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| **EASJ Notes** |
| Object-Oriented Pro-gramming with C# |
| Object-Oriented Programming, Part III |

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# Introduction

We have come quite a long way since the beginning of these notes. We now have a rich palette of language constructions and programming techniques available, and can create rather sophisticated applications, both with regards to user interfaces and un­der­lying logic and data structures.

The next step is to consider how to put it all together. We have to some extent done this already, since we have learned about various ways to relate classes to each other, by means of interfaces, inheritance, composition, etc.. Still, the scenarios we have in­vestigated have usually been rather simple, and perhaps also without a well-defined purpose. A seasoned software developer should also know about techniques for how to use all these tool for various real-life purposes. Such purposes – along with general techniques for achieving them – can be formulated as so-called **Design Patterns**.

A **Design Pattern** is – as the term suggests – a design (in terms of classes and inter­faces) for how to solve a commonly occurring problem in software development. Design patterns are not theoretical constructions, but rather “best practices” which have been recognised over time as sound solutions to common problems. Quite a lot of material is available on design patterns, the most well-known probably being the book Design Patterns[[1]](#footnote-1), which in the mid-90s named and described 23 specific design patterns, divided into three main categories: Creational, Structural and Behavioral. The names assigned to the individual design patterns are still used today, and thus pro­vides a common “vocabulary” for software developers, enabling developers to refer to non-trivial designs by a single phrase. We will investigate a few of these de­sign patterns in more detail in this chapter.

Before diving into specific design patterns, we will try to put them into perspective. As stated above, design patterns are not theoretical constructions thought up by profes­sors in some ivory tower, but rather observed “best practices”, which have been con­densed into their very essence, both with regards to formulation and solu­tion. But when is something considered a “best practice”? If something is a “best practice”, then it must be better than other practices, yes? This in turn requires us to think about how we measure the “goodness” of a practice, which ultimately brings us to a core question

**What goals do we strive at, when we develop software?**

This is a very tricky question, since it will be highly dependent on the specific circum­stances for a specific software development activity. A somewhat subjective answer to the question could be: to develop software of the highest possible quality. But that just begs another question: How do we define “high quality”? If we are developing soft­ware for a nuclear power plant control system, we will probably rate “lack of errors” very high on a quality scale, compared e.g. to ease of use. Sure, the software should also be easy to use, but if we have to spend a bit more money on training the operators in how to use the software, as compared with the potential consequences of releasing the software with (too) many errors in it, we will probably rather spend resources on e.g. testing rather than polishing the GUI. Other scenarios may have very different quality measures; if some company needs to get their product to market as quickly as possible – perhaps because other companies are also pushing a similar pro­duct – it might be much more important to get a “reasonable” version of the product on the market fast, rather than waiting for Quality Assurance to dissect the product for several months. Many of the globally largest software producers have – more or less explicitly – adopted an “always in beta” approach to software life­cycles, meaning that a more traditional perspective on quality as meaning “error-free” does not apply any longer.

If that is indeed the case, does it then even make sense to talk about “best practi­ces”? Yes, it still does. Even though the traditional view on how to manage the lifecycle of a software product may have changed, there are still some properties about the soft­ware which are desira­ble to strive for.

One such property is **reusability**. This has always been a “mantra” in Object­-Oriented software development, and for good reasons. If we can develop truly re­usable classes – or even systems of classes – then it will be easier to develop other systems needing such classes as well. Why does this make it “easier”? If the class is indeed reusable as-is, then we need not spend any resources on development and quality assurance. We get the entire functionality for free. This in turn will enable us to deliver a com­plete product both faster and cheaper, which are two measures of quality that often score quite high on a quality scale. The obvious question is then: How do we develop soft­ware such that it does become reusable? We will return to this question in a moment.

Another property is **extensibility**. It is great if we have a pool of reusable classes at our disposal, but even greater if these classes can be “extended” in certain ways, in a fashion that is unlikely to “break” the existing classes. This will enable us to use these classes in scenarios they were not explicitly developed for, which makes them very versatile. Again, we need to ask: How do we develop soft­ware such that it does beco­me extensible?

This text does not aspire to be a complete treatment of all the useful properties a piece of software should posses. Other desirable properties are e.g. testability, reliability, per­formance, instrumentation, etc.. Discussions about such properties must be found elsewhere; we will primarily focus on reusability and extensibility.

Having convinced ourselves that reusability and extensibility are indeed positive pro­perties worth striving for, can we now jump into specific design patterns? Not quite yet. First, we will have a look at a couple of more general software design **principles**, which come into play again and again when discussing specfic design patterns. More specifically, we will look at two such principles:

* The **Open/Closed** principle
* The **Dependency Injection** principle

These two principles form the **O** and **D** in a larger set of such principles know as the **SOLID** principles, which is also a well-established term in software development. The complete list of SOLID principles is:

* **S**ingle Responsibility
* **O**pen/Closed
* **L**iskov Substitution
* **I**nterface Segregation
* **D**ependency Injection

As for Design Patters, a lot of material detailing the SOLID principles can be found elsewhere[[2]](#footnote-2).

# The Open/Closed Principle

The Open/Closed principle comes in several variations with regards to formulation, but the essense of the principle is:

Software entities should be **open** for extension, but **closed** for modification.

The first time you see this principle, it seems to be almost paradoxical. How can something be open for something, and also closed for something that sounds like almost the same thing? This requires a bit of clarification.

The first clarification concerns the term “software entities”. What is that? In the realm of Object-Oriented software development, we can usually substitute this with “a set of classes and interfaces, designed for one common purpose”. With that out of the way, we can address the “closed” part. This sounds very rigid. Must we then deve­lop perfect software in the first try? That is of course unrealistic. A less draconic version of the “closed” part could be “closed for modification that requires clients of the code to change”, clients being defined as any other part of the software making use of the class in question.

Let’s illustrate these concepts with an example: Suppose a class **Client** makes use of a class **CalculatorV10** (V10: version 1.0) which in turn uses a class **Data** for providing data for some sort of calculation. Code for the **Client** class could look like this:

**public class Client**

**{**

**public CalculatorV10 \_calculator;**

**public Client()**

**{**

**\_calculator = new CalculatorV10();**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

Suppose now that the developers of **CalculatorV10** find a critical error in the class, to an extent where a new version of the class must be released. How would such a bug-fix version be released? As a new release of a class called **CalculatorV10**? Or maybe as an entirely new class called **CalculatorV11**? In the first case, the new release will not require the client code to change, even though it might be required to rebuild the enti­re system, but that is more of a technicality. In the second – and probably more likely – scenario, the client code will indeed need to be updated. Is that a problem? Many companies have a policy of always testing updated versions of their code, so if a part of the client code has been updated, it might be necessary to spend resources on re-testing the system. This comes on top of the cost of actually updating the code. In short, this code is not really designed with the open/closed principle in mind.

How can we change this? In the above example, we have not stated anything about the relation between the classes **CalculatorV10** and **CalculatorV11**. They both offer some sort of (probably identical) calculation functionality, but how are they related at a class level? The worst scenario would be that they have no relation. They might be implementing almost the same functionality, and may even have a method with the same name and the same parameter list, but if they have no relation in terms of inhe­ritance or interfaces, it becomes impossible to migrate from one vesion to the other, with­out having to explicitly modify the client code.

A better strategy is to relate the classes by inheritance. Suppose the **CalculatorV10** class is implemented like this:

**public class CalculatorV10**

**{**

**public virtual int Calculate(Data d)**

**{**

**int result = 0;**

**// Code for calculating a result…**

**return result;**

**}**

**}**

Note that the method **Calculate** has been defined as being **virtual**, indicating that the method can be overrided in a derived class. The class **CalculatorV11** could then be im­plemented in this way:

**public class CalculatorV11 : CalculatorV10**

**{**

**public override int Calculate(Data d)**

**{**

**int result = 0;**

**// Bug-fixed code...**

**return result;**

**}**

**}**

Does this help us with regards to keeping the the client code unchanged? To some extent, but not completely. Let’s look at the code again:

**public class Client**

**{**

**public CalculatorV10 \_calculator;**

**public Client()**

**{**

**\_calculator = new CalculatorV10();**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

Two places in the code are particularly interesting (highlighted above). The first is the declaration of the instance field **\_calculator**. What objects can this instance field refer to? Obviously to objects of type **CalculatorV10**… but also objects of type **Calcula­tor­V11**, due to the inheritane relationship! This is clearly an improvement. However, the second piece of highlighted code is still problematic, since we here explicitly cre­ate an ob­ject of type **CalculatorV10**. This is an extremely central problem in software design; whenever we need to create new objects, we must state their specific type explicitly. The entire category of design patterns known as **creational patterns** are in fact varia­tions over how to “encapsulate” the object creation process.

Are we then stuck here? If we insist on creating a calculation object explicitly in the **Client** class, we cannot really do much more. However, if we assume that a calcula­tion object can be created outside the **Client** class, and somehow be made available to the methods in the **Client** class, we suddenly have more options. Consider the below ver­sion of the **Client** class:

**public class Client**

**{**

**public CalculatorV10 \_calculator;**

**public Client(CalculatorV10 calculator)**

**{**

**\_calculator = calculator;**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

The **Client** class will now no longer create a calculation object, but rather receive a calculation object through the constructor parameter. What type can this object have? Again, both **CalculatorV10** and **Calcula­torV11**, due to inheritance. In this way, the **Client** class is unaware of the specific type of calculation object; it just knows that it is – or inherits from – **CalculatorV10**. We could then release further versions of the calculator class, and make use of them in the **Client** class without any code changes, as long as they inherit from **CalculatorV10**. This idea can be taken a bit further by bringing **interfaces** into play. Suppose an inter­face for calculation has been defined:

**public interface ICalculator**

**{**

**int Calculate(Data d);**

**}**

We now assume that all calculation classes will implement this interface. We can then update the **Client** class further:

**public class Client**

**{**

**public ICalculator \_calculator;**

**public Client(ICalculator calculator)**

**{**

**\_calculator = calculator;**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

As long as all future calculator classes implement this interface, we can make use of them in the **Client** class, without the need for updating the code. This is a quite typi­cal example of how to design with the open/closed principle in mind; the **Client** class is “open” to make use of future calculation classes – without detailed knowledge about how they specifically work – but also “closed” in the sense that there is no need to chan­ge it, just in order to use it with new calculation classes.

One thing has been swept a bit under the rug, though. Somewhere in the client code – but outside the **Client** class – somebody needs to create a calculation object, and pro­vide it to a **Client** object, like this:

**ICalculator aCalculator = new CalculatorV11();**

**Client aClient = new Client(aCalculator);**

We are thus not completely out of the woods yet. Somebody does have to choose a specific implementation of **ICalculate**, and create an object of that type. However, mo­ving that responsibility out of the **Client** class opens up for a lot more flexibility with regards to where to create that object. We will see examples of how to address this problem later in this chapter.

A common theme in strategies for implementing the open/closed principle is to remo­ve knowledge about specific types from the client code, and replace it with e.g. know­ledge about interfaces only. A third party must then somehow supply specific imple­men­­­ta­tions of these interface to the client code, e.g. as constructor parame­ters. This way of building relations between otherwise loosely coupled classes is in fact what the **Dependency Injection** principle is all about.

# The Dependency Injection principle

As discussed in the previous chapter, we often strive at creating “reusable” classes, which makes it possible to use such classes together with entirely new classes, with­out having to modify said reusable classes, or – in the worst of scenarios – having to write an entirely new class ourselves ☺. If we can pick a well-tested, well-documented class off-the-shelf and easily reuse it in our own project, we can probably develop bet­ter, cheaper and less error-ridden applications, as compared to having to develop the en­tire application from scratch.

The principle known as **Dependency In­ject­ion** is generally considered a very impor­tant principle with regards to developing reusable classes, so we will also investigate this principle a bit, before seeing it in action in some specific Design Patterns. We will even look a Dependency Injection in a somewhat broader perspective than just when applied to relations between classes, since it makes sense to discuss it at lower levels as well. In a sense, we have been using this principle for quite some time ☺.

The term **Dependency Injection** seems to suggest that **someone** will **inject** **some­thing** into **something else**, as illustrated below:



The term also suggests that this **something else** did not contain this **something** to begin with. If it did, it would then be inherently “locked” in a tightly coupled relation­ship with this **something**, which is what we want to avoid. Replacing the terms used above with the terms commonly used when discussing Dependency Injection, we get this illustration:



So, an **Injector** will inject a **Service** into a **Client**, and the client can then make use of this service. But how is this different than just having a hard-coded relation between the Service and the Client? Once we have performed the injection, the dependency will be the same anyway, yes? Well, no. The difference lies in the knowledge the Cli­ent will have about the specific nature of the Service.

## Dependency Injection – parameter level

Let’s illustrate this with an example. As mentioned previously, this discussion will perceive Dependency Injection in a broader context than usual, so the definition of the term “service” will be stretched a bit. Please play along…

Consider the below – quite clumsy – attempt to define a method for calculating the square of 4:

**public int SquareOf4()**

**{**

**return 4 \* 4;**

**}**

The method does what it advertises; it calculates the square of the number 4. If some­one later on asks us for a method which can calculate the square of 6, we can quickly deliver:

**public int SquareOf6()**

**{**

**return 6 \* 6;**

**}**

At this point in your software development training, you should hopefully be able to come up with a much better solution to this problem:

**public int Square(int n)**

**{**

**return n \* n;**

**}**

Of course! This is much better than just mindlessly copying the original code, and re­placing 4 with whatever new value someone requests. This solves the problem once and for all. But what did we more specifically do? Something like this:



In the “Before” scenario, we had hard-coded a tight relationship between the met­hod **Square** (the Client) and the number **4** (the Service – yes, a big word for a num­ber…). In the “After” scenario, we removed the explicit dependency between **Square** and **4**, and turned the number into something the Injector – i.e. the caller of **Square** – must inject into the method, by providing it as a parameter to **Square**. Why was it possible to do this? The only operation happening inside **Square** is multiplication, and – and this is a very important point – multiplication works in the same way, no matter the specific number we supply! We can thus loosen up the requirements to that “thing” we do multiplication on. Can it be anything at all, then? No, since multiplica­tion only makes sense on numerical values. It will not make sense to perform multi­pli­cation on a **string** value. So, any numerical value, then? In principle, yes. However, the return type of **Square** has been defined to be **int**, so requiring that the parameter must also be of type **int** seems to be just the right amount of restriction we need to put on the parameter. In this case, the analysis was very simple. Still, it is a valid illustration of perceiving parameterisation as a variant of the Dependency Injection principle.

Let’s see a slightly less obvious example. The below code defines a class **Die**, which is intended to model a standard 6-sided die:

**public class Die**

**{**

**private int \_faceValue;**

**private static Random \_random = new Random();**

**public Die()**

**{**

**Roll();**

**}**

**public int FaceValue**

**{**

**get { return \_faceValue; }**

**}**

**public void Roll()**

**{**

**\_faceValue = \_random.Next(0,6) + 1;**

**}**

**}**

Rolling the die – by calling the **Roll** method – will set the face value to a random num­ber between 1 and 6 (the call of **Next**(0,6) will generate a number between 0 and 5, hence the +1 after the call). So, what exactly makes this a model of a 6-sided die? That is of course the number 6, used in the call of **\_random.Next**. If we wanted a class for modeling a 10-sided die, we could just copy-paste the entire class, and replace 6 with 10, yes? No, let’s not go down that road again… Instead, we will solve the problem by applying the Dependency Injection principle again. But where? Should we turn the hard-coded number into a parameter to **Roll**, like this?:

**public void Roll(int noOfSides)**

**{**

**\_faceValue = \_random.Next(0, noOfSides) + 1;**

**}**

It’s a possible solution, but sort of breaks the idea that a **Die** object models a real-world die. A real die doesn’t change its number of sides between calls, so what then? A better solution would be to specify the number of sides when the object is con­struc­­ted, by adding a parameter to the constructor, plus an instance field to the class:

**public class Die**

**{**

**private int \_faceValue;**

**private int \_noOfSides;**

**private static Random \_random = new Random();**

**public Die(int noOfSides)**

**{**

**\_noOfSides = noOfSides;**

**Roll();**

**}**

**public int FaceValue**

**{**

**get { return \_faceValue; }**

**}**

**public void Roll()**

**{**

**\_faceValue = \_random.Next(0, \_noOfSides) + 1;**

**}**

**}**

The revised class can now be a model for a die with any number of sides; the specific number of sides for a specific object is specified at object creation time, by the object creator, i.e. the Injector. Again, this rests on the observation that die operations are so general that they do not depend on the specific number of sides, as long as that number is an integer number (how does a die with 3.7 sides behave…?). A more com­plete implementation should probably also check that **noOfSides** is at least 2, and per­­haps throw an exception if this is not the case.

## Dependency Injection – method level

We have now (hopefully) gained an understanding of the Dependency Injection prin­ciple, so let’s see it applied at a method level. Applying the principle here is conside­rably harder, and requires use of some of the more advanced language constructions in C#. Consider the problem of filtering out certain values from a list of given values, accor­ding to some criterion. An example is given below:

**public List<int> FilterValues(List<int> values)**

**{**

**List<int> filteredValues = new List<int>();**

**foreach (var value in values)**

**{**

**if (value > 10)**

**{**

**filteredValues.Add(value);**

**}**

**}**

**return filteredValues;**

**}**

In this example, we filter out those numbers which are larger than 10, and add them to the resulting list **filteredValues**, which is returned to the caller. What if we wish to filter according to a different criterion? The method for doing this would actually be identical to the example, except for the criterion specified in the **if**-statement (as high­­lighted in the code). The criterion itself is then a perfect candidate for being turned in-to a parameter. But how? Think about what characterises the criterion. It can be per­ceived as a function, taking one integer value as input, and returning a boolean value. We have learned earlier that such a function characterisation can be expressed as a C# type, in this case the type **Func<int,bool>**. That type identifies exactly those func­tions we just described. We can then rewrite the above to:

**public List<int> FilterValues(List<int> values, Func<int,bool> criterion)**

**{**

**List<int> filteredValues = new List<int>();**

**foreach (var value in values)**

**{**

**if (criterion(value))**

**{**

**filteredValues.Add(value);**

**}**

**}**

**return filteredValues;**

**}**

A caller can then call **filterValues** like this:

**List<int> filteredValues = FilterValues(someValues, v => v > 10);**

The function parameter is here expressed as a lambda expression, but it could also be a named function, as long at it conforms to the type specification. This is definitely a more elaborate example of Dependency Injection through parameterisation, but the line of reasoning behind it is actually quite similar to the next-to-trivial examples we saw earlier. We recognised that part of the logic inside the method did not need to be tightly coupled with a specific “value” (here a selection criterion, which can be expres­sed as a function of a specific type), so we parameterised that value, and let the caller inject a specific value – here a specific selection criterion – when the method is called.

## Dependency Injection – class/interface level

In order to see an example of Dependency Injection at the class/interface level, we need not look any further than one of the examples used when discussing the Open/ Closed principle. Our starting point was a **Client** class as given below:

**public class Client**

**{**

**public CalculatorV10 \_calculator;**

**public Client()**

**{**

**\_calculator = new CalculatorV10();**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

The main problem with this class is the tight coupling to the **CalculatorV10** class. If we at some point need to upgrade to a newer version of the calculation – perhaps in the form of a class **CalculatorV11** – we need to change the implementation of **Client**. We can remedy this to some extent by adding a parameter of type **CalculatorV10** to the **Client** constructor, which will relieve the client of having to explicitly create a new object. Furthermore, this makes the dependency between **Client** and **Calculator­V10** more visible to the outside world. In the above code, a **CalculatorV10** object is crea­ted inside the **Client** constructor, but the only way to become aware of this fact is to inspec­t the actual source code, which may not always be possible (the class could e.g. be a third-party class). This can make it harder to test the class properly.

Adding a parameter of type **CalculatorV10** to the **Client** constructor does however not remove the tight coupling between **CalculatorV10** and **Client**; it just exposes it. If we now introduce a general calculation interface **ICalculator**, and use this interface as the type for the **Client** constructor parameter, the coupling is lifted:

**public class Client**

**{**

**public ICalculator \_calculator;**

**public Client(ICalculator calculator)**

**{**

**\_calculator = calculator;**

**}**

**public void ProcessData(Data d)**

**{**

**int result = \_calculator.Calculate(d);**

**//...**

**}**

**}**

This version of **Client** does not depend on specific calculation classes. Instead, a third party must “inject” a specific calculation object, as part of creating a **Client** object:

**ICalculator aCalculator = new CalculatorV10();**

**Client aClient = new Client(aCalculator);**

This is exactly the same code we saw when discussing the Open/Closed principle, and Dependency Injection is indeed a very useful tool for implementing this principle. Fur­thermore, this makes testing of the **Client** class much more flexible. Whenever an ob­ject only depends on other objects known by interface type – and these objects are inject­ed into the object – it will always be possible to use “surrogate” objects, as long as these objects also implement the interface in question. Instead of having to use an implementation which e.g. connects to a remote database, a surrogate object can be used instead, which is likely to make the test both faster and more reliable.

There is not much more to Dependency Injection than this, except one – quite impor­tant – question: Who should be responsible for actually performing this dependency in­ject­ion? The next chapter will provide a couple of possible answers to this question.

# Design Patterns – Creational Patterns

In the discussions of the Open/Closed and Dependency Injection principles, a recur­ring theme was to remove tight couplings between client code and specific classes. More specifically, we saw that client code should – if at all possible – abstain from explicitly creating new objects, since creation requires the creator to explicitly state the type of the created object. Instead, client code should receive a reference to an object created by a third party, since such a reference can be of e.g. an interface type. This provides much more flexibility with regards to how to couple client code and spe­cific interface implementations together. The act of creating objects of a specific type has thus been externalised to this “third party”.

How should we then implement this “third party”? Does it manifest itself in the form of a method, a class or something else? The design patterns in the **creational patterns** category offer various approaches to this issue. We will here discuss two of these pat­terns, which are fairly closely related: the **Factory Method** pattern and the **Abstract Factory** pattern.

## Factory Method

Suppose we are developing software for a courier service, which needs to plan how to transport goods to certain locations, given e.g. a set of available vans. Such a planning process may have as objective to minimise the total number of kilometers driven, or perhaps to minimise the delays by which goods are delivered. The details are as such not im­por­tant, but planning problems like these tend to be very hard (i.e. require a lot of CPU resources) to solve optimally, where “optimally” means a 100 % guarantee that no better solution exist. However, it is also often the case that approximate solu­tions can be found much faster. There might even exist a whole suite of algo­rithms for producing solutions to the problem, where the quality of the solution will be directly proportional to the time it takes to produce the solution (the more time available, the better the solution).

This situation could be reflected in the implementation of the software. We imagine a class **PlanningManager**, with a central method **ExecutePlanning**. The method takes a single parameter, which indicates the amount of time available for finding a solution. An initial implementation of the method might look like this:

**public void ExecutePlanning(int timeAvailable)**

**{**

**PlanningData data = ReadPlanningDataFromDB();**

**PlanningResult result = null;**

**if (timeAvailable < 3)**

**{**

**ReallyFastPlannerV16 rfp16 = new ReallyFastPlannerV16();**

**result = rfp16.CreatePlanFast(data);**

**}**

**else if (timeAvailable < 12)**

**{**

**PrettyFastPlannerV24 pfp24 = new PrettyFastPlannerV24();**

**result = pfp24.CalculatePlan(data);**

**}**

**else**

**{**

**ExactPlannerV37 ep37 = new ExactPlannerV37();**

**result = ep37.FindExactSolution(data);**

**}**

**WritePlanningResultToDB(result);**

**}**

We assume that the planning process relies on some set of data, here represented by a class **PlanningData**. The planning process will produce a result in the form of a **Plan­ning­Result** object, which is then saved to a database. The specific details about this are not important either. Furthermore, we assume that various algorithms for plan­ning are available in the form of various classes; these classes might be deve­loped in-house, or might be a third-party product. Such algorithms may be improved over time, so we assume that new versions will be produced regularly (indicated by the version numbers at the end of the class names).

The central feature of the **ExecutePlanning** method is the **multi-if-else** statement, which chooses a planning algorithm according to the available time. As it stands, this might be an acceptable implementation, but it is definitely quite fragile with regards to changes. Whenever a new version of one of the algorithms becomes available, we will have to update the code, which in turn may require re-testing, releasing the code into produc­tion, etc.. There is definitely room for improvement.

One major problem with the **ExecutePlanning** method is the dependency of specific planning classes, which induces the problem of having to frequently update the code. The **Factory Method** pattern is an appropriate tool for solving this problem. Instead of depending on specific classes, the client (here the **ExecutePlanning** method) will use a “factory” object to produce planning objects, without knowing about – and thereby depend on – their specific type. A prerequisite for this is to perform a bit of “homo­geni­sation” of the planning classes. We define a planning interface **IPlanner**, like this:

**public interface IPlanner**

**{**

**PlanningResult CreatePlan(PlanningData data);**

**}**

We now require that all planning classes must implement this interface. For planning classes produced in-house, this is probably not a problem, since it just amounts to renaming an existing method. For third-party classes, it may a bit trickier to achieve, but we will later see a design pattern (called **Adapter**) which can help us with this. For now, we assume that this is possible, such that all planning classes contain a method **CreatePlan** for creating a plan.

The **IPlanner** interface does not in itself help us much. We now define an additional inter­face **IPlannerFactory**, like this:

**public interface IPlannerFactory**

**{**

**IPlanner Create(int timeAvailable);**

**}**

The **Create** method in this interface is indeed a **Factory Method**. Calling this method will return an object which implements the **IPlanner** interface, but the caller will not be aware of the specific type of the object! This is the whole point; the caller should only know the interface type, since this is enough to make use of the object. We can now simplify the implementation of the **ExecutePlanning** method considerably:

**public void ExecutePlanning(int timeAvailable, IPlannerFactory factory)**

**{**

**PlanningData data = ReadPlanningDataFromDB();**

**IPlanner planner = factory.Create(timeAvailable);**

**PlanningResult result = planner.CreatePlan(data);**

**WritePlanningResultToDB(result);**

**}**

We have added an extra parameter to **ExecutePlanning**, which is a reference (by interface type) to a planner factory object. We can then use this factory to create a planner object when we need it, simply by calling **Create**. Since the returned object imple­ments **IPlanner**, we can call **CreatePlan** on it. **ExecutePlanning** has no know­ledge about specific planning classes, and will not need to change if new planning classes become available.

The **ExecutePlanning** method is obviously much cleaner now, but the choice of a spe­ci­fic planner class has of course not magically disappeared. It will now be implemen­ted in a factory class, e.g. like this:

**public class PlannerFactoryDay : IPlannerFactory**

**{**

**public IPlanner Create(int timeAvailable)**

**{**

**if (timeAvailable < 3)**

**{**

**return new ReallyFastPlannerV16();**

**}**

**else if (timeAvailable < 12)**

**{**

**return new PrettyFastPlannerV24();**

**}**

**else**

**{**

**return new ExactPlannerV37();**

**}**

**}**

**}**

Note that this class implements the **IPlannerFactory** interface. A call of the planning manager method could now look like this:

**PlanningManager pm = new PlanningManager();**

**pm.ExecutePlanning(GetAvailableTime(), new PlannerFactoryDay());**

We have thus extracted the responsibility of choosing the appropriate planning algo­rithm from the **ExecutePlanning** method, and placed it in a dedicated factory class instead. So, have we just moved code around? Indeed we have, but that is also a qua­lity in itself. The **ExecutePlanning** method can now concentrate on coordinating the planning process – including reading and writing data to a data source – while the factory class can focus on producing the appropriate planner object. Also, this division provides more flexibility.

We have named the above implementation of the **IPlanner­Factory** interface **Planner­FactoryDay**, to suggest that an alternative implementation – maybe named **Planner­FactoryNight** – could exist. We could imagine that the criteria for choosing a specific implementation may vary between day and night, e.g. if more CPU resources are available at night. It will then be a simple matter to configure the **ExecutePlanning** method with a different factory implementation, since it only knows the factory objecty by its interface type.

In the above example, we have created a Factory Method which takes a single para­meter. There are as such no rules w.r.t. how to parameterise a Factory Method, and you can also easily imagine Factory Methods without any parameters, e.g. like this:

**public interface IPlannerFactorySimple**

**{**

**IPlanner Create();**

**}**

An implementation could then look like this:

**public class PlannerFactoryVeryFast : IPlannerFactorySimple**

**{**

**public IPlanner Create()**

**{**

**return new ReallyFastPlannerV16();**

**}**

**}**

This can be perceived as a more “low-level” factory, which only encapsulates a single aspect of planning object creation: creation of “very fast” planning objects. Such fac­to­ries could be used as building blocks in our previous factory implementation:

**public class PlanningFactoryGeneral : IPlannerFactory**

**{**

**private IPlannerFactorySimple \_veryFastFactory;**

**private IPlannerFactorySimple \_fastFactory;**

**private IPlannerFactorySimple \_exactFactory;**

**public PlanningFactoryGeneral(**

**IPlannerFactorySimple veryFastFactory,**

**IPlannerFactorySimple fastFactory,**

**IPlannerFactorySimple exactFactory)**

**{**

**\_veryFastFactory = veryFastFactory;**

**\_fastFactory = fastFactory;**

**\_exactFactory = exactFactory;**

**}**

**public IPlanner Create(int timeAvailable)**

**{**

**if (timeAvailable < 3)**

**{**

**return \_veryFastFactory.Create();**

**}**

**else if (timeAvailable < 12)**

**{**

**return \_fastFactory.Create();**

**}**

**else**

**{**

**return \_exactFactory.Create();**

**}**

**}**

**}**

The final touches could be to turn the hard-coded limits for choosing between the factories into parameters as well. The factory will then be fully configurable (at least with regards to be able to choose between three categories of planners…).

## Abstract Factory

The Factory Method pattern is aimed at creating objects which all imple­ment the same interface. We can easily imagine that we would need to apply this principle several times, i.e. define factory interfaces and classes for multiple elements in an application. One example could be part of an operating system, which needs to dis­play various GUI controls like Windows, Buttons and Icons on the screen. The code for management of this should of course not rely on specific control implementations, so it would be natural to define some interfacce for the controls, like **IWindow**, **IButtton** and **IIcon**. Specific implementations of these interfaces can then present the GUI con­rol in question in a specific way. We could imagine classes like **WindowDefault**, **Win­dow­NatureTheme**, etc., and likewise for other controls. We can then create factory interfaces and classes for each type of control, like this minimal example:

**public interface IWindowFactory**

**{**

**IWindow Create();**

**}**

So far, so good. We can go ahead and create **IButtonFactory** and **IIconFactory** inter­faces as well, and imagine that some central part of the GUI management code gets configured with instances of these factories:

**public class GUIManager**

**{**

**// ...**

**public GUIManager(**

**IWindowFactory windowFac,**

**IButtonFactory buttonFac,**

**IIconFactory iconFac)**

**{**

**// ...**

**}**

**}**

All seems to be well… but there is a slight catch. Nothing prevents a client from crea­ting a new **GUIManager** object in this way:

**GUIManager gm = new GUIManager(**

**new WindowFactoryDefault(),**

**new ButtonFactoryNature(),**

**new IconFactoryIndustrial());**

This will likely result in a somewhat strangely looking GUI ☺. There is nothing in the code which prevents such unintended mixing between “families” of GUI controls. The solution is fortunately fairly straightforward; instead of defining three factory inter­faces with one method in each, we define one factory interface with three methods:

**public interface IGUIControlFactory**

**{**

**IWindow CreateWindow();**

**IButton CreateButton();**

**IIcon CreateIcon();**

**}**

With this interface in place, we can now implement factory classes that produce GUI controls of the same “family”, e.g. a **GUIControlFactoryNature** class. The **GUIManager** con­structor should also be changed:

**public class GUIManager**

**{**

**// ...**

**public GUIManager(IGUIControlFactory igcf)**

**{**

**// ...**

**}**

**}**

Creating a **GUIManager** object is now less error-prone:

**GUIManager gm = new GUIManager(new GUIControlFactoryNature());**

This new strategy does not completely prevent mixing of GUI control factories, since we have no control over the actual content of a factory object. If someone is really intent on messing up the GUI, he could write a factory class which does produce GUI control objects from different families. That aside, this new approach does at least state the intention of GUI control creation much clearer; GUI controls do not stand alone; they are part of a GUI control “family”, and the object creation strategy should reflect this.

# Design Patterns – Structural Patterns

The design patterns in this category are primarily concerned with the relationships needed between classes and objects, in order to achieve some sort of collaborative effort.

At the class level, such relationships are usually established through inheri­tance. A sim­ple example could be a class that implements several interfaces. From the per­spec­tive of the client code – which we assume always refers to objects by inter­face-type references – it makes no difference if the behavior exposed through the inter­faces is implemented by one or several objects, giving us freedom to choose such an approach, if it is indeed a sound approach by other measures as well.

At the object level, the relationships are established through composition. A class may refer to a completely unrelated class – be it by class type or interface type – in order to implement a certain functionality. We have seen this many times as well; a class that uses a class from the .NET class library – say, the **List<>** class – will often do this by composition, which in practice just means that the class contains an instance field of a certain type, and will either create a corresponding object itself, or receive a refe­rence to an object through a constructor or method parameter (the latter appro­ach is often referred to as **Aggregation**).

We will take a closer look at two structural design patterns: the **Adapter** pattern and the **Proxy** pattern. They are both object-level patterns.

## Adapter

During the discussion of the **Factory Method** pattern, the starting point was a met­hod **ExecutePlanning** used for creating a plan for optimal use of certain resources:

**public void ExecutePlanning(int timeAvailable)**

**{**

**PlanningData data = ReadPlanningDataFromDB();**

**PlanningResult result = null;**

**if (timeAvailable < 3)**

**{**

**ReallyFastPlannerV16 rfp16 = new ReallyFastPlannerV16();**

**result = rfp16.CreatePlanFast(data);**

**}**

**else if (timeAvailable < 12)**

**{**

**PrettyFastPlannerV24 pfp24 = new PrettyFastPlannerV24();**

**result = pfp24.CalculatePlan(data);**

**}**

**else**

**{**

**ExactPlannerV37 ep37 = new ExactPlannerV37();**

**result = ep37.FindExactSolution(data);**

**}**

**WritePlanningResultToDB(result);**

**}**

One of the main characteristics of this method is that the specific choice of planning object depends on the value of a parameter. We thus have a set of planning ”provi­ders” avail­able, from which we select a single instance. These planning providers may e.g. be third-party classes, and may therefore not have anything in common, except the ability to perform the given planning. The code above illustrates such a situation, where the three providers have methods with different names.

Our strategy for cleaning up this code required all planning providers to implement the same interface **IPlanner**, as defined below:

**public interface IPlanner**

**{**

**PlanningResult CreatePlan(PlanningData data);**

**}**

This may however not be feasible in practice. If the planning classes are provided by a third party, we cannot just change the definition of the classes, since we might not have access to the actual source code. What then? This is where the **Adapter** design pattern comes into play.

Suppose we create a new class called **ReallyFastPlannerAdapter**. This class must meet two requirements:

* It must implement the **IPlanner** interface.
* It should functionally be identical to the **ReallyFastPlannerV16** class.

This is not particularly hard to achieve:

**public class ReallyFastPlannerAdapter : IPlanner**

**{**

**private ReallyFastPlannerV16 \_adaptee;**

**public ReallyFastPlannerAdapter()**

**{**

**\_adaptee = new ReallyFastPlannerV16();**

**}**

**public PlanningResult CreatePlan(PlanningData data)**

**{**

**return \_adaptee.CreatePlanFast(data);**

**}**

**}**

We simply encapsulate the “adaptee” – which is the original class that did not imple­ment the desired interface – and delegate the call of **CreatePlan** to the **CreatePlan­Fast** method of the adaptee. We can create similar adapter classes for all of the avail­able planning classes, and then achieve our goal of having a common interface for all planning providers.

This is of course a quite simple example, since the adaptation essentially boils down to delegating a method call to an adaptee method, which has the same signature (para­meter list and return type), but a different name. No pre- or post-processing is needed. An example which requires slightly more complex adaptation could be that of adapting a drawing library. Suppose we want to create a small drawing library, with a few methods define by an interface **IDraw** (we assume a class **Point** exists):

**public interface IDraw**

**{**

**void DrawPolyLine(List<Point> points);**

**void DrawRectangle(Point start, double xSide, double ySide);**

**}**

An existing drawing library **SimpleDraw** is actually available, but it only contains a single method **DrawLine**, which takes two **Point** objects as parameters. We must therefore create an adapter class **SimpleDrawAdapter** – which must implement the **IDraw** interface – and implement the methods in **IDraw** by using the (single) method available in **SimpleDraw**:

**public class SimpleDrawAdapter : IDraw**

**{**

**private SimpleDraw \_adaptee;**

**public SimpleDrawAdapter()**

**{**

**\_adaptee = new SimpleDraw();**

**}**

**public void DrawPolyLine(List<Point> points)**

**{**

**for (int i = 0; i < points.Count - 1; i++)**

**{**

**\_adaptee.DrawLine(points[i], points[i+1]);**

**}**

**}**

**public void DrawRectangle(Point start, double xSide, double ySide)**

**{**

**Point endX = new Point(start.X + xSide, start.Y);**

**Point endY = new Point(start.X, start.Y + ySide);**

**Point endXY = new Point(start.X + xSide, start.Y + ySide);**

**\_adaptee.DrawLine(start, endX);**

**\_adaptee.DrawLine(start, endY);**

**\_adaptee.DrawLine(endXY, endX);**

**\_adaptee.DrawLine(endXY, endY);**

**}**

**}**

Not rocket science by any means, but still a bit more effort needed in order to “close the gap” between the required interface and the available implementation.

## Proxy

The purpose of the Adapter pattern was to bridge the gap between an interface requested by the client code, and the actual interface presented by a class offering the services the client needs. The Adapter class will typically contain a reference to the “adapted” object, and will implement the desired interface by calling methods in the interface of the adapted object. The **Proxy** pattern follows a similar strategy, but with a quite important difference; the object which is referenced has the same inter­face as the Proxy class itself!

How can that be useful? Why not just use the object directly, if the interface is the same? The Proxy pattern comes into play if there are reasons to restrict direct access to the object. If such reasons exist, it can be beneficial to hide access to the object behind a “placeholder” class, which is exactly what the Proxy pattern is about.

Suppose a class **RoutePlanner** exist, which is capable of route planning in a detalied road network. The class implements an interface **IRoutePlanner**. In order to be able to calculate a route plan, the **RoutePlanner** needs to load in a large data set, before cal­cu­lation is started. The **RoutePlanner** class is written in such a way that the data set is loaded when a **RoutePlanner** object is created. Crea­ting a **RoutePlanner** object is thus considered an “expensive” operation, since it may take a while to load the data set, and the loaded data set may also consume a significant amount of memory. It would therefore be useful only to create such an object if it is strictly necessary.

Let us also suppose that part of the client code uses a **RoutePlanner** object – or at least an object implementing **IRoutePlanner** – e.g. as a parameter to a method call:

**public void PrepareForPlanning(IRoutePlanner rp)**

**{**

**// Method body…**

**}**

The **PrepareForPlanning** method thus expects to receive a **RoutePlanner** object, but the method might also have a nature where actual planning is only performed when certain conditions apply. In other words; we may often experience that **PrepareFor­Planning** did not make active use of the **RoutePlanner** object, and the effort used for creating the object in the first place may therefore be wasted.

A problem like this can be resolved in various ways, depending on the degree of free­dom you have with regards to revising the code for the **PrepareForPlanning** method and the **RoutePlanner** class, but you may well be in a situation where neither of the two can be revised. Using the Proxy pattern will then be a feasible approach.

We assumed that the **RoutePlanner** class implements an interface **IRoutePlanner**. For simplicity, we assume that the interface only contains a single method:

**public interface IRoutePlanner**

**{**

**PlanningResult CalculatePlan(PlanningData data);**

**}**

We now create a new class **RoutePlannerProxy**, which also implements the **IRoute­Planner** interface. It also contains an instance field of type **RoutePlanner**:

**public class RoutePlannerProxy : IRoutePlanner**

**{**

**private RoutePlanner \_planner;**

**public RoutePlannerProxy()**

**{**

**\_planner = null;**

**}**

**public PlanningResult CalculatePlan(PlanningData data)**

**{**

**InitPlanner();**

**return \_planner.CalculatePlan(data);**

**}**

**private void InitPlanner()**

**{**

**\_planner = \_planner ?? new RoutePlanner();**

**}**

**}**

Let’s review the key features of **RoutePlannerProxy**:

* It has a reference to a **RoutePlanner** object, BUT the reference is set to ***null*** in the constructor.
* It has a method **InitPlanner**, which reads *“if* ***\_planner*** *is* ***null*** *when I’m called, it will be set to a new* ***RoutePlanner*** *object, otherwise* ***\_planner*** *is left unchanged”*
* It implements **CalculatePlan**, BUT does so by first calling **InitPlanner**, and then calling **CalculatePlan** on the **RoutePlanner** object

With this new class available, it will be possible to call the client code method **Pre­pare­ForPlanning** in a new way:

**IRoutePlanner plannerProxy = new RoutePlannerProxy();**

**PrepareForPlanning(plannerProxy);**

From the perspective of the client code, nothing has changed. The method **Pre­pare­ForPlanning** is still called with an object implementing the **IRoutePlanner** interface, and it will use this object just as before. The fact that the “proxied” **RoutePlanner** object is only created if needed (often known as **lazy creation**) is completely hidden.

As the code stands now, the client code will now have explicit knowledge about using a proxy class, since it becomes responsible for creating a proxy object. If you wish to isolate the proxy creation further, you could encapsulate the proxy creation in a fac­tory class. It will then be a configuration issue whether or not to use a proxy; or you could even let the factory decide what to do at run-time (we assume that a class **Con­text** has been defined, which will provide decision information to the factory) :

**public class RoutePlannerFactory**

**{**

**public IRoutePlanner Create(Context c)**

**{**

**if (UseProxy(c))**

**{**

**return new RoutePlannerProxy();**

**}**

**else**

**{**

**return new RoutePlanner();**

**}**

**}**

**private bool UseProxy(Context c)**

**{**

**// Decide whether to use Proxy,**

**// based on provided context.**

**}**

**}**

The above example captures the essence of the Proxy pattern; whenever there are reasons to safeguard the creation of and/or access to an object, consider using a proxy class, which maintains a reference to the original object, and manages creation and/or use of the object. These reasons are typically grouped into a few main cate­gories; for a specific object, reasons from more than one category may apply:

**Object is expensive to create**: Use a proxy to delay creation of the object until it is really needed. Such a proxy is also known as a **virtual proxy**.

**Object is expensive to use**: In the above example, it might also be very expensive to actually perform a route planning. A proxy could be used to cache the results of pre­vious calculations, or maybe delegate the calculation to an approximation algorithm, which may not produce the optimal result, but will be much faster to complete its calculation. Another example of expensive usage occurs if the object being proxied runs remotely, and some sort of network communication is required in order to use it. A proxy can then become a local representative of that object. Such a proxy is also known as a **remote proxy**.

**Object must only be accessed by callers with certain permission**. Instead of hard-coding such permission rules into the object itself, they can be implemented in a proxy class, which will then act as a gatekeeper with regards to access to the object. Such a proxy is also known as a **protective proxy**.

**Additional bookkeeping is needed when an object is accessed**. It may be interest­ing to obtain various statistical data on how the object is used, or it may be required to enforce exclusive access to the object, if it contains elements which are not thread-safe. Just as it was the case for access protection, we gain much more flexibility if we place such “extra” functionality in a proxy class, instead of hard-coding them into the object itself. In the above example, we could e.g. choose to keep the **RoutePlanner** class as clean as possible, in the sense that it should focus entirely on being able to calculate routes, and leave concerns like access protection, lazy creation etc. to proxy classes. Proxies of this nature are also known as **smart proxies**.

If you dive deeper into the world of Design Patterns, you may also come across a pat­tern known as the **Decorator** pattern. The difference between the Decorator pattern and the Proxy pattern is small and somewhat subtle. As we also saw in the example above, a Proxy class will usually be responsible for creating the proxied object itself, either directly or by use of a factory. For the Decorator pattern, the ob­ject-to-be-decorated will be provided to the Decorator, usually as a parameter to the Decorator con­structor. The Decorator pat­tern is thus a bit more flexible than Proxy, since Deco­ra­­tors and decorated objects can be combined more freely at run-time. However, the scope for using Decorators is also smaller, since a Decorator will typically have no con­trol over when the decorated object is created. Examples as the above are there­fore not good candidates for use of the Decorator pat­tern, whereas the Proxy pattern is quite useful.

# Design Patterns – Behavioral Patterns

The design patterns in this category are primarily concerned with the “dynamic” rela­tionships between classes and objects. By “dynamic” is meant that it is not just the way classes and objects are wired together which is of interest here; it is in particular how these classes and objects collaborate in order to achieve a certain functionality. Just as we saw for structural patterns, we can divide these patterns into class-level and object-level patterns.

Behavioral patterns at the class level realise collaboration through inheritance, and by carefully distributing responsibilities between the involved classes. A key issue is often how to distribute responsibilities between base classes and derived classes. The rela­tionships between the involved classes is thus established at compile-time, an cannot easily be changed at run-time.

Behavioral patterns at the object level realise collaboration through composition. Dis­tribution of responsibilities is also a key issue here. Due to the use of composition, the relationships between the involved objects can in principle be changed at run-time, which add another dimension of flexibility to these pattern.

We will take a closer look at two behavioral design patterns: the **Template Method** pattern (which is a class-level pattern) and the **Chain of Responsibility (CoR)** pattern (which is an object-level pattern).

## Template Method

A very common scenario in software design occurs when we can specify a general algorithm for solving a general problem, but cannot “flesh out” all of the steps in the algorithm, because some steps need to be implemented individually for e.g. each type of data we wish to apply the algorithm to. A classic example is an algorithm for con­ver­­­ting data to a text format. If we assume that a small interface **IDataSource** has been defined with operations for Load and Save, the algorithm could look like this:

**public abstract class DataToTextConverter<T>**

**{**

**// General algorithm for data-to-string conversion**

**public List<string> ConvertDataToText(IDataSource<T> source)**

**{**

**// Read data from the data source**

**List<T> data = source.Load();**

**// This list will contain the converted data**

**List<string> dataAsText = new List<string>();**

**// For each data item: convert the item to a string,**

**// and add that string to the dataAsText List**

**foreach (T item in data)**

**{**

**string itemAsText = ConvertItem(item);**

**dataAsText.Add(itemAsText);**

**}**

**return dataAsText;**

**}**

**// This method needs to be implemented in subclasses.**

**public abstract string ConvertItem(T item);**

**}**

This is a general algorithm for data-to-text conversion (if we assume that each data item can be converted to a single self-contained string). The only catch is the method **ConvertItem**. This method has no general implementation, since a spe­ci­fic conver­sion will depend on both the specific text format we wish to convert to, and on the data type **T** itself. With the base class in place, we can however fairly easily create a type-and-format specific derived class, for e.g. converting **Car** objects to XML:

**public class CarToXMLConverter : DataToTextConverter<Car>**

**{**

**public override string ConvertItem(Car item)**

**{**

**// Code for converting a Car object to XML**

**}**

**}**

That’s it. We can now create and use a **Car**-to-XML specific converter object. The derived class has two important features:

* It contains specific code for converting a specific type of object into a specific string format.
* It does not contain code that defines (or modifies) the general algorithm for data conversion.

A derived class cannot in any way interfere with the general algorithm; it only fleshes out a specific step, as it will look under specific circumstances. This is precisely the in­ten­tion of the Template Method pattern. The base class maintains absolute control over the general algorithm, while the derived class only gets called when the specific steps need to be carried out.

A Template Method – which in our example will refer to the top-level method **Con­vertData­To­Text** – will thus call methods that may be defined in the base class itself, or may be defined as abstract, and thereby being defined in derived classes. The stan­dard terminology used for describing these categories of methods follows below:

**Concrete operations**: These are methods or steps which are defined within the base class itself, and cannot be changed by a derived class. In our example, the line:

**List<T> data = source.Load();**

belongs to the group of concrete operations.

**Primitive operations**: These are the methods which are declared as abstract in the base class; in our example the **ConvertItem** method. These methods must be over­rided in a derived class.

**Hook operations**: A hook operation is a method which does have an implementation in the base class, but it may be overrided in a derived class. In C# terminology, this will be a virtual method. We do not have any such methods in our example, but it could make sense to turn the **ConvertItem** method into a hook operation:

**protected virtual string ConvertItem(T item)**

**{**

**return item.ToString();**

**}**

Deciding whether to go for an abstract or virtual approach will – of course – be highly dependent of the speficic scenario to which the pattern is applied.

The above example follows the classic approach to applying the Template Method pat­­tern; create a base class containing the Template Method itself, and create deri­ved classes containing definitions of the primitive and/or hook operations. Cli­ent code for using the classes could then look like this:

**List<Car> cars = new List<Car>();**

**// Populate list with Car objects**

**CarToXMLConverter carToXml = new CarToXMLConverter();**

**List<string> carsAsText = carToXml.ConvertDataToText(source);**

We create an object of the derived type, and use it for conversion. However, you can also achieve the same effect without having to define derived classes. In this exam­ple, we are in practice creating a derived class in order to add in a definition of one single method. But we have learned previously that methods themselves can also be para­meters to other methods! Consider the below version of **Con­vertData­To­Text** (com­ments have been omitted for brevity):

**public List<string> ConvertDataToText(IDataSource<T> source, Func<T,string> converter)**

**{**

**List<T> data = source.Load();**

**List<string> dataAsText = new List<string>();**

**foreach (T item in data)**

**{**

**string itemAsText = converter(item);**

**dataAsText.Add(itemAsText);**

**}**

**return dataAsText;**

**}**

Suppose now that the client code contains the below method definition:

**private string CarToXML(Car item)**

**{**

**// Code for converting a Car object to XML**

**}**

The client code for data conversion would then look like this:

**List<Car> cars = new List<Car>();**

**// Populate list with Car objects**

**DataToTextConverter<Car> carConv = new DataToTextConverter<Car>();**

**List<string> carsAsText = carConv.ConvertDataToText(source, CarToXML);**

In this case, the client code creates an object of the base class type (which may now be a misleading description, since we no longer need to create derived classes…), and simply provides the single type-specific method definition which is missing, as a met­hod parameter to **ConvertDataToText**.

This approach is definitely worth considering in this case, since we only need to pro­vide a single method parameter. If the Template Method contains several primitive and/or hook operations, the benefit becomes more doubtful. Suppose the caller has to provide four methods parameters. It then becomes the responsibility of the caller to ensure that the provided method parameters are compatible with each other. One method may perform part of the conversion, and perform it with XML as the target format. Another method may perform a different part, and the caller might acciden­tally provide a method which targets a different format! That will probably not end well. In that case, it is probably a safer approach to apply the Template Method pat­tern in the traditional way, to avoid unintended mixing of incompatible methods.

## Chain of Responsibility

A pattern like Template Mehtod is usually targeted at scenarios where one particular class will perform (a variant of) a specific algorithm. Some steps may vary from class to class, but the tem­plate method defines the algorithm as a whole. This also implies that the complete algorithm for “handling” a certain request lies within that single method. Some algorithms do however have a nature that is not modeled particularly well by this approach. Consider for instance a help system for an application. The user can try to look up help on any part of the system in a context-sensitive way, e.g. by pressing the **F1** key on the keyword. The algorithm for looking up help could then look like this:

1. If detailed help is available for the specific part of the application the user is currently using, then display that help information. Otherwise:
2. If more general help is available for the general part of the application the user is currently using, then display that help information. Otherwise:
3. Open the web site for the product in a browser.

In short; we try to find help which is as detailed as possible, and if that action fails, we try to find help at a more general level. How will this strategy look in code? If we wish to express this logic in one single method **LookupAndDisplayHelp**, it could look like this (we assume that a num­ber of more specific methods like e.g. **FindDetailed­Help** and **DisplayHelp** have been defined):

**public void LookupAndDisplayHelp(Context c)**

**{**

**HelpInfo info = FindDetailedHelp(c);**

**if (info == null) // No detailed help found**

**{**

**info = FindGeneralHelp(c);**

**}**

**if (info != null) // General help found**

**{**

**DisplayHelp(info); // Display help info**

**}**

**else**

**{**

**OpenProductWebsite(); // Go to website**

**}**

**}**

It’s not super-complicated logic, but it is somewhat fragile to change. If we at some point introduce a medium-level help system, we must update this code. Further­more, the code has a static nature; we cannot alter the order of alternatives at run-time, if that should become necessary.

The **Chain of Responsibility** (**CoR**) pattern offers an alternative strategy for organising code of this nature. The central principle is to implement each handling alternative in a sepa­rate class, but let all classes inherit from the same interface. Objects of these classes can then be chained together to form such a chain of responsibility. That is, each object of these classes will contain a reference to another object implementing the same inter­face. If an object is not capable of handling the given request, it simply forwards the re­qu­est to the object it references. At some point along this chain of handlers, some­one will actually handle the request, and the forwarding of the requ­est stops. The last object in the chain will not refer to any object, so this should be some sort of if-all-else-fails handler.

If we wish to apply this principle in the above example, we first need to define an inter­face for a “help handler”. It looks like we only need a single method:

**public interface IHelpHandler**

**{**

**void LookupAndDisplayHelp(Context c);**

**}**

Let’s try to implement this method in a handler for detailed help. We could call a class corresponding to this level of handling for **HelpHandlerDetailed**:

**// In class HelpHandlerDetailed**

**public void LookupAndDisplayHelp(Context c)**

**{**

**HelpInfo info = FindDetailedHelp(c);**

**if (info != null) // Help found!**

**{**

**DisplayHelp(info);**

**}**

**else**

**{**

**NextHandler?.LookupAndDisplayHelp(c);**

**}**

**}**

The logic is as described above; try to handle the request yourself, and forward the request if this proves impossible. As such, the code is pretty straightforward. How­ever, the class itself contains a few additional elements worth discussing:

**public class HelpHandlerDetailed : IHelpHandler**

**{**

**public HelpHandlerDetailed(IHelpHandler nextHandler = null)**

**{**

**\_nextHandler = nextHandler;**

**}**

**public IHelpHandler NextHandler { get; set; }**

**public void LookupAndDisplayHelp(Context c)**

**{**

**// As above**

**}**

**public HelpInfo FindDetailedHelp(Context c)**

**{**

**// Code for Loking up detailed help**

**}**

**public void DisplayHelp(HelpInfo h)**

**{**

**// Show help on screen**

**}**

**}**

First, we note that the class contains a property **NextHandler**. The key features of this property are:

* It has the type **IHelpHandler**.
* It is set at construction time, through a constructor parameter. If the parameter is not explicitly specified, it defaults to **null**.
* Its value can be changed later, i.e. it is possible at run-time to change the hand­ler to which the object refers.
* If the object cannot handle the request, it forwards the request to the handler referred to by **NextHandler** (unless itis **null**, in which case nothing happens).

All handler classes should follow this strategy, so there seems to be good reasons to introduce a handler base class, e.g. named **HelpHandlerBase**. The **NextHandler** pro­perty is an obvious candidate for being moved to the base class:

**public class HelpHandlerBase : IHelpHandler**

**{**

**public HelpHandlerBase(IHelpHandler nextHandler = null)**

**{**

**NextHandler = nextHandler;**

**}**

**public IHelpHandler NextHandler { get; set; }**

**}**

Can we move additional code into the base class? The method **DisplayHelp** seems to be a general method for displaying help information, so it can likely also be moved to the base class. This leaves the method **FindDetailedHelp**, and the interface method **LookupAndDisplayHelp** itself. **FindDetailedHelp** seems to be quite specific for this level of help retrieval, so it probably needs to stay in the specialised class. But what about the interface method? Let’s have a look at it again:

**// In class HelpHandlerDetailed**

**public void LookupAndDisplayHelp(Context c)**

**{**

**HelpInfo info = FindDetailedHelp(c);**

**if (info != null) // Help found!**

**{**

**DisplayHelp(info);**

**}**

**else**

**{**

**NextHandler?.LookupAndDisplayHelp(c);**

**}**

**}**

How much of this code is general, and how much of it is specific? It is actually only the highlighted part which is specific! The rest of the code will look exactly the same if we implemented it in a class for general help handling, e.g. named **HelpHandler­General**:

**// In class HelpHandlerGeneral**

**public void LookupAndDisplayHelp(Context c)**

**{**

**HelpInfo info = FindGeneralHelp(c);**

**if (info != null) // Help found!**

**{**

**DisplayHelp(info);**

**}**

**else**

**{**

**NextHandler?.LookupAndDisplayHelp(c);**

**}**

**}**

So, we have a general algorithm, with a single step which might vary under specific circumstances… doesn’t that sound familiar? This is exactly a case for the Template Method pattern, which we have just learned about! Applying the Template Method pattern here will give us this implementation of **LookupAndDisplayHelp** in the base class:

**public void LookupAndDisplayHelp(Context c)**

**{**

**HelpInfo info = FindHelp(c);**

**if (info != null) // Help found!**

**{**

**DisplayHelp(info);**

**}**

**else**

**{**

**NextHandler?.LookupAndDisplayHelp(c);**

**}**

**}**

**public abstract HelpInfo FindHelp(Context c);**

All that remains is a fairly trivial implementation of **FindHelp** in the specialised class­es, e.g. like this:

**// In class HelpHandlerDetailed**

**public override HelpInfo FindHelp(Context c)**

**{**

**return FindDetailedHelp(c);**

**}**

What about the if-all-else-fails class? Can we implement this class by using the base class? We can, if we are a little bit creative when implementing **FindHelp**:

**// In class HelpHandlerNoHelpFound**

**public override HelpInfo FindHelp(Context c)**

**{**

**OpenProductWebsite(); // Go to website**

**return null;**

**}**

This will force execution of the **else**-part in the base class implementation of **Lookup­AndDisplayHelp**, and since the **NextHandler** property must be null (otherwise, this would not be the if-all-else-fails handler…), the forwarding stops. If this feels like twist­ing the intention of the base class implementation of **Lookup­AndDisplayHelp** too much, you can still just implement **HelpHandlerNoHelpFound** by only inheriting from the interface **IHelpHandler**:

**public class HelpHandlerNoHelpFound : IHelpHandler**

**{**

**public void LookupAndDisplayHelp(Context c)**

**{**

**OpenProductWebsite();**

**}**

**public void OpenProductWebsite()**

**{**

**// Code for opening product website**

**}**

**}**

The requirement for participating in this particular Chain of Responsibility is (still) only that you implement the interface, not that you inherit from the base class. The base class is just a convenient implementation of the “typical” request handlers.

Proceeding in this way, we can create a set of request handler classes, which are un­aware of each other w.r.t. specific types. Handlers only reference each other by the interface type. The last remaining issue is how to set up a specific chain of responsi­bility. This will be done in a part of the client code, probably a part dedicated to appli­cation configuration in general:

**IHelpHandler noHH = new HelpHandlerNoHelpFound();**

**IHelpHandler generalHH = new HelpHandlerGeneral(noHH);**

**IHelpHandler detailedHH = new HelpHandlerDetailed(generalHH);**

**// …hand reference to detailedHH to relevant parts of the application**

The above example creates a single chain of responsibility, which may be the correct approach in many cases. You could also imagine that separate classes for different types of detailed help handling were created, which would lead to a slightly more complex setup procedure, like this:

**IHelpHandler noHH = new HelpHandlerNoHelpFound();**

**IHelpHandler generalHH = new HelpHandlerGeneral(noHH);**

**IHelpHandler createHH = new HelpHandlerCreate(generalHH);**

**IHelpHandler deleteHH = new HelpHandlerDelete(generalHH);**

**// …hand references to createHH and deleteHH**

**// to relevant parts of the application**

This effectively creates two chains of responsibility; one starting at **createHH**, and another starting at **deleteHH**. Both of these detailed handler objects will forward a request to the (single) general handler object, which makes perfect sense. There is nothing in the pattern as such that forbids many handlers to refer to the same hand­ler down the chain.

As the Chain of Responsibility pattern is described here, a request will only be hand­led by a single handler, i.e. the first handler which can handle the request properly. A use-ful vari­ant of this could be to allow the handler to handle the request and for­ward the request down the chain. This could be relevant if several parties are invol­ved in hand­ling a single request. If we express the original handling principle in more general terms, it could look like this (**Handle** is an abstract method, which returns **true** is the request was successfully handled):

**public void HandleRequest(Request r)**

**{**

**if (!Handle(r))**

**{**

**NextHandler?.HandleRequest(r);**

**}**

**}**

Changing this to giving handlers down the chain the opportunity to the handle the request requires a very modest code change:

**public void HandleRequest(Request r)**

**{**

**Handle(r);**

**NextHandler?.HandleRequest(r);**

**}**

This can be compared with the ”rethrowing” strategy used in relation to exception handling.

This short tour-de-force through a couple of Object-Oriented design principles and a good handful of design patterns is now at an end. The two books mentioned in foot­notes provide a much more thorough treatment of these topic, and are highly recom­mendable.

# Exercises

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| **Exercise** | OOP3.1 |
| **Solutions** | WeaponFactory |
| **Purpose** | Use the Factory Method design pattern in practice |
| **Description** | The **WeaponFactory** project contains:   * Interfaces for weapon classes and weapon factory classes, in the folder **Interfaces**. This folder also contains the enumeration **WeaponType**. * A weapon base class **WeaponBase**, and several classes repre­senting speci­fic weapons, all in the folder **Weapons**. * Two (incomplete) factory classes **WeaponFactoryMedieval** and **Weapon­FactoryFuture**, in the **Factories** folder. * A test class **WeaponFactoryTest**. |
| **Steps** | 1. Complete the implementation of the two factory classes. The intention of both classes is: given a weapon type (the parameter **type** to the **Create** method), create and return a weapon object which matches the weapon type and the “era” for the factory, i.e. medieval weapons for the **Weapon­FactoryMedieval** factory, and futuristic weapons for the **Weapon­Factory­Future** factory. 2. Test your implementation by uncommenting the indicated lines in the **Run** method in the **WeaponFactoryTest** class. 3. This approach to weapon object generation is perhaps a bit fragile. What could go wrong (with regards to how the factory classes are implemen­ted)? What could be improved? |

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| **Exercise** | OOP3.2 |
| **Solutions** | EnvironmentGenerator |
| **Purpose** | Use the Abstract Factory design pattern in practice |
| **Description** | The **EnvironmentGenerator** project can be seen as an extension of the **Weapon­Factory** project from the previous exercise. In addition to weapon objects, we now also want to generate building and creature objects, as part of a general environment generation algorithm.  The **EnvironmentGenerator** project contains:   * Interfaces for the three “environment element” types (weapon, building and creature) and corresponding interfaces for factory classes, all in the folder **Interfaces**. * Specific classes and factories corresponding to the medieval era, in the folder **ImplMedieval**, and likewise for the future era in **ImplFuture**. * An **Environment** folder (more details below) * A test class **EnvironmentGeneratorTest**. |
| **Steps** | 1. Take a quick cruise through the classes, enumerations and interfaces in the three folders **Interfaces**, **ImplMedieval** and **ImplFuture**. They are all quite simple. Do however pay some attention to the grouping of classes. How is it ensured that e.g. all medieval factories can only produce objects belonging to the medieval era? (Hint: does **Create** take any parameters?). 2. In the **Environment** folder, take a look at the **IEnvironmentGenerator** interface, and the **EnvironmentGeneratorBase** class. They are intended to define the interface and implementation of an Abstract Factory. There is however a problem in the **EnvironmentGeneratorBase** class… See if you can spot the problem (Hint: the objects generated by an Abstract Factory should belong to the same “family” of objects). 3. Take a look at the **RunExisting** method in the **EnvironmentGeneratorTest** class. Can you now see what the problem from 2) is? If not, try to run the application, and see the output of the test. 4. Open the (empty) class **EnvironmentGeneratorFuture**. This class should implement the **IEnvironmentGenerator** interface, but in a way that en­sures that all objects created by the factory belong to the future era. Implement the class, and implement **EnvironmentGeneratorMedieval** in a similar way. 5. Modify the **Create** method in the **EnvironmentGeneratorFactory** class, such that it returns the correct environment factory objects. 6. Uncomment the code lines in the **RunImproved** method in the **Environ­ment­Gene­ra­tor­Test** class, run the application, and see the effect ☺. |

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| **Exercise** | OOP3.3 |
| **Solutions** | DataAccess |
| **Purpose** | Use the Adapter design pattern in practice |
| **Description** | The project models a scenario where a legacy database access tool needs to be used still, but through a different interface. The **DataAccess** project contains:   * Two simple domain classes **Car** and **Customer**, plus an interface **IHasKey**, in the folder **DomainClasses**. * A database access tool named **DBTool**, which can access a database (simu­lated by the class **Database**). Both are found in the **DBToolClasses** folder. * The **DataSource** folder, which contains the **IDataSource** interface. This is the interface the adapter class must implement. The folder contains some additional classes, which we return to below. |
| **Steps** | 1. Take a look at the domain classes **Car** and **Customer**. What is the most important difference between those two classes? 2. Take a look at the **Database** class. It is not so important to understand it in details, since it is accessed through the existing **DBTool** class. 3. Take a more thorough look at the **DBTool** class. The most important things to note are:    1. What public methods and properties does **DBTool** contain?    2. What parameters do the methods require? What is returned?    3. What do they do (see the comments for each method/property) 4. Run the application – it contains a small test of the existing **DBTool** class. Take note of the number of objects printed after each operation. 5. Now open the (incomplete) **DBToolAdapter** class. This class is supposed to become an adapter for **DBTool**. That is, it must implement all methods and properties in the **IDataSource** interface, by using the methods and properties available on the **DBTool** class. 6. Implement all methods and properties in the **DBToolAdapter** class. Some implementations are quite simple (i.e. a single line of code), while others will require a bit more work. 7. Once you have finished the implementation, open the **DataAccessTest** class. In the method **Run**, uncomment the first set of code lines, i.e. the lines testing the **DBToolAdapter** class. Run the application; hopefully, the test should produce the same results as the test from step 4). 8. We now also want to be able to use (an adapted) **DBTool** with domain classes that do NOT implement **IHasKey**. Explore the classes **KeyAdapter** and **DataSourceAdapter**, and see if you can make that happen. A test for such an adapter is also found in **DataAccessTest**, using the **Car** class as the adapted domain class. |

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| **Exercise** | OOP3.4 |
| **Solutions** | CalculationProxy |
| **Purpose** | Use the Proxy design pattern in practice |
| **Description** | This project tries to simulate a complex calculation, which has the following fea­tures:   * It takes an integer x- and y-coordinate as input (in the project, x and y are per default integer numbers between 1 and 5, both included). * A calculation takes between 300ms and 700ms, which is simulated by a call to Thread.Sleep in the calculation method. * It always returns the same result for a given x- and y-coordinate   It could therefore be beneficial not to calculate the same result over and over, but rather save a calculated result in a “cache”, which can then be used to look up results rather than calculating them again. |
| **Steps** | 1. Take a look at the **ICalculate** interface in the **Common** folder. It is quite minimal. You can also peek into the **Coordinate** class (it essentially con­tains an X and a Y coordinate pair). 2. Take a look at the **CalculatorFactory** class in the **Common** folder. Note how it returns either a **Calculator** object or a **CalculatorProxy** object. How come that it is possible to return either of these objects? What do they have in common? 3. Take a look at the **Calculator** class in the **ActualCalc** folder. What method must be implemented by this class? 4. Take a thorough look at the (incomplete) **CalculatorProxy** class in the **CalcByProxy** folder. What method must be implemented by this class? What does this class and the **Calculator** class have in common? How are they different? 5. The method **Calculate** in **CalculatorProxy** currently just calls **Calculate** on the proxied calculator object. If you run the application, you will see that the choice of strategy doesn’t make any difference. This must be fixed… 6. Implement the **Calculate** method in **CalculatorProxy** properly, by follow­ing the description given in the comments to the method. This may also require that you peek into the **Cache** class. 7. Re-run the application, and (hopefully) observe the positive effect of using the “calculation-by-proxy” strategy. |

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| **Exercise** | OOP3.5 |
| **Solutions** | Fight1v1 |
| **Purpose** | Use the Template Method design pattern in practice |
| **Description** | The **Fight1v1** project contains:   * An interface for 1v1 fight management, and an enumeration for specific fight types, in the folder **Interfaces**. * A general implementation of 1v1 fight management, in the class **Fight1v1­Manager**, and two (incomplete) classes **Fight1v1­ManagerFair** and **Fight­1v1ManagerBiasedA**, both derived from **Fight1v1Manager**. These classes are found in the folder **Fight­Managers**. * A factory class **Fight1v1ManagerFactory**, and a test class **Fight­1v1­Manager­Test**. |
| **Steps** | 1. Take a look at the enumeration and interface in the **Interfaces** folder. They are both quite simple. 2. Take a look at the **Player** class. It is as such not at the center of attention in this exercise, but make sure you understand its general functionality. 3. Take a thorough look at the class **Fight1v1Manager** in the **FightManagers** folder. This is the central class in the project. Make sure you understand the roles of the methods **Fight**, **SingleFight** and **ExchangeBlows**. 4. In the Template Method design pattern terminology, what kind of method is **Fight**? What kind of operation is **ExchangeBlows**? 5. The method **ExchangeBlows** is abstract in **Fight1v1Manager**. Where do you suppose it will be implemented? 6. Open the classes **Fight1v1ManagerFair** and **Fight1v1ManagerBiasedA**. How are they related to **Fight1v1Manager**? 7. Implement the **ExchangeBlows** method in both of the classes above, and run the application to see how the fighting plays out in both cases (a test which tests both cases is already implemented in the project). Feel free to adjust the setting for the two fighters (in **Fight1v1ManagerTest**), to see how it affects the fighting. 8. Review your implementation of **ExchangeBlows** in the two derived class­es. Could both strategies be implemented in a single class, if we are allow­ed to add more parameters to the **ExchangeBlows** method? |

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| **Exercise** | OOP3.6 |
| **Solutions** | SupportManagement |
| **Purpose** | Use the Chain of Responsibility (CoR) design pattern in practice |
| **Description** | A fictitious IT Support Center receives error tickets (reports on errors in some IT system), that can be at one of four levels of criticality: *Light*, *Moderate*, *Severe* or *Catastrophic*. Furthermore, an error ticket may be written in either Danish or English. An error ticket can be handled by one of four support departments:   * **Local Support**: Can handle *Light* error tickets in Danish or English. * **National Support**: Can handle *Moderate* error tickets in Danish or English. * **Regional Support**: Can handle *Severe* error tickets written in English. * **World Support**: Can handle *Catastrophic* error tickets written in English.   The Support Center also contains a Translation Service, which can translate an error ticket from Danish to English. However, translation is considered expensive, so translation is only done if strictly necessary. In practice, this means that error tickets at level *Severe* or *Catastrophic* are translated, if they are written in Danish.  The **SupportManagement** project implements a model of the Support Center’s strategy for processing of error tickets. The project contains:   * The folder **Error**, which contains the class **ErrorTicket** plus a couple of related enumerations. * The folder **SupportCommon**, which contains two interfaces **ISupport­Action** and **ISupportCenter**, plus corresponding base classes. * The folder **SupportOriginal**, which contains the class **SupportCenter­Original** (implements **ISupportCenter**), plus classes representing the four support departments plus the translation service. * The folder **SupportCoR** (CoR: *Chain of Responsibility*), which we return to later. |
| **Steps** | 1. Start out in the **SupportCommon** folder. Study the two interfaces and the corresponding base class implementations. They define the general struc­ture of a Support Center. Notice the methods **HandleOpenTickets** and **TryHandleTicket**. Which design pattern are these methods implementing? 2. Move on to the **SupportOriginal** folder, and take a quick tour of the four **…Support** classes. What do they have in common? Also take a look at the **TranslatorService** class. How is this class different from the **…Support** classes? 3. Take a thorough look at the class **SupportCenterOriginal**, in particu­lar the method **TryHandleTicket**. Why must this class implement this me­thod? What do you think of this method in terms of flexibility? Can we change the way it works at run-time? 4. Run the application – it will run a small test of **SupportCenterOriginal**. The test creates 10 error tickets, and tries to process them. The test should show that all 10 tickets end up in the list of Closed tickets. 5. Move on to the folder **SupportCenterCoR**. First, go into the subfolder **Support­Handler**, and study the interface **ISup­port­Handler**. It defines the idea of a “support handler”, which either handles an error ticket itself, or passes the ticket on to another handler. Move on to the **SupportHandler­Base** class. Make sure you understand how the methods from the inter­face are implemented. Can you recognise the design pattern being used? 6. Still in the **Support­Handler** subfolder, study the class **SupportHandler­Aggregation**. Can you figure out how this makes it possible to use the existing support classes from the **SupportOriginal** folder? 7. Move on to the **Adapters** subfolder. The idea is to consider translation and the *if-all-else-fails* handling from the **SupportCenterOriginal** implemen­ta­tion as support handlers as well. These two operations must therefore be “adapted” to fit the **ISupportHandler** interface. Study the two **…Adapter** classes, to see how this adaptation is performed. 8. The final step is to build a *Chain of Responsibility* for a Support Center. In the **Config** folder, take a look at the **ISupportCoRConfiguration** interface. Then take a look at the **SupportCoRConfigurationDefault** class. The CoR built in **SetupSupportCoR** is currently very short – it only contains a single handler. Run the application, and observe that the test of **SupportCen­ter­CoR** shows that all 10 error tickets end up in the list of Unhandled tickets. 9. Change the implementation of **SetupSupportCoR**, such that the resulting CoR defines the same support strategy as used in **SupportCenterOriginal**. You can use the test to see if you are on the right track. Hint: The com­ple­te CoR should contain a total of six handler objects. 10. Compare this implementation of support strategy with the original imple­mentation. Can you change the support strategy without changing any code in **SupportCenterCoR**? Where is the decision about using a specific strategy taken? |

1. Design Patterns, by Erich Gamma, Richard Helm, Ralph Johnsen and John Vlissides, ISBN 0-201-63361-2 [↑](#footnote-ref-1)
2. A very recommendable book on SOLID is: “Adaptive Code via C# (Agile codong with design patterns and SOLID principles”, by Gary M. Hall, ISBN 978-0-7356-8320-4 [↑](#footnote-ref-2)