University of the Philippines Cebu

CMSC 23

Programming Paradigms

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September 2020

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Programming Paradigms Introduction

Introduction

I've probably talked about my issue about the title of this course. You see, it's a misnomer, it's not named correctly. Most of this course will actually focus on objective oriented programing, you can see it in the syllabus. That being the case, it should have been named object oriented programming instead. But we ARE going to spend some weeks to talk about programming paradigms at the start of this course.

Learning Outcomes

At the end of this discussion you should be able to:

1. Explain what a programming paradigm is.
2. Identify the four main programming paradigms

3. Explain why programming languages are shifting to multi-paradigmness

The title of this course

Let's start by talking about the notorious title of the course name because it does sound like some forced alliteration buzz phrase that you'll probably hear out of the mouth of some CS student. You will start saying this phrase soon so let's get the definition out of the way.

"Programming paradigms".

You're probably familiar what half of this phrase means, I mean, I hope you are, otherwise I don't know what to do.

Paradigm

Let's focus first on the non-obvious part, the word paradigm. This word comes up often in academia. You probably heard of the term paradigm shift some where, it describes some form of fundamental change in the way we think within scientific disciplines often characterizing a scientific revolution, one notable example of a paradigm is the shift from Ptolemaic or Geocentric cosmology to Copernican or Heliocentric cosmology. Based on this context you can kind of formulate what the word paradigm means. You don't have to take out your dictionaries or whatever, because I'm going to read to you a dictionary definition I found. This one is connotes a similar meaning in the context of programming:

A paradigm is "a worldview underlying the theories and methodology of a particular subject" [1]. It is a set of ideas and concepts that describe some way of thinking.

If we go back to the geocentric vs heliocentric paradigms in astronomy, you can't really definitively say that the heliocentric model is the only correct model of the solar system, you can still reconcile the geocentric model's perspective of putting the earth in the center by imagining heavenly bodies with strange orbits containing epicycles and other mechanics. After all whether or not the earth or the sun is the center is a matter of perspective. It just so happens that placing the sun in the center provided science with a more natural way of describing planetary movement. The heliocentric paradigm ended up uprooting geocentric paradigm as the dominant worldview, providing science with ideas that we still accept as truth until now, the earth is not the center. The earth is just one of the

[1] In Lexico.com, Available at https://www.lexico.com/en/definition/paradigmAccessed August 28, 2020

9 planets, is not that special, gravity and inertia works in way which causes planets to move and etc.

A paradigm shift like this is actually happening in programming language design, well talk about that some time later.

Programming

Now that you understand what paradigm means, let's talk about the first word, programming. It's a strange question to ask in a second year course but I want you all to think about what the definition of programming is. The way you answer this question may actually tell you which perspective or programming PARADIGM you follow. When you say you are "programming" some kind of mechanism or behavior what are you actually doing? How do you define what a program is and what is its relationship to a computer?

I would have loved to hear your answers on this but since we cant do that. I'll tell you instead to seriously think about that question before I proceed.

Since I don't know how you responded to that I'll instead turn to the internet and look for an answer that probably looks like your answer.

Here's one:

"Computer programming is the process that professionals use to write code that instructs how a computer, application or software program performs. At its most basic, computer programming is a set of instructions to facilitate specific actions.[2]"

That is correct. Let me simplify that definition to this.

Programming is when you tell a computer what to do. When you write programs you're writing instructions for your computer.

Step 1. Ask the user for a number

Step 2. Store that number to a variable called x.

Step 3. While x is greater than 7 do step 4 otherwise proceed

Step 4. Subtract 7 to x and store the difference to x

Step 5. Show the user the value of x

That is a good definition of programming. It gives you an understanding on how you write programs that work. All you need to do is to write correct instructions that the computer understands and you'll have a perfectly working program. A programming language is a medium that describes how to write instructions to

[2] What is Computer Programming and How to Become a Computer Programmer, SNHU from https://www.snhu.edu/about-us/newsroom/2018/06/what-is-computer-programming Accessed August 28, 2020

communicate to your computer. If you learn to do that then you can go ahead and program away.

It is a correct definition, but is it the only correct definition? It defines programming under the paradigm imperative programming. I will not begrudge you if this is the only definition you know since there is a huge likelihood that the only paradigm you've been exposed to has been imperative programming.

Taxonomy of Programming Paradigms

For someone who has been exposed to C, C++ and nothing else, you might feel that the natural way to code is the *imperative way* when in fact there are alternatives.

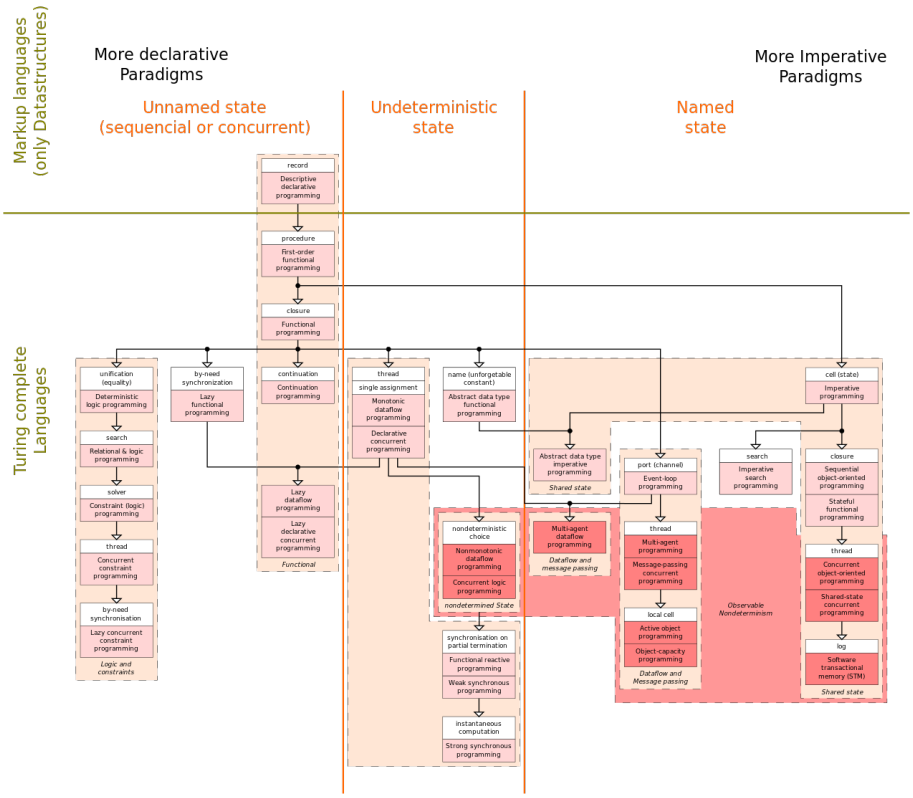


Figure 1.1: Programming Paradigms

The diagram[3] here represents the alternative schools of thoughts describing how to program. This diagram taxonomizes programming languages by identifying which paradigms they are under. Most of these paradigms are either not pragmatic, not popular enough or not unique enough to be studied in this course. Instead we will be focusing on four major programming paradigms:

[3] Programming Paradigms according to VanRoy by MovGP0 used under CC BY-SA from https://en.wikipedia.org/wiki/Programming_paradigm#/media/File:Programming_paradigms.svg

```
graph TD;
Imperative-->Procedural;
Imperative-->ObjectOriented;
Declarative-->Functional;
Declarative-->Logic;
```

Under the imperative family, procedural programming and objective oriented programming.

Under the declarative family, functional programming and logic programming.

This course will give you an overview on these programming paradigms. Each of these are built upon the foundation of some mathematical formalism. We will explore the advantages and disadvantages of each paradigm while we take a tour through these four. Studying the disciplines upheld by these paradigms will also teach us good programming practices for designing elegant programs that transcends any programming paradigm.

Multi-paradigm programming languages

The way it used to be was that a programming language would be written with features adhering to the concepts of a particular paradigm. Sometimes, a language is written with fresh features that follow a different mathematical formalism that births its own programming paradigm. Back then paradigms worked like programming language classifications. The programming language C for example is a strong follower of procedural programming. Therefore, you can think of C as classified under procedural programming.

But as time passed by classifying a newer programming language under one paradigm became harder and harder. A programming language like python for example is mostly procedural, object-oriented, but sometimes functional.

Modern programming languages evolved to become multi-paradigm. This inevitably happened because, as programming languages age and grow, more features are added to it. These features are sometimes borrowed from other paradigms to solve a problem in a better way. This is the reason why established and mainstream programming languages like Java, C++, or Python tend to be multi-paradigm.

The multi-paradigmness of programming languages tend to be the reason why some programming language designers have abandoned the notion of building based on a strict paradigm. Instead a language designer would choose specific **features** that they want to be supported on their programming language and implement it, regardless of its paradigm origins.

Optional Readings

Van Roy, Peter. (2012). Programming Paradigms for Dummies: What Every Programmer Should Know.

Imperative Programming

Introduction

Imperative programming has turned out to be the natural paradigm of programming languages. The members of the imperative programming family has been dominating the market share of programming languages throughout the years with titans like BASIC, Pascal, C, Java and many more.

Learning Outcomes

At the end of this discussion you should be able to

1. Explain how imperative programming became the natural paradigm
2. Explain the concept of state in the context of imperative programming
3. Explain how the assignment statement enables the progression of states
4. Create structure programs to represent algorithms
5. Differentiate the subparadigms procedural programming and object-oriented programming

Quick Note on Imperative Programming and Procedural Programming

People usually use the terms Imperative programming and procedural programming interchangeably. Procedural programming is a sub-paradigm of imperative programming family but some people refer to procedural programming as imperative programming. That's because other imperative paradigms like object-oriented programming is derived from procedural programming. You can think procedural programming as the ancestor if other imperative paradigms.

In this lecture I refer to Imperative paradigm as a whole but I will focus on the main ideas that are common between other imperative paradigms. Ideas from object-oriented programming paradigm can be found on a separate lecture.

Imperative programming has turned out to be the natural paradigm of programming languages. The members of the imperative programming family has been dominating the market share of programming languages throughout the years with titans like BASIC, Pascal, C, Java and many more.

If you think about it, this is not really surprising. This paradigms dominance could be attributed to most computer scientists' preference towards pragmatic and efficient programming languages. Especially since the most straightforward way of communicating to computer hardware is through the explicit manipulation of CPU memory and registers.

If you want the computer to do something for you, then you communicate to the computer that you want this and that to be done. And if you manage to give the computer correct and comprehensive instructions then you'll end up getting what you want.

If we rewind back to the dawn of programming languages you'll see that early programming languages were built to communicate to computer hardware. As a result of this, programming languages naturally adopted syntax with imperative moods.

Assembly programs for example was mostly built from sequences of executable instructions which was patterned from imperative statements from natural language.

```
INC ITER
MOV AH,7
ADD AH, AL
```

For example the assembly instruction, INC ITER, tells the computer to increment the memory variable called ITER. The instruction MOV AH, 7, tells the computer to move the value 7 to the AH register. The instruction ADD AH, AL tells the computer to add the contents of the AH register to the AL register.

As time went by, newer higher level programming languages emerged (higher level meaning farther from hardware and closer to human language) like Basic, Pascal, and C. The syntax of these programming languages were written as abstractions of hardware code. Although programs written in these languages became more human readable compared to its predecessors, these newer languages retained their imperative tones and mechanisms. This progression meant that higher level programming languages built atop of imperative languages naturally adopted the imperative paradigm as well. Java, Python, and C++ for example which were all written in C, followed this progression, thus establishing the imperative family as the dominant paradigm in programming language design.

The STATE

The existence of an explicit state is the foundation of imperative programming. The **state** of a program or a process on a given instance is the snapshot of its immediate relevant environment and context. The state of your CPU on a given instance for example will refer to the values found in the registers and relevant memory. On a specific process the state will refer to the values inside the memory addresses it resides in.

On a computer program the state can refer the conceptual set of variable values related to the program's runtime on some given instance. Lets use this program as an example:

```
int x = 3
int y = 4
x = x + y
```

At the start of runtime, the state of this program would be (*for all intents and purposes*) empty, since there are no relevant variables declared at this point. After executing the first line of code, the state of the program would look something like this:

variable	value
`x`	3

One integer variable named `x` with the value 3. After the next line of code a new variable is is introduced and immediately assigned with the value 4 so the state of the program at this instance will look like this:

variable	value
`x`	3
`y`	4

And at the last line, the value of `x` is updated by adding the value of `y` so the final state of this program will look like this:

variable	value
`x`	7
`y`	4

Assignment Statement

Another important construct of the imperative programming paradigm is the assignment statement. Assignment statements and the concept of state are very related to each other.

Assignment statements allow your program to MUTATE the values of your variables. Mutation in the context of programming is a fancy term that basically means change. And as we learned earlier, changes to the context of a program, which includes variables, creates states.

Therefore every assignment statement, corresponds to new states of a for the program.

Assignment statements are usually executed through the use of the "**=**" operator (some languages like Pascal use "**:=**" instead). Although it borrows the equality operator from math, assignment operators behave very differently from an equality statement. Instead of communicating some kind proposition, the assignment statement has an **imperative mood**. An equality a=b in math **declares** that some a is b, while an assignment operator **a=b commands** that **a**'s value is now the same as **b**. Mutation is introduced once you perform an assignment to **a** again, signifying a **change** in the value of **a**.

By the way, the closest corresponding mathematical construct to an assignment statement is the let statement. A statement in math such as "let x be equal to 3", has an imperative mood. But unlike an assignment statement which can change the value of a variable any number of times, a let statement can only set the value of a variable once.

For every assignment statement you feed to the computer, something meaningful happens. That particular "something" that happens is characterized by changes to your programs context. The context of a program changes for every individual mutation of a variable. And you can compare the difference between the before and after of a specific assignment by comparing the before-assignment state and the after-assignment state. The progression from one state to another characterizes the effect of an assignment.

This is the important take away that you need to remember. Imperative programming is characterized by imperative statements. Statements that tell the computer what to do. The most important type of these statements is the assignment statement. An assignment statements effect to your computer is characterized by the progression from one state to another. Assignment statements make states, and if you combine many of these assignment statements arranged in a particular manner, you can create a meaningful program that does something for you.

Structured Program Theorem

Creating meaningful programs in imperative programming is done by applying the Bohm Jacopini Theorem. This theorem was one of the theoretical frameworks proposed to characterize imperative programming.

The theorem describes a formalism of a class called control flow graphs which are capable of representing any computable function. These control flow graphs are actually something you are intimately familar of. It is known to you as the trusty old flow chart. Any control flow graph can be created by combining subprograms in three specific ways. A subprogram is a recursive unit of control flow graphs. A subprogram can be a single statement or it can be a combination of more than one subprogram. Here are the three ways to combine subprograms:

1. Executing one subprogram, and then another subprogram (sequence)
2. Executing one of two subprograms according to the value of a boolean (selection)
3. Repeatedly executing a subprogram as long as a boolean expression is true (iteration)

Structured programming enjoyed a universal popularity in computer science. The constructs described by this formalism became the natural architecture for programming language designers. This is the reason why CS students like you are introduced to programming using control flow graphs or flow charts. This is also the reason why programming languages like Pascal, C, Java and their derivatives are designed the way they are.

Subparadigms under the Imperative family

Procedural programming

Programming languages like Fortran, ALGOL, BASIC, and C fall under the procedural paradigm. Languages under this paradigm simplify a complex system by subdividing a program into different **procedures** or functions.

Object oriented programming

Object oriented programming focuses on modelling a system based on the real world ontology of objects. It uses an expressive type system to program the interactions within a system.

Optional Readings

Rapaport W. (2004) Great Idea III: The Boehm-Jacopini Theorem and Structured Programming. CSE 111, Fall 2004 Accessed August 31, 2020

Functional Programming Paradigm

Introduction

During the 1930's a mathematician investigating the foundation of mathematics, named Alonzo Church, introduced a formal system of expressing computational logic. The system he created was called **Lambda Calculus**. It was until the 1960's when the system found its way through different disciplines. It became something more than a a mathematical formalism and became an important concept in linguistics and **computer science**[1].

Learning Outcomes

After this discussion you will be able to:

1. Reduce lambda calculus expressions (Optional)
2. Create higher order functions

[1]Church, A. (1932). A Set of Postulates for the Foundation of Logic. *Annals of Mathematics*, 33(2), second series, 346-366. doi:10.2307/1968337

3. Identify pure functions
4. Explain how the advantages of statelessness in functional programming paradigm
5. Explain the disadvantages of statelessness functional programming paradigm

Lambda Calculus

Before we dive into functional programming let's introduce ourselves to the formalism that inspired it, Lambda Calculus. These concepts may seem strange at first since it imagines a mathematical foundation beyond numbers, sets, and logic. You can skip this video and it won't really affect your understanding of functional programming concepts. But I think understanding the concepts of this formalism will give us a better appreciation for functional programming.

Expressions in the Lambda Calculus Formalism

Let Λ be the set of expressions under the Lambda calculus formalism

1. **Variables**. If x is a variable, then $x \in \Lambda$
2. **Abstractions**. If x is a variable and $\mathscr{M} \in \Lambda$, then $(\lambda x.\mathscr{M}) \in \Lambda$.
3. **Applications**. If $\mathscr{M} \in \Lambda \wedge \mathscr{N} \in \Lambda$, then $(\mathscr{M}\mathscr{N}) \in \Lambda$.

Take a look at these important precedence conventions. You might get confused if you read some lambda calculus expressions. Some people often omit parentheses or single-parametrizations to write shorter expressions:

1. Application is left associative

$$\mathscr{M}\mathscr{M}\mathscr{M} \equiv ((\mathscr{M}\mathscr{M})\mathscr{M})$$

2. Consecutive abstractions can be uncurried

$$\lambda xyz.\mathscr{M} \equiv \lambda x.\lambda y.\lambda z.\mathscr{M}$$

3. The body of an abstraction extends to the right

$$\lambda x.\mathscr{M}\mathscr{N} \equiv \lambda x.(\mathscr{M}\mathscr{N})$$

Reductions

Reductions are a ways to simplify and evaluate lambda expressions. You'll learn later that these reductions are basically concepts that are eventually adapted to functional programming concepts.

α *equivalence:*

α equivalence states that any bound variable, has no inherent meaning and can be replaced by another variable:

$$\lambda x.x =_\alpha \lambda y.y$$

Given a lambda calculus abstraction $\lambda x.\mathscr{M}$, this abstraction's bound variable is x. The bound variable x may appear somewhere in $\mathscr{M}$, the body of the abstraction. An alpha equivalence basically shows that the name of the variable has no inherent meaning. Therefore, you can replace it with any other variable name.

β *Reductions*

β reductions state how to simplify abstractions. This process is similar to applying a function in the context of programming. For example we use the identity function ($\lambda x.x$) and apply it to some free variable y.

$$(\lambda x.x)y \rightarrow_\beta y$$

When you beta reduce some application $\mathscr{M}\mathscr{N}$, what you're doing is replacing all instances of the bound variable in $\mathscr{M}$ with $\mathscr{N}$. When, Here's a another example,

$$(\lambda u.\lambda v.uvu)\lambda x.x \rightarrow_\beta$$

η *reductions*

η reductions describe equivalencies that arise because of free variables. If x is a variable and does not appear free in $\mathscr{M}$ then:

$$\lambda x.(\mathscr{M}x) \rightarrow_\eta \mathscr{M}$$

The lambda expression here is just some redundant abstraction. These η reductions characterize higher level simplifications that are not always as obvious as the other reductions.

Reduction example

For example to reduce the following lambda expression, we must first understand what it means.

$$(\lambda x.\lambda y.(xy))(\lambda x.\lambda y.(xy))$$

In the outermost level, the expression is the application of $\lambda x.\lambda y.(xy)$ to itself. It follows the second type of lambda calculus expression discussed earlier, $\mathscr{M}\mathscr{N}$ where $\mathscr{M} \in \Lambda$ and $\mathscr{N} \in \Lambda$. In this context $\mathscr{M} = (\lambda x.\lambda y.(xy))$ and also $\mathscr{N} = (\lambda x.\lambda y.(xy))$.

When you start evaluating this expression, you might be tempted to automatically apply a β reduction by itself:

$$\begin{aligned}(\lambda x.\lambda y.(xy))(\lambda x.\lambda y.(xy)) &\rightarrow_\beta \lambda y.((\lambda x.\lambda y.(xy))y) \\ &\rightarrow_\beta \lambda y.\lambda y.(yy)\end{aligned}$$

But this reduction is actually incorrect because the although x and y appear on both lambda expressions, these variables don't have the same meaning . The x and y variables inside the left lambda expression are **bound** inside this lambda expression. The x and y variables outside the left lambda expression (inside the right lambda expression) are **free** in its context, therefore, even though they look the same, it is incorrect to interchange the two variables.

Two avoid confusion with similarly named variables, it is advisable to apply an α equivalency, to give them different names. This can be done by replacing the right abstractions bound variables with u and v. Again, this alpha reduction doesn't change the meaning of the abstraction, it merely renames the bound variables.

$$(\lambda x.\lambda y.(xy))(\lambda x.\lambda y.(xy)) \equiv_\alpha (\lambda x.\lambda y.(xy))(\lambda u.\lambda v.(uv))$$

The correct reduction now is as follows. Still a β reduction but without the ambiguity of similar variable names.

$$\begin{aligned}(\lambda x.\lambda y.(xy))(\lambda u.\lambda v.(uv)) &\rightarrow_\beta \lambda y.((\lambda u.\lambda v.(uv))y) \\ &\rightarrow_\beta \lambda y.\lambda v.(yv)\end{aligned}$$

The Paradigm

Reimagined functions

Lambda calculus evolved from a system of logic foundation with deep roots to computation theory into something that became a basis for programming language design. Language designers started to consider the unconventional rep-

resentation of lambda calculus expression as a valid and pragmatic way of representing data. Around 1950's programming languages patterned around the framework of lambda calculus started to emerge. One of the earliest and most important of these languages was **Lisp** which evolved to become a large family of programming languages[2]. Soon, more programming languages started to implement the same formalisms described by lambda calculus. This opened a new paradigm of programming languages called **functional programming paradigm**. To explore this paradigm this section will introduce the programming language **Haskell**. This language has become one of the most important functional programming language, setting the standards for other languages paradigm.

How functions are treated Differently

One of the biggest difference between your classic imperative programming languages like C and Java and a functional programming language, is how it treat its function. You might have probably guessed that since the paradigm has "function" in its name. To explore this contrast lets start by introducing a simple function, written in C. This function basically accepts an integer and returns a the same integer but squared:

```
int square(int x){
        return x*x;
}
```

Functions like these are patterned from mathematical functions. It has a **name** to invoke it later called **square**, it has **specifications** on which type of data it accepts (**int x**) and produces (**int**), and finally it has a instructions on what must be done when it is invoked (**return x*x**.) Functional programming functions behave in more or less the same way.

```
square :: Int -> Int
square x = x * x
```

It looks different but all of the parts you can find in a C function can also be found on this Haskell function.

In terms of invocation, they are also used similarly and of course the behave similarly:

[2] Steele, A. (1996). The Evolution of Lisp. *History of programming languages—II*, 233-330. doi:10.1145/234286.1057818

```
square(5);
```

```
square 5
```

Although functions in non-functional programming behave and look similar to functions in functional programming language, they have a huge difference in the way the programming language treats it.

A function in C is treated differently from other types of data. In fact C programmers will rarely call a function a value. What this means is that canonical value types like integers, characters, and arrays (even compound value like structs and objects) can be passed on functions and can be returned as functions.

```
int* add_to_array(int arr*,int x,int size){
 for(int i=0;i<size;i++){
  arr[i]+x;
 }
 return arr;
}
```

C discriminates function from these canonical value types. Therefore, during runtime, non-functional programming languages interpret the expression `square(5)` as "the number 5 squared" while the expression `square` is just some disembodied function name (*square of which number?*). Imperative programming functions during runtime are meaningless unless they are directly invoked.

Higher Order Functions

Passing functions Functional programming languages treat functions the same way it treats values, you can pass them in other functions and you can return them as well.

```
s:: Int -> Int
func x = x + 1

p::Int -> Int
func x = x - 1

applytwice:: (Int-> Int) -> Int -> Int
applytwice f x = f (f x)
```

> *Note these arrow looking characters are actually just dash followed by a greater than character "(->)". My markdown editor formats it to look like a neat arrow inside code fences.*

The code above shows two function definitions (with some type signature annotations for readability). The first is the function `s::Int -> Int` which is applied to an integer and produces an integer. What it does is it simply adds one to `x`. The second function is similar but what it does is subtracting one from `x`.

> *Type signature annotations are not required here, that's why they're called annotations. Adding these annotations will restrict the type the functions can be applied to. Type signature annotation syntax are understood like this*
>
> ```
> f :: Paramtype -> AnotherParamtype -> ... -> OuputType
> ```
>
> *The last type in the `->` series is the type the function produces (like it's return type) and everything else before it are parameter types.*

The third function is what we call a higher order function. A higher order function is a function that either accepts a function as a parameter or returns a function parameter or both. The function `applytwice` as described by it's type signature, is applied to a function `f` and an integer `x`and produces an integer. What it does is it applies the function `f` twice to `x`, something like $(f(f(x)))$.

By defining a function like this we can do something like this during runtime:

```
ghci> applytwice s 3
5
ghci> applytwice p 3
1
```

To a programmer with no experience with functional programming, this feature can be surprising especially since mathematical functions in algebra or calculus don't even explore this capability. But if you remember this is not just some arbitrary added feature added for novelty. This feature isdirectly patterned from lambda calculus:

$$\text{let } S = \lambda n.\lambda s.\lambda z.(s(nsz))$$
$$T = \lambda f.\lambda x.(f(fx))$$
$$\overline{5} = TS\overline{3}$$

In lambda calculus an abstraction and an application does not restrict anyone from the type of expressions bound to variables. In the spirit of implementing lambda calculus, any functional programming language will allow you to do this as well.

Returning functions On the other side of the coin, a function, in functional programming will also let you return functions the same way you return any other kind of data.

To explore this, suppose we have different functions that when applied to an integer, produces that integer plus a certain integer.

```
addTwo::Int -> Int
addTwo x = x + 2

addThree::Int -> Int
addThree x = x + 3

addFour:: Int -> Int
addFour x = x + 4
```

We can generalize these functions into a *function-maker* function, that when applied to an arbitrary integer `x`, will produce an `addx` which is a function (not a number) that adds `x` to your integer.

```
addMaker::Int -> (Int->Int)
addMaker x = (\y -> x + y)
```

We are introducing new syntax here, but this new syntax is a representation of an expression we already know from lambda calculus. The definition for your `addMaker` (`\y -> x + y`) is basically an implementation of the lambda expression below. `y` is the bound variable, and the operator `->` separates the inputs and the output, `x + y`.

$$\lambda y.\text{add } xy$$

> *In fact, the reason why Haskell syntax uses the* `\` *character to represent lambda expressions is because this is the your keyboard's best physical approximation of the Greek letter* λ*. Extra note: "+" does not exist in the universe of lambda calculus so instead what's used here is a reference to a lambda calculus abstraction called "add". The definition of this can be found in the supplemental topic Lambda Calculus Encodings*

What this expression means then is that `addMaker` produces a lambda expression, which essentially behaves exactly like a function. This allows you to create functions during runtime

```
ghci> addSix = addMaker 6
```

Simply writing the expression **addSix** on your terminal will yield you an error, because printing **addSix** doesn't really have a meaning outside the world of lambda calculus. It is a lambda expression which is *basically* a function. *How do you represent a function as a string?*

But since **addSix** is a lambda that behaves exactly like a function, you can apply **addSix** to an integer and it will give you a meaningful answer.

```
ghci> addSix 3
9
```

In fact you can even omit the part where you bind the value returned by **addMaker** to a name, and instead use it directly. Here, **(addMaker 7)** is a lambda expression and therefore it can be applied to an integer.

```
ghci> (addMaker 7) 4
11
```

This nifty trick right here is the reason why lambda expressions are also called **anonymous functions** since these expressions on their own don't have a name. Lambda expressions generally appear in functional programing languages and even non-strictly functional programming languages. Lambdas can be useful if you want to create a function that will be used only once:

```
ghci> applytwice (\x -> x + 2) 3
7
ghci> (\x -> x * x) 4
16
```

Lambdas, just like any other canonical value type can be bound to identifiers. Doing this will **name** the lambda thus allowing it to behave just like any other named function.

> *By the way, bindings are haskell's representation of a mathematical let statement. When you see an* **=** *operator like the following:*
>
> `x = 3`
>
> *This is not an assignment statement, but instead a let binding.* **3** *is bound to the identifier* x*. Similar to what happens when you say let* $x = 3$ *in math.*

Closure A higher order function like `addMaker` above, is not only producing the lambda inside its definition. What is actually being produced is a construct called a **closure** which is the function definition described by the lambda and the environment of the function call. The extra data, called environment, is the reason why the lambda `(\y -> x + y)` makes sense outside the context of `addMaker`. Without passing the environment the variable `x` would be a free variable which will yield you a compilation error.

Inside your `addmaker` when you evaluate `addmaker 6` , the parameter `6` is bound to the variable x. So the resulting lambda that is produced will behave exactly like the lambda `(\y -> 6 + y)`.

Closures are still a direct consequence from lambda calculus' variable binding rules. Specifically how the variables x and y are bound in innermost body of the lambda calculus abstraction $\lambda x.\lambda y.add x$.

Multiple parameters and partial application If we look back to lambda calculus you'll notice how abstractions are defined to be:

$$\lambda x.\mathscr{M}$$

Here we can see that abstractions are defined to have exactly one parameter. One can argue that this is different from the how functional programming represents its own functions and lambdas since functions with multiple parameters are allowed in these languages. Actually these functions are just disguised to have multiple parameters. These functions are just several single parameter functions combined to simulate multiple parameter functions. As an example: a function `add` that adds two numbers may look like multiple parameter functions:

```
plus x y = x + y
```

But internally this function is equivalent to two lambda calculus abstractions, nested together to simulate multiparameterness.

```
plus = \x -> (\y -> x + y)
```

Here plus is a higher level function that accepts a single argument `x` and produces the lambda expression (to be perfectly correct it is returning a closure) `(\y -> x + y)`. This expression is a direct implementation of the following lambda calculus abstraction:

$$\text{plus} = \lambda x.\lambda y.\text{add } xy$$

Just like lambda calculus Haskell's `->` operator is right associative so you can write the same plus function as:

```
plus = \x -> \y -> x + y
```

You can even omit the first `->` and the `\` near `y` and it will mean the same lambda expression:

```
plus = \x y -> x + y
```

Which looks almost exactly similar to a relaxed lambda calculus expression with multiple parameters:

$$\lambda xy.\text{add } xy$$

Now when you want to apply this function we write:

```
ghci> (plus 3) 4
7
```

Which means that first we are evaluating `(plus 3)` which will give us a lambda expression. The lambda expression is then applied to `4` which completes the evaluation to `7`. This is also a direct implementation of a lambda calculus application:

$$(\text{plus } \overline{3})\overline{4}$$

And just like lambda calculus, function applications in Haskell are also left associative so you can omit the parentheses:

```
ghci> plus 3 4
7
```

All multiple parameter functions and lambdas in Haskell are nested single parameter abstractions in disguise, so for all intents and purposes these two definitions for `plus` behave in the exact same way:

```
plus x y = x + y
```

```
plus = \x -> (\y -> x + y)
```

This means that the expression `(plus 3)` will have the same meaning regardless of the way you define `plus`. The expression `(plus 3)` has a special name, it is called a **partial application**. When you apply a function that is supposed to accept n parameters to m values (where $m < n$) (what this means is that you're supplying the function less parameters than it is expecting), instead of getting

the value, you get a partial application of that function which will evaluate to a lambda expression.

The process of converting a multi parameter function or lambda to a nested single parameter lambda is called **currying**. This term is named after the mathematician Haskell Brooks Curry, which is the same Haskell, the programming language is named after.

Functional purity and the absence of states

One of the most distinguishing aspects of functional programming and the declarative family of languages is its philosophy of statelessness. A programmer primarily exposed to mutable imperative programming languages will find that the concept of state is natural and maybe even inevitable. Functional paradigm challenges this concept and offers a much safer and mathematically intuitive philosophy. In the perspective of functional programming, there is no state, and everything is immutable.

Pure functions

To understand the functional programming perspective, we have to take a step away from the imperative programming definition of a function. Let's go back to the definition of a function in mathematics.

Across several, mathematical disciplines a function means the same thing. Consider two sets A and B. we can define a function as the mapping between the elements of A and B. The elements of A and B can be anything, they can be numbers, which shows us how a function can be represented by a formula or a graph. The elements of A and B can be matrices and vectors, which defines a function as a transformation between two vector spaces. On the higher level perspective of category theory, functions are morphisms between objects of a given category. At its core a function basically defines arrows between things.

$$f : (A \to B)$$

If you remember functions from discrete math, functions at its most basic form looks like the one above.

Functions in functional programming languages like Haskell are (arguably) the closest computer representation of a mathematical function. We call these functions, **pure functions**.

They differ from your standard C function because the definition inside pure functions are only instructions on how to produce a result based on the parameters. To fully understand this concept here are some examples of impure functions

```
int square(int x){
        addToExternalLogger("calculating square");
 return x*x;
}
```

The impurity in this function is the line where the function writes to some external logger, `addToExternalLogger("calculating square");`. A function can only be pure if the result of the function can be fully determined by its parameter. The only parameter here is `x`. Invoking this square function with the same parameter value does not do the same thing. The effect of changing the logger is dependent on the previous state of the external logger. The effect on the logger is what we call a **side-effect** of the `square` function. It is a side effect since this line of code modifies values outside boundaries of the function.

```
int* increaseArray(int *a, int size){
 for(int i = 0; i < size; i++)
  a[i]+1;
}
```

A pass by address/reference function which changes the value of a parameter will automatically be an impure function since changing the value of `a` is a **mutation**, which is a side-effect.

```
String headsortails(){
        if(randInt()%2==0)
                return "heads";
        else
                return "tails";
}
```

This function is also impure because the return value is not dependent on the parameters alone. The return value will be dependent on the randomization seed which is something outside the parameters of the function.

A pure function must satisfy these two:

1. A pure function has no side-effects
2. A pure functions output must be dependent on the inputs alone

In fact if $f(a) = b$ and $f(a) = c$ where $b \neq c$ is not a function at all

A good way to test if a function is pure is if you can can (theoretically) create an infinitely long lookup table such that looking up the value for a specific input

is perfectly identical to calling the function with the same input. And if you think about it this is the essence of a function. It is a list of associations between the domain and the range.

The Absence of mutation

One of the hallmarks that make imperative programming imperative is the assignment statement. It enables the program to advance to a new state. Purely functional programming languages like Haskell, lacks the mechanism to mutate anything. Using the "=" operator (which signals an assignment statement in imperative languages) in functional languages binds the value on the right hand side to the left hand side. This mechanism is conceptually different from an assignment operation in C. For example:

```
int x = 0;
x = 1;
```

This code in C starts with a combined declaration and assignment: `int x = 0` . The second line then, **reassigns** the same variable `x` to the new value `1`. These lines of code corresponds to a mutation on the variable `x`, (from `0` to `1`). The value of the variable `x` is not definite since it can change within the runtime of the program. Because of the existence of mutation, the values of variables are dependent on the current **state** of the program.

Replicating this C code in Haskell is in fact not allowed:

```
x = 0
x = 1
```

It will give an error message upon compilation:

```
main.hs:2:1: error:
  Multiple declarations of ‘x’
  Declared at: main.hs:1:1
               main.hs:2:1
```

In Haskell, any "=" is a declaration of a binding. In fact all declarations in haskell are required to be **bound** to a value. These bindings are final (*in the scope of the identifier*). It is even wrong to call `x` here a variable since its value does not vary. The correct way to call `x` is identifier, since it merely identifies the value bound to it.

Consequences of Statelessness and Immutability

Although Haskell's functions are our best representation of a mathematical function, this does not mean that it is pragmatically better than the classic impure functions of C. Restricting a programming language against side-effects seems like an artificial disadvantage introduced only to faithfully implement mathematical functions.

There are several reasons why programming without state is a better way of programming. Eliminating all side-effects is demonstrably safer against accidental errors. Building a library of functions perfectly working without worrying about side-effects makes the system easier to understand and more resilient to changes.

```
void f(int *x, int y){
  *x = *x + y;
  printf("%d\n",*x);
  return;
}
int main(void) {
  int x = 0;
  f(&x, 3);
  x = x - 2;
  f(&x, 3);
}
```

The exact behavior of the function `f` depends on where you call it. Even if you use the same parameters, you're not guaranteed to get the same results.

On small chunks of code, managing the consequences of having states such as global variables, will be trivial since you can reasonably track which variables are global (*or external in general*) and which functions interact with the global variables. (Even this tiny amount of code, the function's effects and side effects are not very obvious).

As the system grows, using functions and variables without double checking for side effects becomes much harder. As a consequence the whole system becomes a nightmare of impure functions on top of impure functions which may unexpectedly affect other parts of the system. On a corporate setting where multiple people are working on the same system, refactoring becomes unsafe without knowledge of all the side-effects of the functions in use. On systems with shared resources and multi-threading it becomes extra-extra difficult to keep track of things without proper documentation.

Don't get this wrong, though. Even with all these disadvantages in the state-full mutable paradigm of imperative programming, one can still code robust and

harmonious systems. You just have to be extra careful writing your code with discipline, only using globals and side-effects when it is safe and necessary (*this is in fact the reason why writing smaller pure functions is considered good practice in any paradigm*). After all, being able to code with states can be thought of as an extra feature. You can be a C programmer and just treat all your variables as immutable and all of your functions as pure. (*calling variables, immutable is kinda oxymoronic because variables are meant to change, but whatever*)

Functional programming has its own set of disadvantages as well, most of them related to this seemingly artificial crutch of statelessness and immutability. The most obvious one is that creating new values instead of changing an existing variable has extra overhead in both processing and memory, making functional programming slower and less efficient. Programming without state can be difficult to do for certain mechanisms (*Like the external logger for example*). Simulating mechanisms like this may introduce conflict on how you compose your functions. It's not impossible though, you just have to learn some category theory concepts such as **monads**. Also, for most people who are used imperative programming, recursion, does not feel natural compared to iteration. But in my opinion, after being exposed to functional programming for some time, recursion makes much more sense than iteration.

Nevertheless, these disadvantages are not insurmountable. In fact, there are a plenty of systems written in functional programming languages running without issues. Functional programming has had the reputation of being more conceptual and fancy than the classic imperative programming language. People mocked Haskell for its pristine white tower "elitist" approach to programming. But recently these functional programming languages like Haskell, F# and Scala has enjoyed improvements that has elevated it to be as pragmatic as your classic C, C++ or Java. In fact, functional programming has gained a considerable rise in popularity to an extent that mainstream programming languages with imperative roots like C#, Python, and JavaScript have started to introduced features patterned from pure functional programming languages. (Features such as higher-order functions and lambdas). With the risk of sounding editorial I even argue that learning functional programming concepts has become a necessity for any programmer, regardless of his/her paradigm preferences.

Optional Readings

Lambda Calculus Encodings

Haskell Cheat Sheet

Setting up Haskell

To start writing Haskell code, install Haskell through stack. Stack is found in the folder called "Haskell/Stack" inside the provided course pack. Copy the Stack folder and place it in your computer. To be able to use stack anywhere, add your copy of the stack folder in the PATH variable of your computer.

Once stack has been set-up using the steps above, you can run the GHC repl using the command

```
> stack ghci
```

The first time you run this code, stack will automatically install the GHC compiler.

After downloading GHC, you will be taken to the Prelude part of the your GHC repl. To test if everything is working properly, try the following Haskell expression:

```
Prelude> show (1 + 3)
```

If everything is good to go, the GHC expression will evaluate to:

```
"4"
```

To exit GHC run the following GHC command

```
:quit
```

To load a Haskell program, enter the GHC repl first

```
> stack ghci
```

While inside **Prelude**, use the command **:load <Path to haskell file>**. For example

```
Prelude> :load "Trying Things.hs"
```

> *If the path to the haskell file contains spaces, you need to enclose the path in braces*

Type annotations

Pattern

The last type in the arrow series is the range type or return type. Every type before it are the domain types or the types of the parameters in order

```
function_name :: Type_of_Param1 -> Type_of_Param1 -> ... ->
↪  Type_of_Paramn -> ReturnType
```

Examples

Double of an integer, double : $\mathbb{Z} \to \mathbb{Z}$

```
double :: Int -> Int
```

Sum of the length of two strings (strings in Haskell are arrays of **Char**, an array of specific types are written enclosed in square brackets, **[Type]** represents an array of **Type**s)

```
len :: [Char] -> [Char] -> Int
```

Check if some integer is even (boolean values are written capitalized, `True` and `False`,)

```
isEven :: Int -> Bool
```

Accept two `(Int -> Int)` functions and produce the composition of those functions (given functions f and g, $f \circ g$)

```
compose :: (Int -> Int) -> (Int -> Int) -> (Int -> Int)
```

Function definitions

Pattern

Every identifier placed in between the function name and `=` are the parameter names. The expression to the right of `=` is the expression evaluated when the function is called.

```
function_name param1 param2 ... paramn = <some expression>
```

Example

Double function

```
double x = x + x
```

isEven function

```
isEven n = n % 1
```

If-then-else expression

Pattern

One of haskell's condition expressions are if-then-else expression. Because a haskell expression is required to evaluate to something, unlike C, all `if` parts must be followed by a `then` part and `else` part.

```
if <bool-exp> then <exp1> else <exp2>
```

The expression inside the if clause must be an expression that evaluates into a boolean value. If the expression **<bool-exp>** evaluates to **True**, then the whole if-then-else expression evaluates to whatever **<exp1>** evaluates to. If **<bool-exp>** evaluates to **False**, then the whole if-then-else expression evaluates to whatever **<exp2>** evaluates to. The then clause and else clause cannot be empty and they must evaluate to the same type

> *Haskell boolean literals start with uppercase letters, **True** and **False**.*

Examples

The expression:

```
if (2 > 1) then 5 else 4
```

evaluates to 5

The expression:

```
8 * (if (3 <= 2) then 2 else 3)
```

evaluates to 24

If-then-else statements can be nested by writing if statements inside the **then** part and **else** part

```
if (2 > 1) then (if (0 == 1) then 2 else (1 + 2)) else (if (2 ==
↪  2) then 5 else (if (3 == 2) then 6 else 7))
```

evaluates to 3.

If else statements can be written neatly with tabs and newlines like this:

```
f :: Int -> Int
f x = if (x > 1)
  then (if (x == 1)
    then 2
    else (1 + 2))
  else (if (x == 2)
    then 5
    else (if (3 == x)
      then 6
      else 7))
```

Lambdas

Pattern

```
\param1 param2 ... paramn -> <some expression>
```

All identifiers between `\` and `->` are the parameters of the lambda. The expression to the right of `->` evaluates when the lambda is applied.

Example

A lambda that doubles a number

```
\x -> x + x
```

A lambda that adds two numbers

```
\a b -> a + b
```

The same function but written in its verbose uncurried form

```
\a -> (\b -> a + b)
```

Let Binding

To bind a value to some identifier use the `=` operator

Pattern

```
identifer = <some expression>
```

The expression to the left of the `=` operator is evaluated and then bound to the identifier to the right of the `=` identifier.

Example

the integer 3 bound to `x`

```
x = 3
```

a lambda bound to `f`

```
f = \x -> x + x
```

Function/Lambda Application

Pattern

Two expression separated by a space is a function application. The expression on the left side must evaluate to a function or a lambda. This function/lambda is applied to the right expression as its parameter

```
<expression1> <expression2>
```

A series of expressions are curried multiparameter applications. The leftmost expression must evaluate to a function or a lambda. This function/lambda is applied to the right expressions as its parameters.

```
<expression1> <expression2> <expression3> ... <expressionn>
```

Example

```
double 3
```

evaluates to 6

```
compose addThree double 2
```

evaluates to 7

Logic Programming Paradigm

Introduction

Just as functional programming paradigm is patterned from the formalisms of lambda calculus, logic programming is patterned from predicate calculus. Computer Scientists usually describe families of programming languages under the logic paradigm as a sub-paradigm of declarative programming (*declarative programming being any paradigm that is not imperative*). In terms of application this paradigm is more closely related to knowledge base programming languages like SQL. While SQL uses relations (not tables) to represent knowledge, logic programming uses rules of logic and predicate calculus to represent knowledge.

Learning Outcomes

1. Create prolog facts, rules, and queries
2. Explain the process of unification
3. Explain how proof search is used to respond to queries

4. Create recursive prolog rules

For this secton we will use the programming language Prolog as the representative of logic paradigm. Other logic programming families are answer set programming, ABYSS and Datalog.

Facts Rules and Queries

Facts

There are three basic constructs in Prolog, facts, rules and queries. A knowledge base is a collection of facts and rules in the same way a c library or a python package is a collection of function definitions. Prolog programs are basically knowledge bases. Here's an example of a knowledge base:

```
firetype(charmander).
firetype(charizard).
watertype(squirtle).
flyingtype(charizard).
```

Each line of code you can in this particular knowledge base is a fact. Just like facts, in logic, facts in Prolog are propositions that are known to be true. This means that your program knows four things. One of those are:

```
firetype(charmander).
```

In Prolog `firetype(X)` represents the mathematical predicate you've learned in discrete math, firetype(x). And just like predicates, this is attached to the meaning `X` is firetype.

Therefore the fact `firetype(charmander)` represents the proposition, "charmander is firetype"

So, to summarize, the fact `firetype(charmander)` is basically a representation of the proposition, $firetype("charmander")$ where $firetype$ is a predicate and $charmander $ is a value assigned to the predicate. Any fact that can be found on the knowledge base are basically true propositions and any proposition that is not in the knowledge base (and cannot be inferred from the knowledge base) are false.

Queries

A knowledge base is used by writing queries to prolog. You can probably guess what this prolog construct means just by looking at its name. Queries represent questions you ask prolog. The answer to a question depends on what prolog knows. And what prolog knows is represented by the knowledge base. For example if you load the knowledge base we created earlier. We can ask prolog the following question below. Writing the following will basically ask prolog, "hey, is it true that charmander is firetype?"

```
?- firetype(charmander).
```

Based on the knowledge base loaded earlier prolog knows that this proposition is indeed true. Therefore it responds with:

```
yes
```

If prolog is asked with the query

```
?- firetype(squirtle).
```

Prolog checks its knowledge base again. Realizing that none of the facts match this proposition, prolog responds with:

```
no
```

Therefore, if you provide prolog with statements it has never seen before like the following:

```
?- grasstype(pigeot)
```

Prolog will interpret this as false statement, responding appropriately with:

```
no
```

Rules

Aside from facts, you can also define rules in your knowledge base. To illustrate this, lets add rules to our knowledge base.

```
firetype(charmander).
firetype(charizard).
watertype(squirtle).
flyingtype(charizard).

resistanttofire(squirtle) :- watertype(squirtle).
```

A rule is basically an implication statement. A rule written as `c :- h` is equivalent to the implication statement $h \rightarrow c$. Prolog rules are written using the "c if h", the reverse of a conventional "if-then" implication "statement. A lot of people get confused here so just remember, `:-` is read as if. Therefore, the left half of a rule is the conclusion and the right half is the hypothesis.

Since we've written that rule we can ask prolog the following:

```
?- resistanttofire(squirtle)
```

Prolog responds with

```
yes
```

Although `resistanttofire(squirtle)` is not written as a fact it can be inferred from the rule `resistanttofire(squirtle) :- watertype(squirtle)` and the fact `watertype(squirtle)`. Therefore it is true via modus ponens:

$$\begin{array}{l} watertype(squirtle) \rightarrow resistanttofire(squirtle) \\ watertype(squirtle) \\ \hline \therefore\ resistanttofire(squirtle) \end{array}$$

Variables

Another important thing about Prolog constructs is that you can write them with variables. For example, writing the query:

```
?- firetype(X)
```

Basically asks the question, which values when substituted to `X` in the predicate `firetype(X)` will yield true statements? This can be interpreted in natural language as "which Pokémon are fire type?" Therefore, this query will yield the response:

```
X = charmander
X = charizard
```

Variables inside facts and rules allows the creation of richer knowledge bases. Instead of the rule `resistanttofire(squirtle) :- watertype(squirtle).` we can write a more general rule using variables:

```
firetype(charmander).
firetype(charizard).
watertype(squirtle).
flyingtype(charizard).

isresistantto(X,Y) :- watertype(X),firetype(Y).
isresistantto(X,Y) :- watertype(X),watertype(Y).
```

This introduces a more complicated rule `isresistanto(X,Y) :- watertype(X),firetype(Y)`. This rule's premise is a conjunction of predicates `watertype(X)` and `firetype(Y)`.

If we imagine that the predicate, $isresistantto(x, y)$ means "x is resistant to y", the whole rule can be interpreted as

> *for all pairs of X and Y, X is resistant to Y, if X is water type and Y is fire type,*

This statement, can be written as the following quantification statement:

$$\forall x \forall y((watertype(x) \land firetype(y)) \rightarrow isresistantto(x, y))$$

By writing this rule, prolog can infer the following facts:

```
?- isresistantto(squirtle,charmander)
```

```
yes
```

```
?- isresistantto(squirtle,charizard)
```

```
yes
```

```
?- isresistantto(squirtle,squirtle)
```

```
yes
```

If you ask prolog a harder question like the following:

```
?- isresistantto(squirtle,X)
```

Prolog interprets this as "which values of `X` make the proposition: squirtle is resistant to X, true? Therefore, Prolog will look for the pokemon, squirtle is resistant to, therefore you with the output:

```
X = charmander
X = charizard
X = squirtle
```

Prolog Syntax

There are three types of prolog terms [1]. By composing these terms you can express rich knowledge bases.

1. Constants. These can either be atoms (known to us as strings such as `squirtle`) or numbers (such as `24`).
2. Variables. (Those that start with an underscore or any uppercase letter such as as `X`, `Z3`,`_4310`, and `List`.)
3. Complex terms. These have the form: `functor(term_1,...,term_n)`. We've seen examples of these in predicates and queries such as `firetype(charmander)` and `isresistantto(X,Y)`

Unification

The way prolog is able to respond to complex queries such as:

```
?- firetype(X)
X = charmander
X = charizard
```

[1] Blackburn P., Bos J., Streignitz K., (2012) Learn Prolog Now http://www.learnprolognow.org Accessed August 21, 2020

is through the use of the logical concept known as **unification**. Unification algorithmically identify logical substitutions in symbolic expressions such as prolog facts, queries and rules. Unification is defined in prolog as the following:

> *Two terms unify if they are the same term or if they contain variables that can be uniformly instantiated with terms in such a way that the resulting terms are equal.*

This definition gives us the unification of trivial cases such as the unification of constants `squirtle` and `squirtle`. Prolog also unifies the complex terms `watertype(squirtle)` and `watertype(squirtle)` and the variables `X` and `X`. The complex terms `watertype(squirtle)` and `watertype(blastoise)` will not unite.

Prolog also unifies the variable `X` with the constant `squirtle`. Although they are not the same, the variable `X` can be uniformly instantiated to `squirtle` (i.e. `X = squirtle`). What this specific unification case means is that, you can find some binding of the constant `squirtle` to the variable `X` without breaking other unification rules. This successful binding means that these values indeed unify. By the same intuition, `watertype(X)` and `watertype(squirtle)` will also unify buy instantiating (`X=squirtle`).

On the other hand the complex terms `isresistantto(X,charmander)` and `isresistantto(squirtle,X)` does not unify since you cannot find an instantiation of `X` that makes them equal. The instantiation `X=squirtle` evaluates to the terms `isresistantto(squirtle,charmander)` and `isresistantto(squirtle,squirtle)`. On the other hand, the instantiation `X=charmander` makes the terms `isresistantto(charmander,charmander)` and `isresistantto(squirtle,charmander)`. Both of these scenarios break because it forces the incorrect unification of the constant `squirtle` and `charmander`.

The process of unification can be summarized by the following[2]:

> *Two terms a and b unify if and only if*
>
> 1. *a and b are constants and they are the same number or atom*
> 2. *a is a variable and b is any type of term (in this case a is instantiated to b) or b is a variable and a is any type of term (in this case b is instantiated to a). This rule automatically unify any pair of variables*
> 3. *a and b are complex terms and:*
>   1. *They have the same functors and the same number of arguments*

[2] Blackburn P., Bos J., Streignitz K., (2012) Learn Prolog Now http://www.learnprolognow.org Accessed August 21, 2020

2. *all their corresponding arguments unify*
3. *the variable instatiations are uniform or compatible (you cannot instantiate x to some constant a when unifying a pair and instantiate x to another constant b when unifying another pair of arguments)*

You can demonstrate unification in the prolog terminal using the predicate `=/2` (this means the `=` functor with two arguments).

```
?- =(squirtle,squirtle)
yes
```

```
?- =(squirtle,charmander)
no
```

```
?- =(squirtle,X)
X=squirtle
yes
```

```
?- =(X,Y)
X=_5071
Y=_5071
yes
```

> *The instantiations `X=_5071` and `Y=_5071` asserts that both `X` and `Y` share the same variables in this case. This is also known as `X` and `Y` being aliased, meaning that they share each others instantiations*

```
?- =(watertype(X),watertype(squirtle))
X=squirtle
yes
```

```
?- =(f(g(X),X),f(Y,a))
X=a
Y=g(X)
yes
```

Programming with unification

Unification is crucial with how one can write interesting logic programs. By creating knowledge bases that take advantage of unification, you can generalize

structures based on the facts and rules of its characteristics. For example, the following is a knowledge base describing the characteristics of vertical and horizontal lines:

```
vertical(line(point(X,Y),point(X,Z))).
horizontal(line(point(X,Y),point(Z,Y))).
```

Instances of line that unify with these predicates, are also instances of vertical and horizontal line. Therefore asking the query:

```
?- vertical(line(point(1,2),point(1,3)))
```

Will yield the response:

```
yes
```

It is indeed a vertical line. And the knowledge base makes sense, since any line that has the same x coordinate is vertical and any line that has the same y coordinate is horizontal.

We can even ask more general queries to haskell such as:

```
?- horizontal(line(point(2,3),point(Y,4)))
```

Which basically asks prolog for horizontal lines starting at $(2, 3)$ and ends at a point with 4 as the y-coordinate. Since prolog can't unify this query with any value for Y (horizontal lines must have the same y-coordinate), prolog responds:

```
no
```

Proof Search

Here we will discuss the process called proof search. This is the algorithm that prolog uses to check for unifications and answer queries. Let's start with an example:

```
f(a).
f(b).

g(a).
g(b).
```

```
h(b).

k(X) :- f(X), g(X), h(X).
```

Asking prolog the query,

```
?- k(Y)
```

This gives prolog a **goal**, unifying `k(Y)` with all possible known facts or inferable facts in the knowledge base.

Whenever prolog unifies queries containing variables, it creates a new internal variable to alias it with `Y`. So in the perspective of prolog, the new goal is now:

```
?- k(_G34)
```

> *This query has the exact same meaning as `k(Y)`, since the variable names have no inherent meanings anyway. Prolog does this to create a goal containing variables guaranteed to be unused anywhere else. This removes any ambiguity with other variables named `Y` (no other variable is named `Y` but prolog still does this anyway).*

Prolog goes through the whole knowledge base from top to bottom and from left to right, attempting to unify the current goal, `k(_G34)` to a fact or a head of a rule. In this case since there are no facts `k(_G34)` can unify with, it unifies with the head (or the conclusion) of a rule, `k(X) :- f(X), g(X), h(X)`.

> *Since there are no other facts or rule heads that can be unified with the goal `k(_G34)` prolog's proof search doesn't branch out.*

Since this is a rule, we can prove that `k(_G34)` is true by proving the premises, `f(_G34), g(_G34), h(_G34)`. This gives prolog three new goals, proving the conjunction of the predicates, `f(_G34), g(_G34), h(_G34)`

> *By unifying `k(_G34)` and `k(X)`, the variables `_G34` and `X` are now aliased therefore they now share the same instantiations*

Prolog unifies the three goals one by one, left to right. So, starting with the goal `f(_G34)`, prolog searches the whole knowledge base again, attempting to unify `f(_G34)` with facts or rule heads. Since the knowledge base contains both facts `f(a)` and `f(b)` there will now be two paths in this search, instantiating `_G34` to `a` and instantiating `_G34` to `b`.

Path 1: `_G34 = a` From this instantiation, prolog is now left with the new goals `g(a), h(a)`. Starting with `g(a)`, prolog searches the knowledge base again and unifies `g(a)` to `g(a)`, reducing the goal to`h(a)`. Since `h(a)` cannot be unified with any fact or rule head, this path ends up unprovable.

Path 2: `_G34 = b` From this instantiation, prolog no has the new goals `g(b), h(b)`. Starting with `g(b)`, prolog searches the knowledge base from the top again and finds the unification `g(b)` to `g(b)`, reducing the goal to `h(b)`. It then finds the unification, `h(b)` thus completing the goal and proving the query for the instantiation`_G34 = b`.

By completing all possible paths prolog responds to the query:

```
Y = b
yes
```

Since there are no other instantiations that prove the goals, `Y = b` is the only possible answer.

Recursive Definitions

Similar to functional programming, logic programming represents repetition using recursion. While functional programming makes heavy use of recursive functions to implement complex behavior, logic programming languages like prolog uses recursive rules to model complex structures. For example: consider the following knowledge base:

```
is_digesting(X,Y)  :-  just_ate(X,Y).
is_digesting(X,Y)  :-
    just_ate(X,Z),
    is_digesting(Z,Y).

just_ate(mosquito,blood(john)).
just_ate(frog,mosquito).
just_ate(stork,frog).
```

You'll notice that the rule `is_digesting` is special since one of its goals is itself. You can interpret this rule as:

> X *is digesting* Y *if* X *just ate* Y *or* X *ate some* Z *that is digesting* Y.

> *The* ***or*** *part of this implications hypothesis is represented in the knowledge base by giving the conclusion* ***is_digesting(X,Y)*** *two separate hypotheses to satisfy.*

Posing the query:

```
?- is_digesting(stork,mosquito)
```

Following the process of proof search, the query `is_digesting(stork,mosquito)` is unified with the line 2, giving it a new goal `just_ate(X,Z), is_digesting(Z,Y)`. The goal`just_ate(X,Z)` will then match to `just_ate(stork, frog)` and the 2nd goal, `is_digesting(X,Y)` is then inferred from `just_ate(frog,mosquito)`.

Representing numbers using logic

Since logic calculus is a formalism for the foundation of mathematics, how do numbers emerge from predicates and propositions?

This is also another concept shared between, logic calculus and lambda calculus. You can represent numerals (specifically natural numbers) using Peano's axioms:

> *0 is a numeral*
>
> *the successor of 0, denoted by s(0) is also a numeral*

You can represent these axioms as a knowledge base:

```
numeral(0).
numeral(s(X)) :- numeral(X).
```

This knowledge base will then define all of the possible natural numbers out there, demonstrated by the query:

```
numeral(X)
```

```
X = 0
X = s(0)
X = s(s(0))
X = s(s(s(0)))
...
```

Using this representation, you can then define arithmetic operations such as addition and multiplication (also based on Peano's axioms)

```
numeral(0).
numeral(s(X)) :- numeral(X).

add(A,0,A).
add(A,s(B),s(C)) :- add(A,B,C).

mult(_,0,0).
mult(A,s(B),C) :- mult(A,B,D), add(A,D,C).
```

Advantages and Disadvantages of Logic Programming

Logic programming shares a lot of similarities with functional programming. It also shares its advantages and disadvantages as well. Both paradigms offer a safer and more consistent framework since they are both patterned form mathematical formalisms. Functional programming has lambda calculus and logic programming has predicate calculus.

Being non-imperative also gives them an edge of automatically being immune to the perils of state and at the same time being prone to the perils of its absence.

Logic programming's way of expressing knowledge gives it a lot of niche uses. Most of the distributions prolog are admittedly meant for a limited use case only. The straight forward way of listing facts and rules makes it suitable for representing complex information that can be usually found in the domains of AI, NLP, and expert systems. The beauty of unification and proof search shines on these domains as they often require, complex representation involving nested rules and recursive structures.

Logic programming's disadvantages are indeed similar to functional programming, but much worse. The obvious inefficiency due to the absence of state is much more evident in logic programming because of the thorough approach of backtracking in proof search. The strangeness of logic programming as compared to the imperative way of thinking is also much worse than functional programming (at least functional and imperative share the concept of functions Prolog only has predicates, Haskell is strange but Prolog is way stranger). Because of these logic programming is relegated to solving niche problems in various domains. Just like functional programming though, the spirit of logic programming can be found in other paradigms through the existence of unification libraries. Although logic paradigm is admittedly less relevant than other paradigms, its strange features are definitely useful and worth studying.

Prolog Cheat Sheet

Setting up prolog

Install the prolog compiler using the installer included in the course pack. To able to use swi-prolog anywhere, add the path to the directory of `swipl` executable in your PATH environment variable. It is generally found in the `bin` folder of the installation.

Once prolog is has been set-up you can run the `swipl` command to start swi-prolog

```
> swipl
```

to exit, use the `halt.` command (swipl will wait for a `.` for every query/command)

```
?- halt.
```

To load prolog knowledge bases (`*.pl`), use the `swipl` command again but this time include the path to the prolog file as an argument.

```
> swipl knowledegebase.pl
```

Writing Prolog knowledge bases

Knowledge bases are made of facts and rules.

Prolog facts

Every prolog fact ends with a period. A prolog fact can be a constant, or a complex term.

Constant

Constants start with a lowercase letter

```
truth.
```

Complex Term

Complex terms follow the pattern `functorName(arg1,arg2,...,arg3)`. Arguments can be a constants, variables, or complex terms. Here are examples

```
isresistantto(squirtle,X).
```

```
vertical(line(point(X,Y),point(X,Z)))
```

> *Functors are prologs representations for predicates. Whenever you see `functorName/2` mentioned, it means it is a functor called "functor" that accepts two parameters.*

Rules

Rules follow the following pattern `head :- tail1,tail2,...tail3`. `head` is the conclusion of the implication statement, it can be any fact. The tails represent the hypothesis of the implication. Writing more than one tail means that the hypothesis is a conjunction of the tails. Examples:

```
isresistantto(X,Y) :- watertype(X),watertype(Y).
```

```
is_digesting(X,Y)  :-  just_ate(X,Y).
```

Writing queries

To ask the knowledge base some questions, you load the knowledge base file using `swipl` and write queries in the `?-` dialog inside `swipl`. Remember to always end the query with a period. Queries are written with the same pattern as prolog facts. For example.

```
?- truth.

true.
```

If the query has multiple lines of answer, prolog will wait for you to either press semicolon/space to show the next answer or the enter key to stop showing more answers.

Object Oriented Programming Paradigm

Introduction

As procedural programming became more and more mainstream, computer scientists started to notice the issues behind states and side effects. Some languages offered a complete paradigm shift, completely abandoning the notion of state. This exodus formed the alternative paradigm family, declarative paradigm. Other languages however, went on a different direction. These languages offered a solution to fixing state by introducing richer features and an intuitive design. From this approach the paradigm object oriented programming was born.

Learning Outcomes

After this discussion you should be able to

1. Explain how programmer's started to focus on writing maintainable code

2. Differentiate between the object and the class
3. Explain OOP's philosophy, the surface vs. the volume
4. Explain what abstraction means
5. Describe the fundamental concepts encapsulation, inheritance, and polymorphism

---

As time went by and as technology evolved, computer scientists noticed new issues on the code they were writing. The goal of building the most optimized machine code became less and less of a priority. Programmers had, under their disposal, faster and better hardware. As the demand for complex systems grew, the priority shifted from *code that runs*, to *code that was intuitive*. As programmers started to build bigger and bigger systems, they started to notice the issues in terms of maintainability.

This shift in focus can be seen from the extremes of procedural paradigm such as the programming language Assembly. Assembly code was not really built to be intuitive. It was built to reliably work. Assembly contained mechanisms to move data around and to control program flow. These features were enough for that time since the objective of programming was to write efficient code that bulky slow CPUs understand. Assembly programmers did not have time to worry about code elegance or intuitiveness.

The landscape started to change when hardware started becoming better and software started becoming more complex. Speed and memory wasn't that much of an issue anymore so computer scientists' focus shifted towards the issue of maintainability. Software became bigger and more complex and understanding other programmers' code became more and more difficult. In fact, understanding your own code was also becoming difficult. Because of this writing code that a computer understands isn't enough anymore, a good programmer must write code that humans understand as well. Code shifted from computer centered to human centered.

But instead of redesigning the concept of imperative paradigm to solve maintainability, object oriented programming sought to build on top of the features of imperative programming. State despite its known issues, still exists but OOP gave imperative programmers extra tools to protect code from being carelessly mutated. Because of this OOP stayed under the imperative family since the programmer is still focused on telling the computer what to do using assignment statements and mutation.

Fundamental Concepts of OOP

Object oriented programming is usually defined using its three core design principles:

- Encapsulation
- Inheritance
- Polymorphism

It is said that any programming language that contains these mechanisms is an object oriented programming language. But calling the entirety of a programming language, OOP can be problematic since you are free to write code written in an "OOP language" without actually using these design principles. At the end of the day OOP is not merely a language classification, but a paradigm. Some programming languages are indeed intentionally written to be used for OOP design but these classifications are less important than judging if the code itself written by the programmer adheres to OOP's design principles.

The Object

Lets start with the star and the building blocks of object oriented programming,. What exactly is an object?

An object is a living organism in your code. To grasp the capabilities and limitations of an object we will anthropomorphize objects. Treating an object as an organism will guide you on how you use objects effectively.

Just like any creature an object has both form (attributes/fields) and behavior (methods) (this is one of the reasons why C's `struct` is not an object since `struct`s only have form). Objects are written to be representations of real world nouns such as a person or an employee or a file. The best way to design objects is to simulate the real world form and behavior of what these objects represent. Think of objects as the **representatives** of things in your code. Since you cannot shove an actual employee in your system, you instead create a representative of that employee using an employee object. If you start thinking about objects like representatives instead of mere data holders you'll be able to design a safe and elegant object.

The Class

Often discussed alongside an object is the class. There's usually a lot of confusion when identifying the difference between a class and an object and it is probably because in the universe of your code, the class and the object will have the same name.

A class is the specifications for the creation of objects. If you want to give a class a more proactive role, you can think of the class as the factory that builds objects. There are a lot of analogies out there to illustrate the relationship of classes and objects. For example, a star shaped cookie cutter (class) that makes star shaped cookies (objects). If you want to make star shaped cookies you use the star shaped cookie cutters. You can also call objects as instances of a class. In fact that's what I call objects most of the time. For example, the Cash class, `$2.75` is an instance of a Cash object. Or a cat named Garfield is an instance of an class called Mammal.

If an object is a representation of a tangible real world object, then the class is the conceptual type/category of that real world object.

The following class diagrams are the representations of a book and an Employee. The attributes of the book are `title`, `author`, `publishDate`, and `pages`. These attributes also simulate the form of a real world book. This object also has methods called `ISBN()` and `numPages()`. The attributes of an employee is `name`, `string`, and `salary` and it has a method called `reassignJob()`.

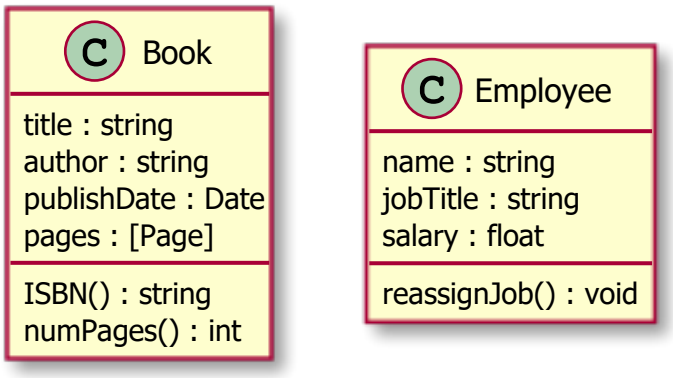


Figure 7.1: Class diagram of a book class

The following are representations of objects:

```
book1{
title: "Corpus Hermeticum"
author: "Hermes Trismegistus"
publishDate: Dec 12, 2008
pages: ......
}

book2{
title: "Behold a Pale Horse"
author: "Milton William Cooper"
publishDate: Dec 1, 1991
```

```
pages: ......
}

employee1{
name: "Rubelito Abella"
jobTitle: "Instructor 1"
salary: [REDACTED]
}
```

The Surface and the Volume

Data Hiding and the Interface

Before we play around with some code, lets dive deep into the philosophy of object oriented paradigm. The base premise of OOP is the concept called **data hiding**. And this formal OOP term describes what I mean when I say that, what OOP did for imperative programming was to allow the programmer to create artificial boundaries between irrelevant data and behavior. In the eyes of an OOP design, procedural code is a mix of data and functions arbitrarily tossed in a spaghetti of mutations and side-effects.

OOP's mechanism to create boundaries in the form of objects brought structure to imperative programming. All the attributes of a `Book` object doesn't need to be accessed by the methods of a `LibraryCard` object. That's because in the real world, a library card doesn't need to know what's written in page 69 of some book. Some of the data in `Book` should be **hidden** from a client object `LibraryCard`.

Object oriented programming's obsession to simulate real world objects is not caused by it's dream to become an exact representation of the real world. Object oriented programming obsesses over structure and simulation because it is a necessity for human comprehension and therefore, maintainability. Systems need good structure not because well structured code is pleasant and elegant to look at, but because our feeble minds can't process poor structure efficiently. In fact the reason why we call a well structured piece code, "elegant" is because our tiny limited minds can process it well.

> *Imagine code, so poorly structured, that your mind breaks when you try to process it. Trying to read this code would be comparable to looking at some Lovecraftian cosmic horror. If such a code exists it'll probably contain the secrets of the universe.*

The process of modeling elegant object representations is basically determining what the **public interface** of that object may be. The interface of an object is

the set of attributes and methods (methods are what we call functions that inside a class) that other objects can use to interact with it. The attributes and methods that are not in the interface is essentially hidden information, inaccessible from the client objects. For example, given a `Book` object that interacts with a `LibraryCard` object, the `LibraryCard` object's interface to interact with the book may only contain, `title` and `author`, because this is all the information it needs to properly do its job. You can even hide those attributes and let the `LibraryCard` only interact with the `Book` using a `borrow()` method which lists the `Book` as borrowed in the library card. It doesn't need access to the attributes of the book to do this. It interacts with the Book itself as a whole.

> *Don't worry if this diagram seems confusing at first since there will be a lecture on UML and how to interpret them*

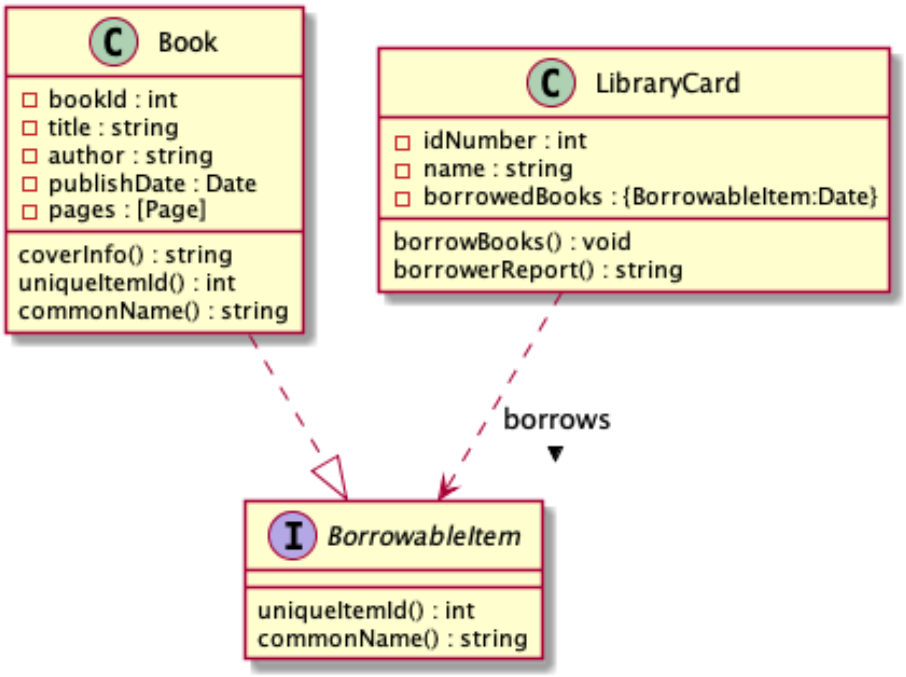


Figure 7.2: Class diagram of a book class

Abstraction of Objects

> *The term abstraction is actually quite overloaded in OOP and CS in general. The "abstraction" I'm talking about in this context is the concept of abstraction.*

Creating interfaces like these provide OOP with the mechanism to create **abstractions** in the object level. An abstraction in computer science is basically a model of computation that is free from its implementation. In the same way

that functional programming creates abstractions of mathematical functions by writing lambdas without side effects, OOP creates abstractions of objects using interfaces that don't specify the exact implementation of an object.

In the example above, the interface `BorrowableItem` is an abstract representation of *something from the library that can be borrowed.* An interface like `BorrowableItem` contains method names and type signatures but it doesn't actually contain code. That is because a `BorrowableItem` is an abstract representation. We are not supposed to care about the implementation of the methods `uniqueItemId()` and `commonName()` all we should care about is that `uniqueItemId()` should return an `int` and `commonName()` should return a `string`.

The reason why this structure still works, is because we have a concrete class called `Book` which is a **realization** or an **implementation** of `BorrowableItem`. A book is *something from the library that can be borrowed.* Because a `Book` is a `BorrowableItem`, it must also behave based on the specifications of a `BorrowableItem`. Meaning it must contain the methods `uniqueItemId()` and `commonName()` (which should also have the same type signature as the methods of `BorrowableItems`). Since `Book` is a concrete class it's methods `uniqueItemId()` and `commonName()` should be implemented (meaning there should be code inside these methods).

Why even go through all this trouble? If *something from the library that can be borrowed* is an abstract idea, what is the point of modelling it's representation? This looks like extra code just to represent something that doesn't really have an exact form in the real world.

For the current structure we created, this feels like extra code because our system is small enough right now. But imagine if our system grows and we need to incorporate other things from the library that are not books but can be borrowed. For example, a library also contains periodicals that you can borrow as well, and these periodicals do not follow the form of the book. You need a different representation for a periodical, therefore you need to create a new concrete class called `Periodical`. Since a periodical is also *something from the library that can be borrowed*, a periodical is another **realization** of `BorrowableItem`. And with the tiny effort of writing the implementation of a periodical (including the realized methods `uniqueItemId()` and `commonName()`), we added an extra interaction that allows a `LibraryCard` to borrow periodicals as well.

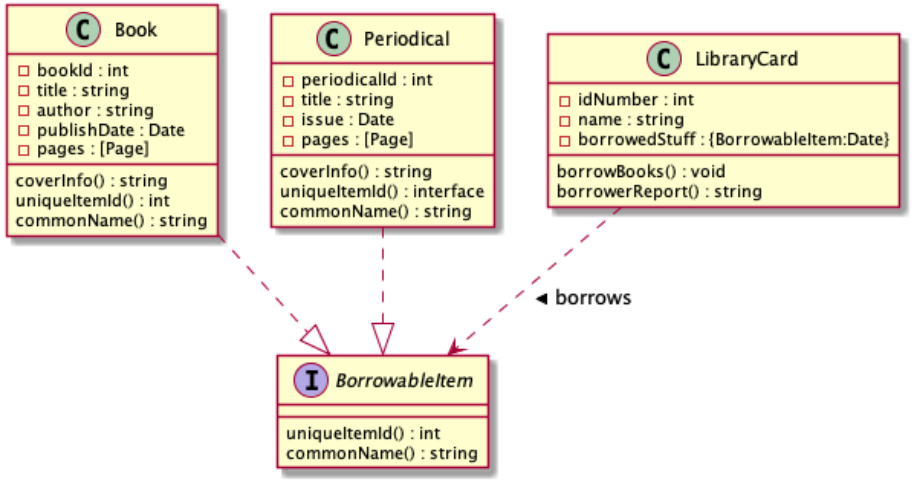


Figure 7.3: Class diagram of a book class

The Interface and the Implementation

Let's summarize what we learned so far by discussing how these capabilities characterize the philosophy of OOP. The paradigm aims to solve the issues of state and maintainability by allowing programmers to create boundaries between its mix of attributes and methods. The boundaries you enforce are basically the object structure you create. A library card name shouldn't mix with a book title so we put a boundary between them by **encapsulating** them into their respective objects.

You can imagine these objects as amorphous blobs with surface separating the methods and attributes inside it from other things in your code. These amorphous blobs have volume and surface. The volume of these blobs represent the **implementation** of these objects and the surface of these blobs represent the **interface** of these objects. The interaction, between two objects is characterized by the surfaces of objects, the implementation. The volume of the object shouldn't dictate how the objects relate to each other, in fact everything inside the object should be inaccessible to other objects. Objects should only see each other's surface. This means that the interaction between objects should be defined by their interface not their implementation.

Your job as an OOP programmer is to make sure that the complexity of the surface grows slower than the complexity of the core. This means that as your system evolves, changes that happen in the core, the implementation hidden inside each object, (as much as possible) shouldn't affect the surface, the interfaces of each object. This is what harmony and elegance in OOP means. Objects interact with each other seamlessly, and intuitively, regardless of what their inside look like.

Encapsulation

One of the most important design principle of object oriented programming is the concept called encapsulation. I've said it again and again and I don't mind saying it again right now, oop's innovation that made the paradigm a solution to the issues of state is its mechanism to construct boundaries wherever you want (you should want to put it between irrelevant data). This mechanism is also called **encapsulation**. Here are a few important points to remember:

- Encapsulation, when done correctly, makes your system approach a more accurate simulation of the real world. The more you encapsulate related data and methods, the more you'll create cohesive classes that have definite and indivisible purpose.
- You should **encapsulate what varies**, meaning, things that always change should be encapsulated deep into the structure of your code. This will help with maintainability since the changing isolated data or behavior will have less impact to the to the whole system.
- Encapsulation means both attributes and behaviors. Concrete objects should be given the responsibility of implementing their own behavior. This means that a method that describes the behavior of a certain class should belong to that class.

Inheritance (you can skip this, there's a better explanation in Class Relationships)

Another important design principle in OOP is the concept of **inheritance**. Inheritance is the concept in which the definition of a class is derived from another class. An existing class, called the **super class** (also called the **base class** or the **parent class**) passes all visible attributes and methods to a **sub class** (also called the **derived class** or the **child class**).

The concept of inheritance is also a representation of the real world. You use inheritance to represent generalizations and specializations. A super class is a generalization of a sub class and a sub class is a specialization of a super class.

In this example the supertype animal is a generaliztion of the subtype mammal. Although it isnt shown, `Mammal` will also have the attributes `name` and `weight` and the method `sound()` since it inherits these from the parent class. Mammal has a method of its own called `lactate()` which it doesn share with animal.

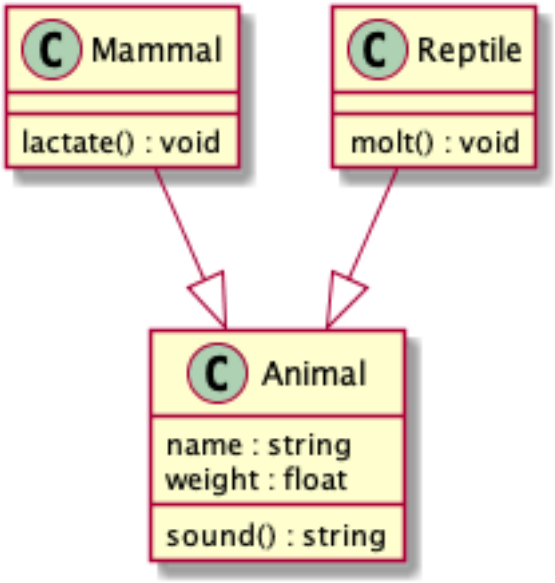


Figure 7.4: inheritance

A subclass can also be a super class for another class. This is used to represent specializations of specializations.

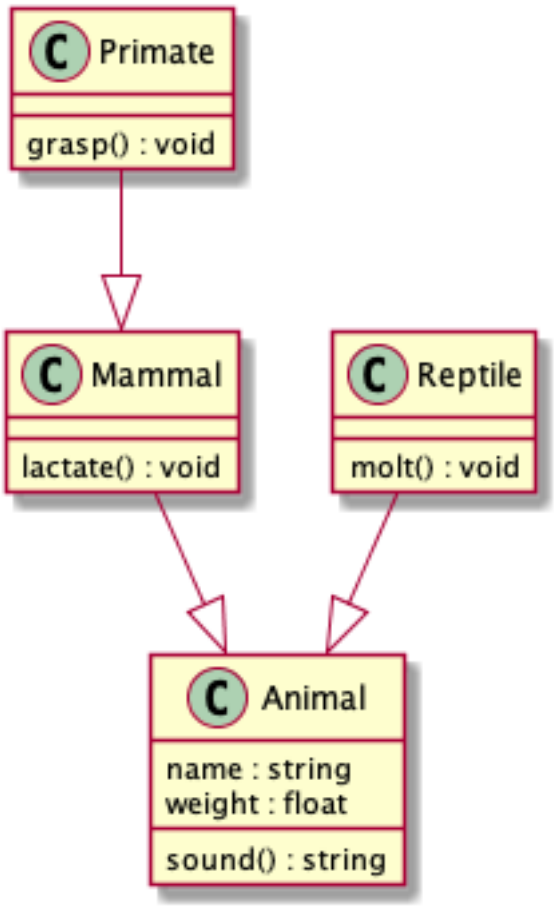


Figure 7.5: inheritance

The class primates will then inherit all visible attributes and mehtods of `Mammal` which include those that are inherited from `Animal`.

Some programming languages will allow you to add restrictions to the inheritance of an attribute or a method. Languages like `C++` or `Java` does this using the modifiers `private` and `protected`

super class visibility	public derivation	protected derivation	private derivation
`public`	`public`	`protected`	`private`
`protected`	`protected`	`protected`	`private`

super class visibility	public derivation	protected derivation	private derivation
`private`	*not inherited*	*not inherited*	*not inherited*

Polymorphism

Polymorphism literally means *multiple forms*. One of the core philosophy of OOP allows object instances to exist in multiple forms. What this means code-wise is that the types of object instances can be decided during runtime.

Compile-time polymorphism

There's also another type of polymorphism that is not necessarily shared by all OOP languages, compile-time polymorphism. This is basically the feature where multiple functions can have the same name as long as they have different parameter type signatures. This is also known as method overloading. This concept is also known as dynamic dispatch.

Run-time polymorphism

Run-time polymorphism on the other hand, is basically achieved using specialization and realization relationships between objects. This is usually what Polymorphism refers to in the scope of OOP.

For example, An object instantiated to be of type **`Primate`** is also an instance of an **`Animal`** because a primate is just a specialization of an animal. This is a reflection of how the real world works because a primate is indeed an animal. On realization relationships like a **`Book`** and a **`BorrowableItem`**, the same is also true, because a book is also something that can be borrowed. Realization and specialization relationships guarantee that you can interact with a sub type as its super type and you can interact with concrete class as its abstraction.

Optional Readings

Abadi, Martin; Luca Cardelli (1998). A Theory of Objects. Springer. ISBN 978-0-387-94775-4.

Python Introduction

starting python from the command line

To start python repl on the command line, use the `python` command. Make sure you have the path to python saved in your OS's `PATH` environment variable. Some python distributions have to be started with the specific version specified. For these distributions use the command `python2` or `python3`.

```
> python
Python 3.8.5 (tags/v3.8.5:580fbb0, Jul 20 2020, 15:43:08) [MSC v.1926 32 bit (Intel)] on w
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

To run a python script (`*.py`), use the same `python` command followed by the path to the script

```
> python script.py
```

python syntax

Lets start by discussing simple python syntax. Python code looks like this

```
x = 5
value = 6
print(x + value)
```

The first thing you notice is that python doesn't use semi-colons to separate statements, python finds the semi-colon redundant since programmers separate statements using newlines. Here python interprets three separate statements, `x = 5` and `value = 6`, and `print(x + value)`. The last line is pythons way of printing to an output stream.

python atomic types

Integers

An `int` in python is of course an implementation of an integer in math. There is no limit to the size of a python integer (except for system memory).

```
99999999999999999999999999 + 1
```

To check the type of a python object, you can use the function `type`.

```
type(99999999999999999999999999 + 1)
```

```
int
```

Floating-Point Numbers

A python `float` is an implementation of a floating point number. Numbers written in scientific notation are also floating point numbers:

```
type(4.2)
```

```
float
```

```
type(4.2e5)
```

```
float
```

Complex numbers

Complex numbers exist in python. The complex number $a + bi$ is represented as `a + bj` where `a` and `b` are integer literals.

```
type(4 + 3j)
```

```
complex
```

Strings

A python **`string`** is a sequence of characters. Strings can be enclosed by single-quotes or double quotes (but you must pair single-quotes with single-quotes and double-quotes with double quotes).

```
type(`This`)
```

```
string
```

```
type("That")
```

```
string
```

Boolean

A `bool` in python is either `True` or `False`.

```
type(True)
```

```
bool
```

```
type(False)
```

```
bool
```

Python typing

Python is a type inferred, mostly strongly typed, dynamically checked language.

There are no explicit declarations in python. The first assignment to a python identifier is its declaration. By assigning a value to that identifier python infers the type based on the value assigned to it. Changing the value assigned to an identifier changes its type as well.

```
x = 4
print(type(x))
x = 'this'
print(type(x))
```

```
<class 'int'>
<class 'str'>
```

Python is mostly strongly typed, which means that most type conversions result in a type error.

> ***Exercise (No submission but try to do this on your own)***
>
> ***Type Coercions***
>
> *What do you think would happen if you try to add different types in python? Without actually executing anything, predict the expected results of the following type surveys,*
>
> 1. *`type(3 + 3.0)`*
> 2. *`type(3 + '3')`*
> 3. *`type(3 + True)`*
> 4. *`type(4/2)`*
> 5. *`type(4/0)`*
>
> *After writing the expected results, write the actual results and compare them to your expectations.*

Python is dynamically checked, this means that it checks for type safety during runtime. This means that code that cannot be reached is not type checked. Which means that the following results in a type error:

```
print("this"+True)
```

But the following doesn't:

```
if 1 == 0:
        print("this"+True)
```

If you choose to do so you can annotate the type of an identifier using the following syntax:

```
x:int = 3
```

Iterable types

List

A python list, is a vector of any mix of python objects:

```
type([1,2,3,"4",True,[]])
```

```
list
```

The length of a list can be found using the built-in function `len` which accepts an iterable type and returns an integer which is the length:

```
len(l)
```

```
6
```

Lists can be concatenated using the `+` operator:

```
[1,2,3]+[4,5]
```

```
[1, 2, 3, 4, 5]
```

You can check if an element exists in an iterable using the `in` operator:

```
2 in [1,2,3,"4",True,[]]
```

```
True
```

List elements are accessed similar to c arrays.

```
l = [1,2,3,"4",True,[]]
l[2]
```

```
3
```

Negative indices count from the right

```
l[-1]
```

```
[]
```

You can extract a copy of a sublist using the following indexing methods

- `list[n:m]` produces a sublist from index n to m (including the nth element but excluding the mth element).
- `list[:m]` equivalent to `list[0:m]`.
- `list[n:]` equivalent to`list[n:-1]`.

```
l[1:3]
```

```
[2,3]
```

> ***Exercise (No submission but try to do this on your own)***
>
> ***Advanced list slicing***
>
> *Play around with lists and test the behavior of the list access operator `::`. What is the result of the expression `list[a::b]` where `list` is a `list` and `a` and `b` are `int`s? What about `list[a::]` and `list[::b]`.*

A python list is mutable, you can change the value of a specific element or range:

```
l[1] = 0
l
```

```
[1, 0, 3, '4', True, []]
```

You can delete an element on a specific index or range:

```
del l[2]
l
```

```
[1, 0, '4', True, []]
```

```
del l[2:4]
l
```

```
[1, 0, []]
```

Tuples

A python **tuple** is an immutable collection of objects. Tuples are written surrounded by parentheses instead of square brackets.

```
t = (1,2,True,5,6)
```

Tuple elements and subtuples can be accessed the same way with lists.

```
t[2]
```

```
True
```

```
t[1:4]
```

```
(2, True, 5)
```

Tuples can also be concatenated similar to lists.

```
(1,2,3) + (5,6)
```

```
(1, 2, 3, 5, 6)
```

Tuples are immutable so you cannot change the elements of a tuple.

```
t[1] = 2
```

```
...
TypeError: 'tuple' object does not support item assignment
```

Dictionaries

A python dictionary is a collection of key-value pairs. It is written surrounded by curly braces. Each pair is written, **<key>:<value>**

```
d = {"a":1,0:"this","b":True}
```

The elements of a dictionary can be accessed using the keys. Here the value associated to the key "a" is accessed.

```
d["a"]
```

```
1
```

Here the value associated to the key **0** is accessed.

```
d[0]
```

```
"this"
```

To check if a specific key exists in the dictionary, use the **in** operator in the same way you use it in lists:

```
"b" in d
```

```
True
```

You can add new entries to the dictionary using the following syntax: Notice how the dictionary has new entries after the second line

```
print(d)
d["newKey"]="newValue"
print(d)
```

```
{'a': 1, 0: 'this', 'b': True}
{'a': 1, 0: 'this', 'b': True, 'newKey': 'newValue'}
```

Key-value associations are injective meaning, a key can only be associated to exactly one value. If you attempt to "add" an entry for a key that already exists, it will not create a new entry, it will instead overwrite the old value:

```
print(d)
d["newKey"]="newerValue"
print(d)
```

```
{'a': 1, 0: 'this', 'b': True, 'newKey': 'newValue'}
{'a': 1, 0: 'this', 'b': True, 'newKey': 'newerValue'}
```

To remove entries in the dictionary use `del` in the same way you use it on lists:

```
del d["a"]
print(d)
```

```
{0: 'this', 'b': True, 'newKey': 'newerValue'}
```

Selection expressions

Python's if else statements follow this pattern (the else part can be omitted if the execution does not need an alternative). The colon and whitespace are part of the syntax and are mandatory. Every tabulated line is inside the scope of the `if` part or the `else` part.

```
if boolean:
    truePart
else:
    alternativePart
```

Nesting if else statements in python has a shortcut. The following code:

```
if False:
    print("won't print")
else:
    if False:
        print("won't print too")
    else:
        print("will print")
```

Can be summarized to this:

```
if False:
    print("won't print")
elif False:
    print("won't print too")
else:
    print("will print")
```

Python also understands ternary expressions:

```
x = "this" if True else "That"
print(x)
```

```
this
```

The value of **x** will depend on the value of the condition. Since this is true, the whole ternary expression reduces to **"this"**

Iteration

Python's **while** loop is similar to C's while loop. The block of code inside the while loop will be executed repeatedly until the condition becomes false.

```
i = 0
while i < 5:
    print(i)
    i+=1
```

```
0
1
```

```
2
3
4
```

Python's **for** loop is different from C. Python's **for** loop is a collections loop similar to Java's **foreach** expression.

```
for i in ["this",2,True,4]:
    print(i)
```

```
this
2
True
4
```

This for loop can be interpreted in common language as, *For every element i in ["this",2,True,4], print i.* Inside the for loop, the value of **i** refers to the elements inside the list. At the first execution of **print(i)**, **i** refers to the first element of the list. At the second execution **i** refers to the 2nd element of the list. and so on until it exhausts the list.

A common pattern for a **for** loop is something like this:

```
for i in range(0,5):
    print(i)
```

```
0
1
2
3
4
```

The function **range** produces a list of integers, starting from **0** until the **4**. **range(0,5)** can even be shortened to **range(5)**.

Python functions

Python functions are written using the following syntax:

```
def f(parameters):
        body
```

For example creating the add function:

```
def add(x,y):
    return x * y
```

Python file reading and writing

Opening a file

To open file in python

```
f = open("input.in","a")
```

The first parameter is the path to the file and the second parameter is the mode the file opening

- `"a"` - append mode
- `"a+"` - append mode but if the file being opened does not exist, create the file and append
- `"w"` - for write mode (overwrites the contents of the file)
- `"w+"` - write mode but if the file being opened does not exist, create the file and write
- `"r"` - read mode
- `"r+"` - read mode but if the file being opened does not exist, create the file and read

Writing to a file

To write a single line in the file use the method `write()`. If the file is opened using `"a"` and `"a+"` mode the string is appended to the file. If it is opened using `w` and `w+` modes, the files contents are overwritten by this new line. Will not work on `"r"` and `"r"+` modes.

```
f.write("foo")
```

Reading from a file

To read an entire file use the method `read()`. This function returns the whole file as a string

```
f.read()
```

Closing a file

```
f.close()
```

Formatted Strings

When working with multiple string concatenations you can use formatted strings. For example, the following string

```
s = "this"
t = "is"
u = "tedious"
v = "times"
w = 100

c = s + " " + t + " " + u + " " + v + " " + str(w)
print(c)
```

```
this is tedious times 100
```

Can be concatenated similar to C's formatting using the `%` operator

```
s = "this"
t = "is"
u = "tedious"
v = "times"
w = 100

c = "%s %s %s %s %d" % (s,t,u,v,w)
print(c)
```

```
this is tedious times 100
```

Type Annotations

Type annotations mark the type of identifiers.

```
x:int = 1
s:str = "Hey"
```

You can also annotations to set the parameter types and the return type of a function

```
def add(x:int,y:int) -> int:
    return x * y
```

Type annotations are only annotations, you don't have to write them. But writing them will help you make sense of a complicated system

Python library import

To import python libraries use the keyword math followed by the python library name. As much as possible write imports at the topmost part of your python files

```
import math
math.ceil(1.5)
```

```
2
```

You can give the library name a shorter alias for convenience

```
import math as m
m.ceil(1.5)
```

```
2
```

You can also choose not to import the whole library, just specific classes and functions. When you do this you can directly access the class or function without the dot reference.

```
from math import floor,ceil #importing floor,and ceil only
floor(1.2) + ceil(1.5)
```

```
3
```

If you are importing your own files, the same syntax will work as long as you are in the same directory as the python file you are importing.

```
from myPythonFile import someMethod, someFile
```

> *Assuming **myPythonFile.py** exists in the same directory you are currently in*

Python comments

Comments are made using the octothorpe/pound/hash/sharp symbol (**#**)

```
1 + 1 #comments are made using the octothorpe/pound/hash/sharp
↪  symbol
```

Class Relationships

Introduction

The interactions between one an instance of a class to another is largely characterized by the relationship between them. Here we talk about relationships that define the polymorphism between classes and relationships that define dependency between objects.

Learning Outcomes

1. Differentiate realization relationships and specialization relationships
2. Describe how class abstract methods work in realization relationships
3. Describe the concept of inheritance
4. Differentiate aggregation relationships and composition relationships

---

Type Based Relationships

Type based relationships are characterized by how two classes are related to each other through ontological hierarchy. A mammal class's relationship with an animal class's relationship is type based. That is because a mammal is considered as an animal while an animal is not necessarily a mammal.

There are two type based relationships (there can be an extra one which is a type relationship that is sort of a hybrid of the two).

Realization

A realization relationship is a one way relationship that describes how something abstract is REALized by something concrete. Given a `Realization` class and an `Abstraction` class, The `Realization` class realizes the `Abstraction` class.

> *A realization relationship is also called an **implementation** relationship. An implementation, implements some interface. **Interface** is also a fitting term for abstractions because it is through these classes that other objects interact with each other.*

An `Abstraction` is a special type of class that does not contain any implementation. This means that `Abstraction` doesn't have code that controls the form and behavior of the class. It only contains code that specify how this class interacts with other objects. This means that abstract classes only contain method names and type signatures with empty bodies.

These `Abstraction` classes appear useless at first since it doesn't do anything at all. In fact you cannot even create an instance of an abstraction. Even if you do it will be pointless since it doesn't have code that controls how it behaves.

An abstraction can only be useful if some other class realizes this abstraction. These `Realization` classes provide abstractions their form and behavior.

What's the point in maintaining some realization relationship between classes? If abstractions can only be used through their realizations , then why create the abstraction at all?

The importance of this seemingly pointless relationship lies in OOP's data hiding principle. We will explore more about why these relationships are very common in a future discussion about SOLID principles. For now I'll show one of the reasons why this is useful through an example:

Realization Relationship Example

Consider a library system. In a library, you are able to borrow resources such as books, newspapers, and computers. When the library system interacts with

these resources to facilitate transactions such as borrowing and returning, the library system treats these resource like general **Borrowable Items**. It doesn't really need to concern itself of the specific type. Operating like this is better for the library system for reasons such as maintainability and future proofing (this will be explained in detail in when we discuss SOLID design principles). Therefore, the best architecture to use in this situation is to make each resource type a realization of Borrowable Item. A `BorrowableItem` class would merely be an abstraction. This class would contain no behavior or form, it only contains specifications of how to interact with it. And it does make sense, I mean, how exactly does a general borrowable item behave or look like? It's abstract. What we know is that any `BorrowableItem` can be borrowed or returned so we write empty `borrow()` and `return()` functions (it specifies how it interacts with others but it doesn't have any specific behavior, these methods are called abstract methods).

Any realization of `BorrowableItem`, such as `Book` or `Newspaper` will be forced to implement the `borrow()` and `return()` methods as well (btw all realizations are forced to implement the methods of its abstraction), meaning it needs to include these methods with each of their own method bodies for borrowing and returning (if books and newspapers are borrowed or returned in different manners, then you write different method bodies for each).

> *Realizations can also have extra methods that are not present in the abstractions.*

This is how realization relationships enable **polymorphism**, a `Book` is a `BorrowableItem`, allowing the library system to interact with it like any `BorrowableItem`. But at the same time `Book` is a book so it behaves in the manner a book behaves.

By building all of these relationships, the library system is able interact with resources without explicitly knowing which exact resource it is. The system knows that it is borrowing some instance of a borrowable item but it does not know if it is a book or a newspaper. The exact type of this instance will then behave depending on its type. Although all this effort may seem unnecessary, you will learn in this course that through the establishment of these relationships, OOP is able to uphold one of its core design principles, **data-hiding**.

Abstractions can also realize abstractions. For example given an abstraction A, another abstraction, called B, can realize A. A class C then realizes B. When this happens, B does not need to implement A's abstract methods because B is an abstraction itself. Therefore, C will inherit all of A and B's abstract methods. The abstract methods of an abstraction cascades down to the realization realizing any of its realizations as well.

In this case C instances can be treated as B instances or A instances but it will behave in the way C behaves.

Specialization

Specialization relationships are very similar to realization relationships. You can think of these specialization relationships as realizations but between two real/concrete classes. A specialized class specializes some general class. By establishing this relationship, you are able to extend the form and behavior of a specific class.

> *Specialization has plenty of names. This relationship is also called* ***extension*** *between the special/child/sub class and general/parent/super class. Another name for it would be* ***inheritance****.*

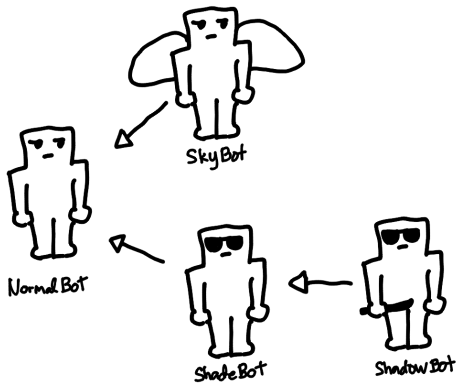


Figure 9.1: Specialization Example

Here's an example that would illustrate what the specialization relationship means. Consider a factory that builds robots. This factory is able to build `NormalBot`s which are the general type of robots. Instead of creating entirely separate mechanisms to build each type of robot, the factory is able to exploit the fact that other robots are just specializations of `NormalBot`. `Skybot` is just the same as `NormalBot` but it has extra flight capabilities. `ShadeBot` is just the same as `NormalBot` but it has UV Protection. Because of this the factory is able to use the building recipes for `NormalBot` to build `Skybot` and `ShadeBot`. All they need to do is to add some extra layers of construction such as adding wings or outfitting shades.

Specialization relationships work like this as well. When you write code for the general class, you do not need to rewrite it for specializations. What you write inside specializations are the the attributes and method that make it special. If this specialization has flight capabilities then add attributes for wings and methods for flight. If this specialization behave in a different manner for some specific method then you only change that specific method.

Because of this relationship, you only need to write one copy of the code that is common for the general class and its specializations. This means that you do not need to rewrite said code, saving time and effort but more importantly, having one copy of code helps for maintainability. When the recipe of all robot types need to change, the factory only needs to change the recipe of `NormalBot`, all of the special robots' recipes will change as well since they all use `NormalBot`'s recipe. When the code for the general class and the special classes need to be updated, changing the shared code found inside the general class will automatically affect special classes. Through this mechanism, specialization relationships enable **inheritance**, one of OOP's core design principle.

> *This is where the terms **inheritance** and extension make sense. Special class inherit all of the attributes and methods of the general class. Special classes can also be thought of as extensions of the general class, since these special classes extend or tweak the capabilities of the general class.*

You can also specialize, specializations. This is illustrated by `ShadowBot`, which is a special `ShadeBot` that has knife. Since `ShadowBot` is a special `ShadeBot` and `ShadeBot` is a special `NormalBot`, `ShadowBot` is automatically a specialization of `NormalBot` as well.

Specializations also allow polymorphism in the same way realizations do. A `ShadowBot` can be interacted with like any `NormalBot` or `ShadeBot` but since it is also a `ShadowBot` it will behave specifically like a `ShadowBot`.

Abstract Classes

An abstract class is something in between an abstraction and a generalization. It contains attributes and methods with bodies but it also contains abstract methods as well. When classes specialize/realize abstract classes, they inherit the attributes and methods with bodies but they are forced to implement the abstract methods as well. These relationships are sometimes used if the system requires a mix of inheritance and implementation between classes.

Multiple Type Relationships

It is possible for a class to realize/specialize multiple abstractions/generalizations. For example, given abstractions, A,B and C, and generalizations E,F, and G, a class X can realize/specialize all of them. When you do this, X will be forced to inherit all of the abstract methods in A, B and C, and automatically inherit everything from E, F, and G.

Dependency Relationships

Dependency relationships, also known as **associations**, characterize how two classes interact with each other. A class which is dependent on another class, needs to know how to interact with it. These interactions range from being used as method parameters, being returned in methods, being used inside method bodies, being used as attributes and etc. A dependency relationship is one way (but it is also possible for two objects to be dependent on each other). A **client** class is dependent on some **dependency**. There are two types of dependencies:

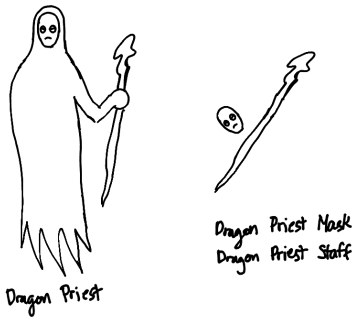


Figure 9.2: Dependency Example

Aggregation

Aggregation relationships are general usage and transactional dependencies. When a dependency is an aggregate of some client, it means that the client merely **uses** the instances of this dependency. These relationships are the looser forms of dependency, because the dependency instance can exist outside the lifetime of the client instance.

For example, in a videogame, a hostile enemy instance of `DragonPriest` spawns equipped with instances of`DragonPriestMask` and `DragonPriestStaff`. The `DragonPriest` instance is a client of the dependencies `DragonPriestMask` and `DragonPriestStaff`. `DragonPriest` interacts with these dependencies to calculate its attack damage, its defenses and etc. But when this specific instance of `DragonPriest` is defeated, it despawns, leaving behind the its `DragonPriestMask` and `DragonPriestStaff`. These instances will continue to exist since it can still be used by other client objects in the game, such as the player character, some storage chest or whatever. This means that the relationship between `DragonPriest` and the dependencies `DragonPriestMask` and `DragonPriestStaff` is aggregation.

Composition

Composition relationships are ownership dependencies. When a client is composed of some dependency, this means that the client **owns** the instances of this dependency. These relationships are stronger forms of dependency since the existence of the dependency instance is tied to the client, meaning, the dependency ceases to exist outside the lifetime of the client instance.

In the same videogame, the hostile enemy instance of `DragonPriest` appears in game using some `DragonPriestCharacterModel` instance. When the `DragonPriest` instance is defeated, it despawns. It makes no sense for the `DragonPriestCharacterModel` instance to stay behind after the `DragonPriest` instance is defeated, therefore it ceases to exist as well. This means that the relationship between `DragonPriest` and the dependency `DragonPriestCharacterModel` is composition.

OOPython

Introduction

Python was never originally meant for pure oop. But OOP is not a classification, it is a paradigm. The language does not make the OOP elegant, it's how you adhere to the design principles of the paradigm.

Learning Outcomes

1. Create python classes and objects/instances
2. Create `__init__()` methods
3. Establish realization relationships in python
4. Establish specialization relationships in python
5. Explain how different levels of visibility affects access and inheritance in python

---

Python Classes

Creating classes in python is very easy, here's an empty class called `EmptyClass`:

> *In python and other OOP languages, naming classes with nouns that start with capital letters is a convention. You can name it with weird names but correct naming is good practice for maintainability.*

```
class EmptyClass:
    pass
```

You write `pass` to indicate that this specific scope is empty. By putting `pass` inside classes the classes will have no attributes or methods, thus an empty class.

To make this class more interesting, lets put something inside it. You can put methods and attributes inside classes. Everything found inside the indent level of a class, belongs to that class.

```
from abc import ABC, abstractmethod

class EmptyClass:
    pass

class VoiceBox:
    name : str = "Vincent"
    def speak():
        print("Hi, I'm " + VoiceBox.name + " the VoiceBox")

VoiceBox.speak()
VoiceBox.name = "Vito"
VoiceBox.speak()
```

```
Hi, I'm Vincent the VoiceBox
Hi, I'm Vito the VoiceBox
```

When the `VoiceBox.speak()` is called, the method `speak()` found inside the scope of `VoiceBox` is called. This function accesses an a identifier called `VoiceBox.name` which refers to the identifier `name` found inside `VoiceBox`. As, you can see, classes in python uses dot-reference similar to C.

When `VoiceBox.name = "Vito"` is executed, it changes the assigned value to "Vito (which was originally"Vincent"). Now when `VoiceBox.speak()` is invoked again, it says"Hi, I'm Vito the VoiceBox".

This usage of classes is not actually interesting at all. Even though it contains attributes and methods, this class is merely used like a data holder. The attributes and methods you see inside `VoiceBox` right now are what we call **static** attributes and **static** methods. We won't really use a lot of static attributes and methods in this course (it's not good practice to use them). Basically, statics are attributes and methods that are not associated to class instances. They exist in the class itself, outside the lifetime of any instance.

Right now, the `VoiceBox` class is unable to create meaningful instances or objects. To do that we need to implement a constructor. Let's make a new class, one that can construct meaningful instances of itself.

`__init__()` Constructor

The `__init__()` method is a special method that is responsible for spawning instances of the class. This method stands for **initialization**. Here it is in action.

> *`__init__` is surrounded by two underscores on each side.*

```
class Robot:
    def __init__(self, n : str):
        self.name = n

    def talk(self):
        print("Howdy, it's me, "+ self.name)

    def communicate(self, partner : 'Robot'):
        print("Howdy, "+ partner.name + " it's me, "+ self.name )

r1 : Robot = Robot("Bonk")
r2 : Robot = Robot("Chonk")

r1.talk()
r2.talk()

r1.name = "Donk"

r2.communicate(r1)
```

```
Howdy, it's me, Bonk
Howdy, it's me, Chonk
Howdy, Donk it's me, Chonk
```

Lets look at this code piece by piece. First the `__init__()` method

```
#Robot
def __init__(self, n : str):
        self.name = n
```

Here you'll notice a special identifier called `self`. The identifier `self` is a special reference to the instance of the class using this. Basically whichever instance is being spawned right now is assigned to `self`. It doesn't actually have to be named `self` you can name it anything (but naming it `self` is a python convention). Python understands that the first identifier found at any non-static method is a reference to the instance invoking the method.

Inside, we are preparing the instance by assigning values to its attributes. We do that by assigning `n`, a string type parameter passed to `__init__()`, to `self.name`. Since name is dot referenced to `self`, which is the instance being spawned, the instance gains the `name` attribute. Unlike, `VoiceBox.name`, this attribute is associated to an instance of `Robot` not the class `Robot` itself.

There's also something not explicitly shown here that python automatically does. The method `__init__()` returns `self`, the instance being spawned at the by `__init__()`.

To use the `__init__()` function, we create two instances of `Robot` using the following code:

```
#outside Robot
r1 : Robot = Robot("Bonk")
r2 : Robot = Robot("Chonk")
```

The identifier `r1` is assigned a new instance of `Robot` named "Bonk", and the identifier `r2` is assigned a new instance of `Robot` named "Chonk".

The expression `Robot("Bonk")` is equivalent to the invoking the `__init__()` function, while passing the string "Bonk" to be assigned to the parameter `n`. Notice how `__init__()` expects two parameters but its invocation `Robot("Bonk")` only provides two, that is because the instance assigned to `self` is automatically passed without being explicitly shown (take note of this because a lot of people forget about the hidden `self`, including me from time to time).

```
#outside Robot
r1.talk()
r2.talk()
```

```
Howdy, it's me, Bonk
Howdy, it's me, Chonk
```

Since there are two separate instances of **Robot** with different names, it prints two different lines. This happens because inside of what we wrote inside the method **talk()**

```
#outside Robot
def talk(self):
        print("Howdy, it's me, "+ self.name)
```

Notice how **talk()** uses the special reference **self** again. **self** which is the first and only parameter passed, is used by concatenating **self.name** to the printed message. Since **self** refers to the instance invoking talk, the instance's own name is used ("Bonk" for **r1** and "Chonk" for **r2**).

Also, notice how when invoked, nothing is passed to **talk()**, despite expecting one parameter. This is again because the instance invoking, is automatically passed and assigned to **self** behind the scenes.

> *When you're writing a non-static method, always include **self**. Even if you do not use the reference to **self** inside the function. That's because python will force the first parameter in the method to accept the instance reference.*

Let's look at the next lines of code.

```
#outside Robot

r1.name = "Donk"

r2.communicate(r1)
```

```
Howdy, Donk it's me, Chonk
```

First, the name of the instance assigned to **r1** is changed from "Bonk" to "Donk". Then, **r2** invokes its method **communicate()** passing the instance **r1**. Let's look at the insides of **communicate()**.

```
#inside Robot
def communicate(self, partner : 'Robot'):
        print("Howdy, "+ partner.name + " it's me, "+ self.name )
```

The instance assigned to **r1** is passed and assigned to **Robot**. The instance **r2** is also passed and assigned to **self** but behind the scenes. Inside this method

both `partner.name` and `self.name` are used. `partner` refers to the instance named "Donk" and `self` refers to the invoker of the method, the one named "Chonk". As, a resilt of all these, the line "Howdy, Donk it's me, Chonk" is printed.

> *If you notice the type annotation* ***`Robot`*** *is surrounded by single quotes. If you remove these quotes, python will spill an error because it doesn't recognize an* ***`Robot`*** *as a class name yet. That's because the* ***`communicate()`*** *function is inside* ***`Robot`****, therefore Robot hasn't been defined yet.*

Python Realizations and Specializations

Specialization

The syntax for establishing realization and specialization relationships are the same in python. It just depends if the classes involved are abstractions or generalizations.

Here's a generalization relationship in action.

```
class SkyBot(Robot):
    def fly(self, height:int):
        print("I'm "+ str(height) +"m high in the air. Skybot go
        ↪  zoom. ")

r3:SkyBot = SkyBot("Zonk")
r3.talk()
r3.fly(3)
```

```
Howdy, it's me, Zonk
I'm 3m high in the air. Skybot go zoom.
```

> *Note how even though,* ***`self`*** *is unused inside the method* ***`fly()`****,* ***`self`*** *is written in the parameter list. If you do not do that, the python will assign the invoking instance to* ***`height`****.*
>
> *Since* ***`height`*** *is* ***`int`*** *you need to convert it using the* ***`str()`*** *function so that concatenation is allowed.*

The class `SkyBot` becomes a specialization of `Robot` through the line, `class SkyBot(Robot):`. The class name between the parentheses will be specialized by the class outside the parentheses.

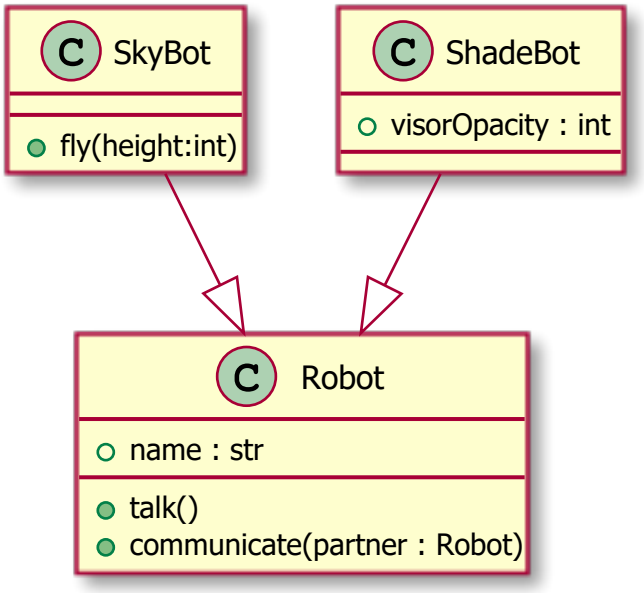


Figure 10.1: robot relationships

Notice how even though the functions `__init__()`, `talk()`, and `communicate()` are not in found in the scope of `SkyBot`, you are still able to use them. That is because `SkyBot` has inherited them.

> *If class relationships haven't been discussed yet. Don't worry we will talk about them in a future lecture. For this lecture focus on python syntax.*

Here's an example that shows how to extend the attributes of a generalization

```
class ShadeBot(Robot):
    def __init__(self, n:str, o:float):
        Robot.__init__(self,n)
        self.visorOpacity = o

    def communicate(self,partner:Robot):
        if self.visorOpacity >= 1:
            print("Howdy, it's me, "+ self.name + ". Sorry I cant
            ↪  see you my shades are too dark")
        else:
            print("Howdy, "+ partner.name + " it's me, "+
            ↪  self.name)

r4:ShadeBot = ShadeBot("Tonk", 1)
```

```
r4.talk()
r4.communicate(r3)
```

```
Howdy, it's me, Tonk
Howdy, it's me, Tonk. Sorry I cant see you my shades are too dark
```

Here, even though `ShadeBot` inherits `__init__` from `Robot`, it has its own definition of `__init__`. When this is done, `ShadeBot` replaces `Robot`'s version of `__init__` with its own. This is called **method overriding**. You will need to do this for `__init__` if you need to extend the class to have more attributes (You also override methods if you need something changed for the specializations). We are doing this for `ShadeBot` since we need to add the attribute `visorOpacity`.

You'll notice the strange line of code, `Robot.__init__(self,n)` inside `Shadebot`'s `__init__`. What you're doing here is statically invoking `Robot`'s `__init__` function to reuse the code inside it (statically invoking means that the class itself is invoking the method not any instance, that's why `self` is being explicitly passed). Calling this is similar to doing the following

```
#ShadeBot
def __init__(self, n:str, o:float):
    self.name = n
    self.visorOpacity = o
```

If you're not changing anything that happens during the `__init__` of the specialization just extending it, then you can statically invoke the generalization's `__init__`. Otherwise, if you need to change how the specialization gets its name for example, then you have to fully write the whole specialization's `__init__`.

```
#ShadeBot
def __init__(self, n:str, o:float):
    self.name = "Mr." + n
    self.visorOpacity = o
```

Realization

The syntax for realization is just the same as specialization. If you put an abstraction inside the parentheses then the relationship becomes realization.

```
from abc import ABC, abstractmethod

class BorrowableItem(ABC):
    @abstractmethod
    def borrow(self):
        pass

    @abstractmethod
    def name(self) -> str:
        pass

class Book(BorrowableItem):
    def __init__(self, title:str):
        self.title = title

    def borrow(self):
        print("I'm a book called "+ self.name() +" and I'm being
        ↪  borrowed")

    def name(self) -> str:
        return self.title

class IMacUnit(BorrowableItem):
    def __init__(self, id:int):
        self.id = id

    def borrow(self):
        print("I'm an iMac called "+ self.name() +" and I'm being
        ↪  borrowed")

    def name(self) -> str:
        return "iMac" + str(self.id)


b : BorrowableItem = Book("Necronomicon")
i : BorrowableItem = IMacUnit(5)

b.borrow()
i.borrow()
```

```
I'm a book called Necronomicon and I'm being borrowed
I'm an iMac called iMac5 and I'm being borrowed
```

First things first, to be able to make use of abstractions, you need to import the `abc` library. We specifically need 2 things, the class `ABC` which stands for **abstract base class** and the decorator `abstractmethod`. You typically put import lines at the top of your code, above everything else.

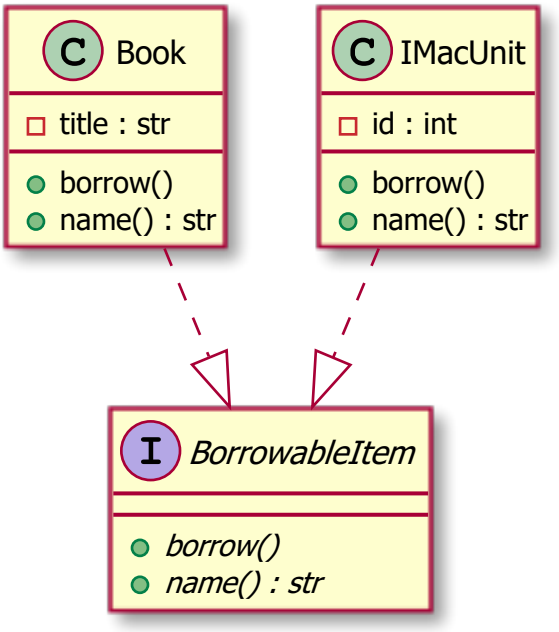


Figure 10.2: realization uml

The abstraction in this case is the class called `BorrowableItem`. For a class to become an abstraction it needs to realize the imported class `ABC`, hence the line `class BorrowableItem(ABC):`.

Inside `BorrowableItem` are two methods called `borrow()` and `name()`. Both of these methods are decorated by `@abstracmethod`. You see this decoration above all methods that you want to be abstracted. Inside each of `borrow()` and `name()` is the special expression `pass`. Which means that these methods are empty. They do not contain any implementation or body. You can put code inside these methods but it wouldn't matter since these methods will be guaranteed to be overwritten by `BorrowableItem`'s realizations.

What `@abstractmethod` does is, it indicate to python that the directly method below it, must be overridden by the abstraction's realizations. You'll notice this if you change the code above by adding another method decorated with `@abstractmethod` without implementing it inside all the realizations, you'll get the following error during instantiation:

```
#BorrowableItem
@abstractmethod
```

```
def implementationRequirement(self):
        pass
```

```
Traceback (most recent call last):
  File ".\OOPython.py", line 95, in <module>
    b : BorrowableItem = Book("Necronomicon")
TypeError: Can't instantiate abstract class Book with abstract methods implementationRequi
```

Without `@abstractmethod` python will not complain

```
#BorrowableItem
def implementationRequirement(self):
        pass
```

```
I'm a book called Necronomicon and I'm being borrowed
I'm an iMac called iMac5 and I'm being borrowed
```

The decorator `@abstractmethod` reminds all realizations of the requirements to remind any class that realizes the abstraction, "hey these are the functions that you need to be considered a `BorrowableItem`".

Moving on to the realizations, you see is that each realization overrides all abstract methods. You can also put methods that are not found in the abstraction. Here, you see both of them contain an `__init__()` method for instantiation.

> *Note on the code inside `Book`'s `__init__()`: although the parameter is called `title` and the attribute is called `title` as well, python can differentiate between them since the instance's title has to be dot referenced as `self.title` while the non-dot referenced `title` can only mean the parameter. It's fine to this, especially if you want to emphasize which parameters are stored to which attributes. In fact, I do this quite a lot.*
>
> *Note how the abstraction `BorrowableItem` does not contain an `__init__()` method. This is because he `BorrowableItem` is not meant to be spawned/instantiated. It is merely an abstraction so it must be ethereal and formless.*

Outside the class scopes you'll see these borrowable items instantiated like these:

```
b : BorrowableItem = Book("Necronomicon")
i : BorrowableItem = IMacUnit(5)
```

Both `b` and `i` are annotated to be of type `BorrowableItem` but they are instantiated from `Book` and `IMacUnit`. This is allowed because of polymorphism. Through realization, instances of `Book` and `IMacUnit` can be treated as `BorrowableItem`'s (they can also be treated specifically as `Book` and `IMacUnit`).

Python Visibility Control

Another important python syntax to remember is how to simulate different visibility levels for methods and attributes. Given the following class below, notice how the attributes and methods have special prefixes. These prefixes tell you that their visibility level.

```
class ClandestineClass:
    def __init__(self, publicValue:int, protectedValue:int,
    ↪  privateValue:int):
        self.publicValue = publicValue
        self._protectedValue = protectedValue
        self.__privateValue = privateValue


    def doPublicly(self):
        print("Hey!, these are my values")
        print(self.publicValue)
        print(self._protectedValue)
        print(self.__privateValue)

    def _doProtectedly(self):
        print("hey")

    def __doPrivately(self):
        print("...")
```

When the following code is ran, you'll notice that private, attributes and methods are not recognized by python:

```
#outside ClandestineClass
print(c.publicValue)
print(c._protectedValue)
print(c.__privateValue)
```

```
1
2
Traceback (most recent call last):
  File ".\OOPython.py", line 122, in <module>
    print(c.__privateValue)
```

In other oop based languages, protected values are not supposed to be accessible outside the class. But python doesn't have this mechanism. What python programmers do instead is to write protected identifiers with a single underscore prefix. Yes you can access them but you are not supposed to.

Of course all of these attributes can be accessed **inside** the class:

```
c.doPublicly()
```

```
Hey!, these are my values
1
2
3
```

Specializations do not have access to the private attributes and methods of its generalizations. . But both public and protected are. If you want some attributes/methods to be inherited but still (sort-of) inaccessible outside, make them protected instead.

```
class SpecialClandestineClass(ClandestineClass):
    def doSomethingSpecial(self):
        print(self.publicValue)
        print(self._protectedValue)
        print(self.__privateValue)

s:SpecialClandestineClass = SpecialClandestineClass(1,2,3)

s.doPublicly()
print() #prints a new line for formatting
s.doSomethingSpecial()
```

```
Hey!, these are my values
1
2
3

1
2
Traceback (most recent call last):
  File ".\OOPython.py", line 133, in <module>
    s.doSomethingSpecial()
  File ".\OOPython.py", line 123, in doSomethingSpecial
    print(self.__privateValue)
AttributeError: 'SpecialClandestineClass' object has no attribute '_SpecialClandestineClas
```

Note how `s.doPublicly()` still works perfectly because its definition lies inside `ClandestineClass`. On the other hand, `s.doSomethingSpecial()` will fail in printing private values since it is outside `ClandestineClass`.

Here's a summary of the access rules.

visibility	prefix	accessed specializations	accessed by clients
public	(none)	yes	yes
protected	_ (single underscore)	yes	technically yes in python (but you're not supposed to)
private	__ (double underscore)	no	no

> *Private values in python can actually be accessed outside using a special syntax. But it is out of scope here and you're not supposed to this anyway so don't worry about it.*

Abstract Classes

Abstract classes in python are implemented similar to how Abstractions are implemented. All methods that you want to be implemented are decorated by

`@abstractmethod` while all methods you want to be inherited are not decorated.

```
class AbstractClass(ABC):
    @abstractmethod
    def printSomethingA(self):
        pass

    def printSomethingB(self):
        print("I'm inherited. You can also override me if you
        ↪  want")

class ConcreteClass1(AbstractClass):
    def printSomethingA(self):
        print("I'm implemented by Concrete Class 1")

class ConcreteClass2(AbstractClass):
    def printSomethingA(self):
        print("I'm implemented by Concrete Class 2")

    def printSomethingB(self):
        print("I'm overriden by Concrete Class 2")
```

Both `ConcreteClass1` and `ConcreteClass2` are realizations/specializations of `AbstractClass` therefore they must implement `printSomethingA()` otherwise it will cause an error (because of the `@abstractmethod` decoration). The other method `printSomethingB()` will automatically be inherited by both, but can still be optionally overridden (`ConcreteClass2` does this).

```
#outside the classes
c1.printSomethingA()
c1.printSomethingB()
print()
c2.printSomethingA()
c2.printSomethingB()
```

```
I'm implemented by Concrete Class 1
I'm inherited. You can also override me if you want

I'm implemented by Concrete Class 2
I'm overriden by Concrete Class 2
```

Unified Modelling Language for Class Diagrams

Introduction

The modelling language we are going to use to represent architecture would be UML or **Unified Modelling Language**. We use this to show the relevant classes in the system including their attributes, methods and relationships with other classes. UML differ a little depending on the source. The syntax we'll be following in this class would be based on PlantUML.

Learning Outcomes

1. Create class diagrams to represent OOP architecture in UML
    1. Create classes with attributes and methods in UML
    2. Establish class relationships in UML

Modelling Classes

The example below shows three classes. One is concrete class called `ExampleClass` (notice the "C" in the title that denotes it is a concrete class). Another is an abstraction called `ExampleAbstraction` (denoted by "I" which stands for interface). The last one is `ExampleAbstractClass` which is an abstract class (denoted by "A").

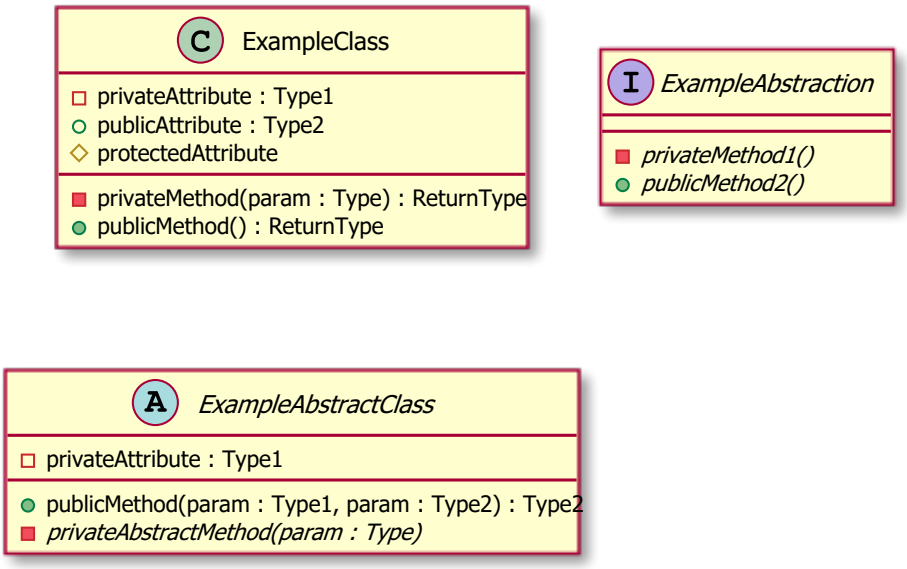


Figure 11.1: Class Diagrams

Attributes are placed in the top portion and methods are placed in the bottom portion. The shape to the left of each attribute or method indicates its visibility. Filled shapes indicate visibilities for methods while unfilled shapes indicate visibilities for attributes.

> *When writing UML for python code, I usually omit writing the* ***`self`*** *special identifier inside method specifications. It is implied that* ***`self`*** *is passed always for all non-static methods in python.*

attribute	method	visibility
□	■	private
◇	◆	protected

attribute	method	visibility
○	●	public

The names for abstract methods, abstractions, and abstract classes are italicized.

If possible, write the expected type of attributes, parameters and function returns. This is written on the right side of their names, to the right of ":".

> ***Disclaimer***: *sometimes you'll find some mistakes in my uml diagrams, sometimes I write the incorrect visibility marker or neglect abstract italicizations. Rest assured the code will contain the correct visibility markers, abstract modifiers and etc.*

Modelling Class Relationships

Here's a reference arrows that indicate the relationship between two classes:

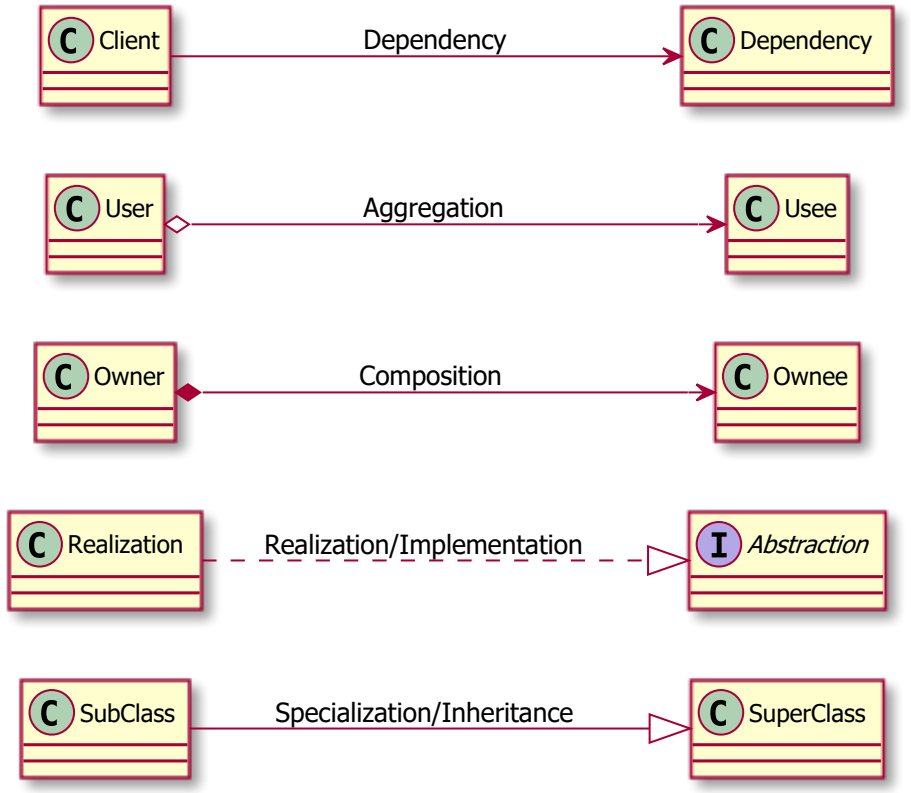


Figure 11.2: class relationships

Sometimes, instead of writing the specific kind of dependency arrow (aggregation or composition), I just write the general dependency arrow instead

Optional Readings

PlantUML Class Diagrams. https://plantuml.com/class-diagram Accessed August 31, 2020

Exceptions

Introduction

One of the features added to imperative programming was the elegant handling of errors. Exception handling provided OOP a mechanism to control what exactly the system does when parts of the fail.

Learning Outcomes

1. Create methods that raise errors in python
2. Create a try-except clause to properly react to errors in python
3. Design systems that correctly assign error handling responsibilties

---

Let's explore this with an example. In the snippet below, the last line is not reached because the system fails during `print(quotientUnsafe(3,0))`.

```
def quotientUnsafe(a:float, b:float) -> float:
    return a/b

print(quotientUnsafe(3,2))
print(quotientUnsafe(3,0))
print("some more behavior")
```

```
1.5
---------------------------------------------------------------------------
ZeroDivisionError                         Traceback (most recent
↪  call last)
 in
      3
      4 print(quotientUnsafe(3,2))
----> 5 print(quotientUnsafe(3,0))
      6 print("some more behavior")

 in quotientUnsafe(a, b)
      1 def quotientUnsafe(a:float, b:float) -> float:
----> 2     return a/b
      3
      4 print(quotientUnsafe(3,2))
      5 print(quotientUnsafe(3,0))

ZeroDivisionError: division by zero
```

> *Python has its own error raised when it encounter division by zero but well create our own for the sake of learning*

Problematic functions and methods like quotient don't always return a float. The problem for this quotient is that there is a possibility you'll end up dividing with zero. This introduces the concept of exception. Where the quotient function works **except** when the denominator is zero.

To implement this kind of behavior. You create an if-else check (or any control statement) to make sure the denominator is not zero. If you do encounter a zero denominator you **raise** an error. Here you are raising a user defined error object called `DivisionByZeroError`.

```
class DivisionByZeroError(Exception):
    def __init__(self,numerator:float, denominator:float):
        self.numerator = numerator
```

```
        self.denominator = denominator

def quotient(a:float, b:float) -> float: #maybe a float
    if b == 0:
        raise DivisionByZeroError(a,b)
    else:
        return a/b
```

When quotient is called where the denominator passed is zero, python will inform you that the function call has resulted in a `DivisionByZeroError`

```
try:
    quotient(3,2)
    quotient(3,0)
except DivisionByZeroError:
    print("there was dividing by zero somewhere but it's okay I'm
    ↪  still fine")

print("some more behavior")
```

```
there was dividing by zero somewhere but it's okay I'm still fine
some more behavior
```

By enclosing the lines of code that could potentially raise errors, you create a safety net for the system. The system **tries** to execute these lines, and if there are no errors raised inside the `try` block then the system runs normally. Nothing abnormal would occur **except** when the problematic lines of code raises an error. In this specific case, the system is catching, a specific type of error called `DivisionByZeroError`. If a specific type of error is not specified in the exception block, the system will catch any general error.

If a method with potential to raise errors like `quotient()`, is invoked inside another method, the caller method becomes a method with potential to raise errors as well.

```
def mixedFraction(a:float, b: float, c:float) -> float: #maybe a
↪  float
    return a + quotient(b,c)

mixedFraction(1,1,0)
```

```
---------------------------------------------------------------------------
DivisionByZeroError                       Traceback (most recent
↪  call last)
 in ()
      2     return a + quotient(b,c)
      3
----> 4 mixedFraction(1,1,0)

 in mixedFraction(a, b, c)
      1 def mixedFraction(a:float, b: float, c:float) -> float:
      ↪  #maybe a float
----> 2     return a + quotient(b,c)
      3
      4 mixedFraction(1,1,0)

 in quotient(a, b)
      7 def quotient(a:float, b:float) -> float: #maybe a float
      8     if b == 0:
----> 9         raise DivisionByZeroError(a,b)
     10     else:
     11         return a/b

DivisionByZeroError: (1, 0)
```

Here, the `quotient()`'s caller,`mixedFraction()`, does not enclose the problematic line with a try-catch block. This means that `mixedFraction` is basically the ignoring any potential error, shifting the responsibility of dealing with the error to wherever `mixedFraction()` is called.

On the example below, `quotient()` is invoked inside `quotientString()`, but instead of ignoring the error, `quotientString()` deals with it using a try-catch block. When quotient fails, the function returns "undefined number" instead of a fraction string.

```
def quotientString(a:float,b:float) -> str: #always a string
    try:
        wholePart = math.floor(quotient(a,b))
        decimalPart = quotient(a,b) - wholePart
        return str(wholePart) + " and " + str(decimalPart)
    except Exception:
        return "undefined number"
print(quotientString(17,7))
print(quotientString(1,0))
```

```
print(quotientString(1,3))
```

```
2 and 0.4285714285714284
undefined number
0 and 0.3333333333333333
```

By dealing with potential errors, `quotientString()` becomes a safe function that has no potential of breaking the system.

You can catch multiple kinds of exceptions if you want to handle different exceptions differently. The exception `IndexError` is raised when an iterable type like list accesses a non-existent member. Here the function `quotientList` wants to append `math.inf` if you're dividing by zero and not append anything if you're dividing with non-existent list members.

```
def quotientList(l:[float],m:[float]) -> [float]: #always a list
↪  of float
    r = []
    for i in range(0,len(l)):
        try:
            r.append(quotient(l[i],m[i]))
        except DivisionByZeroError:
            r.append(math.inf)
        except IndexError:
            pass
    return r
quotientList([1,2,3,4,5,6],[3,0,2,2,1])
```

```
quotientList([1,2,3,4,5,6],[3,0,2,2,1])
```

To ignore errors or to deal with errors?

So you've seen two ways to react with potential errors, to ignore them like `mixedFraction()` or to deal with them like `quotientString()`. Which is the proper way? You might think that dealing with errors is better since it's this way doesn't break the system. But actually the choice to ignore or to deal with errors depends on who has the correct responsibility in fixing the error.

If you immediately deal with the error as quickly as possible, you'll end up missing the importance of raising errors. The method `quotient()` for example, is responsible for providing the caller with a quotient, that must be this method's only responsibility. You should not give quotient the responsibility of fixing division by

zeroes. That responsibility lies on its caller, because different caller's may have different ways to deal with the error. The method `quotientString()` deals with division by zero with "undefined number" while the method `quotientList()` deals with division by zero with "inf". These two callers have different ways of interpreting division by zero so they should be the one's responsible for dealing with the error.

SOLID Objects

Introduction

SOLID is an acronym describing design principles for creating OOP systems. By committing your code to these principles you will naturally build systems that don't only work perfectly, but work elegantly.

Learning Outcomes

1. Design methods and classes with exactly one responsibility
2. Design extension to classes to incorporate new behavior
3. Design proper realization and specialization relationships
4. Design purposeful abstractions and abstract methods
5. Design systems that interact through abstractions

Briefly, these five principles are:

- **Single Responsibility Principle** - Objects should have cohesive and complete responsibilities. It shouldn't be aware of knowledge it doesn't need and it shouldn't perform responsibilities that are irrelevant from it.
- **Open/Closed Principle** - Classes should be open to extension and closed to modification. Instead of changing the form and behavior of an existing class, you should extend the class
- **Liskov-Substitution Principle** - Substituting objects by their subtypes/realizations should always work.
- **Interface Segregation Principle** - A client shouldn't be forced to implement methods that it doesn't use
- **Dependency Inversion Principle** - Object relationships should depend on abstractions instead of implementations

Single Responsibility Principle

The GOD Class

One of the canonical examples of violations against SRP is the concept known as the **god class**. A god class is a class that basically contains all the attributes and methods of the whole system. You'll recognize these god classes as those classes that control the behavior of objects (they contain the implementation of client objects' behavior). These god classes are also aware of all of the objects secrets (they expose and manipulate private attributes and methods).

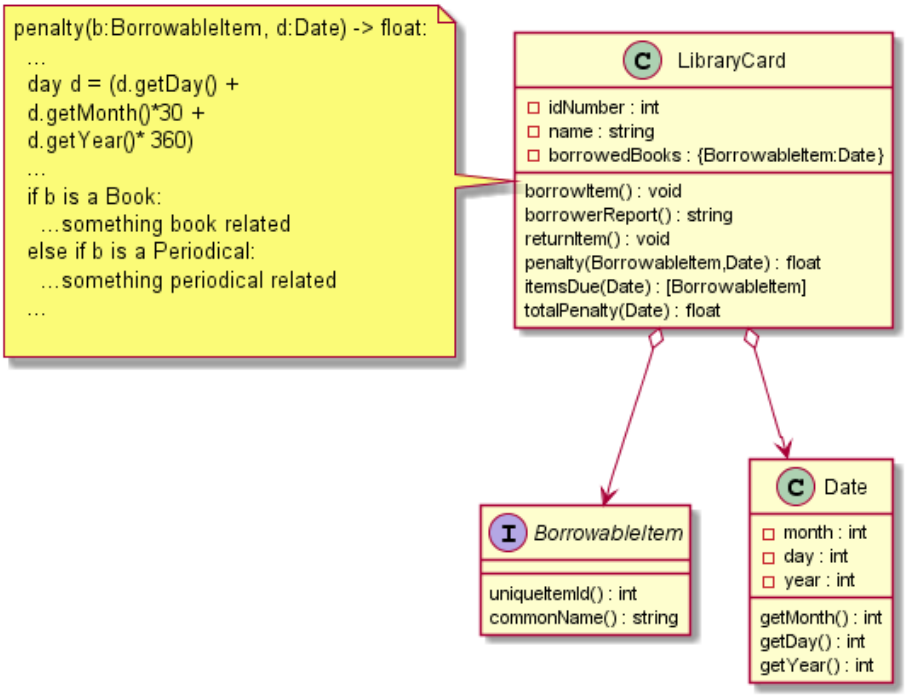


Figure 13.1: god class library card

On the example above `LibraryCard` is a god class since it exposes the secrets of `Date` by forcing the creations of *evil* getters (`getMonth()`, `getDay()`, `getYear()`) for otherwise private details. Although it isn't obvious, it also tampers on the responsibilities of `BorrowableItem` by deciding by itself how penalty is calculated for each realization.

> *The moment you ask an object what it's exact type is, you should consider refactoring your code since introspective checks like* ***`isinstance`*** *,* ***`instanceof typeof`*** *and etc., are symptoms of smelly design. You can think of these checks as analogies to racial discrimination since your client object asks the race (type) of the dependency.*

Assigning the correct responsibilities

When you're introducing new behavior or information to a system, you should ask first: *who should be responsible of this behavior or information?*

- Who should be responsible of calculating the differences between dates? **`Date` should be responsible, not `LibraryCard`**.
- Who should be responsible of calculating the penalties of specific `BorrowableItem` realizations? **`BorrowableItem` realizations should be responsible, not `LibraryCard`**

The best implementation of the system contains multiple examples of SRP. The `Date` class should be responsible of subtracting dates and adding dates, not the `LibraryCard` class. Forcing `LibraryCard` to contain code for `Date` operations will force you into breaking the boundaries of your classes (e.g. creating getters to expose private attributes). `LibraryCard` should not be aware of **how** dates are subtracted to be able to subtract dates. The same is true for a `BorrowableItem`'s due date. The `LibraryCard` shouldn't contain the specifications as to how `BorrowableItem`s calculate their due date. In fact `LibraryCard` shouldn't even be aware of the exact type of the `BorrowableItem` (`isinstance` violates this).

The process of designing these cohesive systems requires not only OOP design techniques but also domain knowledge. The designer of the system, should know how a library system operates so that, he/she can accurately simulate their responsibilities on code.

You can also apply SRP on individual methods inside objects. Methods should be responsible of one thing only. Keeping methods pure like these will help reduce unwanted side effects. The builder/manipulator naming scheme will help you with this. Also a method should not be responsible of handling the problems. The method should delegate that responsibility to the clients of that method.

The methods itself should only report the problem. The best way to do this in OOP is by raising an exception.

Open/Closed Principle

A good class in OOP is both open and closed. It is open for extension but closed for modification.

To understand this principle lets have an example of a system that is closed for extension:

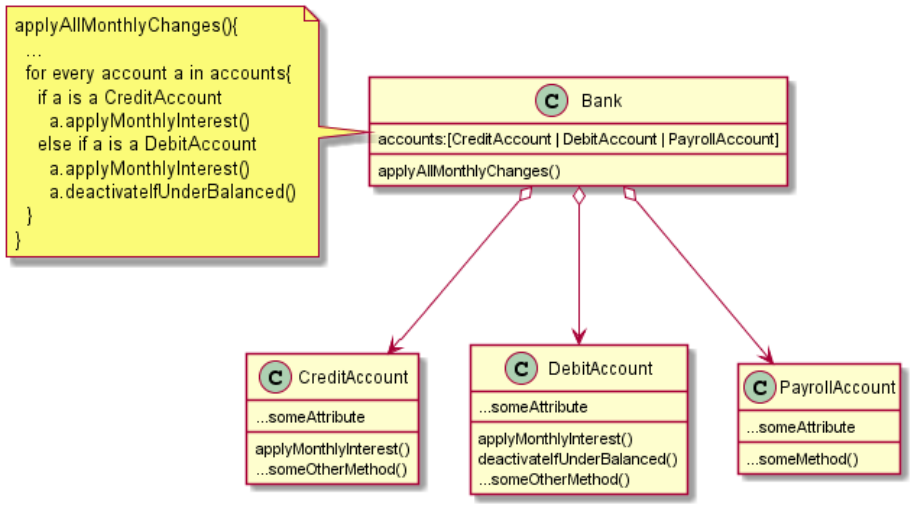


Figure 13.2: god class library card

> *Forgive the long Java-like method names, they're named as descriptive as possible so that I can s skip actually explaining what they do.*

This is a system that indeed works perfectly. The bank will be able to apply the appropriate changes to the account types because of the `if-else` block that segregates the accounts based on its type (another instance of type discrimination so that's a hint that this is wrong). The problem with this is that whenever there are changes regarding the monthly changes or interest calculations, you would have to tamper with the contents of bank. This is **opening `Bank` up for modification**. Every time there's a change related to monthly updates you would have to do some kind of surgical procedure on `Bank` and rearrange its internal organs so that the change may be supported. This is extra rough on `Bank` because `Bank` shouldn't even be responsible for these behaviors (a violation of SRP). If there are new types of account, then you would have to open up `Bank` again and to add another `else if` block. Poor `Bank`, who knows how many more new types of accounts there are in the future.

Instead of rearranging the organs of your classes to accommodate changes to behavior they are not even responsible for, you should close the classes for modification and open them for extension instead:

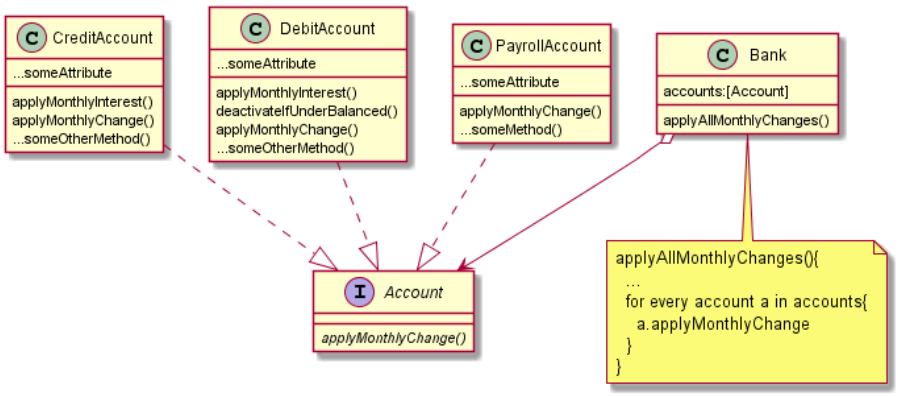


Figure 13.3: open for extension

Since `applyMonthlyChange()` is an abstract method of account, all its realizations are required to implement it. We extend the functionality of `CreditAccount`, `DebitAccount`, and `PayrollAccount` by adding an extra method.

- inside `CreditAccount.applyMonthlyChange()` you just call `applyMonthlyInterest()`,
- inside `DebitAccount.applyMonthlyChange()` you call both `applyMontlyInterest()` and `deactivateIfUnderBalanced()`
- inside `PayrollAccount.applyMonthlyChange()` you do nothing

Is a method that does nothing inelegant? Not really because this is an accurate representation as to how a `PayrollAccount` changes every month— it doesn't. Also, in the future, the inertness of `PayrollAccount` may change so at least you have the function prepared.

> *The previous library card example and bank examples are indeed similar . This is because introspective checks like* ***`isinstance`*** *are again symptoms of inelegant design.*

Another example of this is how you need to augment the `PayrollAccount` class to contain the `recieveFund(float)` or `deposit(float)` method so that it can become a recipient for transfer.

> *Closed for modification does not mean you cannot change literally anything in the class. Of course if there are mistakes in the specific behavior of the class then you have to modify it.*

Liskov-Substitution Principle

This principle basically dictates when should an object be a subtype or a realization of another object. Should `PayrollAccount` be a realization of `Account`? If you can substitute any instance of an `Account`with a `PayrollAccount` then the answer is yes. The same is true if you want to establish an inheritance relationship between `Account` and `PayrollAccount`. The LSP is important because it ensures the polymorphic capabilities of your realizations and subtypes.

Interface Segregation Principle

Sometimes the subtypes/realizations of a certain object may have diverse functionality. Some subtypes can deposit, some subtypes can't, all subtypes can be recipient for transfers but not all can be senders. The diversity of functionality supportability may sometimes force the designer to pollute the system with methods that the subtypes don't actually use. `PayrollAccount` will not use deposit but since it realizes `Account` then we reluctantly add it. This is a violation if LSP which states that an object should not be forced to implement methods it doesn't use.

Role Interfaces

The best way to design these diverse systems it by refactoring your architecture to have diverse role interfaces instead.

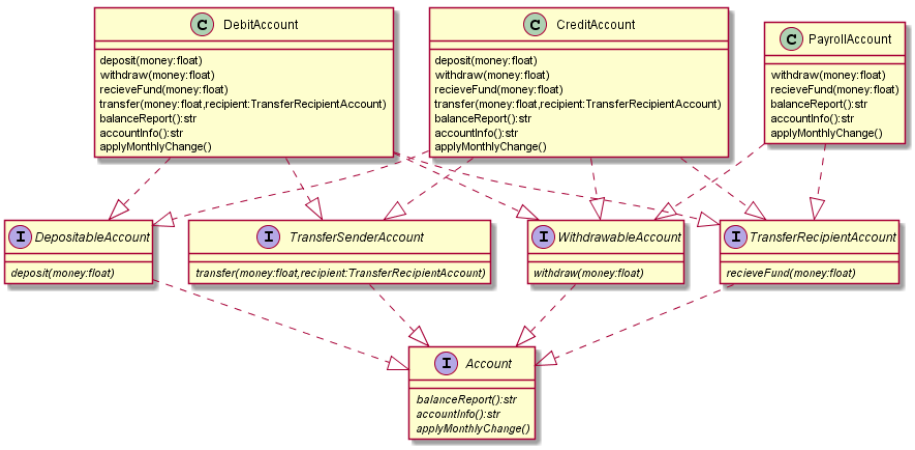


Figure 13.4: god class library card

Now instead of cluttering you realizations with useless methods, your systems is now cluttered with role interfaces. This is a benevolent kind of clutter. Because more objects and looser dependencies make for a maintainable and therefore elegant system (in the same way a language with more words have less chances

for ambiguity). Because of this clutter you can have rich polymorphism without sacrificing ISP. Although be careful not to over do it though. You wouldn't want a role interface for every conceivable method out there.

When you have role interfaces, you can refine lines of your code by describing which exact role interface applies. For example, instead if writing transfer to be an process which is `Account` to `Account` they are `TransferSenderAccount` to `TransferRecipientAccount`.

Dependency Inversion Principle

The relationships between objects should be defined by surface instead of their interior. This means that How a bank interacts with an account should not be dependent on the implementation. The way `Bank` prints the balance report should not be by directly concatenating `"Your balance is" + account.balance` . Bank should interact with an account by printing the return value the abstract builder method, `balanceReport()`. The class `Bank` should not dissect an `Account` to retrieve the balance. It should tell the `Account` to build a balance report.

Optional Reading

Bailey D., (2009) SOLID Development Principles – In Motivational Pictures. Accessed August 31, 2020

Extra Stuff

Here are extra things I want to discuss that do not really fall into specific lectures.

Naming Methods Elegantly

One of the important things to consider about coding in OOP (and in general) is properly naming identifiers, functions, and classes. I'm sure this was talked about in your early programming languages. Creating names is a programming skill in and of itself. Creating concise (unlike Java's verbose naming schemes), descriptive names help in the maintainability of the code you're writing. When the name itself tells you what an identifier is for and when the name of the modifier tells you what it does, then you don't need to explain it in documentation or comments.

Since you're probably experts in naming identifiers from you C coding experience, lets focus on naming methods.

> ***Disclaimer***: *These naming conventions are according to MY standards of code elegance. I'm not saying that this particular way of*

naming is the correct way, to be honest these standards are more subjective than objective. While your in my course I hope you'll at least try incorporate these conventions in your code. I don't care about how you write names in other course, but in my course, these are the names that I consider to be beautiful.

Sometimes, even I forget to adhere to my own conventions, especially when I'm writing code outside OOP. You'll probably notice some contradictions to these conventions somewhere in this course. Just consider these contradictions as proof that the instructor that made these resources is indeed a human being. Let me offer you a preemptive whoops *for all of those contradictions.*

Methods (and functions in general) can be divided into two types, methods that return something, known as **builders**, and methods that do not return something, known as **manipulators**.

Builders

An inelegant method name:

```
def add(addend1:int, addend2:int) -> int:
    return addend1 + addend2
```

Now this seems like a descriptive enough name that describes what the method does. What is wrong with it? The issues start to surface once you invoke the function:

```
solution = 5 - add(3,2)
```

When you see this line of code, your brain reads this as:

"solution becomes five minus add three and two"

Which can still be understood since we're used to what the method `add()` usually means. But consider this alternative way of naming this function:

```
def sum(addend1:int, addend2:int) -> int:
    return addend1 + addend2
```

When called:

```
solution = 5 - sum(3,2)
```

Your brain reads this as:

"solution becomes 5 minus sum of 3 and 2"

Which makes way more sense.

One of the most egregious violations to this convention is the naming of **getter**. Like the following

```
#inside some class
def getName(self):
        return self.__name
```

```
print("Hello " + p.getName())
```

Getter functions are usually created to reveal the values of private attributes. First of all getters, are a bit evil and must be avoided as much as possible since they violate the privacy of private attributes. It's supposed to be a private attribute, other classes are not supposed to access.

But sometimes exposing these attributes are needed. Sometimes, you don't need to be able to change the value of the private attribute, you just need to know its value. The best way to name a getter is the following.

```
#inside some class
def name(self):
        return self.__name
```

```
print("Hello " + p.name())
```

People might complain, that `name()` and `__name` are ambiguous. But for me this ambiguity is fine since they end up meaning the same thing. Plus, they will never be used interchangeably (maybe in functional paradigm they may) because one is a method and the other is an attribute.

So the rule of the thumb that you need to follow when you are naming builders is the following, **A method that returns something (a builder), should be named after a noun that describe what it is returning.**

Some more builders named elegantly

This is a factory method, which is responsible for building new instances of a class called person. Therefore this method is called `newPerson()`

```
#inside some class
def newPerson(self) -> Person:
        return Person()
```

This method returns the element of a given list at position k

```
def kthElement(list:[float],k:int) -> float:
        return list[k]
```

This is a method that returns the concatenation of two strings

```
def concatenation(u:str, v: str) -> str:
        return u + v
```

Manipulators

This is an example of an inelegantly named manipulator:

```
#inside some class
def nameString(self):
        print(self.__name)
```

When your brain reads an invocation of this method it appears out of place:

```
if (value > threshold):
        nameString()
else:
        print("value is invalid")
```

A better name for this function is the following:

```
#inside some class
def printName(self):
        print(self.__name)
```

```
if (value > threshold):
        p.printName()
else:
        print("value is invalid")
```

The original name `nameString()` is inelegant because it is named like a builder, when in fact it doesn't build anything. It returns nothing. This method an example of a **manipulator**. It should be named like a manipulator. This particular method manipulates the output stream of wherever you are printing.

Setter methods are actually named correctly, setter methods are methods that set the value of a specific private attribute:

```
#inside some class
def setName(self, newValue:str):
        self.__name = newValue
```

Setters are also quite evil in the same way getters are evil. These methods change the values of private methods, violating their privacy. Although the usage of setters is unavoidable in some design patterns, avoid them as much as you can. But at least its name follows this convention for naming manipulators.

The rule of thumb for naming manipulators is the following. **A method that doesn't return anything should be a manipulator and must be named from the verb that describes the its manipulation**.

Some more manipulators named elegantly

A method that advances time by 5 seconds:

```
#inside some class
def skipForward(self):
    self.__time = self.__time + 5
```

A method that removes the first element in the list

```
#inside some class
def decapitate(self):
        self.__list = self.__list[1::]
```

> *It's called decapitate because it removes the head of he list. Sometimes, creative and descriptive method names like this help you remember what they do, just because they are accurately named but still memorable*

Predicates

```
def isPositive(n:int) -> bool:
        return n > 0
```

Predicates are methods that return either true or false. Although these methods are technically builders, they follow a different naming convention. These methods are named like predicates in a sentence. Example:

Checks if a word is capitalized

```
def isCapitalized(word:str) -> bool:
        return word[0].isUpper()
```

Checks is a list is empty

```
def isEmpty(list:[int]) -> bool:
        return len(list) == 0
```

The reason why predicates are named like this is because of how they are used inside if statements. The following is way more readable:

```
if (isPositive(n)):
        return n
else:
        return -n
```

"If n is positive then ..."

Compared to this

```
if(positivity(n)):
        return n
else:
        return -n
```

"If positivity of n then ..."

Single Responsibility Principle and correct naming

The correct naming of methods helps with one of OOP's design principle, SRP. The name of the function describes the one thing it does. For example the method `sum()` does exactly one thing, it builds the sum of two numbers. The

method `decapitate()` does exactly one thing, it removes the head of the list. Whenever you encounter a function that gives you trouble in deciding a name because it is both a manipulator and a builder then it means that the method has more than one responsibility. This means that you should break down this method into smaller methods that does exactly one thing.

The following method should be broken down

```
def decapitateAndHead(self):
    head = self.__list[0]
        self.__list = self.__list[1::]
    return head
```

Into these two methods:

```
def decapitate(self):
        self.__list = self.__list[1::]
```

```
def head(self) -> int:
        return self.__list[0]
```

The special function `__str__()`

You will sometimes encounter the following function in the lab exercises. When you add this function inside your class, it makes the instances of that class *stringable* and *printable*. This means that the class now has a string representation, which means that instances of the class can be easily converted to string and can be printed directly using `print()`.

For example, given a person class:

```
class Person:
    def __init__(self,name:str,age:int):
        self.name = name
        self.age = age

    def __str__(self) -> str:
        return self.name + " " + str(self.age)
```

By implementing the `__str__()` method your class instances can now be treated like a stringable or printable instances:

> *`__str__()` should always accept nothing (but the reference to self) as a parameter and return a string.*

Printing the instance itself

When a printable type is placed inside the print function and nothing else, it automatically converts it as a string and prints it

```
print(Person("Cheems",29))
```

```
Cheems 29
```

The string above is printed since this is the value that **Persons**'s' **`__str__()`** method returns.

Conversion to string

A stringable instance can be converted to a string using the builtin **`str()`** function:

```
print("Hi I'm " + str(Person("Cheems",29)) + " years old")
```

```
Hi I'm Cheems 29 years old
```

This will also work for formatted strings if you use the sigil **`%s`**:

```
print("Hi I'm %s years old" % Person("Cheems",29))
```

```
Hi I'm Cheems 29 years old
```

Design Patterns Introduction

Introduction

Design patterns, are general, reusable solutions to a commonly occurring problem within a given context in software design. Unlike algorithms, design patterns are not clear instructions that can automatically be transferred to your system. Design patterns are more like templates that describe the general concept to solve the problem. It doesn't contain implementation details; it contains structural blueprints.

Learning Outcomes

1. Discuss the origins of design patterns in OOP
2. Explain the advantages of design patterns
3. Explain the disadvantages of design patterns
4. Identify the three classifications of design patterns

History of Design Patterns

Design patterns are not novel and sophisticated discoveries, they are instead, typical solutions to common problems. The pattern of these solutions become so ubiquitous that it becomes worthwhile to put a name to it. Design patterns in software engineering are just borrowed concepts from architecture/design.

The concept of design patterns is often attributed to Christopher Alexander, from his book, *A Pattern Language: Towns, Buildings, Construction* [1]. These patterns may describe how high windows should be, how many levels a building should have, how large green areas in a neighborhood are supposed to be, and so on.

Four software engineers, Erich Gamma, John Vlissides, Ralph Johnson, and Richard Helm, used this as an inspiration to publish the famous book, *Design Patterns: Elements of Reusable Object-Oriented Software*. [2] The four became collectively known as the "**Gang of Four**". And their book became known as the GoF book. It contains a catalog of 23 design patterns solving various problems of OOP design.

Why Patterns?

The answer to this problem is similar to the reason as to why you don't "reinvent the wheel". Design patterns are tried and tested solutions, knowing these patterns give programmers a toolset to solve a variety of problems in software design.

Design patterns also help with communication. A team of software engineers well versed in design patterns wouldn't need to explain to each other what exactly must be done to use an "Adapter pattern".

Why not Patterns?

Design patterns are sometimes used to simulate features that the programming language doesn't have. If you use a powerful enough language you wouldn't need the pattern at all. Example of this is how the Strategy pattern can be replaced by lambdas.

Patterns are not end-all be-all solutions to any design problem out there. At the end of the day context matters the most. An inexperienced programmer will implement a problem to the dot, instead of adapting the pattern for the context.

[1] Alexander (1977). *A Pattern Language: Towns, Buildings, Construction.*

[2] Gamma, Vlissides, Johnson, and Helm (1994). *Design Patterns: Elements of Reusable Object-Oriented Software*

Patterns are not end-all be-all solutions to any design problem out there. At the end of the day context matters the most.

Sometimes, you don't even need a pattern at all. A simple problem solved using a complicated solution is inelegant.

Classifications of Design Patterns

- **Creational Patterns** provide object creation mechanisms that increase flexibility and reuse of existing code
- **Structural patterns** explain how to assemble objects and classes into larger structures, while keeping the structures flexible and efficient.
- **Behavioral patterns** take care of effective communication and the assignment of responsibilities between objects.

Optional Reading

Gamma, Vlissides, Johnson, and Helm (1994). Design Patterns: Elements of Reusable Object-Oriented Software

Creational Patterns

Introduction

Almost all programming languages with object oriented support provides you rich features in creating instances of classes using constructor methods. Inside the constructors you can add business logic to initialize objects and make them ready for use. Some programming languages (like Java or C++) even have the capability to have more than one constructor method so that instances can be shipped with different states depending on the chosen constructor.

Unfortunately native constructors capabilities are not powerful enough for our standards of elegance. Some systems have complicated object production mechanisms that require extra capabilities. Sometimes classes have too many attributes for a simple constructors. Sometimes object creation require polymorphic support and decoupling against the exact subtypes or realizations. Sometimes you need to ensure that certain classes have exactly one instance throughout the lifetime of your system.

Learning Outcomes

1. Design systems that apply the factory method design pattern
2. Design systems that apply the abstract factory pattern

Factory Method Pattern

Problem

The exact type of the dependency (a product) created and used by some client (a factory) is decided by a client of that factory. Somewhere, inside this factory class, a specific product is being instantiated and maybe used (this instantiation happens maybe more than once). But, as it turns out, there are different types of products, (there's also the possibility of more product types in the future). You can change the code of the factory class to accommodate multiple product types. For every product, you modify the factory and add some if else clause to produce the correct product type.

As you see this process is quite tedious. For every new product type that is added to your system, you perform surgery to the factory class. This process will end up forcing you to create smelly if-else checks to switch to the correct product type.

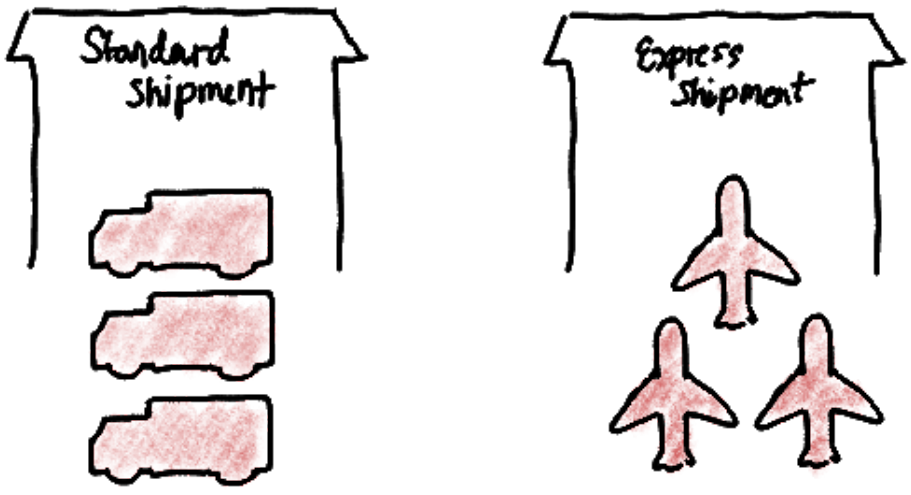


Figure 16.1: Factory Method

Solution

You encapsulate the creation of a class inside a **factory method** that is specified to return an abstraction of the product. If there are other real product types that have to be produced, you create a specialized factory which overrides the factory method.

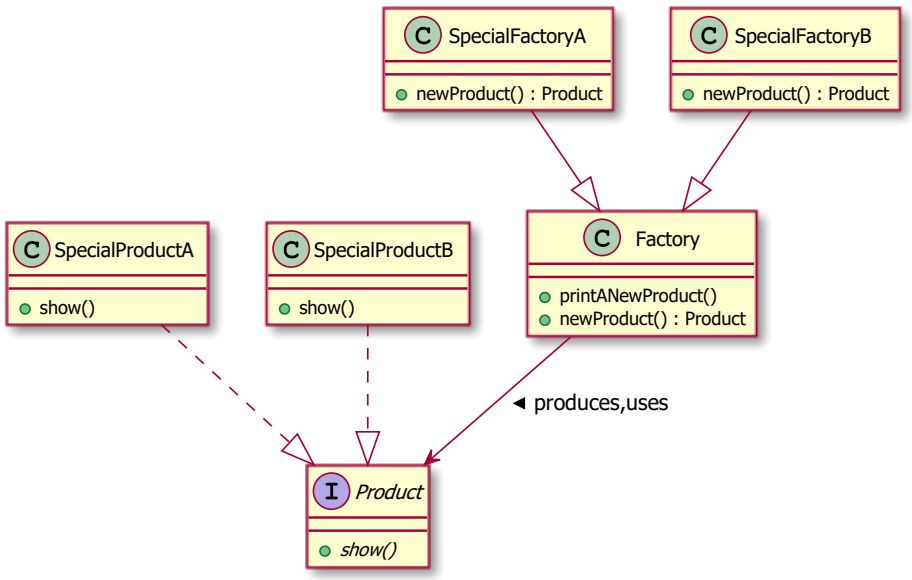


Figure 16.2: factory method class diagram

> *Somewhere inside factory you have one or more instances of creating or using the product.*

If you choose to build `Factory` as a concrete superclass, the factory method inside the `Factory` should return some realization of `Product`. This is the default product returned by any `Factory`. If you need to return a different `Product` realization, you override the factory method to return that particular `Product` realization.

Example

Online Marketplace Delivery

Consider you're developing the product delivery side of an online marketplace app (think Amazon/Lazada). Your app is on its early stage so their is only one delivery option, standard nationwide delivery that takes a minimum of 7 days.

What you have is `Shipment` class that contains a `StandardDelivery` class. Inside the shipment class is the `shipmentDetails()` builder which builds a string

representing the details of the shipment, this includes the delivery details (which requires access to the composed `StandardDelivery` instance). Inside the constructor of `Shipment` an instance of `StandardDelivery` is created so that every `Shipment` is set to be delivered using standard delivery.

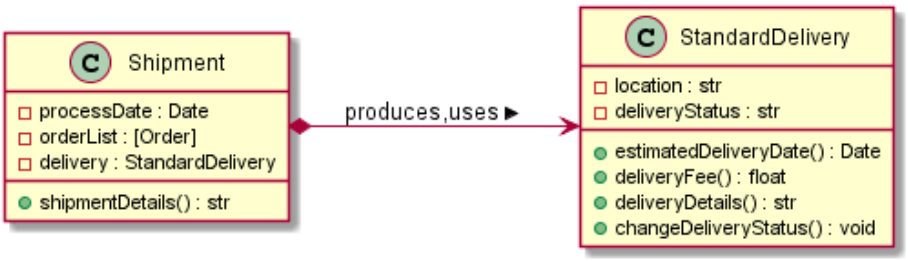


Figure 16.3: online marketplace

This system does work. It works but it is still inelegant. As soon as your app grows, you will incorporate new delivery options like express delivery, or pickups or whatever. Every time you need to add a new delivery method you will need to perform surgery in `Shipment` since the `StandardDelivery` instance is created inside the constructor of `Shipment`. `Shipment`'s code is too coupled with `StandardDelivery`.

To solve this you need to implement the factory method pattern. Right now shipment is a factory since it constructs its own instance of `StandardDelivery`. To refactor this into elegant code, you need to so create an abstraction called`Delivery` first to support polymorphism. Inside `Shipment` instead of creating instances of `Delivery`'s using a constructor, you invoke a factory method that encapsulates the instantiation of `Delivery`. In this case we name this method `newDelivery()`. All it does is return an instance of `StandardDelivery` using its constructor.

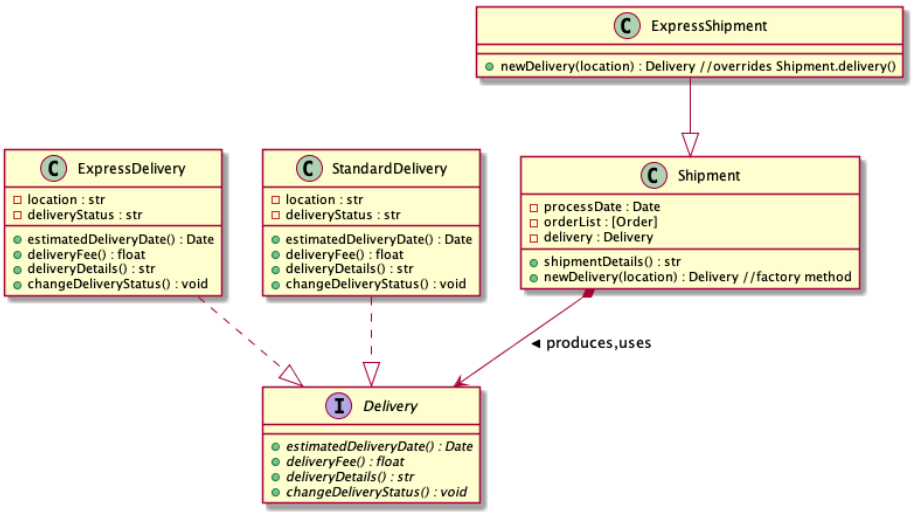


Figure 16.4: online marketplace

In this new architecture, whenever there are new delivery methods a shipment could have, all you have to do is to create a realization of that delivery method. In this case the new delivery method is `ExpressDelivery` which delivers for two days but is twice as expensive. And instead of changing `Shipment` (violates Open/Closed Principle), you make an extension to `Shipment`. This extension is the specialization to shipment called `ExpressShipment` (a shipment that uses express delivery). In this specialization, you only need to override the factory method delivery, so that every instance of delivery construction creates `ExpressDelivery`. The difference between `ExpressDelivery` and `Delivery` is that `ExpressDelivery` has a delivery fee of 1000 and the estimated delivery date is 1 day after the processing date.

Why this is elegant

- **Single Responsibility Principle** - the extra level of encapsulation on the construction of the product (factory method), allows the factory to be responsible of creating the exact product type it needs.
- **Open/Closed Principle** - instead of modifying the factory to incorporate the creation of different product realizations, you instead create an extension of the factory. No need for introspective checks since the factory method supports polymorphism of the product it creates.
- *Encapsulate what varies* - This pattern upholds one of OOP paradigms most important principles. Since the construction of product varies from product type to product type, it is encapsulated into the factory method.
- This avoids tight coupling between the factory and the product

  Coupled classes are classes which are very dependent on each other.

Changing the code of one will most likely affect the other

How to implement it:

1. Create an abstraction for all product types (`Product`).
2. Inside the base factory create the the factory method function `newProduct():Product`. Make sure it is specified to return abstraction `Product`.
3. For every new product type that is added to the system, create 2 new classes: the new product type as a realization of `Product` and, and the factory for the new product type as a realization of `Factory`.
4. Inside each factory specialization override `newProduct()` to return the correct realization of `Product`.
5. Replace every instance of constructor calls inside `Factory` with a call to the factory method `newProduct()`.

Abstract Factory

Problem

Your system consists of a family of related products. These products also have different variants. You need a way to create these products so that the products match the the same variant. The exact variants of the family of products are decided during runtime, somewhere else in the code (similar to product creation in a factory method)

Figure 16.5: Abstract Factory

Solution

You create different kinds of factories that realize under the same abstract factory. The exact type of factory will decide the variant of the family of products that are created. To do this you need to create different factory methods for each product. These factory methods must be abstract methods in the abstract

factory so that every factory realization can create all members of the product family.

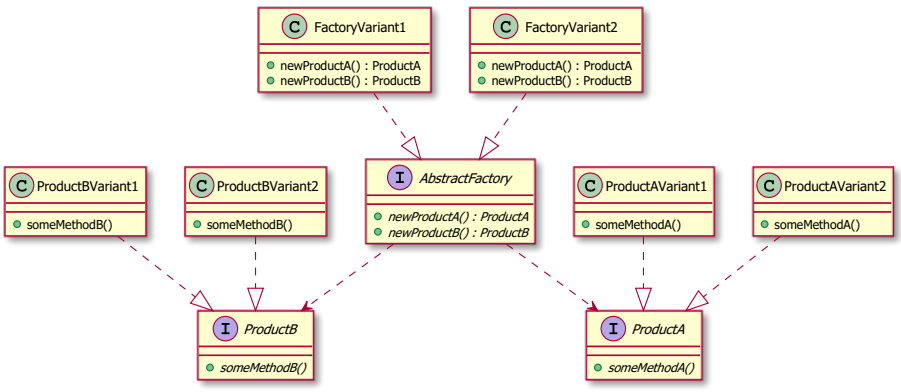


Figure 16.6: abstract factory

The family of products, are `ProductA` and `ProductB`, These products come in two variants, variant 1 and 2. `FactoryVariant1` is a realization of `Factory` which creates all of the product in variant 1 while `FactoryVariant2` creates all the products in variant 2.

> *If it makes sense for the system you can make an abstract* ***`Product`*** *class for all the types of products.*

When the client of an abstract factory produces its products, it doesn't need to know what kind of factory is producing the products. This means that the concrete type of a product (its variant) is not decided during compile time but instead it depends on the concrete type of the factory that is creating it.

Example

Bootleg Text-based Zelda Game

You're creating the dungeon encounter mechanics of some bootleg text-based zelda game. In this game,every time you enter a dungeon, you encounter 0-8 monsters (the exact number is randomly determined). There are 3 types of monsters, bokoblins, moblins, and lizalflos (different types have different moves). The exact type of monster is randomly decided as well.

Right now the game works like this:

As soon as you enter the dungeon, all the enemies are announced:

```
5 monsters appeared
```

```
A lizalflos appeared
A lizalflos appeared
A lizalflos appeared
A moblin appeared
A moblin appeared
```

After this, each enemy in the encounter attacks. They randomly pick an attack from their moveset.

```
Lizalflos thorws its lizal boomerang at you for 2 damage
Lizalflos thorws its lizal boomerang at you for 2 damage
Lizalflos camouflages itself
Moblin stabs you with a spear for 3 damage
Moblin stabs you with a spear for 3 damage
```

The encounter ends with Link dying since you haven't coded anything past this part.

You decide to make things exciting for your game by adding harder dungeons, medium dungeon and hard dungeon.

Medium dungeon Instead of encountering, normal monsters you encounter stronger versions of the monsters, these monsters are blue colored:

- **Blue Bokoblin**
  - equipped with a spiked boko club and a spiked boko shield
  - bludgeon deals 2 damage
- **Blue Moblin**
  - equipped with rusty halberd
  - stab deals 5 damage
  - kick deals 2 damage
- **Blue Lizalflos**
  - equipped with a forked boomerang
  - throw boomerang deals 3 damage

Hard dungeon These monsters are silver colored extra stronger versions of the monsters

- **Silver Bokoblin**
  - equipped with a dragonbone boko club and a dragonbone boko shield

  - bludgeon deals 5 damage

- **Silver Moblin**
  - equipped with knight's halberd
  - stab deals 10 damage
  - kick deals 3 damage
- **Silver Lizalflos**
  - equipped with a tri-boomerang
  - throw boomerang deals 7 damage

To seamlessly incorporate these harder monsters in your system, you need to create an abstract factory for each dungeon difficulty. There are now three variants for each monster. For every variant, there is a factory that spawns new instances of each monster.

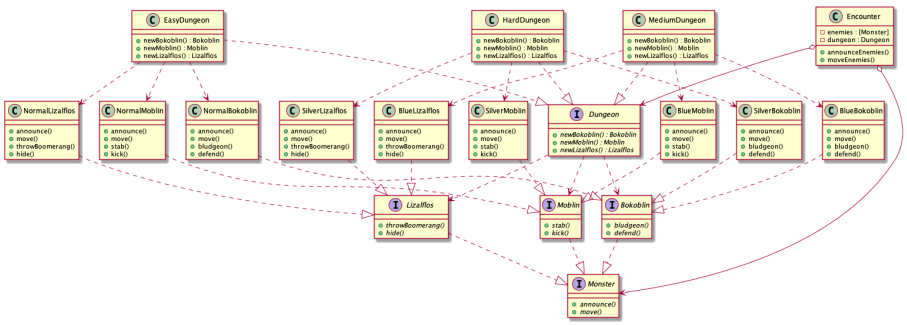


Figure 16.7: abstract factory example

Why this is elegant

- **Open/Closed Principle** - This solution is easier to maintain since you can add more variants of `Product` without touching any existing code. All you have to do is to add new realization for `Product` and a new realization `AbstractFactory`
- Changing the form and behavior of specific variants are isolated since its creation is abstracted.
- You can easily switch between variants by swapping out the factory.

How to implement it:

- For every product in the family of products, create an abstraction of it (`ProductA`, `ProductB`).
- For every variant of the products, create a factory, (`FactoryVariant1`, `FactoryVariant2`). These factories must realize under an abstract

`Factory`. The factory should contain abstract factory methods for each product,

- Inside every factory implement all factory methods.

Singleton (Optional Read)

Problem

Sometimes it wouldn't make sense for a class to have more than one instance in the lifetime of the application. These things are called singletons.

Solution

Inside the singleton. Create a static attribute that represents the singleton. Since it is static all instances of the class will share this value. Create a builder to lazily instantiate the value of the singleton and expose the value of the instance.

Disallow the usage of the normal constructor as much as possible. To access the shared static instance, use the builder.

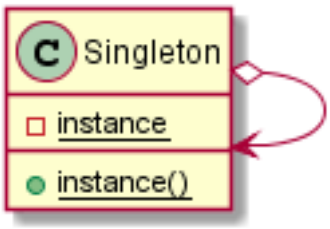


Figure 16.8: singleton

> *Disallowing the creation of a singleton depends on the language you use, you can set the constructor to private, or you can raise an error if you try to use the constructor outside the instance builder.*
>
> *You can also choose to not disallow the use of the constructor, as long as you trust the users to always use the instance builder instead.*

Example

A Catalog of Globals

It doesn't make sense for you to keep multiple copies of global variables in your application, so you decide to place them in a singleton class.

Why this is NOT is elegant

A singleton pattern is actually hated by most developers. Yes you can ensure that there is exactly one instance of a class, but its advantages come with a lot of drawbacks.

- You can ensure single instance classes, just by being vigilant.
- Singletons require the use of static attributes and methods. Statics are anti-pattern because they are global variables and manipulators that can have invisible changes to state.
- Singletons are usually symptoms of bad design.

Optional Reading

Shvets A. (2018) Creational Patterns Accessed August 31, 2020

Behavioral Patterns

Introduction

Some systems require complex and extremely decoupled relationships. Behavioral patterns are used on these tightly interconnected systems so that they are easier to maintain. These patterns separate behavioral responsibilities among the classes in your system in such a way that volatile behaviors are encapsulated deep into your object structure.

Learning Outcomes

1. Design systems that apply the strategy pattern
2. Design systems that apply the state pattern
3. Design systems that apply the command pattern
4. Design systems that apply the observer pattern
5. Design systems that apply the template pattern
6. Design systems that apply the iterator pattern

Strategy pattern

Problem

Some systems require behavior that have to be parametrized for other behavior. This is easily done in a functional programming environment since higher order functions are used to represent these. In programming languages that don't support these features, the strategy pattern is used.

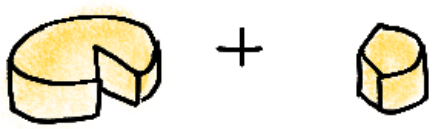


Figure 17.1: strategy

Solution

Functions that are not first class citizens are encapsulated inside a `Strategy` class. A strategy class simply contains the method `execute(params)`, which represents the behavior that should be passed into a higher order function. Any method that can be passed into the higher order function should realize `Strategy`.

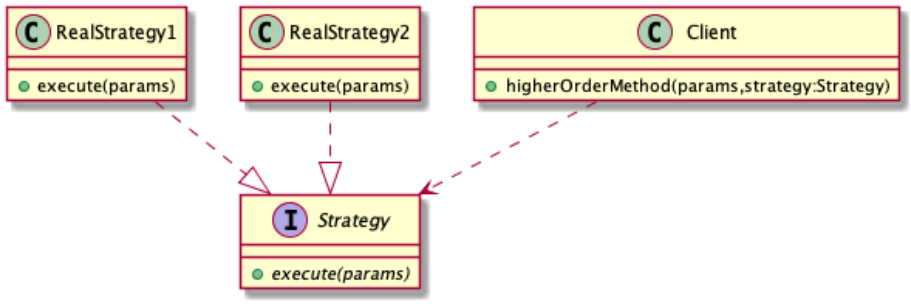


Figure 17.2: Strategy pattern

The object `params` represent the data that you need to pass into the correct class. In this pattern you pass the the whole `Strategy` realization so that

`strategy.execute(params)` perform the desired behavior. You can add other methods in the `Strategy` abstraction, if it makes sense for the system.

Example

Fraction Calculations

You're creating a less sophisticated version of a fraction calculator. This calculator only has arithmetic operations inside it, addition, subtraction, division, and multiplication. Inside this calculator, a calculation is represented in a `Calculation` instance. Every calculation has four parts:

- `__left` - represents the left operand fraction
- `__right` - represents the right operand fraction
- `__operation` - represents the operation (+,−,×,÷)
- `__answer` - represents the solution of the operation

Python does indeed support higher order functions but your boss is anti-functional programming so he forbids the use these features. Because of this you decide to implement the strategy pattern.

To do this, you need to create an abstraction called `Operation` to represent the different operations. For each operation, you create a class that realizes `Operation`.

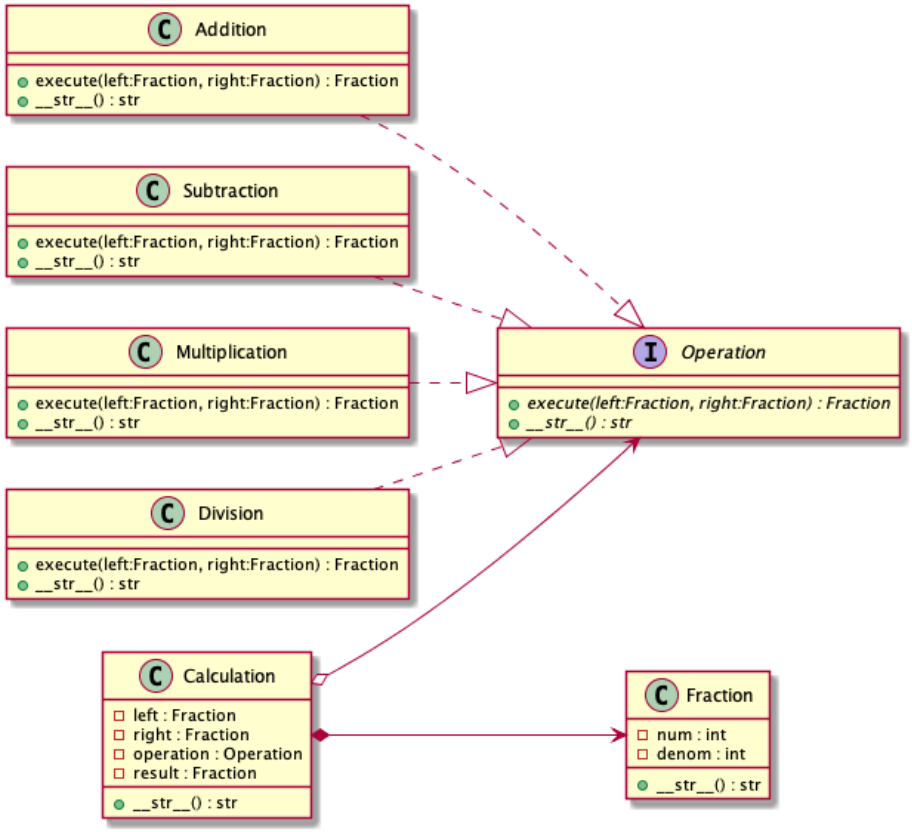


Figure 17.3: strategy pattern example

`execute()` should have been named like a builder method (something like `solution()`), I'm keeping the name `execute()` since this is how Strategy patterns usually names this particular method.

Why this is elegant

- **Open/Closed Principle** - If you want to add new strategies, you wouldn't need to touch any existing code.
- The implementation of a strategy is deeply tucked inside multiple layers of encapsulation. Changing these implementations is very easy.
- You can swap strategies during runtime in the same way you do in functional programming.

How to implement it

1. Create an abstract `Strategy` that contains an abstract method called `execute`. This method should be specified to accept all the necessary parameters needed by your parameterized function.

2. For every strategy, the higher order method can accept, you create a realization for `Strategy` and implement the correct behavior in `execute`.
3. The higher order function should now be specified to accept a `strategy` of type `Strategy`.
4. Inside the higher order function, whenever it wants to perform the strategies embedded behavior, call `strategy.execute(...)`.

State Pattern

Problem

Some objects can change into many different states. If different objects behavior is dependent on its current state, it would require, bulky and annoying if-else blocks to handle its dynamic behavior.

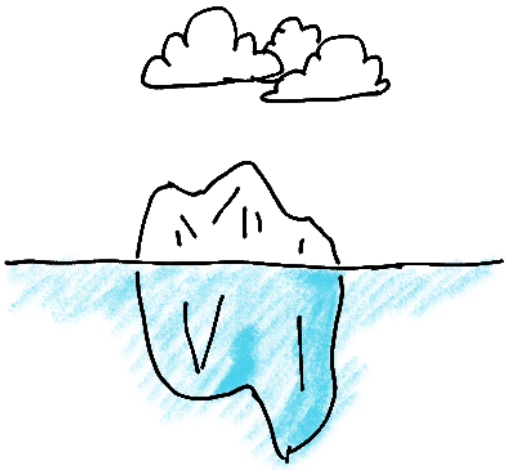


Figure 17.4: State

Solution

An object that can have many states should contain an attribute representing its state. Instead of performing, state dependent behavior directly inside the object, you delegate this responsibility to its embedded state instead. In this way the object will behave according to its current state.

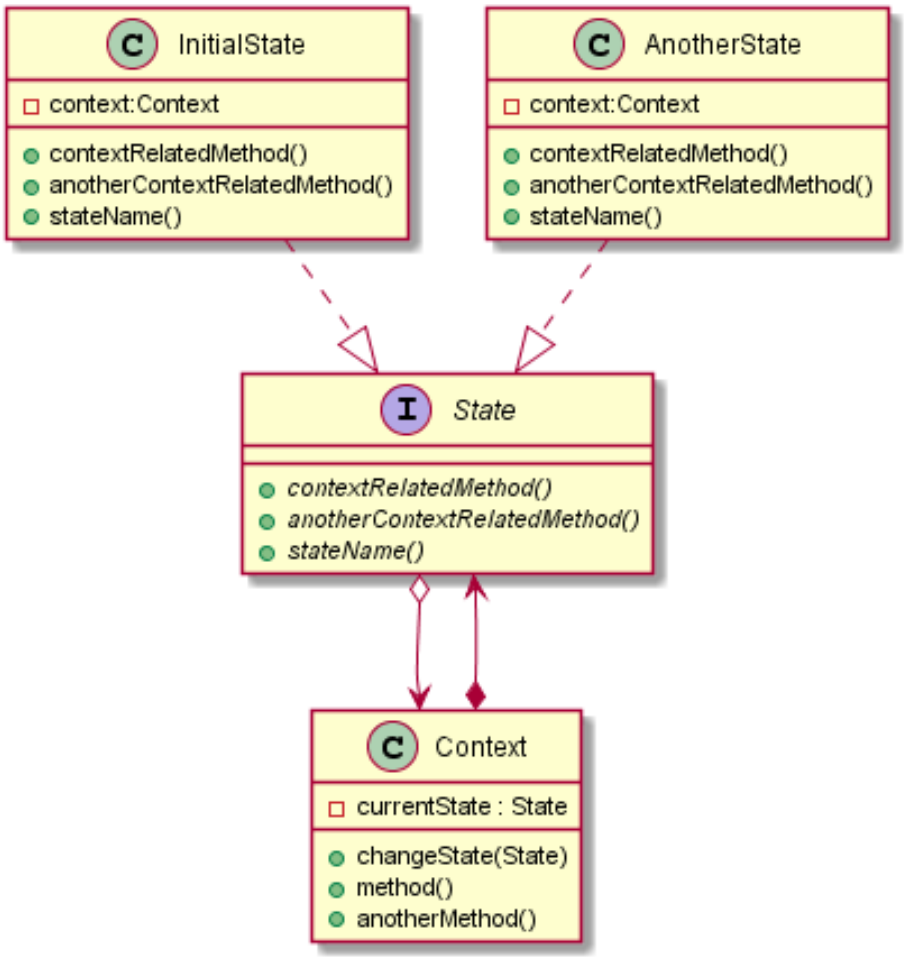


Figure 17.5: state pattern

The state may be required to contain backreference to the context object that owns it. This is only required if state methods requires to access/control the context that owns it.

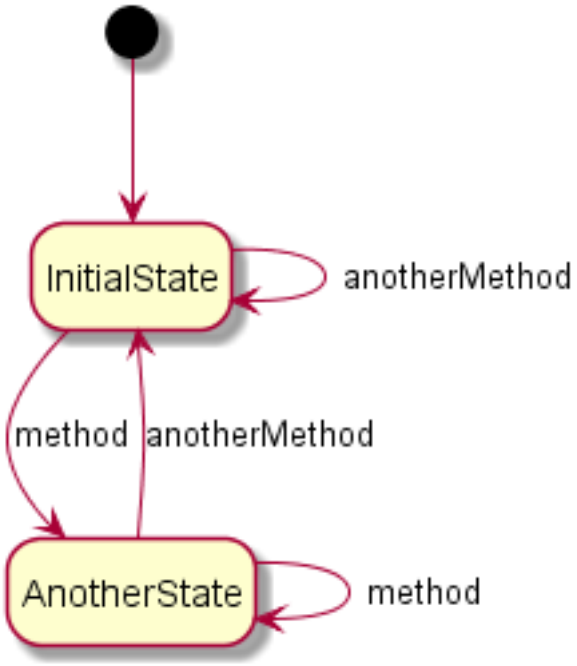


Figure 17.6: state diagram

Example

States of matter

The state of any given matter is dependent on the pressure and temperature of its environment. If you heat up some liquid enough it will turn to gas, if you compress it enough it will become solid.

You are to build a less sophisticated version of this model in code. Matter comes in three states, solid, liquid, and gas. The state of the matter may change if you put/remove pressure on it or heat/cool it.

The state diagram would look something like this:

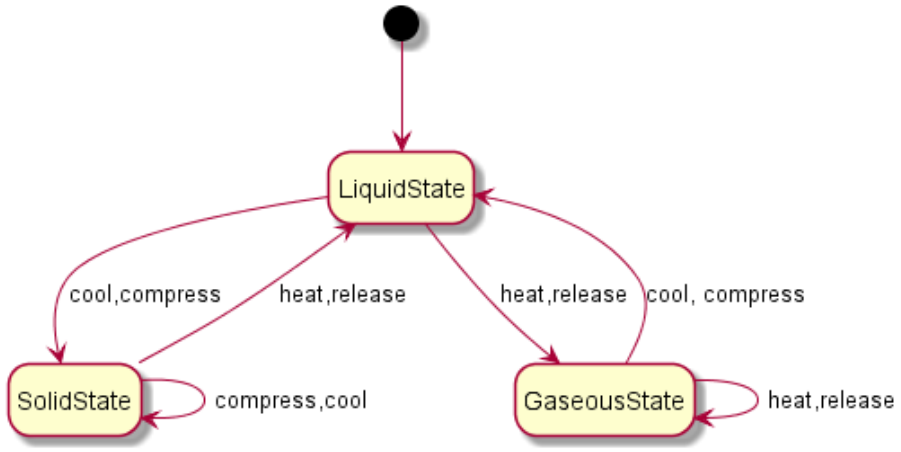


Figure 17.7: state diagram example

To implement something like this, you would need to create matter which owns an attribute called **`state`** which represents the matter's current state. Since there are three states, you create three realizations to a common abstraction to state.

When you compress/release/cool/heat the matter, you delegate the appropriate behavior and state change inside **`state`**'s version of that. Each **`State`** realization will need a backreference to the **`Matter`** that owns it so that it can change it's state.

> *Delegating behavior to the composed state means that, when the* ***`Matter`*** *instances invoke,* ***`compress()`****,* ***`relaease()`*** ***`heat()`****, and* ***`cool()`****, the composed* ***`State`*** *owned by the matter calls its own version of* ***`compress()`****,* ***`relaease()`*** ***`heat()`****, and* ***`cool()`****.*

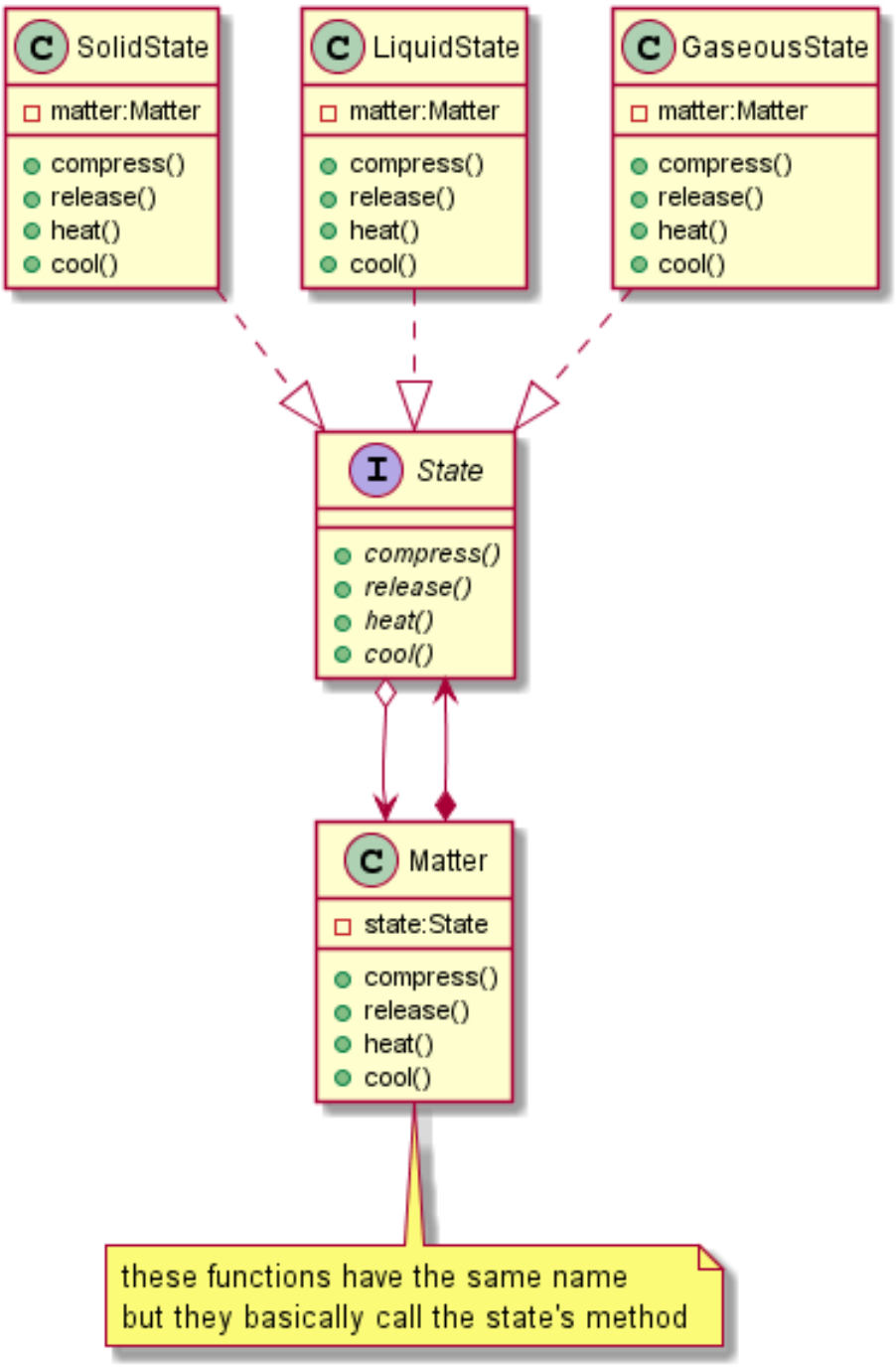


Figure 17.8: state example

Matter owns an instance of ***`State`****, and that instance has an attribute called* ***`matter`****. The attribute* ***`matter`*** *is the reference to the instance of* ***`Matter`*** *that owns it. The* ***`State`*** *instance needs this reference so that it can change the matter's state when it is compressed, released, heated, or cooled.*

Why this is elegant

- **Single Responsibility Principle** - behavior related to state is delegated to the state itself.
- **Open/Closed Principle** - You can incorporate new states to the system without touching any existing client code
- Implementing this pattern will remove bulky and annoying state conditionals

How to implement it

1. Create an abstract `State` that contains abstract methods for all state dependent behavior (context related behaviors that are dependent on context's state).
2. For every state the `Context` can have, create a realization of `State`.
3. `Context` owns an attribute that represents the current state (`currentState`) that it owns.
4. If the state needs to control the `Context` instance that owns it, add a backreference to `Context` inside state.
5. Whenever a `Context` instance performs state dependent methods, it calls `currentState.contextRelatedMethod()` instead so that its behavior is dependent on its current state.

Command Pattern

Problem

Sometimes, object behavior contain complicated constraints. Sometimes, the system require the behavior to be invoked by an object but performed by another (this is common in presentation layer/domain layer separation in MVC enterprise systems). Sometimes, the system requires behavior to be undone. Sometimes the system requires a history of the behaviors that were being performed.

Figure 17.9: Command (What does this strange picture mean?)

Solution

These problems have a common solution, the **command pattern**. A `Command` is a more powerful version of a `Strategy`. While both of them encapsulates behavior, a `Strategy` is just that, a function wrapper. A `Command` on the other hand contains which object performs the behavior, which parameters are needed to perform the behavior, and how to undo the command (if needed).

Creating `Command`s, allow for more flexible behavior responsibility assignments. A separate `Invoker` object triggers the behavior by creating a command. This `Invoker` prepares the command with the appropriate `Reciever` (the object performing the command), and the appropriate parameters. The invoker then executes the prepared command. The command doesn't actually do anything, it just tells the `Reciever` to call the appropriate method.

This separation of responsibility allows for the creation of extra features that may be required for your system:

- If you want to keep a history of the performed commands, the `Invoker` may keep a list of `Commands`. This way the data stored in the list history, is a perfect representation of the previous commands.
- If you want the `Commands` to be undoable, you can store a backup of the receiver (and other affected objects) by the `Command` inside each instance of `Command` . Undoing a command will be as simple as restoring the receiver to its backup.

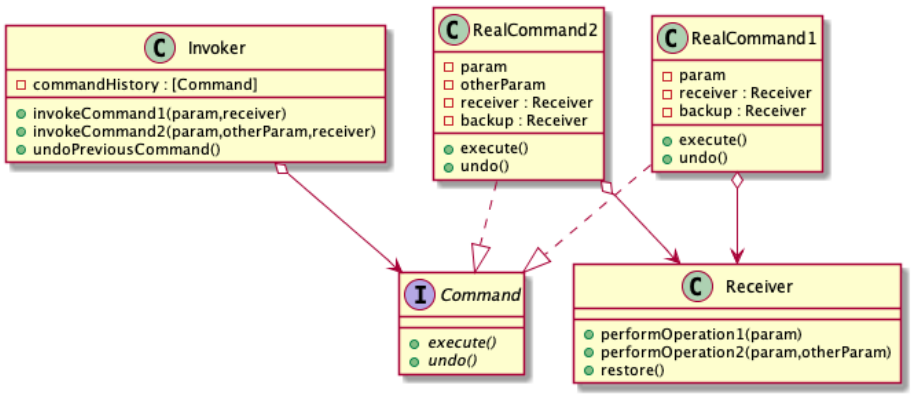


Figure 17.10: command pattern

Instead of passing the receiver in the `Invoker` methods, you can create an attribute called receiver inside `Invoker`. But doing this will make it so there is one `Receiver` instance for every `Invoker` instance.

The commands should only affect the receiver. If the behavior that is performed changes a lot of objects, then make a ***`Receiver`*** *class that encapsulates all of the affected objects. Doing this will make the implementation of undo easier since the backup inside of the command will simply be an older version of* ***`Receiver`***.

Different command realizations are not necessarily of the same ***`Strategy`***. *That's why the parameters of the behavior are stored as attributes of the command, not passed in the* ***`execute()`*** *function. This is so that no matter what the command is, all* ***`execute()`*** *functions will have the same type signatures.*

Example

Zooming through a maze

You're creating a maze navigation game thing. This is what the application currently has right now:

- `Board` - this represents the layout of the maze. The layout is loaded from a file. It has these attributes:
  - `__isSolid` - this is a 2 dimensional grid encoded as a nested list of booleans which represents the solid boundaries of the maze. For example if `__isSolid[row][col]` is true then it means that that cell on (row,col) is a boundary
  - `__start` - a tuple of two integers that represent where the character starts
  - `__end` - tuple of two integers that represent the position of the end of the maze
  - `__cLoc` - tuple of two integers that represents the current location of the character
  - `moveUp()`, `moveDown()`, `moveLeft()`, `moveRight()` - moves the character one space, in the respective direction. The character cannot move to a boundary cell, it will raise an error instead.
  - `canMoveUp()`, `canMoveDown()`, `canMoveLeft()`, `canMoveRight()` - returns true if the cell in the respective direction is not solid.
  - `__str()__` string representation of the board. It shows which are the boundaries and the character location

What's missing right now is controller support. This is how a player controls the character on the maze:

- `dpad_up()`, `dpad_down()`, `dpad_left()`, `dpad_right()` - The character dashes through the maze in the specified direction until it hits a boundary.

- `a_button()` - The character undoes the previous action it did.

To implement controller support you need to create a `Command` abstraction which is realized by all controller commands. The `Controller` (which represents the controller) is the invoker for the commands. Since commands are undoable, this controller needs to keep a command history, represented as a list. Every time a controller button is pressed, it creates the appropriate `Command`, executes it and appends it to the command history. Every time the `a_button()` is pressed to undo, the controller pops the last command from the command history and undoes it.

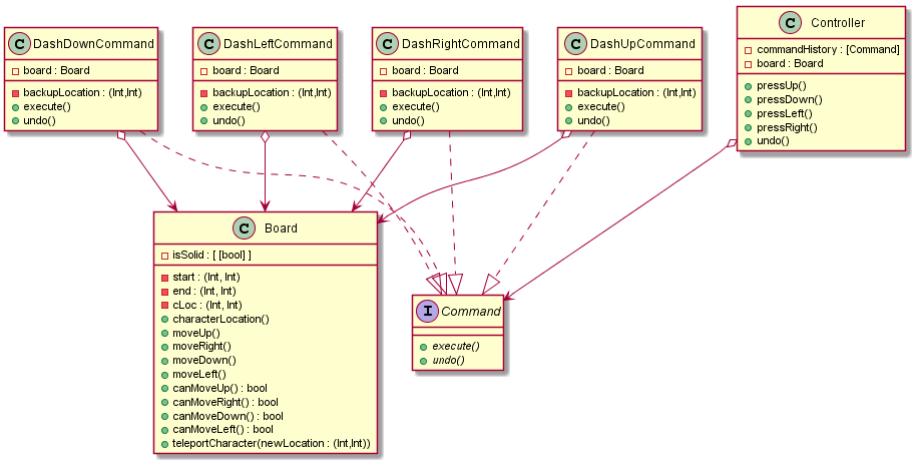


Figure 17.11: command example

Why this is elegant

- **Single Responsibility Principle** - The behavioral responsibilities in the system are thoroughly separated. One invokes the command, and the other performs the behavior associated with the command.
- **Open/Closed Principle** - If there are more commands you want to add, you don't have to touch any existing code.
- Switching between invokers and receivers is easily done
- You can implement undo (and redo)
- You can defer the execution of behavior
- A command may be made of smaller simpler commands

How to implement it

1. Create an abstraction `Command` that contains abstract method `execute()`, and other command related methods like `undo()`.

2. For every command, create a realization to `Command`. These commands uses a reference to a `Reciever` instance. This instance represents the instance/s that are affected whenever `Command` realizations are executed.
3. Create an `Invoker` class that will be responsible for instantiating, preparing, and executing commands. Inside these class are methods for invoking each commands. When these methods are called, the invoker does the following:
    1. Instantiate an instance of `Command` called `c` with the correct realization.
    2. select the receiver of the `Command`, including the related parameters.
    3. invoke `c.execute()`.
4. If the system supports undoable commands, the `Invoker` should keep a list of commands called `commandHistory` and each command instance should keep a reference called `backup` to enable restoration of `Reciever` instances.

Observer Pattern

Problem

What if you need to inform a lot of objects about the changes to some interesting data? If you globalize the data and let your client objects poll for changes all the time, this will affect the security and safety of your interesting data. Plus, global data is something that should be avoided as much as possible. Also, forcing your objects poll for changes all the time will be inefficient if your interesting data has not changed.

Figure 17.12: observer

Solution

The responsibility of sharing information about the changes to interesting data should not be placed in the clients of the data. You should create a notifier class that encapsulates the interesting data. This class should be responsible of notifying interested clients about changes on the data.

To do this you need to encapsulate the interesting data (from now on lets call it the `subject`), into a `Publisher` class. An instance of this class will be responsible of notifying the observers for any change in the `subject`. Whenever there are changes to the subject, the `Publisher` instance calls `notifyObservers()` so that all interested, observers will be informed of the change. Any class that is potentially interested in the `subject` should realize an `Observer` abstraction, which in the bare minimum contains, the `update(updatedSubject)` function. Inside `Publisher`'s `notifyObservers()` method, every subscriber (an interested observer) is updated (`subscriber.update()`).

Any instance of an `Observer` should be subscribed to the change notifications using `Publisher`'s `subscribe()` function. They can also be unsubscribed using the`unsubscribe()` function.

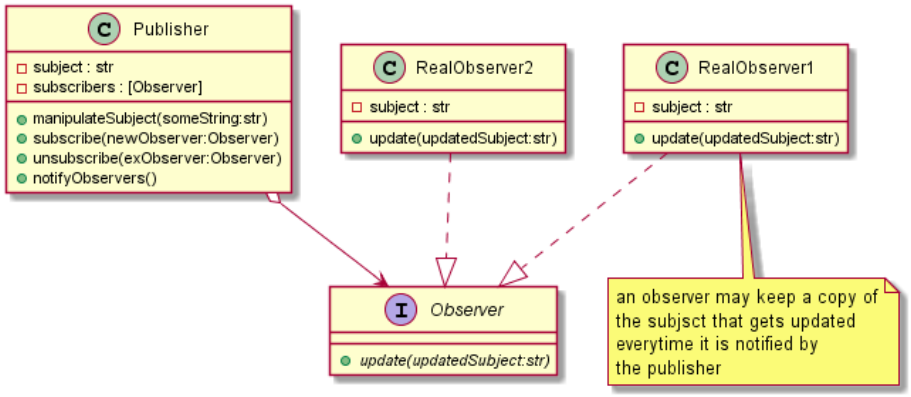


Figure 17.13: observer

> *Whenever an observer has updated, the publisher needs to pass all the necessary details in the notification. This is generally done by passing the updated subject in the* ***`update(updatedSubject)`*** *method.*
>
> *In some cases, the observer needs to keep a copy of the subject as an attribute. Make sure to change the value of this attribute during updates.*
>
> *Make sure that changes to the subject are only done using the* ***`Publisher`*** *class (****`manipulateSubject()`****). If you change the subject without using* ***`Publisher`****'s methods, your subscribers won't be notified.*

Example

Push Notifier for Weather and Headlines

You are creating a push notification system that works for multiple platforms. You want to distribute information about the current weather and news headlines. This system will be potentially used on many platforms so you have to think about the maintainability issues for adding new platform support.

To implement this, you have to apply the observer pattern. Your subject would be `Weather` data and `Headline` data (which are their own classes). These subjects should be encapsulated into a single publisher class (which will be called `PushNotifier`).

Any platform, that is interested in the changes to the subject should realize a `Subscriber` abstraction (Observer), which contains the abstract method update().

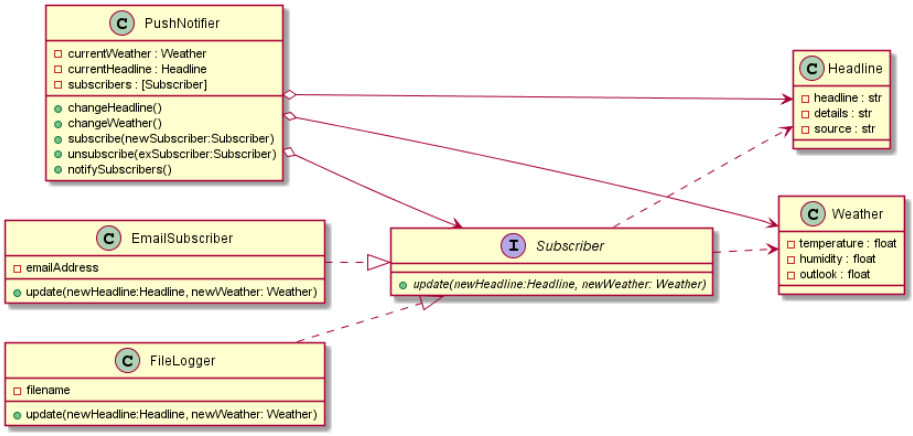


Figure 17.14: observer example

Why this is elegant

- **Open/Closed Principle** - You can add new `Observer` realizations seamlessly every time there are new objects that are interested in the subject.
- A observer can be subscribed/unsubscribed during runtime

How to implement it

1. Create an `Observer` abstraction that represents all classes that can potentially observe changes to the `Publisher`. `Observer` will contain the abstract method `update()`.
2. All classes that want to be notified about changes to the `subject` should realize `Observer`.

3. `Publisher` will either own/use an instance of the `subject` of interest. It will also use an attribute which is stores the list of `Observers` that are interested in the subject. To attach or detach `Observer`s, `Publisher` contains the methods `subscribe()` and `unsubscribe()`.
4. Every time `subject` is manipulated, it should be done through `Publisher`, because `Publisher` needs to notify all `Observers` in its observer list attribute after every manipulation. This notification is done through `notifyObservers()` after the end of every subject manipulation.
5. Inside the `Publisher`s `notifyObservers` method, every `Observer` in its list of observers invoke their `update()` method.

Template Method Pattern

Problem

Say you have two or more *almost* identical behaviors from different classes. Rewriting these object behaviors as separate methods for each class duplicates many parts of the code (especially if the behavior has a lot of lines of code).

Figure 17.15: template

Solution

To avoid code duplication, you break down your code into individual steps. By doing this you can create a superclass that contains the implementation for all common steps. This superclass will also contain the common implementation for the **template method**, the method that combines all steps into the original object behavior. differences between steps will be resolved under different specializations of this superclass.

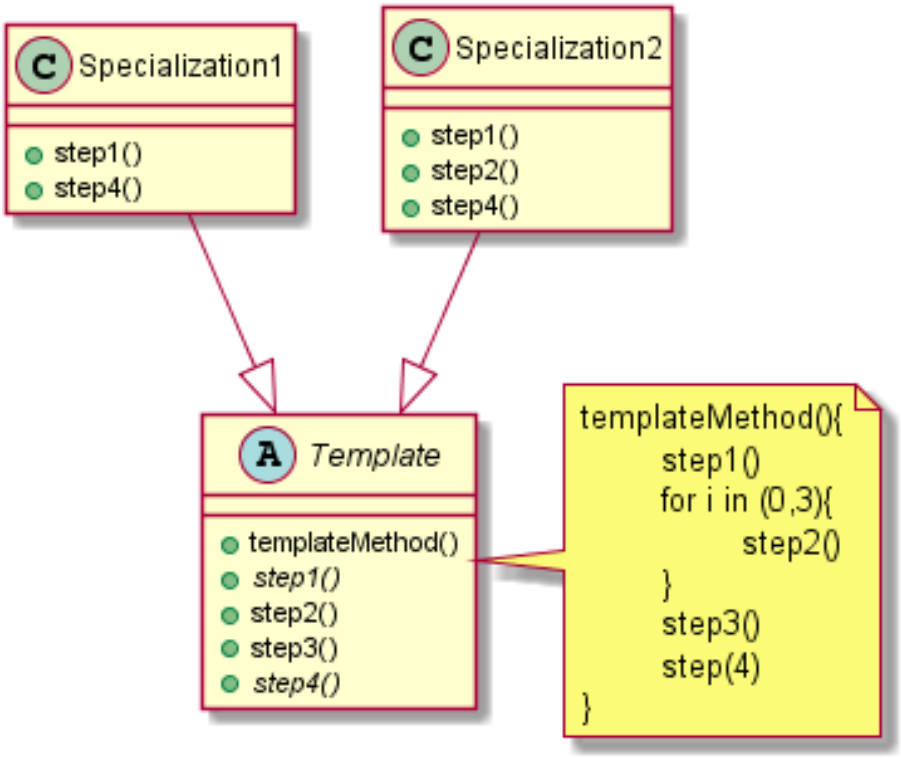


Figure 17.16: template method

If the exact instance of the class is a `Specialization1`, it performs the template method with special versions of `step1()` and `step4()` (since `Specialization1` overrides them) but the other parts are inherited from the `Template`.

> *The steps in the superclass can be a mix of abstract methods and concrete methods. Make a method abstract if you want to force all specializations to override these steps. You'll want to do these if some of the steps in your template doesn't have a default implementation.*

Example

Brute Force Recipe

If you write brute force algorithms as search problems, they will have a common recipe. This is the reason why it is called the exhaustive search algorithm. It will traverse all of the elements in the search space, trying to check the validity of each element, until it completes the solution

Equality Search

Search for integers equal to the target

```
#searchSpace = [2,3,1,0,6,2,4]
#target = 2

i = 0
solutions = []
candidate = searchSpace[0]
while(i<len(searchSpace)):
    if candidate == target:
        solutions.append(candidate)
    candidate = searchSpace[++i]

#solution = [2,2]
```

Divisibility Search

Search for integers divisible by the target

```
#searchSpace = [2,3,1,0,6,2,4]
#target = 2

i = 0
solutions = []
candidate = searchSpace[0]
while(i<len(searchSpace)):
    if candidate % target == 0:
        solution.append(candidate)
    candidate = searchSpace[++i]

#solution = [2,0,6,2,4]
```

Minimum Search

No target, searches for the smallest integer

```
#searchSpace = [2,3,1,0,6,2,4]
#target = None

i = 1
solutions = [searchSpace[0]]
candidate = searchSpace[1]
while(i<len(searchSpace)):
    if candidate <= solutions[0]
        solutions[0] = candidate
```

```
    candidate = searchSpace[++i]

#solution = [0]
```

Common Recipe

```
i = 0
solutions = []
candidate = first()
while(isStillSearching()):
    if valid(candidate):
        updateSolution(candidate)
    candidate = next()
```

Because of this we can write a general brute force template method that would return the solution to brute force problems. To do this you create a superclass `SearchAlgorithm()` that contains the template method for brute force algorithms. If you want to customize this algorithm for special problems, all you have to do is to inherit from `SearchAlgorithm` and override only the necessary steps.

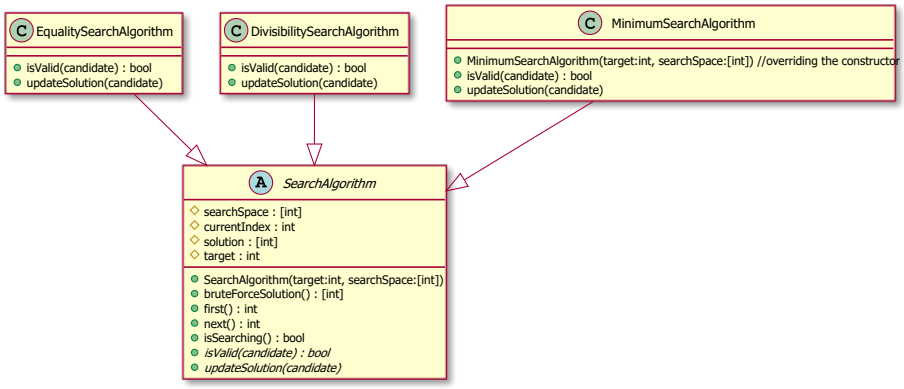


Figure 17.17: template example

> *is `isValid()` and `updateSolution(candidate)` is different for each algorithm so it doesn't have a default implementation. It would be best to make these steps abstract.*

Why this is elegant

- **Open/Closed Principle** - The `Template` is open for extension but closed for modification

- *Encapsulate what varies* - steps can vary from specialization to specialization, therefore they are encapsulated into step methods.
- Implementing this pattern will remove duplicate code in the common parts of the algorithm.
- Clients may override only certain steps in a large algorithm, making it easier to create specializations

How to implement it

1. Create an abstract class called `Template`. It contains the method `templateMethod()` broken down into separate steps through separate `step1()`, `step2()`, ... and etc. methods. When invoked `templateMethod()` will just call these step methods.
2. Each step method inside `Template` will contain the default implementation of that step. If there is no default implementation, the method should be abstract.
3. For every similar behavior to `templateMethod()` a specialization of `Template` is created. These methods will implement all abstract methods and override all step methods that vary for its behavior.

Iterator

Problem

One of the most common iteration recipes that you'll likely implement is the **for-each** loop. This loop traverses a collection, and performing some kind of operation along the way. Most programming languages implement for each loops on built in collections like arrays, sets, and trees. But what about non-built in collections?

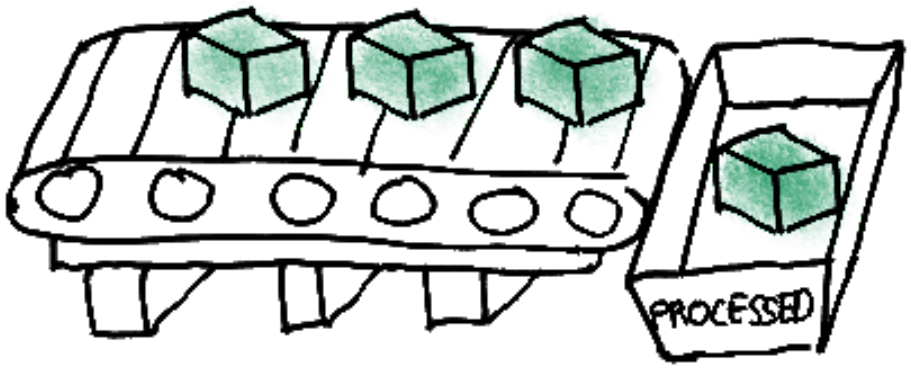


Figure 17.18: iterator

Solution

For non built-in collections, you can create an iterator that does the traversal for you. On the bare minimum these iterators will realize some `Iterator` abstraction that contains the methods, `next()`, and `hasNext()`. From these methods alone you can easily perform complete traversals without knowing the exact type of the collection:

```
i = collection.newIterator()
while i.hasNext():
        print(i.next())
```

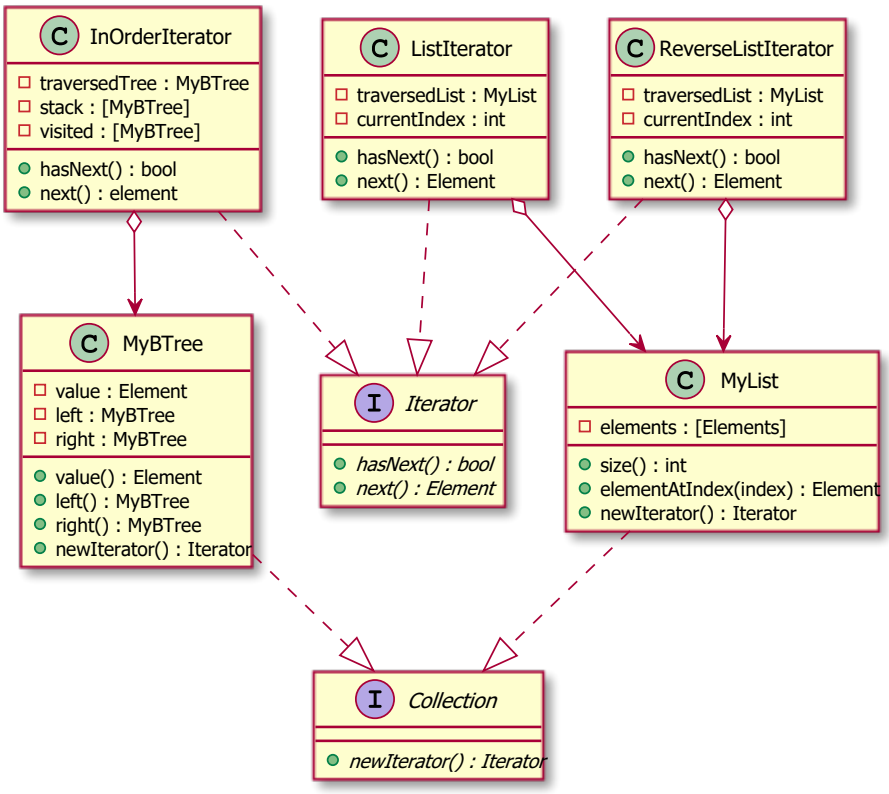


Figure 17.19: iterator

The `hasNext()` method, returns a boolean value that indicates whether or not there are more elements to be traversed. The `next()` method, returns the next element in the traversal.

A collection can have more than one `Iterator`s, if it makes sense for the collection to be travsersed in more than one way. Despite this possibility, a collection must have a default iterator which will be the type of the new instance returned in the factory method, `newIterator()`

Why this is elegant

- **Single Responsibility Principle** - Traversal algorithms can now be placed into separate classes that interact with an iterator instead of the collection itself.
- **Open/Closed Principle** - You can implement new types of collections and iterators without touching any existing code.
- You can traverse all the elements in a collection, even if you don't know the exact type of the said collection.
- Two iterators, can iterate over the same collection without problem as long as the iterators are of different instances.

How to implement it

1. Create an abstraction called `Iterator` which contains the abstract methods `next()` and `hasNext()`.
2. Create an abstraction called `Collection` which contains the abstract method `newIterator()`.
3. For very collection that can be iterated through create a realization to `Collection`. Inside these `Collection` realizations, the `newIterator()` method must be implemented which simply returns a new instance of the default `Iterator`. (for collections that can be iterated through in more than one way, create different methods for creating other iterators as well but always keep `newIterator()` as the one that returns a new instance of the default iteration).
4. For every different way of iterating through a `Collection` realization, a realization to `Iterator` must be created as well.
5. `Iterator` realizations should contain an attribute that refers to the collection instance it is iterating through.

Optional Reading

Shvets A. (2018) Behavioral Patterns Accessed August 31, 2020

Structural Patterns

Introduction

As your system evolves, the structure of your classes could get complicated. As you introduce more features, your classes become bigger and harder to maintain. To alleviate these issues, you can assemble objects into maintainable structural patterns.

Learning Objectives

1. Design systems that apply the decorator pattern
2. Design systems that apply the adapter pattern

Decorator Pattern

Problem

Some of your classes require extra features that can be added and removed during runtime. Sometimes you even need to support a set of extra features that can be arbitrarily combined with each other. You need to do this without breaking how these classes are being used by their clients.

Figure 18.1: decorator

Solution

To solve this issue, all you have to do is to apply the open/closed principle. For every feature that can be arbitrarily added to some simple class, you need to create a `Decorator` that extends the features of classes using inheritance and composition at the same time. The neat thing about this pattern is that the `Decorator`s will have polymorphically the same type as the simple class due to inheritance. `Decorator`s will also be able to control instances of the simple class because of composition.

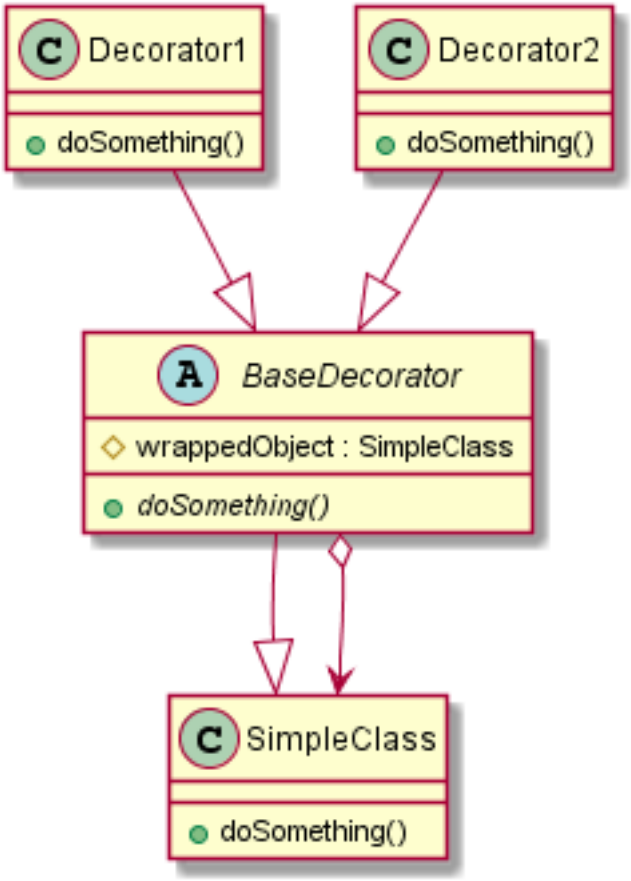


Figure 18.2: decorator

To create an instance of a `SimpleClass` decorated by `Decorator1`, all you need to do is to wrap the `SimpleClass` instance with an instance of `Decorator1`. When this `Decorator1` instance, calls `doSomething()` it calls the wrapped `SimpleClass` instance's `doSomething()` and do some extra behavior.

```
#Decorator1's implementation of doSomething():

def doSomething(self):
    self._wrappedObject.doSomething()
    doSomthingExtra()
```

It would be handy to create a `BaseDecorator` abstract class that is inherited by all decorators. It's not required but this class will form a class hierarchy for all decorators. Plus, you can write all of the common behavior and data into this class. It would be better for this class's `doSomething()` to be abstract, since it doesn't make sense for you to create instances of `BaseDecorator`.

Example

Decorating Sentences

A sentence can be defined as a list of words (words are strings). The string representation of a sentence is the concatenation of all of the words in the list, separated by a space.

Instances of sentences can be printed with formatting:

- **bordered** - Given the sentence, `["hey","there"]` it prints:

  ```
  -----------
  |hey there|
  -----------
  ```

- **fancy** - Given the sentence, `["hey","there"]` it prints:

  ```
  -+hey there+-
  ```

- **uppercase** - Given the sentence, `["hey","there"]` it prints:

  ```
  HEY THERE
  ```

The formatting of a sentence is decided during runtime. These formats should also allow for combinations with other formats:

- **bordered fancy** - Given the sentence, `["hey","there"]` it prints:

  ```
  ---------------
  |-+hey there+-|
  ---------------
  ```

- **fancy uppercase** - Given the sentence, `["hey","there"]` it prints:

  ```
  -+HEY THERE+-
  ```

To accomplish these features, you need to implement the decorator pattern. Each formatting will be a decorator for `Sentence` objects. These formats need to inherit from some abstract `FormattedSentence` class. This abstract class is specified to compose and inherit from sentence. The behavior that needs to be decorated is the `__str__()` function since you need to change how sentence is printed for every format.

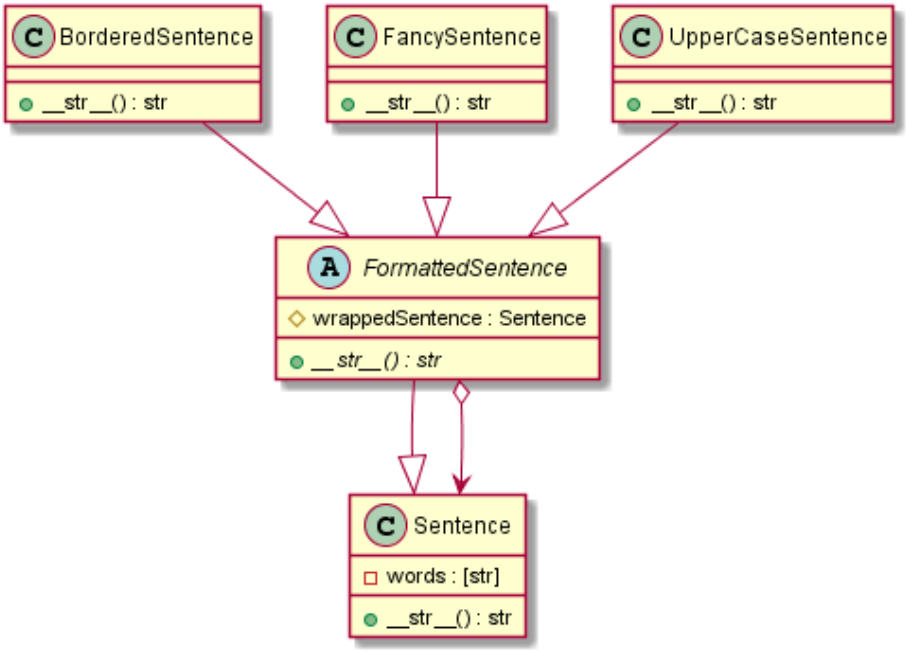


Figure 18.3: decorator example

Why this is elegant

- **Open/Closed Principle** - Decorators extend classes via inheritance. It is easier to add new decorators without touching any exiting code.
- A class which can have many variants because of diverse combinations of behaviors can be cleanly implemented using this pattern.
- You can arbitrarily mix and match decorators without the worry of polymorphic incompatibility during runtime

How to implement it

1. Create an abstract class `BaseDecorator` that specializes some `SimpleClass`. This `BaseDecorator` will also have the attribute `wrappedObject` which is a reference to an instance of the decorated `SimpleClass`. This attribute is set as protected so that it may be inherited by `BaseDecorator`s specializations. `BaseDecorator` also contains the abstract method `doSomething()`. This method's behavior, when invoked by `BaseDecorator`s specializations, changes depending on the decorations attached to `SimpleClass`
2. For every decoration, that can decorate `SimpleClass`, a specialization for `BaseClass` is created. These specializations implement `doSomething()` in a manner that augments/modifies `SimpleClass`'s own `doSomething()`

Adapter Pattern

Problem

As the system evolves, you'll likely encounter interfaces of instances that are incompatible with their intended clients. These interfaces do perform the necessary behavior, but maybe the method names are just different. This happens quite a lot since the interface of the dependency may be originally built for different reason. The interface may be an external module imported on existing client code. You can just change the incompatible interface to support the functionality you need but this is not always possible and may introduce code duplication.

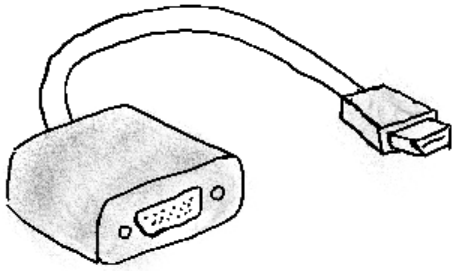


Figure 18.4: adapter

Solution

In the same way a usb-c interface is usable on a usb 2.0 using an adapter, you can use an incompatible service on a client as a compatible instance using the adapter pattern.

Say you have an instance of `AbstractService` (it could be any realization of `AbstractService`), that needs to be used like an instance of `RequiredInterface` by some client. What you need to do is to create an adapter to `AbstractService` called `ServiceAdapter` which realizes `RequiredInterface`. To adapt the instance of `AbstractService`, you have to compose it inside the `ServiceAdapter`. So that `serviceMethod1()` is adapted to `method1()`.

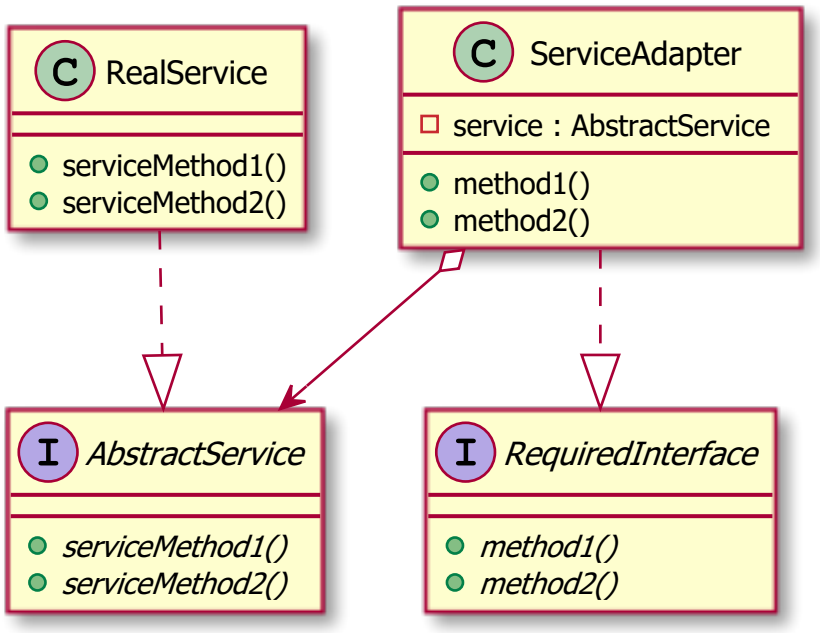


Figure 18.5: adapter

Whenever, a `ServiceAdapter` calls `method1()` it instead delegates the behavior to the embedded service, which instead calls `serviceMethod1()`

Example

Printable Shipments

Looking back at our previous lab exercises, some of the example classes contain string representation but do not implement the `__str__()` function. An example of this is `Shipment` back from the factory method example. It does contain a string representation builder called `shipmentDetails()`, but printing a shipment is quite tedious since you have to print, `s.shipmentDetails()`. You can replace the name of `shipmentDetails()` to `__str__()` but this will potentially affect other clients of shipment. You can add the `__str__()` function which does exactly the same but this may introduce unwanted code duplication.

The best solution for this problem is to create an adapter for shipment called `PrintableShipment`. This adapter will realize some `Printable` abstraction, which only contains the abstract method `__str__()`.

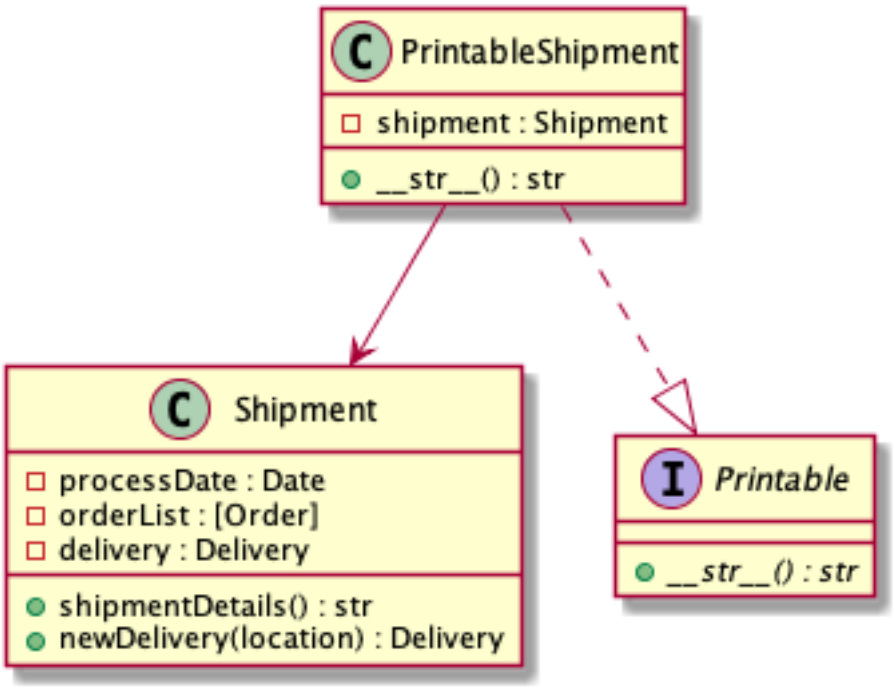


Figure 18.6: adapter example

Why this is elegant

- **Open/Closed Principle** - Instead of changing existing incompatible interfaces, you can extend them by creating adapters.
- Instead of cluttering up your code with duplicate functions and unused interface methods, you instead create adapters only when it is needed.

How to implement it

1. If you want an `AbstractService` to be used like a `RequiredInterface`, Create a `ServiceAdapter` that realizes `RequiredInterface` and contains an attribute `service` that is a reference to an instance of `AbstractService`.
2. Inside `ServiceAdapter`, the implementations of `RequiredInterface`'s abstract methods are merely calls to the methods of the reference `service`.

Composite (Optional Read)

Problem

When entities in your system needs to be represented like trees, then you represent them like trees.

Solution

The composite pattern describes a tree structure described polymorphically. A tree node can either be a general tree or a leaf. in the composite pattern, a `Component` (tree node) can either be `Composites` (general tree), or a `Leaf`. Leaves and Composites are realizations of `Component`.

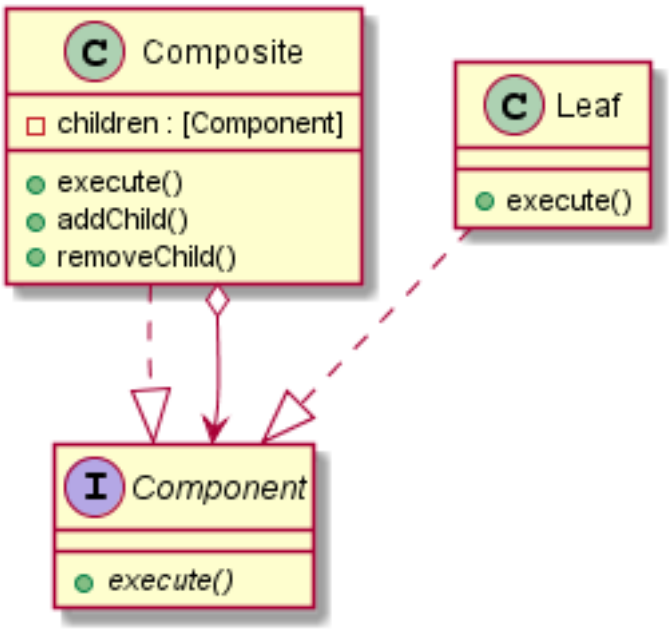


Figure 18.7: composite

Example

File System

The file system in your computers are described using a tree structure. The entities in your file system are either directories or files.

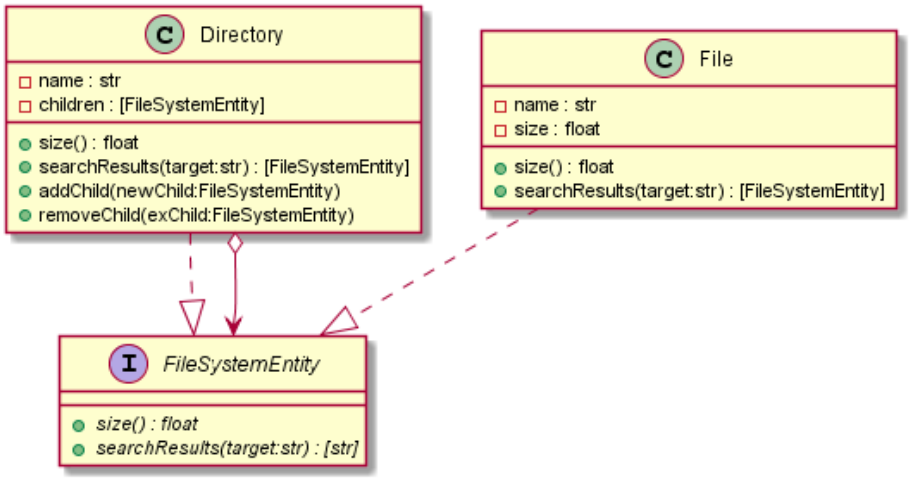


Figure 18.8: composite pattern

What you need to do is to implement a simulation of a file system. Each node of the file system should be able to call the following methods:

- **`size()`** - the size of a `File` is based on the attribute size which is set during the initialization of the `File` instance. The size of a `Directory` is the size of all the `FileSystemEntities` inside it.
- **`searchResults(target)`** - if used by a `File`, if the name of the file matches the `target` it returns a list containing the `File`, if not it returns an empty list. If used by a `Directory` returns a list containing all the of the instances of `FileSystemEntity` (including itself) that matches the target inside the `Directory`.

Why this is elegant

- **Open/Closed Principle** - You can introduce new component realizations in the system without touching any existing code.
- Working with composite trees are easier because of the polymorphism in the pattern

How to implement it

1. Create an abstraction called `Component` that contains the abstract methods that are supposed to be executed across all components.
2. The `Component` has two realizations, `Composite`s and `Leaf`s.
3. `Component` contains an attribute `children` which is a list of `Composite` instance references and the methods `addChild()` and `removeChild()` to attach/detach `Composite`s. It also has `execute()` which an implemented method from `Component`.

4. `Leaf` contains the method `execute()` as well.
5. When a `Composite`'s execute is invoked, it calls invokes all of its children's`execute()`. When `Leaf`'s execute is invoked it performs, leaf related behavior.

Facade (Optional Read)

Problem

When your system becomes large enough, parts of the system which is responsible for a single operation may involve interactions between multiple classes. Creating flexible and maintainable systems tend to look like this.

Looking from the outside, simple functionality (like borrowing a book or depositing money to an account) will appear complex since it involves multiple lines of object interaction.

Solution

To solve this issue, you create a straightforward interface, that contains methods to encapsulate complicated functionality in your subsystem. Instead of using the internal classes to perform some functionality, you call the facade interface's method instead.

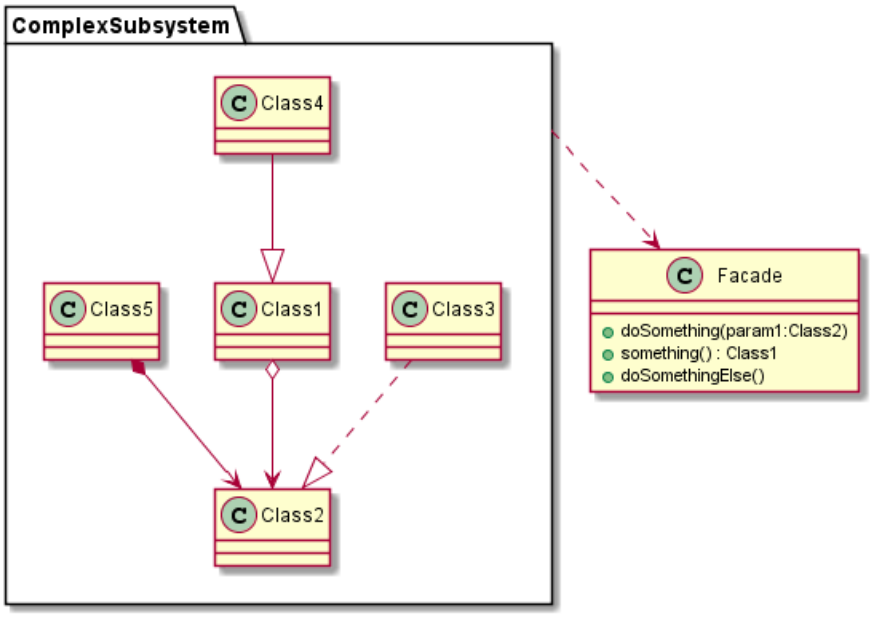


Figure 18.9: facade

Why this is elegant

- Implementing this pattern encapsulates complicated subsystem behavior into simple straightforward functions.

Optional Readings

Shvets A. (2018) Structural Patterns Accessed August 31, 2020

Lab Exercise 1 (Structuring the Document) (Optional)

This is meant as review of imperative programming languages like C.
This Lab Exercise is optional.

Task

A document is represented as a collection paragraphs, a paragraph is represented as a collection of sentences, a sentence is represented as a collection of words and a word is represented as a collection of lower-case ([a-z]) and upper-case ([A-Z]) English characters. **Create a C program that will convert a raw text document into its component paragraphs, sentences and words**. To test your results, queries will ask you to return a specific paragraph, sentence or word as described below.

Words, sentences and paragraphs are represented using C structures

words

```
struct word {
    char* data;
};
```

sentences

```
struct sentence {
    struct word* data;
    int word_count;//the number of words in a sentence
};
```

The words in a sentence are separated by one space. The last word does not end in space (" ").

paragraphs

```
struct paragraph {
    struct sentence* data  ;
    int sentence_count;//the number of sentences in a paragraph
};
```

The sentences in the paragraph are separated by one period ("."). There are no spaces after the period.

document

```
struct document {
    struct paragraph* data;
    int paragraph_count;//the number of paragraphs in document
};
```

The paragraphs in the document are separated by one newline (**\n**). The last paragraph does not end with a newline.

The paragraphs in the document are separated by one newline(**\n**). The last paragraph does not end with a newline.

For example:

```
Learning C is fun.
Learning pointers is more fun.It is good to have pointers.
```

The only sentence in the first paragraph could be represented as:

```
struct sentence first_sentence_in_first_paragraph;

first_sentence_in_first_paragraph.data = {"Learning", "C", "is",
↪  "fun"};
```

The first paragraph itself could be represented as:

```
struct paragraph first_paragraph;

first_paragraph.data = {{"Learning", "C", "is", "fun"}};
```

The first sentence in the second paragraph could be represented as:

```
struct sentence first_sentence_in_second_paragraph;

first_sentence_in_second_paragraph.data = {"Learning",
↪  "pointers", "is", "more", "fun"};
```

The second sentence in the second paragraph could be represented as:

```
struct sentence second_sentence_in_second_paragraph;

second_sentence_in_second_paragraph.data = {"It", "is", "good",
↪  "to", "have", "pointers"};
```

The second paragraph could be represented as:

```
struct paragraph second_paragraph;

second_paragraph.data = {{"Learning", "pointers", "is", "more",
↪  "fun"}, {"It", "is", "good", "to", "have", "pointers"}};
```

Finally, the document could be represented as:

```
struct document Doc;

Doc.data = {{{"Learning", "C", "is", "fun"}}, {{"Learning",
↪  "pointers", "is", "more", "fun"}, {"It", "is", "good", "to",
↪  "have", "pointers"}}};
```

Alicia has sent a document to her friend Teodora as a string of characters, i.e. represented by char* not a struct document. Help her convert the document to struct document form by completing the following functions:

- `void initialize_document(char *text)` - to intialise the document. to return the paragraph in the document.
- `struct paragraph kth_paragraph(int k)` - return the kth paragraph in the document
- `struct sentence kth_sentence_in_mth_paragraph(int k, int m)` - to return the kth sentence in the mth paragraph.
- `struct word kth_word_in_mth_sentence_in_nth_paragraph(int k, int m, int n)` - to return the kth word in the mth sentence of the nth paragraph.

Input Format:

The first line contains the integer `paragraph_count`. Each of the next `paragraph_count` lines contains a paragraph as a single string. The next line contains the integer `q`, the number of queries. Each of the next `q` lines contains a query in one of the following formats:

- `1 k`: This corresponds to calling the function`kth_paragraph`.
- `2 k m`: This corresponds to calling the function `kth_sentence_in_mth_paragraph`.
- `3 k m n`: This corresponds to calling the function `kth_word_in_mth_sentence_in_nth_paragraph`.

Constraints

- The text which is passed to get_document has words separated by a space, sentences separated by a period and paragraphs separated by a newline.
- The last word in a sentence does not end with a space.
- The last paragraph does not end with a newline.
- The words contain only upper-case and lower-case English letters.
- 1 <= number of characters in the entire document <= 1000 .
- 1 <= number of paragraphs in the entire document <= 5.

Output Format

Print the paragraph, sentence or the word corresponding to the query to check the logic of your code.

Sample Input 0

```
2
Learning C is fun.
Learning pointers is more fun.It is good to have pointers.
3
1 2
2 1 1
3 1 1 1
```

Sample Output 0

```
Learning pointers is more fun.It is good to have pointers.
Learning C is fun
Learning
```

Explanation 0

- The first query returns the second paragraph.
- The second query returns the first sentence of the first paragraph.
- The third query returns the first word of the first sentence of the first paragraph

Assessment Criteria

This exercise is optional

Lab Exercise 2

Task

We've discussed functional programming paradigms using the language haskell as a representative. For this exercise, you'll familiarize yourselves on how to write pure functions in haskell. **Create a haskell file (".hs") containing the following functions below.**

For those of you using REPL's haskell compiler add the following snippet of code the the bottom of your function definitions. For those of you using ghc in your computers ignore this.

```
main :: IO ()
main = return ()
```

Easy functions

- `cube :: Int -> Int` - Consumes an integer and produces the cube of that integer

- `double :: Int -> Int` - Consumes an integer and produces the 2 times that integer

Recursive Functions

- `modulus :: Int -> Int -> Int` - Consumes two integers x and m and produces $x \mod m$
- `factorial :: Int -> Int` - Consumes an integer and produces the factorial of the integer
- `summation :: Int -> Int` - Consumes a natural number and produces the summation of numbers from 1 to n. $\sum_{i=1}^{n} i$.

```
summation :: Int -> Int
summation n = if (n <= 1) then n else (n + (summation
↪  (n-1)))
```

Higher order function

- `compose :: (Int -> Int) -> (Int -> Int) -> (Int -> Int)` - Consumes two functions $f : \mathbb{Z} \to \mathbb{Z}$, and $g : \mathbb{Z} \to \mathbb{Z}$ and produces the function $f \circ g$.
- `subtractMaker :: Int -> (Int -> Int)` - Consumes an integer x and produces a function that consumes an integer y and produces $x - y$
- `applyNTimes :: (Int -> Int) -> Int -> Int -> Int` - Consumes a function $f : \mathbb{Z} \to \mathbb{Z}$ and and two integers n and x. `applyNTimes` produces an integer which is the result of the function applied to x, n-times. If n is less than 0 it must produce zero applications of f therefore it produces x.

Assessment Criteria

- Completeness of haskell functions - 40

Deadline November 30, 2020

Lab Exercise 3 (Higher Order Functions for List Comprehension)

Task

After familiarizing yourselves with haskell functions, lets move on to list comprehension functions. These functions are probably functional programming's most well-known contribution to other paradigms. Although these functions are already built in inside haskell, you are going to make your own versions of it. **Create a haskell file (".hs") containing the following functions below.** One of them (`my_filter`) is already written for you but please still include this function in your haskell file.

Lists in Haskell

Before you start implementing the functions in this exercise, you need to understand how lists work in Haskell. Haskell lists are written like a list in math. The Haskell list:

```
[1,2,3,4,5]
```

is basically equivalent to the list:

$$[1, 2, 3, 4, 5]$$

One of the most important things about lists is that you can access the list as a whole and you can access the elements inside the list. One thing you can do is you can concatenate lists using the **++** function:

```
ghci> [1,2,3,4,5] ++ [6,7,8]
[1,2,3,4,5,6,7,8]
```

You can find the length of the list using the **length** function:

```
ghci> length [1,2,3,4,5]
5
```

These are the different ways you can access the elements of the list and the sublists in the list:

head takes a list and returns the first element of the list

```
ghci> head [1,2,3,4,5]
1
```

tail takes a list and returns the same list except the first element of the list

```
ghci> tail [1,2,3,4,5]
[2,3,4,5]
```

init takes a list and returns the same list except the last element of the list

```
ghci> init [1,2,3,4,5]
[1,2,3,4]
```

last takes a list and returns the same list except the last element of the list

```
ghci> last [1,2,3,4,5]
5
```

Using these functions you can traverse a list using the head-tail recipe. For example, if you want to add 1 to each of the elements of the array:

```
addone :: [Int] -> [Int]
addone l =
  if length l == 0 then []
  else [(head l) + 1] ++ addone (tail l)
```

Let's dissect this function one by one, for the first line you can see the type signature `[Int]->[Int]` meaning **addone** accepts a list of **Int**s and returns a list of **Int**s. Any type **a** surrounded by brackets is a list of **a**s (`[a]` is a list of **a**'s, `[Char]` is a list of **Chars**, `[[Int]]` is a list of `[Int]`s or a list of list of **Int**s).

In the second line were binding the list we are passing to `l`.

The third line refers to the base case, this happens when the list is empty. When writing the base case, think about the most simple possible list the function may be applied to. The simplest case would be an empty list. When the list is empty we return `[]` which refers to an empty list.

And finally the last line refers to the general case. Here we are see the subexpression `[(head l) + 1]` which is a list containing one element namely, the first element of the list plus 1. And then we are concatenating this one element list to the result of the call `addone (tail l)` which is a recursive call to the rest of add one to the `tail` of l (or the rest of `l`). Assuming **addone** works perfectly, the recursive call `addone (tail l)` will return the tail of the `l` but the elements are added with one. By concatenating `[(head l) + 1]` with the result of this recursive call, we complete the desired result.

- Implement the higher order functions, **my_map**,**my_filter**, and **my_foldl** and **my_foldr**, **my_zip**
  - **my_map :: (a -> b) -> [a] -> [b]** - The **map** function accepts a function f and a list (with elements of type **A**) $l = [l_1, l_2, l_3, ..., l_n]$. It returns the list (with elements of type **B**): $l' = [f(l_1), f(l_2), f(l_3), ..., f(l_4)]$. The new list **map** produces is a list which is the image of `l` from the function **f**.
  - **my_filter :: (a -> Bool) -> [a] -> [a]** - The **filter** function accepts a predicate f and a list $l = [l_1, l_2, l_3, \cdots, l_n]$. **filter** returns

a new list l' such that the contents satisfy $f(l_i)$ is true, retaining the order it appears in l.

BONUS (here's `my_filter` solved for you, use this as a guide):

```
my_filter :: (a -> Bool) -> [a] -> [a]
my_filter p l =
        if length l == 0 then []
        else (if p (head l) then [head l] else []) ++
        ↪  my_filter p (tail l)
```

The notable part of this `my_filter`'s body is the last. The non-base case clause evaluates the following line

```
(if p (head l) then [head l] else []) ++ my_filter p
↪  (tail l)
```

The first part is the if-then-else clause `(if p (head l) then [head l] else [])` which evaluates to either the list containing the first element of `l` (`[head l]`) or an empty list (`[]`). If the first element (`head l`) satisfies the predicate `p` (therefore the if clause contains the expression `p (head l)`), then the if-then-else clause evaluates to `[head l]` otherwise it evaluates to `[]`. Whatever, the `if-then-else` clause evaluates to is then concatenated to the result of the recursive call to the tail of `l` (`my_filter p (tail l)`). Every time the function recurses, the first element is either concatenated or not concatenated to the rest of the list, this filtering out all elements that do not satisfy the predicate.

- `my_foldl :: (a -> a -> a) -> a -> [a] -> a` - The `foldl` function accepts a function f, a list $l = [l_1, l_2, l_3, ..., l_n]$ and an initial value u. The `foldl` function returns the value $f(f(f(f(u, l_1), l_2), l_3), l_n)$.
- `my_foldr :: (a -> a -> a) -> a -> [a] -> a` - The `foldr` function accepts a function f, a list $l = [l_1, l_2, l_3, ..., l_n]$ and an initial value u. The `foldr` function returns the value $f(l_1, f(l_2, f(l_3, f(l_n, u))))$
- `my_zip :: (a -> b -> c) -> [a] -> [b] -> [c]` - THe `zip` function accepts a function f and two lists $l = [l_1, l_2, l_3, ..., l_n]$, $m = [m_1, m_2, m_3, ..., m_n]$ and returns a new list, $k = [f(l_1, m_1), f(l_2, m_2), f(l_3, m_3), \cdots, f(l_n, m_n)]$

- Without using loops (use the functions above instead), write the following functions.
  - Given a list of numbers, return the sum of the squares of the numbers

- Given three lists, a list of first names, A, a list of middle names B, and a list of surnames C. Return a list of whole name strings (list of chars) (`[firstname] [middle initial]. [lastname]`) where the length of the string (including spaces and period) is an even number. Example

```
ghci> wholeName ["Foo", "Bar", "Foo"] ["Middle",
↪  "Center", "Name"] ["Lastn", "Surname", "Abcd"]
["Foo M. Lastn", "Bar C. Surname"]
```

("Foo S. Abcd" is filtered out because it has 11 characters)

Assessment Criteria

- Completeness of haskell functions - 35

Deadline November 30, 2020

Lab Exercise 4 (Drama in the Clue Mansion)

Task

You can use a knowledge base to represent human relationship networks. This is what you will be doing for this exercise. I've written a few example facts, and rules as your guide below. **Create a prolog knowledge base (".pl") containing the following facts. Also, create a text file containing the answers to to queries you can below.**

- Create a knowledge base and place them all inside a file with a ".pl" extension
    1. *Miss Scarlet, Mrs. White, Mrs. Peacock, Dr. Orchid are female*
    2. Prof. Plum, Colonel Mustard, and Rev. Green are all male
    3. *Miss Scarlet hates Rev. Green.*
    4. Rev. Green and Mrs. White hate each other.
    5. Prof. Plum and Mrs. White hate each other.

6. Col. Mustard hates all females and Prof. Plum.
7. Miss Scarlet and Mrs. Peacock both like Dr. Orchid.
8. Dr. Orchid likes Mrs. Peacock
9. Miss Scarlet likes Mrs. White
10. Miss Scarlet and Prof. Plum like each other.
11. Prof. Plum likes everyone Col. Mustard hates.
12. *People who hate each other are enemies*
13. People who like each other are friends
14. The enemies of someone's enemies is his/her friend.

- Based on the knowledge base you created, ask it the following queries by running `swipl labExer4.pl`. Write the solutions to each query into a text file.

    1. *Which pairs are enemies?*
    2. Which pairs are friends?
    3. Which people are liked by Prof. Plum.
    4. Which people like themselves?
    5. Which males are liked by females? (this query must be written as a conjunction)
    6. Which people are hated by the one they like? (this query must be written as a conjunction)

Some example facts and rules as guide

(don't skip writing these facts and rules in your knowledge base so that it works)

```
%Propositions in item 1
female(scarlet).
female(peacock).
female(orchid).

%Proposition in item 2 (Miss Scarlet hates Rev. Green)
hates(scarlet, green).

%Rule in item 12 (People who hate each other are enemies)
enemies(X,Y) :- hates(X,Y), hates(Y,X).
```

Some example queries

(Although the answers are already provided here, still, copy them on the text file containing the answers from the other queries).

You should get similar answers to the following queries

Which pairs are enemies?

```
?- enemies(A,B).

A = scarlet,
B = green ;
A = green,
B = scarlet ;
A = plum,
B = white ;
A = white,
B = plum ;
false.
```

Which males are liked by females?

```
?- likes(A,B), female(A), male(B).

A = scarlet,
B = plum ;
false.
```

Assessment Criteria

- Completeness of knowledge base - 20
- Accuracy of query results - 20

Deadline November 30, 2020

Lab Exercise 5 (Snakes)

Task

To familiarize yourselves with how python syntax works, create the python library (".py") and **write the following functions inside it:**

```
def doubledInt(x:int) -> int:
        #accepts an in and return the double of that int
```

double

```
def largest(x:float,y:float) -> float:
    #accepts two floats and returns the larger value
```

largest

```
def isVertical(a:(float,float),b:(float,float)) -> bool:
    #accepts two (float,float) tuples which represent two points
    ↪  in a cartesian plane and returns true if the points
    ↪  describe a vertical line and false otherwise
```

vertical line

```
def primes(n:int) -> [int]:
    #accepts an integer n and returns the first n primes
```

primes

```
def fibonacciSequence(n:int) -> [int]:
        #accepts an integer n and returns a list containing the
        ↪  first n elements of fibonacci sequence (starting with
        ↪  0 and 1)
```

fibonacci

```
def sortedIntegers(l:[int]) -> [int]:
        #accepts a list of integers and returns a list with the
        ↪  same integers sorted from smallest to highest
```

sorting

```
def sublists(l:[int]) -> [[int]]:
        #accepts a list of integers and returns all the sublists
        ↪  of the list. Sublists are contiguous chunks of a list
        ↪  (including an empty list and the list itself). [1,2],
        ↪  [2], [], [2,3,4], and [1,2,3,4,5] are sublists of
        ↪  [1,2,3,4,5] but [3,5] and [1,2,3,4,6] are not.
```

sublists

fast modular exponentiation (optional) this should work for large values of b and p. To do this implement fast modular exponentiation from CMSC 56

```
def fme(b:int,p:int,m:int) -> int:
    #accepts 3 ints, b,p and m and computes b^p mod m
```

Assessment Criteria

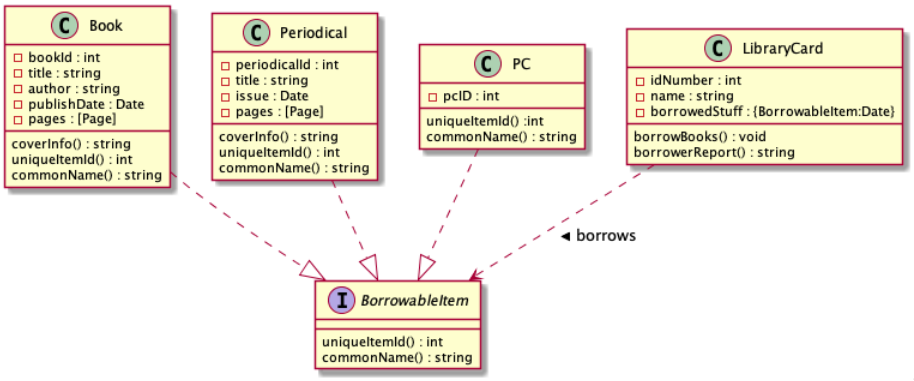
- Completeness of python functions - 35
- Correctness of function names and parameter names - 5

Deadline November 30, 2020

Lab Exercise 6 (Borrowing from the Library)

Task

You are to implement the following system. This system represents the borrowing and returning functions of a library. Here's the class diagram. **Edit the python file that came with this document.** The edited file is what you are going to submit.



There is some code already written for you here:

```
from abc import ABC, abstractmethod

class Date:
    def __init__(self, month:int, day:int, year:int):
        self.__month = month
        self.__day = day
        self.__year = year
    def mdyFormat(self) -> str:
        return str(self.__month) + "/" + str(self.__day) + "/" +
        ↪  str(self.__year)

class Page:
    def __init__(self, sectionHeader:str, body: str):
        self.__sectionHeader = sectionHeader
        self.__body = body

class BorrowableItem(ABC):
    @abstractmethod
    def uniqueItemId(self) -> int:
        pass
    @abstractmethod
    def commonName(self) -> str:
        pass



class Book(BorrowableItem):
    def __init__(self, bookId:int, title:str, author:str,
    ↪  publishDate:Date, pages: [Page]):
        self.__bookId = bookId
        self.__title = title
        self.__publishDate = publishDate
        self.__author = author
        self.__pages = pages
    def coverInfo(self) -> str:
        return "Title: " + self.__title + "\nAuthor: " +
        ↪  self.__author
    def uniqueItemId(self) -> int:
        return self.__bookId
    def commonName(self) -> str:
        return "Borrowed Item:" + self.__title + " by " +
        ↪  self.__author
```

```
class LibraryCard:
    def __init__(self, idNumber: int, name: str, borrowedItems:
    ↪  {BorrowableItem:Date}):
        self.__idNumber = idNumber
        self.__name = name
        self.__borrowedItems = borrowedItems
    def borrowItem(self,book:BorrowableItem, date:Date):
        self.__borrowedItems[book] = date
    def borrowerReport(self) -> str:
        r:str = self.__name + "\n"
        for borrowedItem in self.__borrowedItems:
            r = r + borrowedItem.commonName() + ", borrow date:"
↪  + self.__borrowedItems[borrowedItem].mdyFormat() + "\n"
        return r
```

Creating an instance of a **BorrowableItem** (in this case an instance of the particular realization, **Book**) is done using the following code.

```
b:BorrowableItem = Book(10991,"Corpus Hermeticum", "Hermes
↪  Trismegistus", Date(9,1,1991), [])
print(b.commonName()) #commonName() returns the string
↪  representation of a borrowable item
```

Creating an instance of a **LibraryCard** is done using the following.

```
l:LibraryCard = LibraryCard(9982,"Rubelito Abella",{})
```

A library card borrows something using the **borrowItem(BorrowableItem)** method. And the **borrowerReport()** prints the library card owners name and the items he/she has borrowed.

```
l.borrowItem(b,Date(9,25,2019))
print(l.borrowerReport())
```

What you should do:

The class definitions above are still missing `Periodical` and `PC`.

- a **Periodical** represents a periodical (newspaper, magazines, etc). It is a realization of a **BorrowableItem**. It contains the following methods and

attributes:

  - `__init__`: initializes a periodical instance with the attributes `__periodicalID:int`, `__title:str`, `__title:str`
  - `__periodicalID:int`: unique id for a periodical
  - `__title:str`: The title of the periodical ("National Geographic", "New York Times")
  - `__issue:Date`: The date when the issue was published
  - `__pages:[Page]`: A list of `Page`s that represent the contents
  - `uniqueItemId()`: Returns `periodicalID`
  - `commonName():str`: (Implementation of the abstract method from `BorrowableItem`). It returns the title and the issue date in month/date/year format as a string for example "National Geographic issue: 4/6/2001")

- a `PC` represents a library PC. It is a realization of a `BorrowableItem`. It contains the following methods and attributes:

  - `__init__`: initializes a PC instance with the attribute `__pcID:int`.
  - `__pcID:int` : unique id for a PC
  - `uniqueItemId():int`: Returns `__pcID`
  - `commonName():str`: (Implementation of the abstract method from `BorrowableItem`). It returns "PC<__pcID>" (the string "PC" followed by the value attribute `__pcID`, for example "PC1342")

Add the following methods to `LibraryCard` and implement them

- `returnItem(b:BorrowableItem):` : returns nothing, it removes the `BorrowableItem`, `b` from the `__borrowedItems` dictionary.
- `penalty(b:BorrowableItem,today:Date):float` : returns a float which is the calculated penalty for `BorrowableItem`, `b` when returned today. Every day after the due date the penalty increases by 3.5. An item which is overdue for 4 days has a penalty of 14.
- `itemsDue(today:Date):[BorrowableItem]` : returns a list of `BorrowableItem`s which are on or past the due date. The due date for a `Book` is 7 days, a `Periodical` is 1 day, and a `PC` is 0 days.
- `totalPenalty(today:Date):float` : returns a float which is the total penalty for all the overdue items when calculated today

Feel free (in fact you are encouraged) to add extra methods to any of the classes above that will help you in implementing the whole system. Just make sure the extra methods don't unnecessarily expose hidden attributes.

Assessment Criteria

- Completeness of `BorrowableItems` attributes and methods - 20
- Completeness of `LibraryCard` methods - 20
- Correctness of attribute and methods names - 10

Deadline November 30, 2020

Lab Exercise 7 (Designing an OOP System)

Task

Banking System

You are to design a banking system that supports the following features:

- 3 kinds of bank accounts:
  - payroll - this account can withdraw funds. This account can receive funds from transfers but it cannot transfer.
  - debit - this account can withdraw and deposit. This account can transfer funds to any account. Each month the balance compoundingly increases based on an interest rate. This account has a required balance that must be kept every month. If this balance is not kept the account becomes inactive (It's up to you to set that required balance amount).

  - credit - this account can withdraw. Withdrawing increases the credit balance (the amount owed). This account has a credit limit. The credit balance cannot exceed this credit limit. It can deposit which basically deducts the deposited amount from the current credit balance. This account can also transfer funds to any account which also increases the credit balance. It also has an interest rate where the credit balance increases compundingly each month. (it's also up to you to set the credit limit)

- applying all account changes - every month this is invoked, this changes the debit balances and credit balances based on interest. It also changes account status (deactivating/activating) once this triggers. (Note: you do not actually need to implement this in such a way that the changes happens automatically every month. Assume that this method is invoked every month)
- fund transfer from one account to another (all kinds of accounts can be transferred to, Note: do not allow a debit accounts to transfer an amount greater than the balance or a credit account to transfer an amount that will make the credit balance exceed the credit limit)
- deactivate and activate accounts
- account withdrawal (do not allow withdrawals that exceed the balance and the credit limit as well)
- account deposit (payroll accounts can't deposit)
- show the balance report of an account
- show account information (name of the account owner, type of the account and active/inactive status of the account)

You can place all of the classes into a single python file and you can also separate them into their own python files (just make sure you're importing correctly). If you put them all into a single python file, submit the python file. If you separate them into multiple python files, package them all into a zipped folder and submit the zipped folder.

Feel free to add your own extra methods and extra features to this system. This is an open ended design exercise, go ahead and be creative. For example, I have not specified how the system might react if there are invalid withdrawals or transfers, it's up to you to implement those (do you print a message? or raise an error?)There is no single correct class architecture for this system.

I'm not actually expecting you to build perfectly a elegant architecture for this system, this exercise's purpose is to get you used to building OOP systems from scratch.

Lab Exercise 8 (Shipment)

Task

Online Marketplace Delivery

Consider you're developing the product delivery side of an online marketplace app (think Amazon/Lazada). Your app is on its early stage so their is only one delivery option, standard nationwide delivery that takes a minimum of 7 days.

What you have is `Shipment` class that contains a `StandardDelivery` class. Inside the shipment class is the `shipmentDetails()` builder which builds a string representing the details of the shipment, this includes the delivery details (which requires access to the composed `StandardDelivery` instance). Inside the constructor of `Shipment` an instance of `StandardDelivery` is created so that every `Shipment` is set to be delivered using standard delivery.

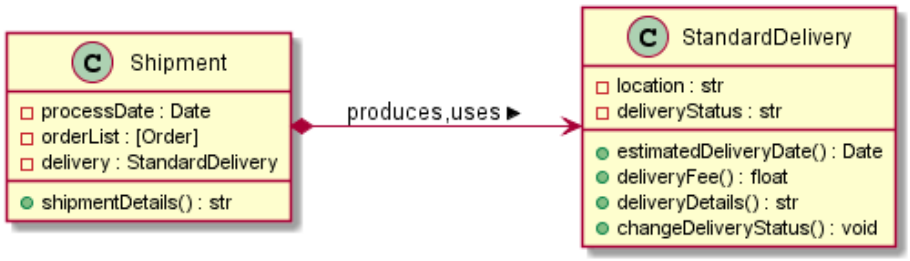


Figure 26.1: online marketplace

```
from datetime import date,timedelta

class Order:
    def __init__(self,productName:str, productPrice:float):
        self.__productName = productName
        self.__productPrice = productPrice
    def orderString(self) -> str:
        return "%s P%.2f" %
        ↪  (self.__productName,self.__productPrice)
    def price(self) -> float:
        return self.__productPrice

class StandardDelivery:
    def __init__(self,location:str):
        self.__location = location
        self.__deliveryStatus = "Processing"
    def deliveryDetails(self) -> str:
        r = "STANDARD DELIVERY\nDELIVER TO:%s\nDELIVERY STATUS:
↪  %s\nDELIVERY FEE: P%.2f" %
↪  (self.__location,self.__deliveryStatus,self.deliveryFee())
        return r
    def deliveryFee(self) -> float:
        return 500
    def estimatedDeliveryDate(self,processDate:date) -> float:
        return processDate + timedelta(days = 7)
    def changeDeliveryStatus(self,newStatus:str):
        self.__deliveryStatus = newStatus

class Shipment:
    def __init__(self, orderList:[Order], processDate: date,
    ↪  location):
        self._orderList = orderList
        self._processDate = processDate
```

```
        self._delivery = StandardDelivery(location)

    def totalPrice(self) -> str:
        t = 0.0
        for order in self._orderList:
            t+=order.price()
        return t

    def shipmentDetails(self) -> str:
        r = "ORDERS:" + str(self._processDate) + "\n"
        for order in self._orderList:
            r += order.orderString() + "\n"
        r += "\n"
        r += "TOTAL PRICE OF ORDERS: P"  + str(self.totalPrice())
↪   + "\n"
        r += self._delivery.deliveryDetails() + "\n\n"
        r += "PRICE WITH DELIVERY FEE : P" +
↪   str(self.totalPrice()+self._delivery.deliveryFee()) + "\n"
        r += "ESTIMATED DELIVERY DATE: " +
↪   str(self._delivery.estimatedDeliveryDate(self._processDate))
        return r

o = [Order("Surface Pro 7",40000),Order("Zzzquil",900)]
s = Shipment(o,date(2019,11,1),"Cebu City")
print(s.shipmentDetails())
```

This system does work. It works but it is still inelegant. As soon as your app grows, you will incorporate new delivery options like express delivery, or pickups or whatever. Every time you need to add a new delivery method you will need to perform surgery in **Shipment** since the **StandardDelivery** instance is created inside the constructor of **Shipment**. **Shipment**'s code is too coupled with **StandardDelivery**.

To solve this you need to implement the factory method pattern. Right now shipment is a factory since it constructs its own instance of **StandardDelivery**. To refactor this into elegant code, you need to so create an abstraction called**Delivery** first to support polymorphism. Inside **Shipment** instead of creating instances of **Delivery**'s using a constructor, you invoke a factory method that encapsulates the instantiation of **Delivery**. In this case we name this method **newDelivery()**. All it does is return an instance of **StandardDelivery** using its constructor.

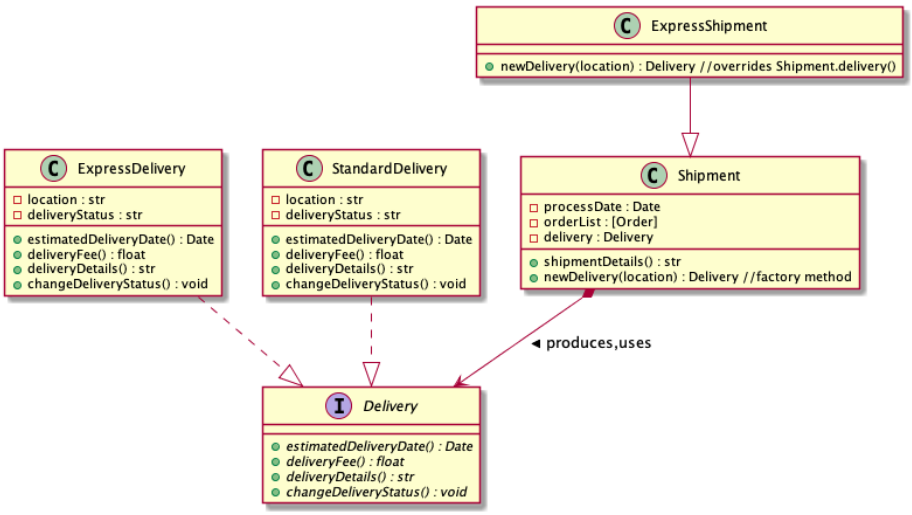


Figure 26.2: online marketplace

In this new architecture, whenever there are new delivery methods a shipment could have, all you have to do is to create a realization of that delivery method. In this case the new delivery method is `ExpressDelivery` which delivers for two days but is twice as expensive. And instead of changing `Shipment` (violates Open/Closed Principle), you make an extension to `Shipment`. This extension is the specialization to shipment called `ExpressShipment` (a shipment that uses express delivery). In this specialization, you only need to override the factory method delivery, so that every instance of delivery construction creates `ExpressDelivery`. The difference between `ExpressDelivery` and `Delivery` is that `ExpressDelivery` has a delivery fee of 1000 and the estimated delivery date is one day after the processing date.

Complete the system using the factory method pattern.

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 9 (Bootleg Text-based Zelda Game)

Task

You're creating the dungeon encounter mechanics of some bootleg text-based zelda game. In this game,every time you enter a dungeon, you encounter 0-8 monsters (the exact number is randomly determined). There are 3 types of monsters, bokoblins, moblins, and lizalflos (different types have different moves). The exact type of monster is randomly decided as well.

```
from random import randint

class NormalBokoblin:
    def bludgeon(self):
        print("Bokoblin bludgeons you with a boko club for 1
        ↪  damage")
    def defend(self):
        print("Bokoblin defends itself with a boko shield")
```

```
    def announce(self):
        print("A bokoblin appeared")
    def move(self):
        if randint(1,3) > 1:
            self.bludgeon()
        else:
            self.defend()

class NormalMoblin:
    def stab(self):
        print("Moblin stabs you with a spear for 3 damage")
    def kick(self):
        print("Moblin kicks you for 1 damage")
    def announce(self):
        print("A moblin appeared")
    def move(self):
        if randint(1,3) > 1:
            self.stab()
        else:
            self.kick()

class NormalLizalflos:
    def throwBoomerang(self):
        print("Lizalflos throws its lizal boomerang at you for 2
        ↪  damage")
    def hide(self):
        print("Lizalflos camouflages itself")
    def announce(self):
        print("A lizalflos appeared")
    def move(self):
        if randint(1,3) > 1:
            self.throwBoomerang()
        else:
            self.hide()



class Encounter:
    def __init__(self):
        self.__enemies = []
        for i in range(randint(0,8)):
            r = randint(1,3)
```

```
            if r == 1:
                self.__enemies.append(NormalBokoblin())
            elif r==2:
                self.__enemies.append(NormalMoblin())
            else:
                self.__enemies.append(NormalLizalflos())

    def announceEnemies(self):
        print("%d monsters appeared" % len(self.__enemies))
        for enemy in self.__enemies:
            enemy.announce()

    def moveEnemies(self):
        for enemy in self.__enemies:
            enemy.move()



encounter = Encounter()
encounter.announceEnemies()
print()
encounter.moveEnemies()
```

Right now the game works like this:

As soon as you enter the dungeon, all the enemies are announced:

```
5 monsters appeared
A lizalflos appeared
A lizalflos appeared
A lizalflos appeared
A moblin appeared
A moblin appeared
```

After this, each enemy in the encounter attacks. They randomly pick an attack from their moveset.

```
Lizalflos thorws its lizal boomerang at you for 2 damage
Lizalflos thorws its lizal boomerang at you for 2 damage
Lizalflos camouflages itself
Moblin stabs you with a spear for 3 damage
Moblin stabs you with a spear for 3 damage
```

The encounter ends with Link dying since you haven't coded anything past this part.

You decide to make things exciting for your game by adding harder dungeons, medium dungeon and hard dungeon.

Medium dungeon Instead of encountering, normal monsters you encounter stronger versions of the monsters, these monsters are blue colored:

- **Blue Bokoblin**
  - equipped with a spiked boko club and a spiked boko shield
  - bludgeon deals 2 damage
- **Blue Moblin**
  - equipped with rusty halberd
  - stab deals 5 damage
  - kick deals 2 damage
- **Blue Lizalflos**
  - equipped with a forked boomerang
  - throw boomerang deals 3 damage

Hard dungeon These monsters are silver colored extra stronger versions of the monsters

- **Silver Bokoblin**
  - equipped with a dragonbone boko club and a dragonbone boko shield
  - bludgeon deals 5 damage
- **Silver Moblin**
  - equipped with knight's halberd
  - stab deals 10 damage
  - kick deals 3 damage
- **Silver Lizalflos**
  - equipped with a tri-boomerang
  - throw boomerang deals 7 damage

To seamlessly incorporate these harder monsters in your system, you need to create an abstract factory for each dungeon difficulty. There are now three variants for each monster. For every variant, there is a factory that spawns new instances of each monster. **Complete the system using the abstract factory pattern.**

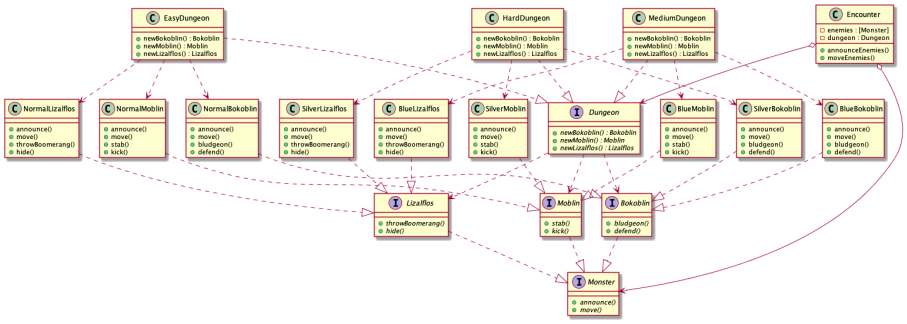


Figure 27.1: abstract factory example

Assessment Criteria

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 10 (Fraction Calculator)

Task

You're creating a less sophisticated version of a fraction calculator. This calculator only has arithmetic operations inside it, addition, subtraction, division, and multiplication. Inside this calculator, a calculation is represented in a `Calculation` instance. Every calculation has four parts:

- `__left` - represents the left operand fraction
- `__right` - represents the right operand fraction
- `__operation` - represents the operation (+,−,×,÷)
- `__answer` - represents the solution of the operation

```
class Fraction:
    def __init__(self,num:int,denom:int):
        self.__num = num
```

```
        self.__denom = denom
    def num(self):
        return self.__num
    def denom(self):
        return self.__denom
    def __str__(self) -> str:
        return str(self.__num) + "/" + str(self.__denom)

class Calculation:
    def __init__-
    ↪  (self,left:Fraction,right:Fraction,operation:Operation):
    ↪  #will cause an error when ran since Operation does not
    ↪  exist yet
        self.__left = left
        self.__right = right
        self.__operation = operation #the parameter that
        ↪  represents the operation
        self.__answer = None #the answer should be calculated
        ↪  here

    def __str__(self):
        return str(self.__left) + " " + str(self.__operation) + "
        ↪  " + str(self.__right) + " = " + str(self.__answer)


f:Fraction = Fraction(1,4)
print(f)
```

Python does indeed support higher order functions but your boss is anti-functional programming so he forbids the use these features. Because of this you decide to implement the strategy pattern.

To do this, you need to create an abstraction called `Operation` to represent the different operations. For each operation, you create a class that realizes `Operation`.

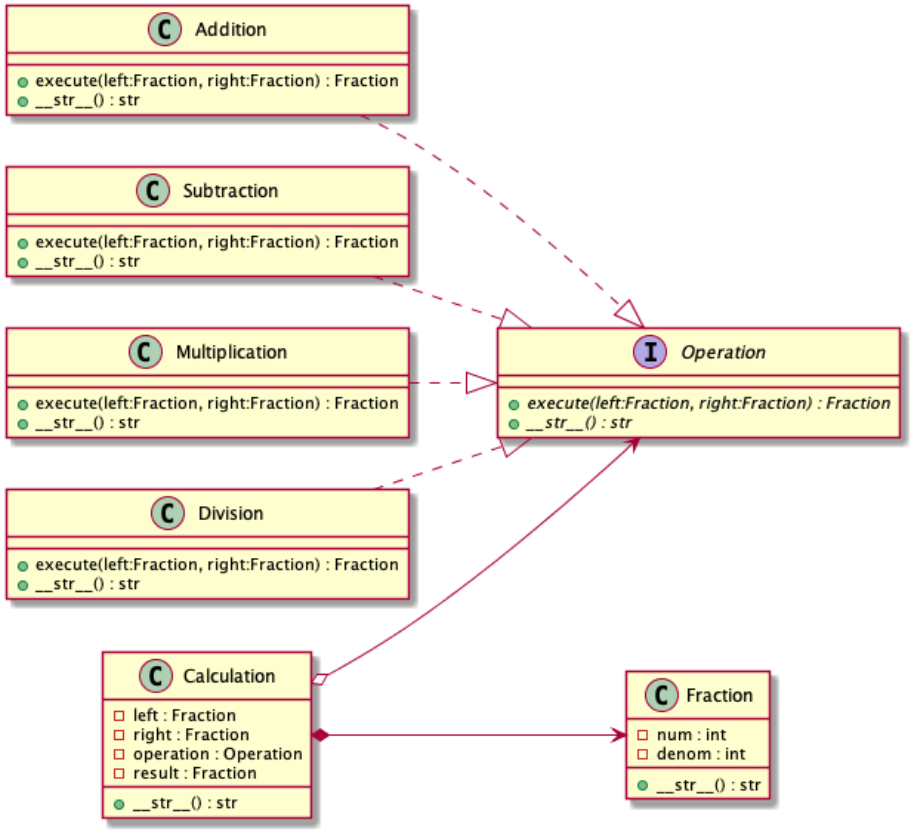


Figure 28.1: strategy pattern example

> *`execute()` should have been named like a builder method (something like `solution()`), I'm keeping the name `execute()` since this is how Strategy patterns usually names this particular method.*

Complete the system using the strategy pattern.

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 11 (States of Matter)

Task

The state of any given matter is dependent on the pressure and temperature of its environment. If you heat up some liquid enough it will turn to gas, if you compress it enough it will become solid.

```
class Matter:
    def __init__(self,name:str):
        self.__name = name
        self.__state = None #change this to the appropriate
        ↪  initial state (liquid)
    def changeState(self,newState):
        pass
    def compress(self):
        pass
    def release(self):
```

```
        pass
    def cool(self):
        pass
    def heat(self):
        pass
    def __str__(self):
        return "%s is currently a %s" %
        ↪  (self.__name,self.__state) #formatting strings just
        ↪  like you format strings in C
```

You are to build a less sophisticated version of this model in code. Matter comes in three states, solid, liquid, and gas. The state of the matter may change if you put/remove pressure on it or heat/cool it.

The state diagram would look something like this:

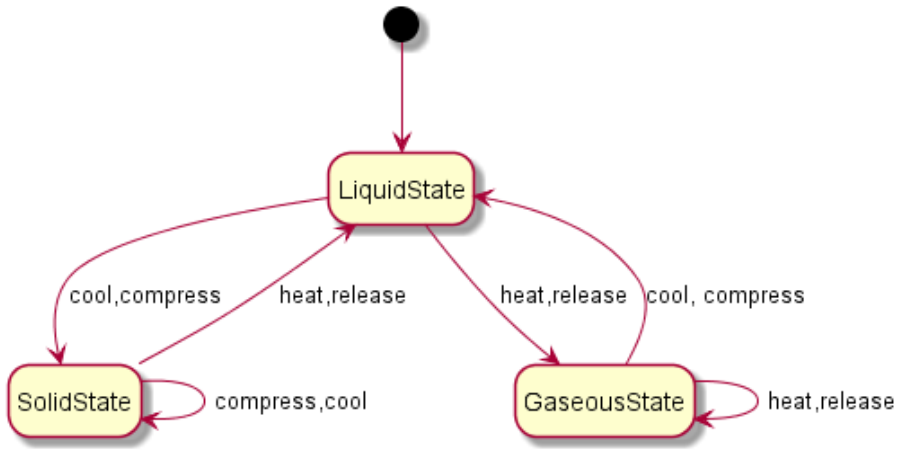


Figure 29.1: state diagram example

To implement something like this, you would need to create matter which owns an attribute called **state** which represents the matter's current state. Since there are three states, you create three realizations to a common abstraction to state.

When you compress/release/cool/heat the matter, you delegate the appropriate behavior and state change inside **state**'s version of that. Each **State** realization will need a backreference to the **Matter** that owns it so that it can change it's state.

> *Delegating behavior to the composed state means that, when the* ***Matter*** *instances invoke,* ***compress()***, ***relaease()*** ***heat()***, *and* ***cool()***, *the composed* ***State*** *owned by the matter calls its own version of* ***compress()***, ***relaease()*** ***heat()***, *and* ***cool()***.

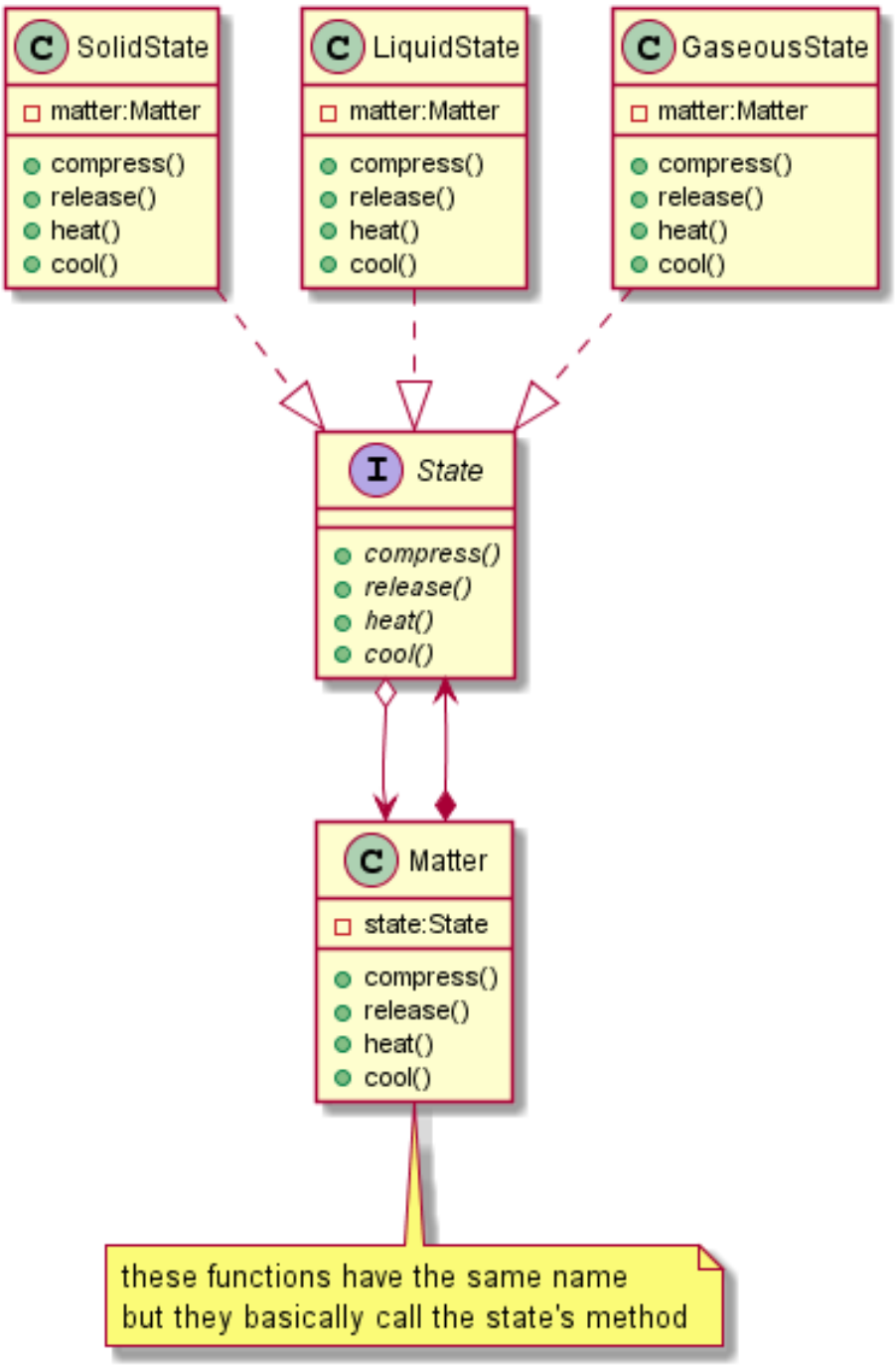


Figure 29.2: state example

Matter owns an instance of ***`State`****, and that instance has an attribute called* ***`matter`****. The attribute* ***`matter`*** *is the reference to the instance of* ***`Matter`*** *that owns it. The* ***`State`*** *instance needs this reference so that it can change the matter's state when it is compressed, released, heated, or cooled.*

Complete the system using the state pattern.

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 12 (Zooming through a Maze)

Task

You're creating a maze navigation game thing. This is what the application currently has right now:

- `Board` - this represents the layout of the maze. The layout is loaded from a file. It has these attributes:
  - `__isSolid` - this is a 2 dimensional grid encoded as a nested list of booleans which represents the solid boundaries of the maze. For example if `__isSolid[row][col]` is true then it means that that cell on (row,col) is a boundary
  - `__start` - a tuple of two integers that represent where the character starts
  - `__end` - tuple of two integers that represent the position of the end of the maze

- `__cLoc` - tuple of two integers that represents the current location of the character
- `moveUp()`, `moveDown()`, `moveLeft()`, `moveRight()` - moves the character one space, in the respective direction. The character cannot move to a boundary cell, it will raise an error instead.
- `canMoveUp()`, `canMoveDown()`, `canMoveLeft()`, `canMoveRight()` - returns true if the cell in the respective direction is not solid.
- `__str()__` string representation of the board. It shows which are the boundaries and the character location

Board

```
class BoundaryCollisionError(Exception):
    def __init__(self,point):
        self.collidingBoundary = point

class Board:
    def __init__(self,filename:str="boardFile.py"):
        self.__isSolid = []
        with open(filename,"r") as f:
            self.__start = tuple(map(int,f.readline().split()))
            self.__end = tuple(map(int,f.readline().split()))
            rawcontents = f.readlines()

            for line in rawcontents:
                self.__isSolid.append(list(map((lambda x:
                ↪  x=="#"), line[:-1])))

        self.__cLoc = self.__start



    def characterLocation(self):
        return self.__cLoc

    def moveRight(self):
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row][col+1]:
                raise BoundaryCollisionError((row,col+1))
            else:
                self.__cLoc = (row,col+1)
        except IndexError:
```

```
            raise BoundaryCollisionError((row,col+1))

    def moveDown(self):
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row+1][col]:
                raise BoundaryCollisionError((row+1,col))
            else:
                self.__cLoc = (row+1,col)
        except IndexError:
            raise BoundaryCollisionError((row+1,col))

    def moveUp(self):
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row-1][col]:
                raise BoundaryCollisionError((row-1,col))
            else:
                self.__cLoc = (row-1,col)
        except IndexError:
            raise BoundaryCollisionError((row-1,col))

    def moveLeft(self):
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row][col-1]:
                raise BoundaryCollisionError((row,col-1))
            else:
                self.__cLoc = (row,col-1)
        except IndexError:
            raise BoundaryCollisionError((row,col-1))

    def canMoveUp(self) -> bool:
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row-1][col]:
                return False
            else:
                return True
        except IndexError:
            return False
```

```
    def canMoveDown(self) -> bool:
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row+1][col]:
                return False
            else:
                return True
        except IndexError:
            return False

    def canMoveRight(self) -> bool:
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row][col+1]:
                return False
            else:
                return True
        except IndexError:
            return False

    def canMoveLeft(self) -> bool:
        (row,col) = self.__cLoc
        try:
            if self.__isSolid[row][col-1]:
                return False
            else:
                return True
        except IndexError:
            return False


    def __str__(self):
        mapString = ""
        for row in range(len(self.__isSolid)):
            for col in range(len(self.__isSolid[0])):
                if ((row,col) == self.__start or (row,col) ==
                ↪  self.__end) and (row,col) != self.__cLoc:
                    mapString += "o"
                elif (row,col) == self.__cLoc:
                    mapString += "+"
                elif self.__isSolid[row][col]:
                    mapString += "#"
```

```
                else:
                    mapString += "."
            mapString += "\n"
        return mapString

    def teleportCharacter(self,newLocation):
        (row,col) = newLocation
        if self.__isSolid[row][col]:
            raise BoundaryCollisionError((row,col))
        else:
            self.__cLoc = newLocation



#to test if board works, uncomment the following
#b = Board("boardfile.in")
#print(b)
#b.moveRight()
#print(b)
```

Controller

```
from board import Board
from commands import
↪  DashUpCommand,DashLeftCommand,DashDownCommand,DashRightCommand

class Controller:
    def __init__(self,board:Board):
        self.__board = board
        self.__commandHistory = []

    def pressUp(self):
        command = DashUpCommand(self.__board)
        self.__commandHistory.append(command)
        command.execute()

    def pressDown(self):
        command = DashDownCommand(self.__board)
        self.__commandHistory.append(command)
        command.execute()

    def pressLeft(self):
```

```
        command = DashLeftCommand(self.__board)
        self.__commandHistory.append(command)
        command.execute()

    def pressRight(self):
        command = DashRightCommand(self.__board)
        self.__commandHistory.append(command)
        command.execute()

    def undo(self):
        undoneCommand = self.__commandHistory.pop()
        undoneCommand.undo()



b = Board("boardFile.in")
c = Controller(b)
print(b)
c.pressRight()
print(b)
c.pressDown()
print(b)
```

What's missing right now is controller support. This is how a player controls the character on the maze:

- `dpad_up()`, `dpad_down()`, `dpad_left()`, `dpad_right()` - The character dashes through the maze in the specified direction until it hits a boundary.
- `a_button()` - The character undoes the previous action it did.

To implement controller support you need to create a **`Command`** abstraction which is realized by all controller commands. The **`Controller`** (which represents the controller) is the invoker for the commands. Since commands are undoable, this controller needs to keep a command history, represented as a list. Every time a controller button is pressed, it creates the appropriate **`Command`**, executes it and appends it to the command history. Every time the **`a_button()`** is pressed to undo, the controller pops the last command from the command history and undoes it.

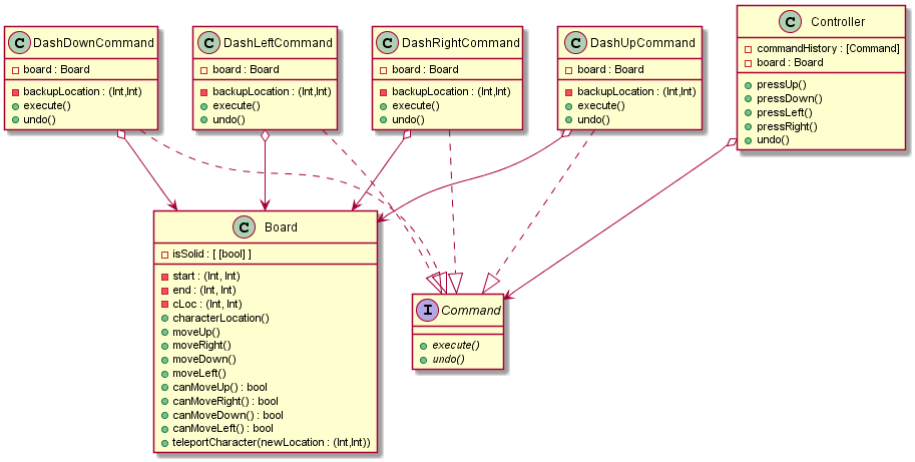


Figure 30.1: command example

Complete the system using the command pattern

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 13 (Weather Notifier)

Task

You are creating a push notification system that works for multiple platforms. You want to distribute information about the current weather and news headlines. This system will be potentially used on many platforms so you have to think about the maintainability issues for adding new platform support.

```
class Headline:
    def __init__(self, headline:str, details:str, source:str):
        self.__headline = headline
        self.__details = details
        self.__source = source

    def __str__(self) -> str:
        return "%s(%s)\n%s" % (self.__headline, self.__source,
        ↪  self.__source)
```

```
class Weather:
    def __init__(self, temp:float, humidity:float, outlook:str):
        self.__temp = temp
        self.__humidity = humidity
        self.__outlook = outlook

    def __str__(self) -> str:
        return "%s: %.1fC %.1f" % (self.__outlook, self.__temp,
        ↪  self.__humidity)


h = Headline("Dalai Lama Triumphantly Names Successor After
↪  Discovering Woman With 'The Purpose Of Our Lives Is To Be
↪  Happy' Twitter Bio","Details","The Onion")
w = Weather(25.0,0.7,"Cloudy")
print(h)
print(w)
```

To implement this, you have to apply the observer pattern. Your subject would be **Weather** data and **Headline** data (which are their own classes). These subjects should be encapsulated into a single publisher class (which will be called **PushNotifier**).

Any platform, that is interested in the changes to the subject should realize a **Subscriber** abstraction (Observer), which contains the abstract method update().

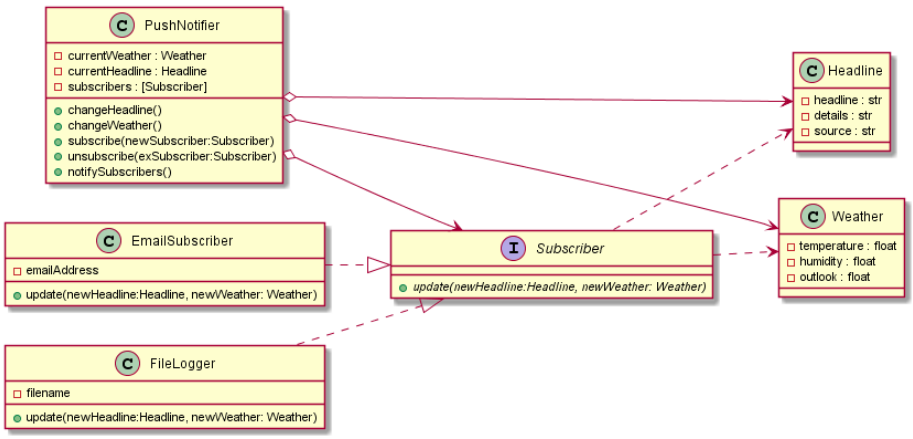


Figure 31.1: observer example

Complete the system using the observer pattern.

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 14 (Brute Force Search)

Task

If you write brute force algorithms as search problems, they will have a common recipe. This is the reason why it is called the exhaustive search algorithm. It will traverse all of the elements in the search space, trying to check the validity of each element, until it completes the solution

Equality Search

Search for integers equal to the target

```
#searchSpace = [2,3,1,0,6,2,4]
#target = 2

i = 0
solutions = []
candidate = searchSpace[0]
```

```
while(i<len(searchSpace)):
    if candidate == target:
        solutions.append(candidate)
    candidate = searchSpace[++i]

#solution = [2,2]
```

Divisibility Search

Search for integers divisible by the target

```
#searchSpace = [2,3,1,0,6,2,4]
#target = 2

i = 0
solutions = []
candidate = searchSpace[0]
while(i<len(searchSpace)):
    if candidate % target == 0:
        solution.append(candidate)
    candidate = searchSpace[++i]

#solution = [2,0,6,2,4]
```

Minimum Search

No target, searches for the smallest integer

```
#searchSpace = [2,3,1,0,6,2,4]
#target = None

i = 1
solutions = [searchSpace[0]]
candidate = searchSpace[1]
while(i<len(searchSpace)):
    if candidate <= solutions[0]
        solutions[0] = candidate
    candidate = searchSpace[++i]

#solution = [0]
```

Common Recipe

```
i = 0
solutions = []
candidate = first()
while(isStillSearching()):
    if valid(candidate):
        updateSolution(candidate)
    candidate = next()
```

Because of this we can write a general brute force template method that would return the solution to brute force problems. To do this you create a superclass `SearchAlgorithm()` that contains the template method for brute force algorithms. If you want to customize this algorithm for special problems, all you have to do is to inherit from `SearchAlgorithm` and override only the necessary steps.

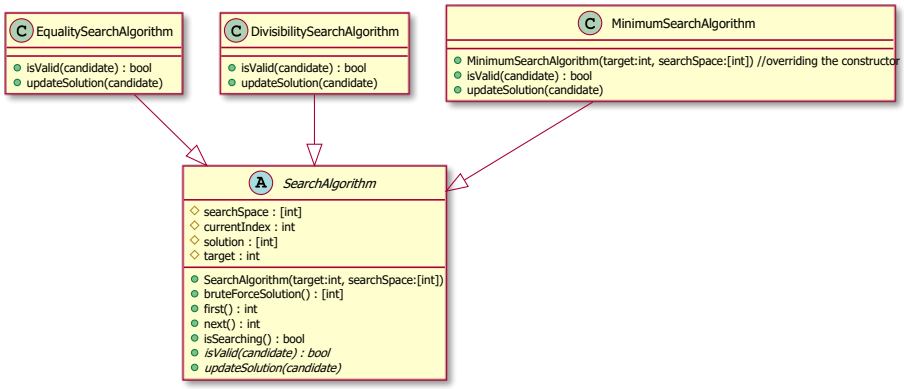


Figure 32.1: template example

```
class SearchAlgorithm(ABC):
    def __init__(self, target:int, searchSpace:[int]):
        self._searchSpace = searchSpace
        self._currentIndex = 0
        self._solutions = []
        self._target = target

    def bruteForceSolution(self):
        candidate = self.first()
        while(self.isSearching()):
            if self.isValid(candidate):
                self.updateSolution(candidate)
            candidate = self.next()
        return self._solutions
```

```
    def first(self) -> int:
        return self._searchSpace[0]

    def next(self) -> int:
        self._currentIndex += 1
        if self.isSearching():
            return self._searchSpace[self._currentIndex]

    def isSearching(self) -> bool:
        return self._currentIndex < len(self._searchSpace)

    @abstractmethod
    def isValid(self, candidate) -> bool:
        pass

    @abstractmethod
    def updateSolution(self, candidate):
        pass
```

*is **`isValid()`** and **`updateSolution(candidate)`** is different for each algorithm so it doesn't have a default implementation. It would be best to make these steps abstract.*

Complete this system using the template pattern

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 15 (Iterator Pattern)

Task

For non built-in collections, you can create an iterator that does the traversal for you. On the bare minimum these iterators will realize some `Iterator` abstraction that contains the methods, `next()`, and `hasNext()`. From these methods alone you can easily perform complete traversals without knowing the exact type of the collection:

```
i = collection.newIterator()
while i.hasNext():
        print(i.next())
```

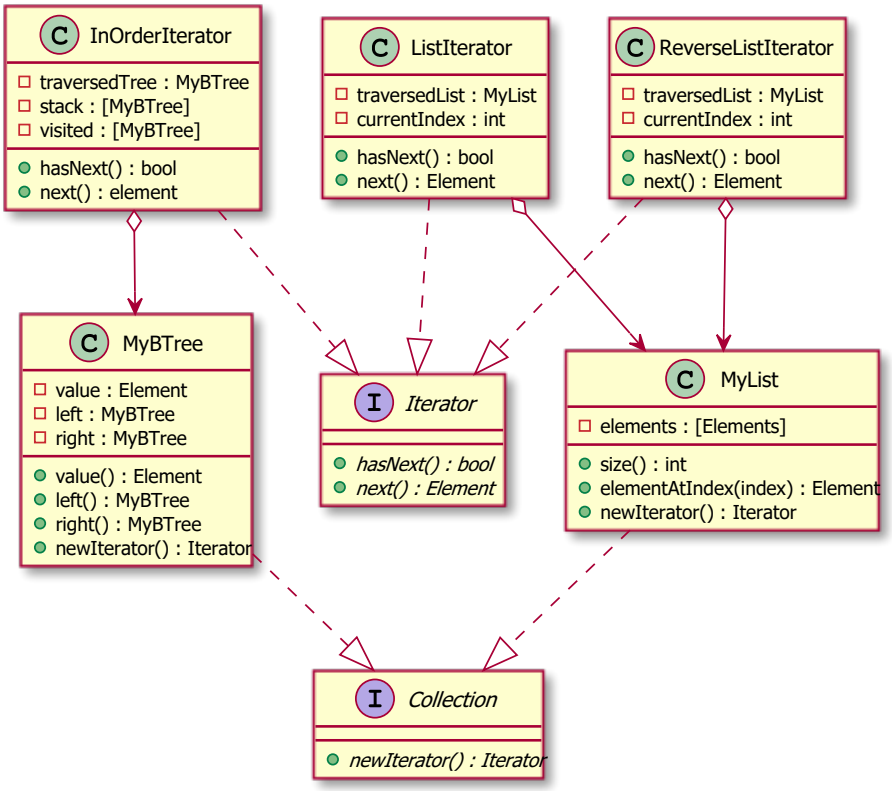


Figure 33.1: iterator

```
from abc import ABC,abstractmethod

class Iterator(ABC):
    @abstractmethod
    def next(self):
        pass

    @abstractmethod
    def hasNext(self):
        pass

class Collection(ABC):
    @abstractmethod
    def newIterator(self):
        pass

class MyList(Collection):
    def __init__(self, elements):
        self.__elements = elements
```

```
    def size(self):
        return len(self.__elements)

    def elementAtIndex(self,index):
        return self.__elements[index]

    def newIterator(self):
        return ListIterator(self)

class ListIterator(Iterator):
    def __init__(self, list):
        self.__traversedList = list
        self.__currentIndex = 0

    def next(self):
        self.__currentIndex += 1
        return self.__traversedList.elementAtIndex(self.__-
        ↪  currentIndex-1)

    def hasNext(self):
        return self.__currentIndex < self.__traversedList.size()

#OPTIONAL
"""
class MyBTree(Collection):
    def __init__(self,value:int,left:'MyBTree' =
↪   None,right:'MyBTree' = None):
        self.__value = value
        self.__left = left
        self.__right = right

    def left(self):
        return self.__left

    def right(self):
        return self.__right

    def value(self):
        return self.__value

    def newIterator(self):
```

```
        return InOrderIterator(self)
"""


c:Collection = MyList([1,2,3,4])
iter:Iterator = c.newIterator()

while(iter.hasNext()):
    print(iter.next())
```

The **hasNext()** method, returns a boolean value that indicates whether or not there are more elements to be traversed. The **next()** method, returns the next element in the traversal.

A collection can have more than one **Iterator**s, if it makes sense for the collection to be travsersed in more than one way. Despite this possibility, a collection must have a default iterator which will be the type of the new instance returned in the factory method, **newIterator()**

> *Note: **MyBTree** and its iterator is optional*

Complete the system using the iterator pattern

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 16 (Formatted Sentence)

Task

A sentence can be defined as a list of words (words are strings). The string representation of a sentence is the concatenation of all of the words in the list, separated by a space.

```
from abc import ABC,abstractmethod

class Sentence:
    def __init__(self,words:[str]):
        self.__words = words

    def __str__(self) -> str:
        sentenceString = ""
        for word in self.__words:
```

```
            sentenceString += word + " "
        return sentenceString[:-1]
```

Instances of sentences can be printed with formatting:

- **bordered** - Given the sentence, `["hey","there"]` it prints:

  ```
  ------------
  |hey there|
  ------------
  ```

- **fancy** - Given the sentence, `["hey","there"]` it prints:

  ```
  -+hey there+-
  ```

- **uppercase** - Given the sentence, `["hey","there"]` it prints:

  ```
  HEY THERE
  ```

The formatting of a sentence is decided during runtime. These formats should also allow for combinations with other formats:

- **bordered fancy** - Given the sentence, `["hey","there"]` it prints:

  ```
  ----------------
  |-+hey there+-|
  ----------------
  ```

- **fancy uppercase** - Given the sentence, `["hey","there"]` it prints:

  ```
  -+HEY THERE+-
  ```

To accomplish these features, you need to implement the decorator pattern. Each formatting will be a decorator for `Sentence` objects. These formats need to inherit from some abstract `FormattedSentence` class. This abstract class is specified to compose and inherit from sentence. The behavior that needs to be decorated is the `__str__()` function since you need to change how sentence is printed for every format.

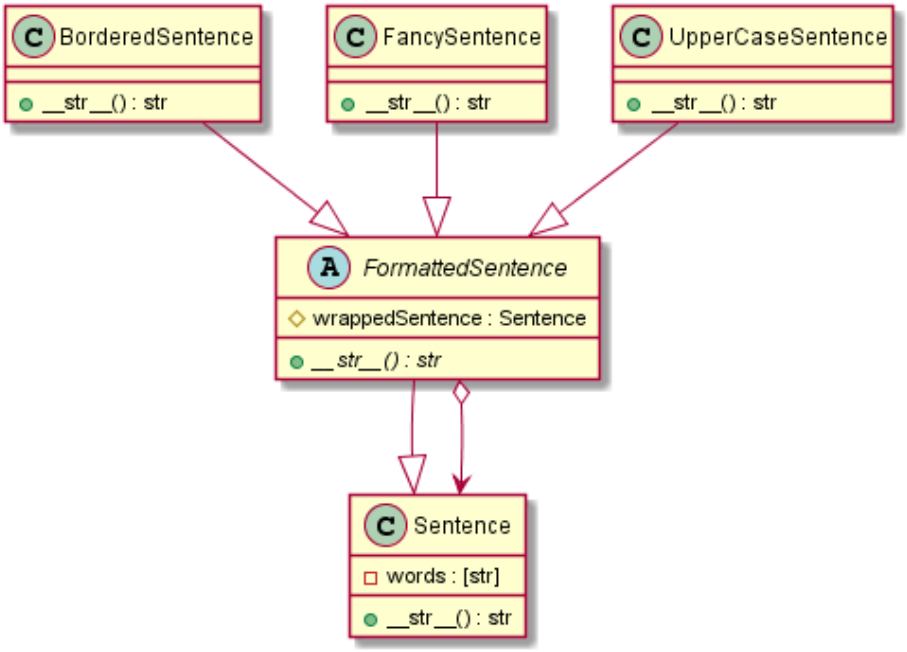


Figure 34.1: decorator example

Complete the system using the decorator pattern

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Lab Exercise 17 (Printable Shipment)

Task

Looking back at our previous lab exercises, some of the example classes contain string representation but do not implement the `__str__()` function. An example of this is `Shipment` back from the factory method example. It does contain a string representation builder called `shipmentDetails()`, but printing a shipment is quite tedious since you have to print, `s.shipmentDetails()`. You can replace the name of `shipmentDetails()` to `__str__()` but this will potentially affect other clients of shipment. You can add the `__str__()` function which does exactly the same but this may introduce unwanted code duplication.

```
from abc import ABC,abstractmethod
from datetime import date,timedelta

class Delivery(ABC):
    @abstractmethod
```

```
    def deliveryDetails(self) -> str:
        pass
    @abstractmethod
    def deliveryFee(self) -> float:
        pass
    @abstractmethod
    def estimatedDeliveryDate(self,processDate:date) -> float:
        pass
    @abstractmethod
    def changeDeliveryStatus(self,newStatus:str):
        pass


class Order:
    def __init__(self,productName:str, productPrice:float):
        self.__productName = productName
        self.__productPrice = productPrice
    def orderString(self) -> str:
        return "%s P%.2f" %
        ↪  (self.__productName,self.__productPrice)
    def price(self) -> float:
        return self.__productPrice
class StandardDelivery(Delivery):
    def __init__(self,location:str):
        self.__location = location
        self.__deliveryStatus = "Processing"
    def deliveryDetails(self) -> str:
        r = "STANDARD DELIVERY\nDELIVER TO:%s\nDELIVERY STATUS:
↪  %s\nDELIVERY FEE: P%.2f" %
↪  (self.__location,self.__deliveryStatus,self.deliveryFee())
        return r
    def deliveryFee(self) -> float:
        return 500
    def estimatedDeliveryDate(self,processDate:date) -> float:
        return processDate + timedelta(days = 7)
    def changeDeliveryStatus(self,newStatus:str):
        self.__deliveryStatus = newStatus

class Shipment:
    def __init__(self, orderList:[Order], processDate: date,
    ↪  location):
        self._orderList = orderList
```

```
        self._processDate = processDate
        self._delivery = self.delivery(location)

    def delivery(self,location:str) -> Delivery:
        return StandardDelivery(location)

    def totalPrice(self) -> str:
        t = 0.0
        for order in self._orderList:
            t+=order.price()
        return t

    def shipmentDetails(self) -> str:
        r = "ORDERS:" + str(self._processDate) + "\n"
        for order in self._orderList:
            r += order.orderString() + "\n"
        r += "\n"
        r += "TOTAL PRICE OF ORDERS: P"  + str(self.totalPrice())
↪   + "\n"
        r += self._delivery.deliveryDetails() + "\n\n"
        r += "PRICE WITH DELIVERY FEE : P" +
↪   str(self.totalPrice()+self._delivery.deliveryFee()) + "\n"
        r += "ESTIMATED DELIVERY DATE: " +
↪   str(self._delivery.estimatedDeliveryDate(self._processDate))
        return r


class ExpressDelivery(Delivery):
    def __init__(self,location:str):
        self.__location = location
        self.__deliveryStatus = "Processing"
    def deliveryDetails(self) -> str:
        r = "EXPRESS DELIVERY\nDELIVER TO:%s\nDELIVERY STATUS:
↪   %s\nDELIVERY FEE: P%.2f" %
↪   (self.__location,self.__deliveryStatus,self.deliveryFee())
        return r
    def deliveryFee(self) -> float:
        return 1000
    def estimatedDeliveryDate(self,processDate:date) -> float:
        return processDate + timedelta(days = 2)
    def changeDeliveryStatus(self,newStatus):
        self.__deliveryStatus = newStatus
```

```
class ExpressShipment(Shipment):
    def delivery(self,location) -> Delivery:
        return ExpressDelivery(location)
```

The best solution for this problem is to create an adapter for shipment called `PrintableShipment`. This adapter will realize some `Printable` abstraction, which only contains the abstract method `__str__()`.

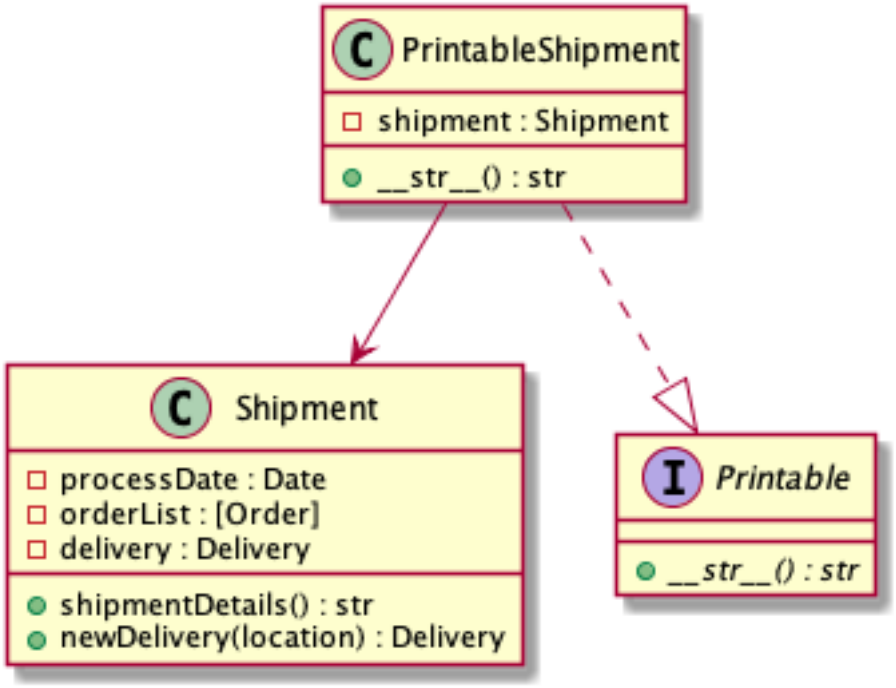


Figure 35.1: adapter example

Complete the system using the adapter pattern

Assessment Criteria

- Completeness of the pattern - 40
- Elegance of method and attribute naming - 10

Deadline November 30, 2020

Word