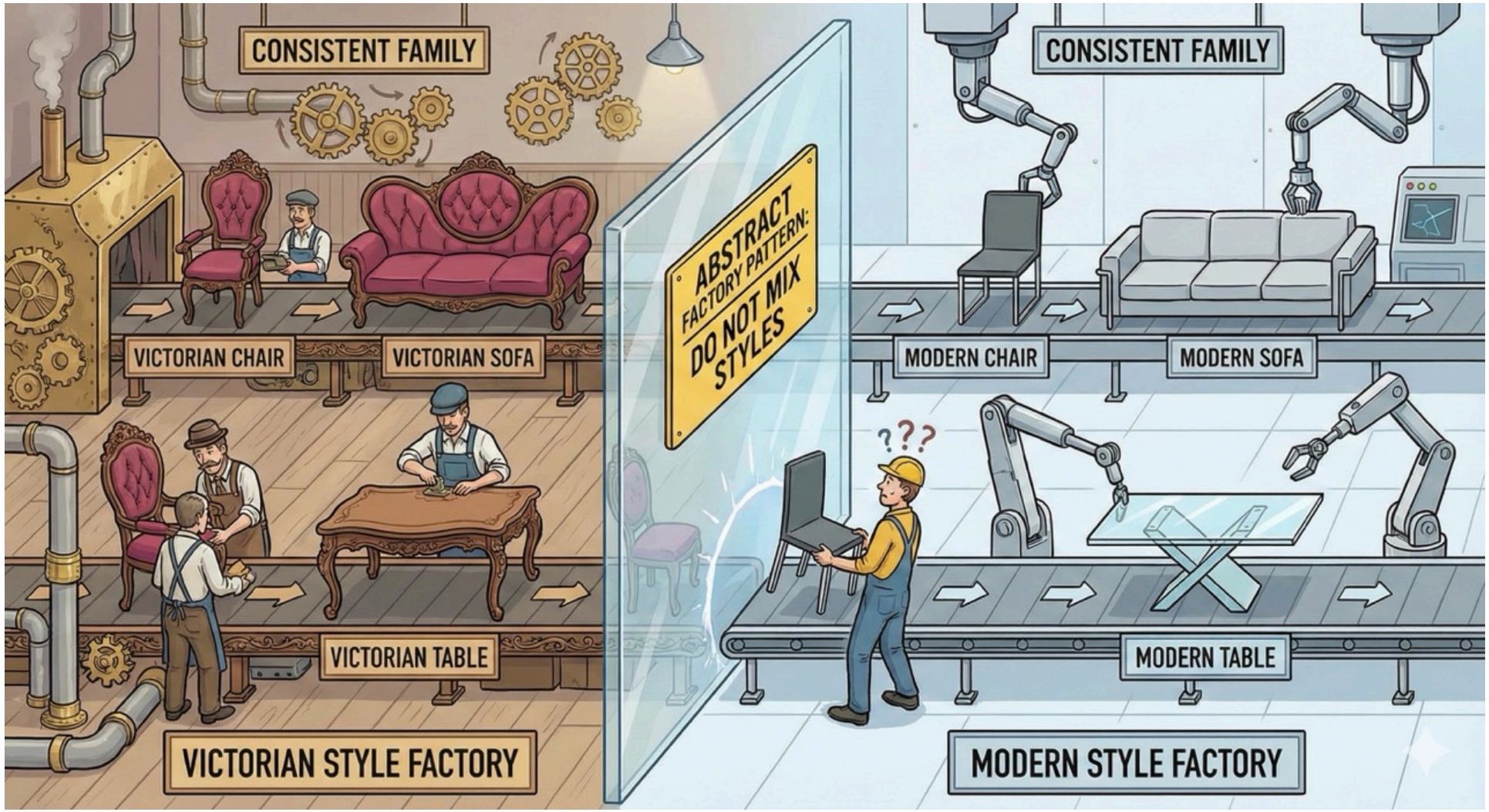
Example: Light theme needs light buttons, light inputs, light modals.

Factory Method vs Abstract Factory:

Factory Method: Creates one type of object
Abstract Factory: Creates families of related objects



Abstract Factory Pattern



Abstract Factory: Implementation (Products)

Abstract Products

```
interface Button {
  render(): void;
}

interface Input {
  render(): void;
}
```

Concrete Products

```
class LightButton implements Button {
  render() { console.log('Light Button'); }
}

class LightInput implements Input {
  render() { console.log('Light Input'); }
}

class DarkButton implements Button {
  render() { console.log('Dark Button'); }
}

class DarkInput implements Input {
  render() { console.log('Dark Input'); }
}
```

Abstract Factory: Implementation (Factories)

```
interface UIFactory {
  createButton(): Button;
  createInput(): Input;
}

class LightUIFactory implements UIFactory {
  createButton(): Button { return new LightButton(); }
  createInput(): Input { return new LightInput(); }
}

class DarkUIFactory implements UIFactory {
  createButton(): Button { return new DarkButton(); }
  createInput(): Input { return new DarkInput(); }
  }
```

```
// Usage
function renderUI(factory: UIFactory) {
  const btn = factory.createButton();
  const inp = factory.createInput();
  btn.render();
  inp.render();
}

const theme = 'dark';
const factory = theme === 'dark'
  ? new DarkUIFactory()
  : new LightUIFactory();

renderUI(factory);
```

4. Builder Pattern

Separate the construction of a complex object from its representation, allowing the same construction process to create different representations

The Problem

Creating complex objects with many optional parameters:

```
new Event( 'title',  'description', '2024-12-10', '18:00',
'location', 100, true,  ['tag1'],  null, false
);
// What does each parameter mean?
```

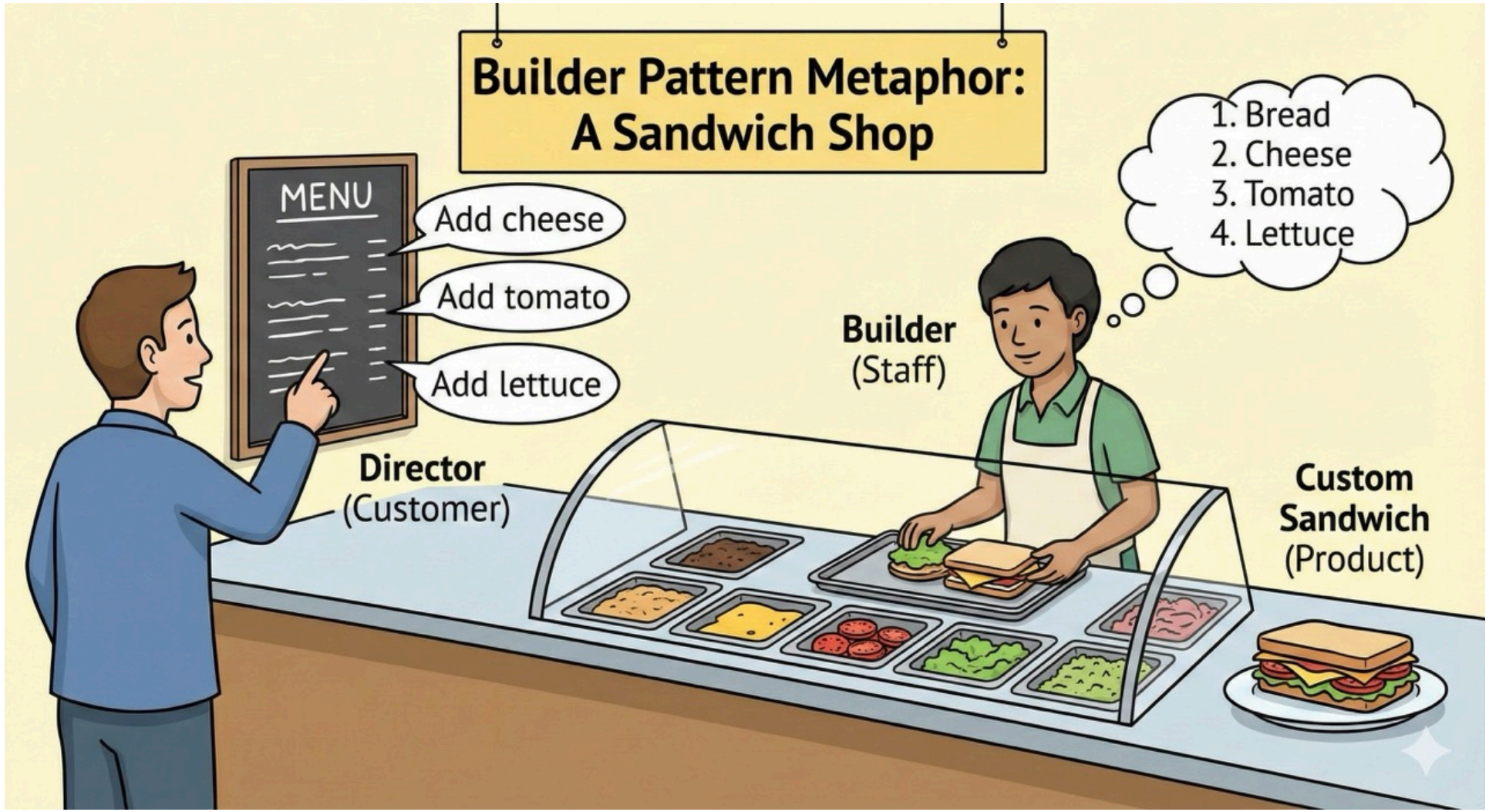
Issues:

- Hard to read
- Easy to make mistakes
- Can't skip optional parameters
- Order matters

The Solution

```
const event = new EventBuilder()
  .setTitle('Tech Talk: AI in Education')
  .setDescription('Learn about AI...')
  .setDate('2024-12-10')
  .setTime('18:00')
  .setLocation('Room 101')
  .setCapacity(100)
  .addTag('technology')
  .addTag('AI')
  .setRequiresRegistration(true)
  .build();
```

Builder Pattern



Builder Pattern - Implementation

```
class Event {
  constructor(
    public title: string,
    public description: string,
    public date: string,
    // ... other fields
  ) {}
}

class EventBuilder {
  private title: string = '';
  // ... other fields

  setTitle(title: string): EventBuilder {
    this.title = title;
    return this;
  }

  // ... other setters

  setTime(time: string): EventBuilder {
    this.time = time;
    return this;
  }

  addTag(tag: string): EventBuilder {
    this.tags.push(tag);
    return this;
  }

  build(): Event {
    // Validation
    if (!this.title || !this.date || !this.time) {
      throw new Error('Title, date, and time are required');
    }

    return new Event(
      this.title,
      this.description,
      this.date,
      // ...
    );
  }
}
```

5. Prototype Pattern

Create new objects by copying an existing object (the prototype) rather than creating from scratch

The Problem

- Creating an object is expensive (database query, API call)
- Object has complex initial state
- Need many similar objects with slight variations

Example: Event Templates

```
// Creating from scratch each time
const event1 = {
  organizerId: 123,
  category: 'workshop',
  requiresRegistration: true,
  capacity: 50,
  tags: ['education', 'workshop'],
  settings: { emailReminder: true, ... }
};

const event2 = { /* copy all above */ };
```

The Solution

```
class Event {
  constructor(/* ... */) {}

  clone(): Event {
    return Object.assign(
      Object.create(Object.getPrototypeOf(this)),
      this
    );
  }
}

const workshopTemplate = new Event({
  category: 'workshop',
  capacity: 50,
  requiresRegistration: true,
  tags: ['education', 'workshop']
});

const aiWorkshop = workshopTemplate.clone();
aiWorkshop.title = 'AI Workshop';
aiWorkshop.date = '2024-12-10';
```

Prototype Pattern

Prototype Pattern - Implementation

JavaScript/TypeScript

```
interface Cloneable {
  clone(): this;
}

class Event implements Cloneable {
  constructor(
    public title: string = '',
    public category: string = '',
    public capacity: number = 0,
    public tags: string[] = [],
    public settings: EventSettings = new EventSettings()
  ) {}

  clone(): Event {
    // Shallow copy
    return new Event(
      this.title,
      this.category,
      this.capacity,
      [...this.tags],  // Copy array
      { ...this.settings }  // Copy object
    );
  }
}

// Usage
const workshopTemplate = new Event('', 'workshop', 50, ['education']);
const myWorkshop = workshopTemplate.clone();
myWorkshop.title = 'React Workshop';
```

Key Concepts

1. **Clone Method**: Creates an exact copy of the object.
2. **Deep vs Shallow Copy**:
    - **Shallow**: Copies values (references for objects).
    - **Deep**: Recursively copies all nested objects.

Performance: Cloning is often faster than running a complex constructor or database query again.

Creational Patterns - Summary

Quick Reference

Pattern	Purpose	Use When
Singleton	One instance only	Global state, shared resources
Factory Method	Create objects without specifying exact class	Type determined at runtime
Abstract Factory	Create families of related objects	Need consistent sets of objects
Builder	Construct complex objects step by step	Many optional parameters
Prototype	Clone existing objects	Object creation is expensive

Practice - CampusPal Pattern Usage

Singleton:

Factory Method:

Abstract Factory:

Builder:

Prototype:

Answer - CampusPal Pattern Usage

Singleton:

- AuthService (current user)

Factory Method:

- NotificationFactory (email/SMS/push)

Abstract Factory:

- ThemeFactory (light/dark themes)

Builder:

- EventBuilder (complex event creation)

Prototype:

- EventTemplateManager (event templates)

Three Categories of Patterns: 2. Structural

Composition and Structure

Problem: Systems grow complex when objects are fixed in static relationships.

Focus: How classes and objects are composed to form larger structures.

Goal: Ensure flexibility in how objects are combined, allowing the structure to grow without collapsing.

Core Idea:
Use inheritance to compose interfaces and define ways to compose objects to obtain new functionality.

Patterns We'll Cover:

1. **Adapter:** Bridge incompatible interfaces
2. **Decorator:** Add behaviors dynamically
3. **Facade:** Simplify complex interfaces
4. **Proxy:** Control access to objects
5. **Composite:** Tree structures

Part 2: Structural Patterns

How Do We Compose Objects?

The Problem:

- Classes and objects need to work together
- Need to adapt incompatible interfaces
- Want to add functionality without changing existing code
- Need to hide complexity

The Solution: Structural Patterns

These patterns help you compose objects and classes into larger structures while keeping them flexible and efficient.

1. Adapter Pattern

Convert the interface of a class into another interface that clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces.

The Problem:

You have two incompatible interfaces:

- Legacy code with old interface
- Third-party library with different interface
- External API that doesn't match your system

Example:

```
// Your system expects
interface PaymentProcessor {
  processPayment(amount: number): Promise<void>;
}

// But Stripe has
class StripeAPI {
  charge(amountInCents: number, currency: string): Promise<void> {}
}
```

The Solution:

Create an adapter that translates translates calls

Adapter Pattern - Implementation

```typescript
// Target interface (what client expects)
interface PaymentProcessor {
  processPayment(amount: number): Promise<void>;
}

// Adaptee (third-party with different interface)
class StripeAPI {
  charge(amountInCents: number, currency: string): Promise<void> {
    console.log(`Charging ${amountInCents} cents in ${currency}`);
    return Promise.resolve();
  }
}

// Adapter
class StripeAdapter implements PaymentProcessor {
  private stripe: StripeAPI;

  constructor() {
    this.stripe = new StripeAPI();
  }

  async processPayment(amount: number): Promise<void> {
    // Adapt the interface:
    // Convert dollars to cents
    const amountInCents = Math.round(amount * 100);
    // Add default currency
    await this.stripe.charge(amountInCents, 'USD');
  }
}
```

```typescript
// Client code doesn't know about Stripe
class CheckoutService {
  constructor(private paymentProcessor: PaymentProcessor) {}

  async checkout(cart: Cart) {
    const total = cart.getTotal();
    await this.paymentProcessor.processPayment(total);
  }
}

// Usage
const stripeAdapter = new StripeAdapter();
const checkout = new CheckoutService(stripeAdapter);
await checkout.checkout(myCart);

// Easy to swap payment providers
class PayPalAdapter implements PaymentProcessor {
  async processPayment(amount: number): Promise<void> {
    // Adapt PayPal API
  }
}

const paypalAdapter = new PayPalAdapter();
const checkout2 = new CheckoutService(paypalAdapter);
```

2. Decorator Pattern

Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.

The Problem:

Need to add features but:

- Inheritance is too rigid
- Want to combine features flexibly
- Don't want to modify existing code

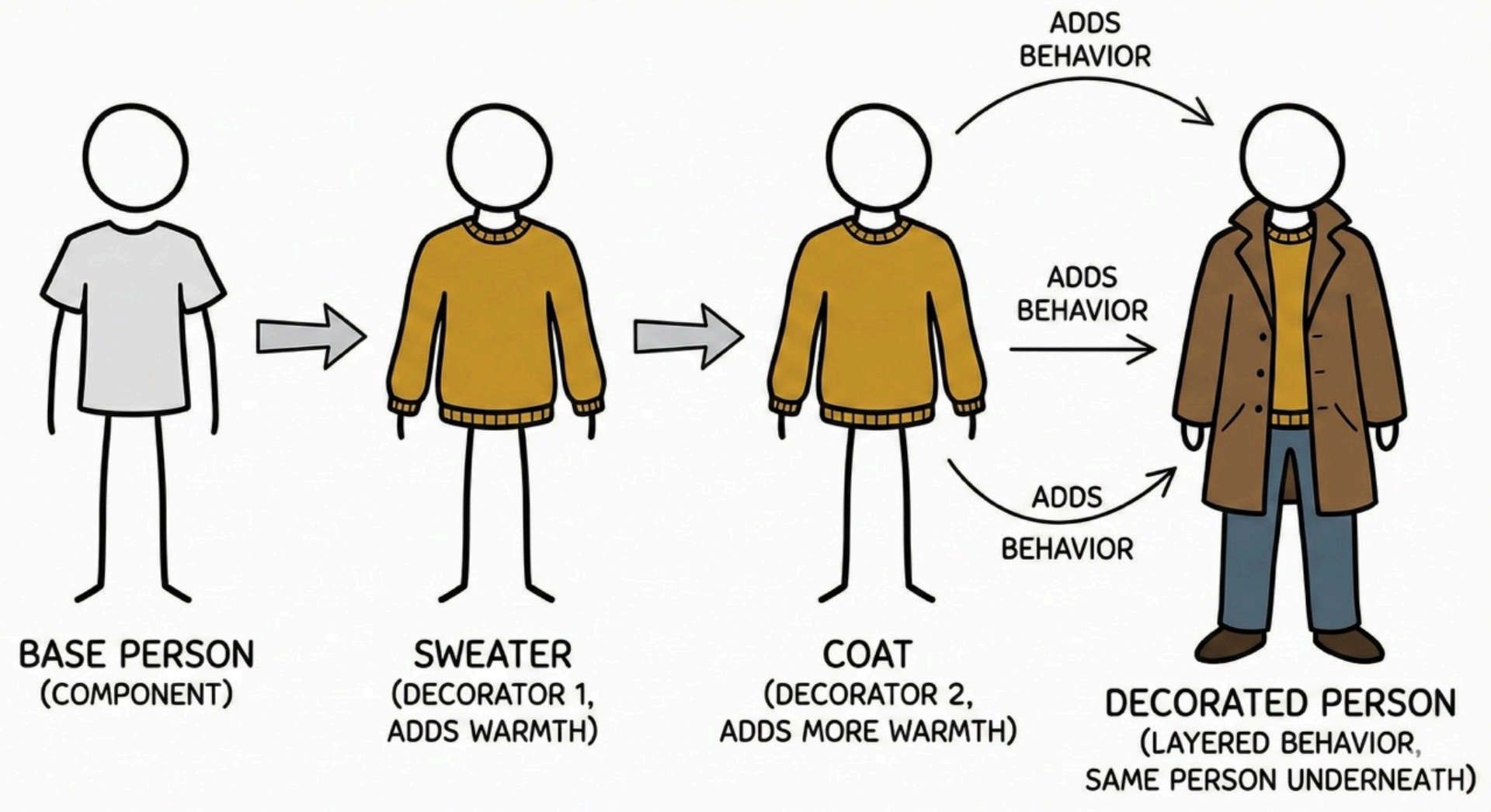
Bad approach:

```
class Notification {}
class EmailNotification extends Notification {}
class SMSNotification extends Notification {}
class EmailSMSNotification extends Notification {}
class EmailWithAttachment extends Notification {}
class SMSWithAttachment extends Notification {}
// Explosion of classes
```

The Solution:

Wrap objects with decorators and stack decorators like layers

Decorator Pattern



Decorator Pattern - Implementation

```typescript
// Component interface
interface Notification {
  send(message: string): void;
  getCost(): number;
}

// Concrete component
class BasicNotification implements Notification {
  send(message: string) {
    console.log(`Basic notification: ${message}`);
  }

  getCost(): number {
    return 0; // Free
  }
}

// Base decorator
abstract class NotificationDecorator implements Notification {
  constructor(protected notification: Notification) {}

  send(message: string) {
    this.notification.send(message);
  }

  getCost(): number {
    return this.notification.getCost();
  }
}
```

```typescript
// Concrete decorators
class EmailDecorator extends NotificationDecorator {
  send(message: string) {
    super.send(message);
    console.log(`  + Sending email: ${message}`);
  }

  getCost(): number {
    return super.getCost() + 0.10; // $0.10 per emai
  }
}

class SMSDecorator extends NotificationDecorator {
  send(message: string) {
    super.send(message);
    console.log(`  + Sending SMS: ${message}`);
  }

  getCost(): number {
    return super.getCost() + 0.50; // $0.50 per SMS
  }
}

// Usage - Stack decorators!
let notification: Notification = new BasicNotification();
notification = new EmailDecorator(notification);
notification = new SMSDecorator(notification);

notification.send('Event reminder');
//   Basic notification: Event reminder
//   + Sending email: Event reminder
//   + Sending SMS: Event reminder

console.log(`Cost: $${notification.getCost()}`); // $0.60
```

3. Facade Pattern

Provide a unified, simplified interface to a set of interfaces in a subsystem. Facade makes the subsystem easier to use.

The Problem:

Complex subsystems with many classes

- Hard to understand
- Many steps required
- Clients need to know internal details

The Solution:

Hide complexity behind simple interface, simple on outside, complex inside.

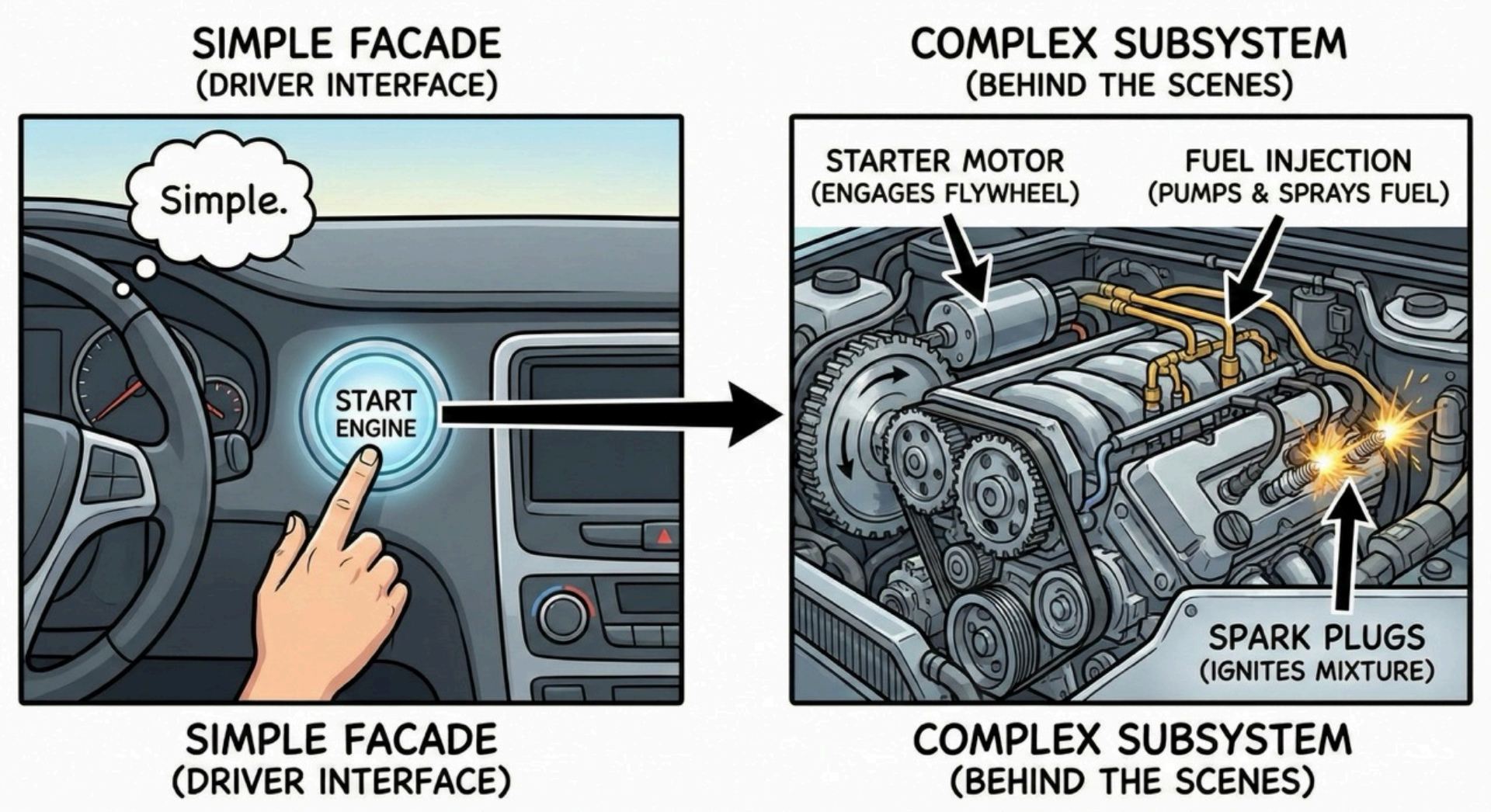
- Provide simple endpoints
- Let complex logic stay hidden

Example: Payment processing

```
const validator = new CardValidator();
const processor = new PaymentProcessor();
const logger = new TransactionLogger();
const notifier = new EmailNotifier();
const inventory = new InventoryManager();

if (validator.validate(card)) {
  const result = await processor.process(payment);
  await logger.log(result);
  await notifier.notify(user, result);
  await inventory.update(order);
}
```

Facade Pattern



Facade Pattern: Implementation (Subsystem)

Complex Subsystem

```
class InventoryService {
  checkStock(id: string): boolean { return true; }
  reserveItem(id: string): void { /*...*/ }
}

class PaymentService {
  process(amount: number): boolean { return true; }
}

class ShippingService {
  createShipment(order: Order): string { return 'TRACK-123'; }
}

class NotificationService {
  sendConfirmation(email: string): void { /*...*/ }
}
```

The Facade Class

```
class OrderFacade {
  private inventory = new InventoryService();
  private payment = new PaymentService();
  private shipping = new ShippingService();
  private notification = new NotificationService();

  async placeOrder(user: User, cart: Cart): Promise<boolean> {
    if (!this.inventory.checkStock(cart.itemId)) return false;

    this.inventory.reserveItem(cart.itemId);
    if (!this.payment.process(cart.total)) return false;

    const tracking = this.shipping.createShipment(cart);
    this.notification.sendConfirmation(user.email);

    return true;
  }
}
```

Facade Pattern: Implementation (Usage)

```
// Without Facade (Complex Client)
const inventory = new InventoryService();
const payment = new PaymentService();
// ... init others
if (inventory.checkStock(item)) {
  inventory.reserveItem(item);
  payment.process(amount);
  // ... maintain order of operations manually
}

// With Facade (Simple Client)
const orderFacade = new OrderFacade();
const success = await orderFacade.placeOrder(user, cart);

if (success) {
  console.log('Order placed successfully!');
}
```

4. Proxy Pattern

Provide a surrogate or placeholder for another object to control access to it.

The Problem:

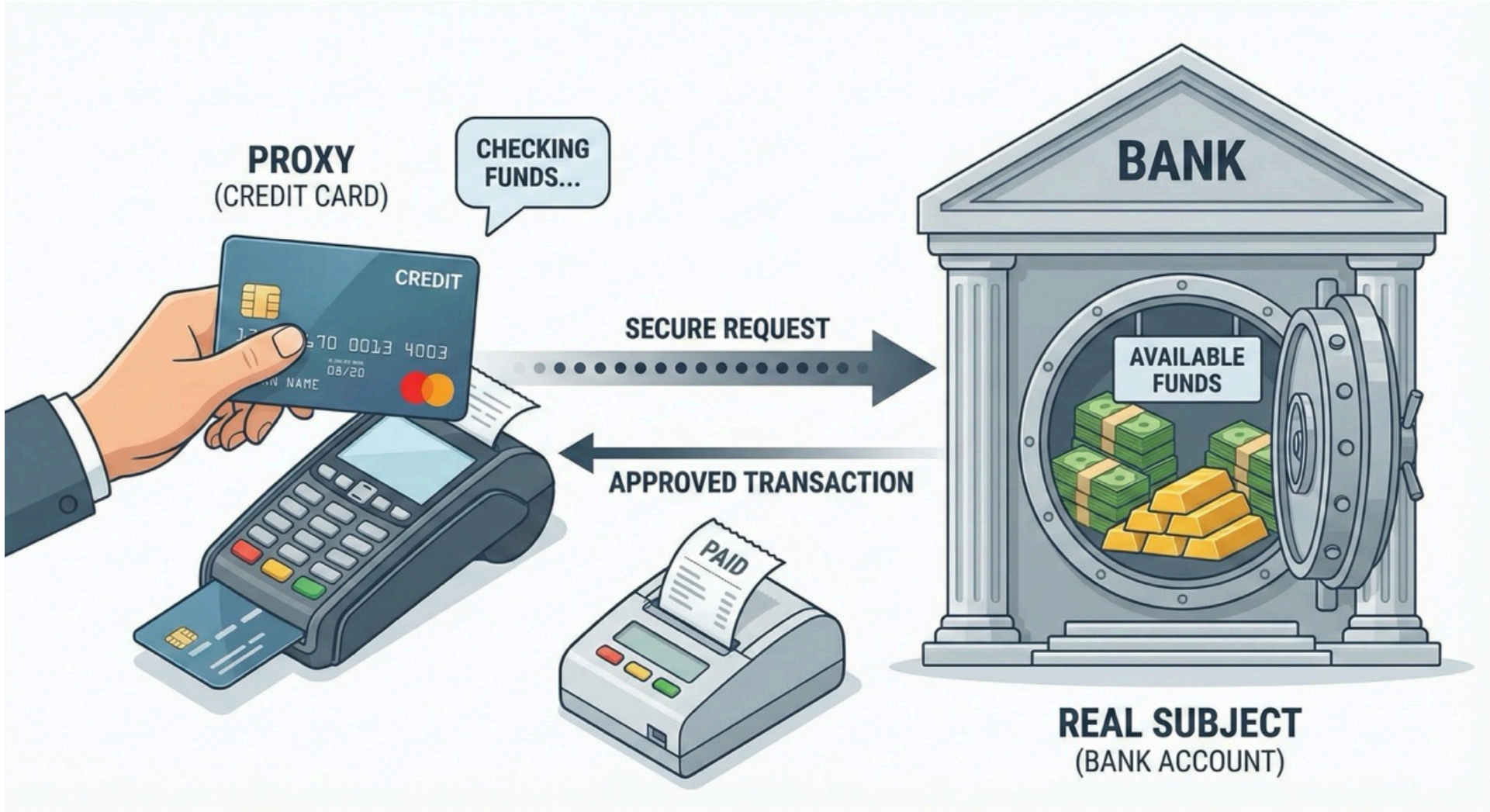
Want to control access to an object:

- Lazy loading (create only when needed)
- Access control (check permissions)
- Logging/caching (add behavior)
- Remote access (object in different process)

Types of Proxies:

Virtual Proxy: Delay creation until needed
Protection Proxy: Control access
Remote Proxy: Represent object in different address space
Caching Proxy: Cache results

Proxy Pattern



Proxy - CampusPal Example (Proxy Class)

```
// Interface
interface EventImage {
  load(): Promise<string>; // Returns image URL
}

class RealEventImage implements EventImage {
  constructor(private id: string) {}

  async load(): Promise<string> {
    // Expensive API call
    const res = await fetch(`/api/images/${this.id}`);
    return (await res.json()).url;
  }
}

// Caching Proxy
class CachedImageProxy implements EventImage {
  private cachedUrl: string | null = null;
  private realImage: RealEventImage;

  constructor(id: string) {
    this.realImage = new RealEventImage(id);
  }

  async load(): Promise<string> {
    if (this.cachedUrl) return this.cachedUrl;

    this.cachedUrl = await this.realImage.load();
    return this.cachedUrl;
  }
}
```

Proxy - CampusPal Example (Usage)

```
// Usage in event gallery component
class EventGallery {
  private images: EventImage[] = [];

  constructor(imageIds: string[]) {
    // Create proxies (cheap operations)
    this.images = imageIds.map(id => new CachedImageProxy(id));
  }

  async onUserClick(index: number) {
    // Load only when needed
    const url = await this.images[index].load();

    // Second click returns cached URL instantly
    this.display(url);
  }

  private display(url: string) { /*...*/ }
}
```

Benefits: Images load only when needed, cached after first load

Structural Patterns - Summary

Quick Reference

Pattern	Purpose	Use When
Adapter	Convert interface	Integrate incompatible interfaces
Decorator	Add responsibilities dynamically	Extend functionality without subclassing
Facade	Simplify complex system	Need simple interface to complex subsystem
Proxy	Control access	Need lazy loading, caching, access control

Practice - CampusPal Pattern Usage

Adapter:

Decorator:

Facade:

Proxy:

Answer - CampusPal Pattern Usage

Adapter:

- GoogleCalendarAdapter (external APIs)
- StripeAdapter, PayPalAdapter (payment)

Decorator:

- Notification enhancements (logging, retry, priority)
- Image filters

Facade:

- EventRegistrationFacade (simplify complex flow)
- CheckoutFacade

Proxy:

- CachedImageProxy (lazy loading + caching)
- VirtualEventProxy (performance)

Three Categories of Patterns: 3. Behavioral

Communication and Responsibility

Problem: Tightly coupled communication makes it hard to change how objects interact.

Focus: Algorithms and the assignment of responsibilities between objects.

Goal: flexible and maintainable communication patterns.

Core Idea:
Characterize complex control flow that's difficult to follow at run-time. shifting your focus away from flow of control to let you concentrate just on the way objects are interconnected.

Patterns We'll Cover:

1. **Observer:** Event subscriptions
2. **Strategy:** Interchangeable algorithms
3. **Template Method:** Workflow skeletons
4. **Command:** Encapsulated requests
5. **State:** State-dependent behavior
6. **Iterator:** Sequential access
7. **Chain of Responsibility:** Request passing

Part 3: Behavioral Patterns

How Do Objects Communicate?

The Problem:

- Objects need to interact and collaborate
- Responsibilities need to be distributed
- Algorithms need to vary independently
- Need flexible communication patterns

The Solution: Behavioral Patterns

These patterns define how objects communicate, assign responsibilities, and vary algorithms independently of the clients that use them.

1. Observer Pattern

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

The Problem:

Need to notify multiple objects when something changes:

- User subscribes to event notifications
- UI components react to data changes
- Multiple listeners for system events

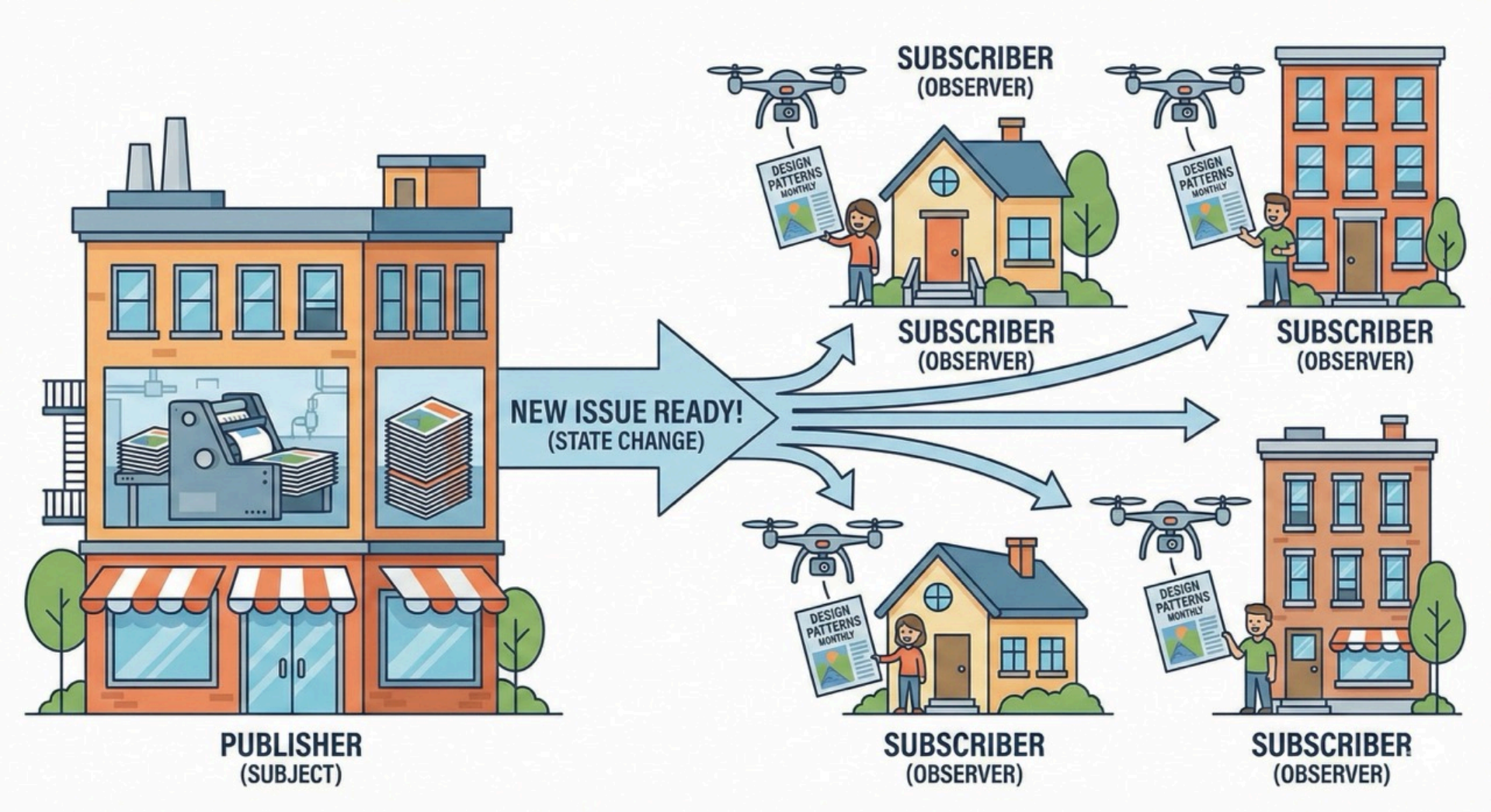
Bad approach:

```
class Event {
  notifyUsers() {
    emailService.send(/*...*/);
    smsService.send(/*...*/);
    pushService.send(/*...*/);
    // Tight coupling!
  }
}
```

The Solution:

Observers subscribe to subject (similar to event-driven architecture)

Observer Pattern



Observer Pattern - Implementation (Subject)

```
// Observer interface
interface Observer {
  update(data: any): void;
}

// Subject (Observable)
class EventPublisher {
  private observers: Observer[] = [];

  subscribe(observer: Observer): void {
    this.observers.push(observer);
  }

  unsubscribe(observer: Observer): void {
    const index = this.observers.indexOf(observer);
    if (index > -1) {
      this.observers.splice(index, 1);
    }
  }

  notify(data: any): void {
    this.observers.forEach(observer =>
      observer.update(data)
    );
  }

  publishEvent(event: Event): void {
    console.log(`Publishing event: ${event.title}`);
    this.notify(event);
  }
}
```

Key Parts

1. **Subject**: Maintains list of observers.
2. **Observer Interface**: Defines update method.
3. **Notify Loop**: Iterates and calls update on all subscribers.

Observer Pattern - Implementation (Usage)

```
// Concrete observers
class EmailObserver implements Observer {
  update(event: Event): void {
    console.log(`Sending email about: ${event.title}`);
  }
}

class SMSObserver implements Observer {
  update(event: Event): void {
    console.log(`Sending SMS about: ${event.title}`);
  }
}

class LogObserver implements Observer {
  update(event: Event): void {
    console.log(`Logging event: ${event.title}`);
  }
}
```

```
// Usage
const publisher = new EventPublisher();

const emailObs = new EmailObserver();
const smsObs = new SMSObserver();
const logObs = new LogObserver();

publisher.subscribe(emailObs);
publisher.subscribe(smsObs);
publisher.subscribe(logObs);

publisher.publishEvent({
  title: 'Tech Workshop',
  date: '2024-12-10'
});
// All observers notified!

// Can unsubscribe
publisher.unsubscribe(smsObs);
```

2. Strategy Pattern

Define a family of algorithms, encapsulate each one, and make them interchangeable. Strategy lets the algorithm vary independently from clients that use it.

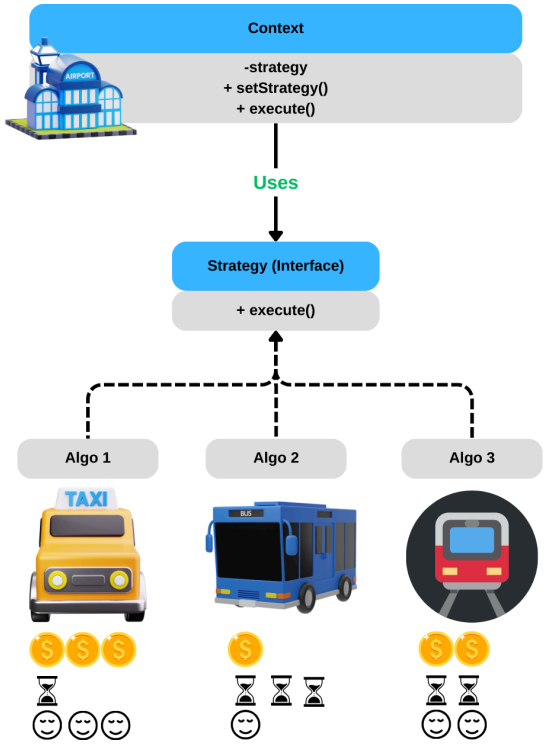
The Problem

Different ways to do the same thing:

- Multiple sorting algorithms
- Different payment methods
- Various compression algorithms

```
class PaymentProcessor {
  process(method: string, amount: number) {
    if (method === 'credit') {
      // Credit card logic
    } else if (method === 'paypal') {
      // PayPal logic
    } else if (method === 'crypto') {
      // Crypto logic
    }
    // Violates Open/Closed! (How to add the new payment method?)
  }
}
```

The Solution



Strategy - CampusPal Example (Strategies)

Event Sorting Strategies

```
interface SortStrategy {
  sort(events: Event[]): Event[];
}

class SortByDate implements SortStrategy {
  sort(events: Event[]): Event[] {
    return [...events].sort((a, b) =>
      new Date(a.date).getTime() - new Date(b.date).getTime()
    );
  }
}

class SortByPopularity implements SortStrategy {
  sort(events: Event[]): Event[] {
    return [...events].sort((a, b) => b.registrationCount - a.registrationCount);
  }
}

class SortByRelevance implements SortStrategy {
  constructor(private user: User) {}
  sort(events: Event[]): Event[] {
    return [...events].sort((a, b) => this.score(b) - this.score(a));
  }
  private score(e: Event) { return /* calculation */ 0; }
}
```

Strategy - CampusPal Example (Context & Usage)

```
// Context
class EventList {
  constructor(
    private events: Event[],
    private sortStrategy: SortStrategy
  ) {}

  setSortStrategy(strategy: SortStrategy): void {
    this.sortStrategy = strategy;
  }

  display(): Event[] {
    return this.sortStrategy.sort(this.events);
  }
}

// Usage
const eventList = new EventList(events, new SortByDate());

// User clicks "Sort by popularity"
eventList.setSortStrategy(new SortByPopularity());
console.log(eventList.display());

// User clicks "Recommended for you"
eventList.setSortStrategy(new SortByRelevance(currentUser));
console.log(eventList.display());
```

3. Template Method Pattern

Define the skeleton of an algorithm in a method, leaving some steps to subclasses. Template Method lets subclasses redefine certain steps without changing the algorithm's structure.

The Problem:

Similar workflows with slight variations:

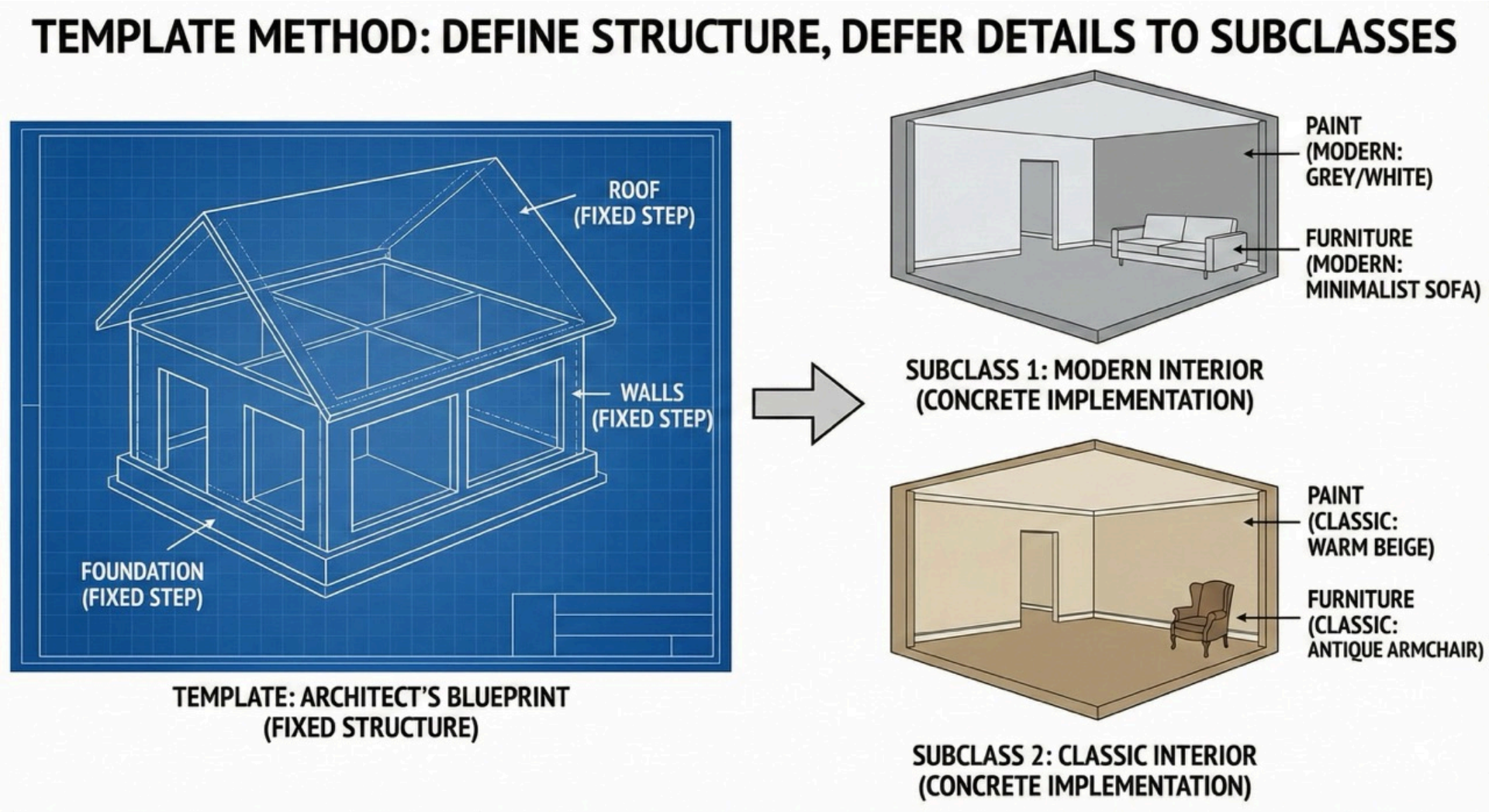
- Data processing pipeline (different sources)
- Report generation (different formats)
- ML training (similar steps, different logic)
- Game AI (different behaviors)

Common structure, different details

The Solution:

- Break down algorithm into a series of steps
- Turn these steps into methods
- Put a series of calls to these methods inside a single *template method*

Template Method Pattern



Template Method - CampusPal Example (Abstract Class)

```
abstract class EventRegistrationHandler {
  // Template method – defines the workflow
  async register(user: User, event: Event): Promise<RegistrationResult> {
    try {
      await this.checkEligibility(user, event);

      if (event.requiresPayment) {
        await this.processPayment(user, event d);
      }

      await this.createRegistration(user, event);
      await this.sendConfirmation(user, event);
      await this.afterRegistration(user, event);

      return { success: true };
    } catch (error) {
      return { success: false, error: error.message };
    }
  }

  // Abstract methods (Must implement)
  protected abstract checkEligibility(user: User, event: Event): Promise<void>;
  protected abstract sendConfirmation(user: User, event: Event): Promise<void>;

  // Common & Hook methods (Optional/Default)
  protected async createRegistration(user: User, event: Event): Promise<void> { /*...*/ }
  protected async processPayment(user: User, event: Event): Promise<void> { /*...*/ }
  protected async afterRegistration(user: User, event: Event): Promise<void> { /*...*/ }
}
```

Template Method - CampusPal Example (Implementation)

```
class WorkshopRegistrationHandler extends EventRegistrationHandler {
  protected async checkEligibility(user: User, event: Event): Promise<void> {
    if (event.prerequisites && !user.hasCompleted(event.prerequisites)) {
      throw new Error('Prerequisites not met');
    }
  }

  protected async sendConfirmation(user: User, event: Event): Promise<void> {
    await emailService.send(user.email, 'Workshop Confirmation', {
      materials: event.workshopMaterials
    });
  }
}

class SocialEventRegistrationHandler extends EventRegistrationHandler {
  protected async checkEligibility(user: User, event: Event): Promise<void> {
    if (event.isFull()) throw new Error('Event is full');
  }

  protected async sendConfirmation(user: User, event: Event): Promise<void> {
    await notificationService.send(user, `Registered for ${event.title}!`);
  }
}
```

4. State Pattern

Allow an object to alter its behavior when its internal state changes. The object will appear to change its class.

The Problem:

Object behavior depends on state:

- Order status (pending, shipped, delivered)
- Document status (draft, review, published)
- Connection status (disconnected, connecting, connected)

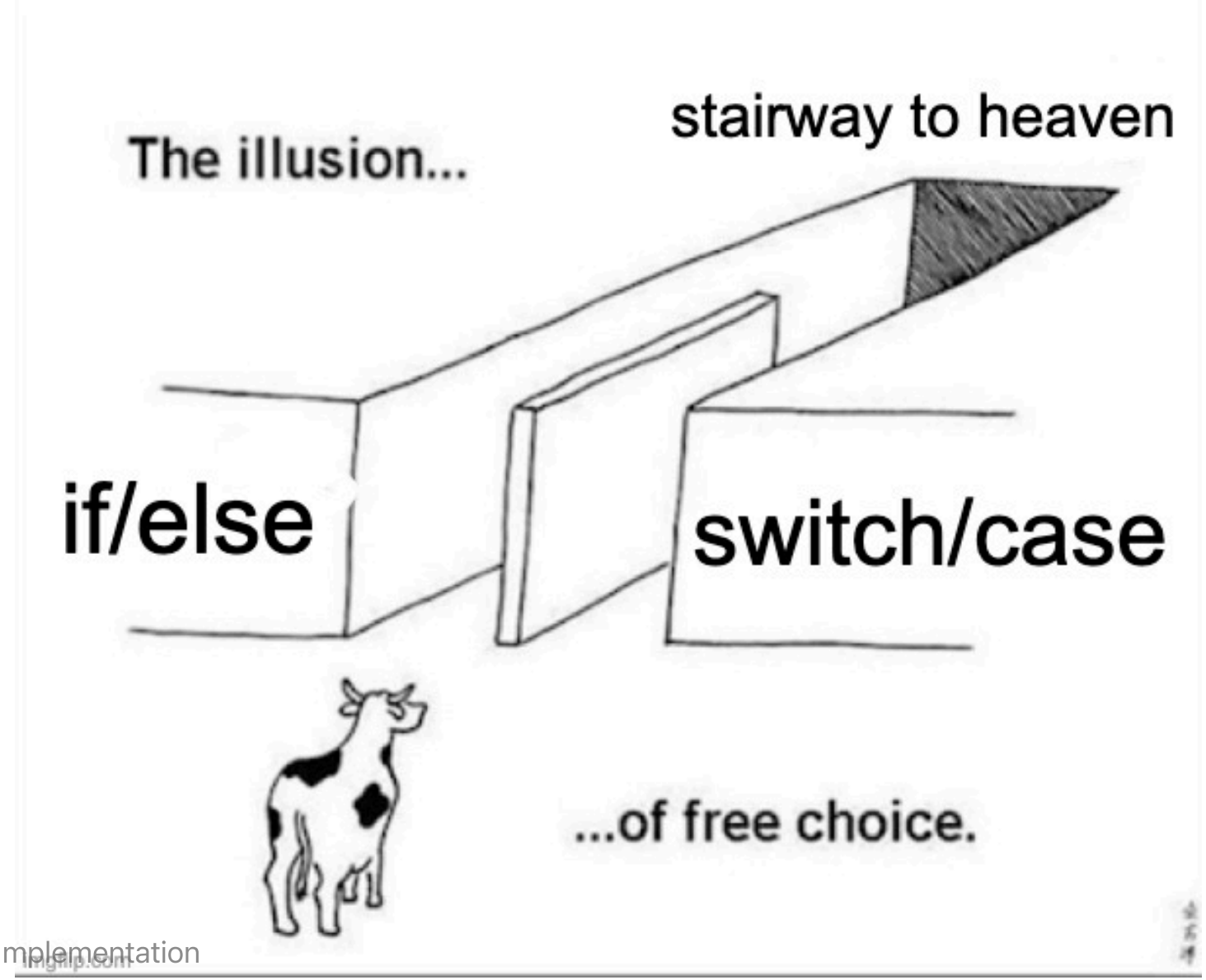
The Solution:

- Create new classes for all possible states of an object
- Extract all state-specific behaviors into these classes
- The original object stores a reference to state objects and delegates all the state-related work to that object.

Similar to the Strategy pattern

- In the State pattern, states may be aware of each other and initiate transitions from one state to another
- Strategies never know about each other

State Pattern



State Pattern - CampusPal Example (States)

```
// State interface
interface EventState {
  publish(event: Event): void;
  cancel(event: Event): void;
  register(event: Event, user: User): void;
}

// Concrete states
class DraftState implements EventState {
  publish(event: Event): void {
    console.log('Publishing event...');
    event.setState(new PublishedState());
  }

  cancel(event: Event): void {
    throw new Error('Cannot cancel draft event');
  }
  // ... register throws error
}
```

```
class PublishedState implements EventState {
  publish(event: Event): void { throw new Error('Already published'); }

  cancel(event: Event): void {
    console.log('Cancelling event...');
    event.setState(new CancelledState());
  }

  register(event: Event, user: User): void {
    if (event.isFull()) {
      event.setState(new FullState());
      throw new Error('Event is full');
    }
    event.addRegistrant(user);
  }
}
```

State Pattern - CampusPal Example (Context)

```
// Context
class Event {
  private state: EventState = new DraftState();

  setState(state: EventState): void {
    this.state = state;
  }

  publish(): void {
    this.state.publish(this);
  }

  cancel(): void {
    this.state.cancel(this);
  }

  register(user: User): void {
    this.state.register(this, user);
  }
}

// Usage
const event = new Event();
event.publish(); // Draft → Published
event.register(user1); // OK

// ... event becomes full
event.register(user100); // → Added to waitlist (Full state)
event.cancel(); // Published → Cancelled
```

5. Command Pattern

Encapsulate a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations.

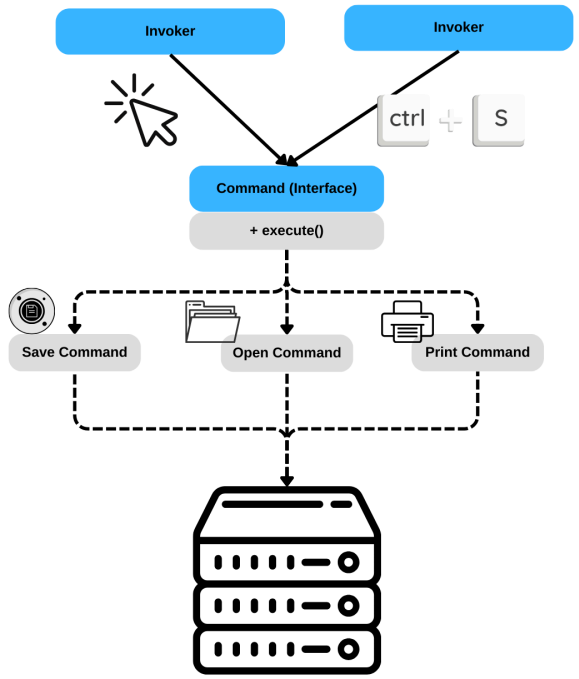
The Problem

A GUI object calls a method of a business logic object, passing it some arguments.

- Each method is another call (save, undo, redo, etc.)
- Coupling between GUI and business logic layers

The Solution

- Extract all of the request details into a separate command class with a single method that triggers this request
- Make your commands implement the same interface
- Commands become a convenient middle layer that reduces coupling between the GUI and business logic layers



Command Pattern - Implementation (Commands)

```
// Command interface
interface Command {
  execute(): void;
  undo(): void;
}

// Concrete command
class EditDescriptionCommand implements Command {
  constructor(
    private editor: EventEditor,
    private textToAppend: string
  ) {}

  execute(): void {
    this.editor.append(this.textToAppend);
  }

  undo(): void {
    this.editor.delete(this.textToAppend.length);
  }
}
```

Command Pattern - Implementation (Invoker & Usage)

```
// Invoker
class CommandManager {
  private history: Command[] = [];

  execute(command: Command): void {
    command.execute();
    this.history.push(command);
  }

  undo(): void {
    const command = this.history.pop();
    if (command) {
      command.undo();
    }
  }
}
```

```
// Usage
const editor = new EventEditor();
const manager = new CommandManager();

manager.execute(
  new EditDescriptionCommand(editor, 'Join us')
);
manager.execute(
  new EditDescriptionCommand(editor, ' today!')
);
// Description: "Join us today!"

manager.undo();
// Description: "Join us"
```

Behavioral Patterns - Summary

Pattern	Purpose	Use When
Observer	1-to-many dependency	Multiple objects need updates
Strategy	Interchangeable algorithms	Algorithm varies at runtime
Template Method	Workflow skeleton	Similar workflows, different details
Command	Encapsulate requests	Need undo/redo, queuing, logging
State	Behavior changes with state	Object behavior depends on state

Practice - CampusPal Pattern Usage

Observer:

Strategy:

Template Method:

State:

Command:

Answer - CampusPal Pattern Usage

Observer:

- Event updates notify subscribers
- Real-time notifications

Strategy:

- Sorting algorithms (date, popularity, relevance)
- Search algorithms

Template Method:

- Registration workflows (workshop, social, academic)
- Data export (CSV, JSON, PDF)

State:

- Event lifecycle (draft → published → full → cancelled)
- User session states

Command:

- Undo/redo in event editor
- Request queuing

Pattern Relationships and Combinations

In real systems, you rarely use just one pattern.

Patterns combine to solve complex problems:

- Factory + Singleton
- Decorator + Strategy
- Facade + Factory
- Observer + Command

Let's look at common combinations...

Common Pattern Combinations

Factory + Singleton

Need to create objects of different types, but each type should have only one instance.

Use case: Resource-heavy objects that you want to reuse (e.g., Service classes).

Factory + Strategy

Create the right strategy based on runtime conditions.

Use case: Dynamic strategy selection based on user input or config.

CampusPal Architecture with Multiple Patterns

```
// 1. Singleton Container
const container = AppContainer.getInstance();

// 2. Facade for complexity
const eventService = container.createEventService();

// 3. Observer for updates
eventService.subscribe(new NotificationSender());

// 4. Command for actions
const cmdManager = new CommandManager();
cmdManager.execute(new CreateEventCommand(eventData));

// 5. State for lifecycle
const event = new Event();
event.setState(new DraftState());
event.publish();
```

Patterns working together:

- **Singleton** manages global resources
- **Factory** creates services
- **Facade** simplifies API
- **Observer** handles reactivity
- **Command** enables undo/redo
- **State** manages lifecycle

Patterns in Real Frameworks

React

Component Pattern: Composite

- Components contain other components

Hooks (useState, useEffect): Observer

- State changes trigger re-renders

Context API: Singleton + Provider

- Global state management

Higher-Order Components: Decorator

- Add behavior to components

Render Props: Strategy

- Inject rendering logic

Express.js

Middleware: Chain of Responsibility

- Request passes through handlers

Router: Facade

- Simplifies route management

Error Handlers: Template Method

- Standard error handling flow

Other Frameworks

Django/Rails: MVC (obviously!)
Redux: Command (actions) + Observer (subscribers)
Angular: Dependency Injection built-in
Vue: Observer (reactivity system)

Summary: All 23 Patterns

Creational (5)

1. ✅ **Singleton** - One instance
2. ✅ **Factory Method** - Create without specifying class
3. ✅ **Abstract Factory** - Families of objects
4. ✅ **Builder** - Complex construction
5. ✅ **Prototype** - Clone objects

Structural (7)

1. ✅ **Adapter** - Convert interfaces
2. ✅ **Decorator** - Add responsibilities
3. ✅ **Facade** - Simplify subsystem
4. ✅ **Proxy** - Control access
5. Composite - Tree structures
6. Bridge - Decouple abstraction
7. Flyweight - Share objects

Behavioral (11)

1. ✅ **Observer** - 1-to-many notifications
2. ✅ **Strategy** - Interchangeable algorithms
3. ✅ **Template Method** - Workflow skeleton
4. ✅ **Command** - Encapsulate requests
5. ✅ **State** - Behavior changes with state
6. ✅ **Iterator** - Sequential access
7. ✅ **Chain of Responsibility** - Handler chain
8. Mediator - Centralize communication
9. Memento - Save/restore state
10. Visitor - Add operations to objects
11. Interpreter - Language grammar

We covered the most important 16!

Team Progress Reports

Thank You!

Contact Information

- **Email:** ekrem.cetinkaya@yildiz.edu.tr

- **Office Hours:** Tuesday 14:00-16:00 - Room F-B21
- **Book a slot before coming:** Booking Link
- **Course Repository:** GitHub

Recommended read

Design Patterns - https://refactoring.guru/design-patterns