Exploration of Design Patterns in Game Development

Technical Work Term Report (Work Term 3)

APSC 310

University of British Columbia

Muchen He

Associate Developer, BioWare Edmonton

Student Number: 44638154

December 10, 2018

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Preface & Foreword

Purpose

The purpose of this report is to explore and observer different kinds of theoretical methods nad patterns and how they're used ot develop components that make up a game.

As well to consolidate my knowledge as a whole in the industry as design patterns are software development concepts and potentially applicable elsewhere in the tech industry.

Background

(Working at EA-Bioware) (Associate Developer (Programmer) for game Anthem) (Using modern game engine Frostbite)

Scope of Coverage

(The scope of this report)(Covers many design patterns outlined in "Gang of Four")(Will not cover detailed breakdown, explaination, and specification of existing proprietary tech; i.e. extended code from the game or Frostbite engine)

The technical coverage cited in this report is limited because the co-op work term position is working in UI/UX. Thus I lack understanding in other areas of the game such as character handling, world rendering, etc. Many of the workflows I describe in this report may only apply to UI/UX development within this project.

As the scope of game development or software development extends wide in breadth, this report will not throughly cover topics of object oriented programming, development methodologies, specific syntax in a programming language, specific implementations of algorithms in a programming language, and psychology of UI/UX.

Contributors

(Tim Gibson - senior software lead, manager: contribution by supervising the report and giving advice) (Chris Johnson)

Summary

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1   Introduction

This enters the discussion portion of the report. We will analyze the current processes in game development for UI/UX at BioWare. Then look at some of the more theoretical, templated solutions known as design patterns in later sections and draw comparisons. We will also look into how the design patterns would be used in a general sense in game development (not specific to BioWare or Bioware's current project, Anthem).

1.1   Game Development Overview

A major portion of the video game market consists of AAA video games. These are titles with very high production value, large budget, and typically consists of a team of hundreds of developers. These developers consist of artists, scripters, programmers, managers, etc. Many of these roles are further grouped into sub-teams such as rendering, physics/simulation, AI, UI/UX, sound design, music production, networking, etc. Individual developers are specialized to work on one part of the game, with the exception of leads, managers, and other executives.

1.1.1   Game Engine

Developers will use a game engine so that many people can work on the project at once. The game engine is generally highly optimized for graphics rendering, physics simulation (such as collision detection), and object handling.

The Frostbite engine is the game engine widely adoped at Electronic Arts (EA) studios. It was originally developed by Digital Illusions CE (DICE).[23] As expected, the game engine is a piece of software, thus it is prone to software development problems that design patterns are ought to solve.

1.2   Game Building

Programmers make primitive entities such as an abstract UI widget, as well as the system that manages these entities.

The scripters and artists then use these entities in *schematics* or *blueprints*, which are used for visual scripting blocks of game content that contains logic and input/output together. Figure 1 shows an example of what it looks like.

These schematics are in game levels, UI widgets, and

prefabricated logic blocks (LogicPrefab). Thousands of these make up functionalities in a game, and are all handled by the game engine.
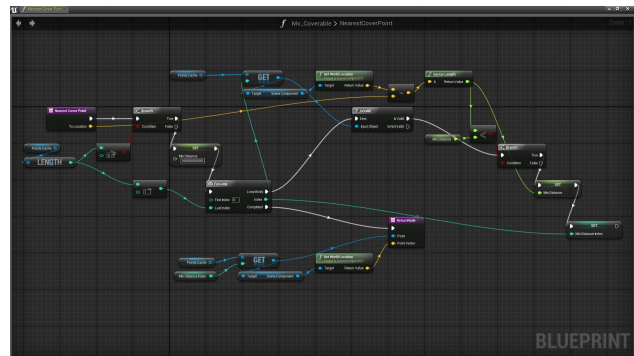
Figure 1: Blueprint (schematics) for development in Unreal Engine[1]

1.2.1   Role of Programmers

At BioWare, most game programmers work with code (in C++ and C#). Programmers are specialized to develop in-game entities, or tools for scripters, designers, and artists. Programmers also integrate systems together, such as making mouse inputs interact with hitzones widgets, which interacts with graphical widgest or animation timelines.[1]

1.3   Object Oriented Programming

1.4   Design Pattern

Design patterns are reusable, general, abstract solutions to common problems in software development.[4] Design patterns are meant to be used when there no problems actually exist – doing so would cause excess undesired complexity.

1.4.1   Antipatterns

Software written without care are difficult to maintain, prone to bugs and errors, and hard to collaborate. Software written with these "hacks" are known as *antipatterns*, where there is more negative consequences than the benefits of its solution. Antipatterns are counter parts to correctly implemented design patterns.[5]

Avoid antipatterns as much as possible. Exploring the negative effects of antipatterns is not part of the scope of this report.

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[1]Animation timelines are timeline that describe how a particular object will animate. Example: a fade in.

1.5 Gang of Four

In software development, the phrase "Gang of Four" refers to the four authors of the Design Patterns book, Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides.[6] The book features the most common design patterns widely in use today.

The design patterns featured in the book outlines the classical design patterns. Thus, many patterns would not be applicable as more recent revisions of programming languages (Python, c++11, etc.). This is because design patterns are inheritantly solutions / workarounds to limitations of the programming language. As there are more improvement in the usability of the language, certain design patterns (such as the *template* pattern) are implemented less as it's less complex, less error prone, and easier to use the existing features built-in to a language.

2 Creational Design Patterns

Creational design patterns involves with object creation.[7] This is especially useful in game development, such as when we need to create many trees or bushes in a level of a game. These patterns become more useful when the objects we're trying to create have relationships, such as *inheritance*, to other objects.

2.1 Builder

In object oriented programming (OOP), the construction of a class instance takes parameters. It is possible that we need a lot of parameters to satisfy more variants of the class. This introduces the telescoping constructor antipattern,[8] where there are numerous variations of constructor methods all delegate to the default constructor. This chains the different constructors together like an upside-down cake, or a telescope shape.

The code is hard to maintain and difficult to use. When creating a new instance (invoking the constructor), it's hard to tell what the actual paramters are if they have the same type. Using default parameters is useful but makes code less usable as it changes the parameter ordering.

The **builder pattern** encapsulates the parameters into a single structure. The structure itself is then passed into the constructor method, where we can access the data inside the structure again. The members of the structure can be accessed and modified by name, thereby eliminating the ambiguity of telescoping constructor.

This is useful in games. For example, a customizable character has many attributes that can be filled in (Figure 2). Realize that as we increase the number of attributes, we also need more parameters in the constructor to populate the attributes.

PlayerCharacter
name: string age: int height: float weight: float
PlayerCharacter(string name, int age, float height, float weight)

Figure 2: PlayerCharacter class with various desired parameters

Using the builder pattern, we create a encapsulated structure that would contain all the parameters in figure 3 and then default all of the struct internal variables to some default value. We then have the flexibility to fill in whichever attribute we want to change by modifying the struct's members (`struct PlayerCharacterBuilder builder; builder.age = 25;`). Optional logic could be added to the builder as well.

struct PlayerCharacterBuilder
name: string = "Alex" age: int = 20 height: float = 175.0 weight: float = 180.0

Figure 3: PlayerCharacterBuilder struct

Now, the PlayerCharacter class constructor only uses a single parameter of the builder type reference (figure 4). The constructor then reads all the values in the struct, and assign them to the corresponding member variables.

PlayerCharacter
name: string
age: int
height: float
weight: float
PlayerCharacter(struct Player-CharacterBuilder &builder)

Figure 4: PlayerCharacter class with various desired parameters

Of course, this pattern is applicable widely in game development, from in game objects that have visual variations, to online player save files, and even the build pipelines used during development to build game assets.

A sample code for this pattern is available in section A.1.

2.2 Factories

Factory is a quintessential creational design pattern because it governs the creation of different types of objects at a scalable level. For programming games, memory allocation and management is tricky, therefore it is helpful to not expose that kind of control to the client code.

The three main factories patterns we will explore is *Simple Factory*, *Abstract Factory*, and *Factory Method*. However, because factory method pattern is very similar to abstract factory[9] in the context we care about, we will only explore abstract factory. The general pattern in all these different factory patterns is that the keyword `new` in C++ is harmful. And that the factory should abstract away the specific steps to instantiation.

Simple Factory

As the name suggests, the *simple factory* is as simple as a factory could get, the simple factory generates an instance for the client but does not expose any instantiation logic.[10]

A real life analogy would be purchasing a burger: the client requests one burger, and the restaurant makes the burger and give it to the client. Without the factory design pattern, the client would need to gather all the ingredients of the burger and make it themselves, which is repetitive and unproductive.

(Simple factory in game developement ehhhhh).

A sample code for this pattern is available in section A.2.

Abstract Factory

Abstract factories are useful in cases where we need to instantiate abstract objects, but we do not know the specific concrete object yet.[11] This pattern is prevalent in cross-platform UI programming where the identical elements have similar characteristics, but behave slightly differently under the hood.

For instance, suppose we have a game that runs on Xbox, PlayStation, and PC, and in it we have a UI widget to enter the player name. The expected behavior would be to open the first-party on screen keyboard for the two consoles, and do nothing for PC (as keyboard is physical). In this case, to make the code more maintainable, we would not program it with two or more variants just to work with different controls.

A similar example is provided in the sample code in section A.3.[12]

Of course, the abstract factory could be generalized to various mechanisms within a game from game objects to player characters.

2.3 Object Pool

An analogy in real life would be a library of books. When a client wants to access some information, instead of writing a new book to the client to use every time, which is expensive, we check if the book already exists in the library. Then we could lend the book to the client. When the client is finished, they return the book for other clients to checkout.

The object pool is a creational design pattern that caches objects for re-use. An object pool can let clients check-out objects from the pool. If a requested object do not exist, the pool can create a new object; although expensive, it only occurs once. Finally, using object pool better organizes object life time of the objects in the pool. Thus we can free memory by clean up unused objects periodically (often known as *garbage collection*).

An example of the object pool design pattern would be

3

2.4 Prototype

The *prototype* design pattern helps when we need to create an object that is similar to an existing one, but instantiating a new instance is relatively expensive.

For instance, suppose we have a procedrally generated 3D model of a rock and we want to clone this model all over the place N times.

We could just generate N rocks like how we generated the first one using the same random seed.[2] The problem is for every clone of the rock, there are computational overheads that hinders efficiency: such as re-computing the normal vectors from all the faces of the polygon, or recalculating teh UV coordinates for the texture.

Using the prototype design pattern, we implement a clone method to the rock object that copies all its data to a new instance, thereby avoiding the re-computation overheads.

2.5 Singleton

In a way, they're just glorified global variable.
In game development, singletons are often reserved for system managers. i.e. a single manager class that overlooks and orchestrates UI system.
Singleton patterns are also used in expensive assets such as levels and personalization libraries (customizations) where we load them into memory during loading screen initially. Then their instance can be accessed via a static function call.

3 Behaviour Design Patterns

3.1 Chain of Responsibility

(InputHandlers and InputDispatchers) in Frostbite engine. A series of input handlers are chained together. Each input handler may hold reference to other input handlers. When an input, such as mouse,

keyboard, or controller action occurs. The calls traverses down the chain of input handlers until one of the input handler entities "consumes" it, which ends the chain.

Another chain of command pattern observed in the Forstbite engine editor, is handling mouse press when there are multiple *hitzones*[3] overlapped (figure 5).

Any press or hovering event will be handled by the top-most hitzone entity first. If the handler does not consume the input event, the event will naturally "flow" down to the next level.
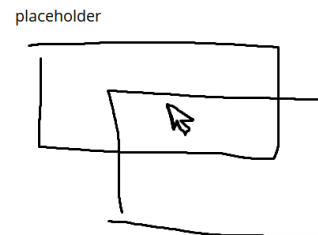
placeholder

Figure 5: Mouse interacting with overlapping mouse hitzones

3.2 Command

Decouples action request and action handlers. The callee who makes the request makes no assumptions about the class the receives the command. Effectively decoupling them. This opens up more flexibility in mapping a requets to a handler. An example is remappable input handling. Instead of listening for a key press, then calling a specific function that the key press corresponds to. It invokes a command object that holds a reference to the *real object* so that the handler can be called. In between we could do

more things. For instance, keep track of how many times the action has requested. Command pattern

also opens up for redo/undo operations.

3.3 Mediator

Mediator acts as a middle-man between communicating objects and decouples them.[13]

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[2] Procedurally generation relies on pseudo-random or noise, which are based off of a seed.

[3] Hitzones are interactive areas for mouse that reports data and events such as mouse position, if mouse is hover, mouse button presses and releases
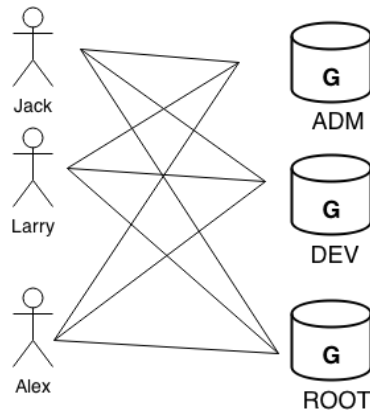
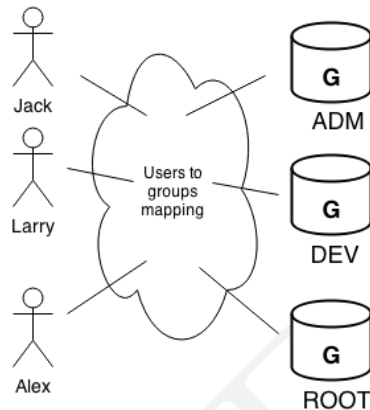Figure 6: Objects communicating without using mediator pattern

Figure 7: Objects communicating using mediator pattern

As seen in figure 6, complexity of interactions between objects become exponentially large as the software grows. Such problem occurs often in UI: An

example would be when a input signal is mapped to multiple elements. In particular, say we have a button to open up the game menu. Then at the same time there are a few systems we need to talk to during this. First, we need to tell the game to lock all inputs to the character in the world, so that when we're navigating the menu, we don't move the character around. We want to enable mouse cursor (and hide it during game play). We might want to pause the game so that enemies don't attack in the background while we have the menu open. We might want to optimize performance by turning off rendering of the world when we're in the menu, since we might not able to see it anyway. Without using a mediator, the

activated event from the button would need to invoke methods in all these different systems. This *antipattern* breaks abstraction, tightly decouples all these systems together which makes it prone to error and crashes, and makes the code highly unmaintainable. Instead, we use pattern as depicted in figure 7. The

button event should communicate with a middle-man that sets a state. The various systems that would be affected does not know anything about the button, or anything that interacts with the mediator. It merely gets the state stored in the mediator, and performs corresponding action.

In Frostbite, a similar mechanism is called a *SharedLock*.

3.4   Memento

3.5   Observer

3.6   Visitor

4   Structural Design Patterns

4.1   Adapter

A middle layer that transforms the interface of a desired object (usually provided by libraries) to work with client.

4.1.1   Difference Between Adapter and Mediator

Different from *mediators* (section 3.3), as mediator manages the communication between two classes, essentially decouples the interaction of the two. Whereas adapter simply translates. Consider a real

life analogy, where two people who speak different languages are fighting. A mediator would be a lawyer such that the two people don't talk to each other directly. An adapter would be a translator so that the two can communicate more directly. Thus, adapter

is structural. And Mediator is behavioral.

4.2   Bridge

4.3   Composite

Useful in architectures such as component-entity-systems model which centers around the idea of "*composition over inheritance*" (section 5.1).

4.4   Decorator

4.5   Facade

4.6   Flyweight

4.7   Proxy

Smart pointers, etc.

5   Architectural Patterns

5.1   Entity-Component-System

Used in physic engines, and when there are a lot of things to handle.
In UI Systems as there are also lots of things to handle. UI widgets do not necessary need to interact with other UI widgets. So using this architecture enables performance optimizations.

Update calls can be queued for all objects at once. Update states can be cached. Cached data are much faster.

5.1.1   Composition over Inheritance

OOP principle that makes inheritance based on composition / behavior rather than inheritance from parent. Consider code in section A.4.1, rather than defin-

ing class by their "likeness", we define it by its function. Then in

5.2   Model-View-Controller

Mostly used in UI development.

6   Conclusions

References

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[3] "Frostbite (game engine)." https://en.wikipedia.org/wiki/Frostbite_%28game_engine%29, 2018. Online; accessed 2018.

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[5] SourceMaking, "AntiPatterns." https://sourcemaking.com/antipatterns, 2018. Online; accessed Nov 2018.

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[12] "Abstract Factory in C++." https://sourcemaking.com/design_patterns/abstract_factory/cpp/2, 2018. Online; accessed Dec 2018.

[13] "Mediator." https://sourcemaking.com/design_patterns/mediator, 2018. Online; accessed Nov 2018.

A Sample Code

A.1 Builder

```cpp
typedef struct
{
    string name = "Alex";
    int age = 20;
    float height = 170.0;
    float weight = 180.0;
} PlayerCharacterBuilder_t;

class PlayerCharacter
{
public:
    PlayerCharacter(PlayerCharacterBuilder_t &builder)
    : m_name(builder.name)
    , m_age(builder.age)
    , m_height(builder.height)
    , m_weight(builder.weight)
    {
        // do stuff...
    }

private:
    string m_name;
    int m_age;
    float m_height;
    float m_weight;
};
```

A.2 Simple Factory

```cpp
// Base class
class Shape
{
public:
    virtual float getArea();
    void setId(int id) { m_id = id; }
protected:
    float m_width;
    float m_height;
    float m_id = 0;
};

// Derived classes
class Rectangle : public Shape
{
public:
    Rectangle(float w, float h)
    {
        m_width = w;
        m_height = h;
    }

    float getArea() override { return m_width * m_height; }
};

class Triangle : public Shape
{
public:
    Triangle(float w, float h)
    {
        m_width = w;
        m_height = h;
```

```
    }

    float getArea() override { return 0.5 * m_width * m_height; }
};

// Factory
class SimpleShapeFactory
{
public:
    static Shape* makeRect(float w, float h)
    {
        Shape* newRect = new Rectangle(w, h);
        newRect->setId(m_idCount++);
        return newRect;
    }

    static Shape* makeTri(float w, float h)
    {
        Shape* newTri = new Triangle(w, h);
        newTri->setId(m_idCount++);
        return newTri;
    }
private:
    static int m_idCount;
};
```

A.2.1   Not using factory

```
void BeforeSimpleFactory()
{
    Shape* shapes[] = { new Rectangle(5, 4), new Triangle(3, 1) };

    // Then we need to apply any applicable instantiation logic to each one
    for (int i = 0; i < 2; i++)
    {
        shapes[i]->setId(i);
    }
}
```

A.2.2   Using factory

```
void AfterSimpleFactory()
{
    Shape* shapes[] = {
        SimpleShapeFactory::makeRect(5, 4),
```

A.3   Abstract Factory

```
}

/// Abstract factory: useful for platform specific things with different concrete implementations
class Button
{
public:
    virtual void draw() = 0;
};

// Derived platform specific
class KeyboardButton : public Button
{
public:
    void draw() override { /* draws a key */ }
```

```
};

class ControllerButton : public Button
{
public:
    void draw() override { /* draws a controller button */ }
};

// The abstract factory to create all related objects
class ButtonAbstractFactory
{
public:
    virtual Button* makeButton();
};

// Concrete factory to create concrete objects in the type of abstract
class KeyboardButtonFactory : public ButtonAbstractFactory
{
public:
    Button* makeButton() override { return new KeyboardButton(); }
};

class ControllerButtonFactory : public ButtonAbstractFactory
{
```

A.4 Composition over Inheritance

A.4.1 Components

```
class GameObject
{
public:
    virtual ~GameObject() {}
    virtual void update() {}
    virtual void draw() {}
    virtual void collide(GameObject objs[]) {}
};

class Visible : public GameObject
{
public:
    void draw() override {};
};

class Solid : public GameObject
{
public:
    void collide(GameObject objs[]) override {}
};

class Movable : public GameObject
{
public:
    void update() override {}
};
```

A.4.2 Usage

```
// Composed classes
class Player : public Visible, public Solid, public Movable
{
    //...
};
```

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```cpp
class Building : public Visible, public Solid
{
    //...
};

class Ghost : public Visible, public Movable
{
    //...
};
```