Software Engineering for Self-Directed Learners

SECTION: SOFTWARE ENGINEERING

Software Engineering

Introduction

Pros and Cons ★★★☆

Software Engineering: Software Engineering is the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software" -- IEEE Standard Glossary of Software Engineering Terminology

The following description of the *Joys of the Programming Craft* was taken from Chapter 1 of the famous book *The Mythical Man-Month*, by Frederick P. Brooks.

> **Why is programming fun? What delights may its practitioner expect as his reward?**
>
> First is the sheer joy of making things. As the child delights in his mud pie, so the adult enjoys building things, especially things of his own design. I think this delight must be an image of God's delight in making things, a delight shown in the distinctness and newness of each leaf and each snowflake.
>
> Second is the pleasure of making things that are useful to other people. Deep within, we want others to use our work and to find it helpful. In this respect the programming system is not essentially different from the child's first clay pencil holder "for Daddy's office."
>
> Third is the fascination of fashioning complex puzzle-like objects of interlocking moving parts and watching them work in subtle cycles, playing out the consequences of principles built in from the beginning. The programmed computer has all the fascination of the pinball machine or the jukebox mechanism, carried to the ultimate.
>
> Fourth is the joy of always learning, which springs from the nonrepeating nature of the task. In one way or another the problem is ever new, and its solver learns something: sometimes practical, sometimes theoretical, and sometimes both.
>
> Finally, there is the delight of working in such a tractable medium. The programmer, like the poet, works only slightly removed from pure thought-stuff. He builds his castles in the air, from air, creating by the exertion of the imagination. Few media of creation are so flexible, so easy to polish and rework, so readily capable of realizing grand conceptual structures....
>
> Yet the program construct, unlike the poet's words, is real in the sense that it moves and works, producing visible outputs separate from the construct itself. It prints results, draws pictures, produces sounds, moves arms. The magic of myth and legend has come true in our time. One types the correct incantation on a keyboard, and a display screen comes to life, showing things that never were nor could be.
>
> Programming then is fun because it gratifies creative longings built deep within us and delights sensibilities we have in common with all men.

Not all is delight, however, and knowing the inherent woes makes it easier to bear them when they appear.

First, one must perform perfectly. The computer resembles the magic of legend in this respect, too. If one character, one pause, of the incantation is not strictly in proper form, the magic doesn't work. Human beings are not accustomed to being perfect, and few areas of human activity demand it. Adjusting to the requirement for perfection is, I think, the most difficult part of learning to program.

Next, other people set one's objectives, provide one's resources, and furnish one's information. One rarely controls the circumstances of his work, or even its goal. In management terms, one's authority is not sufficient for his responsibility. It seems that in all fields, however, the jobs where things get done never have formal authority commensurate with responsibility. In practice, actual (as opposed to formal) authority is acquired from the very momentum of accomplishment.

The dependence upon others has a particular case that is especially painful for the system programmer. He depends upon other people's programs. These are often maldesigned, poorly implemented, incompletely delivered (no source code or test cases), and poorly documented. So he must spend hours studying and fixing things that in an ideal world would be complete, available, and usable.

The next woe is that designing grand concepts is fun; finding nitty little bugs is just work. With any creative activity come dreary hours of tedious, painstaking labor, and programming is no exception.

Next, one finds that debugging has a linear convergence, or worse, where one somehow expects a quadratic sort of approach to the end. So testing drags on and on, the last difficult bugs taking more time to find than the first.

The last woe, and sometimes the last straw, is that the product over which one has labored so long appears to be obsolete upon (or before) completion. Already colleagues and competitors are in hot pursuit of new and better ideas. Already the displacement of one's thought-child is not only conceived, but scheduled.

This always seems worse than it really is. The new and better product is generally not available when one completes his own; it is only talked about. It, too, will require months of development. The real tiger is never a match for the paper one, unless actual use is wanted. Then the virtues of reality have a satisfaction all their own.

Of course the technological base on which one builds is always advancing. As soon as one freezes a design, it becomes obsolete in terms of its concepts. But implementation of real products demands phasing and quantizing. The obsolescence of an implementation must be measured against other existing implementations, not against unrealized concepts. The challenge and the mission are to find real solutions to real problems on actual schedules with available resources.

This then is programming, both a tar pit in which many efforts have floundered and a creative activity with joys and woes all its own. For many, the joys far outweigh the woes....

SECTION: PROGRAMMING PARADIGMS

Object-Oriented Programming

Introduction

What 🎓:★☆☆☆

Object-Oriented Programming (OOP) is a *programming paradigm*. A programming paradigm guides programmers to analyze programming problems, and structure programming solutions, in a specific way.

> Programming languages have traditionally divided the world into two parts—data and operations on data. Data is static and immutable, except as the operations may change it. The procedures and functions that operate on data have no lasting state of their own; they're useful only in their ability to affect data.
>
> This division is, of course, grounded in the way computers work, so it's not one that you can easily ignore or push aside. Like the equally pervasive distinctions between matter and energy and between nouns and verbs, it forms the background against which we work. At some point, all programmers—even object-oriented programmers—must lay out the data structures that their programs will use and define the functions that will act on the data.
>
> With a procedural programming language like C, that's about all there is to it. The language may offer various kinds of support for organizing data and functions, but it won't divide the world any differently. Functions and data structures are the basic elements of design.
>
> Object-oriented programming doesn't so much dispute this view of the world as restructure it at a higher level. It groups operations and data into modular units called objects and lets you combine objects into structured networks to form a complete program. In an object-oriented programming language, objects and object interactions are the basic elements of design.
>
> -- Object-Oriented Programming with Objective-C, Apple

Some other examples of programming paradigms are:

Paradigm	Programming Languages
Procedural Programming paradigm	C
Functional Programming paradigm	F#, Haskel, Scala
Logic Programming paradigm	Prolog

Some programming languages support multiple paradigms.

📦 Java is primarily an OOP language but it supports limited forms of functional programming and it can be used to (although not recommended) write procedural code. e.g. se-edu/addressbook-level1

📦 JavaScript and Python support functional, procedural, and OOP programming.

Objects

What 🎓:★★☆☆

> Every object has both state (data) and behavior (operations on data). In that, they're not much different from ordinary physical objects. It's easy to see how a mechanical device, such as a pocket watch or a piano, embodies both state and behavior. But almost anything that's designed to do a job does, too. Even simple things with no moving parts such as an ordinary bottle combine state (how full the bottle is, whether or not it's open, how warm its contents are) with behavior (the ability to dispense its contents at various flow rates, to be opened or closed, to withstand high or low temperatures).
>
> It's this resemblance to real things that gives objects much of their power and appeal. They can not only model components of real systems, but equally as well fulfill assigned roles as components in software systems.
>
> -- Object-Oriented Programming with Objective-C, Apple

Object Oriented Programming (OOP) views the world as *a network of interacting objects*.

📦 A real world scenario viewed as a network of interacting objects:

You are asked to find out the average age of a group of people Adam, Beth, Charlie, and Daisy. You take a piece of paper and pen, go to each person, ask for their age, and note it down. After collecting the age of all four, you enter it into a calculator to find the total. And then, use the same calculator to divide the total by four, to get the average age. This can be viewed as the objects `You`, `Pen`, `Paper`, `Calculator`, `Adam`, `Beth`, `Charlie`, and `Daisy` interacting to accomplish the end result of calculating the average age of the four persons. These objects can be considered as connected in a certain network of certain structure.

OOP solutions try to create a similar object network inside the computer's memory – a sort of a virtual simulation of the corresponding real world scenario – **so that a similar result can be achieved programmatically.**

OOP does not demand that the virtual world object network follow the real world *exactly*.

📦 Our previous example can be tweaked a bit as follows:

- Use an object called `Main` to represent your role in the scenario.
- As there is no physical writing involved, we can replace the `Pen` and `Paper` with an object called `AgeList` that is able to keep a list of ages.

Every object has both state (data) and behavior (operations on data).

Object	Real World?	Virtual World?	Example of State (i.e. Data)	Examples of Behavior (i.e. Operations)
Adam	✔	✔	Name, Date of Birth	Calculate age based on birthday
Pen	✔	-	Ink color, Amount of ink remaining	Write
AgeList	-	✔	Recorded ages	Give the number of entries, Accept an entry to record
Calculator	✔	✔	Numbers already entered	Calculate the sum, divide
You/Main	✔	✔	Average age, Sum of ages	Use other objects to calculate

Every object has an interface and an implementation.

Every real world object has:

- an interface that other objects can interact with
- an implementation that supports the interface but may not be accessible to the other object

📦 The interface and implementation of some real-world objects in our example:

- Calculator: the buttons and the display are part of the interface; circuits are part of the implementation.
- Adam: In the context of our 'calculate average age' example, the interface of Adam consists of requests that adam will respond to, e.g. "Give age to the nearest year, as at Jan 1st of this year" "State your name"; the implementation includes the mental calculation Adam uses to calculate the age which is not visible to other objects.

Similarly, every object in the virtual world has an interface and an implementation.

📦 The interface and implementation of some virtual-world objects in our example:

- `Adam`: the interface might have a method `getAge(Date asAt)`; the implementation of that method is not visible to other objects.

Objects interact by sending messages.

Both real world and virtual world object interactions can be viewed as objects sending message to each other. The message can result in the sender object receiving a response and/or the receiving object's state being changed. Furthermore, the result can vary based on which object received the message, even if the message is identical (see rows 1 and 2 in the example below).

Examples:

World	Sender	Receiver	Message	Response	State Change
Real	You	Adam	"What is your name?"	"Adam"	-
Real	as above	Beth	as above	"Beth"	-
Real	You	Pen	Put nib on paper and apply pressure	Makes a mark on your paper	Ink level goes down
Virtual	Main	Calculator (current total is 50)	add(int i): int i = 23	73	total = total + 23

Objects as Abstractions :★★☆☆

The concept of ***Objects* in OOP is an abstraction mechanism because it allows us to abstract away the lower level details and work with bigger granularity entities** i.e. ignore details of data formats and the method implementation details and work at the level of objects.

📦 We can deal with a `Person` object that represents the person Adam and query the object for Adam's age instead of dealing with details such as Adam's date of birth (DoB), in what format the DoB is stored, the algorithm used to calculate the age from the DoB, etc.

Encapsulation Of Objects :★★☆☆

> Encapsulation protects an implementation from unintended actions and from inadvertent access.
>
> -- Object-Oriented Programming with Objective-C, Apple

An object is an *encapsulation* of some data and related behavior in two aspects:

1. The *packaging* aspect: An object packages data and related behavior together into one self-contained unit.

2. The *information hiding* aspect: The data in an object is hidden from the outside world and are only accessible using the object's interface.

Classes

What :★☆☆☆

Writing an OOP program is essentially writing instructions that the computer uses to,

1. **create the virtual world of object network, and**
2. **provide it the inputs to produce the outcome we want.**

A *class* contains instructions for creating a specific kind of objects. It turns out sometimes multiple objects have the same behavior because they are of the *same kind*. Instructions for creating a one kind (or 'class') of objects can be done once and that same instructions can be used to *instantiate* objects of that kind. We call such instructions a *Class*.

📦 Classes and objects in an example scenario

Consider the example of writing an OOP program to calculate the average age of Adam, Beth, Charlie, and Daisy.

Instructions for creating objects `Adam`, `Beth`, `Charlie`, and `Daisy` will be very similar because they are all of the same kind : they all represent 'persons' with the same interface, the same kind of data (i.e. `name`, `DoB`, etc.), and the same kind of behavior (i.e. `getAge(Date)`, `getName()`, etc.). Therefore, we can have a class called `Person` containing instructions on how to create `Person` objects and use that class to instantiate objects `Adam`, `Beth`, `Charlie`, and `Daisy`.

Similarly, we need classes `AgeList`, `Calculator`, and `Main` classes to instantiate one each of `AgeList`, `Calculator`, and `Main` objects.

Class	Objects
`Person`	objects representing Adam, Beth, Charlie, Daisy
`AgeList`	an object to represent the age list
`Calculator`	an object to do the calculations
`Main`	an object to represent you who manages the whole operation

Class Level Members 🎓:★★☆☆

While all objects of a class has the same attributes, each object has its own copy of the attribute value.

> 📦 All `Person` objects have the `Name` attribute but the value of that attribute varies between `Person` objects.

However, some attributes are not suitable to be maintained by individual objects. Instead, they should be maintained centrally, shared by all objects of the class. They are like 'global variables' but attached to a specific class. Such **variables whose value is shared by all instances of a class are called *class-level attributes***.

> 📦 The attribute `totalPersons` should be maintained centrally and shared by all `Person` objects rather than copied at each `Person` object.

Similarly, when a normal method is being called, a message is being sent to the receiving object and the result may depend on the receiving object.

> 📦 Sending the `getName()` message to `Adam` object results in the response `"Adam"` while sending the same message to the `Beth` object gets the response `"Beth"`.

However, there can be methods related to a specific class but not suitable for sending message to a specific object of that class. Such **methods that are called using the class instead of a specific instance are called *class-level methods***.

> 📦 The method `getTotalPersons()` is not suitable to send to a specific `Person` object because a specific object of the `Person` class should not know about the total number of `Person` objects.

Class-level attributes and methods are collectively called *class-level members* (also called *static members* sometimes because some programming languages use the keyword `static` to identify class-level members). **They are to be accessed using the class name rather than an instance of the class**.

Enumerations 🎓:★★☆☆

An *Enumeration* is a fixed set of values that can be considered as a data type. An enumeration is often useful when using a regular data type such as `int` or `String` would allow invalid values to be assigned to a variable. **You are recommended to enumeration types any time you need to represent a fixed set of constants.**

> 📦 Suppose you want a variable to store the priority of something. There are only three priority levels: high, medium, and low. You can declare the variable as of type `int` and use only values `2`, `1`, and `0` to indication the three priority levels. However, this opens the possibility of an invalid values such as `9` to be assigned to it. But if you define an enumeration type called `Priority` that has three values `HIGH`, `MEDIUM`, `LOW` only, a variable of type `Priority` will never be assigned an invalid value because the compiler is able to catch such an error.
>
> `Priority`: `HIGH`, `MEDIUM`, `LOW`

Associations

What ★☆☆☆

Objects in an OO solution need to be connected to each other to form a network so that they can interact with each other. Such **connections between objects are called *associations*.**

> 📦 Suppose an OOP program for managing a learning management system creates an object structure to represent the related objects. In that object structure we can expect to have associations between a`Course` object that represents a specific course and `Student` objects that represents students taking that course.

Associations in an object structure can change over time.

> 📦 To continue the previous example, the associations between a `Course` object and `Student` objects can change as students enroll in the module or drop the module over time.

Associations among objects can be generalized as associations between the corresponding classles too.

> 📦 In our example, as some `Course` objects can have associations with some `Student` objects, we can view it as an association between the `Course` class and the `Student` class.

Implementing associations

We use instance level variables to implement associations.

Navigability ★★☆☆

When two classes are linked by an association, it does not necessarily mean both classes know about each other. **The concept of which class in the association knows about the other class is called *navigability*.**

Multiplicity ★★☆☆

***Multiplicity* is the aspect of an OOP solution that dictates how many objects take part in each association.**

> 📦 The navigability of the association between `Course` objects and `Student` objects tells you how many `Course` objects can be associated with one `Student` object and vice versa.

Implementing multiplicity

A normal instance-level variable gives us a `0..1` multiplicity (also called *optional associations*) because a variable can hold a reference to a single object or `null`.

> 📦 In the code below, the `Logic` class has a variable that can hold `0..1` i.e., zero or one `Minefield` objects.

```
class Logic{
    Minefield minefield;
}

class Minefield{
    ...
}
```

A variable can be used to implement a `1` multiplicity too (also called *compulsory associations*).

> 📦 In the code below, the `Logic` class will always have a `ConfigGenerator` object, provided the variable is not set to null at some point.

```
class Logic {
    ConfigGenerator cg = new ConfigGenerator();
    ...
}
```

Bi-directional associations require matching variables in both classes.

📦 In the code below, the `Foo` class has a variable to hold a `Bar` object and vice versa i.e., each object can have an association with an object of the other type.

```
class Foo {
    Bar bar;
    //...
}

class Bar {
    Foo foo;
    //...
}
```

To implement other multiplicities, choose a suitable data structure such as Arrays, ArrayLists, HashMaps, Sets, etc.

```
class Minefield {
    Cell[][] cell;
    ...
}
```

Dependencies ★★★☆

In the context of OOP associations, **a *dependency* is a need for one class to depend on another without having a direction association with it.** One cause of dependencies is interactions between objects that do not have a long-term link between them.

📦 A `Course` object can have a dependency on a `Registrar` object to obtain the maximum number of students it can support.

Implementing dependencies

📦 In the code below, `Foo` has a dependency on `Bar` but it is not an association because it is only a transient interaction and there is no long term relationship between a `Foo` object and a `Bar` object. i.e. the `Foo` object does not keep the `Bar` object it receives as a parameter.

```
class Foo{

    int calculate(Bar bar){
        return bar.getValue();
    }
}

class Bar{
    int value;

    int getValue(){
        return value;
    }
}
```

Composition ★★★☆

A composition is an association that represents a strong *whole-part* relationship. When the *whole* is destroyed, *parts* are destroyed too.

📦 A `Board` (used for playing board games) consists of `Square` objects.

Composition also implies that there cannot be cyclical links.

📦 The 'sub-folder' association between `Folder` objects is a composition type association. That means if the `Folder` object `foo` is a sub folder of `Folder` object `bar`, `bar` cannot be a sub-folder of `foo`.

Implementing composition

Composition is implemented using a normal variable. If correctly implemented, the 'part' object will be deleted when the 'whole' object is deleted. Ideally, the 'part' object may not even be visible to clients of the 'whole' object.

📦 In the code below, the `Email` has a composition type relationship with the `Subject` class, in the sense that the subject is part of the email.

```
class Email {
    private Subject subject;
  ...
}
```

Aggregation ★★★☆

***Aggregation* represents a *container-contained* relationship.** It is a weaker relationship than composition.

📦 `SportsClub` can act as a *container* for `Person` objects who are members of the club. `Person` objects can survive without a `SportsClub` object.

Implementing aggregation

Implementation is similar to that of composition except the *containee* object can exist even after the *container* object is deleted.

📦 In the code below, there is an aggregation association between the `Team` class and the `Person` in that a `Team` contains `Person` a object who is the leader of the team.

```
class Team {
    Person leader;
    ...
    void setLeader(Person p) {
        leader = p;
    }
}
```

Inheritance

What 🎓:★☆☆☆

The OOP concept *Inheritance* allows you to define a new class based on an existing class.

📦 For example, you can use inheritance to define an `EvaluationReport` class based on an existing `Report` class so that the `EvaluationReport` class does not have to duplicate code that is already implemented in the `Report` class. The `EvaluationReport` can inherit the `wordCount` attribute and the `print()` method from the *base class* `Report`.

- Other names for Base class: *Parent* class, *Super* class
- Other names for Derived class: *Child* class, *Sub* class, *Extended* class

A superclass is said to be *more general* than the subclass. Conversely, a subclass is said to be more *specialized* than the superclass.

Applying inheritance on a group of similar classes can result in the common parts among classes being extracted into more general classes.

📦 `Man` and `Woman` behaves the same way for certain things. However, the two classes cannot be simply replaced with a more general class `Person` because of the need to distinguish between `Man` and `Woman` for certain other things. A solution is to add the `Person` class as a superclass (to contain the code common to men and woment) and let `Man` and `Woman` inherit from `Person` class.

Inheritance implies the derived class can be considered as a *sub-type* of the base class (and the base class is a *super-type* of the derived class), resulting in an *is a* relationship.

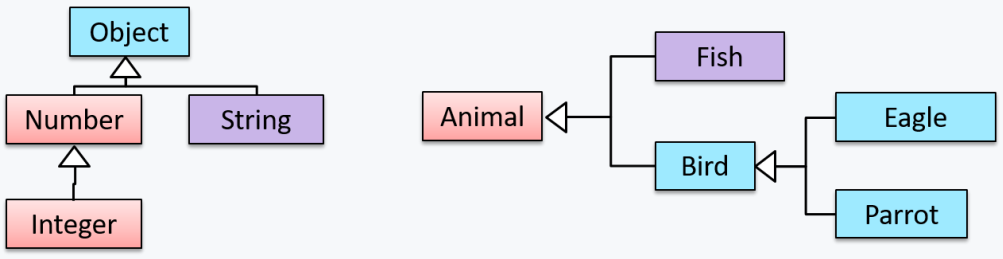
ℹ️ Inheritance does not necessarily mean a sub-type relationship exists. However, the two often go hand-in-hand. For simplicity, at this point let us assume inheritance implies a sub-type relationship.

📦 To continue the previous example,

- `Woman` *is a* `Person`
- `Man` *is a* `Person`

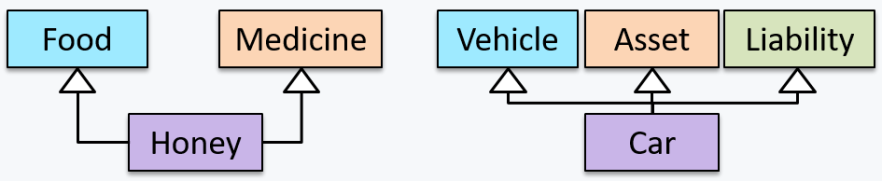
Inheritance relationships through a chain of classes can result in inheritance *hierarchies* (aka inheritance *trees*).

📦 Two inheritance hierarchies/trees are given below. Note that the triangle points to the parent class. Observe how the `Parrot` *is a* `Bird` as well as it *is an* `Animal`.



***Multiple Inheritance* is when a class inherits *directly* from multiple classes.** Multiple inheritance among classes is allowed in some languages (e.g., Python, C++) but not in other languages (e.g., Java, C#).

📦 The `Honey` class inherits from the `Food` class *and* the `Medicine` class because honey can be consumed as a food as well as a medicine (in some oriental medicine practices). Similarly, a `Car` is an `Vehicle`, an `Asset` and a `Liability`.



Overriding 🎓:★★☆☆

Method *overriding* is when a sub-class changes the behavior inherited from the parent class by re-implementing the method. Overridden methods have the same name, same type signature, and same return type.

📦 Consider the following case of `EvaluationReport` class inheriting the `Report` class:

`Report` **methods**	`EvaluationReport` **methods**	**Overrides?**
`print()`	`print()`	Yes
`write(String)`	`write(String)`	Yes
`read():String`	`read(int):String`	No. Reason: the two methods have different signatures; This is a case of *overloading* (rather than overriding).

Overloading 🎓:★★☆☆

Method overloading is when there are multiple methods with the same name but different type signatures. Overloading is used to indicate that multiple operations do similar things but take different parameters.

❗ **Type Signature**: The *type signature* of an operation is the type sequence of the parameters. The return type and parameter names are not part of the type signature. However, the parameter order is significant.

> Examples

📦 In the case below, the `calculate` method is overloaded because the two methods have the same name but different type signatures `(String)` and `(int)`

- `calculate(String): void`
- `calculate(int): void`

Interfaces 🎓:★★★☆

An *interface* is a behavior specification i.e. a collection of method specifications . If a class implements the interface , it means the class is able to support the behaviors specified by the said interface.

> There are a number of situations in software engineering when it is important for disparate groups of programmers to agree to a "contract" that spells out how their software interacts. Each group should be able to write their code without any knowledge of how the other group's code is written. Generally speaking, interfaces are such contracts. --Oracle Docs on Java

📦 Suppose `SalariedStaff` is an interface that contains two methods `setSalary(int)` and `getSalary()`. `AcademicStaff` can declare itself as *implementing* the `SalariedStaff` interface, which means the `AcademicStaff` class must implement all the methods specified by the `SalariedStaff` interface i.e., `setSalary(int)` and `getSalary()`.

A class implementing an interface results in an *is-a* relationship, just like in class inheritance.

📦 In the example above, `AcademicStaff` *is a* `SalariedStaff`. An `AcademicStaff` object can be used anywhere a `SalariedStaff` object is expected e.g. `SalariedStaff ss = new AcademicStaff()`.

Abstract Classes 🎓:★★★☆

🌐 **Abstract Class**: A class declared as an *abstract class* cannot be instantiated, but they can be subclassed.

You can use declare a class as abstract when a class is merely a representation of commonalities among its subclasses in which case it does not make sense to instantiate objects of that class.

📦 The `Animal` class that exist as a generalization of its subclasses `Cat`, `Dog`, `Horse`, `Tiger` etc. can be declared as abstract because it does not make sense to instantiate an `Animal` object.

🌐 **Abstract Method**: An *abstract method* is a method signature without a method implementation.

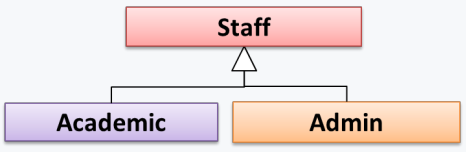
📦 The `move` method of the `Animal` class is likely to be an abstract method as it is not possible to implement a `move` method at the `Animal` class level to fit all subclasses because each animal type can move in a different way.

A class that has an abstract method becomes an abstract class because the class definition is incomplete (due to the missing method body) and it is not possible to create objects using an incomplete class definition.

Evan **a class that does not have any abstract methods *can* be declared as an abstract class.**

Substitutability 🎓:★★★☆

Every instance of a subclass is an instance of the superclass, but not vice-versa. As a result, inheritance allows *substitutability* : the ability to substitute a child class object where a parent class object is expected.



📦 an `Academic` is an instance of a `Staff`, but a `Staff` is not necessarily an instance of an `Academic`. i.e. wherever an object of the superclass is expected, it can be substituted by an object of any of its subclasses.

The following code is valid because an `AcademicStaff` object is substitutable as a `Staff` object.

```
Staff staff = new AcademicStaff (); // OK
```

But the following code is not valid because `staff` is declared as a `Staff` type and therefore its value may or may not be of type `AcademicStaff`, which is the type expected by variable `academicStaff`.

```
Staff staff;
...
AcademicStaff academicStaff = staff; // Not OK
```

Dynamic and Static Binding 🎓:★★★☆

Dynamic Binding (aka late binding) : a mechanism where method calls in code are resolved at runtime , rather than at compile time.

Overridden methods are resolved using dynamic binding, and therefore resolves to the implementation in the actual type of the object.

📦 Consider the code below. The declared type of `s` is `Staff` and it appears as if the `adjustSalary(int)` operation of the `Staff` class is invoked.

```
void adjustSalary(int byPercent) {
    for (Staff s: staff) {
        s.adjustSalary(byPercent);
    }
}
```

However, at runtime s can receive an object of any subclass of `Staff`. That means the `adjustSalary(int)` operation of the actual subclass object will be called. If the subclass does not override that operation, the operation defined in the superclass (in this case, `Staff` class) will be called.

Static binding (aka early binding): When a method call is resolved at compile time.

In contrast, overloaded methods are resolved using static binding.

📦 Note how the constructor is overloaded in the class below. The method call `new Account()` is bound to the first constructor at compile time.

```
class Account {

    Account () {
        // Signature: ()
        ...
    }

    Account (String name, String number, double balance) {
        // Signature: (String, String, double)
        ...
    }
}
```

📦 Similarly, the `calcuateGrade` method is overloaded in the code below and a method call `calculateGrade("A1213232")` is bound to the second implementation, at compile time.

```
void calculateGrade (int[] averages) { ... }
void calculateGrade (String matric) { ... }
```

Polymorphism

What :★★★☆

Polymorphism:

> The ability of different objects to respond, each in its own way, to identical messages is called polymorphism. -- Object-Oriented Programming with Objective-C, Apple

***Polymorphism* allows you to write code targeting superclass objects, use that code on subclass objects, and achieve possibly different results based on the actual class of the object.**

Assume classes `Cat` and `Dog` are both subclasses of the `Animal` class. You can write code targeting `Animal` objects and use that code on `Cat` and `Dog` objects, achieving possibly different results based on whether it is a `Cat` object or a `Dog` object. Some examples:

- Declare an array of type `Animal` and still be able to store `Dog` and `Cat` objects in it.
- Define a method that takes an `Animal` object as a parameter and yet be able to pass `Dog` and `Cat` objects to it.
- Call a method on a `Dog` or a `Cat` object as if it is an `Animal` object (i.e., without knowing whether it is a `Dog` object or a `Cat` object) and get a different response from it based on its actual class e.g., call the `Animal` class' method `speak()` on object `a` and get a `Meow` as the return value if `a` is a `Cat` object and `Woof` if it is a `Dog` object.

Polymorphism literally means "ability to take many forms".

How :★★★☆

Three concepts combine to achieve polymorphism: *substitutability, operation overriding, and dynamic binding*.

- **Substitutability:** Because of substitutability, you can write code that expects object of a parent class and yet use that code with objects of child classes. That is how polymorphism is able to *treat objects of different types as one type*.
- **Overriding:** To get polymorphic behavior from an operation, the operation in the superclass needs to be overridden in each of the subclasses. That is how overriding allows objects of different subclasses to *display different behaviors in response to the same method call*.
- **Dynamic binding**: Calls to overridden methods are bound to the implementation of the actual object's class dynamically during the runtime. That is how the polymorphic code can call the method of the parent class and yet execute the implementation of the child class.

More

Miscellaneous ★★★☆

What's the difference between a Class, an Abstract Class, and an Interface?

- An interface is a behavior specification with no implementation.
- A class is a behavior specification + implementation.
- An abstract class is a behavior specification + a possibly incomplete implementation.

How does overriding differ from *overloading*?

Overloading is used to indicate that multiple operations do similar things but take different parameters. Overloaded methods have the same method name but different method signatures and possibly different return types.

Overriding is when a sub-class redefines an operation using the same method name and the same type signature. Overridden methods have the same name, same method signature, and same return type.

SECTION: REQUIREMENTS

Requirements

Introduction ★★☆☆

A *software requirement* specifies a need to be fulfilled by the software product.

A software project may be,

- **a *brown-field* project** i.e., develop a product to replace/update an existing software product
- **a *green-field* project** i.e., develop a totally new system with no precedent

In either case, requirements need to be gathered, analyzed, specified, and managed.

Requirements come from *stakeholders*.

> **Stakeholder**: A party that is potentially affected by the software project. e.g. users, sponsors, developers, interest groups, government agencies, etc.

Identifying requirements is often not easy. For example, stakeholders may not be aware of their precise needs, may not know how to communicate their requirements correctly, may not be willing to spend effort in identifying requirements, etc.

Non-Functional Requirements ★★☆☆

There are two kinds of requirements:

1. ***Functional requirements* specify what the system should do.**
2. ***Non-functional requirements* specify the constraints under which system is developed and operated.**

Some examples of non-functional requirement categories:

- Data requirements e.g. size, volatility , persistency etc.,
- Environment requirements e.g. technical environment in which system would operate or need to be compatible with.
- Accessibility, Capacity, Compliance with regulations, Documentation, Disaster recovery, Efficiency, Extensibility, Fault tolerance, Interoperability, Maintainability, Privacy, Portability, Quality, Reliability, Response time, Robustness, Scalability, Security, Stability, Testability, and more ...

Some concrete examples of NFRs

- Business/domain rules: e.g. the size of the minefield cannot be smaller than five.
- Constraints: e.g. the system should be backward compatible with data produced by earlier versions of the system; system testers are available only during the last month of the project; the total project cost should not exceed $1.5 million.
- Technical requirements: e.g. the system should work on both 32-bit and 64-bit environments.
- Performance requirements: e.g. the system should respond within two seconds.
- Quality requirements: e.g. the system should be usable by a novice who has never carried out an online purchase.
- Process requirements: e.g. the project is expected to adhere to a schedule that delivers a feature set every one month.
- Notes about project scope: e.g. the product is not required to handle the printing of reports.
- Any other noteworthy points: e.g. the game should not use images deemed offensive to those injured in real mine clearing activities.

We may have to spend an extra effort in digging NFRs out as early as possible because,

1. **NFRs are easier to miss** e.g., stakeholders tend to think of functional requirements first
2. sometimes **NFRs are critical to the success of the software.** E.g. A web application that is too slow or that has low security is unlikely to succeed even if it has all the right functionality.

Prioritizing Requirements ★★★☆

Requirements can be prioritized based the importance and urgency, while keeping in mind the constraints of schedule, budget, staff resources, quality goals, and other constraints.

A common approach is to group requirements into priority categories. Note that all such scales are subjective, and stakeholders define the meaning of each level in the scale for the project at hand.

📦 An example scheme for categorizing requirements:

- `Essential`: The product must have this requirement fulfilled or else it does not get user acceptance
- `Typical`: Most similar systems have this feature although the product can survive without it.
- `Novel`: New features that could differentiate this product from the rest.

📦 Other schemes:

- `High`, `Medium`, `Low`
- `Must-have`, `Nice-to-have`, `Unlikely-to-have`
- `Level 0`, `Level 1`, `Level 2`, ...

Some requirements can be discarded if they are considered 'out of *scope*'.

📦 The requirement given below is for a Calendar application. Stakeholder of the software (e.g. product designers) might decide the following requirement is not in the scope of the software.

> The software records the actual time taken by each task and show the difference between the *actual* and *scheduled* time for the task.

Quality of Requirements ★★★☆

Here are some characteristics of well-defined requirements [📖 zielczynski]:

- Unambiguous
- Testable (verifiable)
- Clear (concise, terse, simple, precise)
- Correct
- Understandable
- Feasible (realistic, possible)
- Independent
- Atomic
- Necessary
- Implementation-free (i.e. abstract)

Besides these criteria for individual requirements, the set of requirements as a whole should be

- Consistent
- Non-redundant
- Complete

Gathering Requirements

Brainstorming ★★★☆

> **Brainstorming**: A group activity designed to *generate a large number of diverse and creative ideas* for the *solution* of a problem.

In a brainstorming session there are no "bad" ideas. The aim is to *generate ideas; not to validate* them. Brainstorming encourages you to "think outside the box" and put "crazy" ideas on the table without fear of rejection.

User Surveys ★★★☆

Surveys can be used to *solicit responses and opinions* from a large number of stakeholders regarding a current product or a new product.

Observation ★★★☆

Observing users in their natural work environment can uncover product requirements. Usage data of an existing system can also be used to gather information about how an existing system is being used, which can help in building a better replacement e.g. to find the situations where the user makes mistakes when using the current system.

Interviews ★★★☆

Interviewing stakeholders and domain experts can produce useful information that project requirements.

-

Focus Groups ★★★☆

Focus groups are a kind of informal interview within an interactive group setting. A group of people (e.g. potential users, beta testers) are asked about their understanding of a specific issue, process, product, advertisement, etc.

Prototyping ★★★☆

> **Prototype**: A prototype is a *mock up, a scaled down version, or a partial system constructed*
>
> - to get users' feedback.
> - to validate a technical concept (a "proof-of-concept" prototype).
> - to give a preview of what is to come, or to compare multiple alternatives on a small scale before committing fully to one alternative.
> - for early field-testing under controlled conditions.

Prototyping can uncover requirements, in particular, those related to *how users interact with the system*. UI prototypes are often used in brainstorming sessions, or in meetings with the users to get quick feedback from them.

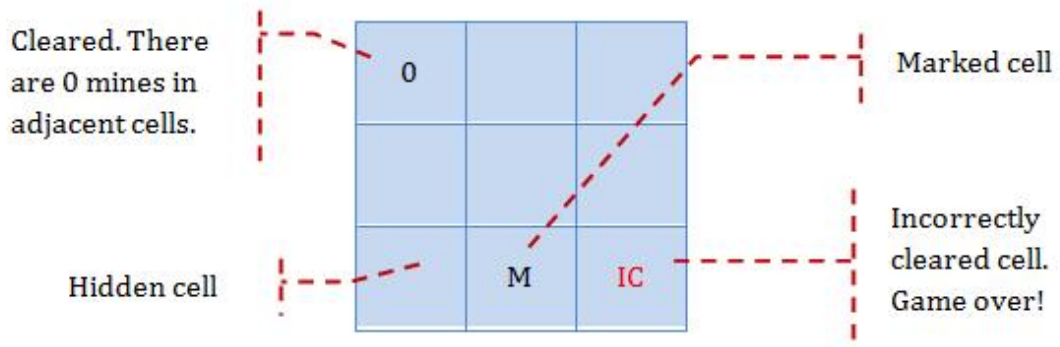
Simple text UI prototype for a primitive CLI (Command Line Interface) Minesweeper:

```
D:\\ >java MinesweeperTextUI
Enter command: new
  [0,0:H][0,1:H][0,2:H]
  [1,0:H][1,1:H][1,2:H]
  [2,0:H][2,1:H][2,2:H]
Enter command: mark 2 1
  [0,0:H][0,1:H][0,2:H]
  [1,0:H][1,1:H][1,2:H]
  [2,0:H][2,1:M][2,2:H]
```

```
Enter command: clear 0 0
  [0,0:0][0,1:H][0,2:H]
  [1,0:H][1,1:H][1,2:H]
  [2,0:H][2,1:M][2,2:H]
Enter command: clear 2 2
  [0,0:0][0,1:H][0,2:H]
  [1,0:H][1,1:H][1,2:H]
  [2,0:H][2,1:M][2,2:IC]
You Lost :-(
```

Format → [coordinates : cell appearance]
Cell appearance: H=hidden, IM=Incorrectly Marked, IC=Incorrectly Cleared,
M=Marked 0-8:number of mines in adjacent cells.

A simple GUI prototype for the same Minesweeper, created using Powerpoint:



A prototype for a mobile app, created using the UI prototyping tool Balsmiq:

[source: http://balsamiq.com/products/mockups]

Prototyping can be used for *discovering* as well as *specifying* requirements e.g. a UI prototype can serve as a specification of what to build.

Product Surveys ★★★☆

Studying existing products can unearth shortcomings of existing solutions that can be addressed by a new product. Product manuals and other forms of technical documentation of an existing system can be a good way to learn about how the existing solutions work.

When developing a game for a mobile device, a look at a similar PC game can give insight into the kind of features and interactions the mobile game can offer.

Specifying Requirements

Prose

What ★★★☆

A textual description (i.e. *prose*) can be used to describe requirements. Prose is especially useful when describing abstract ideas such as the vision of a product.

📦 The product vision of the TEAMMATES Project given below is described using prose.

> TEAMMATES aims to become **the biggest student project in the world** (*biggest* here refers to 'many contributors, many users, large code base, evolving over a long period'). Furthermore, it aims to serve as a training tool for Software Engineering students who want to learn SE skills in the context of **a non-trivial real software product**.

❗ Avoid using lengthy prose to describe requirements; they can be hard to follow.

Feature Lists

What ★★☆☆

Feature List: A list of features of a product *grouped according to some criteria* such as aspect, priority, order of delivery, etc.

📦 A sample feature list from a simple Minesweeper game (only a brief description has been provided to save space):

1. Basic play – Single player play.
2. Difficulty levels
    - Medium-levels
    - Advanced levels
3. Versus play – Two players can play against each other.
4. Timer – Additional fixed time restriction on the player.
5. ...

User Stories

Introduction ★☆☆☆

User story: User stories are short, simple descriptions of a feature told from the perspective of the person who desires the new capability, usually a user or customer of the system. [Mike Cohn]

A common format for writing user stories is:

User story format: `As a {user type/role} I can {function} so that {benefit}`

📦 Examples (from a *Learning Management System*):

1. As a student, I can download files uploaded by lecturers, so that I can get my own copy of the files
2. As a lecturer, I can create discussion forums, so that students can discuss things online
3. As a tutor, I can print attendance sheets, so that I can take attendance during the class

We can write user stories on index cards or sticky notes, and arrange on walls or tables, to facilitate planning and discussion. Alternatively, we can use a software (e.g., GitHub Project Boards, Trello, Google Docs, ...) to manage user stories digitally.

Details ★★☆☆

The `{benefit}` can be omitted if it is obvious.

As a user, I can login to the system ~~so that I can access my data~~

It is recommended to confirm there is a concrete benefit even if you omit it from the user story. If not, you could end up adding features that have no real benefit.

You can add more characteristics to the `{user role}` to provide more context to the user story.

- As a forgetful user, I can view a password hint, so that I can recall my password.
- As an expert user, I can tweak the underlying formatting tags of the document, so that I can format the document exactly as I need.

You can write user stories at various levels. High-level user stories, called *epics* (or *themes*) cover bigger functionality. You can then break down these epics to multiple user stories of normal size.

[Epic] As a lecturer, I can monitor student participation levels

- As a lecturer, I can view the forum post count of each student so that I can identify the activity level of students in the forum
- As a lecturer, I can view webcast view records of each student so that I can identify the students who did not view webcasts
- As a lecturer, I can view file download statistics of each student so that I can identify the students who do not download lecture materials

You can add *conditions of satisfaction* to a user story to specify things that need to be true for the user story implementation to be accepted as 'done'.

- *As a* lecturer, *I can* view the forum post count of each student *so that* I can identify the activity level of students in the forum.

Conditions:

- [ ] Separate post count for each forum should be shown
- [ ] Total post count of a student should be shown
- [ ] The list should be sortable by student name and post count

Other useful info that can be added to a user story includes (but not limited to)

- Priority: how important the user story is
- Size: the estimated effort to implement the user story
- Urgency: how soon the feature is needed

Usage ★★☆☆

User stories capture user requirements in a way that is convenient for scoping , estimation and scheduling .

> [User stories] strongly shift the focus from writing about features to discussing them. In fact, these discussions are more important than whatever text is written. [Mike Cohn, MountainGoat Software]

User stories differ from traditional requirements specifications mainly in the level of detail. User stories should only provide enough details to make a reasonably low risk estimate of how long the user story will take to implement. When the time comes to implement the user story, the developers will meet with the customer face-to-face to work out a more detailed description of the requirements. [more..]

User stories can capture non-functional requirements too because even NFRs must benefit some stakeholder.

An example of a NFR captured as a user story:

As a	I want to	so that
impatient user	to be able experience reasonable response time from the website while up to 1000 concurrent users are using it	I can use the app even when the traffic is at the maximum expected level

Given their lightweight nature, **user stories are quite handy for recording requirements during early stages of requirements gathering**.

Here are some tips for using user stories for early stages of requirement gathering:

- **Define the *target user*:**
  Decide your target user's profile (e.g. a student, office worker, programmer, sales person) and work patterns (e.g. Does he work in groups or alone? Does he share his computer with others?). A clear understanding of the target user will help when deciding the importance of a user story. You can even give this user a name. e.g. Target user Jean is a university student studying in a non-IT field. She interacts with a lot of people due to her involvement in university clubs/societies. ...
- **Define the *problem scope*:** Decide that exact problem you are going to solve for the target user. e.g. Help Jean keep track of all her school contacts
- **Don't be too hasty to discard 'unusual' user stories:**
  Those might make your product unique and stand out from the rest, at least for the target users.
- **Don't go into too much details:**
  For example, consider this user story: `As a user, I want to see a list of tasks that needs my attention most at the present time, so that I pay attention to them first.`
  When discussing this user story, don't worry about what tasks should be considered *needs my attention most at the present time*. Those details can be worked out later.
- **Don't be biased by preconceived product ideas:**
  When you are at the stage of identifying user needs, clear your mind of ideas you have about what your end product will look like.
- **Don't discuss implementation details or whether you are actually going to implement it:**
  When gathering requirements, your decision is whether the user's need is important enough for you to want to fulfil it. Implementation details can be discussed later. If a user story turns out to be too difficult to implement later, you can always omit it from the implementation plan.

While use cases can be recorded on physical paper in the initial stages, an online tool is more suitable for longer-term management of user stories, especially if the team is not co-located .

Use Cases

Introduction ★☆☆☆

Use Case: A description of a set of sequences of actions, including variants, that a system performs to yield an observable result of value to an actor.[🕮 : uml-user-guide]

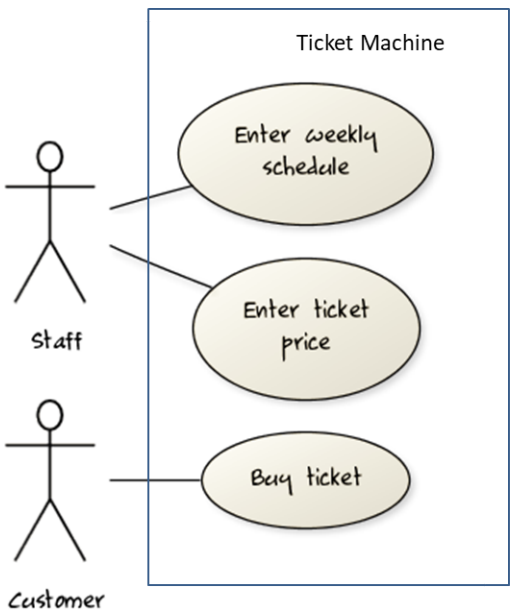
A use case describes an *interaction between the user and the system* for a *specific functionality* of the system.

Example 1: 'check account balance' use case for an ATM

- System: ATM
- Actor: Customer
- Use Case: Check account balance
  1. User inserts an ATM card
  2. ATM prompts for PIN
  3. User enters PIN
  4. ATM prompts for withdrawal amount
  5. User enters the amount
  6. ATM ejects the ATM card and issues cash
  7. User collects the card and the cash.

Example 2: 'upload file' use case of an LMS

UML includes a diagram type called use case diagrams that can illustrate use cases of a system visually , providing a visual 'table of contents' of the use cases of a system. In the example below, note how use cases are shown as ovals and user roles relevant to each use case are shown as stick figures connected to the corresponding ovals.



Use cases capture the *functional requirements* of a system.

Identifying ★★☆☆

A use case is an interaction between a system and its *actors*.

Actors in Use Cases

Actor: An actor (in a use case) is a role played by a user. An actor can be a human or another system. Actors are not part of the system; they reside outside the system.

Some example actors for a Learning Management System

- Actors: Guest, Student, Staff, Admin, ExamSys , LibSys .

A use case can involve multiple actors.

- Software System: LearnSys
- Use case: UC01 conduct survey
- Actors: Staff, Student

An actor can be involved in many use cases.

- Software System: LearnSys
- Actor: Staff
- Use cases: UC01 conduct survey, UC02 Set Up Course Schedule, UC03 Email Class, ...

A single person/system can play many roles.

- Software System: LearnSys
- Person: a student
- Actors (or Roles): Student, Guest, Tutor

Many persons/systems can play a single role.

- Software System: LearnSys
- Actor(or role) : Student
- Persons that can play this role : undergraduate student, graduate student, a staff member doing a part-time course, exchange student

Use cases can be specified at *various levels of detail*.

📦 Consider the three use cases given below. Clearly, (a) is at a higher level than (b) and (b) is at a higher level than (c).

- System: LearnSys
- Use cases:
  a. Conduct a survey
  b. Take the survey
  c. Answer survey question

💡 While modeling user-system interactions,

- Start with high level use cases and progressively work toward lower level use cases.
- Be mindful at which level of details you are working on and not to mix use cases of different levels.

Details ★★☆☆

Writing use case steps

The main body of the use case is the sequence of steps that describes the interaction between the system and the actors. Each step is given as a simple statement describing *who does what*.

📦 An example of the main body of a use case.

1. Student requests to upload file
2. LMS requests for the file location
3. Student specifies the file location
4. LMS uploads the file

A use case describes only the externally visible behavior, not internal details, of a system i.e. should not mention give details that are not part of the interaction between the user and the system.

📦 This example use case step refers to behaviors not externally visible .

1. LMS saves the file into the cache and indicates success.

A step gives the intention of the actor (not the mechanics). That means UI details are usually omitted. The idea is to leave as much flexibility to the UI designer as possible. That is, the use case specification should be as general as possible (less specific) about the UI.

📦 The first example below is not a good use case step because contains UI-specific details. The second one is better because it omits UI-specific details.

👎 **Bad** : User right-clicks the text box and chooses ‘clear’

👍 **Good** : User clears the input

A use case description can show loops too.

📦 An example of how you can show a loop:

Software System: Square game Use case: UC02 - Play a Game Actors: Player (multiple players)

1. A Player starts the game.
2. SquareGame asks for player names.
3. Each Player enters his own name.
4. SquareGame shows the order of play.
5. SquareGame prompts for the current Player to throw die.
6. Current Player adjusts the throw speed.
7. Current Player triggers the die throw.
8. Square Game shows the face value of the die.
9. Square Game moves the Player's piece accordingly.
   Steps 5-9 are repeated for each Player, and for as many rounds as required until a Player reaches the 100th square.

10. Square Game shows the Winner.

Use case ends.

The *Main Success Scenario (MSS)* describes the most straightforward interaction for a given use case, which assumes that nothing goes wrong. This is also called the *Basic Course of Action* or the *Main Flow of Events* of a use case.

- System: Online Banking System (OBS)
- Use case: UC23 - Transfer Money
- Actor: User
- MSS:
    1. User chooses to transfer money.
    2. OBS requests for details of the transfer.
    3. User enters the requested details.
    4. OBS requests for confirmation.
    5. OBS transfers the money and displays the new account balance.

    Use case ends.

Note how the MSS assumes that all entered details are correct and ignores problems such as timeouts, network outages etc. Fro example, MSS does not tell us what happens if the user enters an incorrect data.

***Extensions* are "add-on"s to the MSS that describe *exceptional/alternative flow of events*.** They describe variations of the scenario that can happen if certain things are not as expected by the MSS. Extensions appear below the MSS.

📦 This example adds some extensions to the use case in the previous example.

- System: Online Banking System (OBS)
- Use case: UC23 - Transfer Money
- Actor: User
- MSS:
    1. User chooses to transfer money.
    2. OBS requests for details of the transfer.
    3. User enters the requested details.
    4. OBS requests for confirmation.
    5. OBS transfers the money and displays the new account balance.

    Use case ends.

- Extensions:

    3a. OBS detects an error in the entered data.

    3a1. OBS requests for the correct data.

    3a2. User enters new data.

    Steps 3a1-3a2 are repeated until the data entered are correct.

    Use case resumes from step 4.

    3b. User requests to effect the transfer in a future date.

    3b1. OBS requests for confirmation.

    3b2. User confirms future transfer.

    Use case ends.

    *a. At any time, User chooses to cancel the transfer.

    *a1. OBS requests to confirm the cancellation.

    *a2. User confirms the cancellation.

    Use case ends.

    *b. At any time, 120 seconds lapse without any input from the User.

    *b1. OBS cancels the transfer.

    *b2. OBS informs the User of the cancellation.

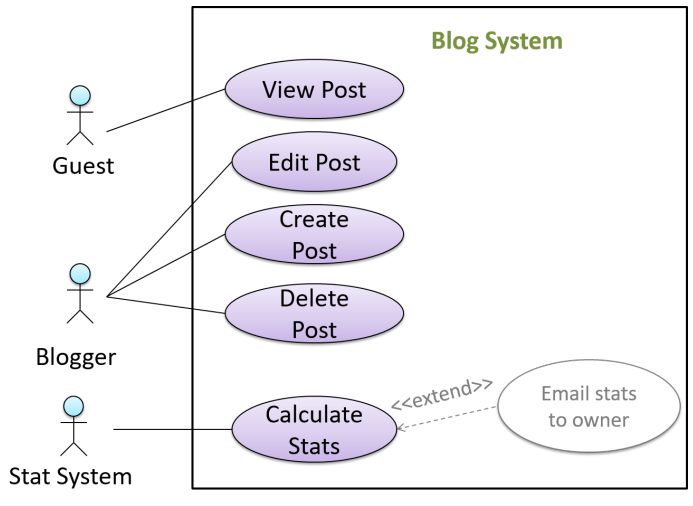
    Use case ends.

Note that the numbering style is not a universal rule but a widely used convention. Based on that convention,

- either of the extensions marked `3a.` and `3b.` can happen just after step `3` of the MSS.
- the extension marked as `*a.` can happen at any step (hence, the `*`).

When separating extensions from the MSS, keep in mind that the **MSS should be self-contained**. That is, the MSS should give us a complete usage scenario.

Also note that it is not useful to mention events such as power failures or system crashes as extensions because the system cannot function beyond such catastrophic failures.



In use case diagrams you can use the `<<extend>>` arrows to show extensions. Note the direction of the arrow is from the extension to the use case it extends and the arrow uses a dashed line.

A use case can include another use case. Underlined text is commonly used to show an inclusion of a use case.

📦 This use case includes two other use cases, one in step 1 and one in step 2.

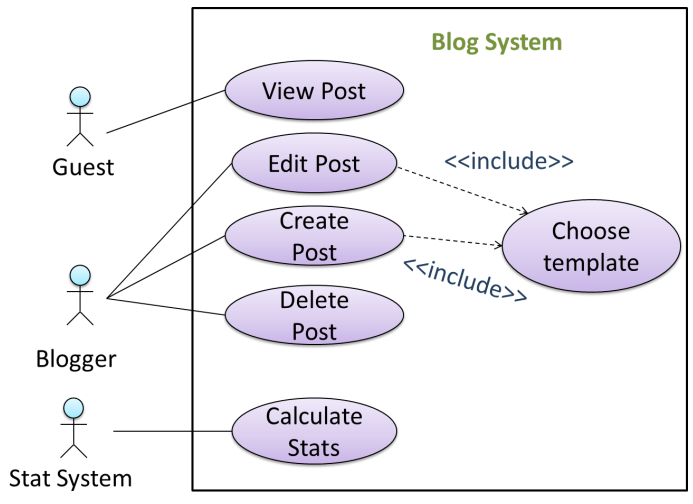
- **Software System:** LearnSys
- **Use case:** UC01 - Conduct Survey
- **Actors:** Staff, Student
- **MSS:**
    1. Staff creates the survey **(UC44)**.
    2. Student completes the survey **(UC50)**.
    3. Staff views the survey results.

       Use case ends.

Inclusions are useful,

- when you don't want to clutter a use case with too many low-level steps.
- when a set of steps is repeated in multiple use cases.

We use a dotted arrow and a `<<include>>` annotation to show use case inclusions in a use case diagram. Note how the arrow direction is different from the `<<extend>>` arrows.



Preconditions **specify the specific state we expect the system to be in before the use case starts.**

- Software System: Online Banking System
- Use case: UC23 - Transfer Money
- Actor: User
- **Preconditions: User is logged in.**
- MSS:
    1. User chooses to transfer money.
    2. OBS requests for details for the transfer.

...

Guarantees **specify what the use case promises to give us at the end of its operation.**

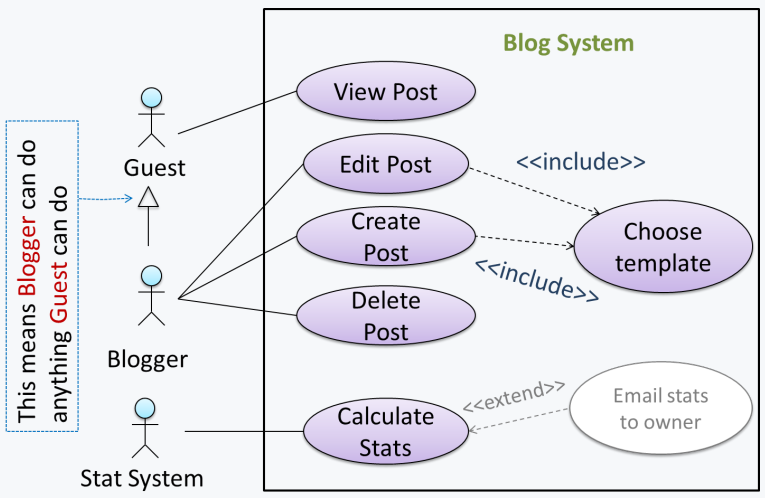
- Software System: Online Banking System
- Use case: UC23 - Transfer Money
- Actor: User
- Preconditions: User is logged in.
- **Guarantees:**
  - **Money will be deducted from the source account only if the transfer to the destination account is successful**
  - **The transfer will not result in the account balance going below the minimum balance required.**
- MSS:
  1. User chooses to transfer money.
  2. OBS requests for details for the transfer.

  ...

Usage ★★★☆

You can use actor generalization in use case diagrams using a symbol similar to that of UML notation for inheritance.

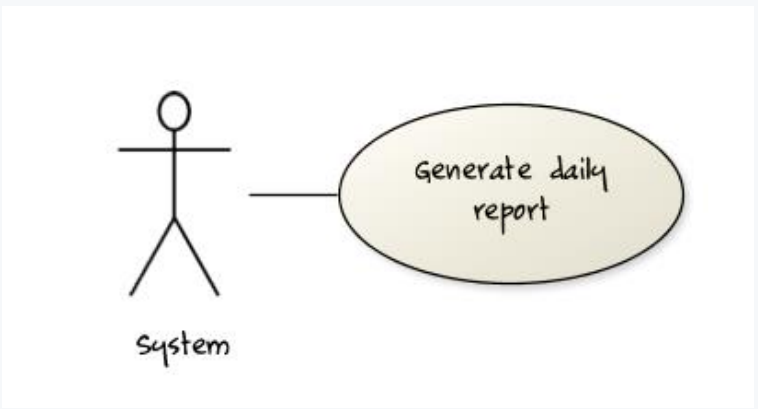
📦 In this example, actor `Blogger` can do all the use cases the actor `Guest` can do, as a result of the actor generalization relationship given in the diagram.



💡 Do not over-complicate use case diagrams by trying to include everything possible. A use case diagram is a brief summary of the use cases that is used as a starting point. Details of the use cases can be given in the use case descriptions.

Some include 'System' as an actor to indicate that something is done by the system itself without being initiated by a user or an external system.

📦 The diagram below can be used to indicate that the system generates daily reports at midnight.



However, others argue that only use cases providing value to an external user/system should be shown in the use case diagram. For example, they argue that 'view daily report' should be the use case and `generate daily report` is not to be shown in the use case diagram because it is simply something the system has to do to support the `view daily report` use case.

We recommend that you follow the latter view (i.e. not to use System as a user). Limit use cases for modeling behaviors that involve an external actor.

UML is not very specific about the text contents of a use case. Hence, there are many styles for writing use cases. For example, the steps can be written as a continuous paragraph. Use cases should be easy to read. Note that there is no strict rule about writing all details of all steps or a need to use all the elements of a use case.

There are some advantages of documenting system requirements as use cases:

- Because they use a simple notation and plain English descriptions, they are easy for users to understand and give feedback.
- They decouple user intention from mechanism (note that use cases should not include UI-specific details), allowing the system designers more freedom to optimize how a functionality is provided to a user.
- Identifying all possible extensions encourages us to consider all situations that a software product might face during its operation.
- Separating typical scenarios from special cases encourages us to optimize the typical scenarios.

One of the main disadvantages of use cases is that they are not good for capturing requirements that does not involve a user interacting with the system. Hence, they should not be used as the sole means to specify requirements.

Glossary

What ★★★☆

Glossary: A glossary serves to ensure that *all stakeholders have a common understanding* of the noteworthy terms, abbreviation, acronyms etc.

Here is a partial glossary from a variant of the *Snakes and Ladders* game:

- Conditional square: A square that specifies a specific face value which a player has to throw before his/her piece can leave the square.
- Normal square: a normal square does not have any conditions, snakes, or ladders in it.

Supplementary Requirements

What ★★★☆

A *supplementary requirements* section can be used to capture *requirements that do not fit elsewhere*. Typically, this is where most Non Functional Requirements will be listed.

SECTION: DESIGN

Software Design

Introduction

What ★★★☆

> Design in the creative process of transforming the problem into a solution; the solution is also called design. -- *Software Engineering Theory and Practice*, Shari Lawrence; Atlee, Joanne M. Pfleeger

Software design has two main aspects:

- **Product/external design: designing the external behavior of the product to meet the users' requirements.** This is usually done by product designers with the input from business analysts, user experience experts, user representatives, etc.
- **Implementation/internal design: designing how the product will be implemented to meet the required external behavior.** This is usually done by software architects and software engineers.

Design Fundamentals

Abstraction

What ★★☆☆

> **Abstraction** is a technique for dealing with complexity. It works by establishing a level of complexity we are interested in, and suppressing the more complex details below that level.

The guiding principle of abstraction is that only details that are relevant to the current perspective or the task at hand needs to be considered. As most programs are written to solve complex problems involving large amounts of intricate details, it is impossible to deal with all these details at the same time. That is where abstraction can help.

Ignoring lower level data items and thinking in terms of bigger entities is called *data abstraction*.

> Within a certain software component, we might deal with a *user* data type, while ignoring the details contained in the user data item such as *name*, and *date of birth*. These details have been 'abstracted away' as they do not affect the task of that software component.

Control abstraction **abstracts away details of the actual control flow to focus on tasks at a simplified level.**

> `print("Hello")` is an abstraction of the actual output mechanism within the computer.

Abstraction can be applied repeatedly to obtain progressively *higher levels of abstractions*.

> An example of different levels of data abstraction: a `File` is a data item that is at a higher level than an array and an array is at a higher level than a bit.
>
> An example of different levels of control abstraction: `execute(Game)` is at a higher level than `print(Char)` which is at a higher than an Assembly language instruction `MOV`.

Abstraction is a general concept that is not limited to just data or control abstractions.

> Some more general examples of abstraction:
>
> - An OOP *class* is an abstraction over related data and behaviors.
> - An *architecture* is a higher-level abstraction of the design of a software.
> - Models (e.g., UML models) are abstractions of some aspect of reality.

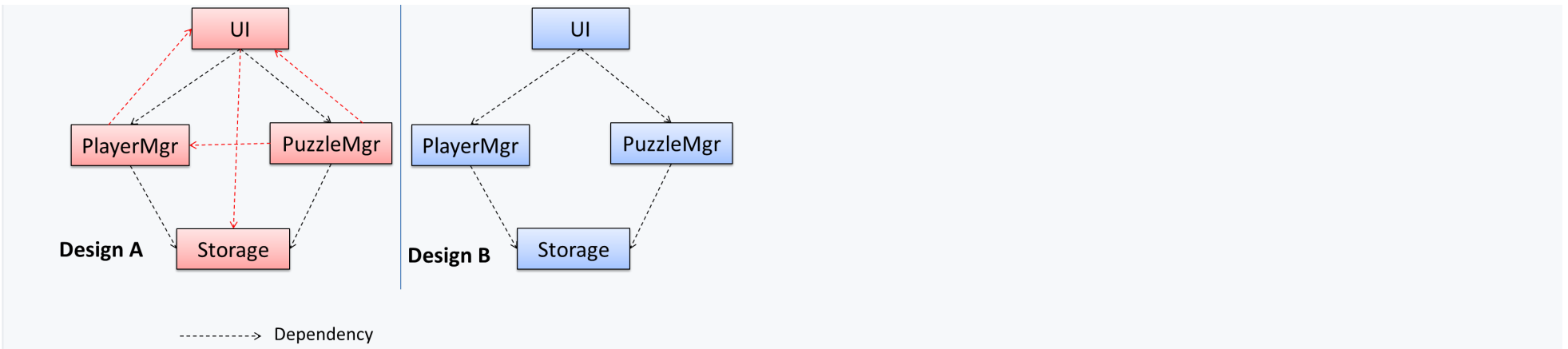
Coupling

What ★★☆☆

Coupling **is a measure of the degree of *dependence*** between components, classes, methods, etc. Low coupling indicates that a component is less dependent on other components. **High coupling (aka *tight* coupling or *strong* coupling) is discouraged** due to the following disadvantages:

- **Maintenance is harder** because a change in one module could cause changes in other modules coupled to it (i.e. a ripple effect).
- **Integration is harder** because multiple components coupled with each other have to be integrated at the same time.
- **Testing and reuse of the module is harder** due to its dependence on other modules.

> In the example below, design `A` appears to have a more coupling between the components than design `B`.



How ★★★☆

X is *coupled* to Y if a change to Y can potentially require a change in X.

📦 If `Foo` class calls the method `Bar#read()`, `Foo` is coupled to `Bar` because a change to `Bar` can potentially (but not always) require a change in the `Foo` class e.g. if the signature of the `Bar#read()` is changed, `Foo` needs to change as well, but a change to the `Bar#write()` method may not require a change in the `Foo` class because `Foo` does not call `Bar#write()`.

› code for the above example

📦 Some examples of coupling: `A` is coupled to `B` if,

- `A` has access to the internal structure of `B` (this results in a very high level of coupling)
- `A` and `B` depend on the same global variable
- `A` calls `B`
- `A` receives an object of `B` as a parameter or a return value
- `A` inherits from `B`
- `A` and `B` are required to follow the same data format or communication protocol

Cohesion

What ★★☆☆

***Cohesion* is a measure of how strongly-related and focused the various responsibilities of a component are.** A highly-cohesive component keeps related functionalities together while keeping out all other unrelated things.

Higher cohesion is better. Disadvantages of low cohesion (aka *weak* cohesion):

- Lowers the understandability of modules as it is difficult to express module functionalities at a higher level.
- Lowers maintainability because a module can be modified due to unrelated causes (reason: the module contains code unrelated to each other) or many many modules may need to be modified to achieve a small change in behavior (reason: because the code realated to that change is not localized to a single module).
- Lowers reusability of modules because they do not represent logical units of functionality.

How ★★★☆

Cohesion can be present in many forms. Some examples:

- Code related to a single concept is kept together, e.g. the `Student` component handles everything related to students.
- Code that is invoked close together in time is kept together, e.g. all code related to initializing the system is kept together.
- Code that manipulates the same data structure is kept together, e.g. the `GameArchive` component handles everything related to the storage and retrieval of game sessions.

📦 Suppose a Payroll application contains a class that deals with writing data to the database. If the class include some code to show an error dialog to the user if the database is unreachable, that class is not cohesive because it seems to be interacting with the user as well as the database.

Modeling

Introduction

What ★★☆☆

A *model* is a representation of something else.

> 📦 A class diagram is a model that represents a software design.

A *model* provides a simpler view of a complex entity because a model captures only a selected aspect. This omission of some aspects implies models are abstractions.

> 📦 A class diagram captures the structure of the software design but not the behavior.

Multiple models of the same entity may be needed to capture it fully.

> 📦 In addition to a class diagram (or even multiple class diagrams), a number of other diagrams may be needed to capture various interesting aspects of the software.

How ★★★☆

In software development, models are useful in several ways:

a) **To analyze a complex entity related to software development.**

> 📦 Some examples of using models for analysis:
>
> 1. Models of the problem domain (i.e. the environment in which the software is expected to solve a problem) can be built to aid the understanding of the problem to be solved.
> 2. When planning a software solution, models can be created to figure out how the solution is to be built. An architecture diagram is such a model.

b) **To communicate information among stakeholders.** Models can be used as a visual aid in discussions and documentations.

> 📦 Some examples of using models to communicate:
>
> 1. We can use an architecture diagram to explain the high-level design of the software to developers.
> 2. A business analyst can use a use case diagram to explain to the customer the functionality of the system.
> 3. A class diagram can be reverse-engineered from code so as to help explain the design of a component to a new developer.

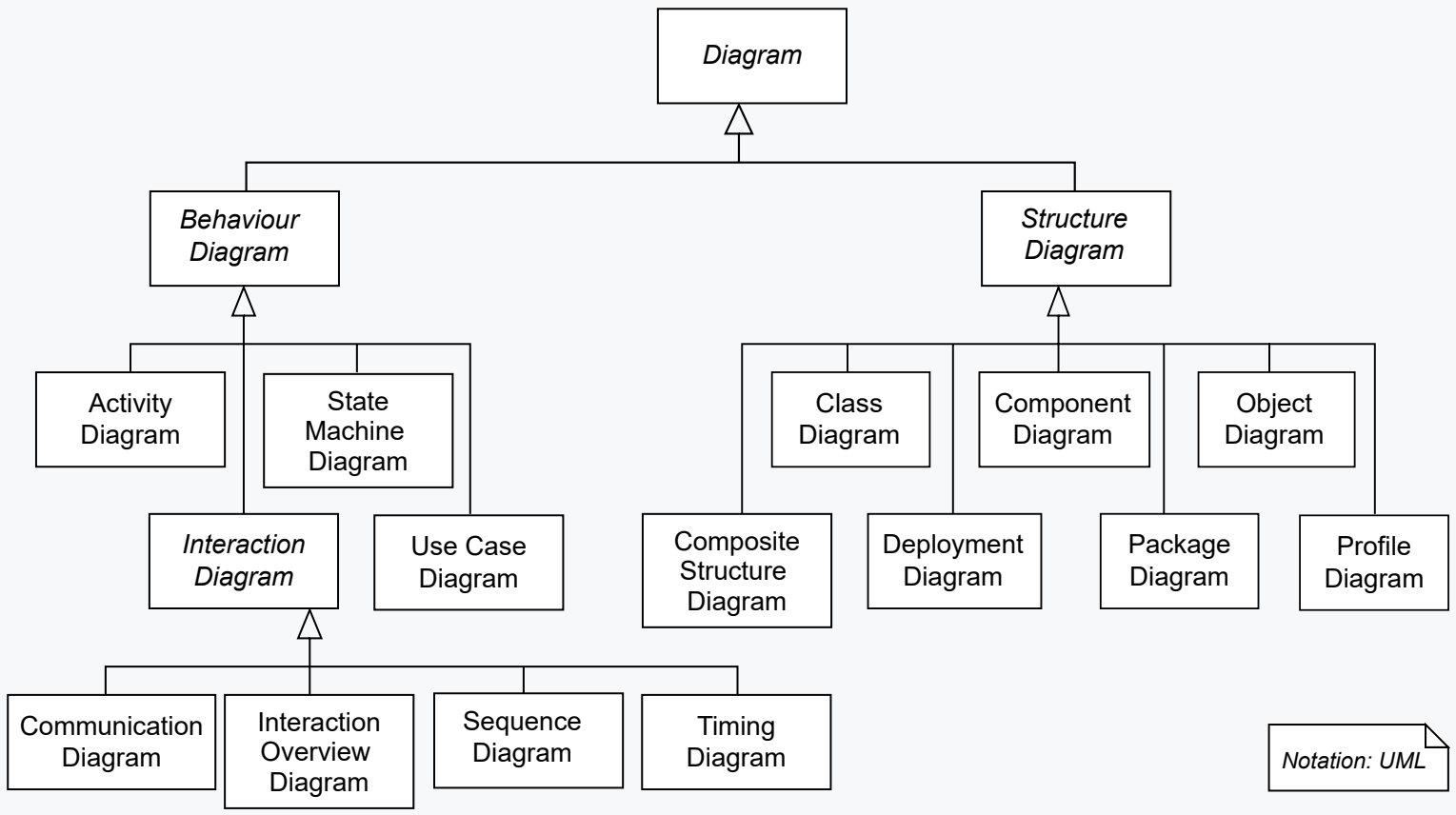
c) **As a blueprint for creating software.** Models can be used as instructions for building software.

> 📦 Some examples of using models to as blueprints:
>
> 1. A senior developer draws a class diagram to propose a design for an OOP software and passes it to a junior programmer to implement.
> 2. A software tool allows users to draw UML models using its interface and the tool automatically generates the code based on the model.

> ▸ Model Driven Development tangential

UML Models ★★★☆

The following diagram uses the class diagram notation to show the different types of UML diagrams.



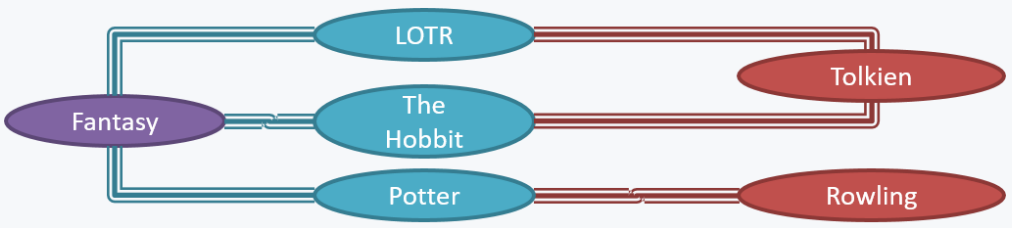
source:https://en.wikipedia.org/

Modeling Structures

OO Structures ★☆☆☆

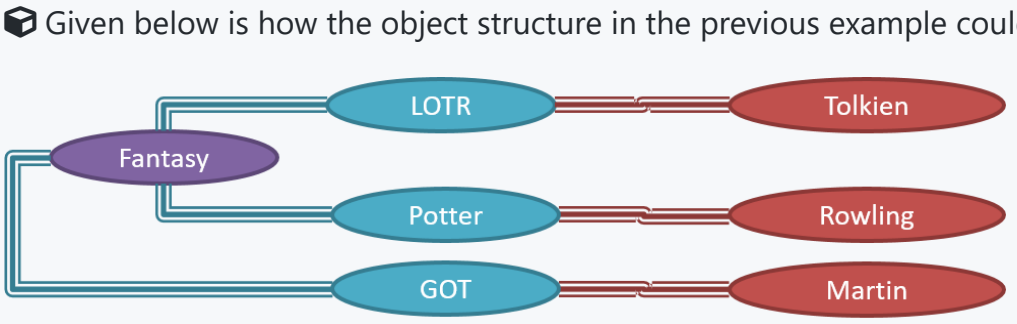
An OO solution is basically a network of objects interacting with each other. Therefore, **it is useful to be able to model how the relevant objects are 'networked' together** inside a software i.e. how the objects are connected together.

📦 Given below is an illustration of some objects and how they are connected together. Note: the diagram uses an ad-hoc notation.



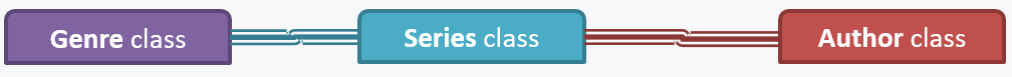
Note that these **object structures within the same software can change over time**.

📦 Given below is how the object structure in the previous example could have looked like at a different time.



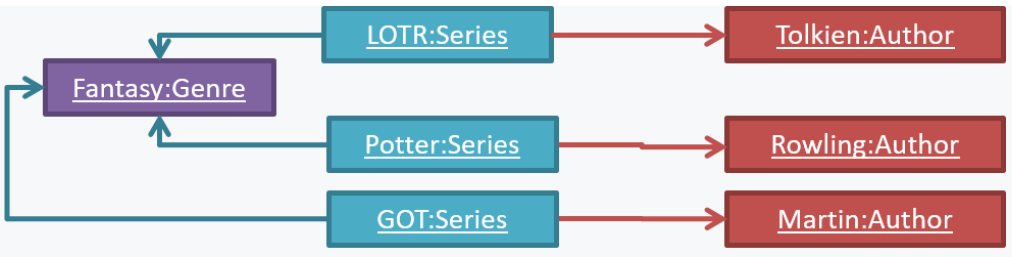
However, object structures do not change at random; they change based on a set of rules, as was decided by the designer of that software. Those **rules that object structures need to follow can be illustrated as a *class structure*** i.e. a structure that exists among the relevant classes.

📦 Here is a class structure (drawn using an ad-hoc notation) that matches the object structures given in the previous two examples. For example, note how this class structure does not allow any connection between `Genre` objects and `Author` objects, a rule followed by the two object structures above.

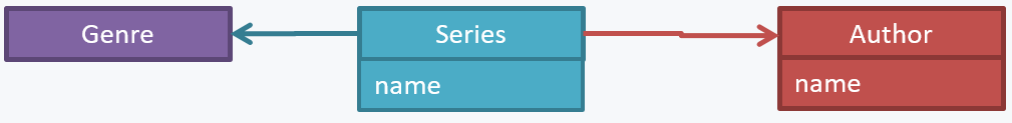


UML *Object Diagrams* are used to model object structures and UML *Class Diagrams* are used to model class structures of an OO solution.

📦 Here is an object diagram for the above example:



And here is the class diagram for it:



Class Diagrams (Basics) ★☆☆☆

- 🎓 UML 📲 Class Diagrams → Introduction → What

Classes form the basis of class diagrams.

- 🎓 UML 📲 Class Diagrams → Classes → What

- 🎓 UML 📲 Class Diagrams → Class-Level Members → What

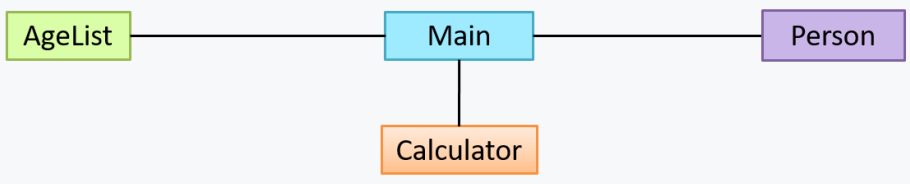
***Associations* are the main connections among the classes in a class diagram.**

- 🎓 OOP 📲 Associations → What

- 🎓 UML 📲 Class Diagrams → Associations → What

The most basic class diagram is a bunch of classes with some solid lines among them to represent associations, such as this one.

An example class diagram showing associations between classes.



In addition, **associations can show additional decorations such as *association labels*, *association roles*, *multiplicity* and *navigability*** to add more information to a class diagram.

- 🎓 UML 📲 Class Diagrams → Associations → Labels

- 🎓 UML 📲 Class Diagrams → Associations → Roles

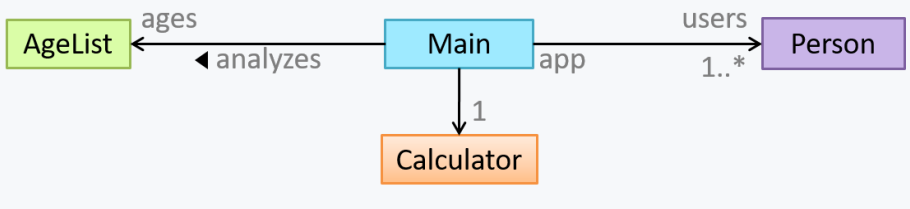
- 🎓 OOP 📲 Associations → Multiplicity

- 🎓 UML 📲 Class Diagrams → Associations → Multiplicity

- 🎓 OOP 📲 Associations → Navigability

- 🎓 UML 📲 Class Diagrams → Associations → Navigability

Here is the same class diagram shown earlier but with some additional information included:



Adding More Info to UML Models ★★★☆

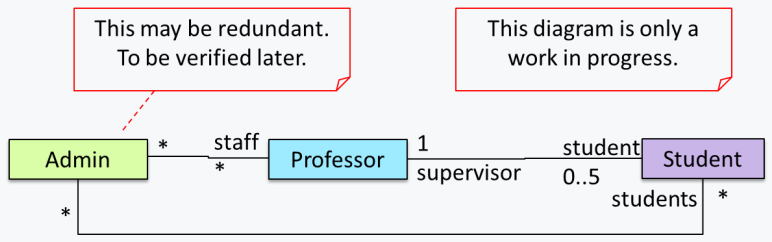
UML notes can be used to add more info to any UML model.

🎓 UML → Notes

Notes

UML notes can augment UML diagrams with additional information. These notes can be shown connected to a particular element in the diagram or can be shown without a connection. The diagram below shows examples of both.

Example:



Class Diagrams - Intermediate ★★☆☆

A class diagram can also show different types of associations: inheritance, compositions, aggregations, dependencies.

Modeling inheritance

- 🎓 OOP → Inheritance → What
- 🎓 UML → Class Diagrams → Inheritance → What

Modeling composition

- 🎓 OOP → Associations → Composition
- 🎓 UML → Class Diagrams → Composition → What

Modeling aggregation

- 🎓 OOP → Associations → Aggregation
- 🎓 UML → Class Diagrams → Aggregation → What

Modeling dependencies

- 🎓 OOP → Associations → Dependencies
- 🎓 UML → Class Diagrams → Dependencies → What

A class diagram can also show different types of class-like entities:

Modeling enumerations

- 🎓 OOP → Classes → Enumerations
- 🎓 UML → Class Diagrams → Enumerations → What

Modeling abstract classes

- 🎓 OOP → Inheritance → Abstract Classes
- 🎓 UML → Class Diagrams → Abstract Classes → What

Modeling interfaces

- 🎓 OOP → Inheritance → Interfaces
- 🎓 UML → Class Diagrams → Interfaces → What

Object Diagrams ★☆☆☆

- 🎓 UML → Object Diagrams → Introduction

Object diagrams can be used to complement class diagrams. For example, you can use object diagrams to model different object structures that can result from a design represented by a given class diagram.

- 🎓 UML → Object Diagrams → Objects
- 🎓 UML → Object Diagrams → Associations

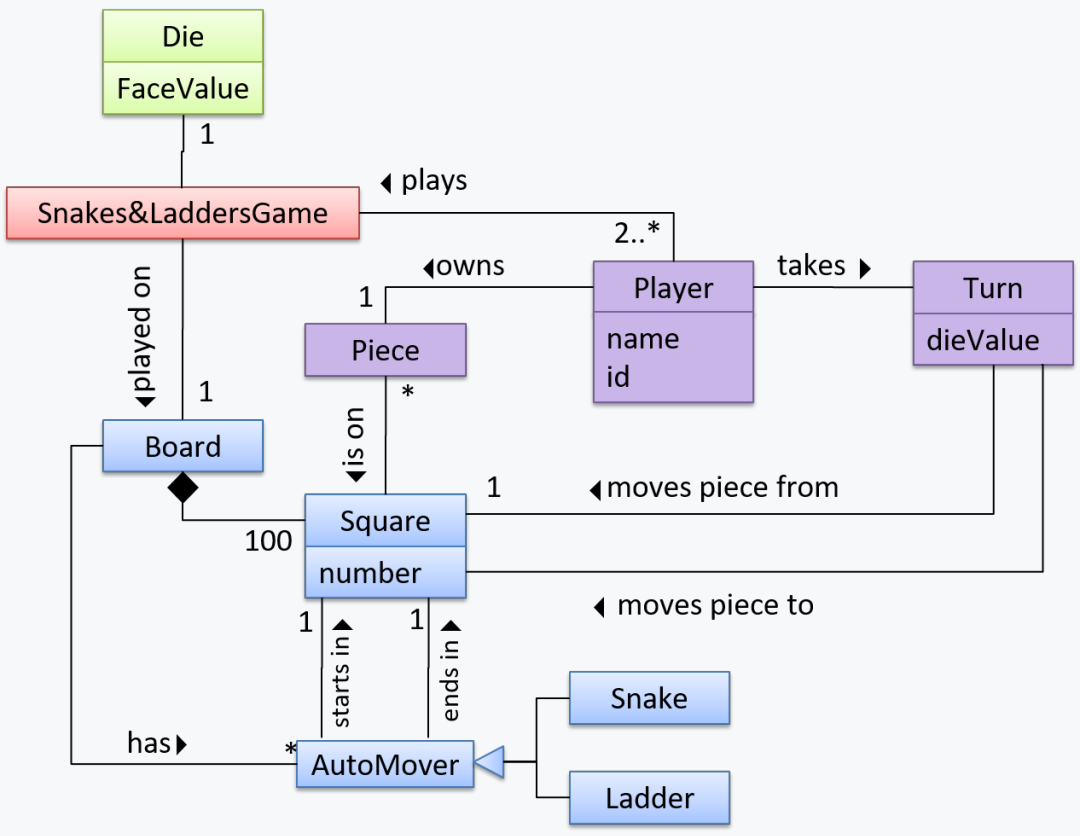
Object Oriented Domain Models ★★★☆

> The analysis process for identifying objects and object classes is recognized as one of the most difficult areas of object-oriented development. --Ian Sommerville, in the book *Software Engineering*

Class diagrams can also be used to model objects in the problem domain (i.e. to model how objects actually interact in the real world, before emulating them in the solution). **Class diagrams are used to model the problem domain are called *conceptual class diagrams* or *OO domain models (OODMs)*.**

📦 OO domain model of a snakes and ladders game is given below.

Description: Snakes and ladders game is played by two or more players using a board and a die. The board has 100 squares marked 1 to 100. Each player owns one piece. Players take turns to throw the die and advance their piece by the number of squares they earned from the die throw. The board has a number of snakes. If a player's piece lands on a square with a snake head, the piece is automatically moved to the square containing the snake's tail. Similarly, a piece can automatically move from a ladder foot to the ladder top. The player whose piece is the first to reach the 100th square wins.



The above OO domain model omits the ladder class for simplicity. It can be included in a similar fashion to the Snake class.

OODMs do not contain solution-specific classes (i.e. classes that are used in the solution domain but do not exist in the problem domain). For example, a class called DatabaseConnection could appear in a class diagram but not usually in an OO domain model because DatabaseConnection is something related to a software solution but not an entity in the problem domain.

OODMs represents the class *structure* of the problem domain and not their behavior, just like class diagrams. To show behavior, use other diagrams such as sequence diagrams.

OODM notation is similar to class diagram notation but typically omit methods and navigability.

Modeling Behaviors

Activity Diagrams - Basic ★★★☆

Software projects often involve *workflows*. Workflows define the flow in which a process or a set of tasks is executed. Understanding such workflows is important for the success of the software project.

Some examples in which a certain workflow is relevant to software project:

📦 A software that automates the work of an insurance company needs to take into account the workflow of processing an insurance claim.

📦 The algorithm of a price of code represents the workflow (i.e. the execution flow) of the code.

- 🎓 UML 📲 Activity Diagrams → Introduction → What
- 🎓 UML 📲 Activity Diagrams → Basic Notation → Linear Paths
- 🎓 UML 📲 Activity Diagrams → Basic Notation → Alternate Paths
- 🎓 UML 📲 Activity Diagrams → Basic Notation → Parellel Paths

Sequence Diagrams - Basic ★★☆☆

- 🎓 UML 📲 Sequence Diagrams → Introduction
- 🎓 UML 📲 Sequence Diagrams → Basic Notation
- 🎓 UML 📲 Sequence Diagrams → Loops
- 🎓 UML 📲 Sequence Diagrams → Object Creation
- 🎓 UML 📲 Sequence Diagrams → Minimal Notation

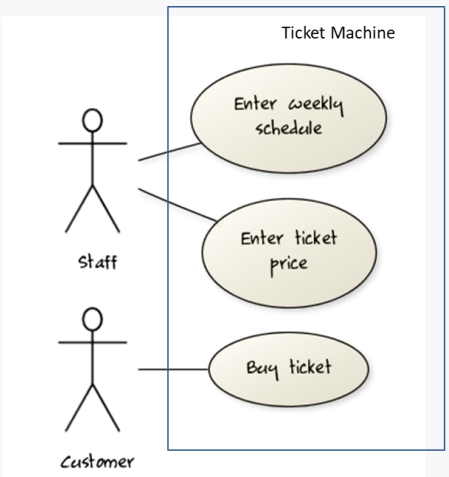
Sequence Diagrams - Intermediate ★★★☆

- 🎓 UML 📲 Sequence Diagrams → Object Deletion
- 🎓 UML 📲 Sequence Diagrams → Self-Invocation
- 🎓 UML 📲 Sequence Diagrams → Alternative Paths
- 🎓 UML 📲 Sequence Diagrams → Optional Paths

Use Case Diagrams ★★★☆

Use case diagrams model the mapping between features of a system and its user roles.

📦 A simple use case diagram:

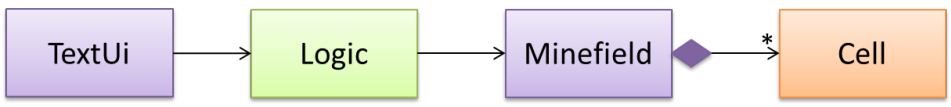


Modeling a Solution

Introduction ★★☆☆

You can use models to analyze and design a software before you start coding.

Suppose You are planning to implement a simple minesweeper game that has a text based UI and a GUI. Given below is a possible OOP design for the game.



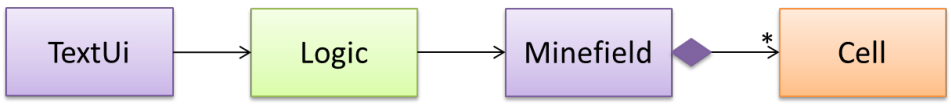
Before jumping into coding, you may want to find out things such as,

- Is this class structure is able to produce the behavior we want?
- What API should each class have?
- Do we need more classes?

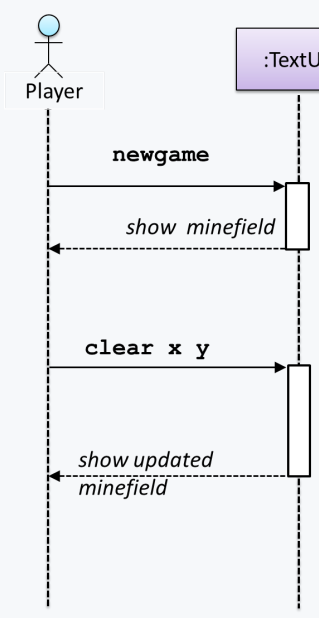
To answer those questions, you can analyze the how the objects of these classes will interact with each other to produce the behavior you want.

Basic ★★★☆

As mentioned in [Design → Modeling → Modeling a Solutions → Introduction], this is the Minesweeper design you have come up with so far. Our objective is to analyze, evaluate, and refine that design.

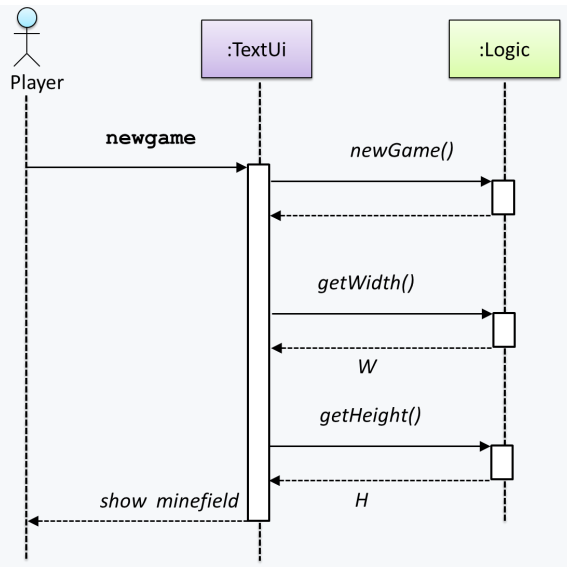


Let us start by modelling a sample interaction between the person playing the game and the `TextUi` object.



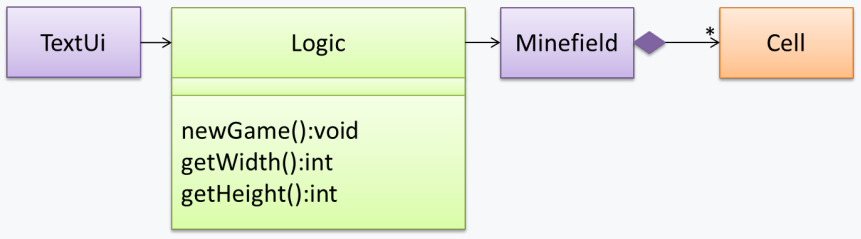
`newgame` and `clear x y` represent commands typed by the `Player` on the `TextUi`.

How does the `TextUi` object carry out the requests it has received from player? It would need to interact with other objects of the system. Because the `Logic` class is the one that controls the game logic, the `TextUi` needs to collaborate with `Logic` to fulfill the `newgame` request. Let us extend the model to capture that interaction.

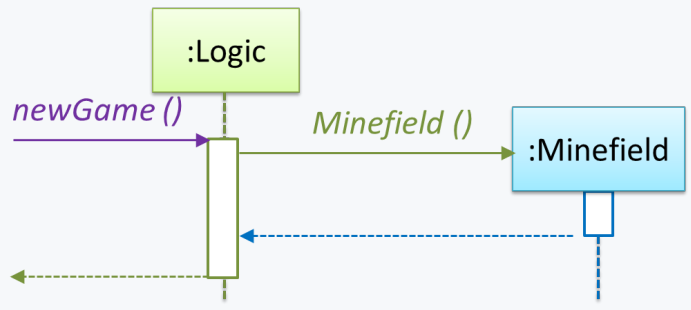


`W` = Width of the minefield; `H` = Height of the minefield

The above diagram assumes that `W` and `H` are the only information `TextUi` requires to display the minefield to the `Player`. Note that there could be other ways of doing this.
The `Logic` methods we conceptualized in our modelling so far are:

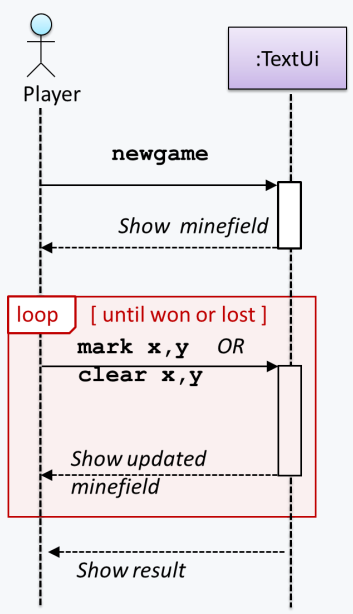


Now, let us look at what other objects and interactions are needed to support the `newGame()` operation. It is likely that a new `Minefield` object is created when the `newGame()` method is called.



Note that the behavior of the `Minefield` constructor has been abstracted away. It can be designed at a later stage.

Given below are the interactions between the player and the Text UI for the whole game.



Note that a similar technique can be used when discovering/defining the architecture-level APIs.

Software Architecture

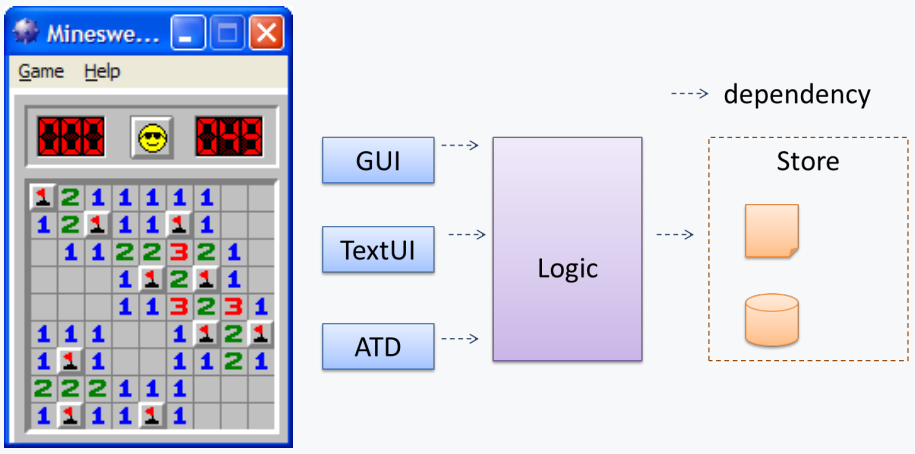
Introduction

What ★☆☆☆

> The software architecture of a program or computing system is the structure or structures of the system, which comprise software elements, the externally visible properties of those elements, and the relationships among them. Architecture is concerned with the public side of interfaces; private details of elements—details having to do solely with internal implementation—are not architectural.
>
> -- *Software Architecture in Practice (2nd edition)*, Bass, Clements, and Kazman

The software architecture shows the overall organization of the system and can be viewed as a very high-level design. It usually consists of a set of interacting components that fit together to achieve the required functionality. It should be a simple and technically viable structure that is well-understood and agreed-upon by everyone in the development team, and it forms the basis for the implementation.

📦 A possible architecture for a *Minesweeper* game



Main components:

- `GUI`: Graphical user interface
- `TextUi`: Textual user interface
- `ATD`: An automated test driver used for testing the game logic
- `Logic`: computation and logic of the game
- `Store`: storage and retrieval of game data (high scores etc.)

The architecture is typically designed by the *software architect*, who provides the technical vision of the system and makes high-level (i.e. architecture-level) technical decisions about the project.

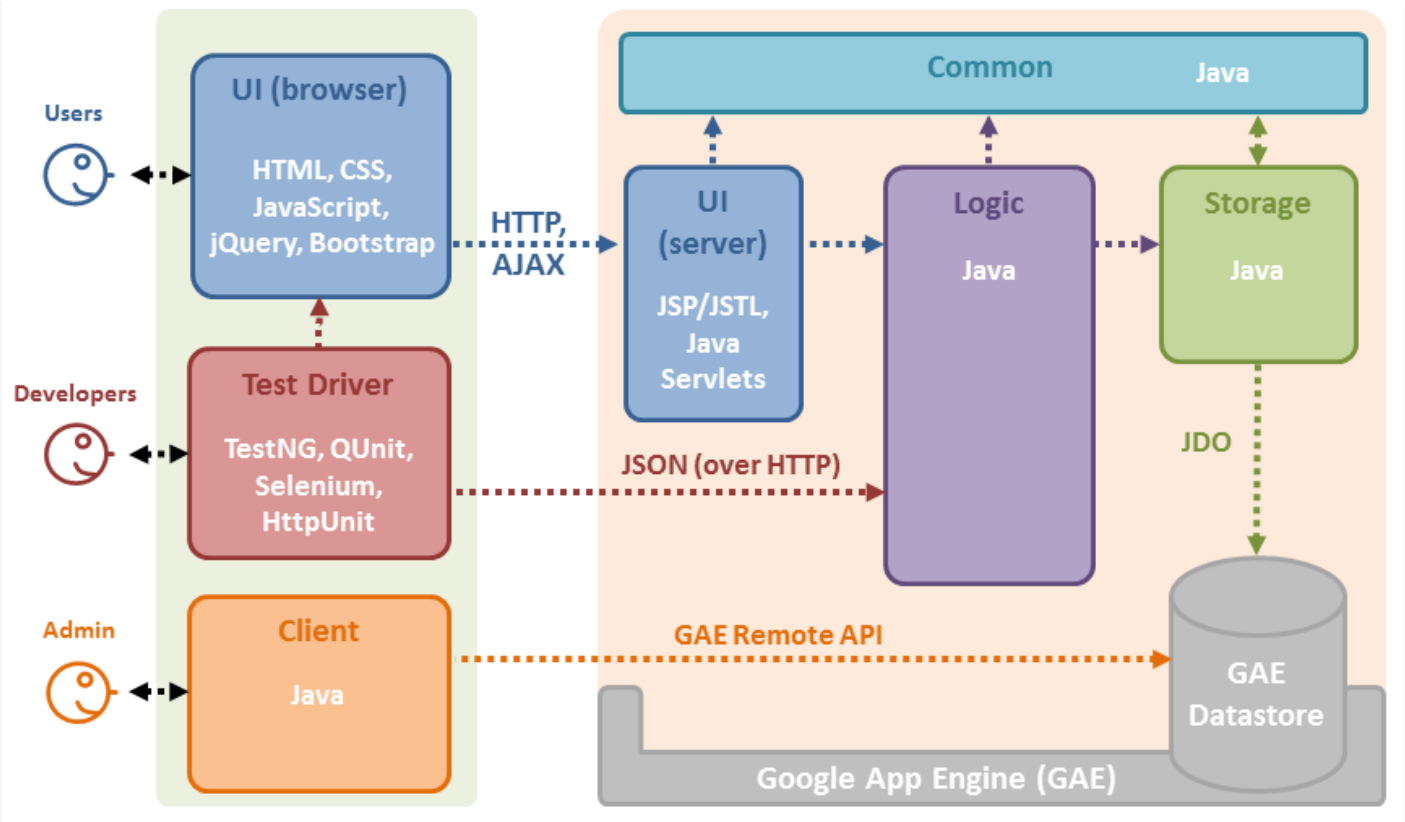
Architecture Diagrams

Reading ★☆☆☆

Architecture diagrams are free-form diagrams. There is no universally adopted standard notation for architecture diagrams. Any symbol that reasonably describes the architecture may be used.

📦 Some example architecture diagrams:

TEAMMATES | se-edu/addressbook-level4 | Example 1 | Example 2 | Example 3

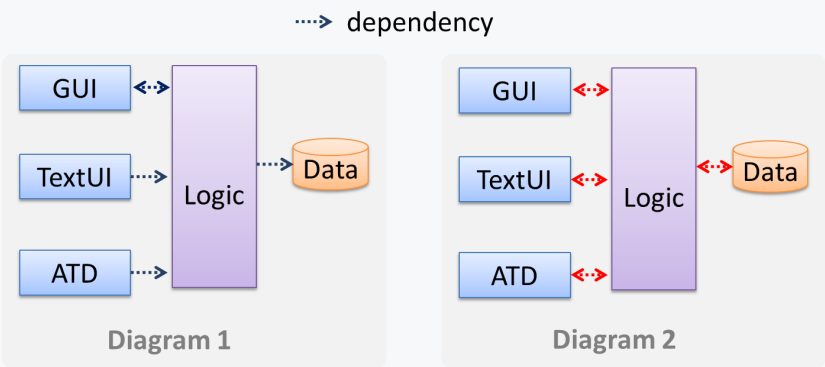


Drawing ★☆☆☆

While architecture diagrams have no standard notation, try to follow these basic guidelines when drawing them.

- Minimize the variety of symbols. If the symbols you choose do not have widely-understood meanings e.g. A drum symbol is widely-understood as representing a database, explain their meaning.
- Avoid the indiscriminate use of double-headed arrows to show interactions between components.

📦 Consider the two architecture diagrams of the same software given below. Because `Diagram 2` uses double headed arrows, the important fact that GUI has a bi-directional dependency with the Logic component is no longer captured.



Architectural Styles

Introduction

What ★★★☆

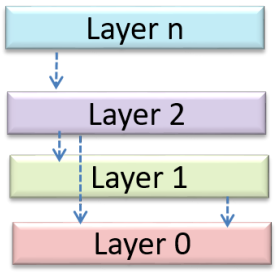
Software architectures follow various high-level styles (aka *architectural patterns*), just like building architectures follow various architecture styles.

📦 n-tier style, client-server style, event-driven style, transaction processing style, service-oriented style, pipes-and-filters style, message-driven style, broker style, ...

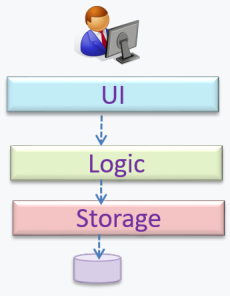
N-tier Architectural Style

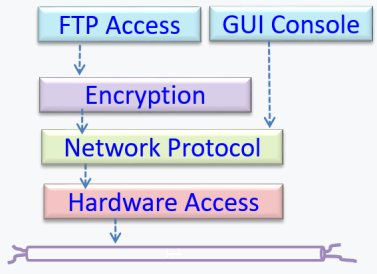
What ★★☆☆

In the *n-tier* style, higher layers make use of services provided by lower layers. Lower layers are independent of higher layers. Other names: *multi-layered*, *layered*.



Operating systems and network communication software often use n-tier style.

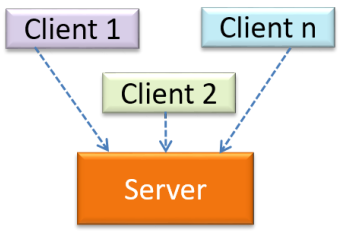




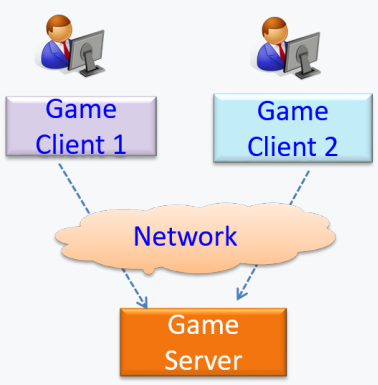
Client-server Architectural Style

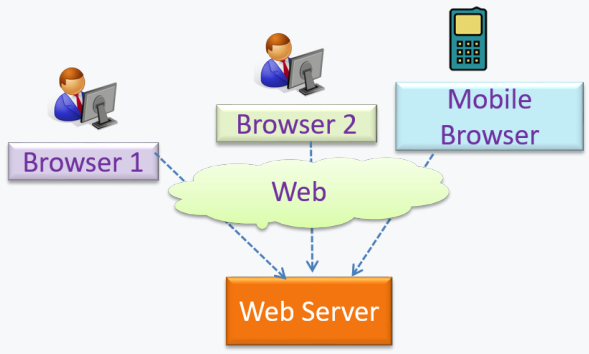
What ★★★☆

The *client-server* style has at least one component playing the role of a server and at least one client component accessing the services of the server. This is an architectural style used often in distributed applications.



The online game and the Web application below uses the client-server style.

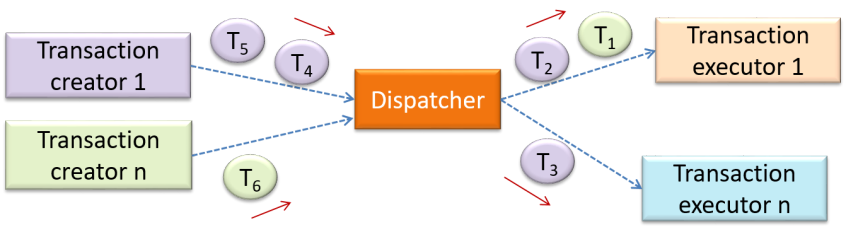




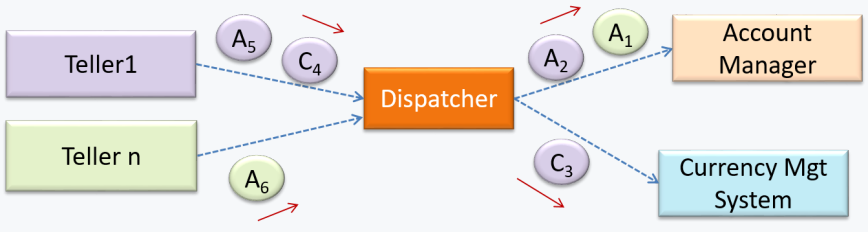
Transaction Processing Architectural Style

What ★★★☆

The *transaction processing* style divides the workload of the system down to a number of *transactions* which are then given to a *dispatcher* that controls the execution of each transaction. Task queuing, ordering, undo etc. are handled by the dispatcher.



In this example from a Banking system, transactions are generated by the terminals used by tellers which are then sent to a central dispatching unit which in turn dispatches the transactions to various other units to execute.

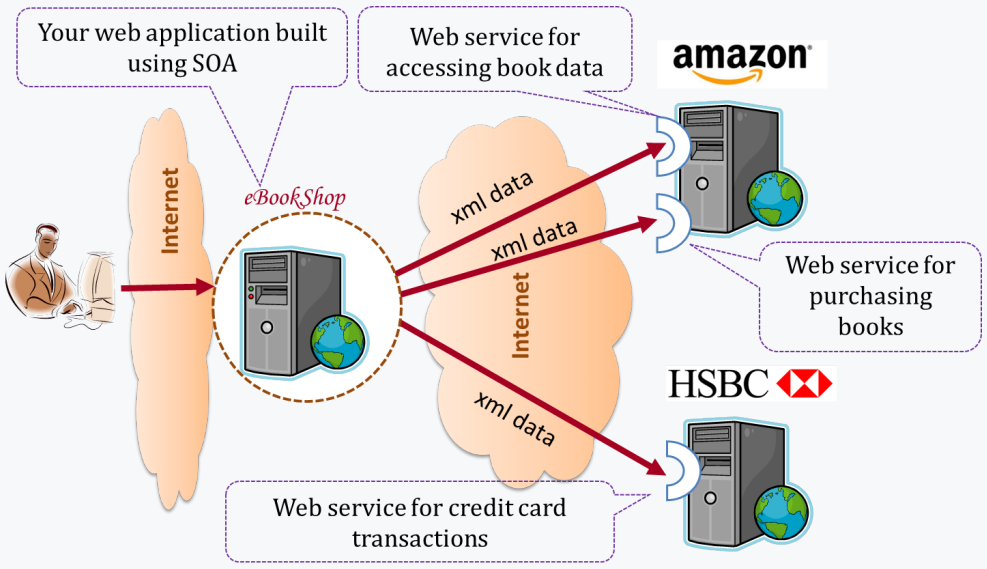


Service-oriented Architectural Style

What ★★★☆

The *service-oriented architecture* (SOA) style builds applications by combining functionalities packaged as *programmatically accessible services*. SOA aims to achieve interoperability between distributed services, which may not even be implemented using the same programming language. A common way to implement SOA is through the use of *XML web services* where the web is used as the medium for the services to interact, and XML is used as the language of communication between service providers and service users.

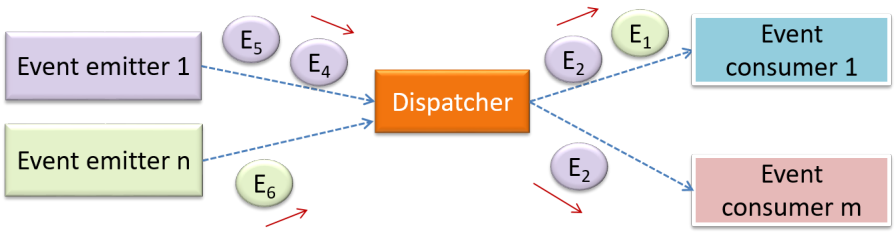
📦 Suppose that Amazon.com provides a web service for customers to browse and buy merchandise, while HSBC provides a web service for merchants to charge HSBC credit cards. Using these web services, an 'eBookShop' web application can be developed that allows HSBC customers to buy merchandise from Amazon and pay for them using HSBC credit cards. Because both Amazon and HSBC services follow the SOA architecture, their web services can be reused by the web application, even if all three systems use different programming platforms.



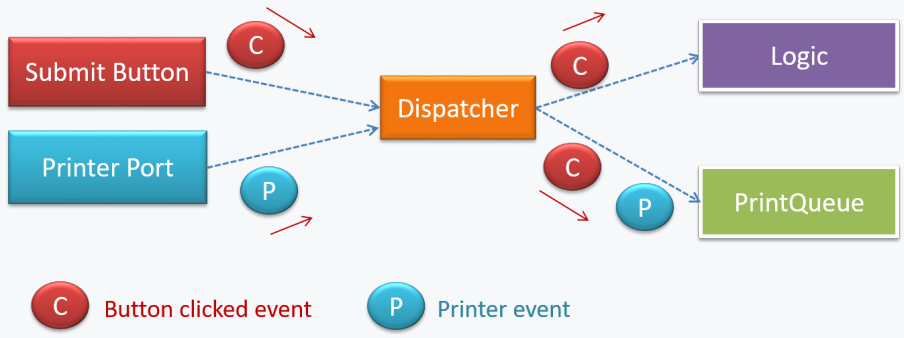
Event-driven Architectural Style

What ★★☆☆

***Event-driven* style controls the flow of the application by detecting events from event *emitters* and communicating those events to interested event *consumers* .** This architectural style is often used in GUIs.



📦 When the 'button clicked' event occurs in a GUI, that event can be transmitted to components that are interested in reacting to that event. Similarly, events detected at a Printer port can be transmitted to components related to operating the Printer. The same event can be sent to multiple consumers too.



More

Using Styles ★★★☆

Most applications use a mix of these architectural styles.

📦 An application can use a client-server architecture where the server component comprises several layers, i.e. it uses the n-Tier architecture.

Software Design Patterns

Introduction

What ★★☆☆

Design Pattern : An *elegant reusable solution* to a *commonly recurring problem* within a *given context* in software design.

In software development, there are certain problems that recur in a certain context.

Some examples of recurring design problems:

Design Context	Recurring Problem
Assembling a system that makes use of other existing systems implemented using different technologies	What is the best architecture?
UI needs to be updated when the data in application backend changes	How to initiate an update to the UI when data changes without coupling the backend to the UI?

After repeated attempts at solving such problems, better solutions are discovered and refined over time. These solutions are known as design patterns, **a term popularized by the seminal book *Design Patterns: Elements of Reusable Object-Oriented Software* by the so-called "Gang of Four" (GoF)** written by Eric Gamma, Richard Helm, Ralph Johnson,and John Vlissides.

Format ★★☆☆

The common format to describe a pattern consists of the following components:

- **Context**: The situation or scenario where the design problem is encountered.
- **Problem**: The main difficulty to be resolved.
- **Solution**: The core of the solution. It is important to note that the solution presented only includes the most general details, which may need further refinement for a specific context.
- **Anti-patterns** (optional): Commonly used solutions, which are usually incorrect and/or inferior to the Design Pattern.
- **Consequences** (optional): Identifying the pros and cons of applying the pattern.
- **Other useful information** (optional): Code examples, known uses, other related patterns, etc.

Singleton Pattern

What ★★☆☆

Context

A certain classes should have no more than just one instance (e.g. the main controller class of the system). These single instances are commonly known as *singletons*.

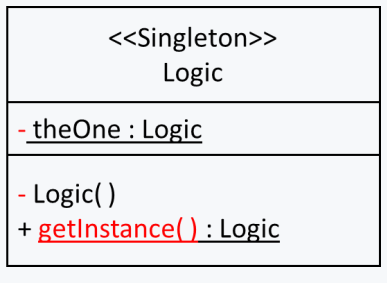
Problem

A normal class can be instantiated multiple times by invoking the constructor.

Solution

Make the constructor of the singleton class `private`, because a `public` constructor will allow others to instantiate the class at will. Provide a `public` class-level method to access the *single instance*.

Example:



Implementation ★★☆☆

Here is the typical implementation of how the Singleton pattern is applied to a class:

```
class Logic {
    private static Logic theOne = null;

    private Logic() {
        ...
    }

    public static Logic getInstance() {
        if (theOne == null) {
            theOne = new Logic();
        }
        return theOne;
    }
}
```

Notes:

- The constructor is `private`, which prevents instantiation from outside the class.
- The single instance of the singleton class is maintained by a `private` class-level variable.
- Access to this object is provided by a `public` class-level operation `getInstance()` which instantiates a single copy of the singleton class when it is executed for the first time. Subsequent calls to this operation return the single instance of the class.

If `Logic` was not a Singleton class, an object is created like this:

```
Logic m = new Logic();
```

But now, the `Logic` object needs to be accessed like this:

```
Logic m = Logic.getInstance();
```

Evaluation ★★★☆

Pros:

- easy to apply
- effective in achieving its goal with minimal extra work
- provides an easy way to access the singleton object from anywhere in the code base

Cons:

- The singleton object acts like a global variable that increases coupling across the code base.
- In testing, it is difficult to replace Singleton objects with stubs (static methods cannot be overridden)
- In testing, singleton objects carry data from one test to another even when we want each test to be independent of the others.

Given there are some significant cons, it is recommended that you apply the Singleton pattern when, in addition to requiring only one instance of a class, there is a risk of creating multiple objects by mistake, and creating such multiple objects has real negative consequences.

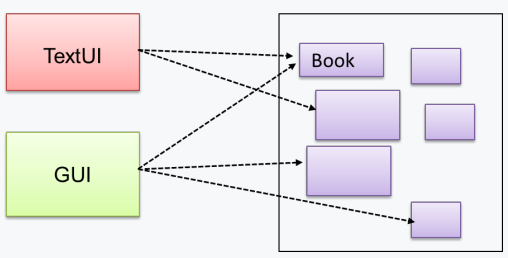
Facade Pattern

What ★★★☆

Context

Components need to access functionality deep inside other components.

The `UI` component of a `Library` system might want to access functionality of the `Book` class contained inside the `Logic` component.



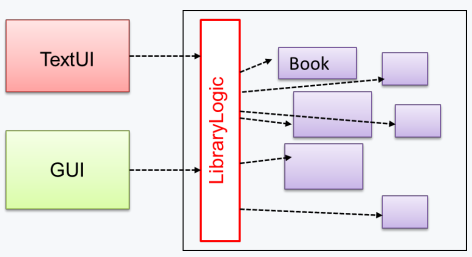
Problem

Access to the component should be allowed without exposing its internal details. e.g. the `UI` component should access the functionality of the `Logic` component without knowing that it contained a `Book` class within it.

Solution

Include a Facade class that sits between the component internals and users of the component such that all access to the component happens through the Facade class.

The following class diagram applies the Façade pattern to the `Library System` example. The `LibraryLogic` class is the Facade class.



Command Pattern

What ★★★☆

Context

A system is required to execute a number of commands, each doing a different task. For example, a system might have to support `Sort`, `List`, `Reset` commands.

Problem

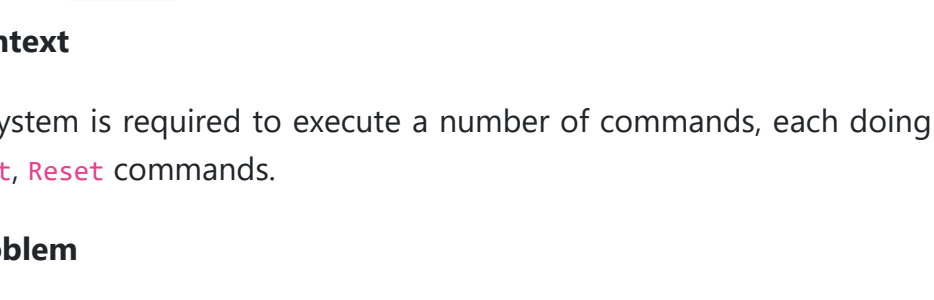
It is preferable that some part of the code executes these commands without having to know each command type. e.g., there can be a `CommandQueue` object that is responsible for queuing commands and executing them without knowledge of what each command does.

Solution

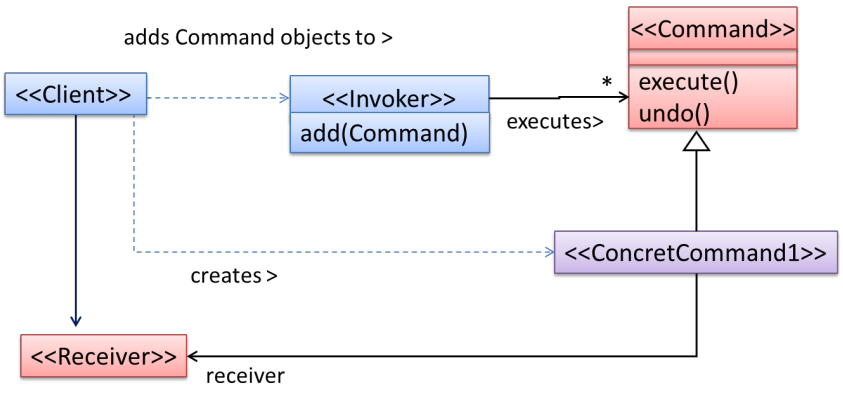
The essential element of this pattern is to have a general `<<Command>>` object that can be passed around, stored, executed, etc without knowing the type of command (i.e. via polymorphism).

Let us examine an example application of the pattern first:

In the example solution below, the `CommandCreator` creates `List`, `Sort`, and `Reset Command` objects and adds them to the `CommandQueue` object. The `CommandQueue` object treats them all as `Command` objects and performs the execute/undo operation on each of them without knowledge of the specific `Command` type. When executed, each `Command` object will access the `DataStore` object to carry out its task. The `Command` class can also be an abstract class or an interface.



The general form of the solution is as follows.



The `<<Client>>` creates a `<<ConcreteCommand>>` object, and passes it to the `<<Invoker>>`. The `<<Invoker>>` object treats all commands as a general `<<Command>>` type. `<<Invoker>>` issues a request by calling `execute()` on the command. If a command is undoable, `<<ConcreteCommand>>` will store the state for undoing the command prior to invoking `execute()`. In addition, the `<<ConcreteCommand>>` object may have to be linked to any `<<Receiver>>` of the command (?) before it is passed to the `<<Invoker>>`. Note that an application of the command pattern does not have to follow the structure given above.

Model View Controller (MVC) Pattern

What ★★☆☆

Context

Most applications support storage/retrieval of information, displaying of information to the user (often via multiple UIs having different formats), and changing stored information based on external inputs.

Problem

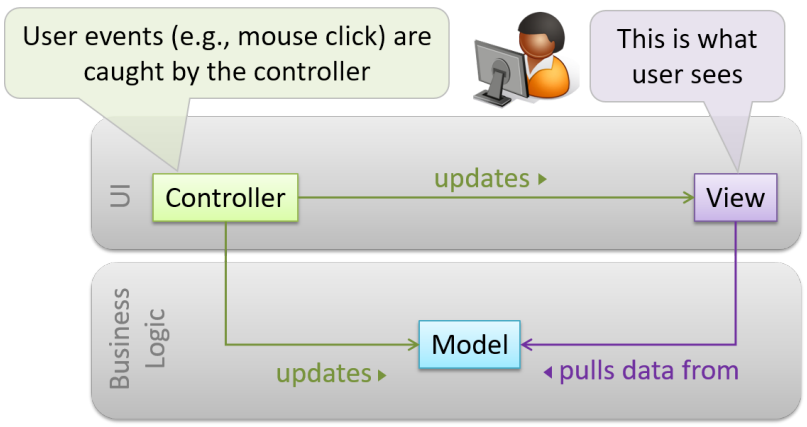
The high coupling that can result from the interlinked nature of the features described above.

Solution

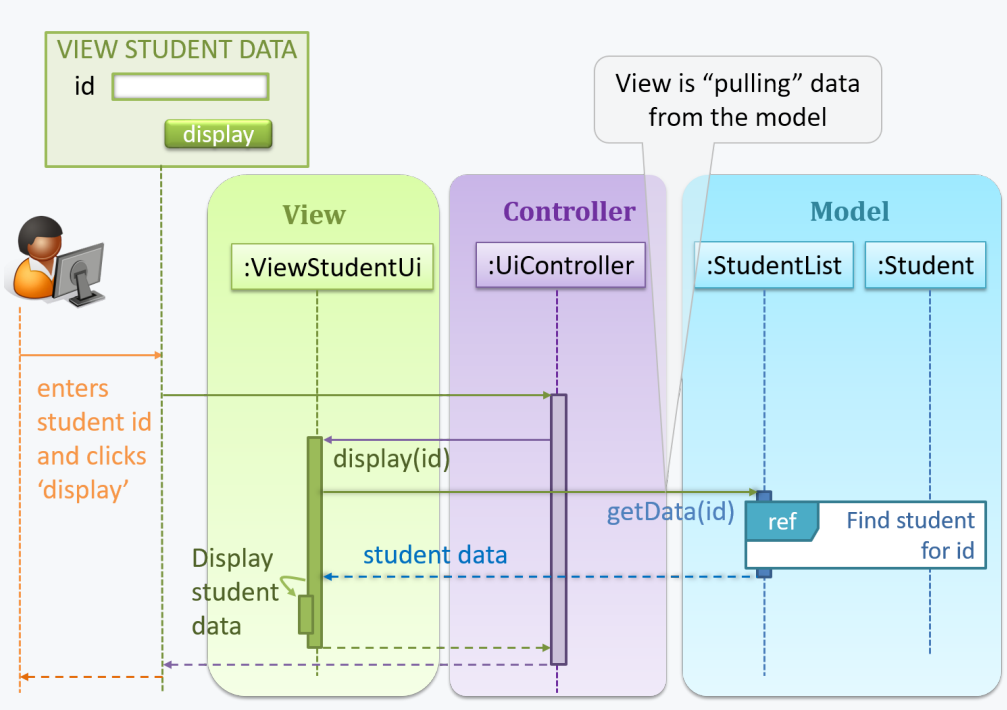
Decouple data, presentation, and control logic of an application by separating them into three different components: *Model*, *View* and *Controller*.

- *View*: Displays data, interacts with the user, and pulls data from the model if necessary.
- *Controller*: Detects UI events such as mouse clicks, button pushes and takes follow up action. Updates/changes the model/view when necessary.
- *Model*: Stores and maintains data. Updates views if necessary.

The relationship between the components can be observed in the diagram below. Typically, the UI is the combination of view and controller.



📦 Given below is a concrete example of MVC applied to a student management system. In this scenario, the user is retrieving data of one student.



In the diagram above, when the user clicks on a button using the UI, the ‘click’ event is caught and handled by the `UiController`. The `ref` frame indicates that the interactions within that frame have been extracted out to another separate sequence diagram.

Note that in a simple UI where there’s only one view, Controller and View can be combined as one class.

There are many variations of the MVC model used in different domains. For example, the one used in a desktop GUI could be different from the one used in a Web application.

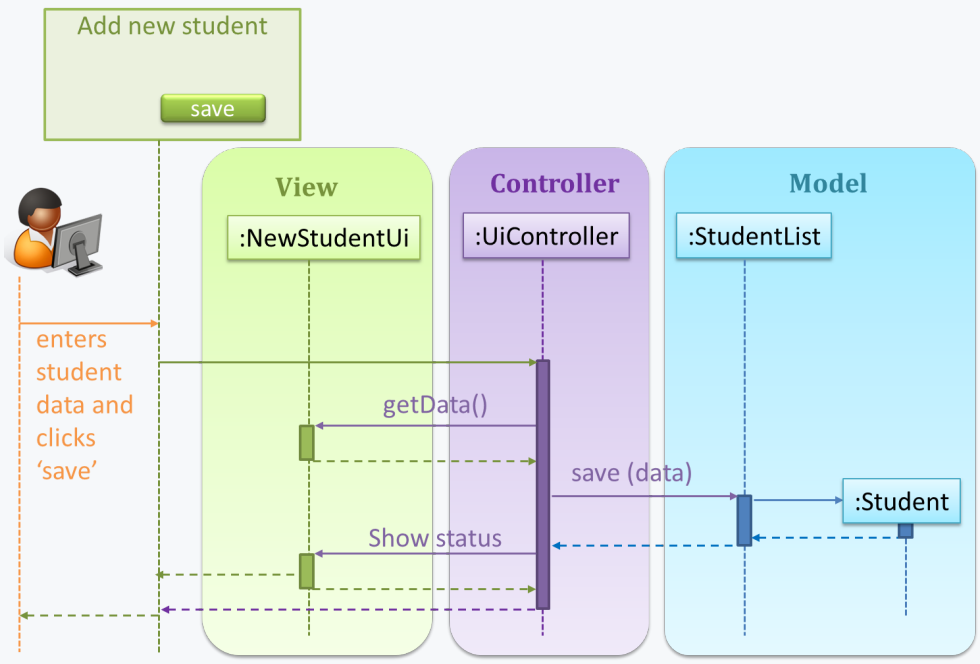
Observer Pattern

What ★★★☆

Context

An object (possibly, more than one) is interested to get notified when a change happens to another object. That is, some objects want to 'observe' another object.

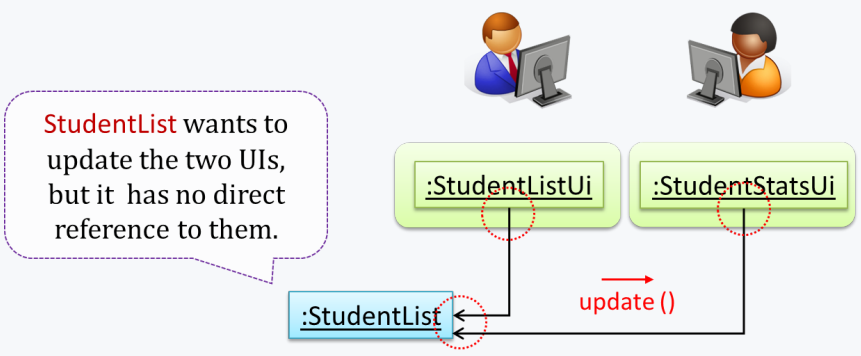
Consider this scenario from the a student management system where the user is adding a new student to the system.



Now, assume the system has two additional views used in parallel by different users:

- `StudentListUi`: that accesses a list of students and
- `StudentStatsUi`: that generates statistics of current students.

When a student is added to the database using `NewStudentUi` shown above, both `StudentListUi` and `StudentStatsUi` should get updated automatically, as shown below.



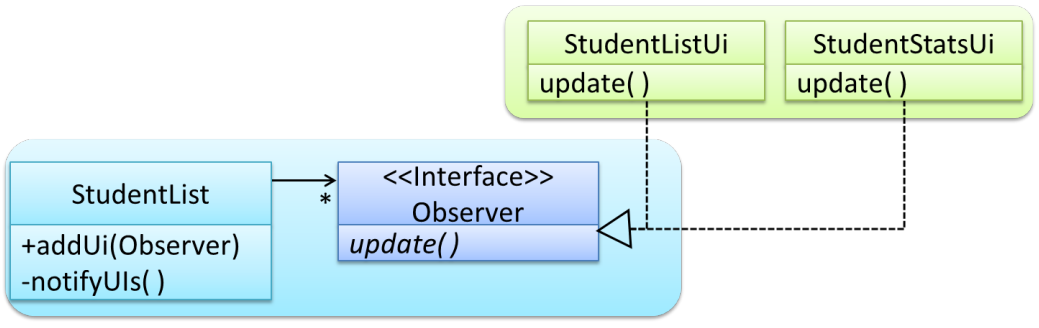
However, the `StudentList` object has no knowledge about `StudentListUi` and `StudentStatsUi` (note the direction of the navigability) and has no way to inform those objects. This is an example of the type of problem addressed by the Observer pattern.

Problem

The 'observed' object does not want to be coupled to objects that are 'observing' it.

Solution

Force the communication through an interface known to both parties.



Here is the Observer pattern applied to the student management system.

During the initialization of the system,

1. First, create the relevant objects.

```
StudentList studentList = new StudentList();
StudentListUi listUi = new StudentListUi();
StudentStatusUi statusUi = new StudentStatsUi();
```

2. Next, the two UIs indicate to the `StudentList` that they are interested in being updated whenever `StudentList` changes. This is also known as 'subscribing for updates'.

```
studentList.addUi(listUi);
studentList.addUi(statusUi);
```

3. Within the `addUi` operation of `StudentList`, all Observer objects subscribers are added to an internal data structure called `observerList`.

```
//StudentList class
public void addUi(Observer o) {
    observerList.add(o);
}
```

Now, whenever the data in `StudentList` changes (e.g. when a new student is added to the `StudentList`),

1. All interested observers are updated by calling the `notifyUIs` operation.

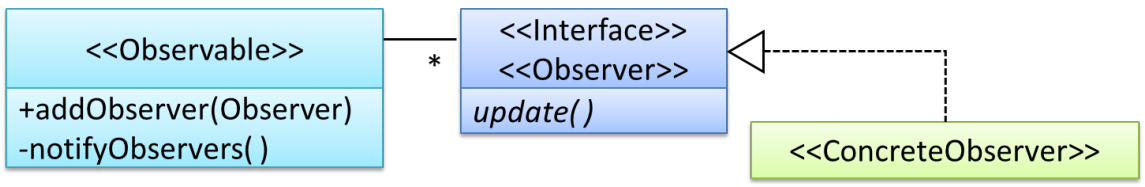
```
//StudentList class
public void notifyUIs() {
    //for each observer in the list
    for(Observer o: observerList){
        o.update();
    }
}
```

2. UIs can then pull data from the `StudentList` whenever the `update` operation is called.

```
//StudentListUI class
public void update() {
    //refresh UI by pulling data from StudentList
}
```

Note that `StudentList` is unaware of the exact nature of the two UIs but still manages to communicate with them via an intermediary.

Here is the generic description of the observer pattern:



- `<<Observer>>` is an interface: any class that implements it can observe an `<<Observable>>`. Any number of `<<Observer>>` objects can observe (i.e. listen to changes of) the `<<Observable>>` object.
- The `<<Observable>>` maintains a list of `<<Observer>>` objects. `addObserver(Observer)` operation adds a new `<<Observer>>` to the list of `<<Observer>>s`.
- Whenever there is a change in the `<<Observable>>`, the `notifyObservers()` operation is called that will call the `update()` operation of all `<<Observer>>s` in the list.

📦 In a GUI application, how is the Controller notified when the "save" button is clicked? UI frameworks such as JavaFX has inbuilt support for the Observer pattern.

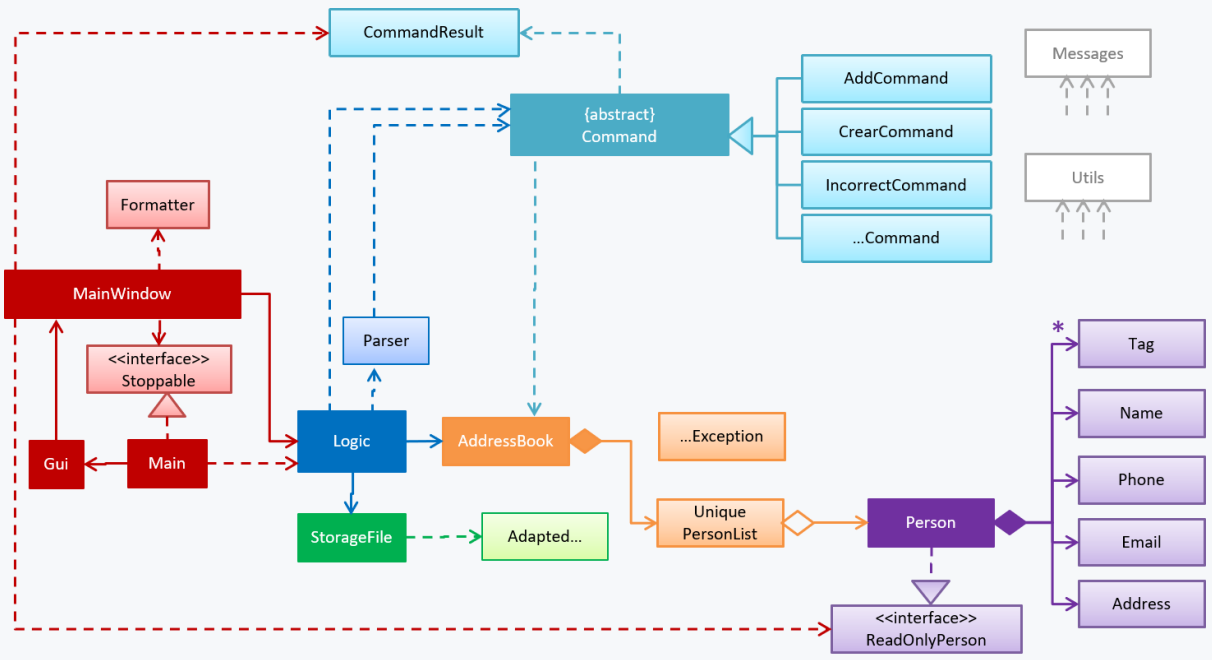
Design Approaches

Multi-Level Design

What ★★☆☆

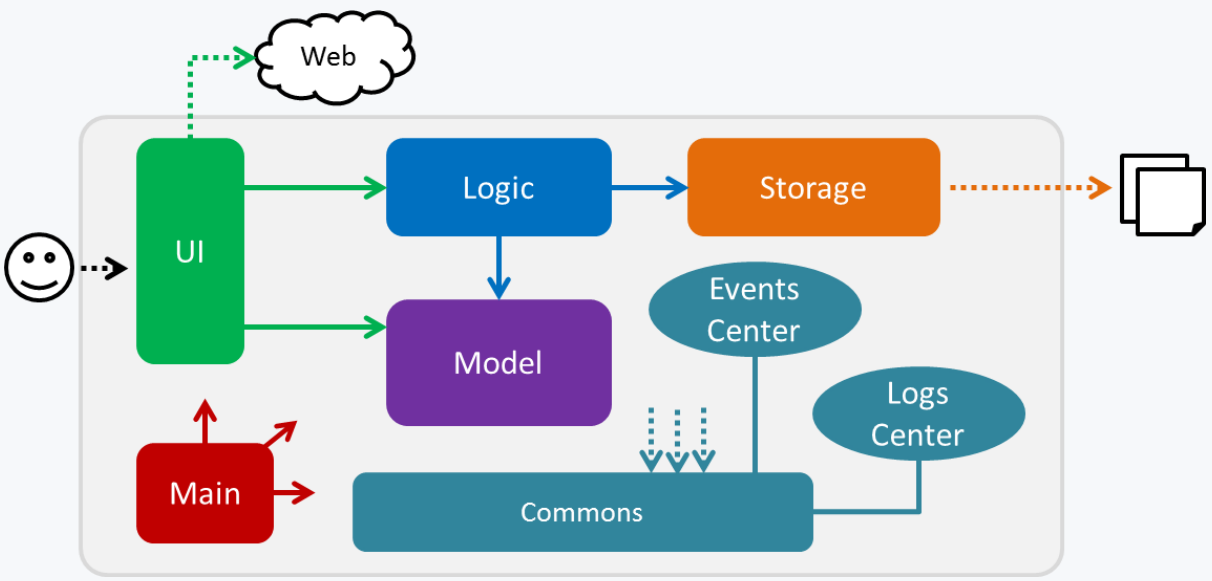
In a smaller system, design of the entire system can be shown in one place.

This class diagram of [se-edu/addressbook-level3] depicts the design of the entire software.



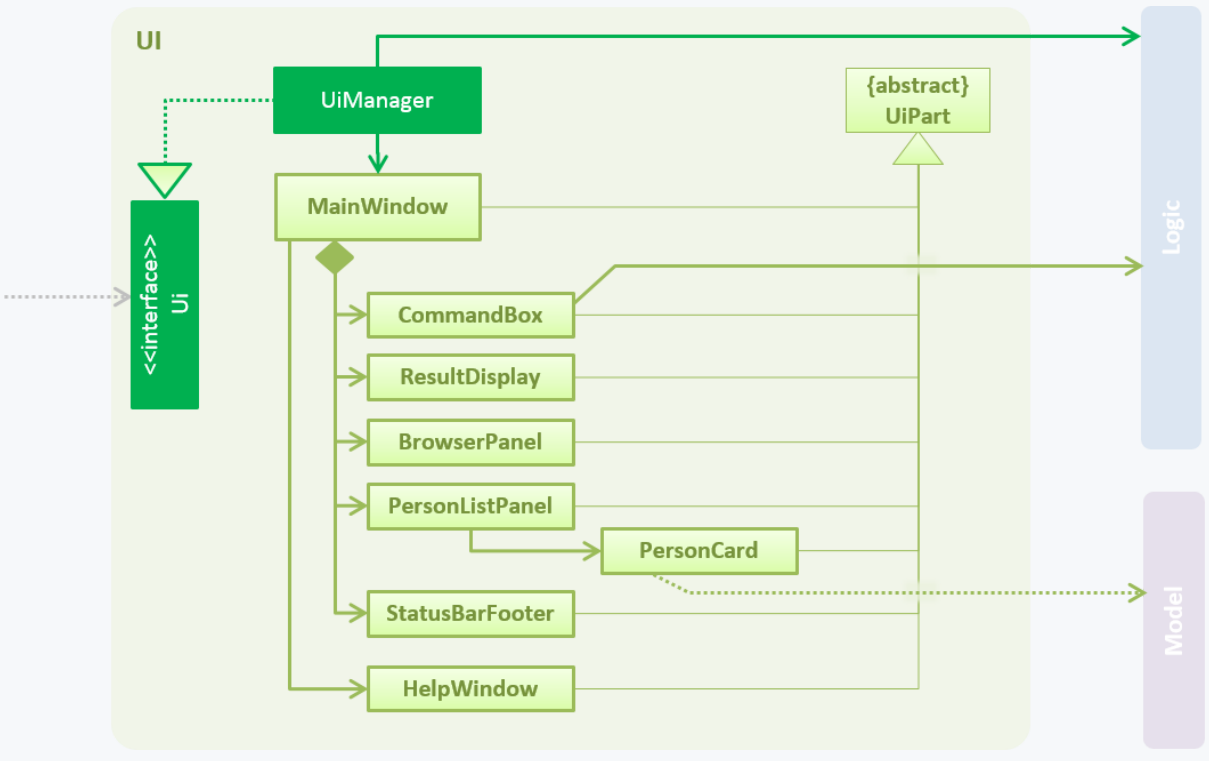
Design of bigger systems needs to be done/shown at multiple levels.

This architecture diagram of [se-edu/addressbook-level4] depicts the high-level design of the software.



Here are examples of lower level designs of some components of the same software:

UI | Logic | Storage



Top-Down and Bottom-Up Design

What ★★★☆

Multi-level design can be done in a top-down manner, bottom-up manner, or as a mix.

- Top-down: Design the high-level design first and flesh out the lower levels later. This is especially useful when designing big and novel systems where the high-level design needs to be stable before lower levels can be designed.
- Bottom-up: Design lower level components first and put them together to create the higher-level systems later. This is not usually scalable for bigger systems. One instance where this approach might work is when designing a variations of an existing system or re-purposing existing components to build a new system.
- Mix: Design the top levels using the top-down approach but switch to a bottom-up approach when designing the bottom levels.

Agile Design

What ★★★☆

***Agile design* can be contrasted with *full upfront design* in the following way**:

> **Agile designs are emergent, they're not defined up front.** Your overall system design will emerge over time, evolving to fulfill new requirements and take advantage of new technologies as appropriate. Although you will often do **some initial architectural modeling at the very beginning** of a project, this will be just enough to get your team going. This approach does not produce a fully documented set of models in place before you may begin coding. -- adapted from agilemodeling.com

SECTION: IMPLEMENTATION

IDEs

Introduction

What ★☆☆☆

Professional software engineers often write code using *Integrated Development Environments (IDEs)*. IDEs support all development-related work within the same tool.

An IDE generally consists of:

- A source code editor that includes features such as syntax coloring, auto-completion, easy code navigation, error highlighting, and code-snippet generation.
- A compiler and/or an interpreter (together with other build automation support) that facilitates the compilation/linking/running/deployment of a program.
- A debugger that allows the developer to execute the program one step at a time to observe the run-time behavior in order to locate bugs.
- Other tools that aid various aspects of coding e.g. support for automated testing, drag-and-drop construction of UI components, version management support, simulation of the target runtime platform, and modeling support.

Examples of popular IDEs:

- Java: Eclipse, Intellij IDEA, NetBeans
- C#, C++: Visual Studio
- Swift: XCode
- Python: PyCharm

Some Web-based IDEs have appeared in recent times too e.g., Amazon's Cloud9 IDE.

Some experienced developers, in particular those with a UNIX background, prefer lightweight yet powerful text editors with scripting capabilities (e.g. Emacs) over heavier IDEs.

Debugging

What ★★★☆

***Debugging* is the process of discovering defects in the program.** Here are some approaches to debugging:

- 👎 **Bad** -- **By inserting temporary print statements**: This is an ad-hoc approach in which print statements are inserted in the program to print information relevant to debugging, such as variable values. e.g. `Exiting process() method, x is 5.347`. This approach is not recommended due to these reasons.
  - Incurs extra effort when inserting and removing the print statements.
  - Unnecessary program modifications increases the risk of introducing errors into the program.
  - These print statements, if not promptly removed, may even appear unexpectedly in the production version.
- 👎 **Bad** -- **By manually tracing through the code**: Otherwise known as ‘eye-balling’, this approach doesn't have the cons of the previous approach, but it too is not recommended (other than as a 'quick try') due to these reasons:
  - It is difficult, time consuming, and error-prone technique.
  - If you didn't spot the error while writing code, you might not spot the error when reading code too.
- 👍 **Good** -- **Using a debugger**: A debugger tool allows you to pause the execution, then step through one statement at a time while examining the internal state if necessary. Most IDEs come with an inbuilt debugger. **This is the recommended approach for debugging**.

Code Quality

Introduction

Basic ★★★☆

> Always code as if the person who ends up maintaining your code will be a violent psychopath who knows where you live. -- Martin Golding

Production code needs to be of high quality . Given how the world is becoming increasingly dependent of software, poor quality code is something we cannot afford to tolerate.

Guideline: Maximise Readability

Introduction ★☆☆☆

> Programs should be written and polished until they acquire publication quality. --Niklaus Wirth

Among various dimensions of code quality, such as run-time efficiency, security, and robustness, one of the most important is understandability. This is because in any non-trivial software project, code needs to be read, understood, and modified by other developers later on. Even if we do not intend to pass the code to someone else, code quality is still important because we all become 'strangers' to our own code someday.

> The two code samples given below achieve the same functionality, but one is easier to read.

Bad

```
int subsidy() {
    int subsidy;
    if (!age) {
        if (!sub) {
            if (!notFullTime) {
                subsidy = 500;
            } else {
                subsidy = 250;
            }
        } else {
            subsidy = 250;
        }
    } else {
        subsidy = -1;
    }
    return subsidy;
}
```

Good

```
int calculateSubsidy() {
    int subsidy;
    if (isSenior) {
        subsidy = REJECT_SENIOR;
    } else if (isAlreadySubsidised) {
        subsidy = SUBSIDISED_SUBSIDY;
    } else if (isPartTime) {
        subsidy = FULLTIME_SUBSIDY * RATIO;
    } else {
        subsidy = FULLTIME_SUBSIDY;
    }
    return subsidy;
}
```

Basic

Avoid Long Methods ★★☆☆

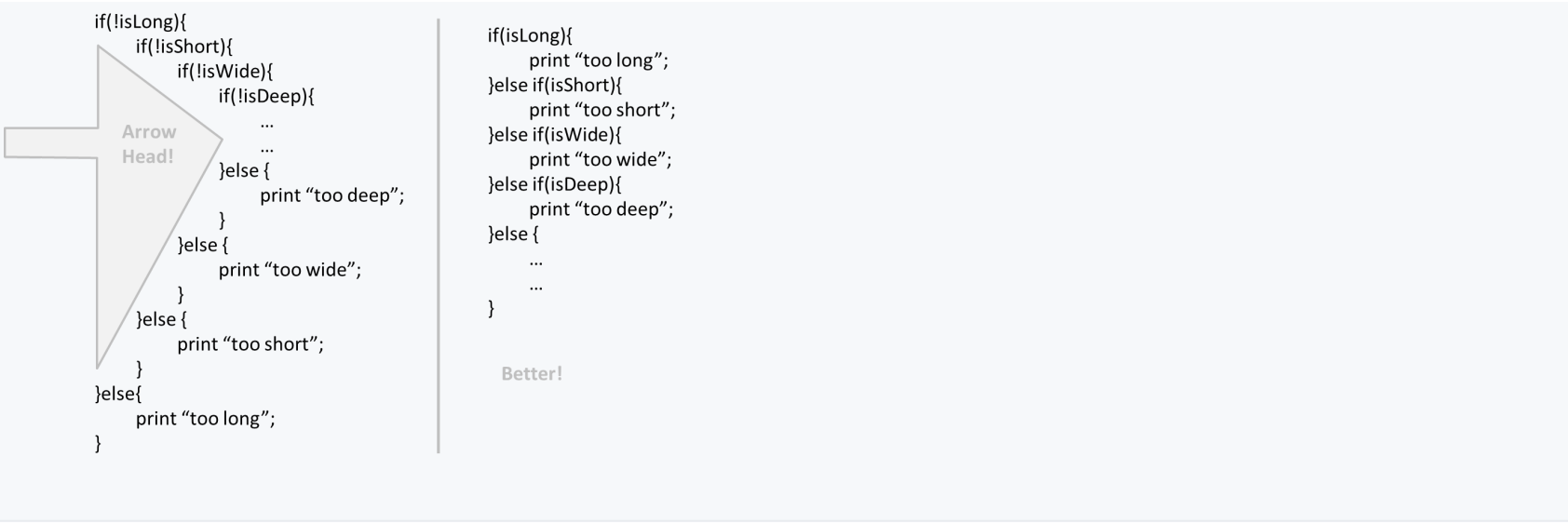
Be wary when a method is longer than the computer screen, and take corrective action when it goes beyond 30 LOC (lines of code). The bigger the haystack, the harder it is to find a needle.

Avoid Deep Nesting ★★☆☆

> If you need more than 3 levels of indentation, you're screwed anyway, and should fix your program. --Linux 1.3.53 CodingStyle

In particular, avoid *arrowhead* style code.

> Example:



Avoid Complicated Expressions ★★☆☆

Avoid complicated expressions, especially those having many negations and nested parentheses. If you must evaluate complicated expressions, have it done in steps (i.e. calculate some intermediate values first and use them to calculate the final value).

📦 Example:

👎 **Bad**

```
return ((length < MAX_LENGTH) || (previousSize != length)) && (typeCode == URGENT);
```

👍 **Good**

```
boolean isWithinSizeLimit = length < MAX_LENGTH;
boolean isSameSize = previousSize != length;
boolean isValidCode = isWithinSizeLimit || isSameSize;

boolean isUrgent = typeCode == URGENT;

return isValidCode && isUrgent;
```

> The competent programmer is fully aware of the strictly limited size of his own skull; therefore he approaches the programming task in full humility, and among other things he avoids clever tricks like the plague. -- Edsger Dijkstra

Avoid Magic Numbers ★★☆☆

When the code has a number that does not explain the meaning of the number, we call that a magic number (as in “the number appears as if by magic”). Using a *named constant* makes the code easier to understand because the name tells us more about the meaning of the number.

📦 Example:

👎 **Bad**

```
return 3.14236;
...
return 9;
```

👍 **Good**

```
static final double PI = 3.14236;
static final int MAX_SIZE = 10;
...
return PI;
...
return MAX_SIZE-1;
```

Similarly, we can have ‘magic’ values of other data types.

👎 **Bad**

```
"Error 1432"  // A magic string!
```

Make the Code Obvious ★★☆☆

Make the code as explicit as possible, even if the language syntax allows them to be implicit. Here are some examples:

- [`Java`] Use explicit type conversion instead of implicit type conversion.
- [`Java`, `Python`] Use parentheses/braces to show grouping even when they can be skipped.
- [`Java`, `Python`] Use enumerations when a certain variable can take only a small number of finite values. For example, instead of declaring the variable 'state' as an integer and using values 0,1,2 to denote the states 'starting', 'enabled', and 'disabled' respectively, declare 'state' as type `SystemState` and define an enumeration `SystemState` that has values `'STARTING'`, `'ENABLED'`, and `'DISABLED'`.

Intermediate

Structure Code Logically ★★★☆

Lay out the code so that it adheres to the logical structure. The code should read like a story. Just like we use section breaks, chapters and paragraphs to organize a story, use classes, methods, indentation and line spacing in your code to group related segments of the code. For example, you can use blank lines to group related statements together. Sometimes, the correctness of your code does not depend on the order in which you perform certain intermediary steps. Nevertheless, this order may affect the clarity of the story you are trying to tell. Choose the order that makes the story most readable.

Do Not 'Trip Up' Reader ★★★☆

Avoid things that would make the reader go 'huh?', such as,

- unused parameters in the method signature
- similar things look different
- different things that look similar
- multiple statements in the same line
- data flow anomalies such as, pre-assigning values to variables and modifying it without any use of the pre-assigned value

Practice KISSing ★★★☆

As the old adage goes, **"keep it simple, stupid" (KISS). Do not try to write 'clever' code.** For example, do not dismiss the brute-force yet simple solution in favor of a complicated one because of some 'supposed benefits' such as 'better reusability' unless you have a strong justification.

> Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it. --Brian W. Kernighan

> Programs must be written for people to read, and only incidentally for machines to execute. --Abelson and Sussman

Avoid Premature Optimizations ★★★☆

Optimizing code prematurely has several drawbacks:

- **We may not know which parts are the real performance bottlenecks**. This is especially the case when the code undergoes transformations (e.g. compiling, minifying, transpiling, etc.) before it becomes an executable. Ideally, you should use a profiler tool to identify the actual bottlenecks of the code first, and optimize only those parts.
- **Optimizing can complicate the code**, affecting correctness and understandability
- **Hand-optimized code can be harder for the compiler to optimize** (the simpler the code, the easier for the compiler to optimize it). In many cases a compiler can do a better job of optimizing the runtime code if you don't get in the way by trying to hand-optimize the source code.

A popular saying in the industry is ***make it work, make it right, make it fast*** which means in most cases getting the code to perform correctly should take priority over optimizing it. If the code doesn't work correctly, it has no value on matter how fast/efficient it it.

> Premature optimization is the root of all evil in programming. --Donald Knuth

Note that **there are cases where optimizing takes priority over other things** e.g. when writing code for resource-constrained environments. This guideline simply a caution that you should optimize only when it is really needed.

SLAP Hard ★★★☆

Avoid varying the level of abstraction within a code fragment. Note: The *Productive Programmer* (by Neal Ford) calls this the *SLAP principle* i.e. Single Level of Abstraction Per method.

> Example:

👎 **Bad**

```
readData();
salary = basic*rise+1000;
tax = (taxable?salary*0.07:0);
displayResult();
```

👍 **Good**

```
readData();
processData();
displayResult();
```

Advanced

Make the Happy Path Prominent ★★★☆

The happy path (i.e. the execution path taken when everything goes well) should be clear and prominent in your code. Restructure the code to make the happy path unindented as much as possible. It is the 'unusual' cases that should be indented. Someone reading the code should not get distracted by alternative paths taken when error conditions happen. One technique that could help in this regard is the use of guard clauses.

Example:

👎 **Bad**

```
if (!isUnusualCase) {  //detecting an unusual condition
    if (!isErrorCase) {
        start();    //main path
        process();
        cleanup();
        exit();
    } else {
        handleError();
    }
} else {
    handleUnusualCase(); //handling that unusual condition
}
```

In the code above,

- Unusual condition detection is separated from their handling.
- Main path is nested deeply.

👍 **Good**

```
if (isUnusualCase) { //Guard Clause
    handleUnusualCase();
    return;
}

if (isErrorCase) { //Guard Clause
    handleError();
    return;
}

start();
process();
cleanup();
exit();
```

In contrast, the above code

- deals with unusual conditions as soon as they are detected so that the reader doesn't have to remember them for long.
- keeps the main path un-indented.

Guideline: Follow a Standard

Introduction ★★☆☆

One essential way to improve code quality is to follow a consistent style. That is why software engineers follow a strict coding standard (aka *style guide*).

The aim of a coding standard is to make the entire code base look like it was written by one person. A coding standard is usually specific to a programming language and specifies guidelines such as the location of opening and closing braces, indentation styles and naming styles (e.g. whether to use *Hungarian style*, *Pascal casing*, *Camel casing*, etc.). It is important that the whole team/company use the same coding standard and that standard is not generally inconsistent with typical industry practices. If a company's coding standards is very different from what is used typically in the industry, new recruits will take longer to get used to the company's coding style.

💡 IDEs can help to enforce some parts of a coding standard e.g. indentation rules.

Basic ★★★☆

Learn *basic* guidelines of the **Java** coding standard (by OSS-Generic)

Guideline: Name Well

Introduction ★★☆☆

Proper naming improves the readability. It also reduces bugs caused by ambiguities regarding the intent of a variable or a method.

> There are only two hard things in Computer Science: cache invalidation and naming things. -- Phil Karlton

Basic

Use Nouns for Things and Verbs for Actions ★★☆☆

> ❝ Every system is built from a domain-specific language designed by the programmers to describe that system. Functions are the verbs of that language, and classes are the nouns. — Robert C. Martin, *Clean Code: A Handbook of Agile Software Craftsmanship*

Use nouns for classes/variables and verbs for methods/functions.

Examples:

Name for a	👎 Bad	👍 Good
Class	`CheckLimit`	`LimitChecker`
method	`result()`	`calculate()`

Distinguish clearly between single-valued and multivalued variables.

📦 Examples:

👍 **Good**

```
Person student;
ArrayList<Person> students;
```

Use Standard Words ★★★☆

Use correct spelling in names. Avoid 'texting-style' spelling. **Avoid foreign language words, slang, and names that are only meaningful within specific contexts/times** e.g. terms from private jokes, a TV show currently popular in your country

Intermediate

Use Name to Explain ★★★☆

A name is not just for differentiation; it should explain the named entity to the reader accurately and at a sufficient level of detail.

Examples:

👎 Bad	👍 Good
`processInput()` (what 'process'?)	`removeWhiteSpaceFromInput()`
`flag`	`isValidInput`
`temp`	

If the name has multiple words, they should be in a sensible order.

Examples:

👎 Bad	👍 Good
`bySizeOrder()`	`orderBySize()`

Imagine going to the doctor's and saying "My eye1 is swollen"! Don't use numbers or case to distinguish names.

Examples:

👎 Bad	👎 Bad	👍 Good
`value1`, `value2`	`value`, `Value`	`originalValue`, `finalValue`

Not Too Long, Not Too Short ★★★☆

While it is preferable not to have lengthy names, names that are 'too short' are even worse. If you must abbreviate or use acronyms, do it consistently. Explain their full meaning at an obvious location.

Avoid Misleading Names ★★★☆

Related things should be named similarly, while unrelated things should NOT.

Example: Consider these variables

- `colorBlack` : hex value for color black
- `colorWhite` : hex value for color white
- `colorBlue` : number of times blue is used
- `hexForRed` : : hex value for color red

This is misleading because `colorBlue` is named similar to `colorWhite` and `colorBlack` but has a different purpose while `hexForRed` is named differently but has very similar purpose to the first two variables. The following is better:

- `hexForBlack` `hexForWhite` `hexForRed`
- `blueColorCount`

Avoid misleading or ambiguous names (e.g. those with multiple meanings), similar sounding names, hard-to-pronounce ones (e.g. avoid ambiguities like "is that a lowercase L, capital I or number 1?", or "is that number 0 or letter O?"), almost similar names.

Examples:

👎 Bad	👍 Good	Reason
`phase0`	`phaseZero`	Is that zero or letter O?

👎 Bad	👍 Good	Reason
`rwrLgtDirn`	`rowerLegitDirection`	Hard to pronounce
`right left wrong`	`rightDirection leftDirection wrongResponse`	`right` is for 'correct' or 'opposite of 'left'?
`redBooks readBooks`	`redColorBooks booksRead`	`red` and `read` (past tense) sounds the same
`FiletMignon`	`egg`	If the requirement is just a name of a food, `egg` is a much easier to type/say choice than `FiletMignon`

Guideline: Avoid Unsafe Shortcuts

Introduction ★★☆☆

It is safer to use language constructs in the way they are meant to be used, even if the language allows shortcuts. Some such coding practices are common sources of bugs. Know them and avoid them.

Basic

Use the Default Branch ★★☆☆

Always include a default branch in `case` statements.

Furthermore, use it for the intended default action and not just to execute the last option. If there is no default action, you can use the 'default' branch to detect errors (i.e. if execution reached the `default` branch, throw an exception). This also applies to the final `else` of an `if-else` construct. That is, the final `else` should mean 'everything else', and not the final option. Do not use `else` when an `if` condition can be explicitly specified, unless there is absolutely no other possibility.

👎 **Bad**

```
if (red) print "red";
else print "blue";
```

👍 **Good**

```
if (red) print "red";
else if (blue) print "blue";
else error("incorrect input");
```

Don't Recycle Variables or Parameters ★★☆☆

- Use one variable for one purpose. Do not reuse a variable for a different purpose other than its intended one, just because the data type is the same.
- Do not reuse formal parameters as local variables inside the method.

👎 **Bad**

```
double computeRectangleArea(double length, double width) {
    length = length * width;
    return length;
}
```

👍 **Good**

```
double computeRectangleArea(double length, double width) {
    double area;
    area = length * width;
    return area;
}
```

Avoid Empty Catch Blocks ★★☆☆

Never write an empty `catch` statement. At least give a comment to explain why the `catch` block is left empty.

Delete Dead Code ★★☆☆

We all feel reluctant to delete code we have painstakingly written, even if we have no use for that code any more ("I spent a lot of time writing that code; what if we need it again?"). Consider all code as baggage you have to carry; get rid of unused code the moment it becomes redundant. If you need that code again, simply recover it from the revision control tool you are using. Deleting code you wrote previously is a sign that you are improving.

Intermediate

Minimise Scope of Variables ★★★☆

Minimize global variables. Global variables may be the most convenient way to pass information around, but they do create implicit links between code segments that use the global variable. Avoid them as much as possible.

Define variables in the least possible scope. For example, if the variable is used only within the `if` block of the conditional statement, it should be declared inside that `if` block.

> **The most powerful technique for minimizing the scope of a local variable is to declare it where it is first used.** -- *Effective Java*, by Joshua Bloch

📎 Resources:

- Refactoring: Reduce Scope of Variable

Minimise Code Duplication ★★★☆

Code duplication, especially when you copy-paste-modify code, often indicates a poor quality implementation. While it may not be possible to have zero duplication, always think twice before duplicating code; most often there is a better alternative.

This guideline is closely related to the DRY Principle.

Guideline: Comment Minimally, but Sufficiently

Introduction ★★☆☆

> Good code is its own best documentation. As you're about to add a comment, ask yourself, 'How can I improve the code so that this comment isn't needed?' Improve the code and then document it to make it even clearer. --Steve McConnell, Author of *Clean Code*

Some think commenting heavily increases the 'code quality'. This is not so. Avoid writing comments to explain bad code. Improve the code to make it self-explanatory.

Basic

Do Not Repeat the Obvious ★★☆☆

If the code is self-explanatory, refrain from repeating the description in a comment just for the sake of 'good documentation'.

👎 Bad

```
// increment x
x++;

//trim the input
trimInput();
```

Write to the Reader ★★☆☆

Do not write comments as if they are private notes to self. Instead, write them well enough to be understood by another programmer. One type of comments that is almost always useful is the *header comment* that you write for a class or an operation to explain its purpose.

📦 Examples:

👎 **Bad** Reason: this comment will only make sense to the person who wrote it

```
// a quick trim function used to fix bug I detected overnight
void trimInput(){
    ....
}
```

👍 **Good**

```
/** Trims the input of leading and trailing spaces */
void trimInput(){
    ....
}
```

Intermediate

Explain WHAT and WHY, not HOW ★★★☆

Comments should explain *what* and *why* aspect of the code, rather than the *how* aspect.

✔ **What** : The specification of what the code *supposed* to do. The reader can compare such comments to the implementation to verify if the implementation is correct

📦 Example: This method is possibly buggy because the implementation does not seem to match the comment. In this case the comment could help the reader to detect the bug.

```
/** Removes all spaces from the {@code input} */
void compact(String input){
    input.trim();
}
```

✔ **Why** : The rationale for the current implementation.

📦 Example: Without this comment, the reader will not know the reason for calling this method.

```
// Remove spaces to comply with IE23.5 formatting rules
compact(input);
```

✘ **How** : The explanation for how the code works. This should already be apparent from the code, if the code is self-explanatory. Adding comments to explain the same thing is redundant.

📦 Example:

👎 **Bad** Reason: Comment explains how the code works.

```
// return true if both left end and right end are correct or the size has not incremented
return (left && right) || (input.size() == size);
```

👍 **Good** Reason: Code refactored to be self-explanatory. Comment no longer needed.

```

boolean isSameSize = (input.size() == size) ;
return (isLeftEndCorrect && isRightEndCorrect) || isSameSize;
```

Refactoring

What ★★☆☆

The first version of the code you write may not be of production quality. It is OK to first concentrate on making the code work, rather than worry over the quality of the code, as long as you improve the quality later. This process of **improving a program's internal structure in small steps without modifying its external behavior is called *refactoring*.**

- **Refactoring is not rewriting**: Discarding poorly-written code entirely and re-writing it from scratch is not refactoring because refactoring needs to be done in small steps.
- **Refactoring is not bug fixing**: By definition, refactoring is different from bug fixing or any other modifications that alter the external behavior (e.g. adding a feature) of the component in concern.

💡 Improving code structure can have many secondary benefits: e.g.

- hidden bugs become easier to spot
- improve performance (sometimes, simpler code runs faster than complex code because simpler code is easier for the compiler to optimize).

Given below are two common refactorings (more).

Refactoring Name: **Consolidate Duplicate Conditional Fragments**

Situation: The same fragment of code is in all branches of a conditional expression.

Method: Move it outside of the expression.

📦 Example:

```
if (isSpecialDeal()) {
    total = price * 0.95;
    send();
} else {
    total = price * 0.98;
    send();
}
```

→

```
if (isSpecialDeal()){
    total = price * 0.95;
} else {
    total = price * 0.98;
}
send();
```

Refactoring Name: **Extract Method**

Situation: You have a code fragment that can be grouped together.

Method: Turn the fragment into a method whose name explains the purpose of the method.

📦 Example:

```
void printOwing() {
    printBanner();

    //print details
    System.out.println("name:   " + name);
    System.out.println("amount  " + getOutstanding());
}
```

↓

```java
void printOwing() {
    printBanner();
    printDetails(getOutstanding());
}

void printDetails (double outstanding) {
    System.out.println("name:   " + name);
    System.out.println("amount  " + outstanding);
}
```

💡 Some IDEs have built in support for basic refactorings such as automatically renaming a variable/method/class in all places it has been used.

❗ Refactoring, even if done with the aid of an IDE, may still result in regressions. Therefore, each small refactoring should be followed by regression testing.

How ★★★☆

Given below are some more commonly used refactorings. A more comprehensive list is available at refactoring.com/catalog .

1. Consolidate Conditional Expression
2. Decompose Conditional
3. Inline Method
4. Remove Double Negative
5. Replace Magic Number with Symbolic Constant
6. Replace Nested Conditional with Guard Clauses
7. Replace Parameter with Explicit Methods
8. Reverse Conditional
9. Split Loop
10. Split Temporary Variable

Documentation

Introduction

What ★★☆☆

Developer-to-developer documentation can be in one of two forms:

1. **Documentation for *developer-as-user***: Software components are written by developers and reused by other developers, which means there is a need to document how such components are to be used. Such documentation can take several forms:
    - API documentation: APIs expose functionality in small-sized, independent and easy-to-use chunks, each of which can be documented systematically.
    - Tutorial-style instructional documentation: In addition to explaining functions/methods independently, some higher-level explanations of how to use an API can be useful.

    - 📦 Example of API Documentation: String API.
    - 📦 Example of tutorial-style documentation: Java Internationalization Tutorial

2. **Documentation for *developer-as-maintainer***: There is a need to document how a system or a component is designed, implemented and tested so that other developers can maintain and evolve the code. Writing documentation of this type is harder because of the need to explain complex internal details. However, given that readers of this type of documentation usually have access to the source code itself, only *some* information need to be included in the documentation, as code (and code comments) can also serve as a complementary source of information.

    - 📦 An example: se-edu/addressbook-level4 Developer Guide.

Guidelines

Guideline: Go Top-down, Not Bottom-up

What ★★☆☆

When writing project documents, a top-down breadth-first explanation is easier to understand than a bottom-up one.

Why ★★★☆

The main advantage of the top-down approach is that the document is structured like an upside down tree (root at the top) and **the reader can travel down a path she is interested in until she reaches the component she is interested to learn in-depth**, without having to read the entire document or understand the whole system.

How ★★☆☆

📦 To explain a system called `SystemFoo` with two sub-systems, `FrontEnd` and `BackEnd`, start by describing the system at the highest level of abstraction, and progressively drill down to lower level details. An outline for such a description is given below.

[First, explain what the system is, in a black-box fashion (no internal details, only the external view).]

> `SystemFoo` is a ....

[Next, explain the high-level architecture of `SystemFoo`, referring to its major components only.]

> `SystemFoo` consists of two major components: `FrontEnd` and `BackEnd`.
>
> The job of `FrontEnd` is to ... while the job of `BackEnd` is to ...
>
> And this is how `FrontEnd` and `BackEnd` work together ...

[Now we can drill down to `FrontEnd`'s details.]

> `FrontEnd` consists of three major components: `A`, `B`, `C`
>
> `A`'s job is to ...
> `B`'s job is to...
> `C`'s job is to...
>
> And this is how the three components work together ...

[At this point, further drill down the internal workings of each component. A reader who is not interested in knowing nitty-gritty details can skip ahead to the section on `BackEnd`.]

> In-depth description of `A`
>
> In-depth description of `B`
>
> ...

[At this point drill down details of the `BackEnd`.]

> ...

Guideline: Aim for Comprehensibility

What ★★☆☆

Technical documents exist to help others understand technical details. Therefore, **it is not enough for the documentation to be accurate and comprehensive, it should also be comprehensible too**.

How ★★★☆

Here are some tips on writing effective documentation.

- **Use plenty of diagrams**: It is not enough to explain something in words; complement it with visual illustrations (e.g. a UML diagram).
- **Use plenty of examples**: When explaining algorithms, show a running example to illustrate each step of the algorithm, in parallel to worded explanations.
- **Use simple and direct explanations**: Convoluted explanations and fancy words will annoy readers. Avoid long sentences.
- **Get rid of statements that do not add value**: For example, 'We made sure our system works perfectly' (who didn't?), 'Component X has its own responsibilities' (of course it has!).
- **It is not a good idea to have separate sections for each type of artifact**, such as 'use cases', 'sequence diagrams', 'activity diagrams', etc. Such a structure, coupled with the indiscriminate inclusion of diagrams without justifying their need, indicates a failure to understand the purpose of documentation. Include diagrams when they are needed to explain something. If you want to provide additional diagrams for completeness' sake, include them in the appendix as a reference.

Guideline: Document Minimally, but Sufficiently

What ★★☆☆

Aim for 'just enough' developer documentation.

- Writing and maintaining developer documents is an overhead. You should try to minimize that overhead.
- If the readers are developers who will eventually read the code, the documentation should complement the code and should provide only just enough guidance to get started.

How ★★★☆

Anything that is already clear in the code need not be described in words. Instead, **focus on providing higher level information that is not readily visible in the code or comments**.

Refrain from duplicating chunks or text. When describing several similar algorithms/designs/APIs, etc., do not simply duplicate large chunks of text. Instead, **describe the similarity in one place and emphasize only the differences in other places.** It is very annoying to see pages and pages of similar text without any indication as to how they differ from each other.

Tools

JavaDoc

What ★★☆☆

Javadoc is a tool for generating API documentation in HTML format from doc comments in source. In addition, modern IDEs use JavaDoc comments to generate explanatory tool tips.

📦 An example method header comment in JavaDoc format (adapted from Oracle's Java documentation)

```
/**
 * Returns an Image object that can then be painted on the screen.
 * The url argument must specify an absolute {@link URL}. The name
 * argument is a specifier that is relative to the url argument.
 * <p>
 * This method always returns immediately, whether or not the
 * image exists. When this applet attempts to draw the image on
 * the screen, the data will be loaded. The graphics primitives
 * that draw the image will incrementally paint on the screen.
 *
 * @param url an absolute URL giving the base location of the image
 * @param name the location of the image, relative to the url argument
 * @return the image at the specified URL
 * @see Image
 */
public Image getImage(URL url, String name) {
        try {
            return getImage(new URL(url, name));
        } catch (MalformedURLException e) {
            return null;
        }
}
```

📦 Generated HTML documentation:

getImage
`public Image getImage(URL url, String name)`
Returns an `Image` object that can then be painted on the screen. The `url` argument must specify an absolute URL. The `name` argument is a specifier that is relative to the `url` argument.

This method always returns immediately, whether or not the image exists. When this applet attempts to draw the image on the screen, the data will be loaded. The graphics primitives that draw the image will incrementally paint on the screen.

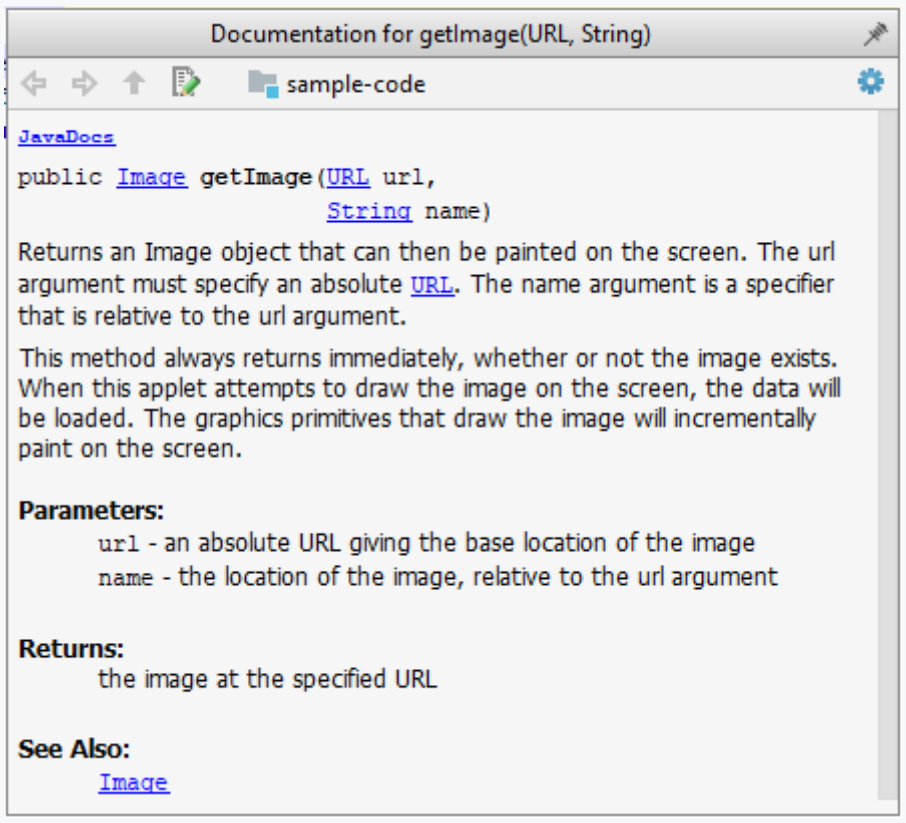
Parameters:
`url` - an absolute URL giving the base location of the image.

`name` - the location of the image, relative to the `url` argument.

Returns:
the image at the specified URL.

See Also:
`Image`

📦 Tooltip generated by Intellij IDE:



How ★★★☆

In the absence of more extensive guidelines (e.g., given in a coding standard adopted by your project), you can follow the two examples below in your code.

A minimal javadoc comment example for methods:

```
/**
 * Returns lateral location of the specified position.
 * If the position is unset, NaN is returned.
 *
 * @param x  X coordinate of position.
 * @param y Y coordinate of position.
 * @param zone Zone of position.
 * @return Lateral location.
 * @throws IllegalArgumentException  If zone is <= 0.
 */
public double computeLocation(double x, double y, int zone)
    throws IllegalArgumentException {
  ...
}
```

A minimal javadoc comment example for classes:

```
package ...

import ...

/**
 * Represents a location in a 2D space. A <code>Point</code> object corresponds to
 * a coordinate represented by two integers e.g., <code>3,6</code>
 */
public class Point{
    //...
}
```

AsciiDoc

What ★★☆☆

AsciiDoc is similar to Markdown but has more powerful (but also more complex) syntax.

- AsciiDoc Writers Guide --from Asciidoctor.org

Error Handling

Introduction

What 🎓:★★☆☆

> Well-written applications include error-handling code that allows them to recover gracefully from unexpected errors. When an error occurs, the application may need to request user intervention, or it may be able to recover on its own. In extreme cases, the application may log the user off or shut down the system. --Microsoft

Exceptions

What 🎓:★☆☆☆

Exceptions are used to deal with '*unusual*' *but not entirely unexpected* situations that the program might encounter at run time.

Exception:

> The term *exception* is shorthand for the phrase "exceptional event." An *exception* is an event, which occurs during the execution of a program, that disrupts the normal flow of the program's instructions. –- Java Tutorial (Oracle Inc.)

📦 Examples:

- A network connection encounters a timeout due to a slow server.
- The code tries to read a file from the hard disk but the file is corrupted and cannot be read.

How 🎓:★☆☆☆

Most languages allow code that encountered an "exceptional" situation to encapsulate details of the situation in an *Exception* object and *throw/raise* that object so that another piece of code can *catch* it and deal with it. This is especially useful when the code that encountered the unusual situation does not know how to deal with it.

The extract below from the -- Java Tutorial (with slight adaptations) explains how exceptions are typically handled.

> **When an error occurs at some point in the execution, the code being executed creates an *exception object* and hands it off to the runtime system.** The exception object contains information about the error, including its type and the state of the program when the error occurred. Creating an exception object and handing it to the runtime system is called *throwing* an exception.
>
> **After a method throws an exception, the runtime system attempts to find something to handle it in the *call stack* .** The runtime system searches the call stack for a method that contains a block of code that can handle the exception. This block of code is called an *exception handler*. The search begins with the method in which the error occurred and proceeds through the call stack in the reverse order in which the methods were called. When an appropriate handler is found, the runtime system passes the exception to the handler. An exception handler is considered appropriate if the type of the exception object thrown matches the type that can be handled by the handler.
>
> **The exception handler chosen is said to *catch* the exception.** If the runtime system exhaustively searches all the methods on the call stack without finding an appropriate exception handler, the program terminates.

Advantages of exception handling in this way:

- The ability to propagate error information through the call stack.
- The separation of code that deals with 'unusual' situations from the code that does the 'usual' work.

When 🎓:★★☆☆

In general, use exceptions only for 'unusual' conditions. Use normal `return` statements to pass control to the caller for conditions that are 'normal'.

Assertions

What ★★☆☆

***Assertions* are used to define assumptions about the program state so that the runtime can verify them.** An assertion failure indicates a possible bug in the code because the code has resulted in a program state that violates an assumption about how the code *should* behave.

📦 An assertion can be used to express something like *when the execution comes to this point, the variable `v` cannot be null*.

If the runtime detects an *assertion failure*, it typically take some drastic action such as terminating the execution with an error message. This is because an assertion failure indicates a possible bug and the sooner the execution stops, the safer it is.

📦 In the Java code below, suppose we set an assertion that `timeout` returned by `Config.getTimeout()` is greater than `0`. Now, if the `Config.getTimeout()` returned `-1` in a specific execution of this line, the runtime can detect it as a *assertion failure* -- i.e. an assumption about the expected behavior of the code turned out to be wrong which could potentially be the result of a bug -- and take some drastic action such as terminating the execution.

```
int timeout = Config.getTimeout();
```

How ★★★☆

Use the `assert` keyword to define assertions.

📦 This assertion will fail with the message `x should be 0` if `x` is not 0 at this point.

```
x = getX();
assert x == 0 : "x should be 0";
...
```

Assertions can be disabled without modifying the code.

📦 `java -enableassertions HelloWorld` (or `java -ea HelloWorld`) will run `HelloWorld` with assertions enabled while `java -disableassertions HelloWorld` will run it without verifying assertions.

🚩 **Java disables assertions by default.** This could create a situation where you think all assertions are being verified as `true` while in fact they are not being verified at all. Therefore, remember to enable assertions when you run the program if you want them to be in effect.

💡 Enable assertions in Intellij (how?) and get an assertion to fail temporarily (e.g. insert an `assert false` into the code temporarily) to confirm assertions are being verified.

ℹ️ **Java `assert` vs JUnit assertions: They are similar in purpose but JUnit assertions are more powerful and customized for testing.** In addition, JUnit assertions are not disabled by default. We recommend you use JUnit assertions in test code and Java `assert` in functional code.

When ★★★☆

It is recommended that assertions be used liberally in the code. Their impact on performance is considered low and worth the additional safety they provide.

Do not use assertions to do *work* because assertions can be disabled. If not, your program will stop working when assertions are not enabled.

📦 The code below will not invoke the `writeFile()` method when assertions are disabled. If that method is performing some work that is necessary for your program, your program will not work correctly when assertions are disabled.

```
...
assert writeFile() : "File writing is supposed to return true";
```

Assertions are suitable for verifying assumptions about *Internal Invariants*, *Control-Flow Invariants*, *Preconditions*, *Postconditions*, and *Class Invariants*. Refer to [Programming with Assertions (second half)] to learn more.

Exceptions and assertions are two complementary ways of handling errors in software but they serve different purposes. Therefore, both assertions and exceptions should be used in code.

- The raising of an exception indicates an unusual condition created by the user (e.g. user inputs an unacceptable input) or the environment (e.g., a file needed for the program is missing).
- An assertion failure indicates the programmer made a mistake in the code (e.g., a null value is returned from a method that is not supposed to return null under any circumstances).

Logging

What ★★☆☆

***Logging* is the deliberate recording of certain information during a program execution for future reference.** Logs are typically written to a log file but it is also possible to log information in other ways e.g. into a database or a remote server.

***Logging* can be useful for troubleshooting problems**. A good logging system records some system information regularly. When bad things happen to a system e.g. an unanticipated failure, their associated log files may provide indications of what went wrong and action can then be taken to prevent it from happening again.

💡 **A log file is like the black box of an airplane**; they don't prevent problems but they can be helpful in understanding what went wrong after the fact.

How ★★★☆

Most programming environments come with logging systems that allow sophisticated forms of logging. They have features such as the ability to enable and disable logging easily or to change the logging intensity .

📦 This sample Java code uses Java's default logging mechanism.

First, import the relevant Java package:

```
import java.util.logging.*;
```

Next, create a `Logger`:

```
private static Logger logger = Logger.getLogger("Foo");
```

Now, you can use the `Logger` object to log information. Note the use of logging level for each message. When running the code, the logging level can be set to `WARNING` so that log messages specified as `INFO` level (which is a lower level than `WARNING`) will not be written to the log file at all.

```
// log a message at INFO level
logger.log(Level.INFO, "going to start processing");
//...
processInput();
if(error){
    //log a message at WARNING level
    logger.log(Level.WARNING, "processing error", ex);
}
//...
logger.log(Level.INFO, "end of processing");
```

Defensive Programming

What ★★☆☆

A defensive programmer codes under the assumption "if we leave room for things to go wrong, they *will* go wrong". Therefore, a defensive programmer proactively tries to eliminate any room for things to go wrong.

📦 Consider a `MainApp#getConfig()` a method that returns a `Config` object containing configuration data. A typical implementation is given below:

```
class MainApp{
    Config config;

    /** Returns the config object */
    Config getConfig(){
        return config;
    }
}
```

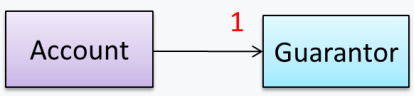
If the returned Config object is not meant to be modified, a defensive programmer might use a more *defensive* implementation given below. This is more defensive because even if the returned `Config` object is modified (although it is not meant to be) it will not affect the `config` object inside the `MainApp` object.

```
    /** Returns a copy of the config object */
    Config getConfig(){
        return config.copy(); //return a defensive copy
    }
```

Enforcing Compulsory Associations ★★★☆

Consider two classes, `Account` and `Guarantor`, with an association as shown in the following diagram:

Example:



Here, the association is compulsory i.e. an `Account` object should always be linked to a `Guarantor`. One way to implement this is to simply use a reference variable, like this:

```
class Account {
    Guarantor guarantor;

    void setGuarantor(Guarantor g) {
        guarantor = g;
    }
}
```

However, what if someone else used the `Account` class like this?

```
Account a = new Account();
a.setGuarantor(null);
```

This results in an `Account` without a `Guarantor`! In a real banking system, this could have serious consequences! The code here did not try to prevent such a thing from happening. We can make the code more defensive by proactively enforcing the multiplicity constraint, like this:

```
class Account {
    private Guarantor guarantor;

    public Account(Guarantor g){
        if (g == null) {
            stopSystemWithMessage("multiplicity violated. Null Guarantor");
        }
        guarantor = g;
    }
    public void setGuarantor (Guarantor g){
        if (g == null) {
            stopSystemWithMessage("multiplicity violated. Null Guarantor");
        }
        guarantor = g;
    }
    …
}
```

When ★★★☆

It is not necessary to be 100% defensive all the time. While defensive code may be less prone to be misused or abused, such code can also be more complicated and slower to run.

The suitable degree of defensiveness depends on many factors such as:

- How critical is the system?
- Will the code be used by programmers other than the author?
- The level of programming language support for defensive programming
- The overhead of being defensive

Integration

Introduction

What ★☆☆☆

Combining parts of a software product to form a whole is called *integration*. It is also one of the most troublesome tasks and it rarely goes smoothly.

Approaches

'Late and One Time' vs 'Early and Frequent' ★★☆☆

In terms of timing and frequency, there are two general approaches to integration: *late and one-time*, *early and frequent*.

***Late and one-time*: wait till all components are completed and integrate all finished components near the end of the project.**

✖ This approach is not recommended because integration often causes many component incompatibilities (due to previous miscommunications and misunderstandings) to surface which can lead to delivery delays i.e. Late integration → incompatibilities found → major rework required → cannot meet the delivery date.

***Early and frequent*: integrate early and evolve each part in parallel, in small steps, re-integrating frequently.**

📦 A *walking skeleton* can be written first. This can be done by one developer, possibly the one in charge of integration. After that, all developers can flesh out the skeleton in parallel, adding one feature at a time. After each feature is done, simply integrate the new code to the main system.

Big-Bang vs Incremental Integration ★★★☆

***Big-bang integration*: integrate all components at the same time.**

✖ Big-bang is not recommended because it will uncover too many problems at the same time which could make debugging and bug-fixing more complex than when problems are uncovered incrementally.

***Incremental integration*: integrate few components at a time.** This approach is better than the big-bang integration because it surfaces integration problems in a more manageable way.

Build Automation

What ★☆☆☆

Build automation tools automate the steps of the build process, usually by means of build scripts.

In a non-trivial project, building a product from source code can be a complex multi-step process. For example, it can include steps such as to pull code from the revision control system, compile, link, run automated tests, automatically update release documents (e.g. build number), package into a distributable, push to repo, deploy to a server, delete temporary files created during building/testing, email developers of the new build, and so on. Furthermore, this build process can be done 'on demand', it can be scheduled (e.g. every day at midnight) or it can be triggered by various events (e.g. triggered by a code push to the revision control system).

Some of these build steps such as to compile, link and package are already automated in most modern IDEs. For example, several steps happen automatically when the 'build' button of the IDE is clicked. Some IDEs even allow customization to this build process to some extent.

However, most big projects use specialized build tools to automate complex build processes.

📦 Some popular build tools relevant to Java developers:

- Gradle
- Maven
- Apache Ant
- GNU Make

📦 Some other build tools : Grunt (JavaScript), Rake (Ruby)

Some build tools also serve as *dependency management tools*. Modern software projects often depend on third party libraries that evolve constantly. That means developers need to download the correct version of the required libraries and update them regularly. Therefore, dependency management is an important part of build automation. Dependency Management tools can automate that aspect of a project.

📦 Maven and Gradle, in addition to managing the build process, can play the role of dependency management tools too.

Continuous Integration and Continuous Deployment ★★☆☆

An extreme application of build automation is called *continuous integration (CI)* in which integration, building, and testing happens automatically after each code change.

A natural extension of CI is *Continuous Deployment (CD)* where the changes are not only integrated continuously, but also deployed to end-users at the same time.

📦 Some examples of CI/CD tools:

- Travis
- Jenkins
- Appveyor
- CircleCI

Reuse

Introduction

What ★★☆☆

Reuse is a major theme in software engineering practices. **By reusing tried-and-tested components, the robustness of a new software system can be enhanced while reducing the manpower and time requirement.** Reusable components come in many forms; it can be reusing a piece of code, a subsystem, or a whole software.

When ★★★☆

While you may be tempted to use many libraries/frameworks/platform that seem to crop up on a regular basis and promise to bring great benefits, note that **there are costs associated with reuse**. Here are some:

- The reused code **may be an overkill** (think *using a sledgehammer to crack a nut*) increasing the size of, or/and degrading the performance of, your software.
- The reused software **may not be mature/stable enough** to be used in an important product. That means the software can change drastically and rapidly, possibly in ways that break your software.
- Non-mature software has the **risk of dying off** as fast as they emerged, leaving you with a dependency that is no longer maintained.
- The license of the reused software (or its dependencies) **restrict how you can use/develop your software**.
- The reused software **might have bugs, missing features, or security vulnerabilities** that are important to your product but not so important to the maintainers of that software, which means those flaws will not get fixed as fast as you need them to.
- **Malicious code can sneak into your product** via compromised dependencies.

APIs

What ★★☆☆

An *Application Programming Interface (API)* specifies the interface through which other programs can interact with a software component. It is a contract between the component and its clients.

> 📦 A class has an API (e.g., API of the Java `String` class, API of the Python `str` class) which is a collection of public methods that you can invoke to make use of the class.
>
> 📦 The GitHub API is a collection of Web request formats GitHub server accepts and the corresponding responses. We can write a program that interacts with GitHub through that API.

When developing large systems, if you define the API of each components early, the development team can develop the components in parallel because the future behavior of the other components are now more predictable.

Libraries

What ★☆☆☆

A library is a collection of modular code that is general and can be used by other programs.

> 📦 Java classes you get with the JDK (such as `String`, `ArrayList`, `HashMap`, etc.) are library classes that are provided in the default Java distribution.
>
> 📦 Natty is a Java library that can be used for parsing strings that represent dates e.g. `The 31st of April in the year 2008`

How ★★☆☆

These are the typical steps required to use a library.

1. Read the documentation to confirm that its functionality fits your needs
2. Check the license to confirm that it allows reuse in the way you plan to reuse it. For example, some libraries might allow non-commercial use only.
3. Download the library and make it accessible to your project. Alternatively, you can configure your dependency management tool to do it for you.
4. Call the library API from your code where you need to use the library functionality.

Frameworks

What ★★☆☆

The overall structure and execution flow of a specific category of software systems can be very similar. The similarity is an opportunity to reuse at a high scale.

📦 Running example:

IDEs for different programming languages are similar in how they support editing code, organizing project files, debugging, etc.

A *software framework* is a reusable implementation of a software (or part thereof) providing *generic* functionality that can be selectively customized to produce a *specific* application.

📦 Running example:

Eclipse is an IDE framework that can be used to create IDEs for different programming languages.

Some frameworks provide a complete implementation of a *default* behavior which makes them immediately usable.

📦 Running example:

Eclipse is a fully functional Java IDE out-of-the-box.

A framework facilitates the adaptation and customization of some desired functionality.

📦 Running example:

Eclipse plugin system can be used to create an IDE for different programming languages while reusing most of the existing IDE features of Eclipse. E.g. https://marketplace.eclipse.org/content/pydev-python-ide-eclipse

Some frameworks cover only a specific components or an aspect.

📦 JavaFx a framework for creating Java GUIs. TkInter is a GUI framework for Python.

📦 More examples of frameworks

- Frameworks for Web-based applications: Drupal(PHP), Django(Python), Ruby on Rails (Ruby), Spring (Java)
- Frameworks for testing: JUnit (Java), unittest (Python), Jest (Java Script)

Frameworks vs Libraries ★★★☆

Although both frameworks and libraries are reuse mechanisms, there are notable differences:

- **Libraries are meant to be used 'as is' while frameworks are meant to be customized/extended.** e.g., writing plugins for Eclipse so that it can be used as an IDE for different languages (C++, PHP, etc.), adding modules and themes to Drupal, and adding test cases to JUnit.
- **Your code calls the library code while the framework code calls your code. Frameworks use a technique called *inversion of control*, aka the "Hollywood principle"** (i.e. don't call us, we'll call you!). That is, you write code that will be called by the framework, e.g. writing test methods that will be called by the JUnit framework. In the case of libraries, your code calls libraries.

Platforms

What ★★★☆

A *platform* provides a runtime environment for applications. A platform is often bundled with various libraries, tools, frameworks, and technologies in addition to a runtime environment but the defining characteristic of a software platform is the presence of a runtime environment.

📦 Technically, an operating system can be called a platform. For example, Windows PC is a platform for desktop applications while iOS is a platform for mobile apps.

📦 **Two well-known examples of platforms are JavaEE and .NET**, both of which sit above Operating systems layer, and are used to develop enterprise applications. Infrastructure services such as connection pooling, load balancing, remote code execution, transaction management, authentication, security, messaging etc. are done similarly in most enterprise applications. Both JavaEE and .NET provide these services to applications in a customizable way without developers having to implement them from scratch every time.

- JavaEE (Java Enterprise Edition) is both a framework and a platform for writing enterprise applications. The runtime used by the JavaEE applications is the JVM (Java Virtual Machine) that can run on different Operating Systems.
- .NET is a similar platform and a framework. Its runtime is called CLR (Common Language Runtime) and usually used on Windows machines.

SECTION: QUALITY ASSURANCE

Quality Assurance

Introduction

What ★★☆☆

Software *Quality Assurance* (QA) is the process of ensuring that the software being built has the required levels of quality.

While testing is the most common activity used in QA, there are other complementary techniques such as *static analysis, code reviews,* and *formal verification*.

Validation vs Verification ★★★☆

Quality Assurance = Validation + Verification

QA involves checking two aspects:

1. Validation: are we *building the right system* i.e., are the requirements correct?
2. Verification: are we *building the system right* i.e., are the requirements implemented correctly?

Whether something belongs under validation or verification is not that important. What is more important is both are done, instead of limiting to verification (i.e., remember that the requirements can be wrong too).

Code Reviews

What ★★★☆

Code review is the systematic examination code with the intention of finding where the code can be improved.

Reviews can be done in various forms. Some examples below:

- **In pair programming**
  - As pair programming involves two programmers working on the same code at the same time, there is an implicit review of the code by the other member of the pair.
- **Pull Request reviews**
  - Project Management Platforms such as GitHub and BitBucket allows the new code to be proposed as Pull Requests and provides the ability for others to review the code in the PR.
- **Formal inspections**
  - Inspections involve a group of people systematically examining a project artifacts to discover defects. Members of the inspection team play various roles during the process, such as:
    - the author - the creator of the artifact
    - the moderator - the planner and executor of the inspection meeting
    - the secretary - the recorder of the findings of the inspection
    - the inspector/reviewer - the one who inspects/reviews the artifact.

Advantages of code reviews over testing:

- It can detect functionality defects as well as other problems such as coding standard violations.
- Can verify non-code artifacts and incomplete code
- Do not require test drivers or stubs.

Disadvantages:

- It is a manual process and therefore, error prone.

Static Analysis

What ★★★☆

Static analysis: Static analysis is the analysis of code without actually executing the code.

Static analysis of code can find useful information such unused variables, unhandled exceptions, style errors, and statistics. Most modern IDEs come with some inbuilt static analysis capabilities. For example, an IDE can highlight unused variables as you type the code into the editor.

Higher-end static analyzer tools can perform for more complex analysis such as locating potential bugs, memory leaks, inefficient code structures etc.

> 📦 Some example static analyzer for Java:
>
> - CheckStyle
> - PMD
> - FindBugs

Linters are a subset of static analyzers that specifically aim to locate areas where the code can be made 'cleaner'.

Formal Verification

What ★★★☆

Formal verification uses mathematical techniques to prove the correctness of a program.

Advantages:

- **Formal verification can be used to prove the absence of errors**. In contrast, testing can only prove the presence of error, not their absence.

Disadvantages:

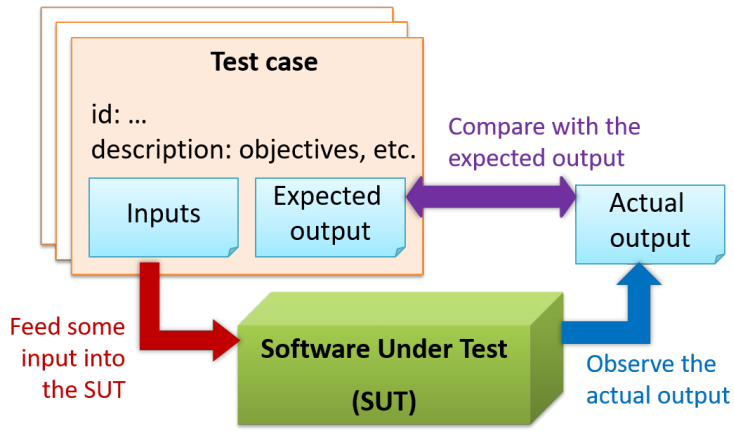
- It only proves the compliance with the specification, but not the actual utility of the software.
- It requires highly specialized notations and knowledge which makes it an expensive technique to administer. Therefore, **formal verifications are more commonly used in safety-critical software such as flight control systems**.

Testing

Introduction

What ★★☆☆

> **Testing**: Testing is operating a system or component under specified conditions, observing or recording the results, and making an evaluation of some aspect of the system or component. –- source: IEEE



When testing, we execute a set of *test cases*. A test case specifies how to perform a test. At a minimum, it specifies the input to the *software under test (SUT)* and the expected behavior.

📦 Example: A minimal test case for testing a browser:

- **Input** – Start the browser using a blank page (vertical scrollbar disabled). Then, load `longfile.html` located in the `test data` folder.
- **Expected behavior** – The scrollbar should be automatically enabled upon loading `longfile.html`.

Test cases can be determined based on the specification, reviewing similar existing systems, or comparing to the past behavior of the SUT.

<details>
<summary>Other details a test case can contain</summary>

For each test case we do the following:

1. Feed the input to the SUT
2. Observe the actual output
3. Compare actual output with the expected output

A test case *failure* is a mismatch between the expected behavior and the actual behavior. A failure is caused by a *defect* (or a bug).

📦 Example: In the browser example above, a test case failure is implied if the scrollbar remains disabled after loading `longfile.html`. The defect/bug causing that failure could be an uninitialized variable.
</details>

<details>
<summary>A deeper look at the definition of testing</summary>
</details>

Testability ★★★☆

***Testability* is an indication of how easy it is to test an SUT.** As testability depends a lot on the design and implementation. You should try to increase the testability when you design and implement a software. The higher the testability, the easier it is to achieve a better quality software.

Testing Types

Unit Testing

What ★☆☆☆

***Unit testing* : testing individual units (methods, classes, subsystems, ...) to ensure each piece works correctly.**

In OOP code, it is common to write one or more unit tests for each public method of a class.

📦 Here are the code skeletons for a `Foo` class containing two methods and a `FooTest` class that contains unit tests for those two methods.

```
class Foo{
    String read(){
        //...
    }

    void write(String input){
        //...
    }

}

class FooTest{

    @Test
    void read(){
        //a unit test for Foo#read() method
    }

    @Test
    void write_emptyInput_exceptionThrown(){
        //a unit tests for Foo#write(String) method
    }

    @Test
    void write_normalInput_writtenCorrectly(){
        //another unit tests for Foo#write(String) method
    }
}
```

Stubs ★★★☆

A proper unit test requires the *unit* to be tested in isolation so that bugs in the dependencies cannot influence the test i.e. bugs outside of the unit should not affect the unit tests.

📦 If a `Logic` class depends on a `Storage` class, unit testing the `Logic` class requires isolating the `Logic` class from the `Storage` class.

***Stubs* can isolate the SUT from its dependencies**.

Stub: A stub has the same interface as the component it replaces, but its implementation is so simple that it is unlikely to have any bugs. It mimics the responses of the component, but only for the a limited set of predetermined inputs. That is, it does not know how to respond to any other inputs. Typically, these mimicked responses are hard-coded in the stub rather than computed or retrieved from elsewhere, e.g. from a database.

📦 Consider the code below:

```
class Logic {
    Storage s;

    Logic(Storage s) {
        this.s = s;
    }

    String getName(int index) {
        return "Name: " + s.getName(index);
    }
}

interface Storage {
    String getName(int index);
}

class DatabaseStorage implements Storage {

    @Override
    public String getName(int index) {
        return readValueFromDatabase(index);
    }

    private String readValueFromDatabase(int index) {
        // retrieve name from the database
    }
}
```

Normally, you would use the `Logic` class as follows (not how the `Logic` object depends on a `DatabaseStorage` object to perform the `getName()` operation):

```
Logic logic = new Logic(new DatabaseStorage());
String name = logic.getName(23);
```

You can test it like this:

```
@Test
void getName() {
    Logic logic = new Logic(new DatabaseStorage());
    assertEquals("Name: John", logic.getName(5));
}
```

However, this `logic` object being tested is making use of a `DataBaseStorage` object which means a bug in the `DatabaseStorage` class can affect the test. Therefore, this test is not testing `Logic` *in isolation from its dependencies* and hence it is not a pure unit test.

Here is a stub class you can use in place of `DatabaseStorage`:

```
class StorageStub implements Storage {

    @Override
    public String getName(int index) {
        if(index == 5) {
            return "Adam";
        } else {
            throw new UnsupportedOperationException();
        }
    }
}
```

Note how the stub has the same interface as the real dependency, is so simple that it is unlikely to contain bugs, and is pre-configured to respond with a hard-coded response, presumably, the correct response `DatabaseStorage` is expected to return for the given test input.

Here is how you can use the stub to write a unit test. This test is not affected by any bugs in the `DatabaseStorage` class and hence is a pure unit test.

```java
@Test
void getName() {
    Logic logic = new Logic(new StorageStub());
    assertEquals("Name: Adam", logic.getName(5));
}
```

In addition to Stubs, there are other type of replacements you can use during testing. E.g. *Mocks*, *Fakes*, *Dummies*, *Spies*.

Integration Testing

What ★★☆☆

***Integration testing* : testing whether different parts of the software *work together* (i.e. integrates) as expected.** Integration tests aim to discover bugs in the 'glue code' related to how components interact with each other. These bugs are often the result of misunderstanding of what the parts are supposed to do vs what the parts are actually doing.

📦 Suppose a class `Car` users classes `Engine` and `Wheel`. If the `Car` class assumed a `Wheel` can support 200 mph speed but the actual `Wheel` can only support 150 mph, it is the integration test that is supposed to uncover this discrepancy.

How ★★★☆

Integration testing is not simply a repetition of the unit test cases but run using the actual dependencies (instead of the stubs used in unit testing). Instead, integration tests are additional test cases that focus on the interactions between the parts.

📦 Suppose a class `Car` uses classes `Engine` and `Wheel`. Here is how you would go about doing pure integration tests:

a) First, unit test `Engine` and `Wheel`.
b) Next, unit test `Car` in isolation of `Engine` and `Wheel`, using stubs for `Engine` and `Wheel`.
c) After that, do an integration test for `Car` using it together with the `Engine` and `Wheel` classes to ensure the `Car` integrates properly with the `Engine` and the `Wheel`.

In practice, developers often use a hybrid of unit+integration tests to minimize the need for stubs.

📦 Here's how a hybrid unit+integration approach could be applied to the same example used above:

(a) First, unit test `Engine` and `Wheel`.
~~(b) Next, unit test `Car` in isolation of `Engine` and `Wheel`, using stubs for `Engine` and `Wheel`.~~
(c) After that, do an integration test for `Car` using it together with the `Engine` and `Wheel` classes to ensure the `Car` integrates properly with the `Engine` and the `Wheel`. This step should include test cases that are meant to test the unit `Car` (i.e. test cases used in the step (b) of the example above) as well as test cases that are meant to test the integration of `Car` with `Wheel` and `Engine` (i.e. pure integration test cases used of the step (c) in the example above).

💡 Note that you no longer need stubs for `Engine` and `Wheel`. The downside is that `Car` is never tested in isolation of its dependencies. Given that its dependencies are already unit tested, the risk of bugs in `Engine` and `Wheel` affecting the testing of `Car` can be considered minimal.

System Testing

What ★★☆☆

***System testing*: take the *whole system* and test it *against the system specification*.**

System testing is typically done by a testing team (also called a QA team).

System test cases are based on the specified external behavior of the system. Sometimes, system tests go beyond the bounds defined in the specification. This is useful when testing that the system fails 'gracefully' having pushed beyond its limits.

📦 Suppose the SUT is a browser supposedly capable of handling web pages containing up to 5000 characters. Given below is a test case to test if the SUT fails gracefully if pushed beyond its limits.

```
Test case: load a web page that is too big
* Input: load a web page containing more than 5000 characters.
* Expected behavior: abort the loading of the page and show a meaningful error message.
```

This test case would fail if the browser attempted to load the large file anyway and crashed.

System testing includes testing against non-functional requirements too. Here are some examples.

- *Performance testing* – to ensure the system responds quickly.
- *Load testing* (also called *stress testing* or *scalability testing*) – to ensure the system can work under heavy load.
- *Security testing* – to test how secure the system is.
- *Compatibility testing, interoperability testing* – to check whether the system can work with other systems.
- *Usability testing* – to test how easy it is to use the system.
- *Portability testing* – to test whether the system works on different platforms.

Alpha and Beta Testing

What ★★★☆

***Alpha testing* is performed by the users, under controlled conditions set by the software development team.**

***Beta testing* is performed by a selected subset of target users of the system in their natural work setting.**

An *open beta release* is the release of not-yet-production-quality-but-almost-there software to the general population. For example, Google's Gmail was in 'beta' for many years before the label was finally removed.

Dogfooding

What ★★★☆

***Eating your own dog food* (aka dogfooding), is a creators of a product use their own product to test the product.**

Developer Testing

What ★★☆☆

***Developer testing* is the testing done by the developers themselves** as opposed to professional testers or end-users.

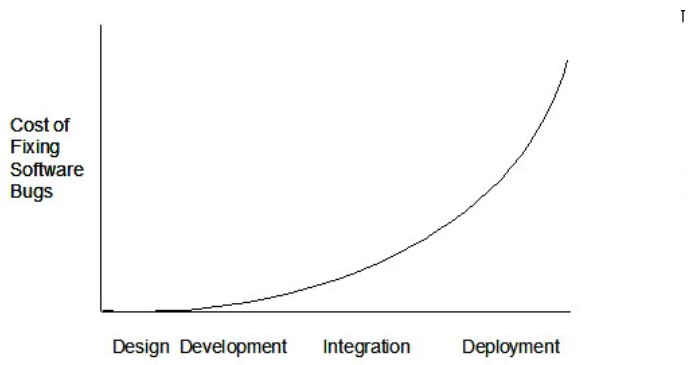
Why ★★★☆

Delaying testing until the full product is complete has a number of disadvantages:

- **Locating the cause of such a test case failure is difficult due to a large search space;** in a large system, the search space could be millions of lines of code, written by hundreds of developers! The failure may also be due to multiple inter-related bugs.
- **Fixing a bug found during such testing could result in major rework**, especially if the bug originated during the design or during requirements specification i.e. a faulty design or faulty requirements.
- **One bug might 'hide' other bugs**, which could emerge only after the first bug is fixed.
- **The delivery may have to be delayed** if too many bugs were found during testing.

Therefore, it is better to do early testing, as hinted by the popular rule of thumb given below, also illustrated by the graph below it.

> The earlier a bug is found, the easier and cheaper to have it fixed.



Such early testing of partially developed software is usually, and by necessity, done by the developers themselves i.e. developer testing.

Exploratory vs Scripted Testing

What ★★★☆

Here are two alternative approaches to testing a software: *Scripted* testing and *Exploratory* testing

1. **Scripted testing:** First write a set of test cases based on the expected behavior of the SUT, and then perform testing based on that set of test cases.

2. **Exploratory testing:** Devise test cases on-the-fly, creating new test cases based on the results of the past test cases.

Exploratory testing is 'the simultaneous learning, test design, and test execution' [source: bach-et-explained] whereby the nature of the follow-up test case is decided based on the behavior of the previous test cases. In other words, running the system and trying out various operations. It is called *exploratory testing* because testing is driven by observations during testing. Exploratory testing usually starts with areas identified as error-prone, based on the tester's past experience with similar systems. One tends to conduct more tests for those operations where more faults are found.

📦 Here is an example thought process behind a segment of an exploratory testing session:

> "Hmm... looks like feature x is broken. This usually means feature n and k could be broken too; we need to look at them soon. But before that, let us give a good test run to feature y because users can still use the product if feature y works, even if x doesn't work. Now, if feature y doesn't work 100%, we have a major problem and this has to be made known to the development team sooner rather than later..."

💡 **Exploratory testing is also known as *reactive testing, error guessing technique, attack-based testing,* and *bug hunting*.**

When ★★★☆

Which approach is better – **scripted or exploratory? A mix is better.**

The success of exploratory testing depends on the tester's prior experience and intuition. Exploratory testing should be done by experienced testers, using a clear strategy/plan/framework. Ad-hoc exploratory testing by unskilled or inexperienced testers without a clear strategy is not recommended for real-world non-trivial systems. While **exploratory testing may allow us to detect some problems in a relatively short time, it is not prudent to use exploratory testing as the sole means of testing a critical system**.

Scripted testing is more systematic, and hence, likely to discover more bugs given sufficient time, while exploratory testing would aid in quick error discovery, especially if the tester has a lot of experience in testing similar systems.

> In some contexts, you will achieve your testing mission better through a more scripted approach; in other contexts, your mission will benefit more from the ability to create and improve tests as you execute them. I find that most situations benefit from a mix of scripted and exploratory approaches. --[source: bach-et-explained]

Acceptance Testing

What ★★☆☆

***Acceptance testing* (aka *User Acceptance Testing (UAT)*): test the delivered system to ensure it meets the user requirements.**

Acceptance tests give an assurance to the customer that the system does what it is intended to do. Acceptance test cases are often defined at the beginning of the project, usually based on the use case specification. Successful completion of UAT is often a prerequisite to the project sign-off.

Acceptance vs System Testing ★★★☆

Acceptance testing comes after system testing. Similar to system testing, acceptance testing involves testing the whole system.

Some differences between system testing and acceptance testing:

System Testing	Acceptance Testing
Done against the system specification	Done against the requirements specification
Done by testers of the project team	Done by a team that represents the customer
Done on the development environment or a test bed	Done on the deployment site or on a close simulation of the deployment site
Both negative and positive test cases	More focus on positive test cases

Note: *negative* test cases: cases where the SUT is not expected to work normally e.g. incorrect inputs; *positive* test cases: cases where the SUT is expected to work normally

Requirement Specification vs System Specification

The requirement specification need not be the same as the system specification. Some example differences:

Requirements Specification	**System Specification**
limited to how the system behaves in normal working conditions	can also include details on how it will fail gracefully when pushed beyond limits, how to recover, etc. specification
written in terms of problems that need to be solved (e.g. provide a method to locate an email quickly)	written in terms of how the system solve those problems (e.g. explain the email search feature)
specifies the interface available for intended end-users	could contain additional APIs not available for end-users (for the use of developers/testers)

However, **in many cases one document serves as both a requirement specification and a system specification.**

Passing system tests does not necessarily mean passing acceptance testing. Some examples:

- The system might work on the testbed environments but might not work the same way in the deployment environment, due to subtle differences between the two environments.
- The system might conform to the system specification but could fail to solve the problem it was supposed to solve for the user, due to flaws in the system design.

Regression Testing

What ★★☆☆

When we modify a system, the modification may result in some unintended and undesirable effects on the system. Such an effect is called a *regression*.

***Regression testing* is re-testing the software to detect regressions.** Note that to detect regressions, we need to retest all related components, even if they were tested before.

Regression testing is more effective when it is done frequently, after each small change. However, doing so can be prohibitively expensive if testing is done manually. Hence, **regression testing is more practical when it is automated**.

Test Automation

What ★★☆☆

An automated test case can be run programmatically and the result of the test case (pass or fail) is determined programmatically. Compared to manual testing, automated testing reduces the effort required to run tests repeatedly and increases precision of testing (because manual testing is susceptible to human errors).

Automated Testing of CLI Apps ★★☆☆

A simple way to semi-automate testing of a CLI(Command Line Interface) app is by using input/output re-direction.

- First, we feed the app with a sequence of test inputs that is stored in a file while redirecting the output to another file.
- Next, we compare the actual output file with another file containing the expected output.

Let us assume we are testing a CLI app called `AddressBook`. Here are the detailed steps:

1. Store the test input in the text file `input.txt`.

   Example `input.txt`

2. Store the output we expect from the SUT in another text file `expected.txt`.

   ▶ 📦 Example `expected.txt`

3. Run the program as given below, which will redirect the text in `input.txt` as the input to `AddressBook` and similarly, will redirect the output of AddressBook to a text file `output.txt`. Note that this does not require any code changes to `AddressBook`.

   ```
   java AddressBook < input.txt > output.txt
   ```

   - 💡 The way to run a CLI program differs based on the language.
     e.g., In Python, assuming the code is in `AddressBook.py` file, use the command
     `python AddressBook.py < input.txt > output.txt`
   - 💡 If you are using Windows, use a normal command window to run the app, not a Power Shell window.

4. Next, we compare `output.txt` with the `expected.txt`. This can be done using a utility such as Windows `FC` (i.e. File Compare) command, Unix `diff` command, or a GUI tool such as *WinMerge*.

   ```
   FC output.txt expected.txt
   ```

Note that the above technique is only suitable when testing CLI apps, and only if the exact output can be predetermined. If the output varies from one run to the other (e.g. it contains a time stamp), this technique will not work. In those cases we need more sophisticated ways of automating tests.

Test Automation Using Test Drivers ★★★☆

A test driver is the code that 'drives' the SUT for the purpose of testing i.e. invoking the SUT with test inputs and verifying the behavior is as expected.

📦 `PayrollTest` 'drives' the `PayRoll` class by sending it test inputs and verifies if the output is as expected.

```
public class PayrollTestDriver {
    public static void main(String[] args) throws Exception {

        //test setup
        Payroll p = new Payroll();

        //test case 1
        p.setEmployees(new String[]{"E001", "E002"});
        // automatically verify the response
        if (p.totalSalary() != 6400) {
            throw new Error("case 1 failed ");
        }

        //test case 2
        p.setEmployees(new String[]{"E001"});
        if (p.totalSalary() != 2300) {
            throw new Error("case 2 failed ");
        }

        //more tests...

        System.out.println("All tests passed");
    }
}
```

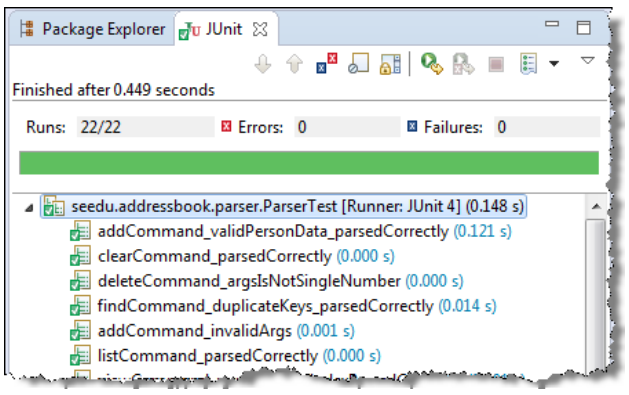
Test Automation Tools ★★★☆

JUnit is a tool for automated testing of Java programs. Similar tools are available for other languages and for automating different types of testing.

📦 This an automated test for a `Payroll` class, written using JUnit libraries.

```java
@Test
public void testTotalSalary(){
    Payroll p = new Payroll();

    //test case 1
    p.setEmployees(new String[]{"E001", "E002"});
    assertEquals(6400, p.totalSalary());

    //test case 2
    p.setEmployees(new String[]{"E001"});
    assertEquals(2300, p.totalSalary());

    //more tests...
}
```

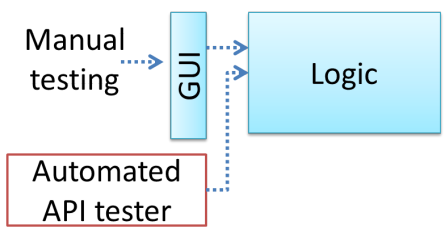
Most modern IDEs has integrated support for testing tools. The figure below shows the JUnit output when running some JUnit tests using the Eclipse IDE.



Automated Testing of GUIs ★★★☆

If a software product has a GUI component, all product-level testing (i.e. the types of testing mentioned above) need to be done using the GUI. However, **testing the GUI is much harder than testing the CLI (command line interface) or API**, for the following reasons:

- Most GUIs can support a large number of different operations, many of which can be performed in any arbitrary order.
- GUI operations are more difficult to automate than API testing. Reliably automating GUI operations and automatically verifying whether the GUI behaves as expected is harder than calling an operation and comparing its return value with an expected value. Therefore, automated regression testing of GUIs is rather difficult.
- The appearance of a GUI (and sometimes even behavior) can be different across platforms and even environments. For example, a GUI can behave differently based on whether it is minimized or maximized, in focus or out of focus, and in a high resolution display or a low resolution display.



One approach to overcome the challenges of testing GUIs is to minimize logic aspects in the GUI. Then, bypass the GUI to test the rest of the system using automated API testing. While this still requires the GUI to be tested manually, the number of such manual test cases can be reduced as most of the system has been tested using automated API testing.

There are testing tools that can automate GUI testing.

📦 Some tools used for automated GUI testing:

- **TestFx** can do automated testing of JavaFX GUIs
- **VisualStudio** supports 'record replay' type of GUI test automation.
- **Selenium** can be used to automate testing of Web application UIs

Test Coverage

What ★★☆☆

***Test coverage* is a metric used to measure the extent to which testing exercises the code** i.e., how much of the code is 'covered' by the tests.

Here are some examples of different coverage criteria:

- **Function/method coverage** : based on functions executed e.g., testing executed 90 out of 100 functions.
- **Statement coverage** : based on the number of line of code executed e.g., testing executed 23k out of 25k LOC.
- **Decision/branch coverage** : based on the decision points exercised e.g., an `if` statement evaluated to both `true` and `false` with separate test cases during testing is considered 'covered'.
- **Condition coverage** : based on the boolean sub-expressions, each evaluated to both true and false with different test cases. Condition coverage is not the same as the decision coverage.

📦 `if(x > 2 && x < 44)` is considered one decision point but two conditions.

For 100% branch or decision coverage, two test cases are required:

- `(x > 2 && x < 44) == true` : [e.g. `x == 4`]
- `(x > 2 && x < 44) == false` : [e.g. `x == 100`]

For 100% condition coverage, three test cases are required

- `(x > 2) == true` , `(x < 44) == true` : [e.g. `x == 4`]
- `(x < 44) == false` : [e.g. `x == 100`]
- `(x > 2) == false` : [e.g. `x == 0`]

- **Path coverage** measures coverage in terms of possible paths through a given part of the code executed. 100% path coverage means all possible paths have been executed. A commonly used notation for path analysis is called the *Control Flow Graph (CFG)*.
- **Entry/exit coverage** measures coverage in terms of possible *calls to* and *exits* from the operations in the SUT.

How ★★★☆

Measuring coverage is often done using *coverage analysis tools*. Most IDEs have inbuilt support for measuring test coverage, or at least have plugins that can measure test coverage.

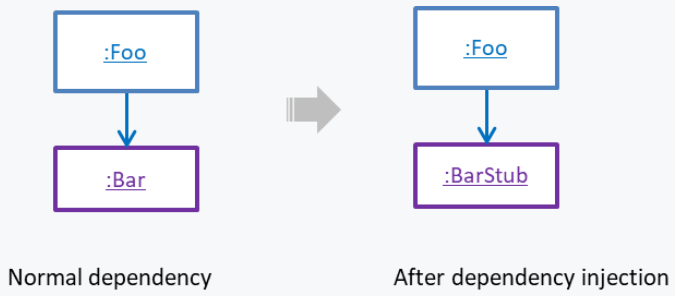
Coverage analysis can be useful in improving the quality of testing e.g., if a set of test cases does not achieve 100% branch coverage, more test cases can be added to cover missed branches.

Dependency Injection

What ★★★☆

***Dependency injection* is the process of 'injecting' objects to replace current dependencies with a different object.** This is often used to inject stubs to isolate the SUT from its dependencies so that it can be tested in isolation.

📦 A `Foo` object normally depends on a `Bar` object, but we can inject a `BarStub` object so that the `Foo` object no longer depends on a `Bar` object. Now we can test the `Foo` object in isolation from the `Bar` object.



Normal dependency After dependency injection

Test Case Design

Introduction

What ★★★☆

Except for trivial SUTs , exhaustive testing is not practical because such testing often requires a massive/infinite number of test cases.

📦 Consider the test cases for adding a string object to a collection :

- Add an item to an empty collection.
- Add an item when there is one item in the collection.
- Add an item when there are 2, 3, ... n items in the collection.
- Add an item that has an English, a French, a Spanish, ... word.
- Add an item that is the same as an existing item.
- Add an item immediately after adding another item.
- Add an item immediately after system startup.
- ...

Exhaustive testing of this operation can take many more test cases.

> Program testing can be used to show the presence of bugs, but never to show their absence!
>
> --Edsger Dijkstra

Every test case adds to the cost of testing. In some systems, a single test case can cost thousands of dollars e.g. on-field testing of flight-control software. Therefore, **test cases need to be designed to make the best use of testing resources.** In particular:

- **Testing should be *effective*** i.e., it finds a high percentage of existing bugs e.g., a set of test cases that finds 60 defects is more effective than a set that finds only 30 defects in the same system.
- **Testing should be *efficient*** i.e., it has a high rate of success (bugs found/test cases) a set of 20 test cases that finds 8 defects is more efficient than another set of 40 test cases that finds the same 8 defects.

For testing to be E&E , each new test we add should be targeting a potential fault that is not already targeted by existing test cases. There are test case design techniques that can help us improve E&E of testing.

Positive vs Negative Test Cases ★★☆☆

A *positive test case* is when the test is designed to produce an expected/valid behavior. A negative test case is designed to produce a behavior that indicates an invalid/unexpected situation, such as an error message.

📦 Consider testing of the method `print(Integer i)` which prints the value of `i`.

- A positive test case: `i == new Integer(50)`
- A negative test case: `i == null;`

Black Box vs Glass Box ★★☆☆

Test case design can be of three types, based on how much of SUT internal details are considered when designing test cases:

- ***Black-box* (aka *specification-based or responsibility-based*) approach**: test cases are designed exclusively based on the SUT's specified external behavior.
- ***White-box* (aka *glass-box or structured or implementation-based*) approach**: test cases are designed based on what is known about the SUT's implementation, i.e. the code.
- ***Gray-box* approach**: test case design uses *some* important information about the implementation. For example, if the implementation of a sort operation uses different algorithms to sort lists shorter than 1000 items and lists longer than 1000 items, more meaningful test cases can then be added to verify the correctness of both algorithms.

▶ 📹 Black-box and white-box testing

Equivalence Partitions

What ★★☆☆

Consider the testing of the following operation.

> `isValidMonth(m)` : returns `true` if `m` (and `int`) is in the range [1..12]

It is inefficient and impractical to test this method for all integer values `[-MIN_INT to MAX_INT]`. Fortunately, there is no need to test all possible input values. For example, if the input value `233` failed to produce the correct result, the input `234` is likely to fail too; there is no need to test both.

In general, **most SUTs do not treat each input in a unique way. Instead, they process all possible inputs in a small number of distinct ways.** That means a range of inputs is treated the same way inside the SUT. ***Equivalence partitioning (EP)* is a test case design technique that uses the above observation to improve the E&E of testing.**

> **Equivalence partition (aka equivalence class)**: A group of test inputs that are likely to be processed by the SUT in the same way.

By dividing possible inputs into equivalence partitions we can,

- **avoid testing too many inputs from one partition.** Testing too many inputs from the same partition is unlikely to find new bugs. This increases the efficiency of testing by reducing redundant test cases.
- **ensure all partitions are tested.** Missing partitions can result in bugs going unnoticed. This increases the effectiveness of testing by increasing the chance of finding bugs.

Basic ★★☆☆

Equivalence partitions (EPs) are usually derived from the specifications of the SUT.

> 📦 These could be EPs for the isValidMonth example:
>
> - [MIN_INT ... 0] : **below** the range that produces `true` (produces `false`)
> - [1 ... 12] : the range that produces `true`
> - [13 ... MAX_INT] : **above** the range that produces `true` (produces `false`)

-

When the SUT has multiple inputs, you should identify EPs for each input.

> 📦 Consider the method `duplicate(String s, int n): String` which returns a `String` that contains `s` repeated `n` times.
>
> Example EPs for `s`:
>
> - zero-length strings
> - string containing whitespaces
> - ...
>
> Example EPs for `n`:
>
> - `0`
> - negative values
> - ...

An EP may not have adjacent values.

> 📦 Consider the method `isPrime(int i): boolean` that returns true if `i` is a prime number.
>
> EPs for `i`:
>
> - prime numbers
> - non-prime numbers

Some inputs have only a small number of possible values and a potentially unique behavior for each value. In those cases we have to consider each value as a partition by itself.

📦 Consider the method `showStatusMessage(GameStatus s): String` that returns a unique `String` for each of the possible value of s (`GameStatus` is an `enum`). In this case, each possible value for `s` will have to be considered as a partition.

Note that the EP technique is merely a heuristic and not an exact science, especially when applied manually (as opposed to using an automated program analysis tool to derive EPs). The partitions derived depend on how one 'speculates' the SUT to behave internally. Applying EP under a glass-box or gray-box approach can yield more precise partitions.

📦 Consider the method EPs given above for the `isValidMonth`. A different tester might use these EPs instead:

- [1 … 12] : the range that produces `true`
- [all other integers] : the range that produces `false`

📦 Some more examples:

Specification	Equivalence partitions
`isValidFlag(String s): boolean` Returns `true` if s is one of [`"F"`, `"T"`, `"D"`]. The comparison is case-sensitive.	[`"F"`] [`"T"`] [`"D"`] [`"f"`, `"t"`, `"d"`] [any other string][null]
`squareRoot(String s): int` Pre-conditions: s represents a positive integer Returns the square root of `s` if the square root is an integer; returns `0` otherwise.	[`s` is not a valid number] [`s` is a negative integer] [`s` has an integer square root] [`s` does not have an integer square root]

Intermediate ★★★☆

When deciding EPs of OOP methods, we need to identify EPs of all data participants that can potentially influence the behaviour of the method, such as,

- the target object of the method call
- input parameters of the method call
- other data/objects accessed by the method such as global variables. This category may not be applicable if using the black box approach (because the test case designer using the black box approach will not know how the method is implemented)

📦 Consider this method in the `DataStack` class: `push(Object o): boolean`

- Adds o to the top of the stack if the stack is not full.
- returns `true` if the push operation was a success.
- throws
  - `MutabilityException` if the global flag `FREEZE==true`.
  - `InvalidValueException` if o is null.

EPs:

- `DataStack` object: [full] [not full]
- `o`: [null] [not null]
- `FREEZE`: [true][false]

📦 Consider a simple Minesweeper app. What are the EPs for the `newGame()` method of the `Logic` component?

As `newGame()` does not have any parameters, the only obvious participant is the `Logic` object itself.

Note that if the glass-box or the grey-box approach is used, other associated objects that are involved in the method might also be included as participants. For example, `Minefield` object can be considered as another participant of the `newGame()` method. Here, the black-box approach is assumed.

Next, let us identify equivalence partitions for each participant. Will the `newGame()` method behave differently for different `Logic` objects? If yes, how will it differ? In this case, yes, it might behave differently based on the game state. Therefore, the equivalence partitions are:

- `PRE_GAME` : before the game starts, minefield does not exist yet
- `READY` : a new minefield has been created and waiting for player's first move
- `IN_PLAY` : the current minefield is already in use
- `WON`, `LOST` : let us assume the `newGame` behaves the same way for these two values

📦 Consider the `Logic` component of the Minesweeper application. What are the EPs for the `markCellAt(int x, int y)` method?. The partitions in **bold** represent valid inputs.

- `Logic`: PRE_GAME, **READY**, **IN_PLAY**, WON, LOST
- `x`: [MIN_INT..-1] **[0..(W-1)]** [W..MAX_INT] (we assume a minefield size of WxH)
- `y`: [MIN_INT..-1] **[0..(H-1)]** [H..MAX_INT]
- `Cell` at `(x,y)`: **HIDDEN**, MARKED, CLEARED

Boundary Value Analysis

What ★★☆☆

***Boundary Value Analysis (BVA)* is test case design heuristic that is based on the observation that bugs often result from incorrect handling of boundaries of equivalence partitions.** This is not surprising, as the end points of the boundary are often used in branching instructions etc. where the programmer can make mistakes.

📦 `markCellAt(int x, int y)` operation could contain code such as if `(x > 0 && x <= (W-1))` which involves boundaries of x's equivalence partitions.

BVA suggests that when picking test inputs from an equivalence partition, values near boundaries (i.e. boundary values) are more likely to find bugs.

Boundary values are sometimes called *corner cases*.

How ★★★☆

Typically, we choose three values around the boundary to test: one value from the boundary, one value just below the boundary, and one value just above the boundary. The number of values to pick depends on other factors, such as the cost of each test case.

📦 Some examples:

Equivalence partition	**Some possible boundary values**
[1-12]	0,1,2, 11,12,13
[MIN_INT, 0] (MIN_INT is the minimum possible integer value allowed by the environment)	MIN_INT, MIN_INT+1, -1, 0 , 1
[any non-null String]	Empty String, a String of maximum possible length
[prime numbers] ["F"] ["A", "D", "X"]	No specific boundary No specific boundary No specific boundary

[non-empty Stack] (we assume a fixed size stack)	Stack with: one element, two elements, no empty spaces, only one empty space

Combining Test Inputs

Why ★★☆☆

An SUT can take multiple inputs. You can select values for each input (using equivalence partitioning, boundary value analysis, or some other technique).

📦 an SUT that takes multiple inputs and some values chosen as values for each input:

- Method to test: `calculateGrade(participation, projectGrade, isAbsent, examScore)`
- Values to test:

Input	valid values to test	invalid values to test
participation	0, 1, 19, 20	21, 22
projectGrade	A, B, C, D, F	
isAbsent	true, false	
examScore	0, 1, 69, 70,	71, 72

Testing all possible combinations is effective but not efficient. If you test all possible combinations for the above example, you need to test 6x5x2x6=360 cases. Doing so has a higher chance of discovering bugs (i.e. effective) but the number of test cases can be too high (i.e. not efficient). Therefore, **we need smarter ways to combine test inputs that are both effective and efficient.**

Test Input Combination Strategies ★★☆☆

Given below are some basic strategies for generating a set of test cases by combining multiple test input combination strategies.

📦 Let's assume the SUT has the following three inputs and you have selected the given values for testing:

SUT: `foo(p1 char, p2 int, p3 boolean)`

Values to test:

Input	Values
p1	a, b, c
p2	1, 2, 3
p3	T, F

The *all combinations* strategy generates test cases for each unique combination of test inputs.

📦 the strategy generates 3x3x2=18 test cases

Test Case	p1	p2	p3
1	a	1	T
2	a	1	F

Test Case	p1	p2	p3
3	a	2	T
...	...	...	...
18	c	3	F

The *at least once* strategy includes each test input at least once.

📦 this strategy generates 3 test cases.

Test Case	p1	p2	p3
1	a	1	T
2	b	2	F
3	c	3	VV/IV

VV/IV = Any Valid Value / Any Invalid Value

The *all pairs* strategy creates test cases so that for any given pair of inputs, all combinations between them are tested. It is based on the observations that a bug is rarely the result of more than two interacting factors. The resulting number of test cases is lower than the *all combinations* strategy, but higher than the *at least once* approach.

📦 this strategy generates 9 test cases:

> see steps

Test Case	p1	p2	p3
1	a	1	T
2	a	2	T
3	a	3	F
4	b	1	F
5	b	2	T
6	b	3	F
7	c	1	T
8	c	2	F
9	c	3	T

A variation of this strategy is to test all pairs of inputs but only for inputs that could influence each other.

📦 Testing all pairs between p1 and p3 only while ensuring all p3 values are tested at least once

Test Case	p1	p2	p3

Test Case	p1	p2	p3
1	a	1	T
2	a	2	F
3	b	3	T
4	b	VV/IV	F
5	c	VV/IV	T
6	c	VV/IV	F

The *random* strategy generates test cases using one of the other strategies and then pick a subset randomly (presumably because the original set of test cases is too big).

There are other strategies that can be used too.

Heuristic: Each Valid Input at Least Once in a Positive Test Case ★★★☆

Consider the following scenario.

SUT: `printLabel(fruitName String, unitPrice int)`

Selected values for `fruitName` (invalid values are underlined):

Values	Explanation
Apple	Label format is round
Banana	Label format is oval
Cherry	Label format is square
Dog	Not a valid fruit

Selected values for `unitPrice`:

Values	Explanation
1	Only one digit
20	Two digits
0	Invalid because 0 is not a valid price
-1	Invalid because negative prices are not allowed

Suppose these are the test cases being considered.

Case	fruitName	unitPrice	Expected
1	Apple	1	Print label
2	Banana	20	Print label
3	Cherry	0	Error message “invalid price”

Case	fruitName	unitPrice	Expected
4	Dog	-1	Error message “invalid fruit"

It looks like the test cases were created using the *at least once* strategy. After running these tests can we confirm that square-format label printing is done correctly?

- Answer: No.
- Reason: `Cherry` -- the only input that can produce a square-format label -- is in a negative test case which produces an error message instead of a label. If there is a bug in the code that prints labels in square-format, these tests cases will not trigger that bug.

In this case a useful heuristic to apply is **each valid input must appear at least once in a positive test case**. `Cherry` is a valid test input and we must ensure that it appears at least once in a positive test case. Here are the updated test cases after applying that heuristic.

Case	fruitName	unitPrice	Expected
1	Apple	1	Print round label
2	Banana	20	Print oval label
2.1	Cherry	VV	Print square label
3	VV	0	Error message “invalid price”
4	Dog	-1	Error message “invalid fruit"

VV/IV = Any Invalid or Valid Value VV=Any Valid Value

Heuristic: No More Than One Invalid Input In A Test Case ★★★☆

Consider the test cases designed in [Heuristic: each valid input at least once in a positive test case].

After running these test cases can you be sure that the error message “invalid price” is shown for negative prices?

- Answer: No.
- Reason: `-1` -- the only input that is a negative price -– is in a test case that produces the error message “invalid fruit”.

In this case a useful heuristic to apply is **no more than one invalid input in a test case**. After applying that, we get the following test cases.

Case	fruitName	unitPrice	Expected
1	Apple	1	Print round label
2	Banana	20	Print oval label
2.1	Cherry	VV	Print square label
3	VV	0	Error message “invalid price”
4	VV	-1	Error message “invalid price"
4.1	Dog	VV	Error message “invalid fruit"

VV/IV = Any Invalid or Valid Value VV=Any Valid Value

Mix ★★★☆

Consider the calculateGrade scenario given below:

- SUT : `calculateGrade(participation, projectGrade, isAbsent, examScore)`
- Values to test: invalid values are underlined
  - participation: 0, 1, 19, 20, 21, 22
  - projectGrade: A, B, C, D, F
  - isAbsent: true, false
  - examScore: 0, 1, 69, 70, 71, 72

To get the first cut of test cases, let's apply the *at least once* strategy.

Test cases for calculateGrade V1

Case No.	participation	projectGrade	isAbsent	examScore	Expected
1	0	A	true	0	...
2	1	B	false	1	...
3	19	C	VV/IV	69	...
4	20	D	VV/IV	70	...
5	21	F	VV/IV	71	Err Msg
6	22	VV/IV	VV/IV	72	Err Msg

VV/IV = Any Valid or Invalid Value, Err Msg = Error Message

Next, let's apply the *each valid input at least once in a positive test case* heuristic. Test case 5 has a valid value for `projectGrade=F` that doesn't appear in any other positive test case. Let's replace test case 5 with 5.1 and 5.2 to rectify that.

Test cases for calculateGrade V2

Case No.	participation	projectGrade	isAbsent	examScore	Expected
1	0	A	true	0	...
2	1	B	false	1	...
3	19	C	VV	69	...
4	20	D	VV	70	...
5.1	VV	F	VV	VV	...
5.2	21	VV/IV	VV/IV	71	Err Msg
6	22	VV/IV	VV/IV	72	Err Msg

VV = Any Valid Value VV/IV = Any Valid or Invalid Value

Next, we apply the *no more than one invalid input in a test case* heuristic. Test cases 5.2 and 6 don't follow that heuristic. Let's rectify the situation as follows:

Test cases for calculateGrade V3

Case No.	participation	projectGrade	isAbsent	examScore	Expected

Case No.	participation	projectGrade	isAbsent	examScore	Expected
1	0	A	true	0	...
2	1	B	false	1	...
3	19	C	VV	69	...
4	20	D	VV	70	...
5.1	VV	F	VV	VV	...
5.2	21	VV	VV	VV	Err Msg
5.3	22	VV	VV	VV	Err Msg
6.1	VV	VV	VV	71	Err Msg
6.2	VV	VV	VV	72	Err Msg

Next, let us assume that there is a dependency between the inputs `examScore` and `isAbsent` such that an absent student can only have `examScore=0`. To cater for the hidden invalid case arising from this, we can add a new test case where `isAbsent=true` and `examScore!=0`. In addition, test cases 3-6.2 should have `isAbsent=false` so that the input remains valid.

Test cases for calculateGrade V4

Case No.	participation	projectGrade	isAbsent	examScore	Expected
1	0	A	true	0	...
2	1	B	false	1	...
3	19	C	false	69	...
4	20	D	false	70	...
5.1	VV	F	false	VV	...
5.2	21	VV	false	VV	Err Msg
5.3	22	VV	false	VV	Err Msg
6.1	VV	VV	false	71	Err Msg
6.2	VV	VV	false	72	Err Msg
7	VV	VV	true	!=0	Err Msg

More

Testing Based on Use Cases ★★★☆

Use cases can be used for system testing and acceptance testing. For example, the main success scenario can be one test case while each variation (due to extensions) can form another test case. However, note that use cases do not specify the exact data entered into the system. Instead, it might say something like `user enters his personal data into the system`. Therefore, the tester has to choose data by considering equivalence partitions and boundary values. The combinations of these could result in one use case producing many test cases.

To increase E&E of testing, high-priority use cases are given more attention. For example, a scripted approach can be used to test high priority test cases, while an exploratory approach is used to test other areas of concern that could emerge during testing.

SECTION: PROJECT MANAGEMENT

Revision Control

What ★★☆☆

***Revision control* is the process of managing multiple versions of a piece of information.** In its simplest form, this is something that many people do by hand: every time you modify a file, save it under a new name that contains a number, each one higher than the number of the preceding version.

Manually managing multiple versions of even a single file is an error-prone task, though, so software tools to help automate this process have long been available. The earliest automated revision control tools were intended to help a single user to manage revisions of a single file. Over the past few decades, the scope of revision control tools has expanded greatly; they now manage multiple files, and help multiple people to work together. The best modern revision control tools have no problem coping with thousands of people working together on projects that consist of hundreds of thousands of files.

Revision control software will track the history and evolution of your project, so you don't have to. For every change, you'll have a log of who made it; why they made it; when they made it; and what the change was.

Revision control software makes it easier for you to collaborate when you're working with other people. For example, when people more or less simultaneously make potentially incompatible changes, the software will help you to identify and resolve those conflicts.

It can help you to recover from mistakes. If you make a change that later turns out to be an error, you can revert to an earlier version of one or more files. In fact, a really good revision control tool will even help you to efficiently figure out exactly when a problem was introduced.

It will help you to work simultaneously on, and manage the drift between, multiple versions of your project. Most of these reasons are equally valid, at least in theory, whether you're working on a project by yourself, or with a hundred other people.

-- [adapted from bryan-mercurial-guide

RCS : **Revision Control Software** are the software tools that automate the process of *Revision Control* i.e. managing revisions of software artifacts.

Revision: A *revision* (some seem to use it interchangeably with *version* while others seem to distinguish the two -- here, let us treat them as the same, for simplicity) is a state of a piece of information at a specific time that is a result of some changes to it e.g., if you modify the code and save the file, you have a new revision (or a version) of that file.

Revision control is also known as *Version Control Software (VCS)*, and a few other names.

Repositories ★☆☆☆

Repository (*repo* for short): The database of the history of a directory being tracked by an RCS software (e.g. Git).

The *repository* is the database where the meta-data about the revision history are stored. Suppose you want to apply revision control on files in a directory called `ProjectFoo`. In that case you need to set up a *repo* (short for repository) in `ProjectFoo` directory, which is referred to as the *working directory* of the repo. For example, Git uses a hidden folder named `.git` inside the working directory.

You can have multiple repos in your computer, each repo revision-controlling files of a different working directly, for examples, files of different projects.

Saving History ★☆☆☆

Tracking and Ignoring

In a repo, we can specify which files to track and which files to `ignore`. Some files such as temporary log files created during the build/test process should not be revision-controlled.

Staging and Committing

Committing **saves a snapshot of the current state of the tracked files in the revision control history. Such a snapshot is also called a *commit* (i.e. the noun).**

When ready to commit, we first *stage* the specific changes we want to commit. This intermediate step allows us to commit only some changes while saving other changes for a later commit.

Identifying Points in History

Each commit in a repo is a recorded point in the history of the project that is uniquely identified by an auto-generated `hash` e.g. `a16043703f28e5b3dab95915f5c5e5bf4fdc5fc1`.

We can `tag` a specific commit with a more easily identifiable name e.g. `v1.0.2`

Using History ★★☆☆

RCS tools store the history of the working directory as a series of commits. This means we should commit after each change that we want the RCS to 'remember' for us.

To see what changed between two points of the history, you can ask the RCS tool to *diff* the two commits in concern.

To restore the state of the working directory at a point in the past, you can *checkout* the commit in concern. i.e., we can traverse the history of the working directory simply by checking out the commits we are interested in.

Remote Repositories ★★☆☆

Remote repositories are copies of a repo that are hosted on remote computers. They are especially useful for sharing the revision history of a codebase among team members of a multi-person project. They can also serve as a remote backup of your code base.

You can *clone* a remote repo onto your computer which will create a copy of a remote repo on your computer, including the version history as the remote repo.

You can *push* new commits in your clone to the remote repo which will copy the new commits onto the remote repo. Note that pushing to a remote repo requires you to have write-access to it.

You can *pull* from the remote repos to receive new commits in the remote repo. Pulling is used to *sync* your local repo with latest changes to the remote repo.

While it is possible to set up your own remote repo on a server, an easier option is to use a remote repo hosting service such as GitHub or BitBucket.

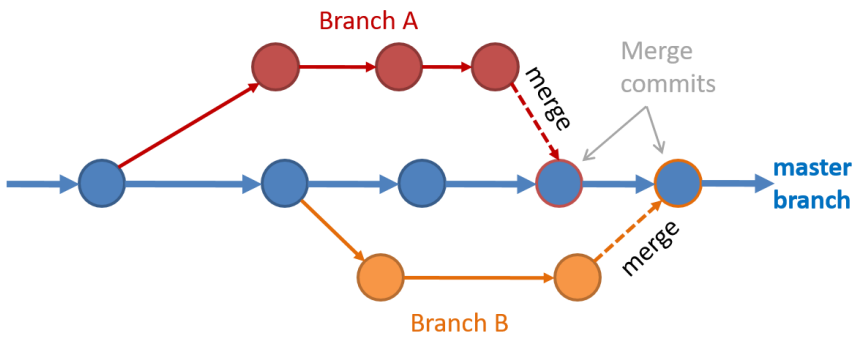
A *fork* is a remote copy of a remote repo. If there is a remote repo that you want to push to but you do not have write access to it, you can fork the remote repo, which gives you your own remote repo that you can push to.

A *pull request* is mechanism for contributing code to a remote repo. It is a formal request sent to the maintainers of the repo asking them to pull your new code to their repo.

Branching ★★☆☆

Branching **is the process of evolving multiple versions of the software in parallel.** For example, one team member can create a new branch and add an experimental feature to it while the rest of the team keeps working on another branch. Branches can be given names e.g. `master`, `release`, `dev`.

A branch can be *merged* into another branch. Merging usually result in a new commit that represents the changes done in the branch being merged.



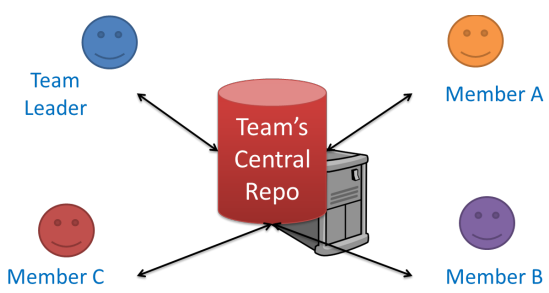
Branching and merging

Merge conflicts **happen when you try to merge two branches that had changed the same part of the code** and the RCS software cannot decide which changes to keep. In those cases we have to 'resolve' those conflicts manually.

DRCS vs CRCS ★★★☆

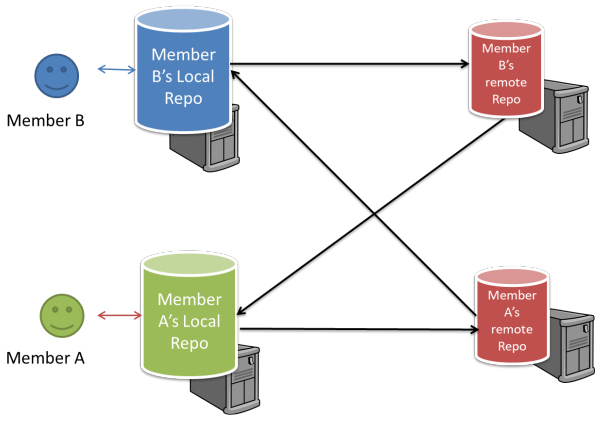
RCS can be done in two ways: the *centralized* way and the *distributed* way.

Centralized RCS (CRCS for short)uses a central remote repo that is shared by the team. Team members download ('pull') and upload ('push') changes between their own local repositories and the central repository. Older RCS tools such as CVS and SVN support only this model. Note that these older RCS do not support the notion of a local repo either. Instead, they force users to do all the versioning with the remote repo.



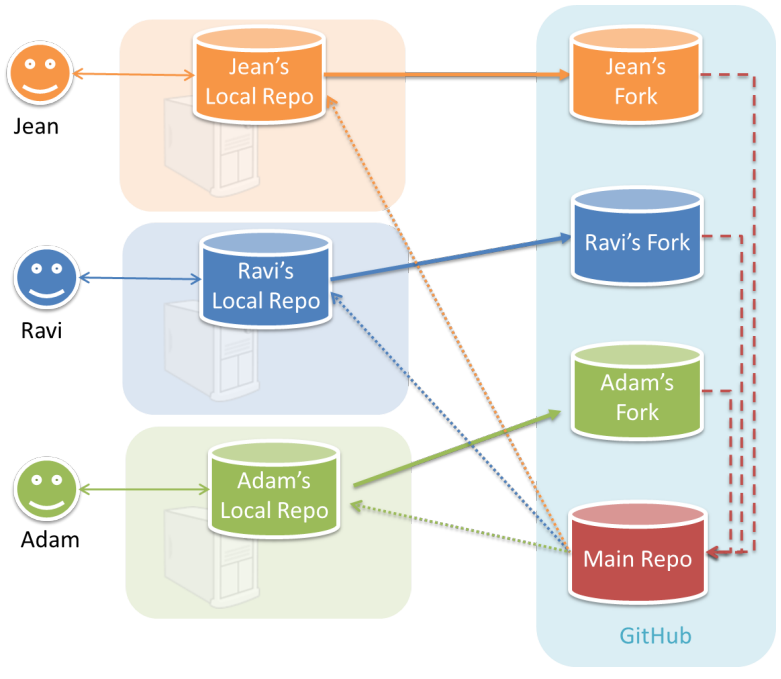
The centralized RCS approach without any local repos (e.g., CVS, SVN)

Distributed RCS (DRCS for short, also known as Decentralized RCS) allows multiple remote repos and pulling and pushing can be done among them in arbitrary ways. The workflow can vary differently from team to team. For example, every team member can have his/her own remote repository in addition to their own local repository, as shown in the diagram below. Git and Mercurial are some prominent RCS tools that support the distributed approach.



The decentralized RCS approach

Forking Flow ★★☆☆



In the *forking workflow*, the 'official' version of the software is kept in a remote repo designated as the 'main repo'. All team members fork the main repo create pull requests from their fork to the main repo.

To illustrate how the workflow goes, let's assume Jean wants to fix a bug in the code. Here are the steps:

1. Jean creates a separate branch in her local repo and fixes the bug in that branch.
2. Jean pushes the branch to her fork.
3. Jean creates a pull request from that branch in her fork to the main repo.
4. Other members review Jean's pull request.
5. If reviewers suggested any changes, Jean updates the PR accordingly.
6. When reviewers are satisfied with the PR, one of the members (usually the team lead or a designated 'maintainer' of the main repo) merges the PR, which brings Jean's code to the main repo.
7. Other members, realizing there is new code in the upstream repo, sync their forks with the new upstream repo (i.e. the main repo). This is done by pulling the new code to their own local repo and pushing the updated code to their own fork.

Project Planning

Work Breakdown Structure ★★★☆

A *Work Breakdown Structure (WBS)* depicts information about tasks and their details in terms of subtasks. When managing projects it is useful to divide the total work into smaller, well-defined units. Relatively complex tasks can be further split into subtasks. In complex projects a WBS can also include prerequisite tasks and effort estimates for each task.

📦 The high level tasks for a single iteration of a small project could look like the following:

Task ID	Task	Estimated Effort	Prerequisite Task
A	Analysis	1 man day	-
B	Design	2 man day	A
C	Implementation	4.5 man day	B
D	Testing	1 man day	C
E	Planning for next version	1 man day	D

The effort is traditionally measured in *man hour/day/month* i.e. work that can be done by one person in one hour/day/month. The *Task ID* is a label for easy reference to a task. Simple labeling is suitable for a small project, while a more informative labeling system can be adopted for bigger projects.

📦 An example WBS for a project for developing a game.

Task ID	Task	Estimated Effort	Prerequisite Task
A	High level design	1 man day	-
B	Detail design 1. User Interface 2. Game Logic 3. Persistency Support	2 man day • 0.5 man day • 1 man day • 0.5 man day	A
C	Implementation 1. User Interface 2. Game Logic 3. Persistency Support	4.5 man day • 1.5 man day • 2 man day • 1 man day	• B.1 • B.2 • B.3
D	System Testing	1 man day	C
E	Planning for next version	1 man day	D

All tasks should be well-defined. In particular, it should be clear as to when the task will be considered *done*.

📦 Some examples of ill-defined tasks and their better-defined counterparts:

👎 Bad	👍 Better
more coding	implement component X
do research on UI testing	find a suitable tool for testing the UI

Milestones ★★☆☆

A *milestone* is the end of a stage which indicates a significant progress. We should take into account dependencies and priorities when deciding on the features to be delivered at a certain milestone.

📦 Each intermediate product release is a milestone.

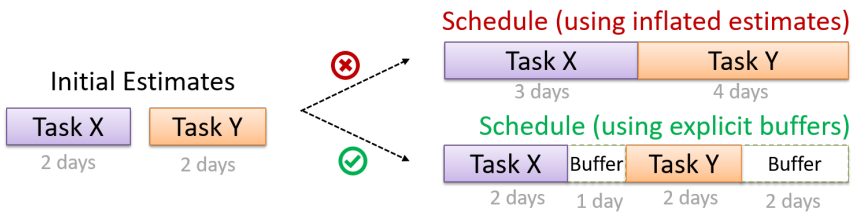
In some projects, it is not practical to have a very detailed plan for the whole project due to the uncertainty and unavailability of required information. In such cases, we can use a high-level plan for the whole project and a detailed plan for the next few milestones.

📦 Milestones for the Minesweeper project, iteration 1

Day	Milestones
Day 1	Architecture skeleton completed
Day 3	'new game' feature implemented
Day 4	'new game' feature tested

Buffers ★★★☆

A *buffer* is a time set aside to absorb any unforeseen delays. It is very important to include buffers in a software project schedule because effort/time estimations for software development is notoriously hard. However, **do not inflate task estimates to create hidden buffers**; have explicit buffers instead. Reason: With explicit buffers it is easier to detect incorrect effort estimates which can serve as a feedback to improve future effort estimates.

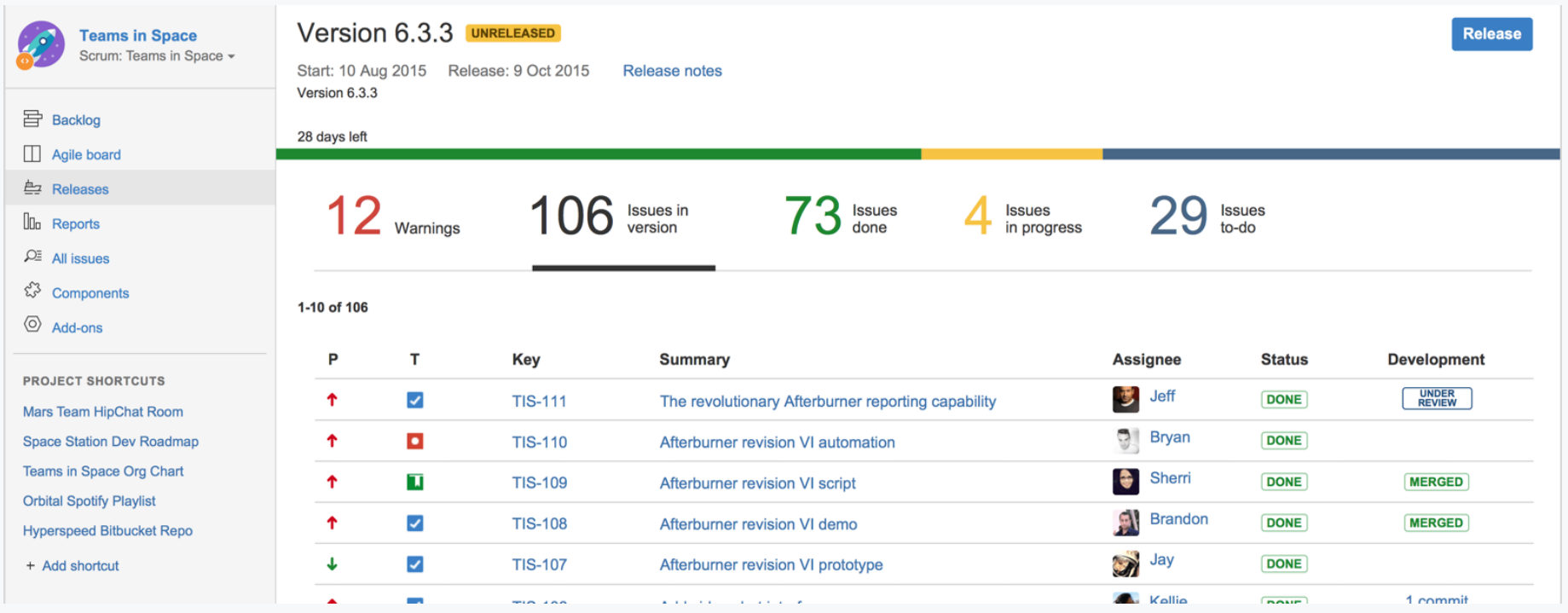


Issue Trackers ★★☆☆

Keeping track of project tasks (who is doing what, which tasks are ongoing, which tasks are done etc.) is an essential part of project management. In small projects it may be possible to track tasks using simple tools as online spreadsheets or general-purpose/light-weight tasks tracking tools such as Trello. Bigger projects need more sophisticated task tracking tools.

Issue trackers (sometimes called bug trackers) are commonly used to track task assignment and progress. Most online project management software such as GitHub, SourceForge, and BitBucket come with an integrated issue tracker.

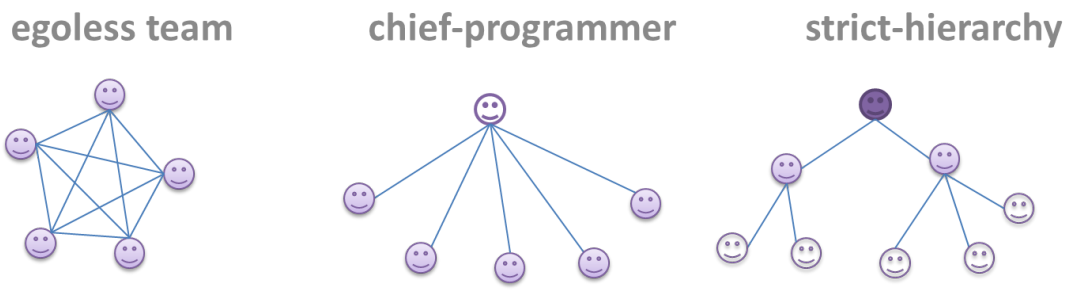
📦 A screenshot from the Jira Issue tracker software (Jira is part of the BitBucket project management tool suite):



Teamwork

Team Structures ★★★☆

Given below are three commonly used team structures in software development. Irrespective of the team structure, it is a good practice to assign roles and responsibilities to different team members so that someone is clearly in charge of each aspect of the project. In comparison, the 'everybody is responsible for everything' approach can result in more chaos and hence slower progress.



Egoless team

In this structure, **every team member is equal in terms of responsibility and accountability**. When any decision is required, consensus must be reached. This team structure is also known as a *democratic* team structure. This team structure usually finds a good solution to a relatively hard problem as all team members contribute ideas.

However, the democratic nature of the team structure bears a higher risk of falling apart due to the absence of an authority figure to manage the team and resolve conflicts.

Chief programmer team

Frederick Brooks proposed that software engineers learn from the medical surgical team in an operating room. In such a team, there is always a chief surgeon, assisted by experts in other areas. Similarly, in a chief programmer team structure, **there is a single authoritative figure, the chief programmer**. Major decisions, e.g. system architecture, are made solely by him/her and obeyed by all other team members. The chief programmer directs and coordinates the effort of other team members. When necessary, the chief will be assisted by domain specialists e.g. business specialists, database expert, network technology expert, etc. This allows individual group members to concentrate solely on the areas where they have sound knowledge and expertise.

The success of such a team structure relies heavily on the chief programmer. Not only must he be a superb technical hand, he also needs good managerial skills. Under a suitably qualified leader, such a team structure is known to produce successful work. .

Strict hierarchy team

In the opposite extreme of an egoless team, a strict hierarchy team has **a strictly defined organization among the team members**, reminiscent of the military or bureaucratic government. Each team member only works on his assigned tasks and reports to a single "boss".

In a large, resource-intensive, complex project, this could be a good team structure to reduce communication overhead.

SDLC Process Models

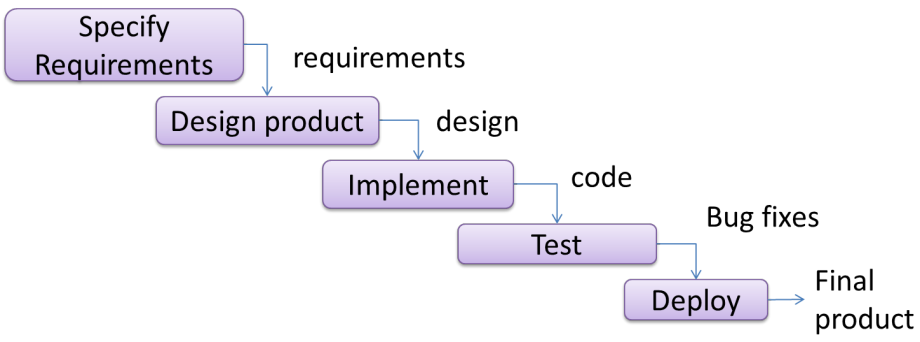
Introduction

What ★★☆☆

Software development goes through different stages such as *requirements, analysis, design, implementation* and *testing*. These stages are collectively known as the *software development life cycle* (SDLC). There are several approaches, known as *software development life cycle models* (also called *software process models*) that describe different ways to go through the SDLC. Each process model prescribes a "roadmap" for the software developers to manage the development effort. The roadmap describes the aims of the development stage(s), the artifacts or outcome of each stage as well as the workflow i.e. the relationship between stages.

Sequential Models ★★☆☆

The *sequential model*, also called the *waterfall* model, models software development as a linear process, in which the project is seen as progressing steadily in one direction through the development stages. The name *waterfall* stems from how the model is drawn to look like a waterfall (see below).



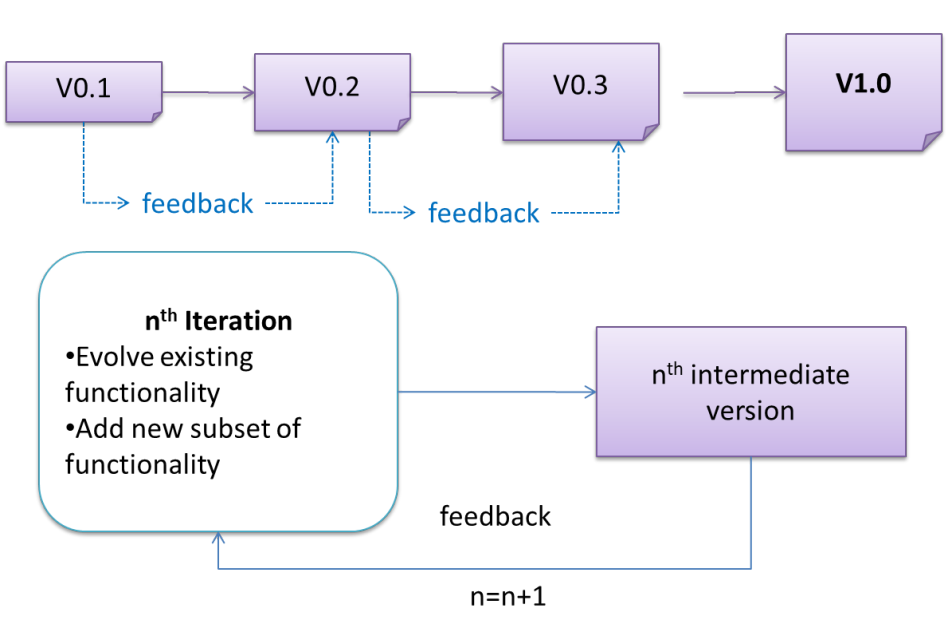
When one stage of the process is completed, it should produce some artifacts to be used in the next stage. For example, upon completion of the requirement stage a comprehensive list of requirements is produced that will see no further modifications. A strict application of the sequential model would require each stage to be completed before starting the next.

This could be a useful model when the problem statement that is well-understood and stable. In such cases, using the sequential model should result in a timely and systematic development effort, provided that all goes well. As each stage has a well-defined outcome, the progress of the project can be tracked with a relative ease.

The major problem with this model is that requirements of a real-world project are rarely well-understood at the beginning and keep changing over time. One reason for this is that users are generally not aware of how a software application can be used without prior experience in using a similar application.

Iterative Models ★★☆☆

The iterative model (sometimes called *iterative* and *incremental*) advocates having several *iterations* of SDLC. Each of the iterations could potentially go through all the development stages, from requirement gathering to testing & deployment. Roughly, it appears to be similar to several cycles of the sequential model.



In this model, each of the iterations produces a new version of the product. Feedback on the version can then be fed to the next iteration. Taking the Minesweeper game as an example, the iterative model will deliver a fully playable version from the early iterations. However, the first iteration will have primitive functionality, for example, a clumsy text based UI, fixed board size, limited randomization etc. These functionalities will then be improved in later releases.

The iterative model can take a *breadth-first* or a *depth-first* approach to iteration planning.

- **breadth-first**: an iteration evolves all major components in parallel.
- **depth-first**: an iteration focuses on fleshing out only some components.

Most project use a mixture of breadth-first and depth-first iterations. Hence, the common phrase 'an iterative and incremental process'.

Agile Models ★★★☆

In 2001, a group of prominent software engineering practitioners met and brainstormed for an alternative to documentation-driven, heavyweight software development processes that were used in most large projects at the time. This resulted in something called the *agile manifesto* (a vision statement of what they were looking to do).

> We are uncovering better ways of developing software by doing it and helping others do it.
>
> Through this work we have come to value:
>
> - **Individuals and interactions** over processes and tools
> - **Working software** over comprehensive documentation
> - **Customer collaboration** over contract negotiation
> - **Responding to change** over following a plan
>
> That is, while there is value in the items on the right, we value the items on the left more.
>
> Extract from the Agile Manifesto

Subsequently, some of the signatories of the manifesto went on to create process models that try to follow it. These processes are collectively called agile processes. Some of the key features of agile approaches are:

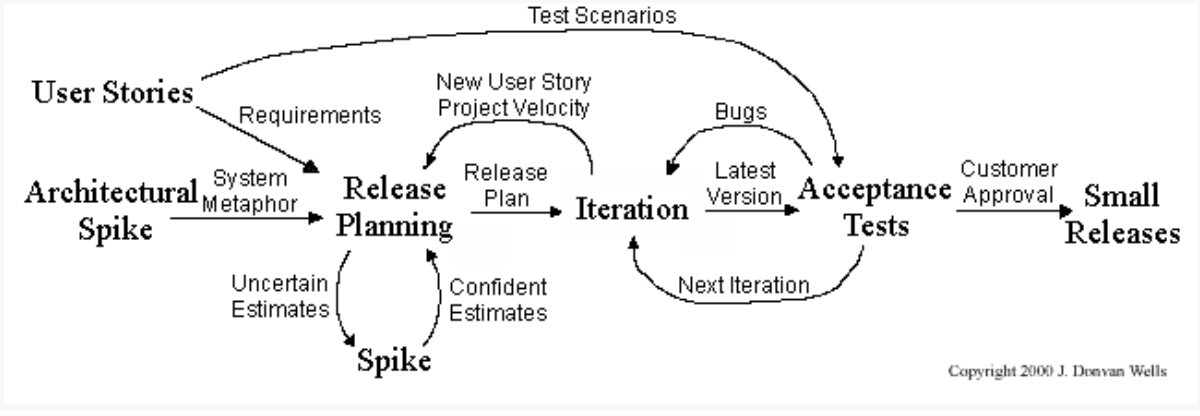
- Requirements are prioritized based on the needs of the user, are clarified regularly (at times almost on a daily basis) with the entire project team, and are factored into the development schedule as appropriate.
- Instead of doing a very elaborate and detailed design and a project plan for the whole project, the team works based on a rough project plan and a high level design that evolves as the project goes on.
- Strong emphasis on complete transparency and responsibility sharing among the team members. The team is responsible together for the delivery of the product. Team members are accountable, and regularly and openly share progress with each other and with the user.

There are a number of agile processes in the development world today. *eXtreme Programming (XP)* and *Scrum* are two of the well-known ones.

Example Process Models

XP ★★★☆

The following description was adapted from the XP home page, emphasis added:

> **Extreme Programming (XP) stresses customer satisfaction.** Instead of delivering everything you could possibly want on some date far in the future, this process delivers the software you need as you need it.
>
> **XP aims to empower developers to confidently respond to changing customer requirements**, even late in the life cycle.
>
> **XP emphasizes teamwork.** Managers, customers, and developers are all equal partners in a collaborative team. XP implements a simple, yet effective environment enabling teams to become highly productive. The team self-organizes around the problem to solve it as efficiently as possible.
>
> **XP aims to improve a software project in five essential ways: communication, simplicity, feedback, respect, and courage.** Extreme Programmers constantly communicate with their customers and fellow programmers. They keep their design simple and clean. They get feedback by testing their software starting on day one. Every small success deepens their respect for the unique contributions of each and every team member. With this foundation, Extreme Programmers are able to courageously respond to changing requirements and technology.
>
> **XP has a set of simple rules.** XP is a lot like a jig saw puzzle with many small pieces. Individually the pieces make no sense, but when combined together a complete picture can be seen. This flow chart shows how Extreme Programming's rules work together.
>
> 
>

***Pair programming, CRC cards, project velocity*, and *standup meetings* are some interesting topics related to XP.** Refer to extremeprogramming.org to find out more about XP.

Scrum ★★★☆

This description of Scrum was adapted from Wikipedia [retrieved on 18/10/2011], emphasis added:

Scrum is a process skeleton that contains sets of practices and predefined roles. The main roles in Scrum are:

- **The Scrum Master**, who maintains the processes (typically in lieu of a project manager)
- **The Product Owner**, who represents the stakeholders and the business
- **The Team**, a cross-functional group who do the actual analysis, design, implementation, testing, etc.

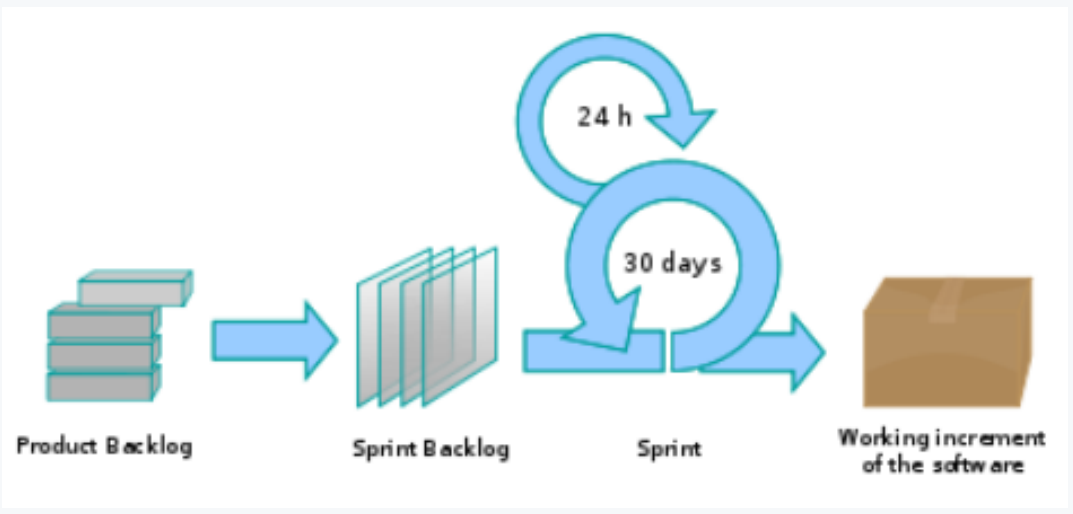
A Scrum project is divided into iterations called Sprints. A sprint is the basic unit of development in Scrum. Sprints tend to last between one week and one month, and are a timeboxed (i.e. restricted to a specific duration) effort of a constant length.

Each sprint is preceded by a planning meeting, where the tasks for the sprint are identified and an estimated commitment for the sprint goal is made, and followed by a review or retrospective meeting, where the progress is reviewed and lessons for the next sprint are identified.

During each sprint, the team creates a potentially deliverable product increment (for example, working and tested software). The set of features that go into a sprint come from the product backlog, which is a prioritized set of high level requirements of work to be done. Which backlog items go into the sprint is determined during the sprint planning meeting. During this meeting, the Product Owner informs the team of the items in the product backlog that he or she wants completed. The team then determines how much of this they can commit to complete during the next sprint, and records this in the sprint backlog. During a sprint, no one is allowed to change the sprint backlog, which means that the requirements are frozen for that sprint. Development is timeboxed such that the sprint must end on time; if requirements are not completed for any reason they are left out and returned to the product backlog. After a sprint is completed, the team demonstrates the use of the software.

Scrum enables the creation of self-organizing teams by encouraging co-location of all team members, and verbal communication between all team members and disciplines in the project.

A key principle of Scrum is its recognition that during a project the customers can change their minds about what they want and need (often called requirements churn), and that unpredicted challenges cannot be easily addressed in a traditional predictive or planned manner. As such, Scrum adopts an empirical approach—accepting that the problem cannot be fully understood or defined, focusing instead on maximizing the team's ability to deliver quickly and respond to emerging requirements.



***Daily Scrum* is another key scrum practice**. The description below was adapted from https://www.mountaingoatsoftware.com (emphasis added):

In Scrum, on each day of a sprint, the team holds a daily scrum meeting called the "daily scrum." Meetings are typically held in the same location and at the same time each day. Ideally, a daily scrum meeting is held in the morning, as it helps set the context for the coming day's work. These scrum meetings are strictly time-boxed to 15 minutes. This keeps the discussion brisk but relevant.

...

During the daily scrum, each team member answers the following three questions:

- What did you do yesterday?
- What will you do today?
- Are there any impediments in your way?

...

The daily scrum meeting is not used as a problem-solving or issue resolution meeting. **Issues that are raised are taken offline and usually dealt with by the relevant subgroup immediately after the meeting.**

SECTION: PRINCIPLES

Principles

Single Responsibility Principle ★★★☆

> ! **Single Responsibility Principle (SRP)**: A class should have one, and only one, reason to change. -- Robert C. Martin

If a class has only one responsibility, it needs to change only when there is a change to that responsibility.

Consider a `TextUi` class that does parsing of the user commands as well as interacting with the user. That class needs to change when the formatting of the UI changes as well as when the syntax of the user command changes. Hence, such a class does not follow the SRP.

> Gather together the things that change for the same reasons. Separate those things that change for different reasons. —*Agile Software Development, Principles, Patterns, and Practices* by Robert C. Martin

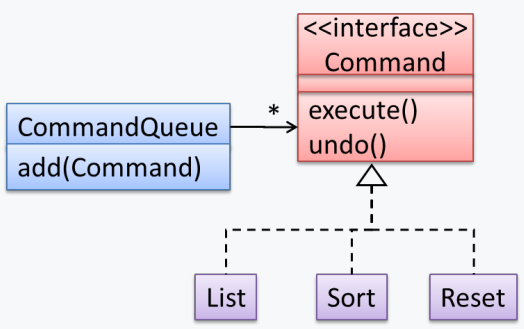
Open-Closed Principle ★★★☆

The Open-Close Principle aims to make a code entity easy to adapt and reuse without needing to modify the code entity itself.

> **Open-Closed Principle (OCP)**: A module should be *open* for extension but *closed* for modification. That is, modules should be written so that they can be extended, without requiring them to be modified. -- proposed by Bertrand Meyer

In object-oriented programming, OCP can be achieved in various ways. This often requires separating the *specification (i.e. interface)* of a module from its *implementation*.

In the design given below, the behavior of the `CommandQueue` class can be altered by adding more concrete `Command` subclasses. For example, by including a `Delete` class alongside `List`, `Sort`, and `Reset`, the `CommandQueue` can now perform delete commands without modifying its code at all. That is, its behavior was extended without having to modify its code. Hence, it was open to extensions, but closed to modification.



The behavior of a Java generic class can be altered by passing it a different class as a parameter. In the code below, the `ArrayList` class behaves as a container of `Students` in one instance and as a container of `Admin` objects in the other instance, without having to change its code. That is, the behavior of the `ArrayList` class is extended without modifying its code.

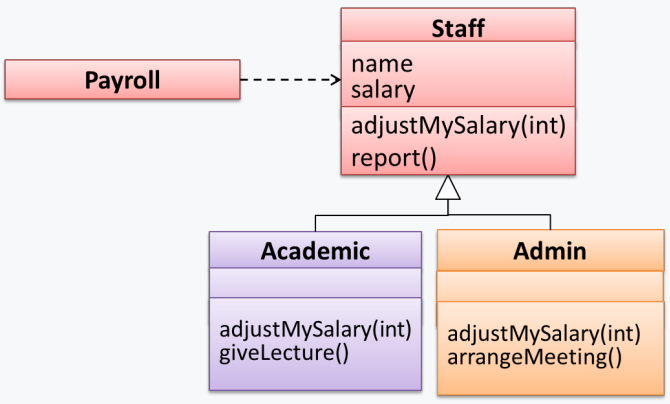
```
ArrayList students = new ArrayList< Student >();
ArrayList admins = new ArrayList< Admin >();
```

Liskov Substitution Principle : ★★★☆

> **Liskov Substitution Principle (LSP)**: Derived classes must be substitutable for their base classes. -- proposed by Barbara Liskov

LSP sounds same as substitutability but it goes beyond substitutability; **LSP implies that a subclass should not be more restrictive than the behavior specified by the superclass.** As we know, Java has language support for substitutability. However, if LSP is not followed, substituting a subclass object for a superclass object can break the functionality of the code.

📦 Suppose the `Payroll` class depends on the `adjustMySalary(int percent)` method of the `Staff` class. Furthermore, the `Staff` class states that the `adjustMySalary` method will work for all positive percent values. Both `Admin` and `Academic` classes override the `adjustMySalary` method.



Now consider the following:

- `Admin#adjustMySalary` method works for both negative and positive percent values.
- `Academic#adjustMySalary` method works for percent values `1..100` only.

In the above scenario,

- `Admin` class follows LSP because it fulfills `Payroll`'s expectation of `Staff` objects (i.e. it works for all positive values). Substituting `Admin` objects for Staff objects will not break the `Payroll` class functionality.
- `Academic` class violates LSP because it will not work for percent values over `100` as expected by the `Payroll` class. Substituting `Academic` objects for `Staff` objects can potentially break the `Payroll` class functionality.

Another example

Separation of Concerns Principle ★★☆☆

❗ **Separation of Concerns Principle (SoC)**: To achieve better modularity, separate the code into distinct sections, such that each section addresses a separate *concern*. -- Proposed by Edsger W. Dijkstra

A *concern* in this context is a set of information that affects the code of a computer program.

📦 Examples for *concerns*:

- A specific feature, such as the code related to `add employee` feature
- A specific aspect, such as the code related to `persistence` or `security`
- A specific entity, such as the code related to the `Employee` entity

Applying SoC reduces functional overlaps among code sections and also limits the ripple effect when changes are introduced to a specific part of the system.

📦 If the code related to *persistence* is separated from the code related to *security*, a change to how the data are persisted will not need changes to how the security is implemented.

This principle can be applied at the class level, as well as on higher levels.

📦 The n-tier architecture utilizes this principle. Each layer in the architecture has a well-defined functionality that has no functional overlap with each other.

This principle should lead to higher cohesion and lower coupling.

Law of Demeter ★★★☆

Law of Demeter (LoD):

- An object should have limited knowledge of another object.
- An object should only interact with objects that are closely related to it.

Also known as

- Don't talk to strangers.
- Principle of least knowledge

More concretely, a method `m` of an object `O` should invoke only the methods of the following kinds of objects:

- The object `O` itself
- Objects passed as parameters of `m`
- Objects created/instantiated in `m` (directly or indirectly)
- Objects from the direct association of `O`

📦 The following code fragment violates LoD due to the reason: while `b` is a 'friend' of `foo` (because it receives it as a parameter), `g` is a 'friend of a friend' (which should be considered a 'stranger'), and `g.doSomething()` is analogous to 'talking to a stranger'.

```
void foo(Bar b) {
    Goo g = b.getGoo();
    g.doSomething();
}
```

LoD aims to prevent objects navigating internal structures of other objects.

📦 An analogy for LoD can be drawn from Facebook. If Facebook followed LoD, you would not be allowed to see posts of friends of friends, unless they are your friends as well. If Jake is your friend and Adam is Jake's friend, you should not be allowed to see Adam's posts unless Adam is a friend of yours as well.

SECTION: TOOLS

UML

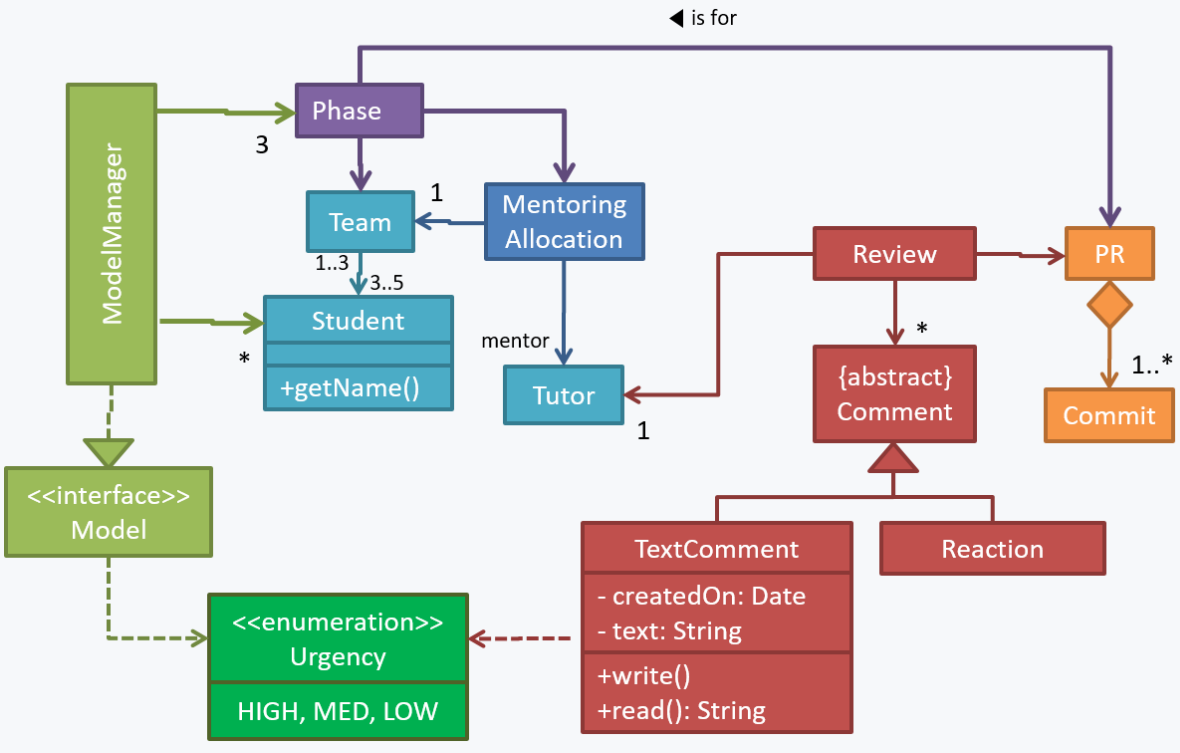
Class Diagrams

Introduction

What ★☆☆☆

UML *class diagrams* describe the structure (but not the behavior) of an OOP solution. These are possibly the most often used diagrams in the industry and an indispensable tool for an OO programmer.

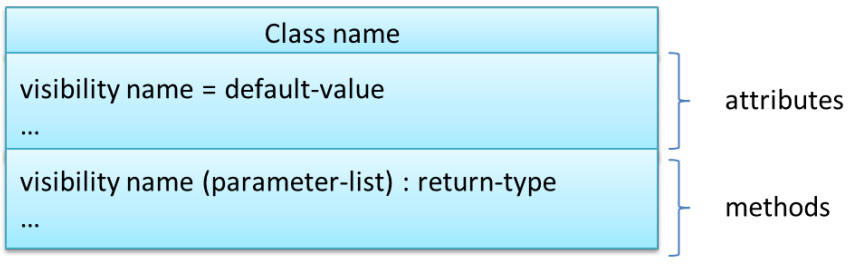
An example class diagram:



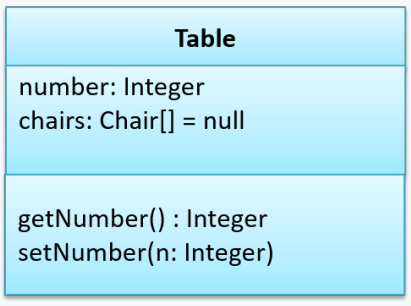
Classes

What ★☆☆☆

The basic UML notations used to represent a *class*:

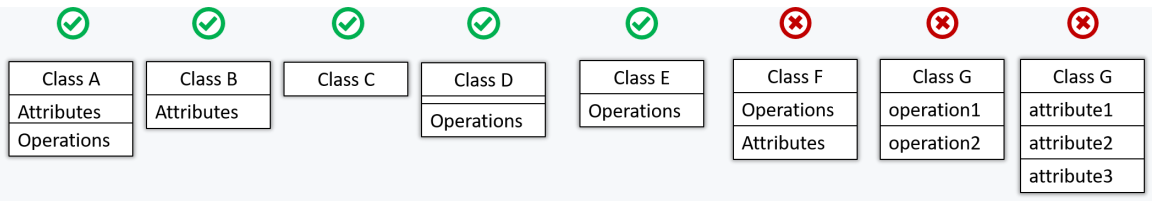


A `Table` class shown in UML notation:



The equivalent code

The 'Operations' compartment and/or the 'Attributes' compartment may be omitted if such details are not important for the task at hand. 'Attributes' always appear above the 'Operations' compartment. All operations should be in one compartment rather than each operation in a separate compartment. Same goes for attributes.

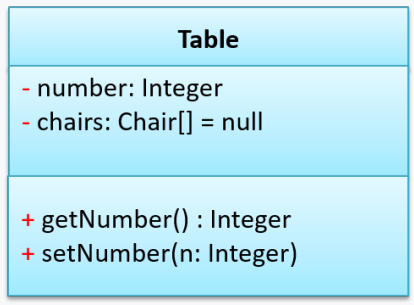


The *visibility* of attributes and operations is used to indicate the level of access allowed for each attribute or operation. The types of visibility and their exact meanings depend on the programming language used. Here are some common visibilities and how they are indicated in a class diagram:

- `+` : public
- `-` : private
- `#` : protected
- `~` : package private

▶ How visibilities map to programming language features

📦 `Table` class with visibilities shown:

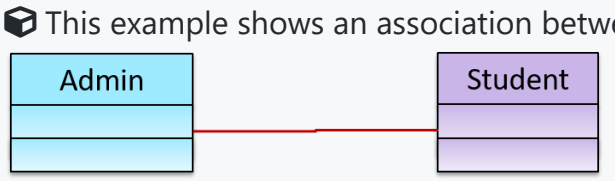


Associations

What ★☆☆☆

We use a solid line to show an association between two classes.

📦 This example shows an association between the `Admin` class and the `Student` class:



Navigability ★★☆☆

We use arrow heads to indication the navigability of an association.

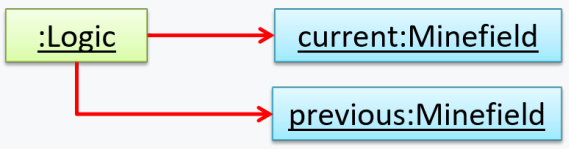
📦 `Logic` is aware of `Minefield`, but `Minefield` is not aware of `Logic`


```
class Logic{
    Minefield minefield;
}

class Minefield{
    ...
}
```

📦 Here is an example of a bidirectional navigability; each class is aware of the other.

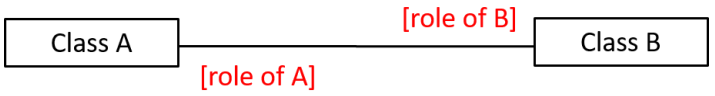
Navigability can be shown in class diagrams as well as object diagrams.

📦 According to this object diagram the given `Logic` object is associated with and aware of two `MineField` objects.

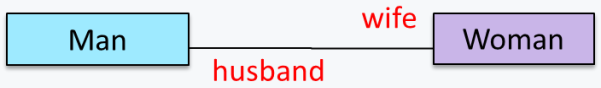


Roles ★★★☆

***Association Role* labels are used to indicate the role played by the classes in the association.**



📦 This association represents a marriage between a `Man` object and a `Woman` object. The respective roles played by objects of these two classes are `husband` and `wife`.



Note how the variable names match closely with the association roles.

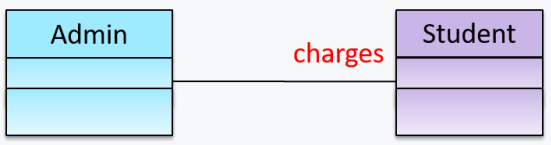
Java ↓

```
class Man{
    Woman wife;
}

class Woman{
    Man husband;
}
```

Python ↓

```
class Man:
  def __init__(self):
    self.wife = None # a Woman object

class Woman:
   def __init__(self):
     self.husband = None # a Man object
```

📦 The role of `Student` objects in this association is `charges` (i.e. Admin is in charge of students)



Java ↓

```
class Admin{
    List<Student> charges;
}
```

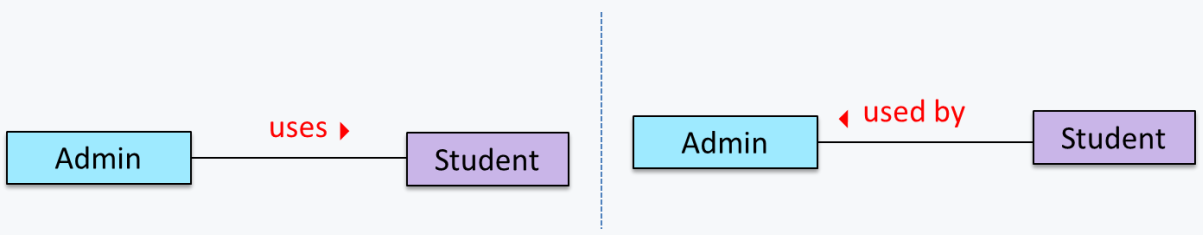
Python ↓

```
class Admin:
  def __init__(self):
    self.charges = [] # list of Student objects
```

Labels ★★☆☆

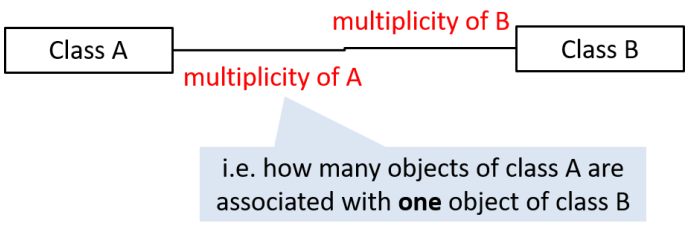
***Association labels* describe the meaning of the association.** The arrow head indicates the direction in which the label is to be read.

📦 In this example, the same association is described using two different labels.



- Diagram on the left: `Admin` class is associated with `Student` class because an `Admin` object *uses* a `Student` object.
- Diagram on the right: `Admin` class is associated with `Student` class because a `Student` object is *used by* an `Admin` object.

Multiplicity ★★★☆



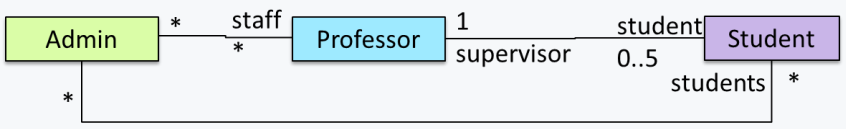
Commonly used multiplicities:

- `0..1` : *optional*, can be linked to 0 or 1 objects
- `1` : *compulsory*, must be linked to one object at all times.
- `*` : can be linked to 0 or more objects.
- `n..m` : the number of linked objects must be `n` to `m` inclusive

📦 In the diagram below, an `Admin` object administers (in charge of) any number of students but a `Student` object must always be under the charge of exactly one `Admin` object

📦 In the diagram below,

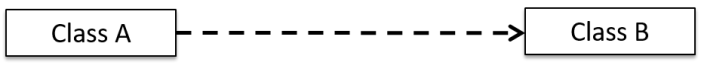
- Each student must be supervised by exactly one professor. i.e. There cannot be a student who doesn't have a supervisor or has multiple supervisors.
- A professor cannot supervise more than 5 students but can have no students to supervise.
- An admin can handle any number of professors and any number of students, including none.
- A professor/student can be handled by any number of admins, including none.



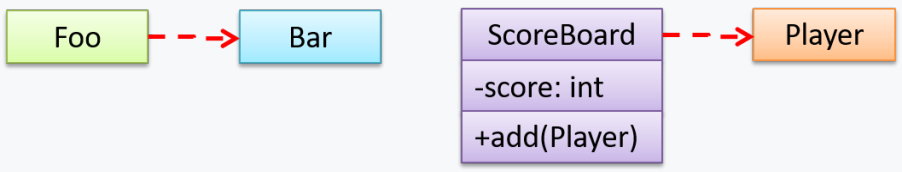
Dependencies

What ★★★☆

UML uses a dashed arrow to show dependencies.



📦 Two examples of dependencies:



Associations as Attributes

What ★★★☆

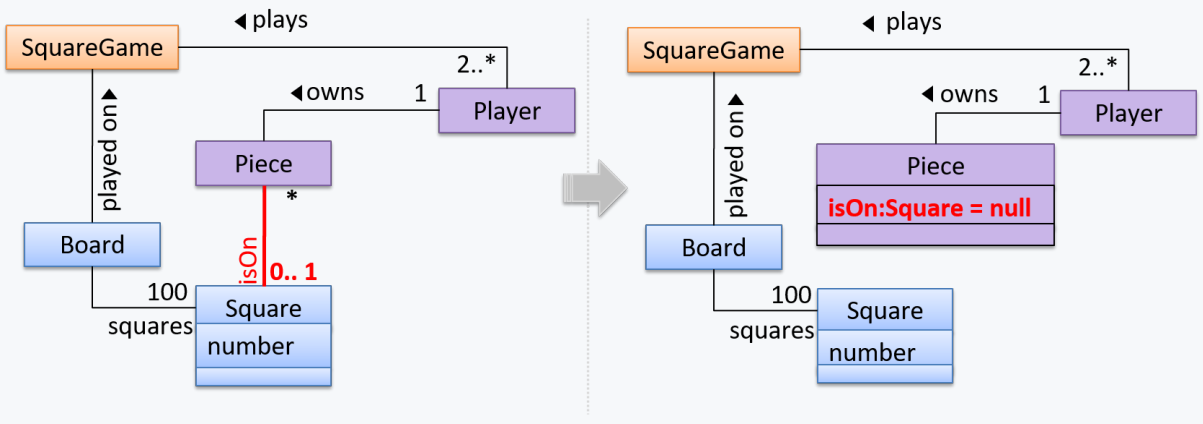
An association can be shown as an attribute instead of a line.

Association multiplicities and the default value too can be shown as part of the attribute using the following notation. Both are optional.

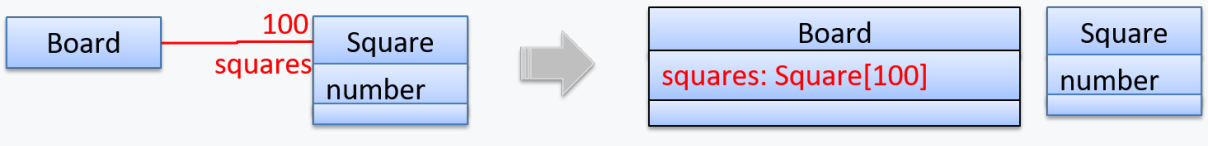
```
name: type [multiplicity] = default value
```

📦 The diagram below depicts a multi-player *Square Game* being played on a board comprising of 100 squares. Each of the squares may be occupied with any number of pieces, each belonging to a certain player.

A `Piece` may or may not be on a `Square`. Note how that association can be replaced by an `isOn` attribute of the `Piece` class. The `isOn` attribute can either be `null` or hold a reference to a `Square` object, matching the `0..1` multiplicity of the association it replaces. The default value is `null`.



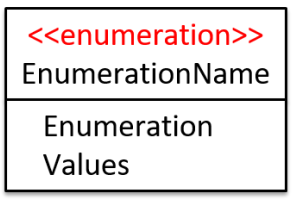
The association that a `Board` has 100 `Sqaures` can be shown in either of these two ways:



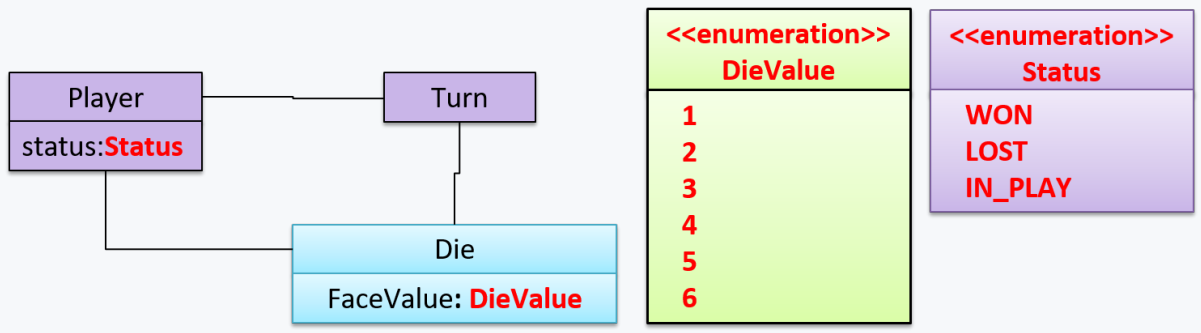
Enumerations

What ★★★☆

Notation:



📦 In the class diagram below, there are two enumerations in use:

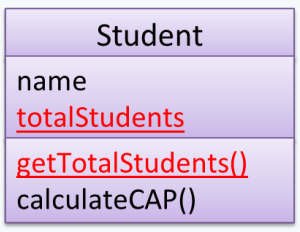


Class-Level Members

What ★★★☆

In UML class diagrams, **underlines denote class-level attributes and variables.**

📦 In the class below, `totalStudents` attribute and the `getTotalStudents` method are class-level.



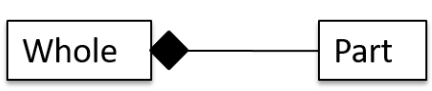
Association Classes

Composition

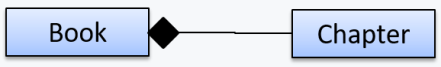
What ★★☆☆

UML uses a solid diamond symbol to denote composition.

Notation:



A `Book` consists of `Chapter` objects. When the `Book` object is destroyed, its `Chapter` objects are destroyed too.

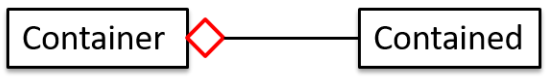


Aggregation

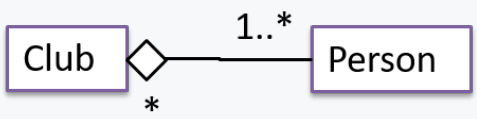
What ★★★☆

UML uses a hollow diamond is used to indicate an aggregation.

Notation:



Example:



Aggregation vs Composition

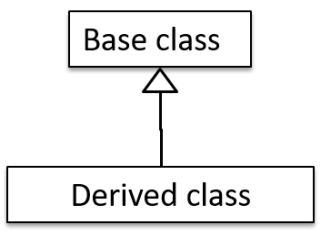
The distinction between composition (◆) and aggregation (◇) is rather blurred. Martin Fowler's famous book *UML Distilled* advocates omitting the aggregation symbol altogether because using it adds more confusion than clarity.

Class Inheritance

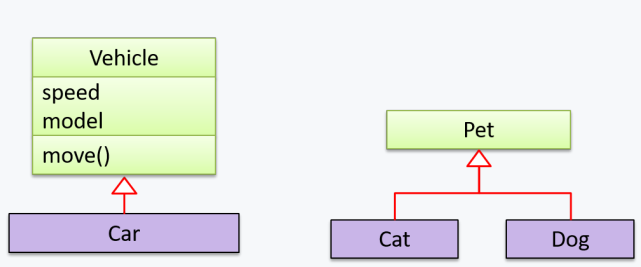
What ★★☆☆

You can use a triangle and a solid line (not to be confused with an arrow) to indicate class inheritance.

Notation:



Examples: The `Car` class *inherits* from the `Vehicle` class. The `Cat` and `Dog` classes *inherit* from the `Pet` class.

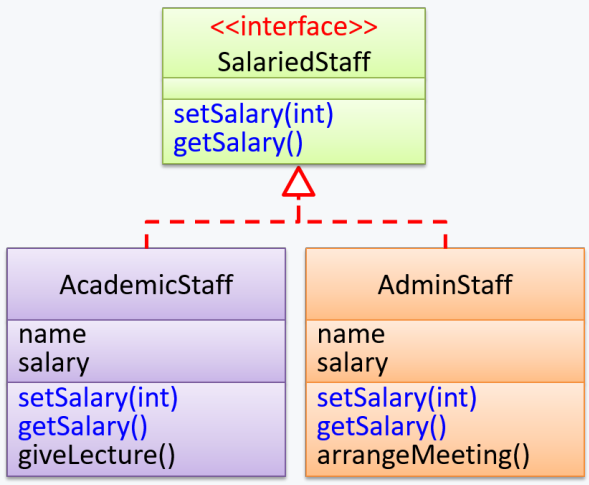


Interfaces

What ★★☆☆

An interface is shown similar to a class with an additional keyword `<< interface >>`. When a class implements an interface, it is shown similar to class inheritance except a dashed line is used instead of a solid line.

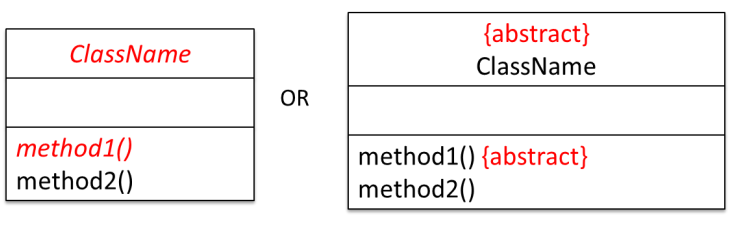
The `AcademicStaff` and the `AdminStaff` classes *implement* the `SalariedStaff` interface.



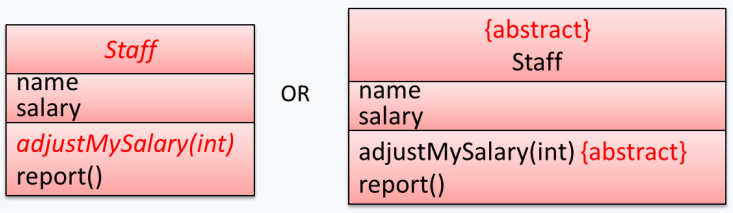
Abstract Classes

What ★★★☆

You can use *italics* or `{abstract}` (preferred) keyword to denote abstract classes/methods.



Example:



Sequence Diagrams

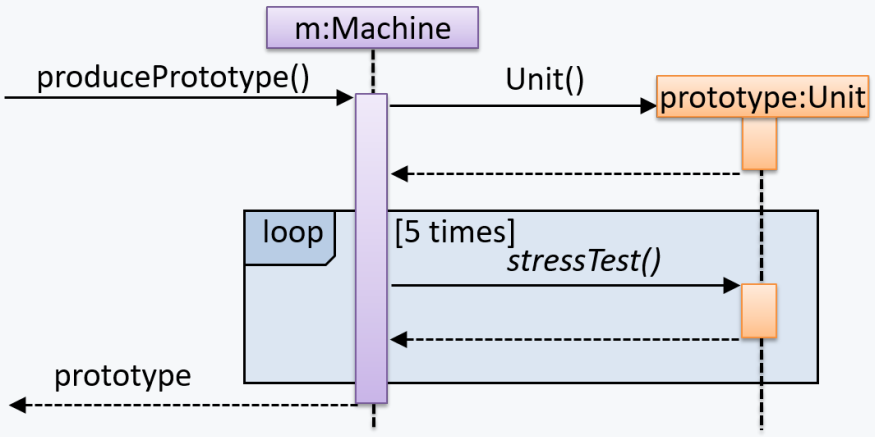
Introduction ★☆☆☆

A UML sequence diagram *captures the interactions between multiple objects for a given scenario.*

📦 Consider the code below.

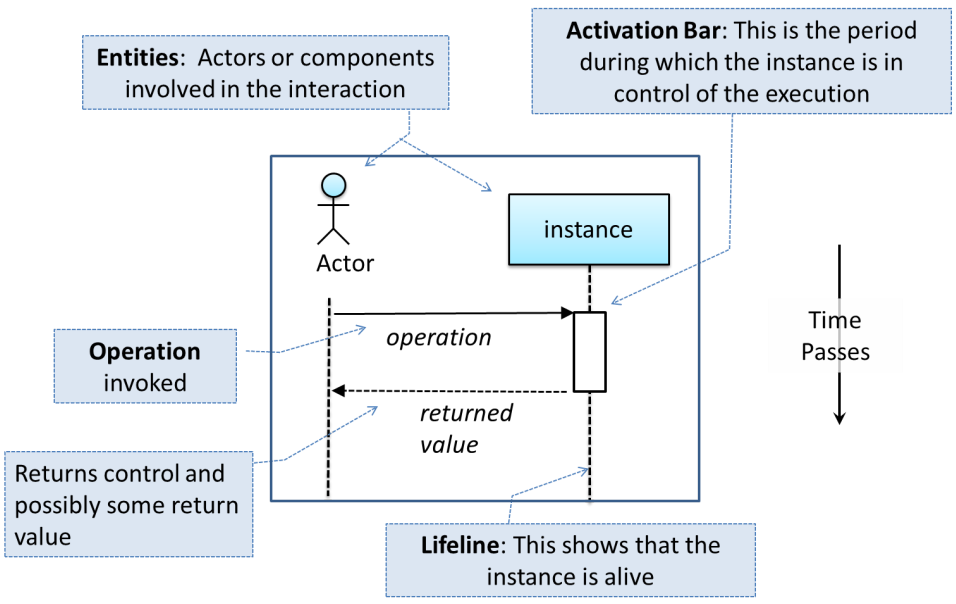
```
class Machine {

    Unit producePrototype() {
        Unit prototype = new Unit();
        for (int i = 0; i < 5; i++) {
            prototype.stressTest();
        }
        return prototype;
    }
}

class Unit {

    public void stressTest() {

    }
}
```

Here is the sequence diagram to model the interactions for the method call `producePrototype()` on a `Machine` object.

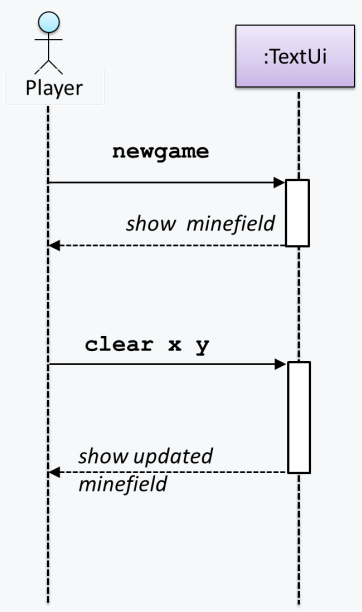


Basic ★☆☆☆

Notation:



This sequence diagram shows some interactions between a human user and the Text UI of a CLI Minesweeper game.



The player runs the `newgame` action on the `TextUi` object which results in the `TextUi` showing the minefield to the player. Then, the player runs the `clear x y` command; in response, the `TextUi` object shows the updated minefield.

The `:TextUi` in the above example denotes *an unnamed instance of the class TextUi*. If there were two instances of `TextUi` in the diagram, they can be distinguished by naming them e.g. `TextUi1:TextUi` and `TextUi2:TextUi`.

Arrows representing method calls should be solid arrows while those representing method returns should be dashed arrows.

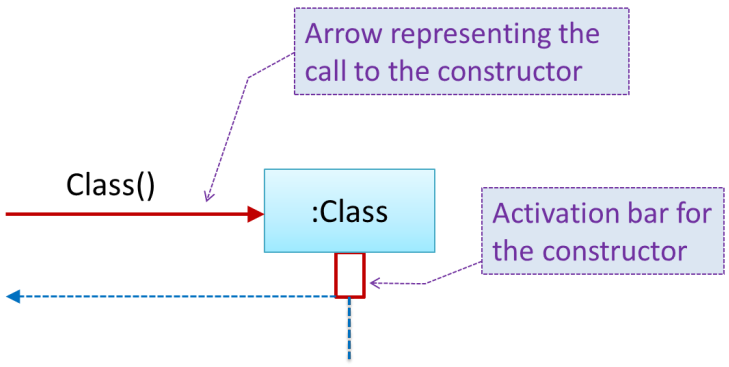
Note that unlike in object diagrams, the **class/object name is not underlined in sequence diagrams**.

✗ **[Common notation error] Activation bar too long:** The activation bar of a method cannot start before the method call arrives and a method cannot remain active after the method had returned. In the two sequence diagrams below, the one on the left commits this error because the activation bar starts *before* the method `Foo#xyz()` is called and remains active *after* the method returns.

❌ **[Common notation error] Broken activation bar:** The activation bar should remain unbroken from the point the method is called until the method returns. In the two sequence diagrams below, the one on the left commits this error because the activation bar for the method `Foo#abc()` is not contiguous, but appears as two pieces instead.

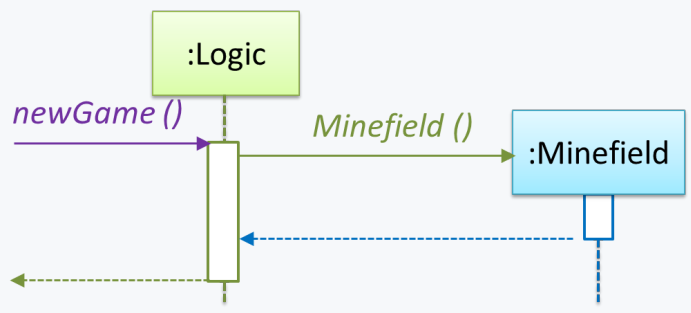
Object Creation ★★☆☆

Notation:



- The arrow that represents the constructor arrives at the side of the box representing the instance.
- The activation bar represents the period the constructor is active.

The `Logic` object creates a `Minefield` object.

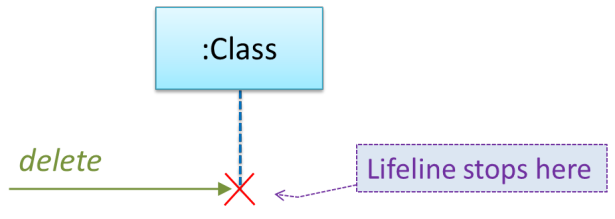


Object Deletion ★★★☆

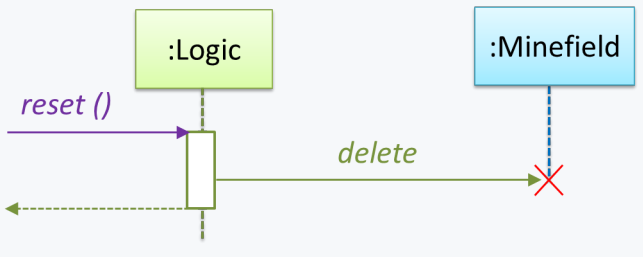
UML uses an `X` at the end of the lifeline of an object to show it's deletion.

Although object deletion is not that important in languages such as Java that support automatic memory management, you can still show object deletion in UML diagrams to indicate the point at which the object ceases to be used.

Notation:

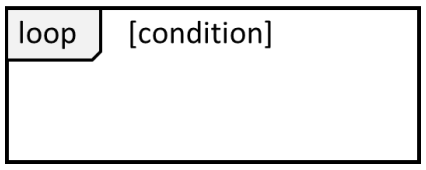


Note how the diagrams shows the deletion of the `Minefield` object

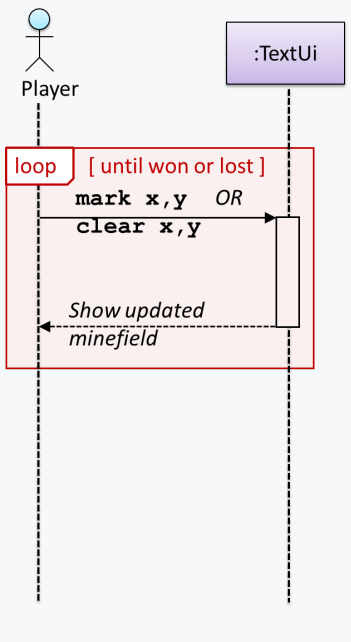


Loops ★★☆☆

Notation:



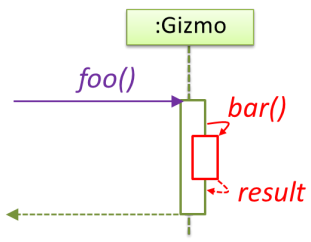
The `Player` calls the `mark x,y` command or `clear x y` command repeatedly until the game is won or lost.



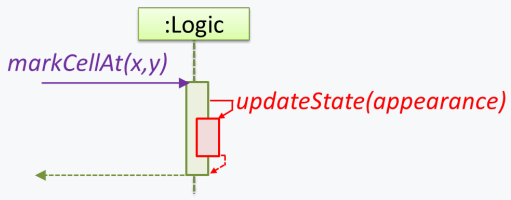
Self Invocation ★★★☆

UML can show a method of an object calling another of its own methods.

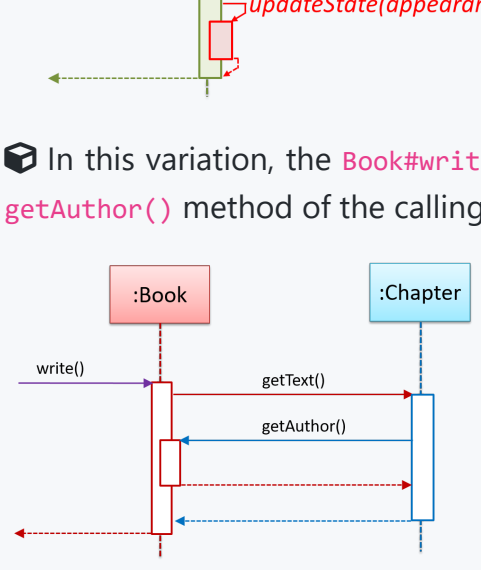
Notation:



The `markCellAt(...)` method of a `Logic` object is calling its own `updateState(...)` method.



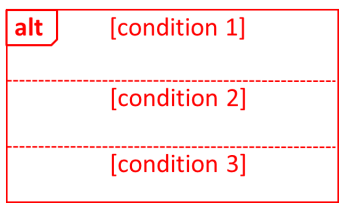
In this variation, the `Book#write()` method is calling the `Chapter#getText()` method which in turn does a *call back* by calling the `getAuthor()` method of the calling object.



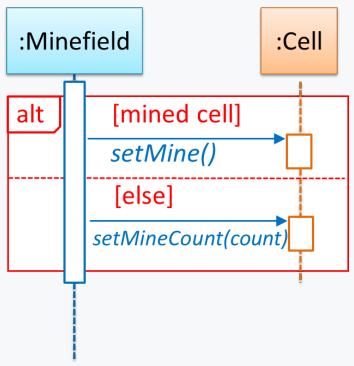
Alternative Paths ★★★☆

UML uses `alt` frames to indicate alternative paths.

Notation:



`Minefield` calls the `Cell#setMine` if the cell is supposed to be a mined cell, and calls the `Cell:setMineCount(...)` method otherwise.

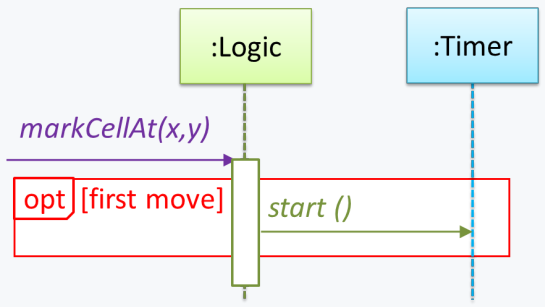


Optional Paths ★★★☆

UML uses `opt` frames to indicate optional paths.

Notation:

`Logic#markCellAt(...)` calls `Timer#start()` only if it is the first move of the player.



Minimal Notation ★★★☆

To reduce clutter, **activation bars and return arrows may be omitted** if they do not result in ambiguities or loss of information. Informal operation descriptions such as those given in the example below can be used, if more precise details are not required for the task at hand.

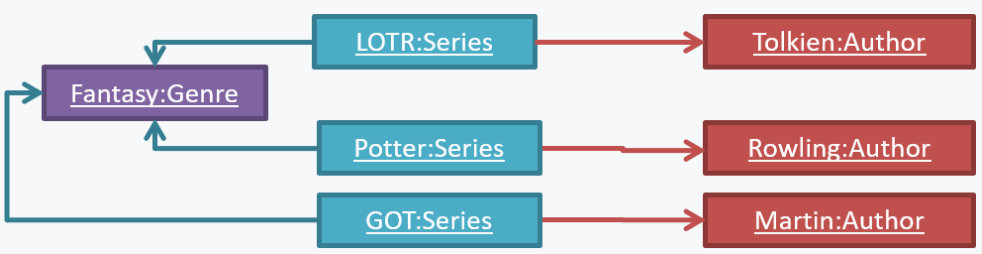
A minimal sequence diagram

Object Diagrams

Introduction ★☆☆☆

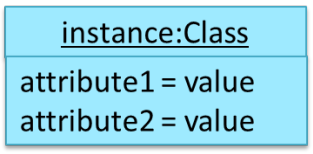
An object diagram shows an object structure at a given point of time.

An example object diagram:



Objects ★☆☆☆

Notation:



Notes:

- The class name and object name e.g. `car1:Car` are underlined.
- `objectName:ClassName` is meant to say 'an instance of `ClassName` identified as `objectName`'.
- Unlike classes, there is no compartment for methods.
- *Attributes* compartment can be omitted if it is not relevant to the task at hand.
- Object name can be omitted too e.g. `:Car` which is meant to say 'an *unnamed* instance of a Car object'.

📦 Some example objects:

Associations ★☆☆☆

A solid line indicates an association between two objects.

📦 An example object diagram showing two associations:

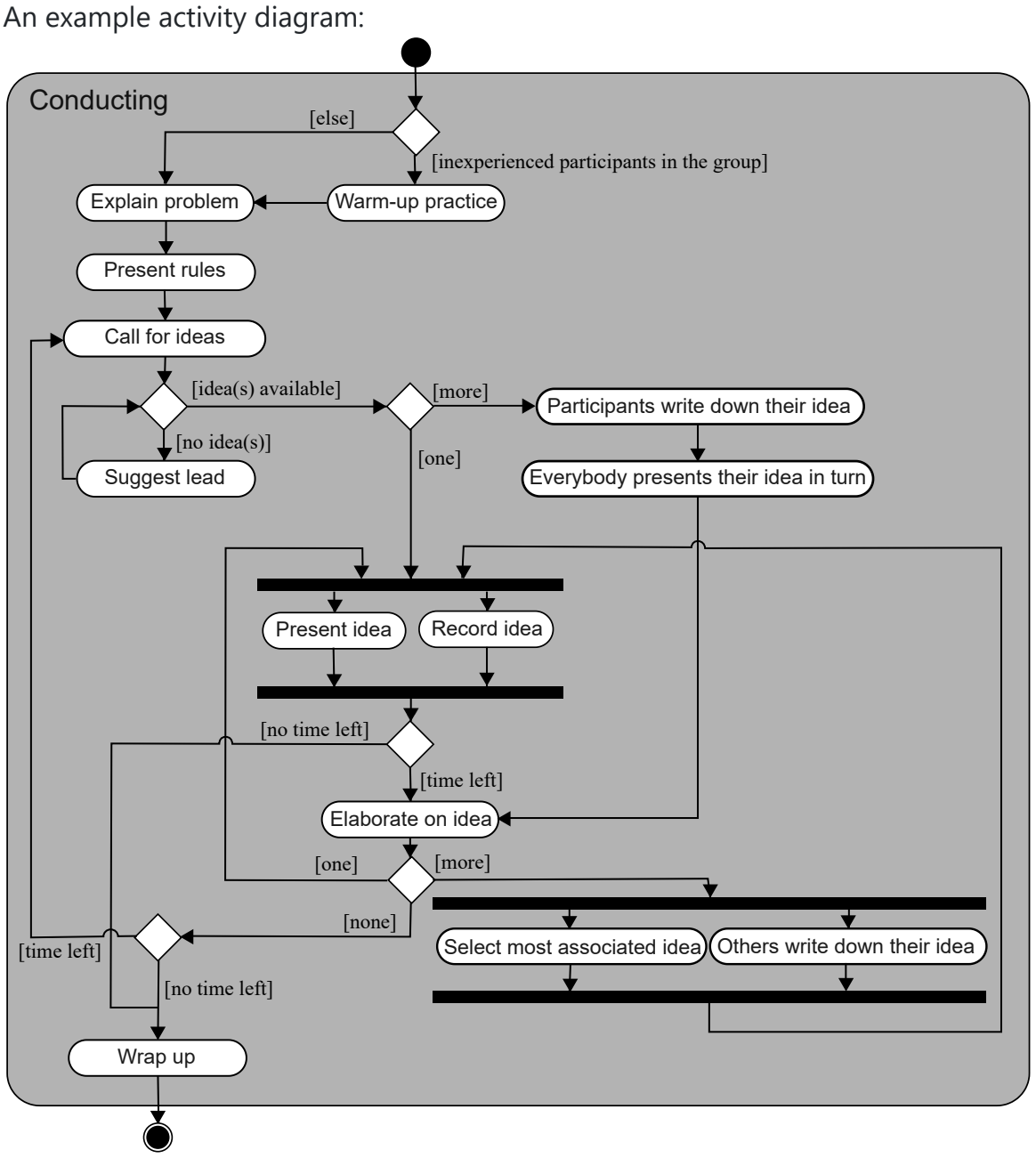
Activity Diagrams

Introduction

What ★☆☆☆

UML *activity diagrams* (AD) can model workflows. *Flow charts* is another type of diagrams that can model workflows. Activity diagrams are the UML equivalent of flow charts.

An example activity diagram:



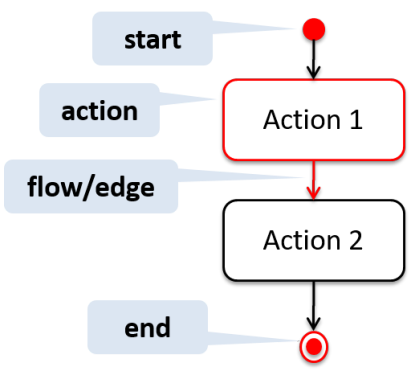
[source:wikipeida]

Basic Notations

Linear Paths ★★☆☆

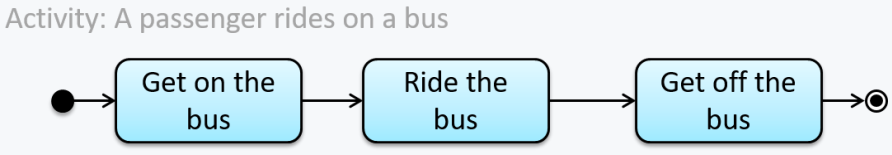
An activity diagram (AD) captures an *activity* of *actions* and *control flows* that makes up the activity.

- An *action* is a single step in an activity. It is shown as a rectangle with rounded corners.
- A *control flow* shows the flow of control from one action to the next. It is shown by drawing a line with an arrow-head to show the direction of the flow.



Note the slight difference between the *start node* and the *end node* which represent the start and the end of the activity, respectively.

This activity diagram shows the action sequence of the activity *a passenger rides the bus*:

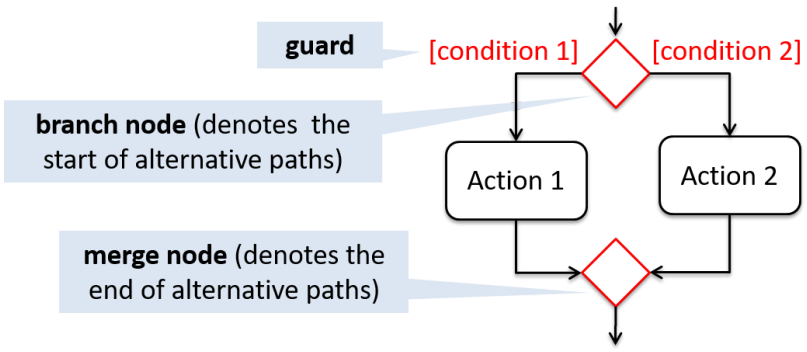


Alternate Paths ★★☆☆

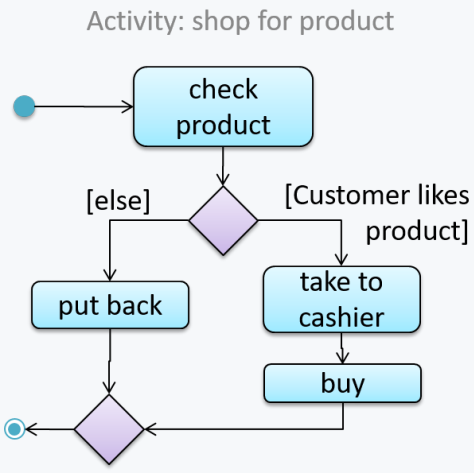
A *branch node* shows the start of alternate paths. Each control flow exiting a branch node has a *guard condition* : a boolean condition that should be true for execution to take that path. Only one of the guard condition can be true at any time.

A *merge node* shows the end of alternate paths.

Both branch nodes and merge nodes are diamond shapes. Guard conditions must be in square brackets.



The AD below shows alternate paths involved in the workflow of the activity *shop for product*:



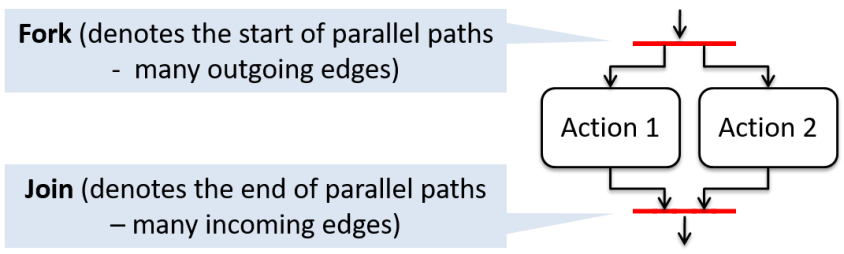
Parallel Paths ★★☆☆

***Fork* nodes indicate the start of concurrent flows of control.**

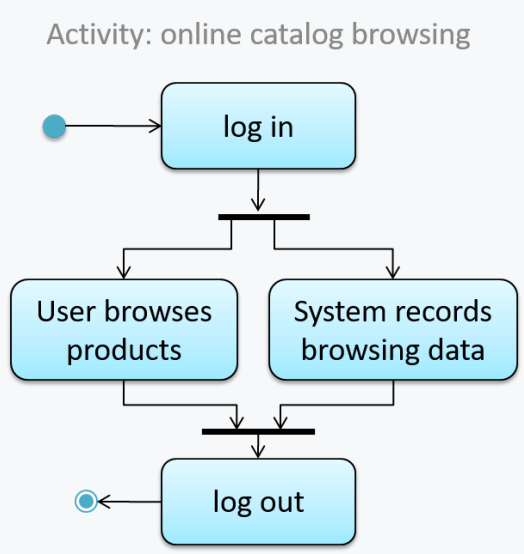
***Join* nodes indicate the end of parallel paths.**

Both have the same notation: a bar.

In a set of parallel paths , execution along **all parallel paths should be complete before the execution can start on the outgoing control flow of the *join*.**



In this activity diagram (from an online shop website) the actions *User browsers products* and *System records browsing data* happen in parallel. Both of them need to finish before the *log out* action can take place.

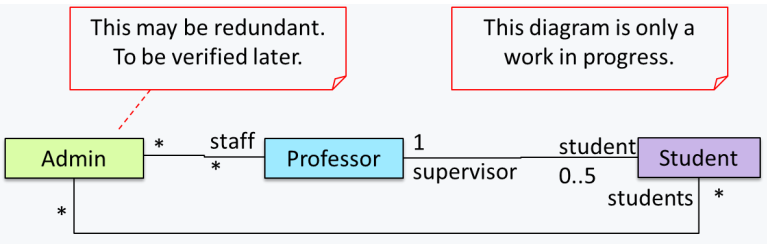


Notes

Notes ★★★☆

UML notes can augment UML diagrams with additional information. These notes can be shown connected to a particular element in the diagram or can be shown without a connection. The diagram below shows examples of both.

Example:



Miscellaneous

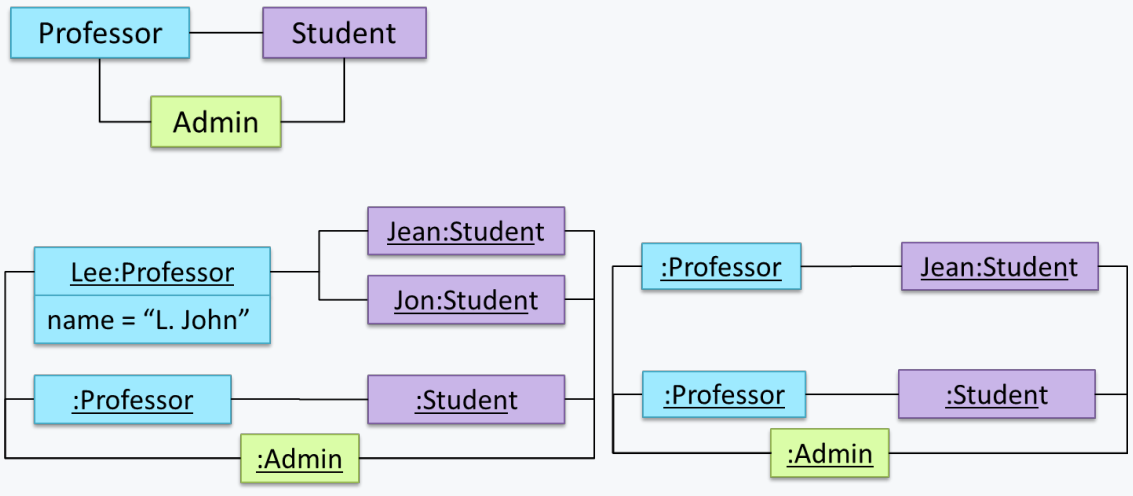
Object vs Class Diagrams ★★☆☆

Compared to the notation for a class diagrams, object diagrams differ in the following ways:

- Shows objects instead of classes:
  - Instance name may be shown
  - There is a : before the class name
  - Instance and class names are underlined
- Methods are omitted
- Multiplicities are omitted

Furthermore, **multiple object diagrams can correspond to a single class diagram**.

📦 Both object diagrams are derived from the same class diagram shown earlier. In other words, each of these object diagrams shows 'an instance of' the same class diagram.



Git and Github

Init ★☆☆☆

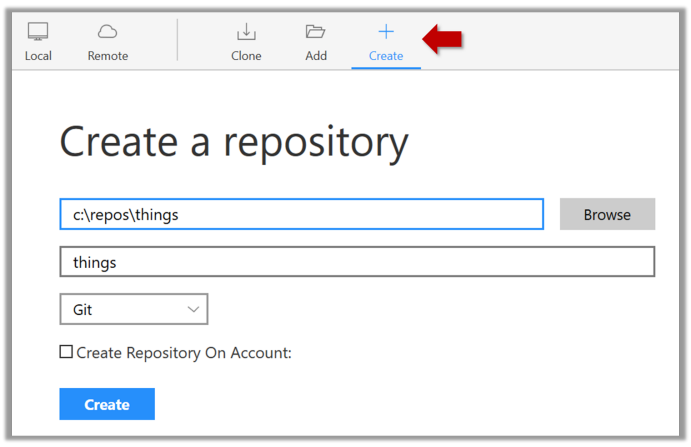
Install SourceTree which is Git + a GUI for Git. If you prefer to use Git via the command line (i.e., without a GUI), you can install Git instead.

Suppose you want to create a repository in an empty directory `things`. Here are the steps:

SourceTree | CLI

Windows: Click `File` → `Clone/New...`. Click on `Create` button.
Mac: `New...` → `Create New Repository`.

Enter the location of the directory (Windows version shown below) and click `Create`.



Go to the `things` folder and observe how a hidden folder `.git` has been created.

Note: If you are on Windows, you might have to configure Windows Explorer to show hidden files.

Commit ★☆☆☆

Create an empty repo.

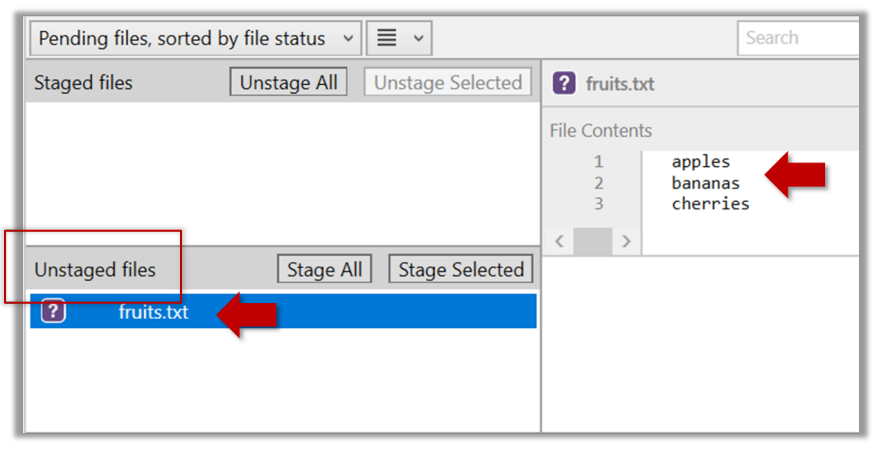
Create a file named `fruits.txt` in the working directory and add some dummy text to it.

> **Working directory**: The directory the repo is based in is called the *working directory*.

Observe how the file is detected by Git.

SourceTree | CLI

The file is shown as 'unstaged'



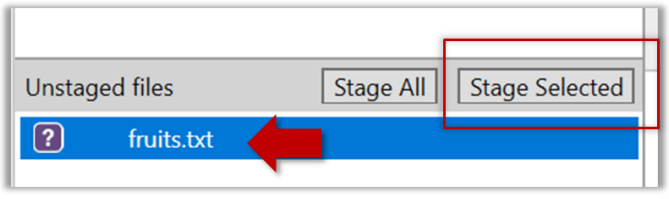
Although git has detected the file in the working directory, it will not do anything with the file unless you tell it to. Suppose we want to commit the current state of the file. First, we should stage the file.

> **Commit**: Saving the current state of the working folder into the Git revision history.

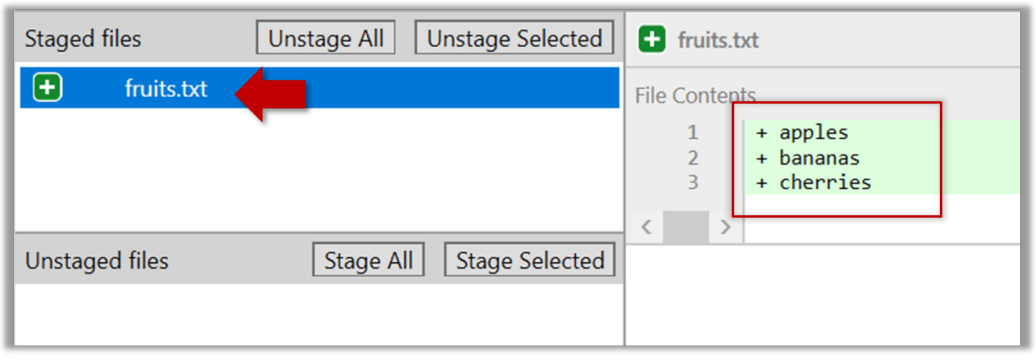
> **Stage**: Instructing Git to prepare a file for committing.

SourceTree | CLI

Select the `fruits.txt` and click on the `Stage Selected` button



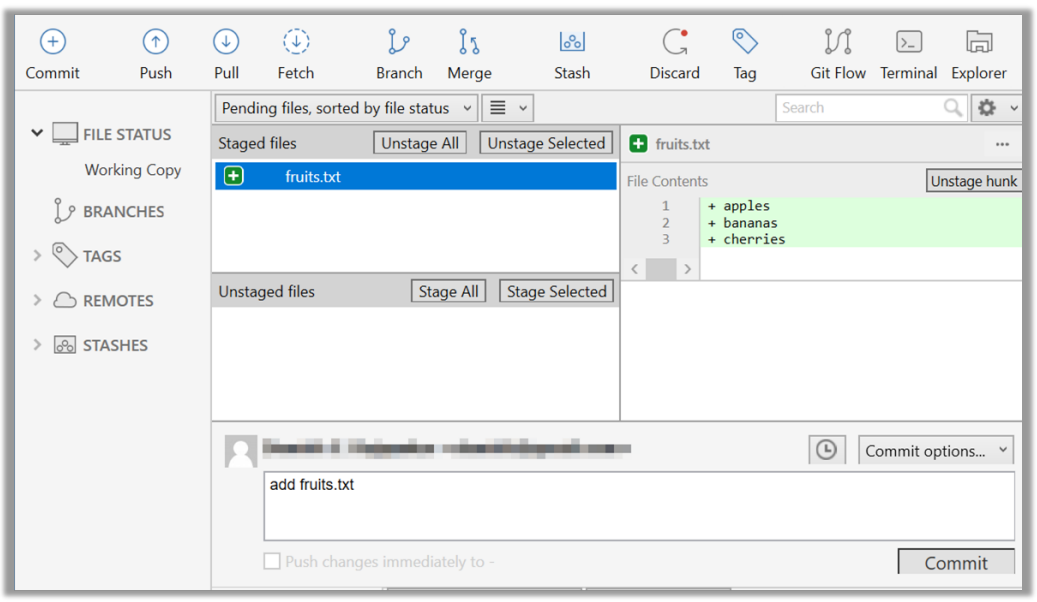
`fruits.txt` should appear in the `Staged files` panel now.



Now, you can commit the staged version of `fruits.txt`

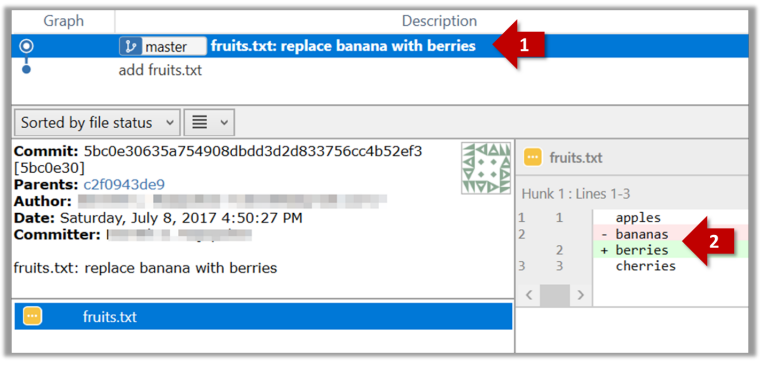
SourceTree | CLI

Click the `Commit` button, enter a commit message e.g. `add fruits.txt` in to the text box, and click `Commit`

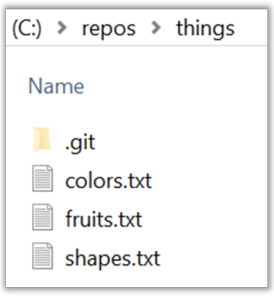


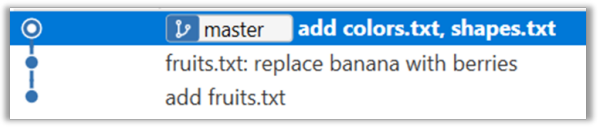
Note the existence of something called the `master` branch. Git allows you to have multiple branches (i.e. it is a way to evolve the content in parallel) and Git creates a default branch named `master` on which the commits go on by default.

Do some changes to `fruits.txt` (e.g. add some text and delete some text). Stage the changes, and commit the changes using the same steps you followed before. You should end up with something like this.



Next, add two more files `colors.txt` and `shapes.txt` to the same working directory. Add a third commit to record the current state of the working directory.





Ignore ★★☆☆

Add a file names `temp.txt` to the `things` repo you created. Suppose we don't want this file to be revision controlled by Git. Let's instruct Git to ignore `temp.txt`

SourceTree | CLI

The file should be currently listed under `Unstaged files`. Right-click it and choose `Ignore...`. Choose `Ignore exact filename(s)` and click `OK`.

Observe that a file named `.gitignore` has been created in the working directory root and has the following line in it.

```
temp.txt
```

The `.gitignore` file tells Git which files to ignore when tracking revision history. That file itself can be either revision controlled or ignored.

- To version control it (the more common choice – which allows you to track how the `.gitignore` file changed over time), simply commit it as you would commit any other file.
- To ignore it, follow the same steps we followed above when we set Git to ignore the `temp.txt` file.

Tag ★★★☆

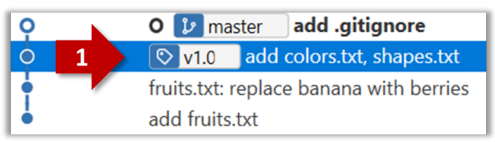
Let's tag a commit in a local repo you have (e.g. the `sampelrepo-things` repo)

SourceTree | CLI

Right-click on the commit (in the graphical revision graph) you want to tag and choose `Tag...`

Specify the tag name e.g. `v1.0` and click `Add Tag`.

The added tag will appear in the revision graph view.

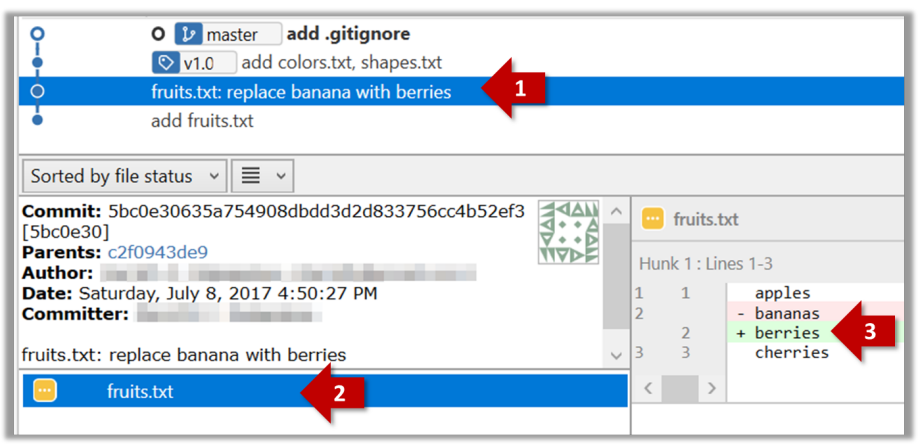


Checkout ★★☆☆

Git can show you what changed in each commit.

SourceTree | CLI

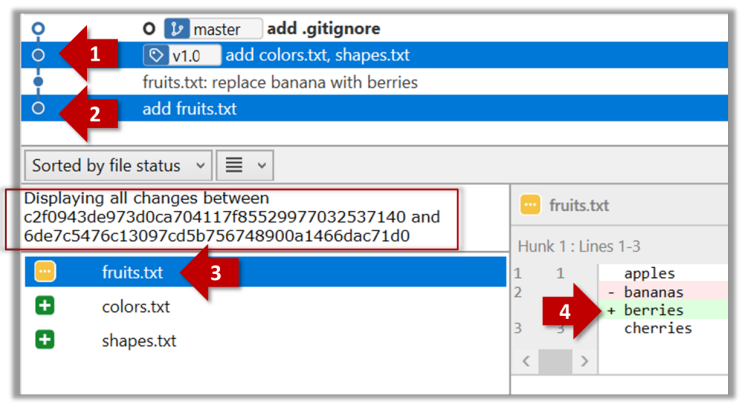
To see which files changed in a commit, click on the commit. To see what changed in a specific file in that commit, click on the file name.



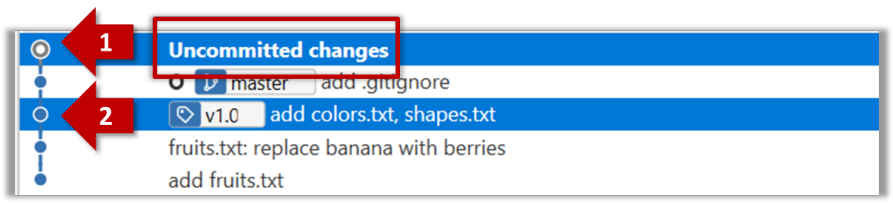
Git can also show you the difference between two points in the history of the repo.

SourceTree | CLI

Select the two points you want to compare using `Ctrl`+`Click`.



The same method can be used to compare the current state of the working directory (which might have uncommitted changes) to a point in the history.

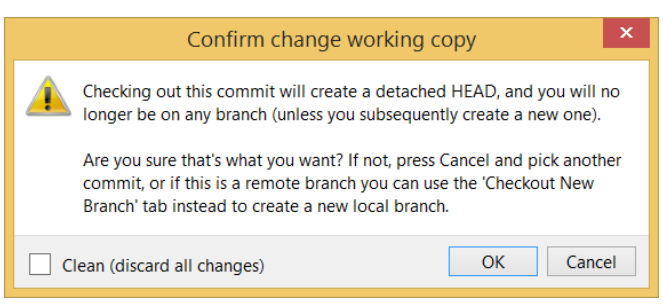


Git can load a specific version of the history to the working directory. Note that if you have uncommitted changes in the working directory, you need to stash them first to prevent them from being overwritten.

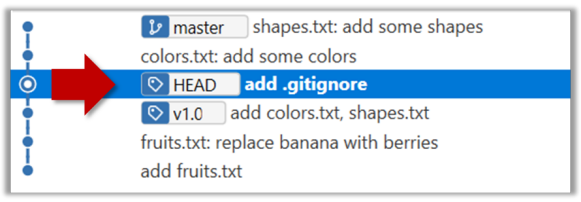
SourceTree | CLI

Double-click the commit you want to load to the working directory, or right-click on that commit and choose `Checkout...`.

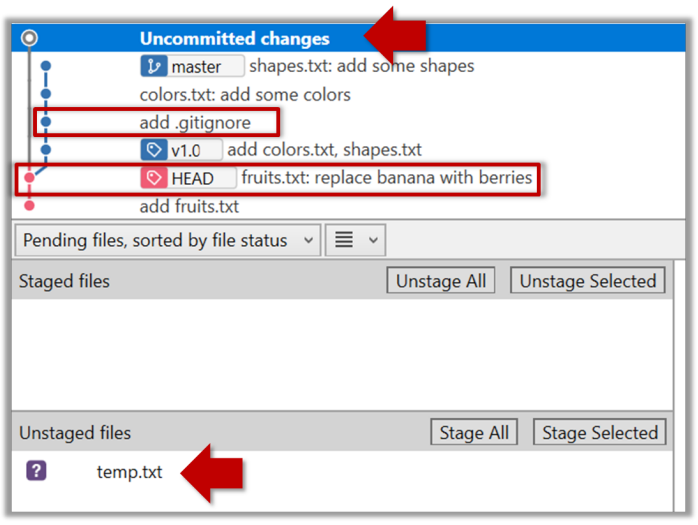
Click `OK` to the warning about 'detached HEAD' (similar to below).



The specified version is now loaded to the working folder, as indicated by the `HEAD` label. `HEAD` is a reference to the currently checked out commit.



If you checkout a commit that come before the commit in which you added the `.gitignore` file, Git will now show ignored fiels as 'unstaged modifications' because at that stage Git hasn't been told to ignore those files.



To go back to the latest commit, double-click it.

Clone ★☆☆☆

Clone the sample repo samplerepo-things to your computer.

> ! Note that the URL of the Github project is different form the URL you need to clone a repo in that Github project. e.g.
>
> Github project URL: `https://github.com/se-edu/samplerepo-things`
> Git repo URL: `https://github.com/se-edu/samplerepo-things.git` (note the `.git` at the end)

SourceTree | CLI

`File` → `Clone / New...` and provide the URL of the repo and the destination directory.

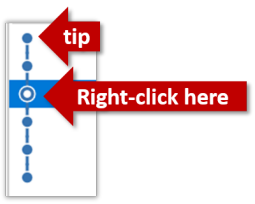
Pull ★☆☆☆

Clone the sample repo as explained in [Textbook → Tools → Git & GitHub → Clone].

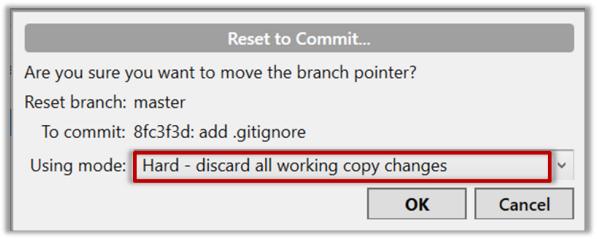
Delete the last two commits to simulate cloning the repo 2 commits ago.

SourceTree | CLI

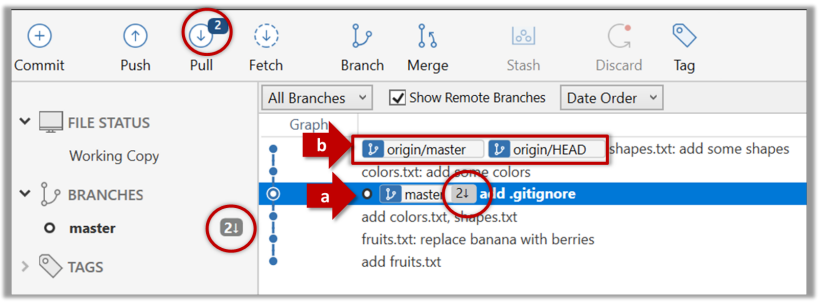
Right-click the target commit (i.e. the commit that is 2 commits behind the tip) and choose `Reset current branch to this commit`.



Choose the `Hard - ...` option and click `OK`.



This is what you will see.



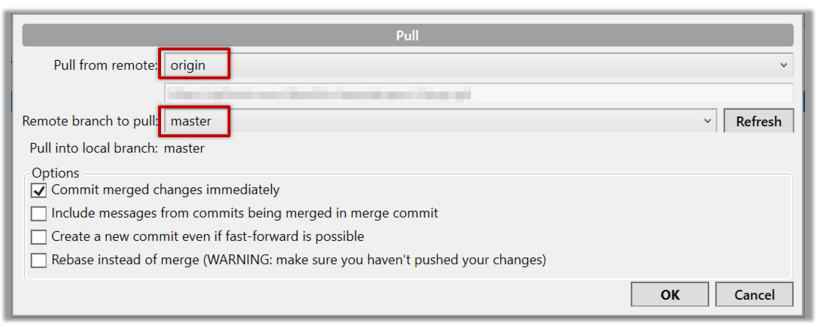
Note the following (cross refer the screenshot above):

Arrow marked as `a`: The local repo is now at this commit, marked by the `master` label.
Arrow marked as `b`: `origin/master` label shows what is the latest commit in the `master` branch in the remote repo.

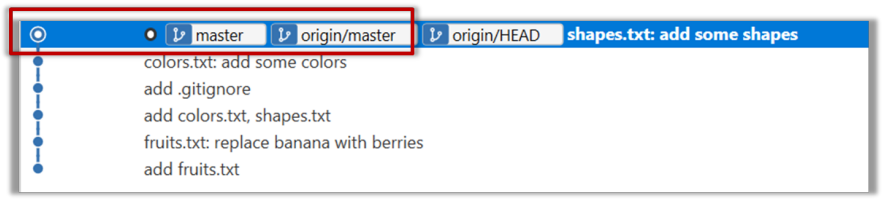
Now, your local repo state is exactly how it would be if you had cloned the repo 2 commits ago, as if somebody has added two more commits to the remote repo since you cloned it. To get those commits to your local repo (i.e. to sync your local repo with upstream repo) you can do a pull.

SourceTree | CLI

Click the `Pull` button in the main menu, choose `origin` and `master` in the next dialog, and click `OK`.



Now you should see something like this where `master` and `origin/master` are both pointing the same commit.



Push ★☆☆☆

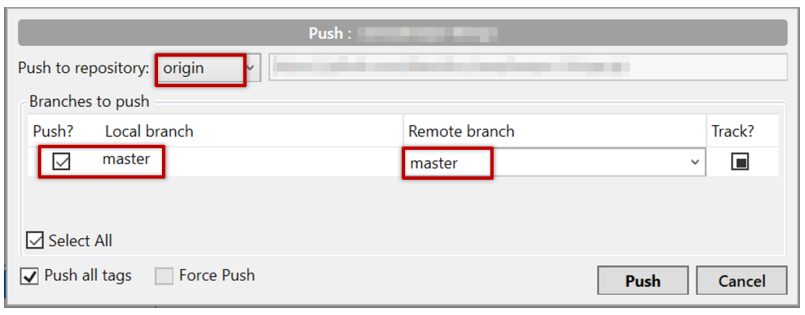
1. Create a GitHub account if you don't have one yet.
2. Fork the samplerepo-things to your GitHub account:

   > How to fork a repo?

3. Clone the fork (not the original) to your computer.
4. Create some commits in your repo.
5. Push the new commits to your fork on GitHub

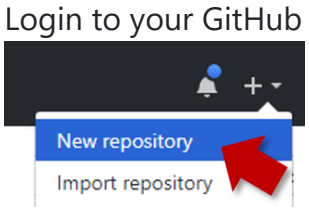
SourceTree | CLI

Click the `Push` button on the main menu, ensure the settings are as follows in the next dialog, and click the `Push` button on the dialog.

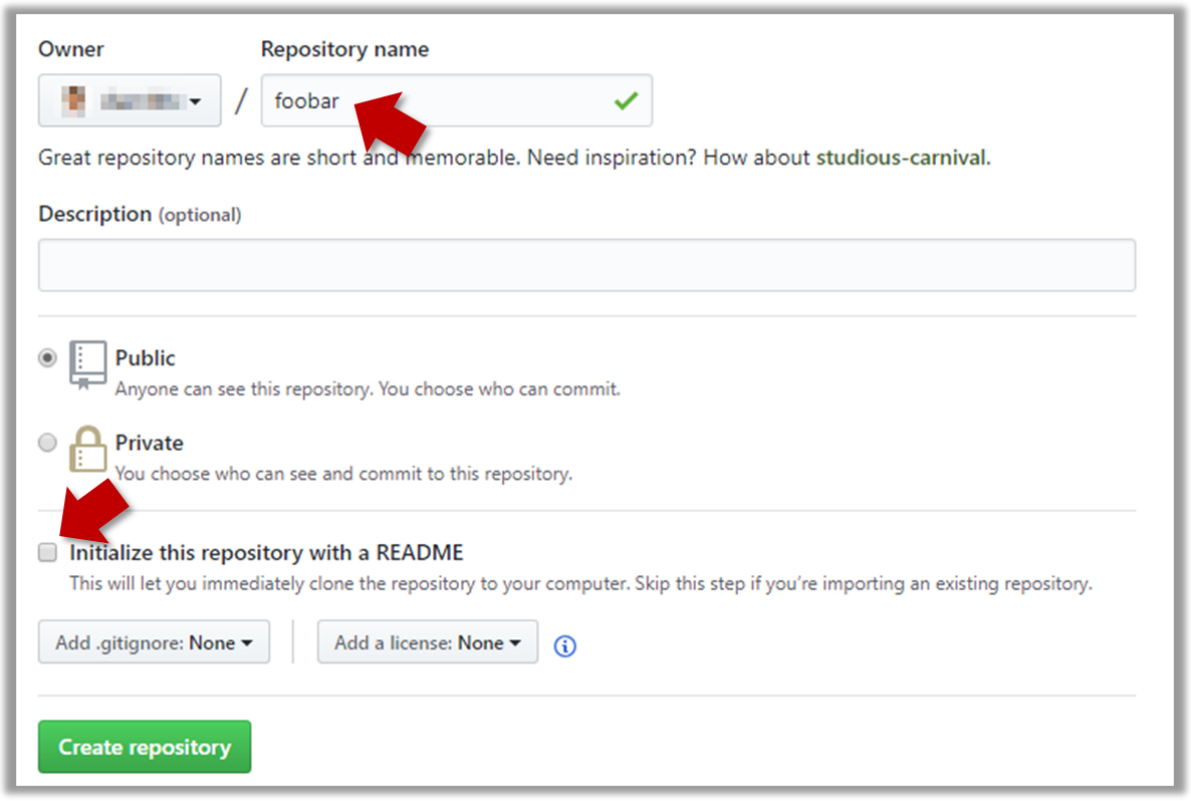


To push an existing local repo into a new remote repo on GitHub, first you need to create an empty remote repo on GitHub.

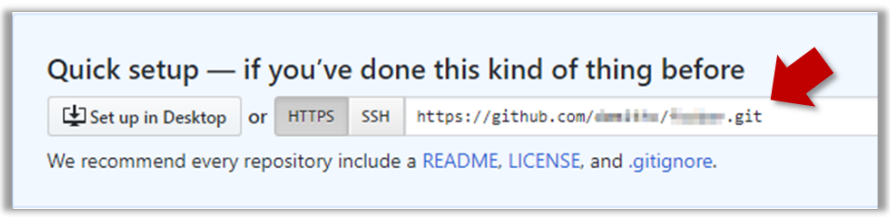
1. Login to your GitHub account and choose to create a new Repo.



2. In the next screen, provide a name for your repo but keep the `Initialize this repo ...` tick box unchecked.



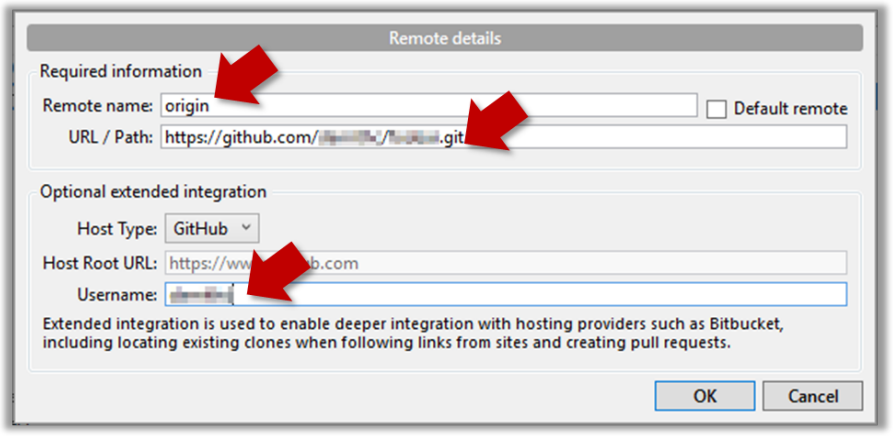
3. Note the URL of the repo. It will be of the form `https://github.com/{your_user_name}/{repo_name}.git`
   e.g., `https://github.com/johndoe/foobar.git`



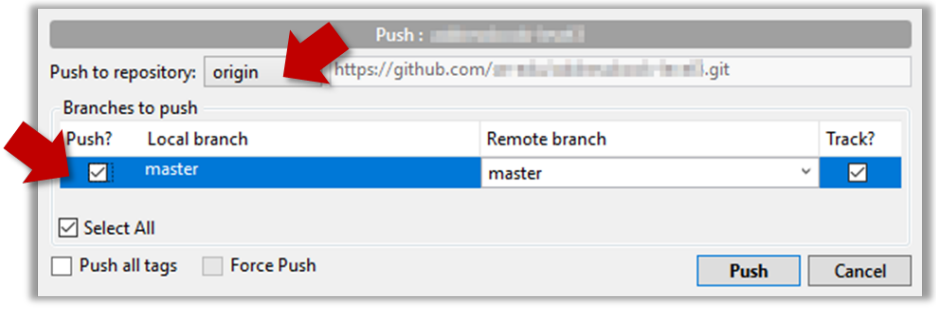
Next, you can push the existing local repo to the new remote repo as follows:

SourceTree | CLI

1. Open the local repo in SourceTree.
2. Choose `Repository` → `Repository Settings` menu option.
3. Add a new *remote* to the repo with the following values.
   - `Remote name`: the name you want to assign to the remote repo. Recommended `origin`
   - `URL/path`: the URL of your repo (ending in `.git`) that you collected earlier.
   - `Username`: your GitHub username



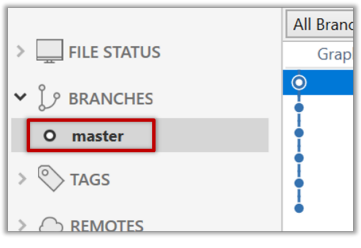
4. Now you can push your repo to the new remote the usual way.



Branch ★★☆☆

0. Observe that you are normally in the branch called `master`. For this, you can take any repo you have on your computer (e.g. a clone of the samplerepo-things).

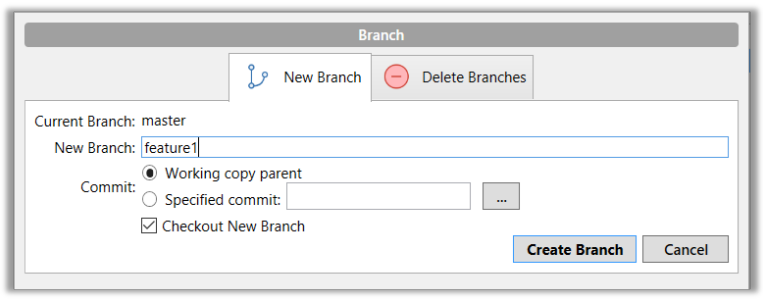
SourceTree | CLI



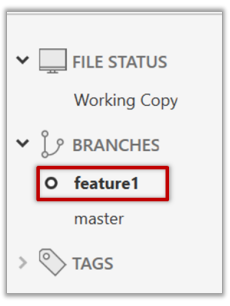
1. Start a branch named `feature1` and switch to the new branch.

SourceTree | CLI

Click on the `Branch` button on the main menu. In the next dialog, enter the branch name and click `Create Branch`



Note how the `feature1` is indicated as the current branch.

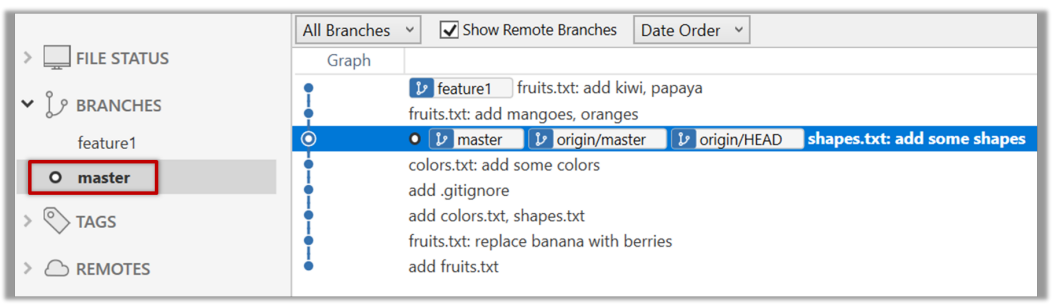


2. Create some commits in the new branch. Just commit as per normal. Commits you add while on a certain branch will become part of that branch.

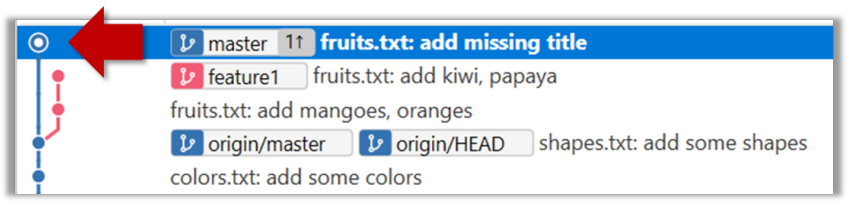
3. Switch to the `master` branch. Note how the changes you did in the `feature1` branch are no longer in the working directory.

SourceTree | CLI

Double-click the `master` branch

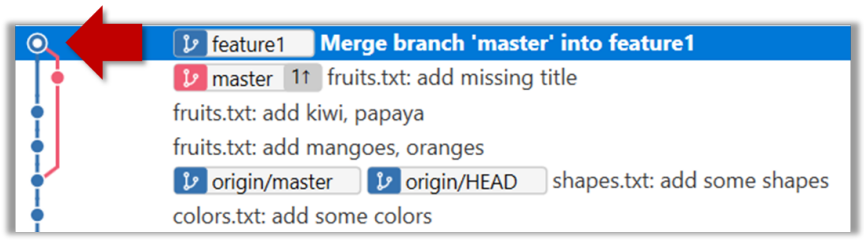


4. Add a commit to the master branch. Let's imagine it's a bug fix.



5. Switch back to the `feature1` branch (similar to step 3).

6. Merge the `master` branch to the `feature1` branch, giving an end-result like the below. Also note how Git has created a *merge commit*.



SourceTree | CLI

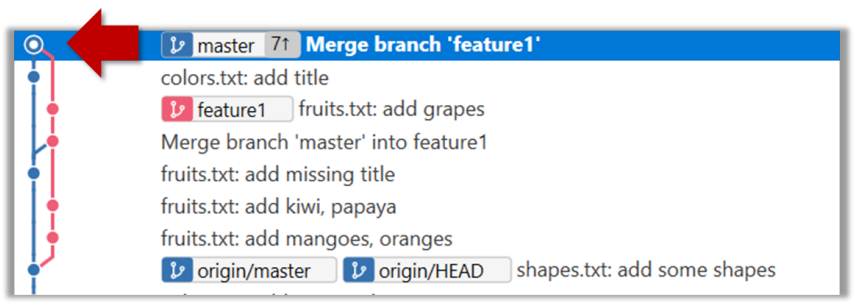
Right-click on the `master` branch and choose `merge master into the current branch`. Click `OK` in the next dialog.

Observe how the changes you did in the `master` branch (i.e. the imaginary bug fix) is now available even when you are in the `feature1` branch.

7. Add another commit to the `feature1` branch.

8. Switch to the `master` branch and add one more commit.

9. Merge `feature1` to the master branch, giving and end-result like this:

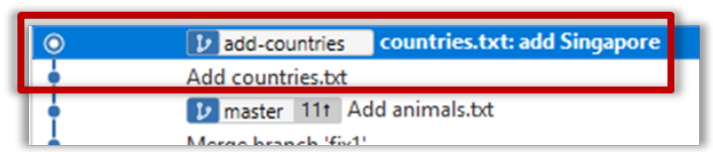


SourceTree | CLI

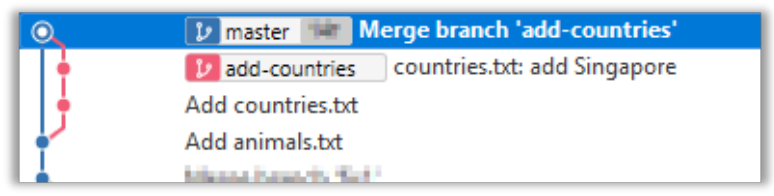
Right-click on the `feature1` branch and choose `Merge...`.

---

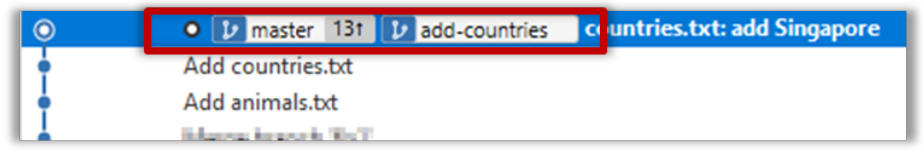
10. Create a new branch called `add-countries`, switch to it, and add some commits to it (similar to steps 1-2 above). You should have something like this now:



11. Go back to the `master` branch and merge the `add-countries` branch onto the `master` branch (similar to steps 8-9 above). While you might expect to see something like the below,



... you are likely to see something like this instead:

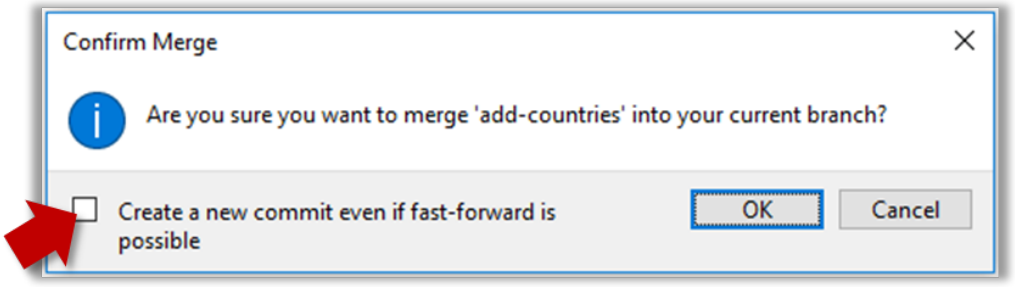


That is because **Git does a *fast forward* merge if possible**. Seeing that the `master` branch has not changed since you started the `add-countries` branch, Git has decided it is simpler to just put the commits of the `add-countries` branch in front of the `master` branch, without going into the trouble of creating an extra merge commit.

It is possible to force Git to create a merge commit even if fast forwarding is possible.

SourceTree | CLI

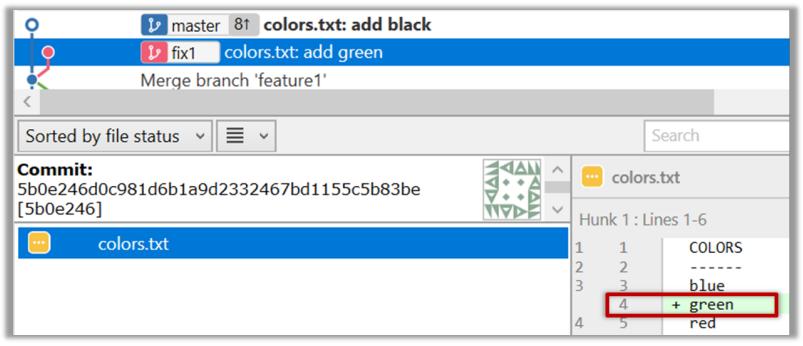
Tick the box shown below when you merge a branch:

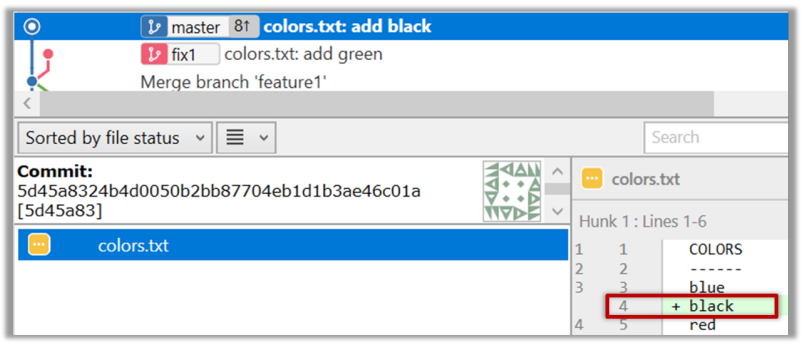


Merge Conflicts ★★☆☆

1. Start a branch named `fix1` in a local repo. Create a commit that adds a line with some text to one of the files.

2. Switch back to `master` branch. Create a commit with a conflicting change i.e. it adds a line with some different text in the exact location the previous line was added.





3. Try to merge the `fix1` branch onto the `master` branch. Git will pause mid-way during the merge and report a merge conflict. If you open the conflicted file, you will see something like this:

```
COLORS
------
blue
<<<<<<< HEAD
black
=======
green
>>>>>>> fix1
red
white
```

4. Observe how the conflicted part is marked between a line starting with `<<<<<<<` and a line starting with `>>>>>>>`, separated by another line starting with `=======`.

This is the conflicting part that is coming from the `master` branch:

```
<<<<<<< HEAD
black
=======
```

This is the conflicting part that is coming from the `fix1` branch:

```
=======
green
>>>>>>> fix1
```

5. Resolve the conflict by editing the file. Let us assume you want to keep both lines in the merged version. You can modify the file to be like this:

```
COLORS
------
blue
black
green
red
white
```

6. Stage the changes, and commit.

Create PRs ★☆☆☆

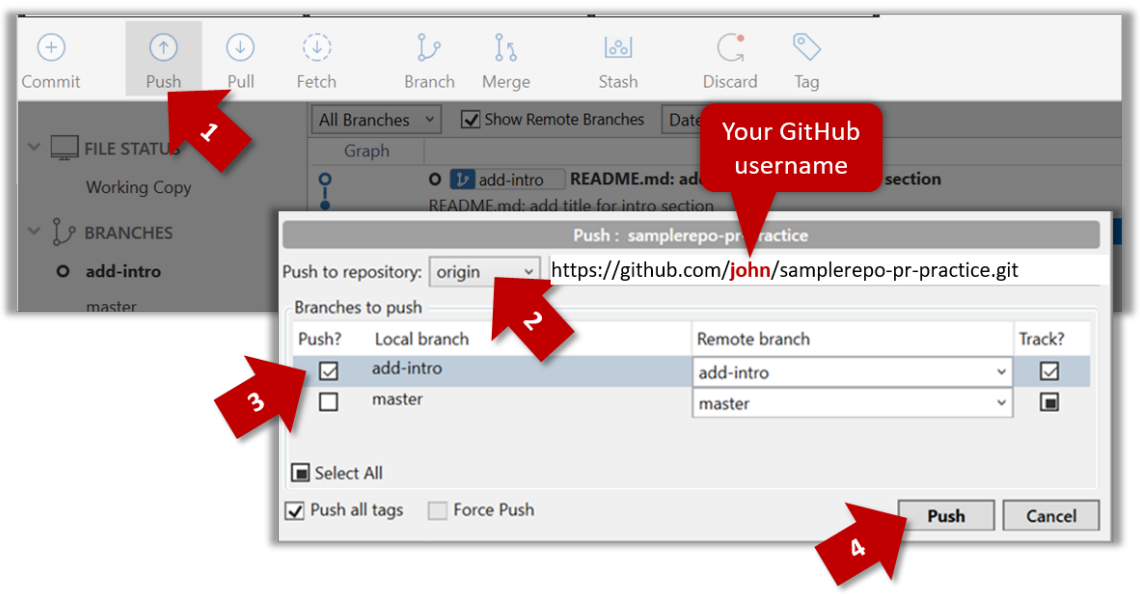
1. Fork the samplerepo-pr-practice onto your GitHub account. Clone it onto your computer.

2. Create a branch named `add-intro` in your clone. Add a couple of commits which adds/modifies an *Introduction* section to the `README.md`. Example:

```
# Introduction
Creating Pull Requsts (PRs) is needed when using RCS in a multi-person projects.
This repo can be used to practice creating PRs.
```

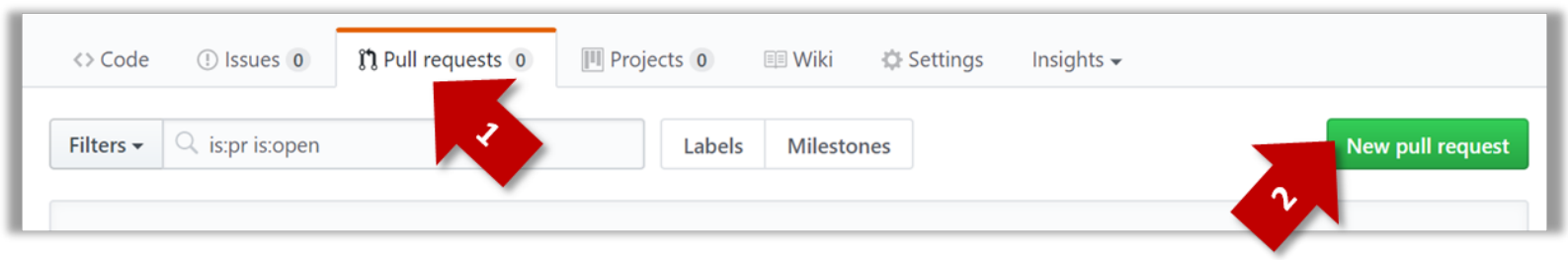
3. Push the `add-intro` branch to your fork.

SourceTree | CLI



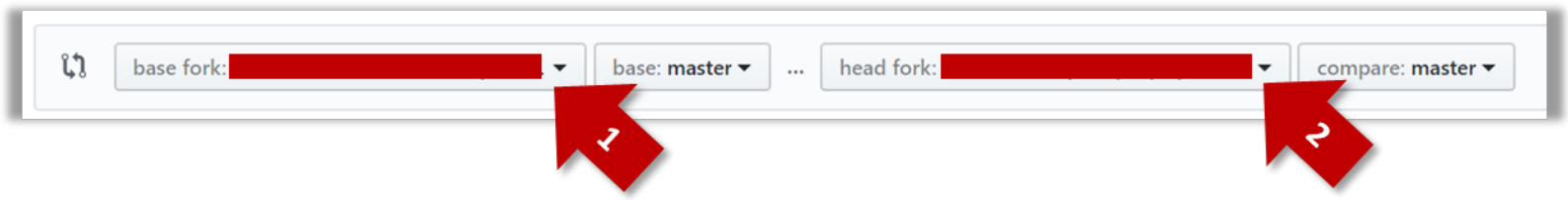
4. Create a Pull Request from the `add-intro` branch in your fork to the `master` branch of the same fork (i.e. `your-user-name/samplerepo-pr-practice`, not `se-edu/samplerepo-pr-practice`), as described below.

4a. Go to the GitHub page of your fork (i.e. `https://github.com/{your_username}/samplerepo-pr-practice`), click on the `Pull Requests` tab, and then click on `New Pull Request` button.



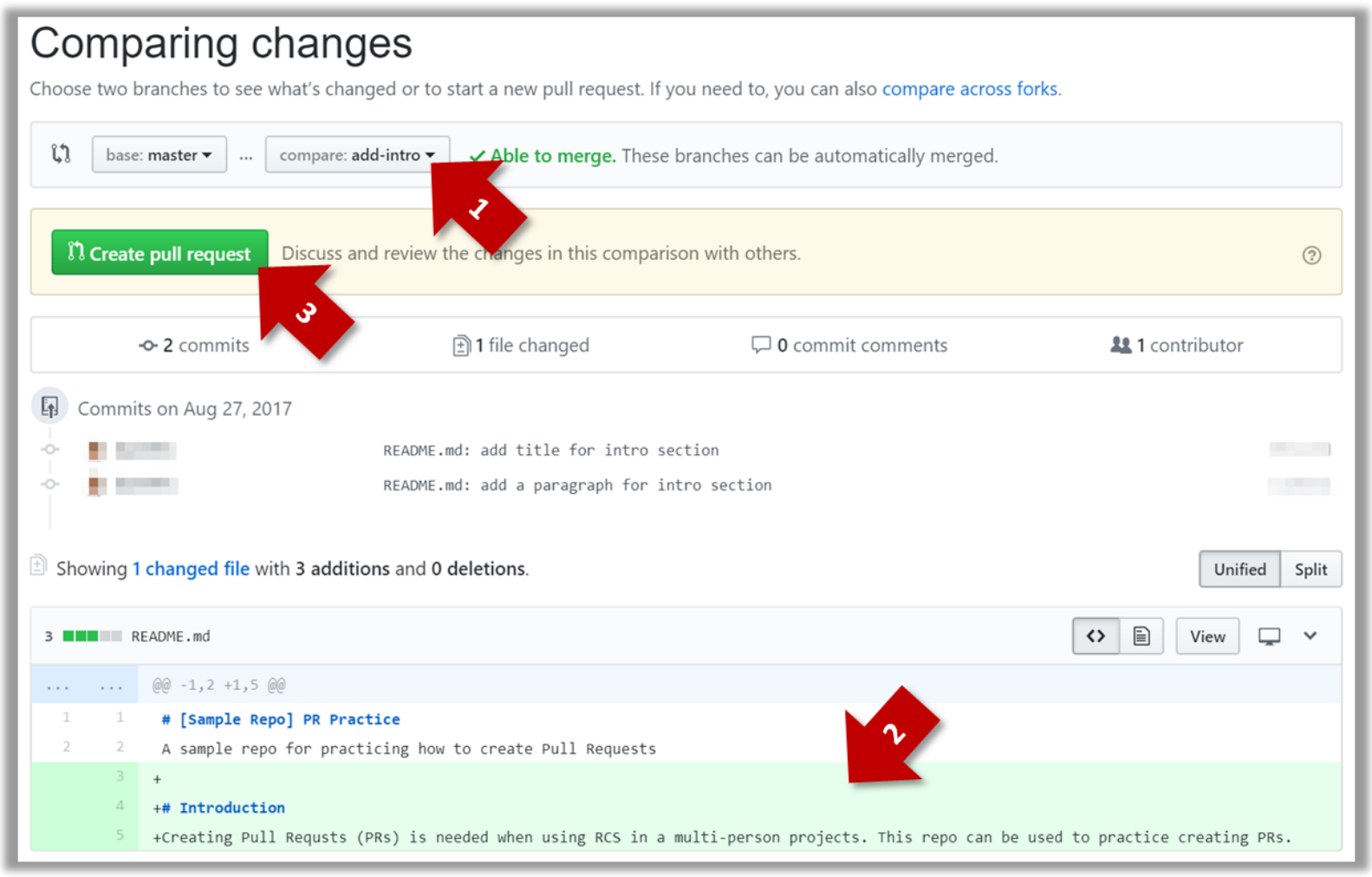
4b. Select `base fork` and `head fork` as follows:

- `base fork`: your own fork (i.e. `{your user name}/samplerepo-pr-practice`, NOT `se-edu/samplerepo-pr-practice`)
- `head fork`: your own fork.

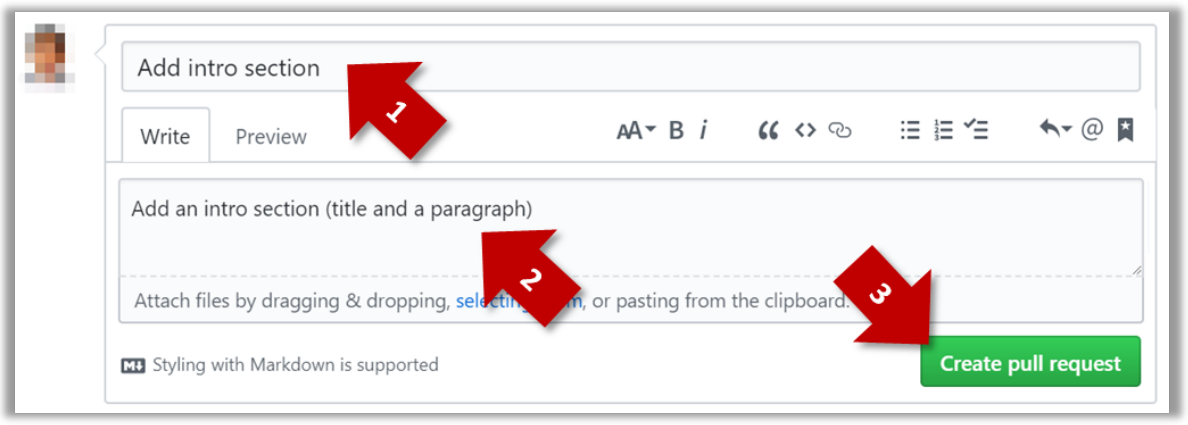


ℹ The *base fork* is where changes should be applied. The *head fork* contains the changes you would like to be applied.

4c. (1) Set the base branch to `master` and head branch to `add-intro`, (2) confirm the *diff* contains the changes you propose to merge in this PR (i.e. confirm that you did not accidentally include extra commits in the branch), and (3) click the `Create pull request` button.



4d. (1) Set PR name, (2) set PR description, and (3) Click the `Create pull request` button.

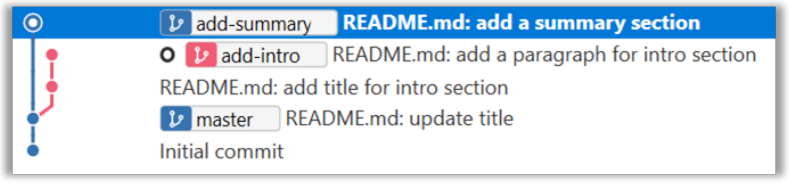


🚩 A common newbie mistake when creating branch-based PRs is to mix commits of one PR with another. To learn how to avoid that mistake, you are encouraged to continue and create another PR as explained below.

5. In your local repo, create a new branch `add-summary` off the `master` branch.

❗ When creating the new branch, it is very important that you switch back to the `master` branch first. If not, the new branch will be created off the current branch `add-intro`. And that is how you end up having commits of the first PR in the second PR as well.

6. Add a commit in the `add-summary` branch that adds a *Summary* section to the `README.md`, in exactly the same place you added the *Introduction* section earlier.



7. Push the `add-summary` to your fork and create a new PR similar to before.

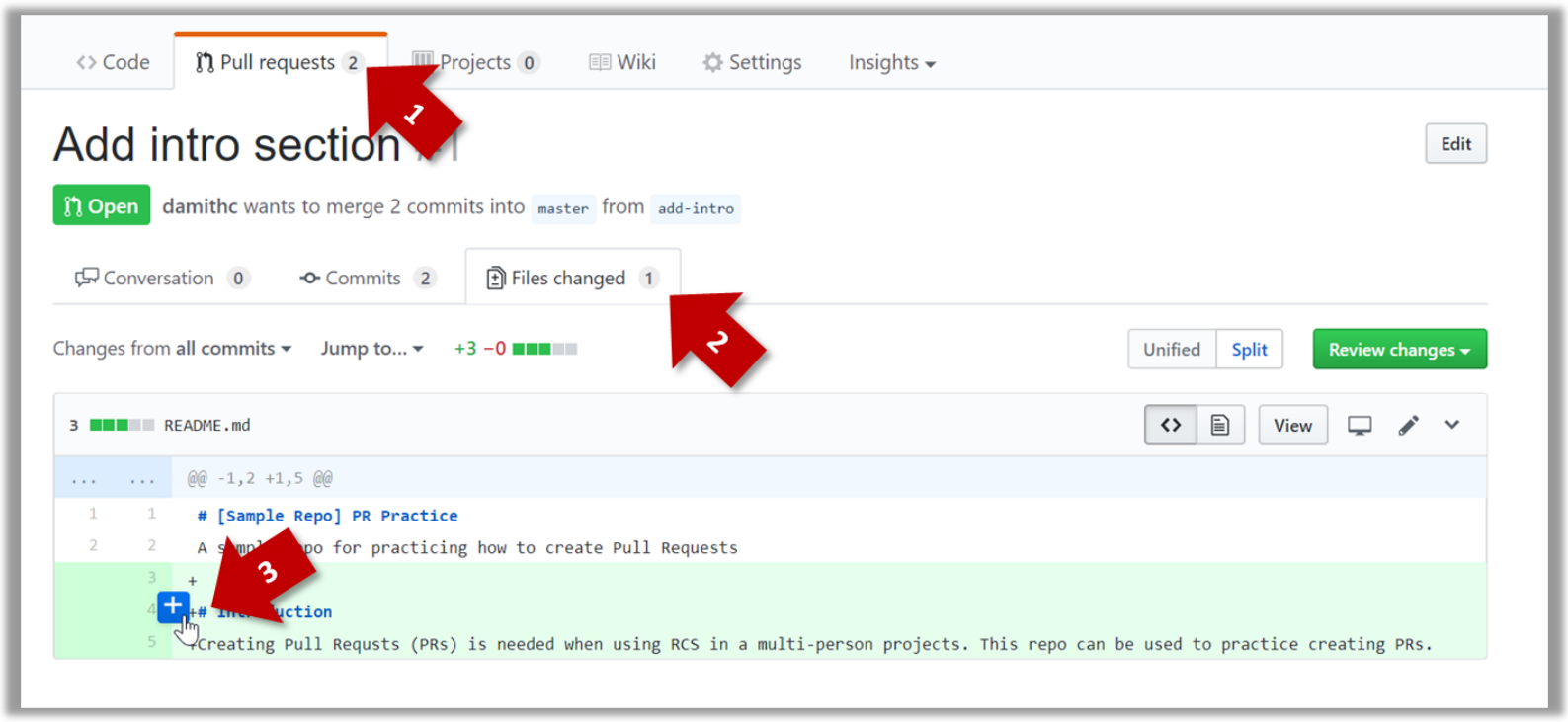
📎 Resources

- GitHub's own documentation on creating a PR

Manage PRs ★★☆☆

1. Go to GitHub page of your fork and review the `add-intro` PR you created previously in [Tools → Git & GitHub → Create PRs] to simulate the PR being reviewed by another developer, as explained below. Note that some features available to PR reviewers will be unavailable to you because you are also the author of the PR.

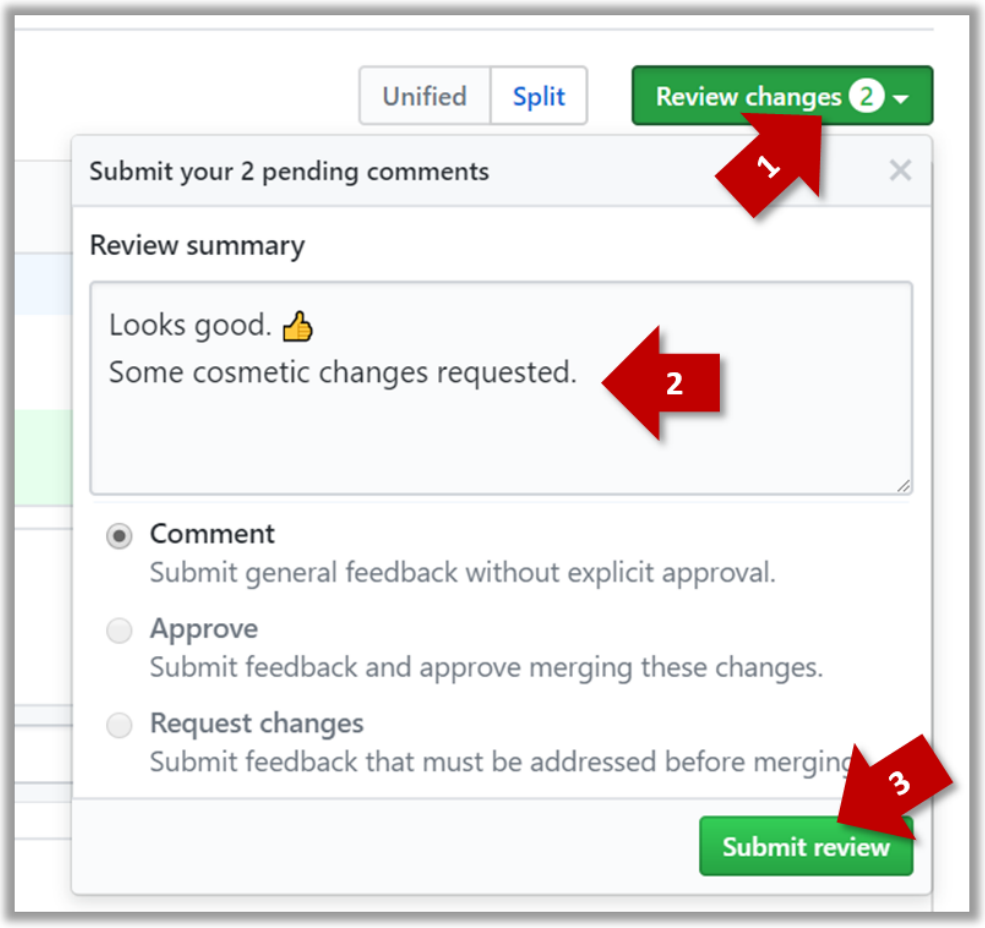
1a. Go to the respective PR page and click on the `Files changed` tab. Hover over the line you want to comment on and click on the ➕ icon that appears on the left margin. That should create a text box for you to enter your comment.



1b. Enter some dummy comment and click on `Start a review` button.

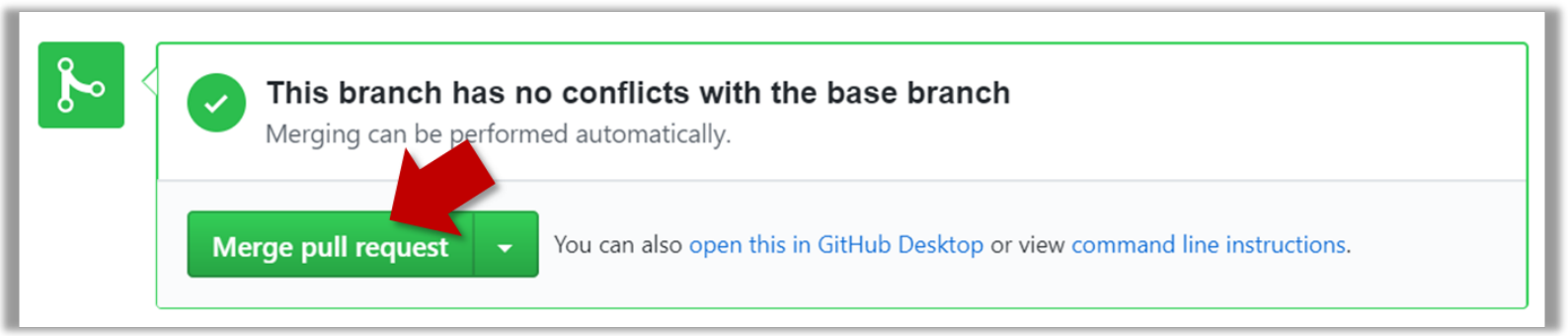
1c. Add a few more comments in other places of the code.

1d. Click on the `Review Changes` button, enter an overall comment, and click on the `Submit review` button.



2. Update the PR to simulate revising the code based on reviewer comments. Add some more commits to the `add-intro` branch and push the new commits to the fork. Observe how the PR is updated automatically to reflect the new code.

3. Merge the PR. Go to the GitHub page of the respective PR, scroll to the bottom of the `Conversation` tab, and click on the `Merge pull request` button, followed by the `Confirm merge` button. You should see a `Pull request successfully merged and closed` message after the PR is merged.



4. Sync the local repo with the remote repo. Because of the merge you did on the GitHub, the `master` branch of your fork is now ahead of your local repo by one commit. To sync the local repo with the remote repo, pull the `master` branch to the local repo.

```
git checkout master
git pull origin master
```

Observe how the `add-intro` branch is now merged to the `master` branch in your local repo as well.

5. De-conflict the `add-summary` PR that you created earlier. Note that GitHub page for the `add-summary` PR is now showing a conflict (when you scroll to the bottom of that page, you should see a message `This branch has conflicts that must be resolved`). You can resolve it locally and update the PR accordingly, as explained below.

5a. Switch to the `add-summary` branch. To make that branch up-to-date with the `master` branch, merge the `master` branch to it, which will surface the merge conflict. Resolve it and complete the merge.

5b. Push the updated `add-summary` branch to the fork. That will remove the 'merge conflicts' warning in the GitHub page of the PR.

6. Merge the `add-summary` PR using the GitHub interface, similar to how you merged the previous PR.

ℹ️ Note that you could have merged the `add-summary` branch to the `master` branch locally before pushing it to GitHub. In that case, the PR will be merged on GitHub automatically to reflect that the branch has been merged already.

Forking Workflow ★★★☆

ℹ️ This activity is best done as a team. If you are learning this alone, you can simulate a team by using two different browsers to log into GitHub using two different accounts.

1. **One member: set up the team org and the team repo.**
   - **Create a GitHub organization** for your team. The org name is up to you. We'll refer to this organization as *team org* from now on.

    - **Add a team** called `developers` to your team org.
    - **Add your team members** to the `developers` team.
    - **Fork se-edu/samplerepo-workflow-practice to your team org**. We'll refer to this as the *team repo*.
    - **Add the forked repo to the `developers` team.** Give write access.
2. **Each team member: create PRs via own fork**

    - **Fork that repo** from your team org to your own GitHub account.
    - **Create a PR** to add a file `yourName.md` (e.g. `jonhDoe.md`) containing a brief resume of yourself (branch → commit → push → create PR)
3. **For each PR: review, update, and merge.**

    - A team member (not the PR author): Review the PR by adding comments (can be just dummy comments).
    - PR author: Update the PR by pushing more commits to it, to simulate updating the PR based on review comments.
    - Another team member: Merge the PR using the GitHub interface.
    - All members: Sync your local repo (and your fork) with upstream repo. In this case, your *upstream repo* is the repo in your team org.
4. **Create conflicting PRs.**

    - Each team member: Create a PR to add yourself under the `Team Members` section in the `README.md`.
    - One member: in the `master` branch, remove John Doe and Jane Doe from the `README.md`, commit, and push to the main repo.
5. **Merge conflicting PRs one at a time.** Before merging a PR, you'll have to resolve conflicts. Steps:

    - [Optional] A member can inform the PR author (by posting a comment) that there is a conflict in the PR.
    - PR author: Pull the `master` branch from the repo in your team org. Merge the pulled `master` branch to your PR branch. Resolve the merge conflict that crops up during the merge. Push the updated PR branch to your fork.
    - Another member or the PR author: When GitHub does not indicate a conflict anymore, you can go ahead and merge the PR.

Java

Varargs 🎓:★★★☆

📎 Resources:

- Java Varargs feature (from Oracle.com)
- Java Varargs tutorial (for javaTpoint.com)

JavaFX: Basic ★★☆☆

Adapted (with permissions) from Marco Jakob's JavaFX 8 tutorial.

After going through the two parts above, you should be familiar with building basic JavaFX GUIs using IntelliJ. You can continue with the original tutorial (which is written for Eclipse), with the following links:

- **Part 3: Interacting with the User**
- **Part 4: CSS Styling**
- **Part 5: Storing Data as XML**

Streams: Basic 🎓:★★★☆

Java 8 introduced a number of new features (e.g. Lambdas, Streams) that are not trivial to learn but also extremely useful to know.

Here is an overview of new Java 8 features . (written by Benjamin Winterberg)

JUnit

JUnit: Basic ★★☆☆

When writing JUnit tests for a class `Foo`, the common practice is to create a `FooTest` class, which will contain various test methods.

📦 Suppose we want to write tests for the `IntPair` class below.

```
public class IntPair {
    int first;
    int second;

    public IntPair(int first, int second) {
        this.first = first;
        this.second = second;
    }

    public int intDivision() throws Exception {
        if (second == 0){
            throw new Exception("Divisor is zero");
        }
        return first/second;
    }

    @Override
    public String toString() {
        return first + "," + second;
    }
}
```

Here's a `IntPairTest` class to match.

```
import org.junit.Test;
import org.junit.Assert;

public class IntPairTest {

    @Test
    public void testStringConversion() {
        Assert.assertEquals("4,7", new IntPair(4, 7).toString());
    }

    @Test
    public void intDivision_nonZeroDivisor_success() throws Exception {
        Assert.assertEquals(2, new IntPair(4, 2).intDivision());
        Assert.assertEquals(0, new IntPair(1, 2).intDivision());
        Assert.assertEquals(0, new IntPair(0, 5).intDivision());
    }

    @Test
    public void intDivision_zeroDivisor_exceptionThrown() {
        try {
            Assert.assertEquals(0, new IntPair(1, 0).intDivision());
            Assert.fail(); // the test should not reach this line
        } catch (Exception e) {
            Assert.assertEquals("Divisor is zero", e.getMessage());
        }
    }
}
```

Notes:

- Each test method is marked with a `@Test` annotation.
- Tests use `Assert.assertEquals(expected, actual)` methods to compare the expected output with the actual output. If they do not match, the test will fail. JUnit comes with other similar methods such as `Assert.assertNull` and `Assert.assertTrue`.
- Java code normally use camelCase for method names e.g., `testStringConversion` but when writing test methods, sometimes another convention is used: `whatIsBeingTested_descriptionOfTestInputs_expectedOutcome` e.g., `intDivision_zeroDivisor_exceptionThrown`

- There are several ways to verify the code throws the correct exception. The third test method in the example above shows one of the simpler methods. If the exception is thrown, it will be caught and further verified inside the `catch` block. But if it is not thrown as expected, the test will reach `Assert.fail()` line and will fail as a result.
- The easiest way to run JUnit tests is to do it via the IDE. For example, in Intellij you can right-click the folder containing test classes and choose 'Run all tests...'
- Optionally, you can use static imports to avoid having to specify `Assert.` everywhere.

```
import static org.junit.Assert.assertEquals;
//...
@Test
public void testStringConversion() {
    assertEquals("4,7", new IntPair(4, 7).toString());
}
```

JUnit: Intermediate ★★★☆

Some intermediate JUnit techniques that may be useful:

- **It is possible for a JUnit test case to verify if the SUT throws the right exception**.
- ***JUnit Rules* are a way to add additional behavior to a test.** e.g. to make a test case use a temporary folder for storing files needed for (or generated by) the test.
- **It is possible to write methods thar are automatically run before/after a test method/class**. These are useful to do pre/post cleanups for example.
- **Testing private methods is possible, although not always necessray**