Design Patterns

Contents

Notes and code is @ https://github.com/nishithjain/Creational_Design_Patterns

1. Introduction

- Design patterns are general, reusable solutions to common problems that occur in software design.
- They are not finished designs that can be directly converted into code but are templates that guide you in solving particular design issues.
- Design patterns capture best practices and proven strategies, making code more maintainable, flexible, and easier to understand.
- GOF – Gang of Four – 23 Design Patterns
- Why we need to learn?
    - Standard solution to common problems.
    - Common vocabulary across software industry.

Types of Object-Oriented Desing Patterns

Creational Design Pattern

- Deals with "How an object can be created"?
- Different ways of creating an object.
- How many objects can be created?

Structural Desing Pattern

- How a class will be structured?
- How should different classes relate to each other?
- What all the attributes and behavior will be there in a class (Interface or Abstract class)

Behavioral Design Pattern

- Deals with the methods.

2. Creational Design Patterns

- Here we will study
    - Singleton
    - Builder
    - Factory
        - Factory Method
        - Abstract Factor
        - Practical Factor
    - Prototype

Singleton Desing Pattern

- Singleton allows us to create a class for which a single object can be created.
- Some of the use cases of Singleton Desing Patterns are…
    - Configuration or Settings Manager:
        - When an application needs a single, centralized access point for configuration settings that are used across the system.
    - Logging Service:
        - Ensures that there is a single logging instance for the entire application to avoid multiple log files and to manage logging in a consistent way.
    - Database Connection Pool:
        - A singleton can manage a pool of database connections, ensuring controlled access and minimizing resource usage by reusing connections.
    - Thread Pool Manager:
        - Managing thread pools where you need a centralized object that manages the creation, reuse, and destruction of threads.
    - Resource Manager (e.g., Printer Spooler):
        - Managing access to a shared resource like a printer or file handler, ensuring that only one instance is coordinating resource usage.

Configuration Manager – Singleton

- A `Configuration Manager` (often referred to as a Configuration or Settings Manager) is a component in software systems that centralizes the management and access to configuration settings used throughout an application. It plays a crucial role in ensuring that various parts of an application have consistent and easy access to configuration data, which can include settings like:
    - Application settings (e.g., UI preferences, language, theme).
    - Database connection strings.
    - API keys and secrets.
    - Environment-specific settings (e.g., development, testing, production configurations).
    - Feature toggles (to enable/disable specific features dynamically).

- Let's build singleton `ConfigManager` `class` from basic.

```
class ConfigManager
{
    // Storage for settings
    std::unordered_map<std::string, std::string> settings_;
public:
    void setSetting(const std::string& key, const std::string& value);
    std::string getSetting(const std::string& key) const;
    void loadSettings();
};
```

- Is the `ConfigManager` `class` a Singleton?
    - No, because we can any number of objects of the `ConfigManager` `class`.
- Can we say, till the time the `class` has a public constructor, that `class` can never be a Singleton.
    - So, we can make the constructor `private`.

```
class ConfigManager
{
    // Storage for settings
    std::unordered_map<std::string, std::string> settings_;
    ConfigManager(); // Private constructor
public:
    void setSetting(const std::string& key, const std::string& value);
    std::string getSetting(const std::string& key) const;
    void loadSettings();
};
```

- If we make the constructor `private`, we **cannot create any objects**. But we can access the `private` things of a `class` inside the methods of the `class`. So, we can define a method inside the `ConfigManager` `class` which creates a `static` instance of itself.

```
class ConfigManager
{
    // Storage for settings
    std::unordered_map<std::string, std::string> settings_;
    ConfigManager(); // Private constructor
public:
    void setSetting(const std::string& key, const std::string& value);
    std::string getSetting(const std::string& key) const;
    void loadSettings();

    ConfigManager& getInstance()
    {
        static ConfigManager instance;
        return instance;
    }
};
```

- But to call `getInstance()` method, we need to create an object of the `class` `ConfigManager`. Since we cannot create an object because the constructor is `private`, we can make the method `getInstance()` `static`.

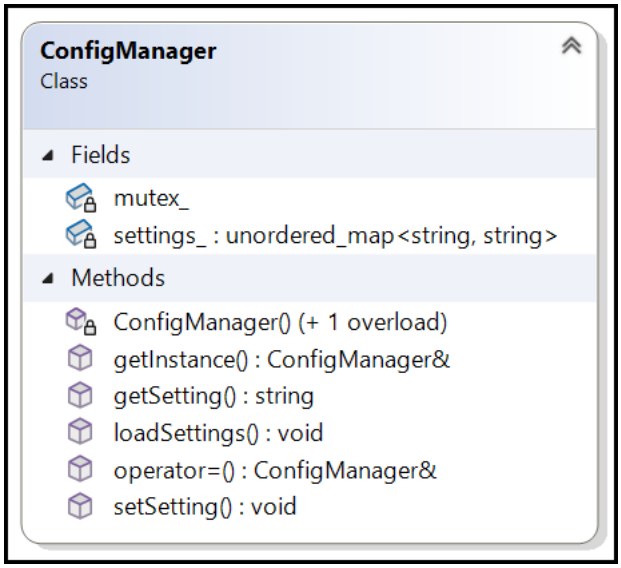
```
class ConfigManager
{
    // Storage for settings
    std::unordered_map<std::string, std::string> settings_;
    ConfigManager(); // Private constructor
public:
    void setSetting(const std::string& key, const std::string& value);
    std::string getSetting(const std::string& key) const;
    void loadSettings();

    static ConfigManager& getInstance()
    {
        static ConfigManager instance;
        return instance;
    }
};
```

- The `static` keyword ensures that the `ConfigManager instance` is initialized only once, even if the containing function `getInstance()` is called multiple times.
- The initialization happens the first time the control flow reaches the line containing the definition of `static ConfigManager instance` during the program's execution.
- Since C++11, the initialization of local `static` variables is guaranteed to be thread-safe, meaning that the initialization will be correctly synchronized if multiple threads try to access the `instance` simultaneously.
- `static ConfigManager instance` is initialized during program load because `static` local variables within functions are specifically designed to be initialized when the function is called, not before the program's execution begins.
- The `static` local variables are initialized at their first use during runtime.
- The `static` member variables and `static` global/namespace variables are initialized at program load time, before `main()` starts.
- We also need to `delete` copy constructor and assignment operator. If we don't delete them, we can do the following…

```
    ConfigManager config2 = config;  // This creates a new instance
    config2.show();

    // Assigning one instance to another
    ConfigManager config3 = ConfigManager::getInstance();
    config3 = config;  // This copies s1 to s3
    config3.show();
```

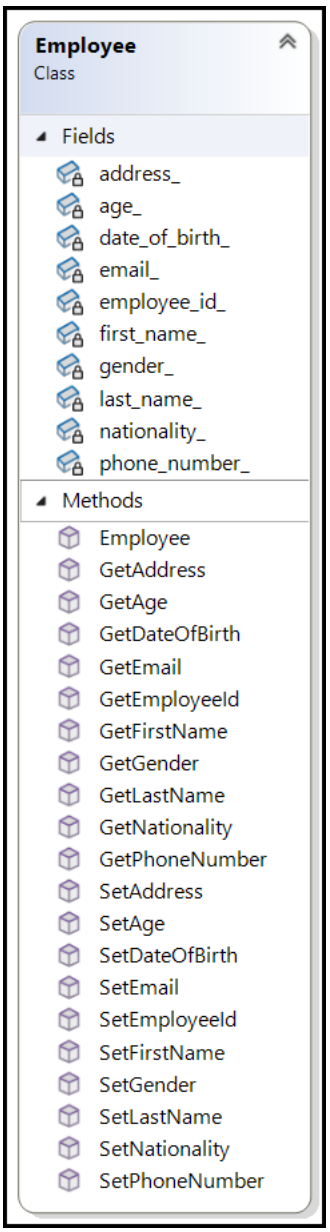
- The line `ConfigManager config2 = config;` uses the copy constructor to create a new instance `config2`. This instance is a separate object with the same state but a different memory address.
- The line `config3 = config;` uses the assignment operator to copy `config` into `config3`. Although `config3` already exists, it now contains the state of `config1`, making it another unwanted copy.

- Final `ConfigManager` Singleton is given below…




```cpp
class ConfigManager
{
    // Storage for settings
    std::unordered_map<std::string, std::string> settings_;
    ConfigManager();            // Private constructor
    mutable std::mutex mutex_;
public:
    // Delete copy constructor.
    ConfigManager(const ConfigManager&) = delete;
    // Delete assignment operator.
    ConfigManager& operator=(const ConfigManager&) = delete;
    static ConfigManager& getInstance(); // Static method.

    void setSetting(const std::string& key, const std::string& value);
    std::string getSetting(const std::string& key) const;
    void loadSettings();
};
ConfigManager& ConfigManager::getInstance()
{
    static ConfigManager instance;
    return instance;
}


ConfigManager::ConfigManager()
{
    loadSettings();
}

void ConfigManager::setSetting(const std::string& key, const std::string& value)
{
    std::lock_guard<std::mutex> lock(mutex_);
    settings_[key] = value;
    std::cout << "Setting updated: " << key << " = " << value << std::endl;
}
```

Builder Design Pattern



- Why do we need Builder Design Pattern?
  - Requirement 1: Imagine we have to design a `class Employee` with lot of attributes.
  - If we want to create an object of `Employee class` and set these attributes, we can do…

```
Employee st;
st.SetFirstName("Nishith");
st.SetLastName("Jain");
st.SetAge(42);
st.SetEmployeeId("ISICE035");
// We have to use all the setters.
```

  - Requirement 2: We want to validate the `Employee` object before creation.
    - We only want to create an `Employee` object if the first and last names are given.
    - We only want to create an `Employee` object if the age of the employee is > 21.
    - We only want to create an `Employee` object if a phone number is given.
    - We only want to create an `Employee` object if the nationality is Indian.
    - No object of the `Employee class` should be created until all the validation passes.
- Validation can be done inside the constructor. If validations are coming inside the constructor, then setters are needed.
- Constructor should take all the attribute values as parameter in order to validate the attributes as shown…

```
Employee(std::string employee_id, std::string first_name, std::string last_name,
         std::string date_of_birth, std::string gender, int age, std::string nationality,
         std::string address, std::string phone_number, std::string email)
    : employee_id_(std::move(employee_id)), first_name_(std::move(first_name)),
      last_name_(std::move(last_name)), date_of_birth_(std::move(date_of_birth)),
      gender_(std::move(gender)), age_(age),
      nationality_(std::move(nationality)), address_(std::move(address)),
      phone_number_(std::move(phone_number)), email_(std::move(email))
{
}
```

- This is not at all readable, difficult to understand, prone to error.
- During the creation, we might not have all the parameter values. There can be lot of overloaded constructors. Sometimes it is not possible to have few constructors.

```
Employee(std::string first_name, std::string last_name, std::string date_of_birth);
Employee(std::string first_name, std::string last_name, std::string employee_id);
// Error: Constructor already defined
```

- As per coding guidelines and best practices, a method or function should take fewer parameters to maintain readability, maintainability, and simplicity. The ideal range is 3 to 5 parameters, with a maximum of 7 parameters.

Towards Builder - Step 1

- So we can think of passing a `std::map<std::string, std::string>` as an argument.
- Reasons Not to Use `std::map` for Passing Multiple Parameters
  - Loss of Type Safety: When using a `std::map<std::string, std::string>` (or similar), all values are stored as `string`s, which leads to a loss of type safety.
  - Error-Prone: Key names in a `map` are usually hard-coded strings, leading to potential runtime errors if there are typos in the key names or if a key is missing.
  - Difficulty in Validation: Validating the input parameters (like checking if the `first_name` is given or the `age` is above 21) becomes more complex and less efficient when values are stored in a `map`. Each validation check involves extracting values from the `map` and handling potential errors, increasing code complexity.
  - Lack of Self-Documentation: Parameter names provide useful information about the data being passed to a function. Using a `std::map` obfuscates this intent, as it relies on arbitrary `string` keys that don't provide any compile-time checks.

Towards Builder - Step 2

- Instead of a `std::map`, we can create an `Helper class`, which has the same attributes as that of `Employee class`.

```
class Helper
{
public:
	std::string employee_id_;
	std::string first_name_;
	std::string last_name_;
	std::string date_of_birth_;
	std::string gender_;
	int age_ = 0;
	std::string nationality_;
	std::string address_;
	std::string phone_number_;
	std::string email_;
};
```

- We can set the values for all the parameters for this `Helper class` object.

```
int main() {
    Helper h;
    h.first_name_ = "Nishith";
    h.last_name_ = "Jain";
    h.age_ = 42;
    ...
    ...


    return 0;
}
```

- After setting the `Helper class` object, we can pass this object as parameter to the constructor of the `Employee class`.

```
class Employee
{
        // General Information
        std::string employee_id_;
        std::string first_name_;
        std::string last_name_;
        std::string date_of_birth_;
        std::string gender_;
        int age_ = 0;
        std::string nationality_;
        std::string address_;
        std::string phone_number_;
        std::string email_;

public:
        explicit Employee(const Helper& h);
};
```

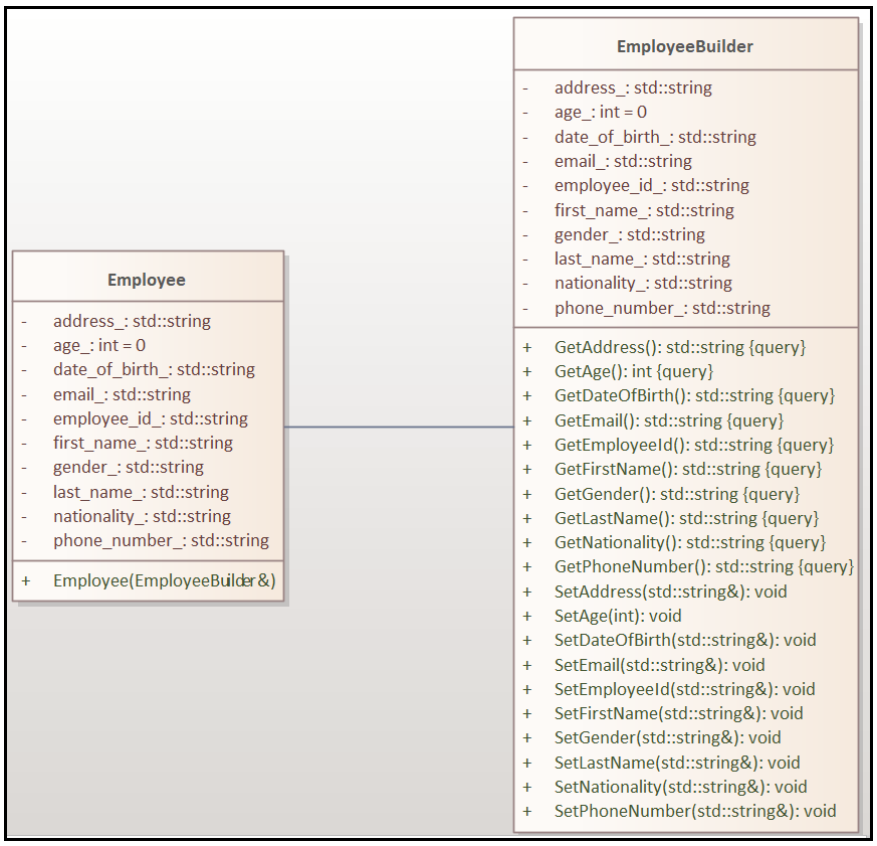
```
int main() {
    Helper h;
    h.first_name_ = "Nishith";
    h.last_name_ = "Jain";
    h.age_ = 42;
    ...
    ...



    Employee anEmployeeObj(h);

    return 0;
}
```

- In the constructor `Employee class`, we can do the validation of `Helper class` object, if the validation fails, we throw an exception. If validation passes, then we can create the `Employee` object.

```
class Employee {
	// General Information
	std::string employee_id_;
	std::string first_name_;
	std::string last_name_;
	std::string date_of_birth_;
	std::string gender_;
	int age_ = 0;
	std::string nationality_;
	std::string address_;
	std::string phone_number_;
	std::string email_;

public:
	explicit Employee(const Helper& h) {
		if (h.first_name_.empty() || h.last_name_.empty()) {
			throw std::invalid_argument("First and last names are required.");
		}
		if (age_ <= 21) {
			throw std::invalid_argument("Age must be greater than 21.");
		}
		if (phone_number_.empty()) {
			throw std::invalid_argument("Phone number is required.");
		}
		if (nationality_ != "Indian") {
			throw std::invalid_argument("Only Indian nationality is allowed.");
		}

		// After validation, we can create Employee object...
		this->first_name_ = h.first_name_;
		this->last_name_ = h.last_name_;
		...
		...

	}
};
```

Towards Builder - Step 3

- This `Helper class`, is called as Builder.
- Let's create a `EmployeeBulider class` from scratch. This `class` contains all the attributes of the `Employee class` and all the attributes are `private`.
- To set and get the attributes, we will have getters and setters.
- Now in the `Employee class`, we create a constructor that take `EmployeeBulider` object as parameter.




```cpp
class Employee
{
    std::string employee_id_;
    std::string first_name_;
    std::string last_name_;
    std::string date_of_birth_;
    std::string gender_;
    int age_ = 0;
    std::string nationality_;
    std::string address_;
    std::string phone_number_;
    std::string email_;

public:
    Employee(const
         EmployeeBuilder& emp_builder);
};
```

- We can create an object of `EmployeeBulider` and set all the values using setters.
- Then we can pass this `EmployeeBulider` object as the argument to the constructor while creating `Employee` object.

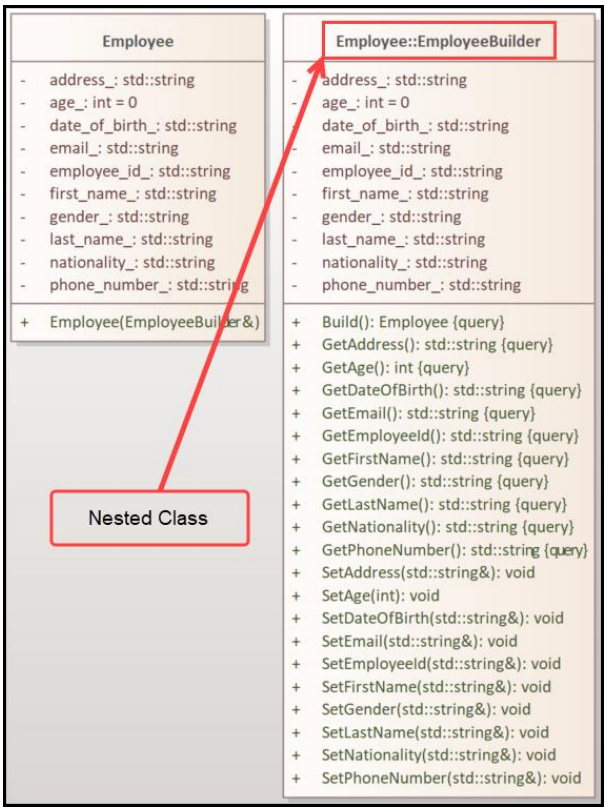
```cpp
int main() {
    EmployeeBuilder employee_builder;
    employee_builder.SetFirstName("Nishith");
    employee_builder.SetLastName("Jain");
    employee_builder.SetAge(42);
    employee_builder.SetPhoneNumber("1234567890");
    employee_builder.SetNationality("Indian");

    Employee anEmployeeObj(employee_builder);

    return 0;
}
```

- We do all the validations in the `Employee` constructor. If the validation fails, we `throw` an exception or else we create `Employee` object!

```cpp
Employee::Employee(const EmployeeBuilder& emp_builder)
{
	if (emp_builder.GetFirstName().empty() || emp_builder.GetLastName().empty())
	{
		throw std::invalid_argument("First and last names are required.");
	}
	if (emp_builder.GetAge() <= 21) {
		throw std::invalid_argument("Age must be greater than 21.");
	}
	if (emp_builder.GetPhoneNumber().empty()) {
		throw std::invalid_argument("Phone number is required.");
	}
	if (emp_builder.GetNationality() != "Indian") {
		throw std::invalid_argument("Only Indian nationality is allowed.");
	}

	// After validation, we can create Employee object...
	this->first_name_ = emp_builder.GetFirstName();
	this->last_name_ = emp_builder.GetLastName();

}
```

Towards Builder - Step 4

- What other enhancements we can make to this code so that the code is more readable, maintainable and production ready?
- We can make the `EmployeeBuilder class` is nested within the `Employee class` to encapsulate the building logic tightly within the `Employee class` itself. This encapsulation provides the following benefits:
    - **Scoping**: The `EmployeeBuilder class` is directly tied to the `Employee class`, which makes it clear that its sole purpose is to construct `Employee` objects.
    - **Access**: The nested `class` can access `private` members of the `Employee class`, which can simplify the building process.
    - **Readability and Organization**: Nesting the `EmployeeBuilder class` keeps related code together, which can improve readability and make the code easier to maintain.



- First, we create the `EmployeeBuilder` object and then we set the values using the setters.
- Once all the values are set, then we can pass this `EmployeeBuilder` object to `Employee` constructor to create `Employee` object.

```
auto builder = Employee::EmployeeBuilder();
builder.SetFirstName("Nishith");
builder.SetLastName("Jain");
...
...

Employee emp(builder);
```

Towards Builder - Step 5

- First, we accumulate the necessary data in a flexible, readable manner by **method chaining**. This can be achieved by returning `*this`. For example…

Before:

```
void Employee::EmployeeBuilder::SetEmployeeId(const std::string& employee_id)
{
	employee_id_ = employee_id;
}
```

After:

```
Employee::EmployeeBuilder& Employee::EmployeeBuilder::SetEmployeeId(const std::string& employee_id)
{
	employee_id_ = employee_id;
	return *this;
}
```

- **Setter Methods Return** `EmployeeBuilder&`:
  - Each **setter** method in the `EmployeeBuilder` `class` `return`s a reference to the `EmployeeBuilder` object itself (`EmployeeBuilder&`).
- Chaining in Action:
  - When we call a setter, like `SetAddress`, it modifies the internal state of the `EmployeeBuilder` and then `return`s the current `EmployeeBuilder` instance, allowing another setter to be called immediately. For example…

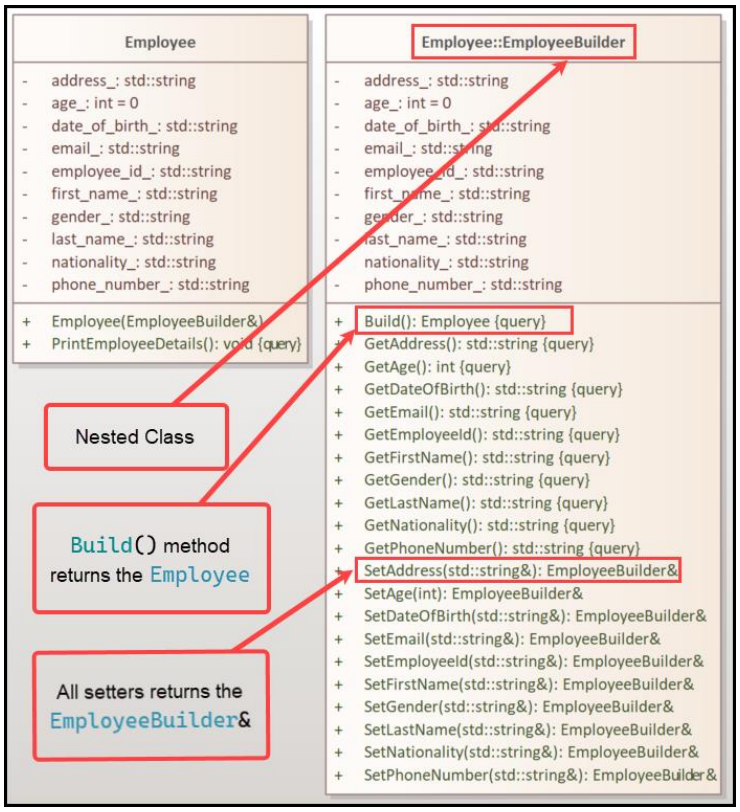
```
const auto builder = Employee::EmployeeBuilder().
	SetFirstName("Nishith").
	SetLastName("Jain").
	SetAge(42).
	SetDateOfBirth("09-May-1982");
```

- Now we have the `EmployeeBuilder` object with all the data which will be used in the construction of the `Employee` object.

- We can expose a `Build()` method in the `EmployeeBuilder` that directly creates and `return`s an `Employee` object. This approach eliminates the need to create an `EmployeeBuilder` object separately and avoids passing it to the `Employee` constructor manually.

```
Employee Employee::EmployeeBuilder::Build() const
{
	return Employee(*this);
}
```

- From the client code perspective, the `Build()` method provides a clean, understandable way to finalize the object creation without directly calling a constructor.




```
int main() {
    Employee employee = Employee::EmployeeBuilder()
        .SetEmployeeId("E12345")
        .SetFirstName("Nishith")
        .SetLastName("Jain")
        .SetDateOfBirth("09-May-1982")
        .SetGender("Male")
        .SetAge(42)
        .SetNationality("Indian")
        .SetAddress("G236, Brigade Northridge")
        .SetPhoneNumber("+919876543210")
        .SetEmail("nishith.jain@example.com")
        .Build();

    employee.PrintEmployeeDetails();

       return 0;
}
```

Click how to open file.

Employee.h Employee.cpp Source.cpp

Prototype Design Pattern

Problem statement: Given an object of a `class`, we need to create a copy of that object with same attributes.

Example: We have an object of `Player` `class`, we need to create a copy of that object.

Towards Prototype - Step 1

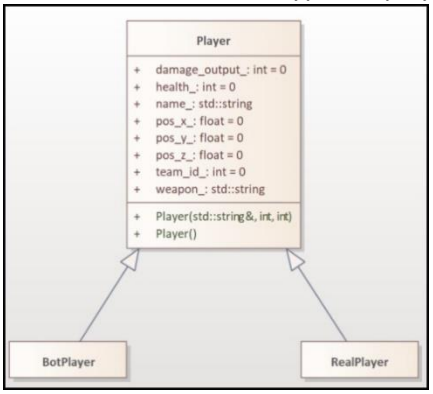
- We can do a member wise copy.

```
Player player("DefaultPlayer", 101, 1000);
Player playerCopy;

playerCopy.name_ = "SoleMortal";
playerCopy.health_ = player.health_;
playerCopy.damage_output_ = player.damage_output_;
```

- What is the disadvantage of doing this way…
  - Some fields in the `Player` `class` can be `private`, hence cannot be copied.
  - Client needs to know the implementation details of the `Player` `class` to copy so that client won't miss any attributes while copying.

Towards Prototype - Step 2

- There can be 2 types of players, `BotPlayer` and `RealPlayer`.



- If we are creating a copy, from pointer to base `class` `Player` and object from which we are copying can be a `Player` or `BotPlayer` or `RealPlayer`, then the copy should also be of the respective type.
- Not a good approach.

```
const auto player = make_unique<Player>();
std::unique_ptr<Player> playerCopy;

if (dynamic_cast<BotPlayer*>(player.get())) {
    playerCopy = std::make_unique<BotPlayer>(*dynamic_cast<BotPlayer*>(player.get()));
}
else if (dynamic_cast<RealPlayer*>(player.get())) {
    playerCopy = std::make_unique<RealPlayer>(*dynamic_cast<RealPlayer*>(player.get()));
}
else if (player) {
    playerCopy = std::make_unique<Player>();
}
else {
    std::cout << "Unknown Player Type!\n";
}
```

Towards Prototype - Step 3

- Let's try to use copy constructor.

```
class BotPlayer : public Player
{
	int difficulty_level_ = 0;
public:
	// Copy constructor
	BotPlayer(const BotPlayer& other)
		: Player(other), difficulty_level_(other.difficulty_level_)
	{
	}

};

class RealPlayer : public Player
{
	int experience_points_ = 0;
public:
	// Copy constructor
	RealPlayer(const RealPlayer& other)
		: Player(other), experience_points_(other.experience_points_)
	{
	}
};
```

- Copy constructors are not polymorphic and cannot be used on base `class` pointers to create copies of derived `class` objects. Attempting to use a base `class` copy constructor would result in slicing, where derived `class`-specific data is lost.
- So, we have to use `if-else` to check the type and create a copy…

```
std::unique_ptr<Player> player = std::make_unique<BotPlayer>("Bot1", 1, 2);

std::unique_ptr<Player> playerCopy;

// Determine the type of player and copy accordingly using copy constructors
if (const auto botPlayer = dynamic_cast<BotPlayer*>(player.get())) {
    // If player is of type BotPlayer, copy as BotPlayer
    playerCopy = std::make_unique<BotPlayer>(*botPlayer);
}
else if (const auto realPlayer = dynamic_cast<RealPlayer*>(player.get())) {
    // If player is of type RealPlayer, copy as RealPlayer
    playerCopy = std::make_unique<RealPlayer>(*realPlayer);
}
else if (auto basePlayer = dynamic_cast<Player*>(player.get())) {
    // If player is of type Player, copy as Player
    playerCopy = std::make_unique<Player>(*basePlayer);
}
else {
    std::cout << "Unknown Player Type!" << std::endl;
}
```

- This approach is also not good.

Towards Prototype - Step 4

- Let's outsource the work of creating copy/clone so that client need not worry about all these issues.
- For example, if client wants to create a copy/clone of `Player`, it will simply call a method on the object.
- Irrespective of the type of `Player` (`Player`, `BotPlayer`, `RealPlayer`)copy/clone of the object is created.

```
// Create different types of players
std::unique_ptr<Player> player1 = std::make_unique<BotPlayer>("Bot1", 2);
std::unique_ptr<Player> player2 = std::make_unique<RealPlayer>("Player1", 1500);

// Copying the players
std::unique_ptr<Player> playerCopy1 = player1->clone(); // Copy of BotPlayer
std::unique_ptr<Player> playerCopy2 = player2->clone(); // Copy of RealPlayer
```

- To achieve this, we need to define `virtual clone()` method in base `Player class`.

```
class Player
{
protected:
    std::string name_;
    int health_ = 0;
    int team_id_ = 0;
    float pos_x_ = 0;
    float pos_y_ = 0;
    float pos_z_ = 0;
    std::string weapon_;
    int damage_output_ = 0;
public:
    Player() = default;
    virtual ~Player() = default;
    virtual std::unique_ptr<Player> clone() const = 0;
};
```

- Each derived class (`BotPlayer`, `RealPlayer`) implements the `clone()` method, which `return`s a `std::make_unique` of the correct type by using `std::make_unique<T>(*this)`, ensuring a deep copy is made.

```
std::unique_ptr<Player> BotPlayer::clone() const
{
        return std::make_unique<BotPlayer>(*this);
}
```

- The above code calls the copy constructor…
    - The expression `*this` is passed as an argument to `std::make_unique<BotPlayer>`.
    - Internally, `std::make_unique<BotPlayer>` forwards the arguments (`*this` in this case) to the constructor of `BotPlayer`.

- Since `*this` is an instance of `BotPlayer`, the compiler looks for the `BotPlayer` constructor that matches the parameter type.
- In this case, `BotPlayer(const BotPlayer& other)` (the copy constructor) is a match, so it gets called.

- If we are taking this approach, we have to **make sure all the child `classes` `override` the `clone()` method**.

Registry Design Pattern

Problem statement: Given an application that manages **multiple intern batches** (one inter batch can have 100s of intern objects) each with distinct batch-specific(there are many such batches) attributes, we need a mechanism to create intern objects dynamically based on different batch.

- Prototype Design Pattern:
  - Creating Intern Objects: The Prototype Pattern is used to create new intern objects by cloning existing prototypes. Each batch of interns can be represented as a prototype, allowing you to efficiently create new instances of interns based on these prototypes.
- Registry Design Pattern:
  - Based on Batches: The Registry Pattern is employed to manage these prototypes. It provides a centralized mechanism (the registry) for storing and retrieving prototypes based on batch identifiers or keys. This allows you to dynamically access and clone prototypes for different intern batches without having to hardcode the creation logic.
- As per the problem statement, there are many batches. Each batch has a prototype.
- Example, for the batch "`January 2024`", we can create a prototype…

```
auto prototype_jan_2024 = std::make_unique<Intern>("January 2024", "2024-01-01",
    "2024-06-30", "6 months", "Location A");
```

- For the batch "`February 2024`", we create a prototype…

```
auto prototype_feb_2024 = std::make_unique<Intern>("February 2024", "2024-02-01",
    "2024-07-31", "6 months", "Location B");
```

- Using these prototypes we create hundreds of objects.

```
// This will create an inter object for the batch Jan 2024
auto intern_jan_2024 = prototype_jan_2024->clone();
// This will create an inter object for the batch Feb 2024
auto intern_feb_2024 = prototype_feb_2024->clone();
```

- To create hundreds of objects during runtime based on the batch, we need to store prototypes in a map which acts as a registry and retrieve it based on batch. Batch is the key.

```
std::unordered_map<std::string, std::unique_ptr<Intern>> registry_;
```

- We can have a `class` that serves as a centralized registry to store and manage different `Intern` prototypes. We can call it `InternRegistry`.
- To store the prototype, we can expose a method `RegisterIntern()` which takes batch and prototype as parameters.

```
void RegisterIntern(const std::string& key, std::unique_ptr<Intern> prototype);
```

- To store the prototype, we can expose a method `RegisterIntern()` which takes batch and prototype as parameters.
- We can expose a methos `CreateIntern()` which creates new `Intern` object by cloning a registered prototype based on the provided key.

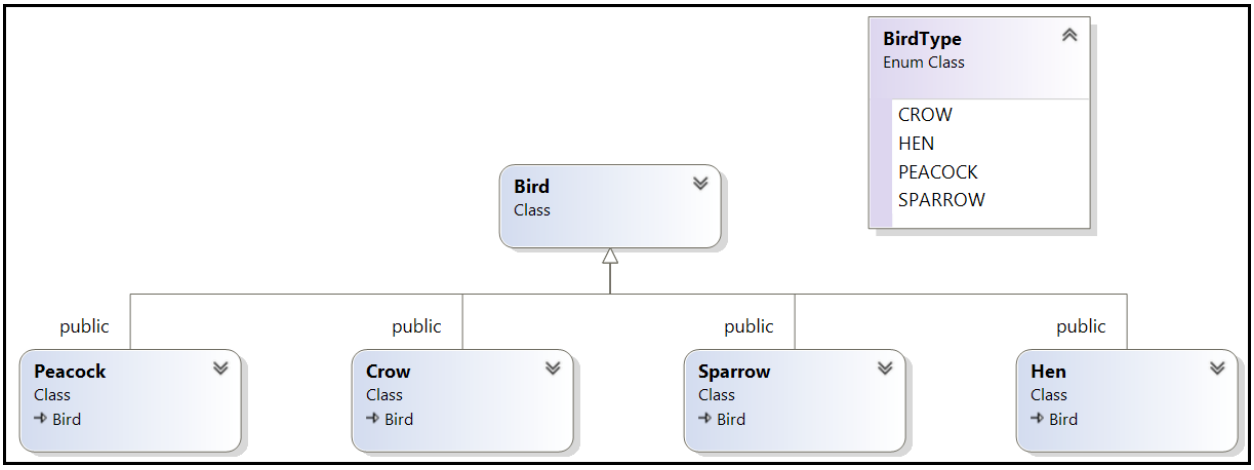
```
std::unique_ptr<Intern> CreateIntern(const std::string& key) const;
```

- This is the Registry Design Pattern. In this example, the Registry Design Pattern is used to manage the creation of `Intern` objects based on different batches, such as "Jan2024" and "Feb2024".

```
int main()
{
    InternRegistry registry;

    // Registering January 2024 batch prototype
    registry.RegisterIntern("Jan2024", std::make_unique<Intern>(
        "January 2024", "2024-01-01", "2024-06-30", "6 months", "Location A"));

    // Registering February 2024 batch prototype
    registry.RegisterIntern("Feb2024", std::make_unique<Intern>(
        "February 2024", "2024-02-01", "2024-07-31", "6 months", "Location B"));

    if (const auto intern1 = registry.CreateIntern("Jan2024")) {
        intern1->SetName("Alice");
        intern1->SetAge(22);
        intern1->SetUniversity("XYZ University");
        intern1->SetGender("Female");
        intern1->SetPhoneNumber("1234567890");
        intern1->SetEmail("alice@example.com");
        intern1->Display();
    }

    if (const auto intern2 = registry.CreateIntern("Feb2024")) {
        intern2->SetName("Bob");
        intern2->SetAge(23);
        intern2->SetUniversity("ABC University");
        intern2->SetGender("Male");
        intern2->SetPhoneNumber("0987654321");
        intern2->SetEmail("bob@example.com");
        intern2->Display();
    }

      return 0;
}
```

Practical/Static/Simple Factory

- Not considered a formal pattern by some, but commonly used.
- This pattern moves the responsibility of creating object of corresponding `class` from the client code to the factory `class`.
- Imagine, we have a `Bird` `class` and `Crow`, `Hen`, `Peacock` and `Sparrow` inherit from this `Bird` `class` as shown below.



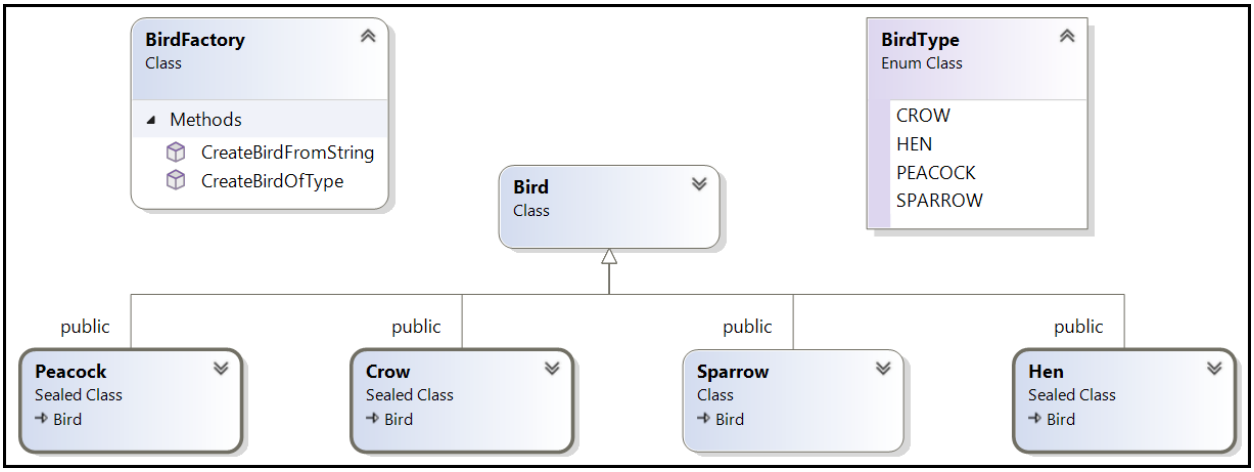
- In the client, we have to create concrete birds based on the `BirdType`. So, we can write…

```
int main()
{
	unique_ptr<Bird> bird;

	if(const auto birdType = GetIndianBirdType(); birdType == BirdType::CROW)
	{
		bird = make_unique<Crow>();
	}
	else if(birdType == BirdType::HEN)
	{
		bird = make_unique<Hen>();
	}
	else if(birdType == BirdType::PEACOCK)
	{
		bird = make_unique<Peacock>();
	}
	else if (birdType == BirdType::SPARROW)
	{
		bird = make_unique<Sparrow>();
	}

	bird->MakeSound();

	return 0;
}
```

- The above code even though works, it is bad code…

- **Violation of the Open/Closed Principle**: This code is not easily extendable. If a new `BirdType` is introduced, you must modify the `main()` function to add another `else if` condition.
- **High Coupling**: The `main()` function is tightly coupled with the specific bird `class`es (`Crow`, `Hen`, `Peacock`, `Sparrow`). If the `class` names, constructors, or other details change, you'll need to update this section of the code.
- **Hard to Unit Test:** Testing the object creation logic requires setting up the entire `main()` function environment.

- To address these issues, we can encapsulate the object creation logic into a separate `function` or `class`, making our code cleaner, more maintainable, and easier to extend. Let's call this `class` as `BirdFactory` which implements a `static` function.




```
class BirdFactory
{
public:
	static std::unique_ptr<Bird> CreateBirdOfType(BirdType bird_type);
	static std::unique_ptr<Bird> CreateBirdFromString(const std::string& bird_type);
};

std::unique_ptr<Bird> BirdFactory::CreateBirdOfType(const BirdType bird_type)
{
	switch (bird_type)
	{
	case BirdType::CROW:
		return std::make_unique<Crow>();
	case BirdType::HEN:
		return std::make_unique<Hen>();
	case BirdType::PEACOCK:
		return std::make_unique<Peacock>();
	case BirdType::SPARROW:
		return std::make_unique<Sparrow>();
	default:
		return nullptr;
	}
}
```

```
std::unique_ptr<Bird> BirdFactory::CreateBirdFromString(const std::string& bird_type)
{
	const std::string lowerBirdType = ToLower(bird_type);
	if (lowerBirdType == "crow") {
		return std::make_unique<Crow>();
	}
	if (lowerBirdType == "hen") {
		return std::make_unique<Hen>();
	}
	if (lowerBirdType == "peacock") {
		return std::make_unique<Peacock>();
	}
	if (lowerBirdType == "sparrow") {
		return std::make_unique<Sparrow>();
	}
	std::cerr << "Unknown bird type: " << bird_type << '\n';
	return nullptr;
}


BirdType GetIndianBirdType()
{
	// Some logic for getting Indian Bird from BirdType
	return BirdType::PEACOCK;
}

int main()
{
	const unique_ptr<Bird> bird = BirdFactory::CreateBirdOfType(GetIndianBirdType());
	bird->MakeSound();

	return 0;
}
```

- Advantages of Using the Factory Function
  - **Simplifies the main function**: The main logic is now simple and focused only on invoking the factory and using the created object.
  - **Centralized Object Creation**: All instantiation logic is centralized in the factory function, making it easier to manage.
  - **Scalability**: To add a new bird type, you only need to add a new case in the factory function without modifying any client code.

Factory Method Desing Pattern

- The Factory Method pattern defines an interface (Behavior) for creating objects but allows subclasses to alter the type of objects that will be created.

Requirement: Imagine a scenario where we are developing a game that needs to handle different types of vehicles, such as Car, Buggy, Monster Truck, Dacia, Motorcycle etc...

- First let's define common interface or base `class` for all `Vehicle` types.

```
class Vehicle {
public:
    virtual ~Vehicle() = default;
    virtual void Drive() const = 0;
};
```

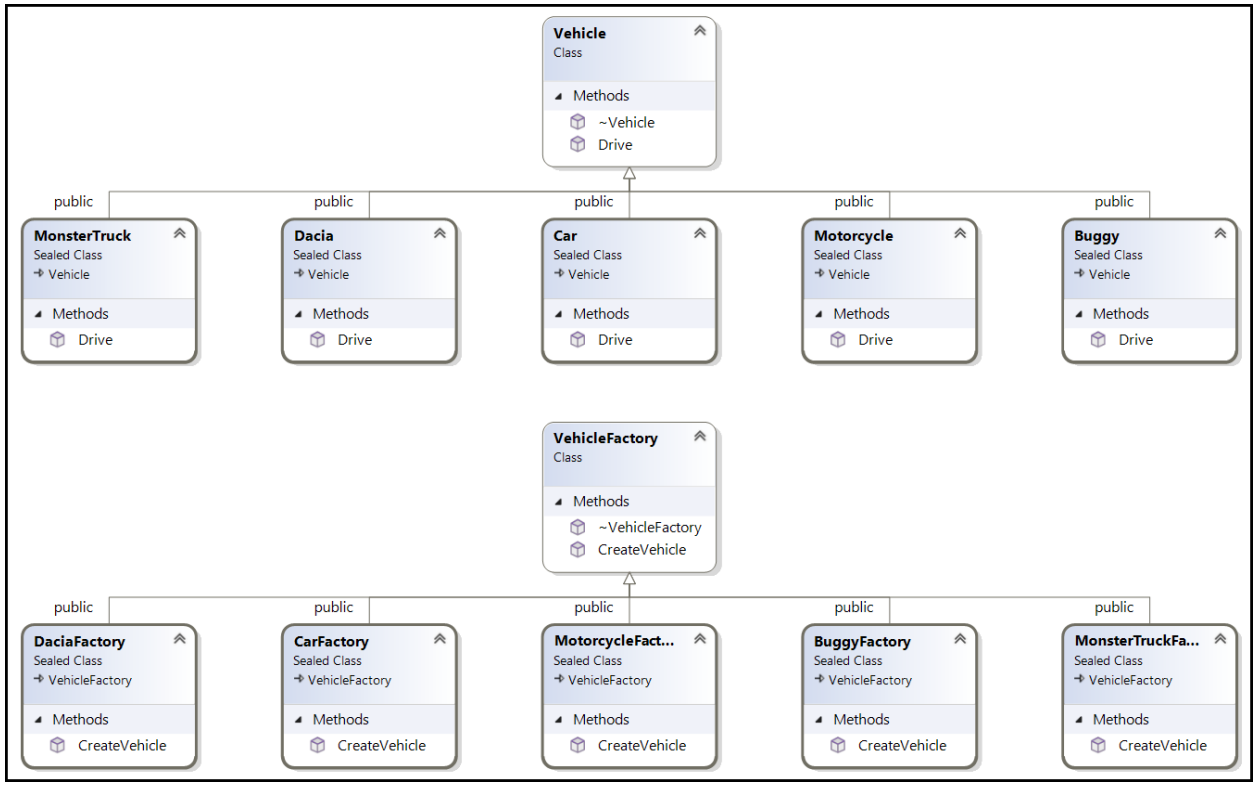
- Each concrete vehicle (`Car`, `Buggy`, `MonsterTruck`, `Dacia`, `Motorcycle`) `class` implements the common interface.

```
class Car final : public Vehicle {
public:
    void Drive() const override;
};

class Buggy final : public Vehicle {
public:
    void Drive() const override;
};

class MonsterTruck final : public Vehicle
{
public:
    void Drive() const override;
};

class Dacia final : public Vehicle {
public:
    void Drive() const override;
};

class Motorcycle final : public Vehicle {
public:
    void Drive() const override;
};
```

- We declare the factory method `CreateVehicle()` in the abstract `VehicleFactory` `class`.

```
class VehicleFactory {
public:
    virtual ~VehicleFactory() = default;
    // The Factory Method that subclasses will override
    // to create specific vehicles.
    virtual std::unique_ptr<Vehicle> CreateVehicle() const = 0;
};
```

- The subclasses of `VehicleFactory` (such as `CarFactory`, `BuggyFactory`, `DaciaFactory`, `MonsterTruckFactory`, and `MotorcycleFactory`) override this `CreateVehicle()` method. These subclasses are responsible for the creation of specific objects (`Car`, `Buggy`, `MonsterTruck`, `Dacia`, `Motorcycle`) by implementing the `CreateVehicle()` method according to their respective types.




```cpp
class CarFactory : public VehicleFactory {
public:
    std::unique_ptr<Vehicle> CreateVehicle() const override {
        return std::make_unique<Car>();
    }
};

class BuggyFactory : public VehicleFactory {
public:
    std::unique_ptr<Vehicle> CreateVehicle() const override {
        return std::make_unique<Buggy>();
    }
};

class MonsterTruckFactory : public VehicleFactory {
public:
    std::unique_ptr<Vehicle> CreateVehicle() const override {
        return std::make_unique<MonsterTruck>();
    }
};
```

```
class DaciaFactory : public VehicleFactory {
public:
    std::unique_ptr<Vehicle> CreateVehicle() const override {
        return std::make_unique<Dacia>();
    }
};

class MotorcycleFactory : public VehicleFactory {
public:
    std::unique_ptr<Vehicle> CreateVehicle() const override {
        return std::make_unique<Motorcycle>();
    }
};
```

- The client who wants to create an object (Car, Buggy, etc.) and use that object uses `VehicleFactory`.
- In our example shown below, the `CreateAndDriveVehicle()` function receives a reference to a `VehicleFactory` object, which could be any subclass of `VehicleFactory` (e.g., `CarFactory`, `BuggyFactory`).
- It calls `CreateVehicle()` on this factory object, which returns a `std::unique_ptr<Vehicle>`. The specific type of vehicle (`Car`, `Buggy`, etc.) is determined by the factory, not by the client.
- The client code then calls `Drive()` on the vehicle object, demonstrating that it doesn't need to know the specifics of the vehicle's instantiation—only how to use it via the common Vehicle interface.

```
void CreateAndDriveVehicle(const VehicleFactory& factory) {
    // Create the vehicle using the factory method
    const auto vehicle = factory.CreateVehicle();
    vehicle->Drive();
}

int main() {
    const CarFactory carFactory;
    const BuggyFactory buggyFactory;
    const MonsterTruckFactory monsterTruckFactory;
    const DaciaFactory daciaFactory;
    const MotorcycleFactory motorcycleFactory;

    CreateAndDriveVehicle(carFactory);
    CreateAndDriveVehicle(buggyFactory);
    CreateAndDriveVehicle(monsterTruckFactory);
    CreateAndDriveVehicle(daciaFactory);
    CreateAndDriveVehicle(motorcycleFactory);

    return 0;
}
```

- Benefits of Using the Factory Method Here
    - **Scalability**: New vehicle types can be added easily by creating a new vehicle and a corresponding factory class without modifying existing code. If a new vehicle type (e.g., `Truck`) is introduced, you only need to add a new subclass (`TruckFactory`) implementing

the `CreateVehicle()` method. The client code remains the same, making the system more maintainable.

- **Encapsulation of Creation Logic**: The creation logic for each vehicle type is encapsulated within its respective factory class, making the codebase more organized and maintainable.
- **Loose Coupling**: The client code remains decoupled from the specific vehicle implementations, making it more flexible and easier to maintain. Each class has a single responsibility: the factories handle object creation, while the client code handles object usage.

Abstract Factory Desing Pattern

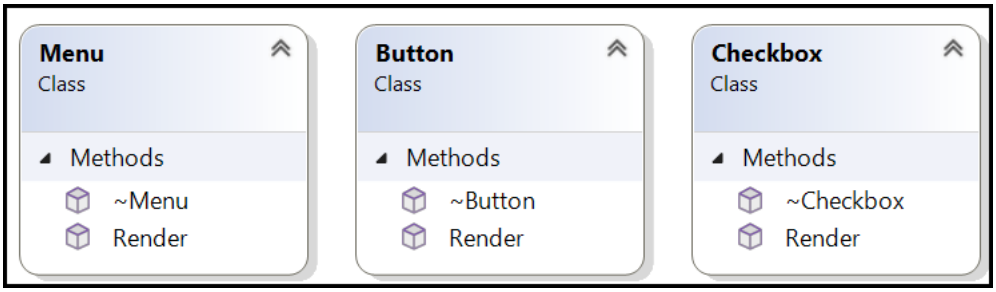
- A super-factory that creates other factories.
- It typically involves multiple factory methods for creating a variety of related objects, which are all part of a family.

Problem Statement:

- You are developing a cross-platform Graphical User Interface (GUI) library that needs to support different operating systems such as **Windows**, **Mac** and **Linux**.
- The library includes common UI components like **buttons**, **checkboxes**, and **menus**, but each platform has a unique way of rendering these components to match the native look and feel of the operating system.
- Your goal is to create a system that can dynamically create and render UI components suitable for the target platform without changing the client code that uses these components.

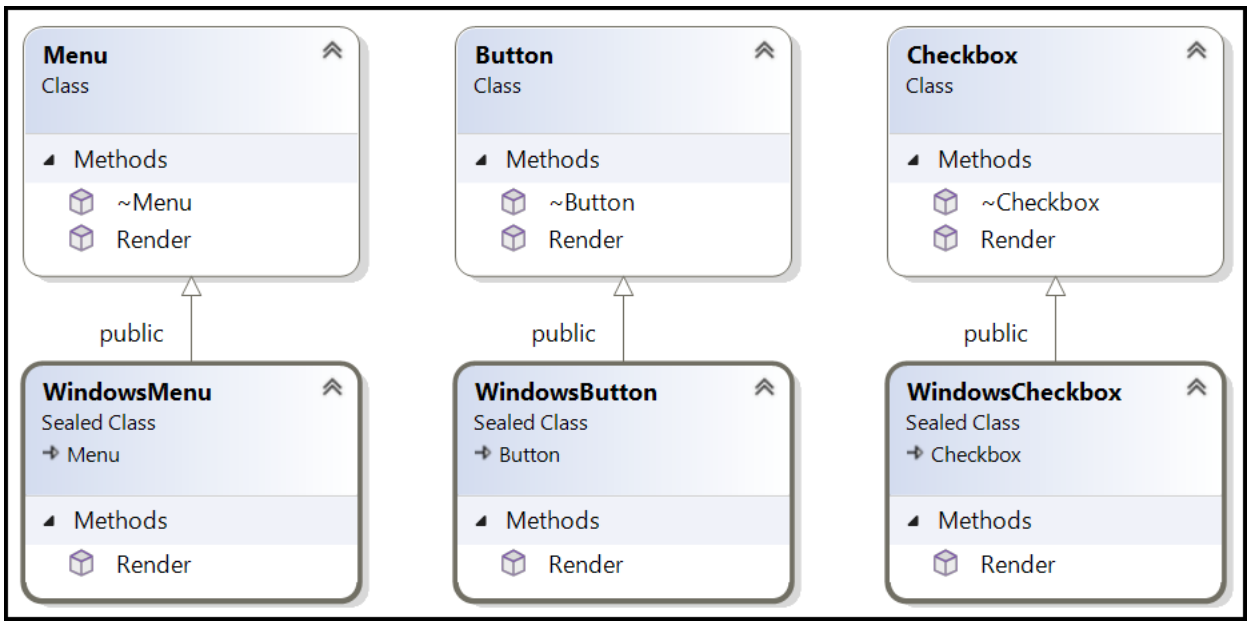
Solution:

- We have 3 products at this time (Products can be added later also) which are `Buttons`, `Checkboxes`, and `Menus`. These can be treated as abstract products.




```cpp
class Button {
public:
    virtual ~Button() = default;
    virtual void Render() const = 0;
};

class Checkbox {
public:
    virtual ~Checkbox() = default;
    virtual void Render() const = 0;
};

class Menu {
public:
    virtual ~Menu() = default;
    virtual void Render() const = 0;
};
```

- Windows has `Buttons`, `Checkboxes`, and `Menus`. So, it inherits all these abstract classes and implements `WindowsButton`, `WindowsCheckbox`, and `WindowsMenu`.




```
void WindowsButton::Render() const
{
	std::cout << "Rendering Windows Button\n";
}

void WindowsCheckbox::Render() const
{
	std::cout << "Rendering Windows Checkbox\n";
}

void WindowsMenu::Render() const
{
	std::cout << "Rendering Windows Menu\n";
}
```

- Similarly, Max also inherits for the `Buttons`, `Checkboxes`, and `Menus` classes and implements `MacButton`, `MaxCheckbox`, and `MacMenu`.
- Similarly, Linux also inherits for the `Buttons`, `Checkboxes`, and `Menus` classes and implements `LinuxButton`, `LinuxCheckbox`, and Linux`Menu`.

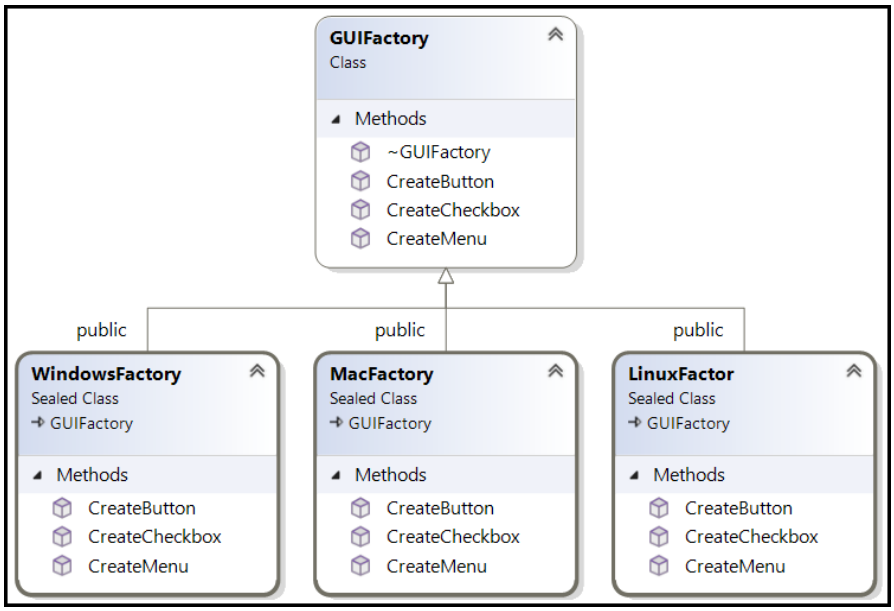
- Now we create an abstract factory. An interface that declares methods to create **families** of **components**.

```
class GUIFactory {
public:
    virtual ~GUIFactory() = default;
    virtual std::unique_ptr<Button> CreateButton() const = 0;
    virtual std::unique_ptr<Checkbox> CreateCheckbox() const = 0;
    virtual std::unique_ptr<Menu> CreateMenu() const = 0;
};
```

  - **Components** refer to the individual products or objects that the factory creates. `Buttons`, `Checkboxes`, and `Menus`. Each component typically has an abstract base class (or interface) that defines its common behavior (e.g., `Render()`).

- **Families** refer to groups of related components that are designed to work together within the same context, such as a specific operating system or platform.
- Windows family include, `WindowsButton`, `WindowsCheckbox` and `WindowsMenu`.
- `CreateButton()`: A method that creates a `Button` component specific to the family (e.g., `WindowsButton` or `LinuxButton`).
- `CreateCheckbox()`: A method that creates a `Checkbox` component specific to the family (e.g., `WindowsCheckbox` or `LinuxCheckbox`).
- `CreateMenu()`: A method that creates a `Menu` component specific to the family (e.g., `WindowsMenu` or `LinuxMenu`).

- We implement 3 concrete factories from this abstract factory namely `WindowsFactory`, `MacFactory` and `LinuxFactor`. These factories implement the `GUIFactory` interface and ensure that all created components (`Button`, `Checkbox`, `Menu`) belong to the same family (Windows or Mac or Linux).



- Imagine an application needs to render a user interface. The client code requests the components from a specific factory without knowing which concrete implementation is being used.

```
void RenderUI(const GUIFactory& factory) {
    const auto button = factory.CreateButton();
    const auto checkbox = factory.CreateCheckbox();
    const auto menu = factory.CreateMenu();

    button->Render();
    checkbox->Render();
    menu->Render();
}
```

- If we pass, `WindowsFactory` object to the `RenderUI()` method, it would render Windows specific button, checkbox and menu.

```
int main() {
	// Create Windows UI
	const std::unique_ptr<GUIFactory> factory =
		std::make_unique<WindowsFactory>();
	RenderUI(*factory);

	return 0;
}
/*
Rendering Windows Button
Rendering Windows Checkbox
Rendering Windows Menu
 */
```

Visual Studio 2022 Solution File