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Software Engineering for Self-Directed Learners CS2113/T edition - 2021 Jan-May

This is a **printer-friendly** version. It omits exercises, optional topics (i.e., four-star topics), and other extra content such as learning outcomes.

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, you want others to use your 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 you 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 you 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#, Haskell, 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 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, you 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 through which other objects can interact with it
- 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 messages to each other. The message can result in the sender object receiving a response and/or the receiver 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.

📦 You 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 terms of 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 will use to,

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

A *class* contains instructions for creating a specific kind of objects. It turns out sometimes multiple objects keep the same type of data and have the same behavior because they are of the *same kind*. Instructions for creating a 'kind' (or 'class') of objects can be done once and those same instructions can be used to *instantiate* objects of that kind. You 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`, `dateOfBirth`, etc.), and the same kind of behavior (i.e. `getAge(Date)`, `getName()`, etc.). Therefore, you 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, you need classes `AgeList`, `Calculator`, and `Main` classes to instantiate one each of `AgeList`, `Calculator`, and `Main` objects.

Class	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 (i.e., the one who manages the whole operation)

Class Level Members ★★☆☆

While all objects of a class have 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 the `Adam` object results in the response `"Adam"` while sending the same message to the `Beth` object results in the response `"Beth"`.

However, there can be methods related to a specific class but not suitable for sending messages 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 have to 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.

📦 Suppose you want a variable called `priority` to store the priority of something. There are only three priority levels: high, medium, and low. You can declare the variable `priority` as of type `int` and use only values `2`, `1`, and `0` to indicate the three priority levels. However, this opens the possibility of an invalid value such as `9` being assigned to it. But if you define an enumeration type called `Priority` that has three values `HIGH`, `MEDIUM` and `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 you can expect to have associations between a `Course` object that represents a specific course and `Student` objects that represent 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 classes too.

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

Implementing associations

You 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 multiplicity 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.

📦 This code uses a two-dimensional array to implement a 1-to-many association from the `Minefield` to `Cell`.

```
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 direct 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 i.e., the *part* should not exist without being attached to a *whole*.

📦 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`.

Whether a relationship is a composition can depend on the context.

Is the relationship between `Email` and `EmailSubject` composition? That is, is the email subject *part* of an email to the extent that an email subject cannot exist without an email?

- When modeling an application that sends emails, the answer is 'yes'.
- When modeling an application that gather analytics about email traffic, the answer may be 'no' (e.g., the application might collect just the email subjects for text analysis).

A common use of composition is when parts of a big class are carved out as smaller classes for the ease of managing the internal design. In such cases, the classes extracted out still act as *parts* of the bigger class and the outside world has no business knowing about them.

Cascading deletion alone is not sufficient for composition. Suppose there is a design in which `Person` objects are attached to `Task` objects and the former get deleted whenever the latter is deleted. This fact alone does not mean there is a composition relationship between the two classes. For it to be composition, a `Person` must be an integral *part* of a `Task` in the context of that association, at the concept level (not simply at implementation level).

Identifying and keeping track of composition relationships in the design has benefits such as helping to maintain the data integrity of the system. For example, when you know that a certain relationship is a composition, you can take extra care in your implementation to ensure that when the *whole* object is deleted, all its *parts* are deleted too.

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 this code, 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` class in that a `Team` contains a `Person` 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 data/behaviors that are 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, *Superclass*
- Other names for Derived class: *Child* class, *Subclass*, *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` behave 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 women) 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.

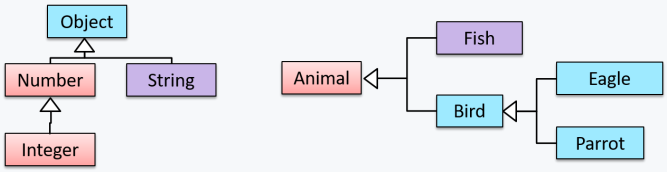
Inheritance does not necessarily mean a sub-type relationship exists. However, the two often go hand-in-hand. For simplicity, at this point let us assume inheritance implies a sub-type relationship.

To continue the previous example,

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

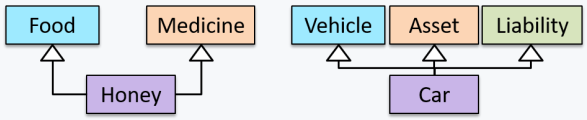
Inheritance relationships through a chain of classes can result in inheritance *hierarchies* (aka inheritance *trees*).

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 a `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.

Example:

Method	Type Signature
`int add(int X, int Y)`	`(int, int)`
`void add(int A, int B)`	`(int, int)`
`void m(int X, double Y)`	`(int, double)`
`void m(double X, int Y)`	`(double, int)`

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 it can be subclassed.

You can 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 exists 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.

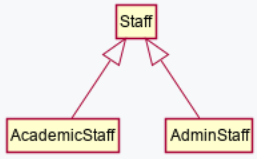
Abstract method: An *abstract method* is a method signature without a method implementation.

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.

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 `AcademicStaff` is an instance of a `Staff`, but a `Staff` is not necessarily an instance of an `AcademicStaff`. 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.

```java
class Account {

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

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

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

```java
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's 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 objects 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 is 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 ★★☆☆

Requirements can be divided into two in the following way:

1. ***Functional requirements* specify what the system should do.**
2. ***Non-functional requirements* specify the constraints under which the 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 the system would operate in or needs 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.

You 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 on 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. Stakeholders 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 about project requirements.

Focus Groups ★★★☆

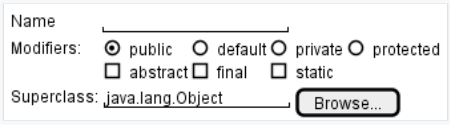
Focus groups are a kind of informal interview within an interactive group setting. A group of people (e.g. potential users, beta testers) are asked about their understanding of a specific issue, process, product, advertisement, etc.

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 or *mock ups* are often used in brainstorming sessions, or in meetings with the users to get quick feedback from them.

A mock up (also called a *wireframe* diagram) of a dialog box:



[source: plantuml.com]

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 documentation of an existing system can tell us 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`

You can write user stories on index cards or sticky notes, and arrange them on walls or tables, to facilitate planning and discussion. Alternatively, you 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 did 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 an 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**.

A recipe for brainstorming user stories

Given below is a possible *recipe* you can take when using user stories for early stages of requirement gathering.

Step 0: Clear your mind of preconceived product ideas

Even if you already have some idea of what your product will look/behave like in the end, clear your mind of those ideas. The product is the *solution*. At this point, we are still at the stage of figuring out the *problem* (i.e., user requirements). Let's try to get from the problem to the solution in a systematic way, one step at a time.

Step 1: Define the *target user* as a *persona*:

Decide your target user's profile (e.g. a student, office worker, programmer, salesperson) 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 narrow it down to a *persona*. Here is an example:

> 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. ...

Step 2: Define the *problem scope*:

Decide the exact problem you are going to solve for the target user. It is also useful to specify what related problems it will *not* solve so that the exact scope is clear.

> ProductX helps Jean keep track of all her school contacts. It does not cover communicating with contacts.

Step 3: List *scenarios* to form a *narrative*:

Think of the various scenarios your target user is likely to go through as she uses your app. Following a chronological sequence as if you are telling a story might be helpful.

> **A. First use:**
>
> 1. Jean gets to know about ProductX. She downloads it and launches it to check out what it can do.
> 2. After playing around with the product for a bit, Jean wants to start using it for real.
> 3. ...
>
> **B. Second use:** (Jean is still a beginner)
>
> 1. Jean launches ProductX. She wants to find ...
> 2. ...
>
> **C. 10th use:** (Jean is a little bit familiar with the app)
>
> 1. ...
>
> **D. 100th use:** (Jean is an expert user)
>
> 1. Jean launches the app and does ... and ... followed by ... as per her usual habit.
> 2. Jean feels some of the data in the app are no longer needed. She wants to get rid of them to reduce clutter.
> 3.

More examples that might apply to some products:

> - Jean uses the app at the start of the day to ...
> - Jean uses the app before going to sleep to ...
> - Jean hasn't used the app for a while because she was on a three-month training programme. She is now back at work and wants to resume her daily use of the app.
> - Jean moves to another company. Some of her clients come with her but some don't.
> - Jean starts freelancing in her spare time. She wants to keep her freelancing clients separate from her other clients.

Step 4: List the user stories to support the scenarios:

Based on the scenarios, decide on the user stories you need to support. For example, based on the scenario 'A. First use', you might have user stories such as these:

> - As a potential user exploring the app, I can see the app populated with sample data, so that I can easily see how the app will look like when it is in use.
> - As a user ready to start using the app, I can purge all current data, so that I can get rid of sample/experimental data I used for exploring the app.

To give another example, based on the scenario 'D. 100th use', you might have user stories such as these:

> - As an expert user, I can create shortcuts for tasks, so that I can save time on frequently performed tasks.
> - As a long-time user, I can archive/hide unused data, so that I am not distracted by irrelevant data.

Do not 'evaluate' the value of user stories while brainstorming. Reason: an important aspect of brainstorming is not judging the ideas generated.

Other tips:

- **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. That is, don't try to reverse-engineer a preconceived product idea into user stories.
- **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: 'transfer money' use case for an online banking system

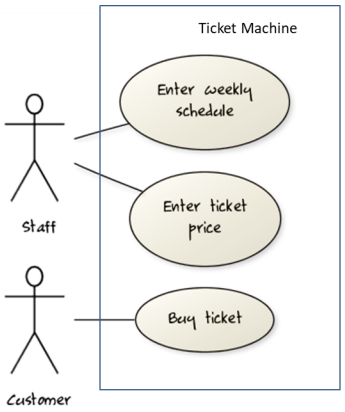
```
System: Online Banking System (OBS)
Use case: UC23 - Transfer Money
Actor: User
MSS:
  1. User chooses to transfer money.
  2. OBS requests for details of the transfer.
  3. User enters the requested details.
  4. OBS requests for confirmation.
  5. User confirms.
  6. OBS transfers the money and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

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 on the right, 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.

Glossary

What ★★★☆

Glossary: A glossary serves to ensure that *all stakeholders have a common understanding* of the noteworthy terms, abbreviations, 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 is 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 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 need 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.

***Data abstraction*: abstracting away the lower level data items and thinking in terms of bigger entities**

> Within a certain software component, you 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*: abstracting away details of the actual control flow to focus on tasks at a higher 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 abstraction*.

> 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 level 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.

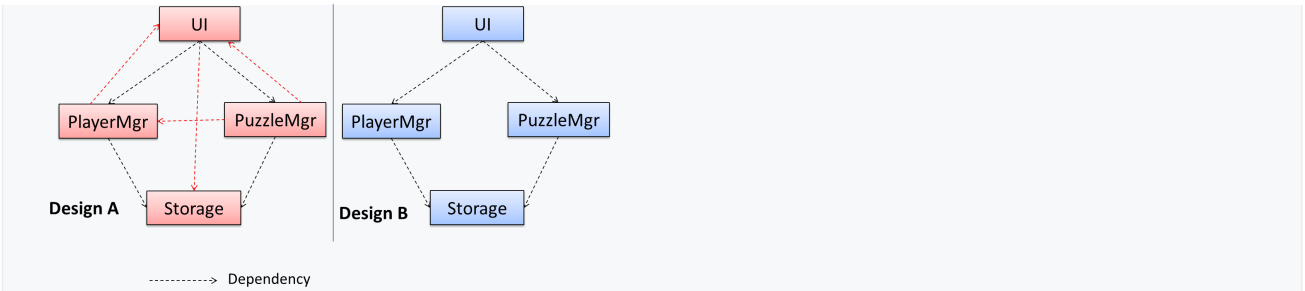
Coupling

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 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 the `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 `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 modules may need to be modified to achieve a small change in behavior (reason: because the code related 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 includes 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 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 documentation.

📦 Some examples of using models to communicate:

1. You 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.

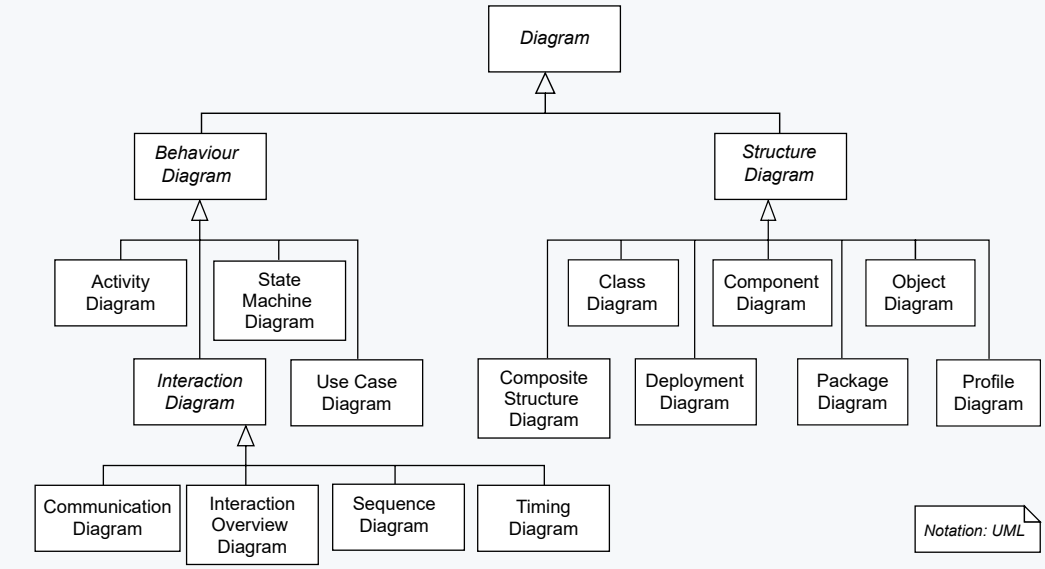
📦 Some examples of using models as blueprints:

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 + extra

UML Models ★★★☆

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



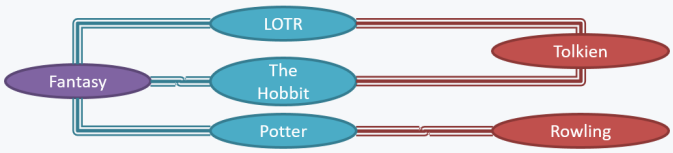
source:https://en.wikipedia.org/

Modeling structures

OO Structures ★☆☆☆

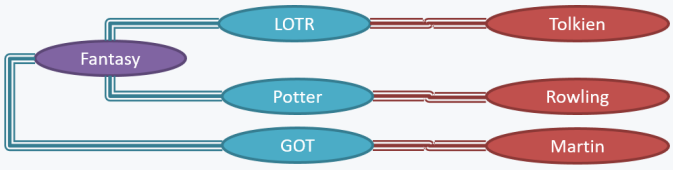
An OO solution is basically a network of objects interacting with each other. Therefore, **it is useful to be able to model how the relevant objects are 'networked' together** inside a software i.e. how the objects are connected together.

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



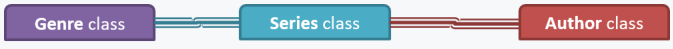
Note that these **object structures within the same software can change over time**.

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



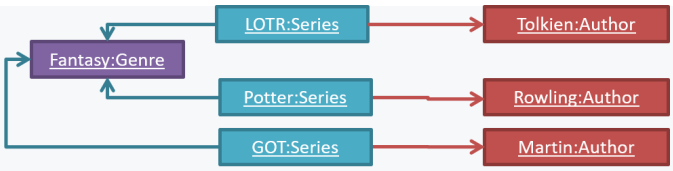
However, object structures do not change at random; they change based on a set of rules, as was decided by the designer of that software. Those **rules that object structures need to follow can be illustrated as a *class structure*** i.e. a structure that exists among the relevant classes.

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) ★☆☆☆

Contents of the panels given below belong to a different chapter; they have been embedded here for convenience and are collapsed by default to avoid content duplication in the printed version.

- UML Class Diagrams → Introduction → What

Classes form the basis of class diagrams.

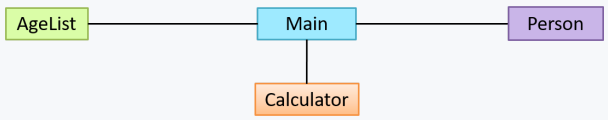
- UML Class Diagrams → Classes → What
- UML Class Diagrams → Class-Level Members → What

***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.

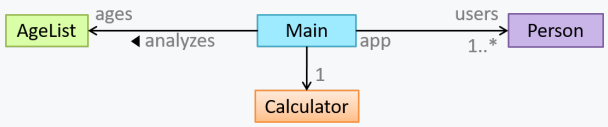
An example class diagram showing associations between classes.



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 ★★★☆

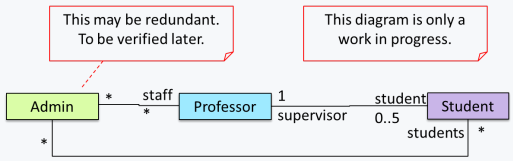
UML notes can be used to add more info to any UML model.

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 relationships between classes: 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

Modeling behaviors

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
- 🎓 UML 🔜 Sequence Diagrams → Calls to Static Methods

Software architecture

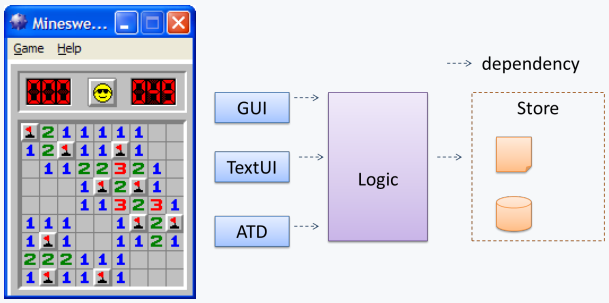
Introduction

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.

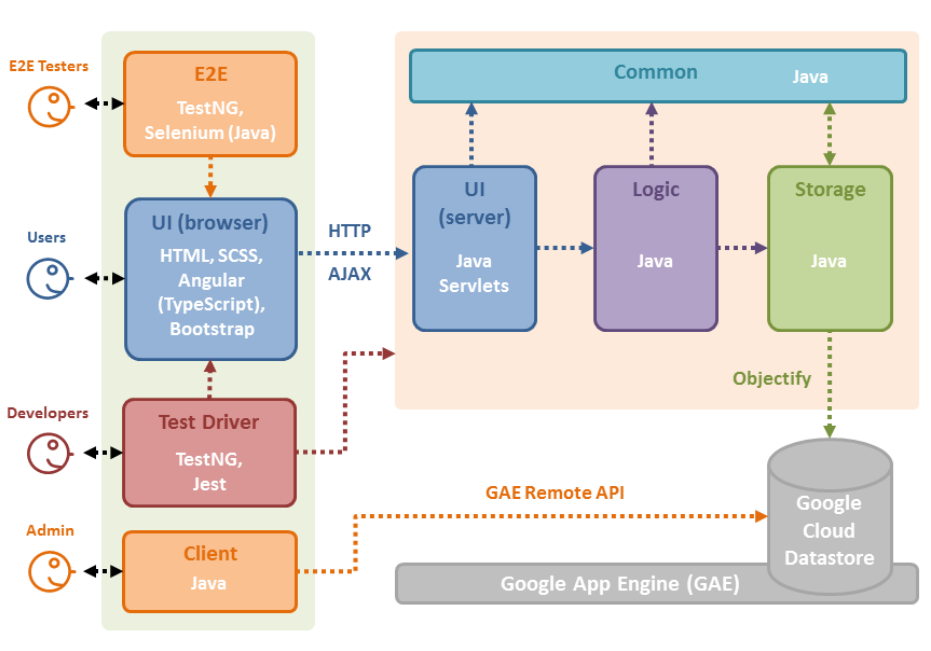
Architecture diagrams

Reading ★☆☆☆

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

📦 Some example architecture diagrams:

TEAMMATES | se-edu/addressbook-level3 | Example 1 | Example 2 | Example 3

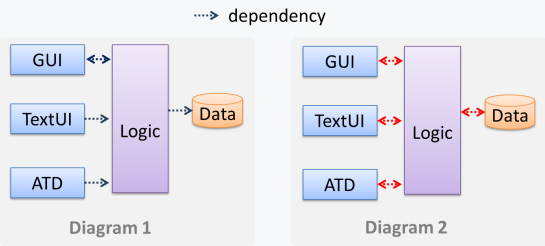


Drawing ★☆☆☆

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 ★★☆☆

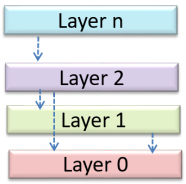
Software architectures follow various high-level styles (aka *architectural patterns*), just like how building architectures follow various architecture styles.

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

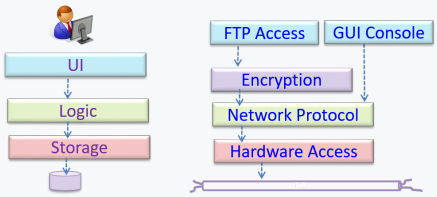
N-tier architectural style

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*.



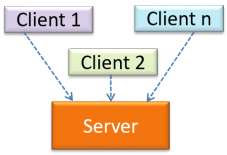
Operating systems and network communication software often use n-tier style.



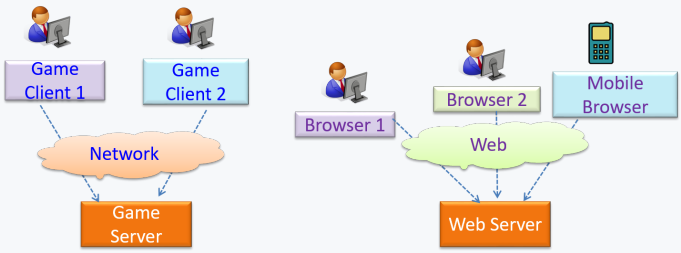
Client-server architectural style

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 use the client-server style.



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 the 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

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*.

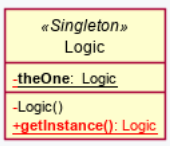
Problem

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 you want each test to be independent of the others.

Given that 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.

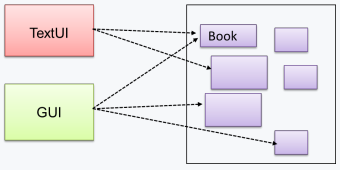
Facade pattern

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.



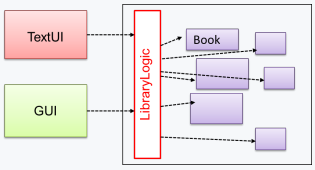
Problem

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 contains a `Book` class within it.

Solution

Include a Façade 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 Facade pattern to the `Library System` example. The `LibraryLogic` class is the Facade class.



SECTION: IMPLEMENTATION

IDEs

Introduction

What ★☆☆☆

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

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.
  - These extraneous program modifications increase the risk of introducing errors into the program.
  - These print statements, if not removed promptly after the debugging, 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 a difficult, time consuming, and error-prone technique.
  - If you didn't spot the error while writing the code, you might not spot the error when reading the code either.
- 👍 **Good** -- **Using a debugger**: A debugger tool allows you to pause the execution, then step through the code 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 on software, poor quality code is something no one can 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 you do not intend to pass the code to someone else, code quality is still important because you will become a 'stranger' to your 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 (isAlreadySubsidized) {
        subsidy = SUBSIDIZED_SUBSIDY;
    } else if (isPartTime) {
        subsidy = FULLTIME_SUBSIDY * RATIO;
    } else {
        subsidy = FULLTIME_SUBSIDY;
    }
    return subsidy;
}
```

Basic

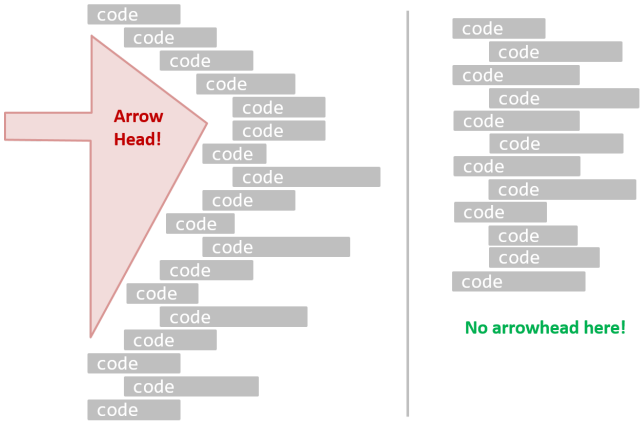
Avoid Long Methods ★★☆☆

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 Coding Style

In particular, avoid *arrowhead* style code.



A real code example:

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 (isAlreadySubsidized) {
        subsidy = SUBSIDIZED_SUBSIDY;
    } else if (isPartTime) {
        subsidy = FULLTIME_SUBSIDY * RATIO;
    } else {
        subsidy = FULLTIME_SUBSIDY;
    }
    return subsidy;
}
```

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, it is called 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, you can have 'magic' values of other data types.

Bad

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

In general, try to avoid any magic literals.

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 groupings 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 how you 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 that 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:

- **You 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 it is for the compiler to optimize). 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 no matter how fast/efficient it is.

> 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 is 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 book *The Productive Programmer* (by Neal Ford) calls this the ***Single Level of Abstraction Principle*** **(SLAP)** while the book *Clean Code* (by Robert C. Martin) calls this *One Level of Abstraction per Function*.

Example:

Bad (`readData();` and `salary = basic * rise + 1000;` are at different levels of abstraction)

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

Good (all statements are at the same level of abstraction)

```
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 detections are separated from their handling.
- the 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 locations 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 uses the same coding standard and that the standard is generally not inconsistent with typical industry practices. If a company's coding standard is very different from what is typically used 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.

Guideline: Name well

Introduction ★★☆☆

Proper naming improves the readability of code. 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 multi-valued 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 a 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 a 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?
`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. 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, raise a suitable error). 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 ★★☆☆

You might feel reluctant to delete code you have painstakingly written, even if you have no use for that code anymore ("I spent a lot of time writing that code; what if I 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'. That 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 yourself. Instead, write them well enough to be understood by another programmer. One type of comment 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 the *what* and *why* aspects of the code, rather than the *how* aspect.

✔ **What**: The specification of what the code is *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());
}
```

↓

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

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

Some IDEs have builtin 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-catalog.

1. Consolidate Conditional Expression
2. Decompose Conditional
3. Inline Method
4. Remove Double Negative
5. Replace Magic Literal
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 needs 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.

Another view proposed by Daniele Procida in this article is as follows:

> **There is a secret that needs to be understood in order to write good software documentation: there isn't one thing called documentation, there are four. They are: tutorials, how-to guides, explanation and technical reference.** They represent four different purposes or functions, and require four different approaches to their creation. Understanding the implications of this will help improve most software documentation - often immensely. ...
>
> | TUTORIALS | HOW-TO GUIDES |
> |---|---|
> | A tutorial:
• is learning-oriented
• allows the newcomer to get started
• is a lesson
Analogy: teaching a small child how to cook | A how-to guide:
• is goal-oriented
• shows how to solve a specific problem
• is a series of steps
Analogy: a recipe in a cookery book |
> | **EXPLANATION** | **REFERENCE** |
> | An explanation:
• is understanding-oriented
• explains
• provides background and context
Analogy: an article on culinary social history | A reference guide:
• is information-oriented
• describes the machinery
• is accurate and complete
Analogy: a reference encyclopedia article |

Software documentation (applies to both user-facing and developer-facing) is best kept in a text format for ease of version tracking. **A writer-friendly source format is also desirable** as non-programmers (e.g., technical writers) may need to author/edit such documents. As a result, formats such as Markdown, AsciiDoc, and PlantUML are often used for software documentation.

Tools

JavaDoc

What ★★☆☆

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

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

```java
/**
 * 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.

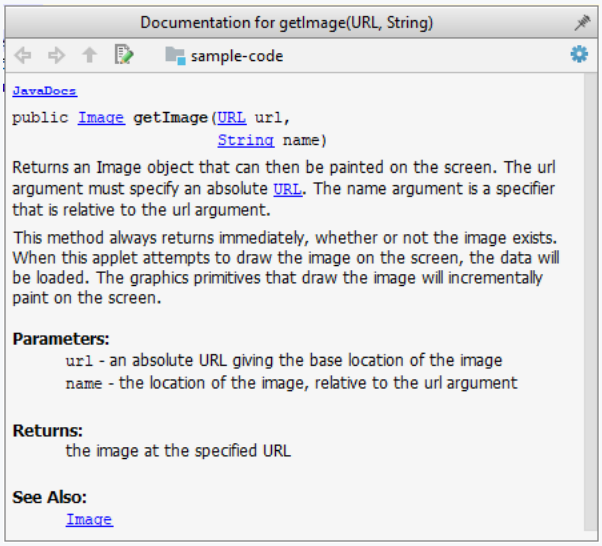
This method always returns immediately, whether or not the image exists. When this applet attempts to draw the image on the screen, the data will be loaded. The graphics primitives that draw the image will incrementally paint on the screen.

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:

```java
/**
 * 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:

```java
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 {
    // ...
}
```

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 runtime.

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 takes 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 you set an assertion that `timeout` returned by `Config.getTimeout()` is greater than `0`. Now, if `Config.getTimeout()` returns `-1` in a specific execution of this line, the runtime can detect it as an *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.

```
1 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.

```
1 x = getX();
2 assert x == 0 : "x should be 0";
3 ...
```

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.

ℹ **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.

```
1 ...
2 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 actions 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:

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

Next, create a `Logger`:

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

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

```
1  // log a message at INFO level
2  logger.log(Level.INFO, "going to start processing");
3  // ...
4  processInput();
5  if (error) {
6      // log a message at WARNING level
7      logger.log(Level.WARNING, "processing error", ex);
8  }
9  // ...
10 logger.log(Level.INFO, "end of processing");
```

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.

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 its source code can be a complex multi-step process. For example, it can include steps such as: 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 compiling, linking and packaging, 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 of 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, GitHub Actions

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/platforms 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, and/or 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 that the GitHub server accepts and their corresponding responses. You can write a program that interacts with GitHub through that API.

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

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 you *building the right system* i.e., are the requirements correct?
2. Verification: are you *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 that both are done, instead of limiting to only verification (i.e., remember that the requirements can be wrong too).

Code reviews

What ★★★☆

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

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

- **Pull Request reviews**
  - Project Management Platforms such as GitHub and BitBucket allow the new code to be proposed as *Pull Requests* and provide the ability for others to review the code in the PR.
- **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.
- **Formal inspections**
  - Inspections involve a group of people systematically examining 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 review over testing:

- It can detect functionality defects as well as other problems such as coding standard violations.
- It can verify non-code artifacts and incomplete code.
- It does 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 as 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.

The term *static* in static analysis refers to the fact that the code is analyzed without executing the code. **In contrast, *dynamic analysis* requires the code to be executed to gather additional information about the code** e.g., performance characteristics.

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

> 📦 Some example static analyzers 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 errors, not their absence.

Disadvantages:

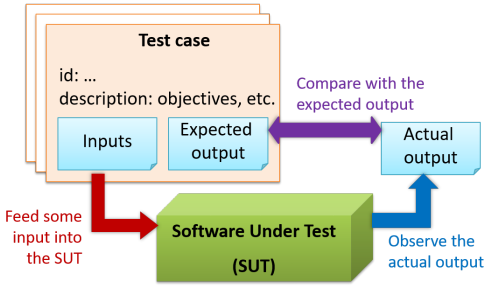
- It only proves the compliance with the specification, but not the actual utility of the software.
- It requires highly specialized notations and knowledge which makes it an expensive technique to administer. Therefore, **formal verifications are more commonly used in safety-critical software such as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

Testing

Introduction

What ★★☆☆

Testing: 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, you 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.

Other details a test case can contain + extra

For each test case you should 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 indicates a potential *defect* (or a bug), unless the error is in the test case itself.

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.

A deeper look at the definition of testing + extra

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 software. The higher the testability, the easier it is to achieve 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 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 (note 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 `StorageStub` has the same interface as `DatabaseStorage`, but 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.

```
@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 what the parts are supposed to do vs what the parts are actually doing.

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

How ★★★☆

Integration testing is not simply a case of repeating the unit test cases 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` by using it together with the `Engine` and `Wheel` classes to ensure that `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` by using it together with the `Engine` and `Wheel` classes to ensure that `Car` integrates properly with the `Engine` and the `Wheel`. This step should include test cases that are meant to unit test `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' when pushed beyond its limits.

📦 Suppose the SUT is a browser that is 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 when creators use their own product so as 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.

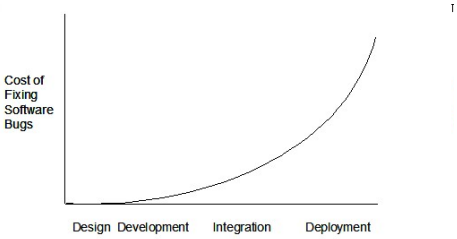
Why ★★★☆

Delaying testing until the full product is complete has a number of disadvantages:

- **Locating the cause of 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 from 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 are 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 versus 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; you need to look at them soon. But before that, you should 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%, you 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 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 versus 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

Requirements specification	System 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 solves 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 you 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 the re-testing of the software to detect regressions.** Note that to detect regressions, you need to retest all related components, even if they had been 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, you feed the app with a sequence of test inputs that is stored in a file while redirecting the output to another file.
- Next, you compare the actual output file with another file containing the expected output.

Let's assume you 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 you 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 PowerShell window.

4. Next, you compare `output.txt` with the `expected.txt`. This can be done using a utility such as Windows' `FC` (i.e. File Compare) command, Unix's `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, you 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 if the behavior is as expected.

`PayrollTest` 'drives' the `Payroll` class by sending it test inputs and verifies if the output is as expected.

```
1  public class PayrollTest {
2      public static void main(String[] args) throws Exception {
3
4          // test setup
5          Payroll p = new Payroll();
6
7          // test case 1
8          p.setEmployees(new String[]{"E001", "E002"});
9          // automatically verify the response
10         if (p.totalSalary() != 6400) {
11             throw new Error("case 1 failed ");
12         }
13
14         // test case 2
15         p.setEmployees(new String[]{"E001"});
16         if (p.totalSalary() != 2300) {
17             throw new Error("case 2 failed ");
18         }
19
20         // more tests...
21
22         System.out.println("All tests passed");
23     }
24 }
```

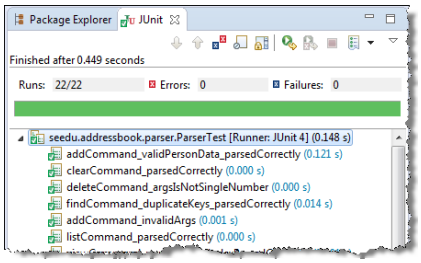
Test Automation Tools ★★★☆

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 is an automated test for a `Payroll` class, written using JUnit libraries.

```
1  @Test
2  public void testTotalSalary() {
3      Payroll p = new Payroll();
4
5      // test case 1
6      p.setEmployees(new String[]{"E001", "E002"});
7      assertEquals(6400, p.totalSalary());
8
9      // test case 2
10     p.setEmployees(new String[]{"E001"});
11     assertEquals(2300, p.totalSalary());
12
13     // more tests...
14 }
```

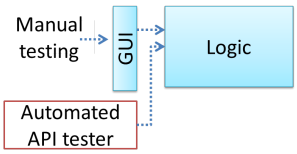
Most modern IDEs have integrated support for testing tools. The figure below shows the JUnit output when running some JUnit tests using the Eclipse IDE.



Automated Testing of GUIs ★★★☆

If a software product has a GUI (Graphical User Interface) 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.



Moving as much logic as possible out of the GUI can make GUI testing easier. That way, you can bypass the GUI to test the rest of the system using automated API testing. While this still requires the GUI to be tested, the number of such test cases can be reduced as most of the system will have 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
- **Visual Studio** supports the '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 lines 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.

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 you 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 the 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. On the other hand, a *negative test case* is designed to produce a behavior that indicates an invalid/unexpected situation, such as an error message.

Consider the 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 the SUT's 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` fails 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 you 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, you 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 values

of s (`GameStatus` is an `enum`). In this case, each possible value of `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 EPs given above for the method `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, you need to identify the 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, the `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 the app is waiting for the player's first move
- `IN_PLAY`: the current minefield is already in use
- `WON`, `LOST`: let us assume that `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] (assuming 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 a 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 boundaries are often used in branching instructions, etc., where the programmer can make mistakes.

📦 The `markCellAt(int x, int y)` operation could contain code such as `if (x > 0 && x <= (W-1))` which involves the 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, you should 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 test values (boundaries are in bold)
[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] (assuming string length is the aspect of interest)	**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] (assuming a fixed size stack)	Stack with: no elements, **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 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 will be too high (i.e. not efficient). Therefore, **you 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 inputs.

📦 Let's assume the SUT has the following three inputs and you have selected the given values for testing:

SUT: `foo(char p1, int p2, boolean p3)`

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.

📦 This strategy generates 3x3x2=18 test cases.

Test Case	p1	p2	p3
1	a	1	T
2	a	1	F
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 observation 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 p2 values are tested at least once:

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 picks a subset randomly (presumably because the original set of test cases is too big).

There are other strategies that can be used too.

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 the 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 software are also known as *Version Control Software (VCS)*, and by 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 the `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 directory, for examples, files of different projects.

Saving History ★☆☆☆

Tracking and ignoring

In a repo, you 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, you first *`stage`* the specific changes you want to commit. This intermediate step allows you to commit only some changes while saving other changes for a later commit.

Using History ★★☆☆

RCS tools store the history of the working directory as a series of commits. This means you should commit after each change that you want the RCS to 'remember'.

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`.

You can `tag` a specific commit with a more easily identifiable name e.g. `v1.0.2`.

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., you can traverse the history of the working directory simply by checking out the commits you are interested in.

Remote Repositories ★★☆☆

Remote repositories are repos that are hosted on remote computers and allow remote access. 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 codebase.

It is possible to set up your own remote repo on a server, but the easier option is to use a remote repo hosting service such as GitHub or BitBucket.

You can *`clone`* a repo to create a copy of that repo in another location on your computer. The copy will even have the revision history of the original repo i.e., identical to the original repo. For example, you can clone a remote repo onto your computer to create a local copy of the remote repo.

When you clone from a repo, the original repo is commonly referred to as the *`upstream`* repo. A repo can have multiple upstream repos. For example, let's say a repo `repo1` was cloned as `repo2` which was then cloned as `repo3`. In this case, `repo1` and `repo2` are upstream repos of `repo3`.

You can *`pull`* from one repo to another, to receive new commits in the second repo, if the repos have a shared history. Let's say some new commits were added to the upstream repo after you cloned it and you would like to copy over those new commits to your own clone i.e., `sync` your clone with the upstream repo. In that case, you pull from the upstream repo to your clone.

You can *`push`* new commits in one repo to another repo which will copy the new commits onto the destination repo. Note that pushing to a repo requires you to have write-access to it. Furthermore, you can push between repos only if those repos have a shared history among them (i.e., one was created by copying the other at some point in the past).

Cloning, pushing, and pulling can be done between two local repos too, although it is more common for them to involve a remote repo.

A repo can work with any number of other repositories as long as they have a shared history e.g., `repo1` can pull from (or push to) `repo2` and `repo3` if they have a shared history between them.

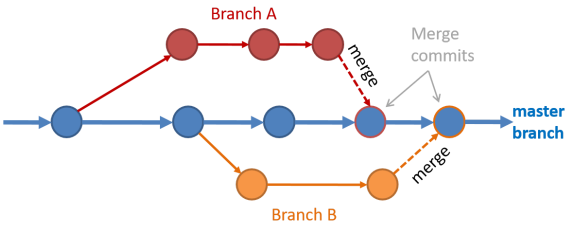
A *`fork`* is a remote copy of a remote repo. As you know, cloning creates a local copy of a repo. In contrast, forking creates a remote copy of a Git repo hosted on GitHub. This is particularly useful if you want to play around with a GitHub repo but you don't have write permissions to it; you can simply fork the repo and do whatever you want with the fork as you are the owner of the fork.

A *`pull request`* (PR for short) is a mechanism for contributing code to a remote repo, i.e., "I'm *requesting* you to *pull* my proposed changes to your repo". For this to work, the two repos must have a shared history. The most common case is sending PRs from a fork to its upstream 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 results in a new commit that represents the changes done in the branch being merged.



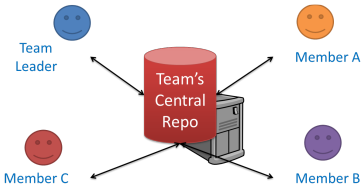
Branching and merging

Merge conflicts **happen when you try to merge two branches that had changed the same part of the code** and the RCS cannot decide which changes to keep. In those cases, you have to 'resolve' the conflicts manually.

DRCS vs CRCS ★★★☆

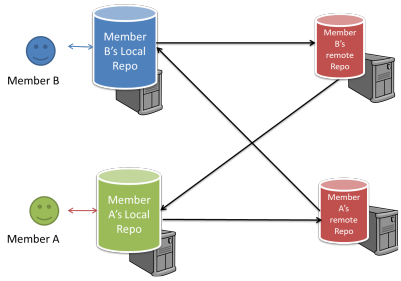
RCS can be done in two ways: the *centralized* way and the *distributed* way.

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.



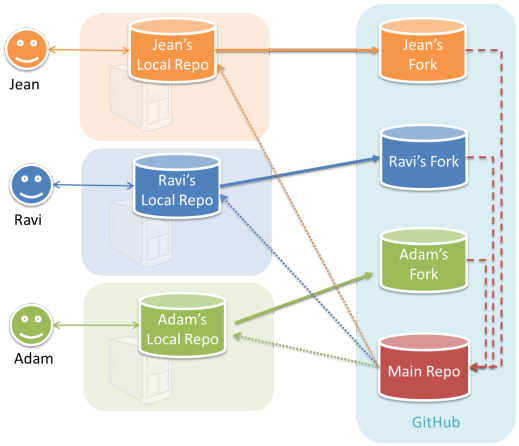
The centralized RCS approach without any local repos (e.g., CVS, SVN)

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 and 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.
   Common mistake: Doing the proposed changes in the `master` branch -- if Jean does that, she will not be able to have more than one PR open at any time because any changes to the `master` branch will be reflected in all open PRs.
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.
   Possible mistake: Creating another 'reverse' PR from the team repo to the team member's fork to sync the member's fork with the merged code. PRs are meant to go from downstream repos to upstream repos, not in the other direction.

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 game development project.

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 significant progress. You 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.

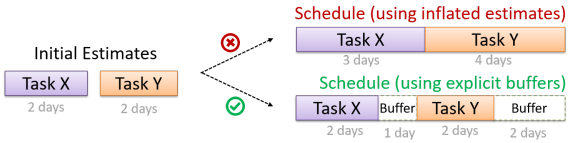
In some projects, it is not practical to have a very detailed plan for the whole project due to the uncertainty and unavailability of required information. In such cases, you can use a high-level plan for the whole project and a detailed plan for the next few milestones.

📦 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 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 are 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 feedback to improve future effort estimates.

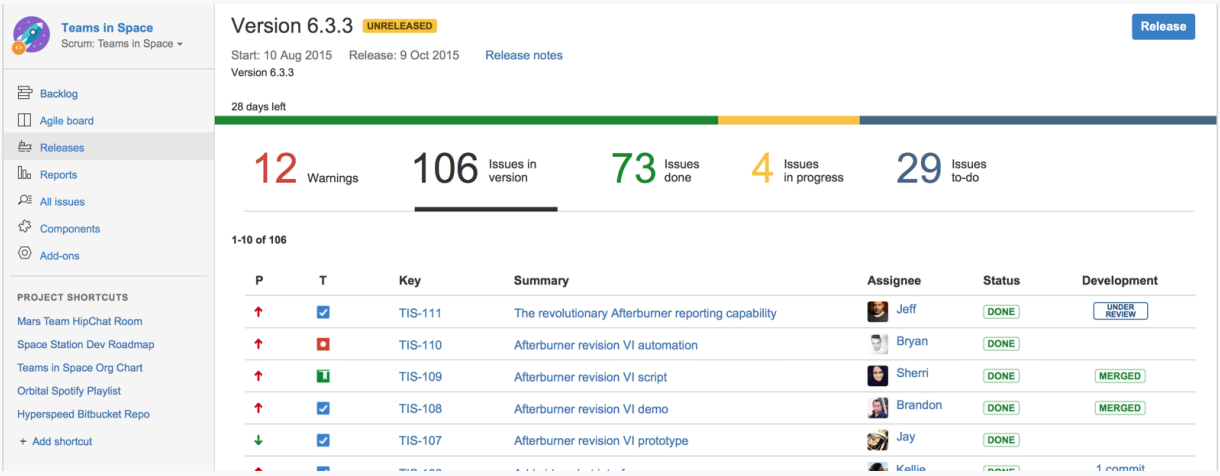


Issue Trackers ★★☆☆

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 keep track of tasks using simple tools such as online spreadsheets or general-purpose/light-weight task 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.

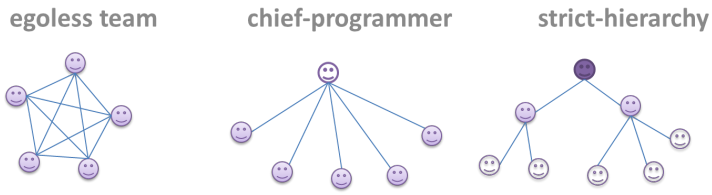
📦 A screenshot from the Jira Issue tracker software (Jira is part of the BitBucket project management tool suite):



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 experts, network technology experts, etc. This allows individual group members to concentrate solely on the areas in which they have sound knowledge and expertise.

The success of such a team structure relies heavily on the chief programmer. Not only must he/she be a superb technical hand, he/she also needs good managerial skills. Under a suitably qualified leader, such a team structure is known to produce successful work.

Strict hierarchy team

At 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 a bureaucratic government. Each team member only works on his/her 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

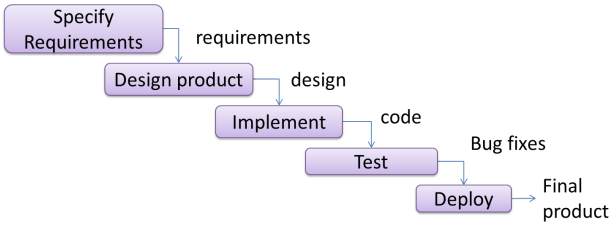
Introduction

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).



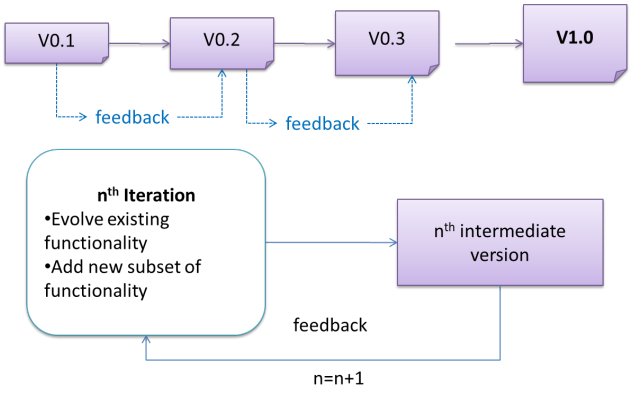
When one stage of the process is completed, it should produce some artifacts to be used in the next stage. For example, upon completion of the requirements stage, a comprehensive list of requirements is produced that will see no further modifications. A strict application of the sequential model would require each stage to be completed before starting the next.

This could be a useful model when the problem statement 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 relative ease.

The major problem with this model is that the 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 requirements 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 new 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 e.g., add a new feature fully, or enhance an existing feature.

- **depth-first**: an iteration focuses on fleshing out only some components e.g., update the backend to support a new feature that will be added in a future iteration.

Most projects use a mixture of breadth-first and depth-first iterations i.e., an iteration can contain some breadth-first work as well as some depth-first work.

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).

> You are uncovering better ways of developing software by doing it and helping others do it.
>
> Through this work you 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, you 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.
- There is a 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.

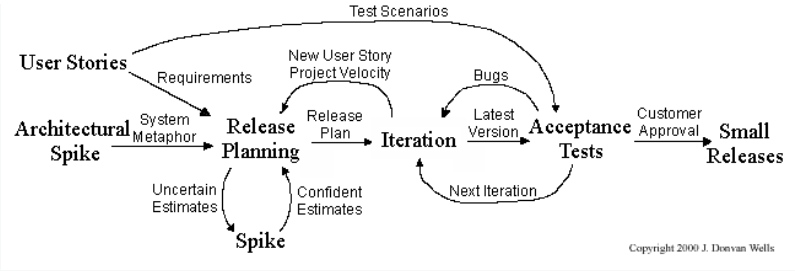
There are a number of agile processes in the development world today. *eXtreme Programming (XP)* and *Scrum* are two of the well-known ones.

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.

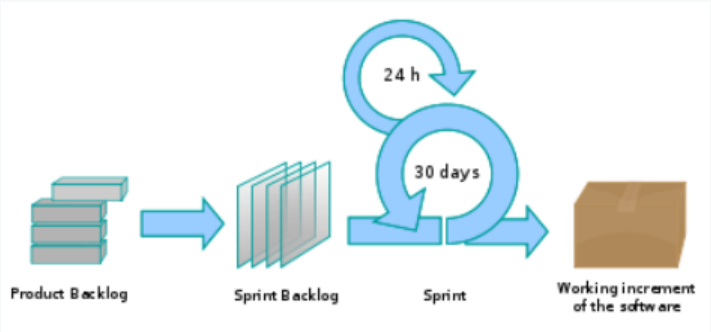
A Scrum project is divided into iterations called Sprints. A sprint is the basic unit of development in Scrum. Sprints tend to last between one week and one month, and are a timeboxed (i.e. restricted to a specific duration) effort of a constant length.

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

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 the `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 at 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.

SECTION: TOOLS

UML

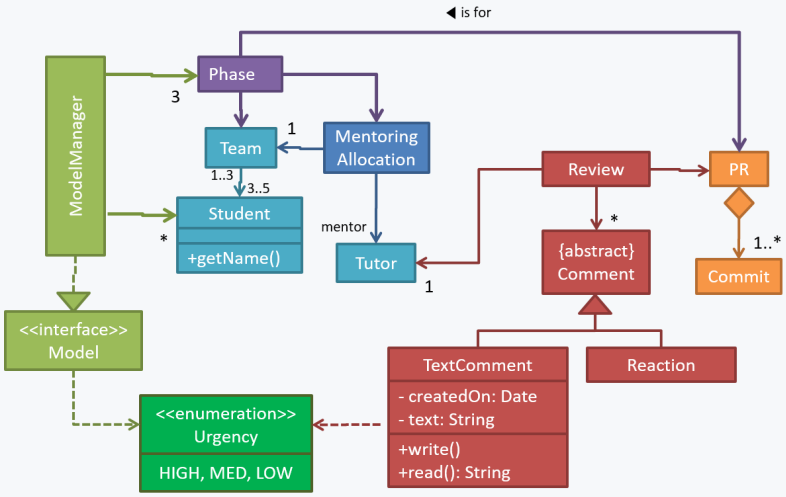
Class diagrams

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 are an indispensable tool for an OO programmer.

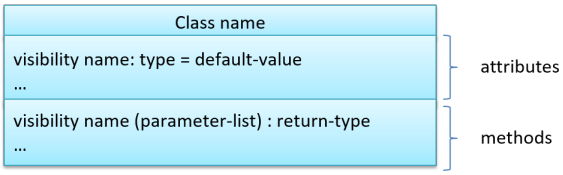
An example class diagram:



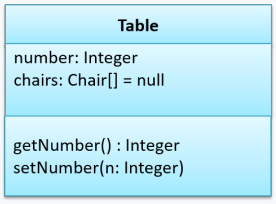
Classes

What ★☆☆☆

The basic UML notations used to represent a *class*:

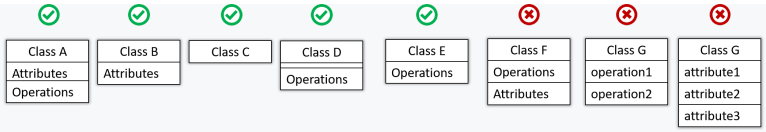


A `Table` class shown in UML notation:



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.

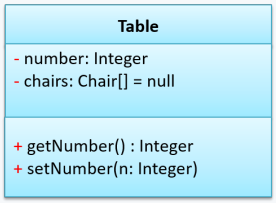


The *visibility* of attributes and operations is used to indicate the level of access allowed for each attribute or operation. The types of visibility and their exact meanings depend on the programming language used. Here are some common visibilities and how they are indicated in a class diagram:

- `+` : public
- `-` : private
- `#` : protected
- `~` : package private

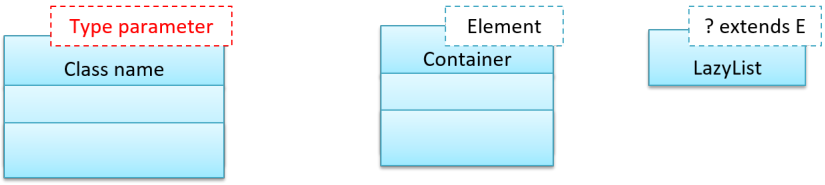
▶ How visibilities map to programming language features

`Table` class with visibilities shown:



▶ The equivalent code

Generic classes can be shown as given below. The notation format is shown on the left, followed by two examples.



Associations

What ★☆☆☆

You should 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 ★★☆☆

You should use arrow heads to indicate the navigability of an association.

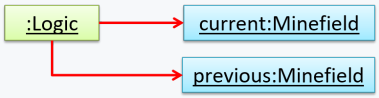
`Logic` is aware of `Minefield`, but `Minefield` is not aware of `Logic`.

```java
class Logic {
    Minefield minefield;
}

class Minefield {
    ...
}
```

Here is an example of a bidirectional navigability; each class is aware of the other.

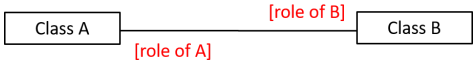
Navigability can be shown in class diagrams as well as object diagrams.

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.**

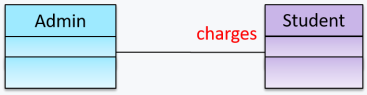


This association represents a marriage between a `Man` object and a `Woman` object. The respective roles played by objects of these two classes are `husband` and `wife`.

Note how the variable names match closely with the association roles.

```java
class Man {
    Woman wife;
}

class Woman {
    Man husband;
}
```

The role of `Student` objects in this association is `charges` (i.e. Admin is in charge of students)

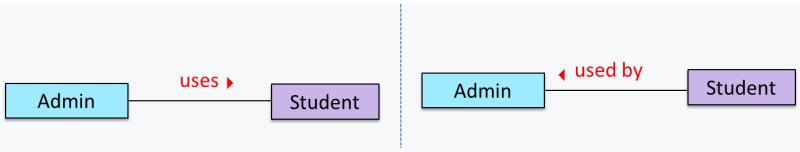



```java
class Admin {
    List<Student> charges;
}
```

Labels ★★☆☆

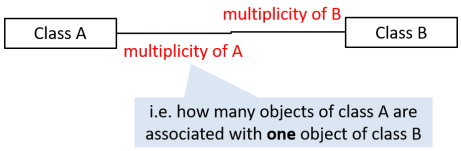
***Association labels* describe the meaning of the association.** The arrow head indicates the direction in which the label is to be read.

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.

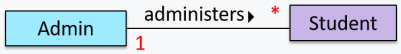
Multiplicity ★★★☆



Commonly used multiplicities:

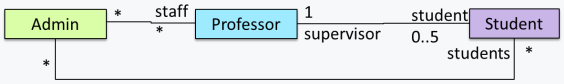
- `0..1` : *optional*, can be linked to 0 or 1 objects.
- `1` : *compulsory*, must be linked to one object at all times.
- `*` : can be linked to 0 or more objects.
- `n..m` : the number of linked objects must be within `n` to `m` inclusive.

In the diagram below, an `Admin` object administers (is 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,

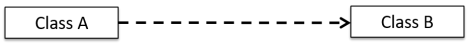
- Each student must be supervised by exactly one professor. i.e. There cannot be a student who doesn't have a supervisor or has multiple supervisors.
- A professor cannot supervise more than 5 students but can have no students to supervise.
- An admin can handle any number of professors and any number of students, including none.
- A professor/student can be handled by any number of admins, including none.



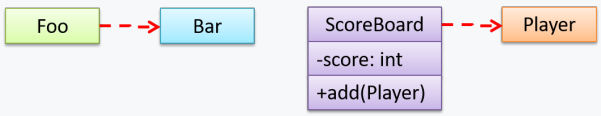
Dependencies

What ★★★☆

UML uses a dashed arrow to show dependencies.



Two examples of dependencies:



Dependencies vs associations:

- An association is a relationship resulting from one object keeping a reference to another object (i.e., storing an object in an instance variable). While such a relationship forms a *dependency*, we need not show that as a dependency arrow in the class diagram if the association is already indicated in the diagram. That is, showing a dependency arrow does not add any value to the diagram.
  Similarly, an inheritance results in a dependency from the child class to the parent class but we don't show it as a dependency arrow either, for the same reason as above.

- **Use a dependency arrow to indicate a dependency only if that dependency is not already captured by the diagram in another way** (for instance, as an association or an inheritance) e.g., class `Foo` accessing a constant in `Bar` but there is no association/inheritance from `Foo` to `Bar`.

Associations as attributes

What ★★★☆

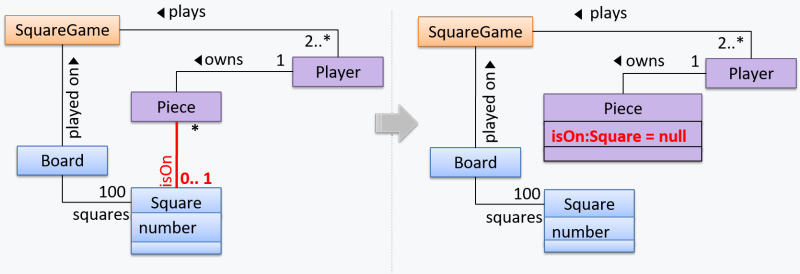
An association can be shown as an attribute instead of a line.

Association multiplicities and the default value 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`.



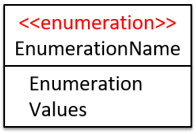
The association that a `Board` has 100 `Square`s can be shown in either of these two ways:

Show each association as **either an attribute or a line but not both**. A line is preferred as it is easier to spot.

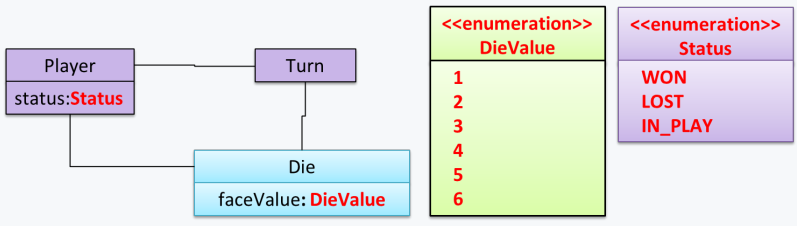
Enumerations

What ★★★☆

Notation:



In the class diagram below, there are two enumerations in use:

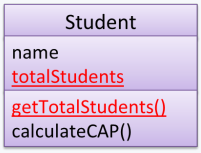


Class-level members

What ★★★☆

In UML class diagrams, **underlines denote class-level attributes and variables.**

In the class diagram below, the `totalStudents` attribute and the `getTotalStudents` method are class-level.

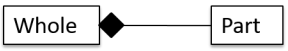


Composition

What ★★☆☆

UML uses a solid diamond symbol to denote composition.

Notation:



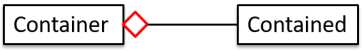
A `Book` consists of `Chapter` objects. When the `Book` object is destroyed, its `Chapter` objects are destroyed too.

Aggregation

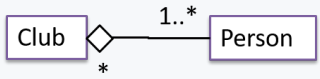
What ★★★☆

UML uses a hollow diamond to indicate an aggregation.

Notation:



Example:



Aggregation vs Composition

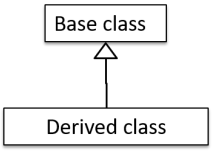
The distinction between composition (◆) and aggregation (◇) is rather blurred. Martin Fowler's famous book *UML Distilled* advocates omitting the aggregation symbol altogether because using it adds more confusion than clarity.

Class inheritance

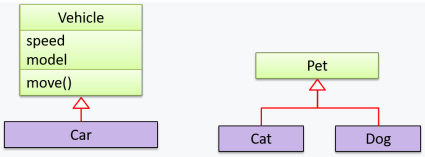
What ★★☆☆

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.

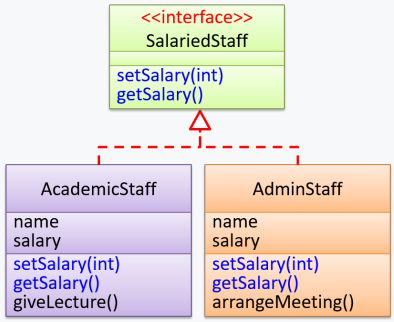


Interfaces

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.

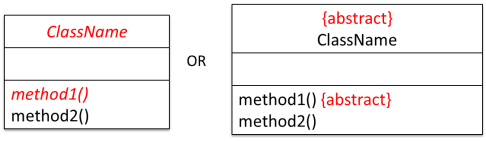
The `AcademicStaff` and the `AdminStaff` classes *implement* the `SalariedStaff` interface.



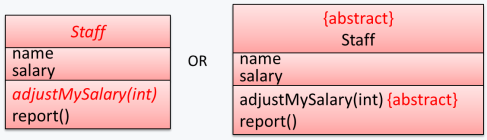
Abstract classes

What ★★★☆

You can use *italics* or `{abstract}` (preferred) keyword to denote abstract classes/methods.



Example:



Sequence diagrams

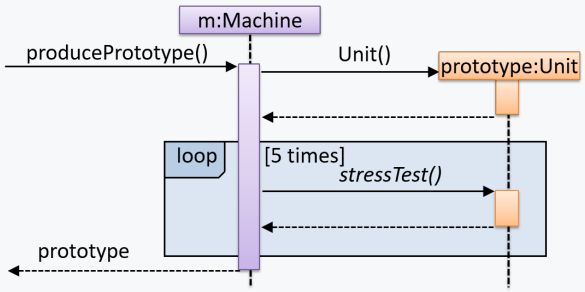
Introduction ★☆☆☆

A UML sequence diagram *captures the interactions between multiple objects for a given scenario.*

Consider the code below.

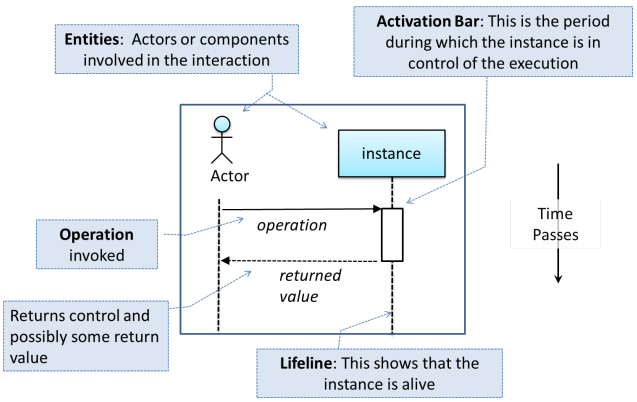
```java
class Machine {

    Unit produceProtype() {
        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 `produceProtype()` on a `Machine` object.

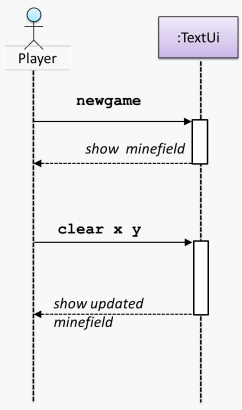


Basic ★☆☆☆

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.

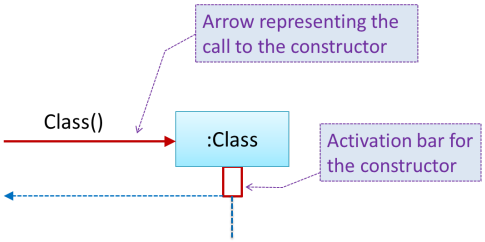
Note that unlike in object diagrams, the **class/object name is not underlined in sequence diagrams**.

❌ **[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 has 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.

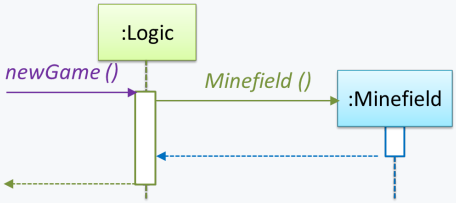
Object Creation ★★☆☆

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.

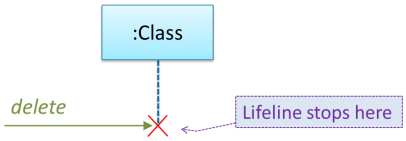


Object Deletion ★★★☆

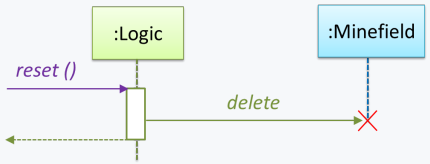
UML uses an `X` at the end of the lifeline of an object to show its deletion.

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:

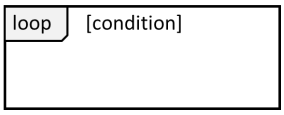


Note how the below diagram shows the deletion of the `Minefield` object.

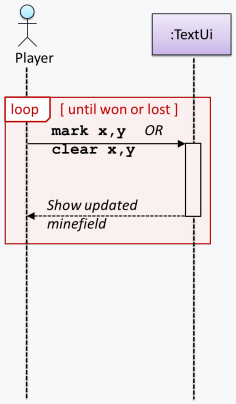


Loops ★★☆☆

Notation:



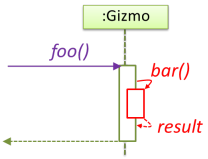
The `Player` calls the `mark x,y` command or `clear x y` command repeatedly until the game is won or lost.



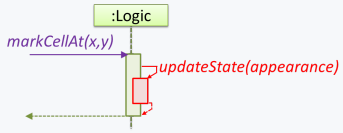
Self Invocation ★★★☆

UML can show a method of an object calling another of its own methods.

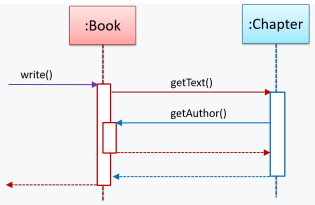
Notation:



The `markCellAt(...)` method of a `Logic` object is calling its own `updateState(...)` method.



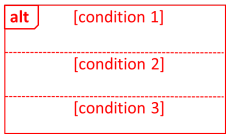
In this variation, the `Book#write()` method is calling the `Chapter#getText()` method which in turn does a *call back* by calling the `getAuthor()` method of the calling object.



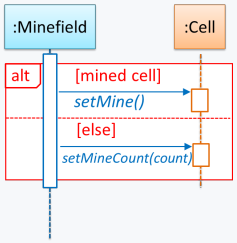
Alternative Paths ★★★☆

UML uses `alt` frames to indicate alternative paths.

Notation:



`Minefield` calls the `Cell#setMine` method if the cell is supposed to be a mined cell, and calls the `Cell:setMineCount(...)` method otherwise.

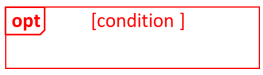


No more than one alternative partitions be executed in an `alt` frame. That is, it is acceptable for none of the alternative partitions to be executed but it is not acceptable for multiple partitions to be executed.

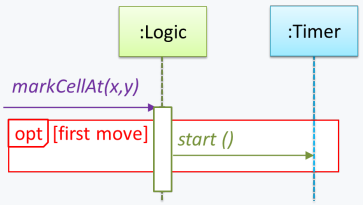
Optional Paths ★★★☆

UML uses `opt` frames to indicate optional paths.

Notation:



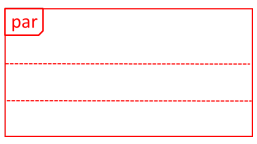
`Logic#markCellAt(...)` calls `Timer#start()` only if it is the first move of the player.



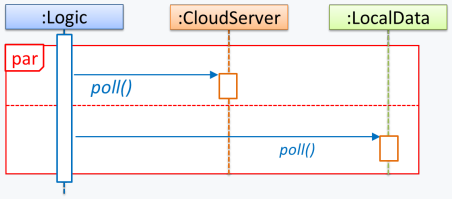
Parallel Paths ★★★☆

UML uses `par` frames to indicate parallel paths.

Notation:



`Logic` is calling methods `CloudServer#poll()` and `LocalServer#poll()` in parallel.

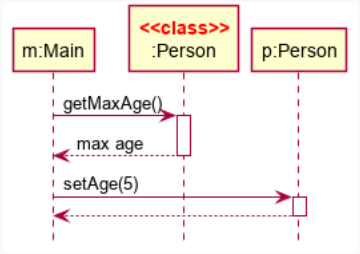


If you show parallel paths in a sequence diagram, the corresponding Java implementation is likely to be *multi-threaded* because a normal Java program cannot do multiple things at the same time.

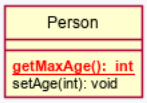
Calls to Static Methods ★★★☆

Method calls to `static` (i.e., class-level) methods are received by the class itself, not an instance of that class. You can use `<<class>>` to show that a participant is the class itself.

In this example, `m` calls the static method `Person.getMaxAge()` and also the `setAge()` method of a `Person` object `p`.



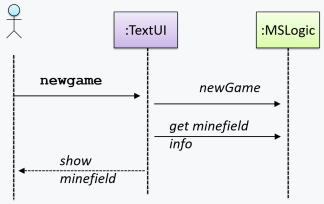
Here is the `Person` class, for reference:



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

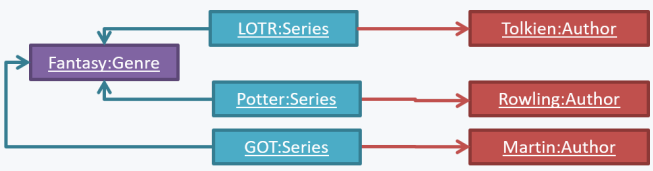


Object diagrams

Introduction ★☆☆☆

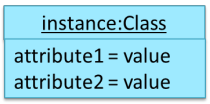
An object diagram shows an object structure at a given point of time.

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.

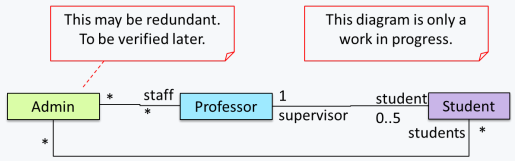
An example object diagram showing two associations:

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

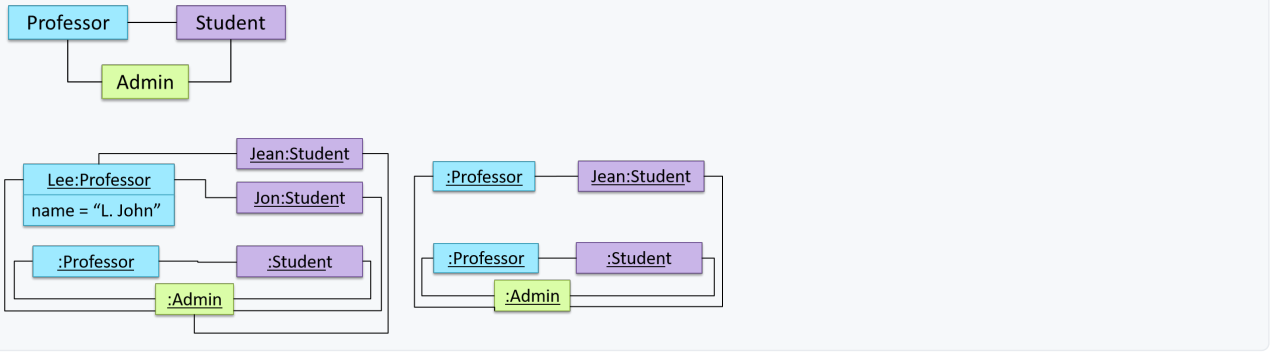
Object vs Class Diagrams ★★☆☆

Compared to the notation for class diagrams, object diagrams differ in the following ways:

- Show 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.


Professor
Student
Admin
Lee:Professor
name = “L. John”
Jean:Student
Jon:Student
:Professor
:Student
:Admin
:Professor
Jean:Student
:Professor
:Student
:Admin

Git and GitHub

`init`: Getting started ★☆☆☆

Let's take your first few steps in your Git (with GitHub) journey.

1. The first step is to 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.

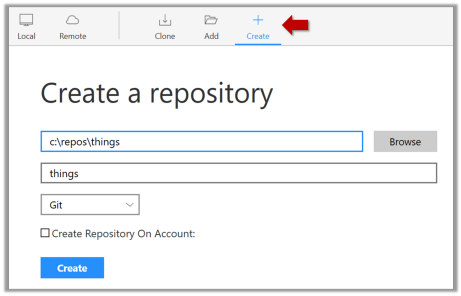
2. Next, initialize a repository. Let us assume you want to version control content in a specific directory. In that case, you need to initialize a Git repository in that directory. Here are the steps:

Create a directory for the repo (e.g., a directory named `things`).

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.

Windows: you might have to configure Windows Explorer to show hidden files.

`commit`: Saving changes to history ★☆☆☆

After initializing a repository, Git can help you with revision controlling files inside the *working directory*. However, it is not automatic. It is up to you to tell Git which of your changes (aka *revisions*) should be *committed* to its memory for later use. Saving changes into Git's memory in that way is often called *committing* and a change saved to the revision history is called a *commit*.

> **Working directory**: the root directory revision-controlled by Git (e.g., the directory in which the repo was initialized).

> **Commit** (noun): a change (aka a *revision*) saved in the Git revision history.
> (verb): the act of creating a commit i.e., saving a change in the working directory into the Git revision history.

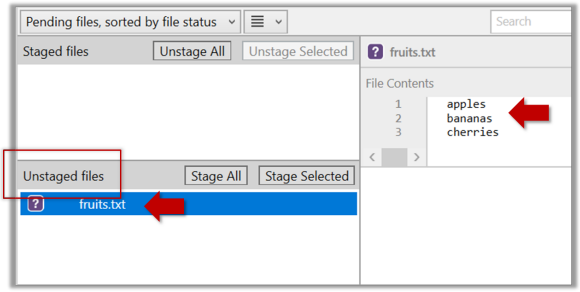
Here are the steps you can follow to learn how to work with Git commits:

1. Do some changes to the content inside the *working directory* e.g., create a file named `fruits.txt` in the `things` directory and add some dummy text to it.

2. Observe how the file is detected by Git.

SourceTree | CLI

The file is shown as 'unstaged'.

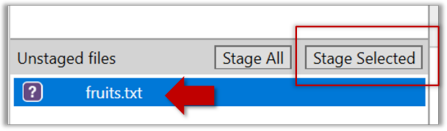


3. Stage the changes to commit: Although Git has detected the file in the working directory, it will not do anything with the file unless you tell it to. Suppose you want to commit the current changes to the file. First, you should *stage* the file.

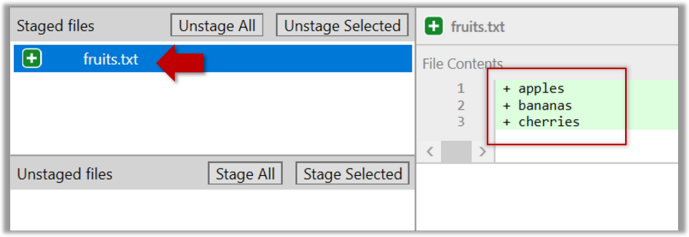
> **Stage** (verb): Instructing Git to prepare a file for committing.

SourceTree | CLI

Select the `fruits.txt` and click on the `Stage Selected` button.



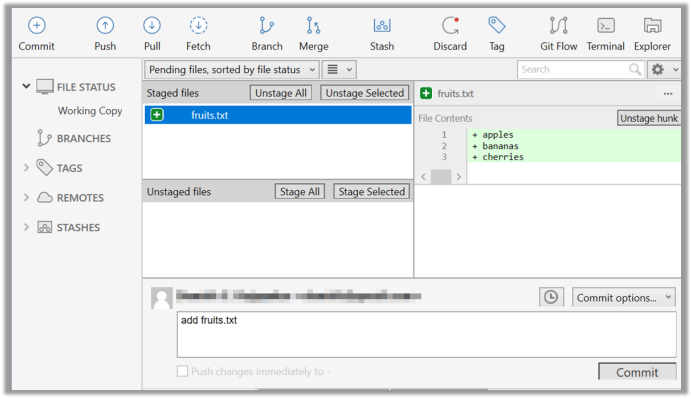
`fruits.txt` should appear in the `Staged files` panel now.



4. Commit the staged version of `fruits.txt`.

SourceTree | CLI

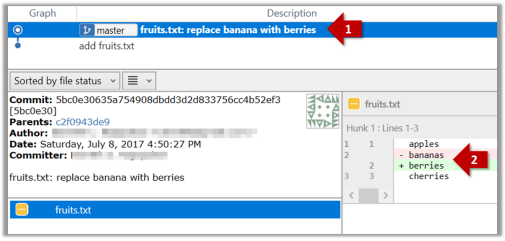
Click the `Commit` button, enter a commit message e.g. `add fruits.txt` into the text box, and click `Commit`.



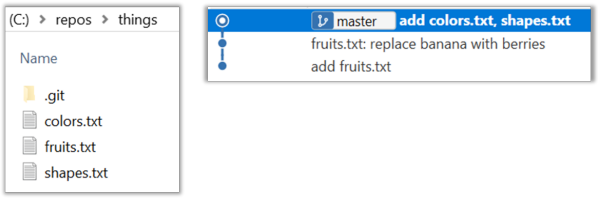
Note the existence of something called the `master` branch. Git allows you to have multiple branches (i.e. it is a way to evolve the content in parallel) and Git auto-creates a branch named `master` on which the commits go on by default.

5. Do a few more commits.

1. Make 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.



2. 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.



6. See the revision graph: Note how commits form a path-like structure aka the *revision tree/graph*. In the revision graph, each commit is shown as linked to its 'parent' commit (i.e., the commit before it).

SourceTree | CLI

To see the revision graph, click on the `History` item on the menu on the right edge of SourceTree.

Omitting files from revision control ★★☆☆

Often, there are files inside the Git working folder that you don't want to revision-control e.g., temporary log files. Follow the steps below to learn how to configure Git to ignore such files.

1. Add a file into your repo's working folder that you supposedly don't want to revision-control e.g., a file named `temp.txt`. Observe how Git has detected the new file.

2. Tell Git to ignore that file:

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.

```
1 temp.txt
```

The `.gitignore` file

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 changes over time), simply commit it as you would commit any other file.
- To ignore it, follow the same steps you followed above when you set Git to ignore the `temp.txt` file.
- It supports file patterns e.g., adding `temp/*.tmp` to the `.gitignore` file prevents Git from tracking any `.tmp` files in the `temp` directory.

More information about the `.gitignore` file: git-scm.com/docs/gitignore

`tag`: Naming commits ★★★☆

Each Git commit is uniquely identified by a hash e.g., `d670460b4b4aece5915caf5c68d12f560a9fe3e4`. As you can imagine, using such an identifier is not very convenient for our day-to-day use. As a solution, Git allows adding a more human-readable *tag* to a commit e.g., `v1.0-beta`.

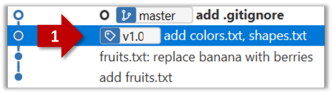
Here's how you can tag a commit in a local repo (e.g. in the `samplerepo-things` repo):

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.



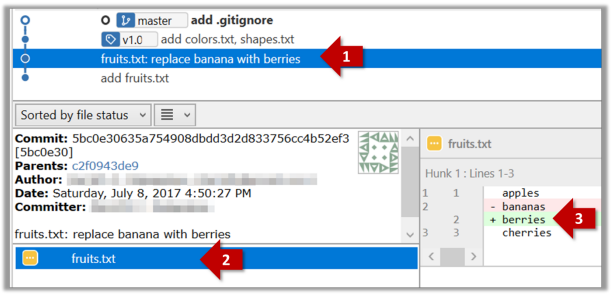
After adding a tag to a commit, you can use the tag to refer to that commit, as an alternative to using the hash.

`diff`: Comparing revisions ★★☆☆

Git can show you what changed in each commit.

SourceTree | CLI

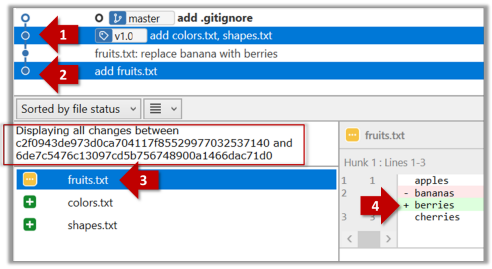
To see which files changed in a commit, click on the commit. To see what changed in a specific file in that commit, click on the file name.



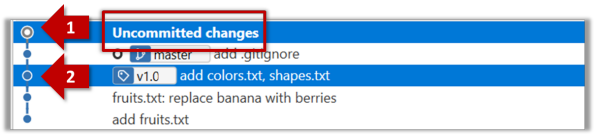
Git can also show you the difference between two points in the history of the repo.

SourceTree | CLI

Select the two points you want to compare using `Ctrl` + `Click`. The differences between the two selected versions will show up in the bottom half of SourceTree, as shown in the screenshot below.



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.



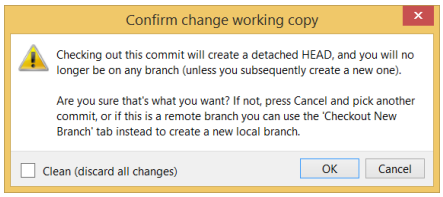
`checkout`: Retrieving a specific revision ★★☆☆

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.

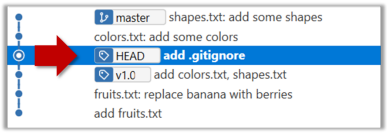
SourceTree | CLI

Double-click the commit you want to load to the working directory, or right-click on that commit and choose `Checkout...`.

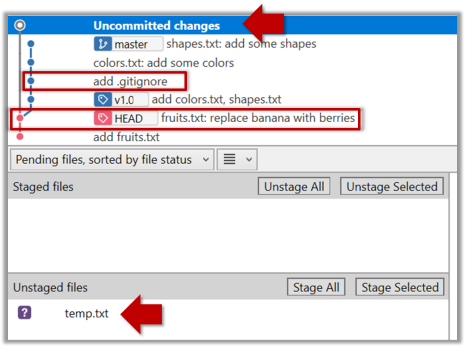
Click `OK` to the warning about 'detached HEAD' (similar to below).



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 comes before the commit in which you added the `.gitignore` file, Git will now show ignored files 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.

`stash`: Shelving changes temporarily ★★★☆

You can use Git's *stash* feature to temporarily shelve (or stash) changes you've made to your working copy so that you can work on something else, and then come back and re-apply the stashed changes later on. -- adapted from Atlassian

Source Tree | CLI

Follow this article from SourceTree creators. Note that the GUI shown in the article is slightly outdated but you should be able to map it to the current GUI.

`clone`: Copying a repo ★☆☆☆

Given below is an example scenario you can try yourself to learn Git cloning.

Suppose you want to clone the sample repo samplerepo-things to your computer.

> ! Note that the URL of the GitHub project is different from 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`, `fetch`: Downloading data from other repos ★☆☆☆

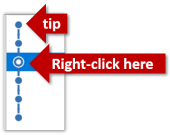
Here's a scenario you can try in order to learn how to pull commits from another repo to yours.

1. Clone a repo (e.g., the repo used in [Git & GitHub → Clone]) to be used for this activity.

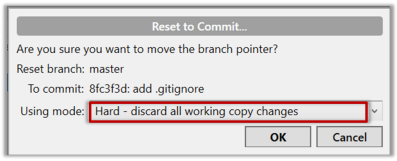
2. Delete the last few commits to simulate cloning the repo a few commits ago.

SourceTree | CLI

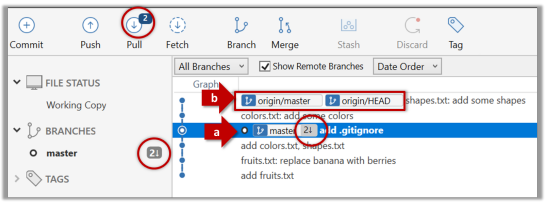
Right-click the target commit (i.e. the commit that is 2 commits behind the tip) and choose `Reset current branch to this commit`.



Choose the `Hard - ...` option and click `OK`.



This is what you will see.



Note the following (cross refer the screenshot above):

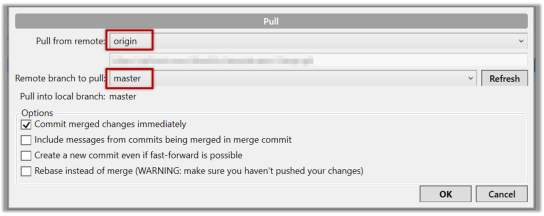
Arrow marked as `a`: The local repo is now at this commit, marked by the `master` label.
Arrow marked as `b`: The `origin/master` label shows what is the latest commit in the `master` branch in the remote repo.

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.

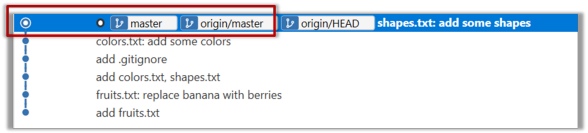
3. Pull from the other repo: To get those missing commits to your local repo (i.e. to sync your local repo with upstream repo) you can do a pull.

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.



You can also do a `fetch` instead of a `pull` in which case the new commits will be downloaded to your repo but the working directory will remain at the current commit. To move the current state to the latest commit that was downloaded, you need to do a `merge`. A `pull` is a shortcut that does both those steps in one go.

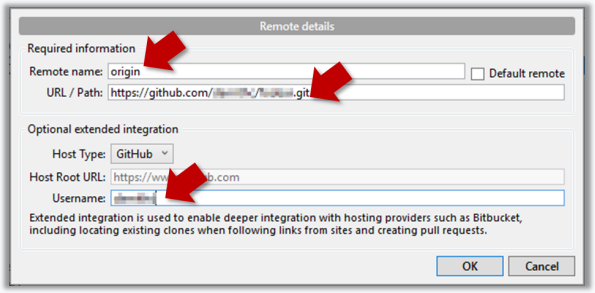
Working with multiple remotes

When you clone a repo, Git automatically adds a *remote* repo named `origin` to your repo configuration. As you know, you can pull commits from that repo. As you know, a Git repo can work with remote repos other than the one it was cloned from.

To communicate with another remote repo, you can first add it as a *remote* of your repo. Here is an example scenario you can follow to learn how to pull from another repo:

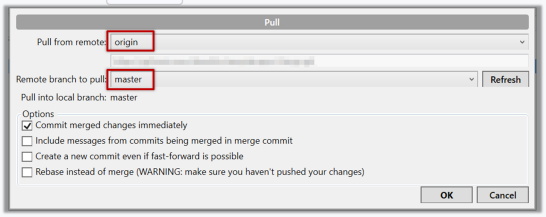
SourceTree | CLI

1. Open the local repo in SourceTree. Suggested: Use your local clone of the `samplerepo-things` repo.
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 e.g., `upstream1`
   - `URL/path`: the URL of your repo (ending in `.git`) that. Suggested: `https://github.com/se-edu/samplerepo-things-2.git` (`samplerepo-things-2` is another repo that has a shared history with `samplerepo-things`)
   - `Username`: your GitHub username

4. Now, you can pull from the added repo as you did before but choose the remote name of the repo you want to pull from (instead of `origin`):



   If the `Remote branch to pull` dropdown is empty, click the `Refresh` button on its right.

5. If the pull from the `samplerepo-things-2` was successful, you should have received one more commit into your local repo.

Fork: Creating a remote copy ★☆☆☆

Given below is a scenario you can try in order to learn how to fork a repo:.

0. Create a GitHub account if you don't have one yet.

1. Go to the GitHub repo you want to fork e.g., samplerepo-things

2. Click on the Fork **button** on the top-right corner. In the next step, choose to fork to your own account or to another GitHub organization that you are an admin of.

ℹ GitHub does not allow you to fork the same repo more than once to the same destination. If you want to re-fork, you need to delete the previous fork.

`push`: Uploading data to other repos ★☆☆☆

Given below is a scenario you can try in order to learn how to push commits to a remote repo hosted on GitHub:

1. Fork an existing GitHub repo (e.g., samplerepo-things) to your GitHub account.

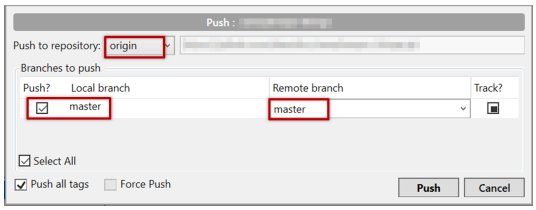
2. Clone the fork (not the original) to your computer.

3. Commit some changes in your local repo.

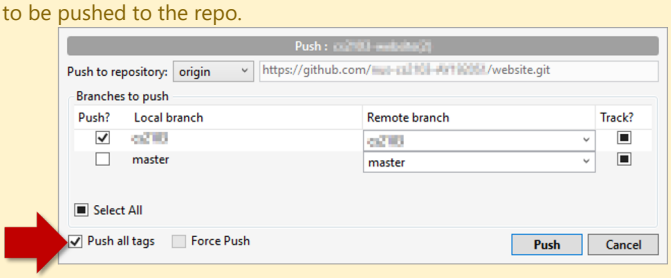
4. Push the new commits to your fork on GitHub

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.



! Tags are not included in a normal push. Remember to tick `Push all tags` when pushing to the remote repo if you want them to be pushed to the repo.

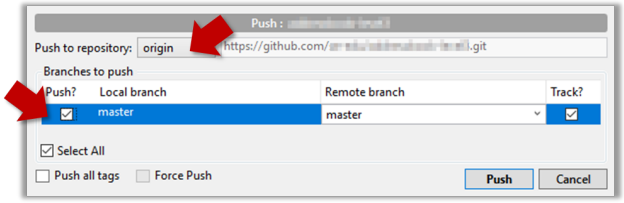


You can push to repos other than the one you cloned from, as long as the target repo and your repo have a shared history.

1. Add the GitHub repo URL as a remote, if you haven't done so already.
2. Push to the target repo.

SourceTree | CLI

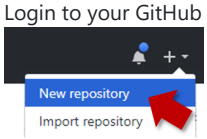
Push your repo to the new remote the usual way, but select the name of target remote instead of `origin` and remember to select the `Track` checkbox.



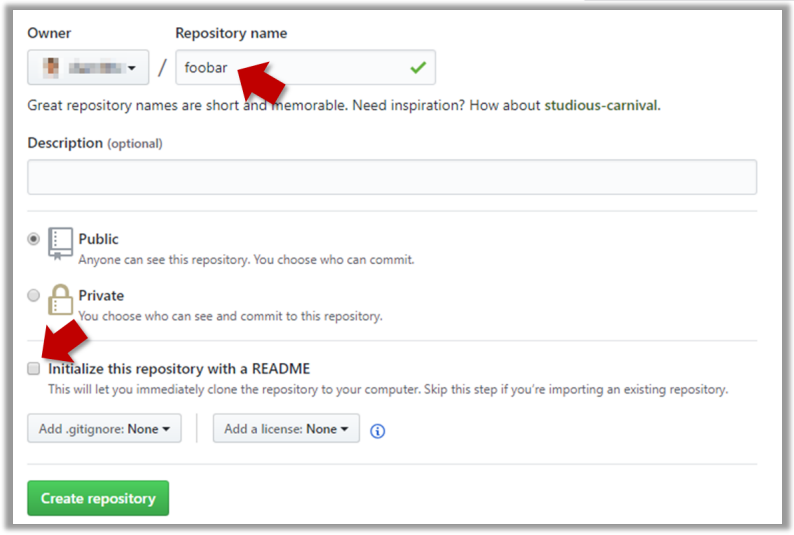
You can even push an entire local repository to GitHub, to form an entirely new remote repository. For example, you created a local repo and worked with it for a while but now you want to upload it onto GitHub (as a backup or to share it with others). The steps are given below.

1. Create an empty remote repo on GitHub.

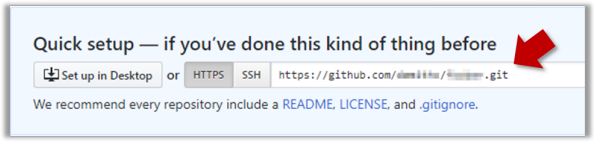
1. Login to your GitHub account and choose to create a new Repo.



2. In the next screen, provide a name for your repo but keep the `Initialize this repo ...` tick box unchecked.



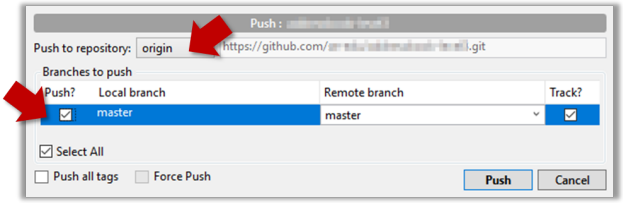
3. Note the URL of the repo. It will be of the form `https://github.com/{your_user_name}/{repo_name}.git`.
   e.g., `https://github.com/johndoe/foobar.git` (note the `.git` at the end)



2. Add the GitHub repo URL as a remote of the local repo. You can give it the name `origin` (or any other name).

3. Push the repo to the remote.

SourceTree | CLI

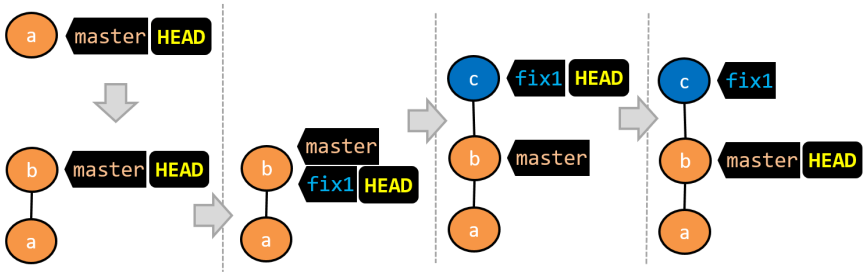


`branch`: Doing multiple parallel changes ★★☆☆

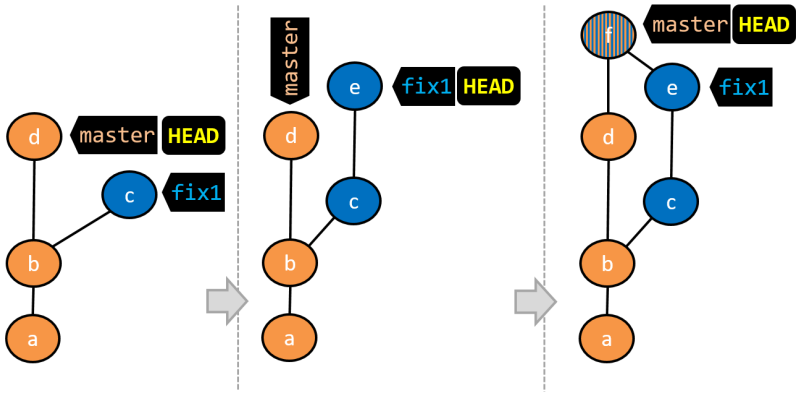
Git supports branching, which allows you to do multiple parallel changes to the content of a repository.

A Git branch is simply a *named label* pointing to a commit. The `HEAD` label indicates which branch you are on. Git creates a branch named `master` by default. When you add a commit, it goes into the branch you are currently on, and the branch label (together with the `HEAD` label) moves to the new commit.

Given below is an illustration of how branch labels move as branches evolve.



1. There is only one branch (i.e., `master`) and there is only one commit on it.
2. A new commit has been added. The `master` and the `HEAD` labels have moved to the new commit.
3. A new branch `fix1` has been added. The repo has switched to the new branch too (hence, the `HEAD` label is attached to the `fix1` branch).
4. A new commit (`c`) has been added. The current branch label `fix1` moves to the new commit, together with the `HEAD` label.
5. The repo has switched back to the `master` branch.

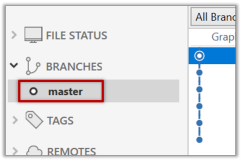


6. A new commit (`d`) has been added. The `master` label has moved to that commit.
7. The repo has switched back to the `fix1` branch and added a new commit (`e`) to it.
8. The repo has switched to the `master` branch and the `fix1` branch has been merged into the `master` branch, creating a *merge commit* `f`. The repo is currently on the `master` branch.

Follow the steps below to learn how to work with branches. You can use any repo you have on your computer (e.g. a clone of the samplerepo-things) for this.

0. Observe that you are normally in the branch called `master`.

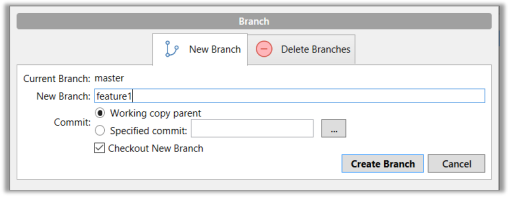
SourceTree | CLI



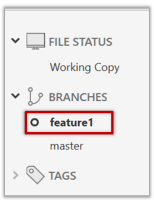
1. Start a branch named `feature1` and switch to the new branch.

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.

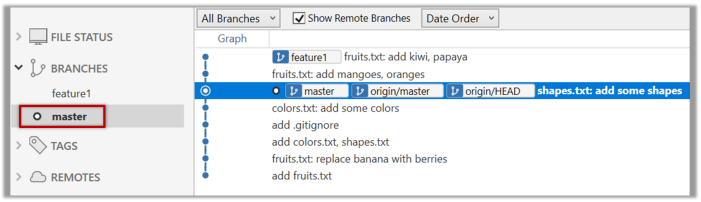


2. Create some commits in the new branch. Just commit as per normal. Commits you add while on a certain branch will become part of that branch.
Note how the `master` label and the `HEAD` label moves to the new commit (The `HEAD` label of the local repo is represented as ● in SourceTree).

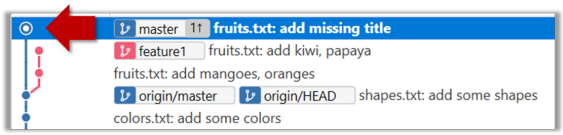
3. Switch to the `master` branch. Note how the changes you did in the `feature1` branch are no longer in the working directory.

SourceTree | CLI

Double-click the `master` branch.

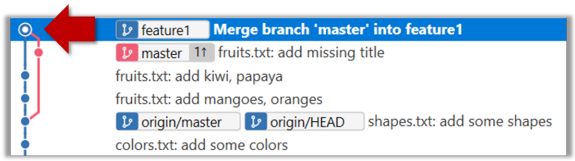


4. Add a commit to the master branch. Let's imagine it's a bug fix.
To keep things simple for the time being, this commit should not involve the same content that you changed in the `feature1` branch. To be on the safe side, this commit can change an entirely different file.



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 following. 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.

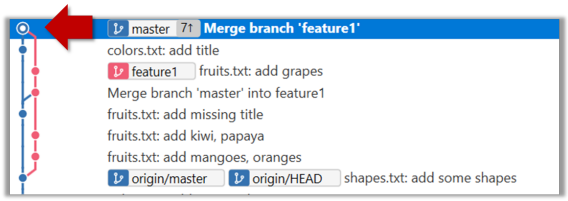
The objective of that merge was to *sync* the `feature1` branch with the `master` branch. Observe how the changes you did in the `master` branch (i.e. the imaginary bug fix) is now available even when you are in the `feature1` branch.

> ℹ Instead of merging `master` to `feature1`, an alternative is to *rebase* the `feature1` branch. However, rebasing is an advanced feature that requires modifying past commits. If you modify past commits that have been pushed to a remote repository, you'll have to *force-push* the modified commit to the remote repo in order to update the commits in it.

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

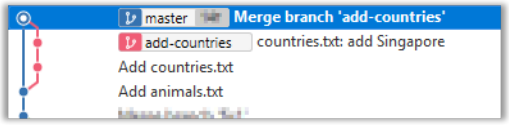
Right-click on the `feature1` branch and choose `Merge...`.

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:

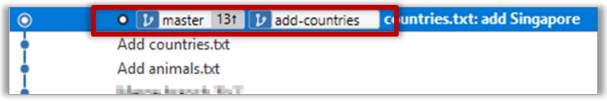
> ✖ **Avoid this common rookie mistake!**

> Always remember to switch back to the `master` branch before creating a new branch. If not, your new branch will be created on top of the current branch.

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 following,



... you are likely to see something like this instead:

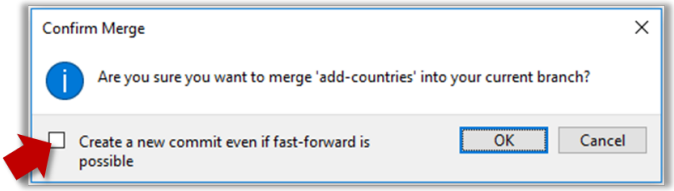


That is because **Git does a *fast forward* merge if possible**. Seeing that the `master` branch has not changed since you started the `add-countries` branch, Git has decided it is simpler to just put the commits of the `add-countries` branch in front of the `master` branch, without going into the trouble 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:

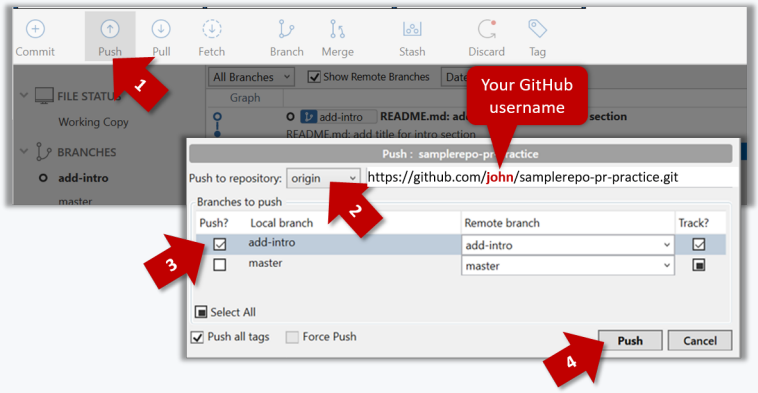


Pushing a branch to a remote repo

Here's how to push a branch to a remote repo:

SourceTree | CLI

Here's how to push a branch named `add-intro` to your own fork of a repo named `samplerepo-pr-practice`:



Dealing with merge conflicts ★★☆☆

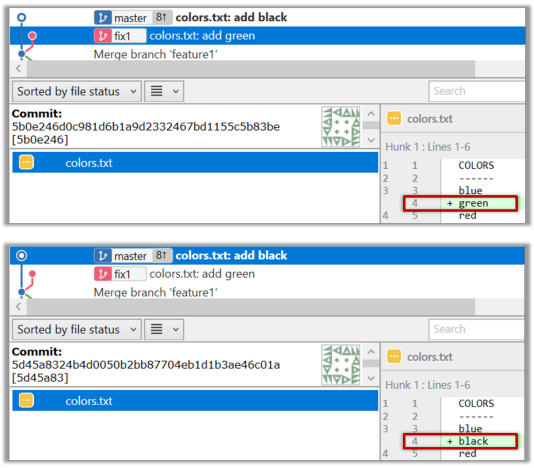
Merge conflicts happen when you try to combine two incompatible versions (e.g., merging a branch to another but each branch changed the same part of the code in a different way).

Here are the steps to simulate a merge conflict and use it to learn how to resolve merge conflicts.

0. Create an empty repo or clone an existing repo, to be used for this activity.

1. Start a branch named `fix1` in the 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:

```
1  COLORS
2  ------
3  blue
4  <<<<<< HEAD
5  black
6  =======
7  green
8  >>>>>> fix1
9  red
10 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 `=======`.

Highlighted below is the conflicting part that is coming from the `master` branch:

```
3  blue
4  <<<<<< HEAD
5  black
6  =======
7  green
8  >>>>>> fix1
9  red
```

This is the conflicting part that is coming from the `fix1` branch:

```
3  blue
4  <<<<<< HEAD
5  black
6  =======
7  green
8  >>>>>> fix1
9  red
```

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:

```
1  COLORS
2  ------
3  blue
4  black
5  green
6  red
7  white
```

6. Stage the changes, and commit.

Creating PRs ★☆☆☆

Suppose you want to propose some changes to a GitHub repo (e.g., samplerepo-pr-practice) as a pull request (PR). Here is a scenario you can try in order to learn how to create PRs:

1. Fork the repo onto your GitHub account.

2. Clone it onto your computer.

3. Commit your changes e.g., add a new file with some contents and commit it.

- **Option A - Commit changes to the `master` branch**
- **Option B - Commit to a new branch** e.g., create a branch named `add-intro` (remember to switch to the `master` branch before creating a new branch) and add your commit to it.

4. Push the branch you updated (i.e., `master` branch or the new branch) to your fork, as explained here.

5. Initiate the PR creation:

1. Go to your fork.
2. Click on the `Pull requests` tab followed by the New pull request **button**. This will bring you to the 'Comparing changes' page.
3. Set the appropriate target repo and the branch that should receive your PR, using the `base repository` and `base` dropdowns. e.g.,
   base repository: **se-edu/samplerepo-pr-practice** base: **master**

   > ℹ Normally, the default value shown in the dropdown is what you want but in case your fork has multiple upstream repos, the default may not be what you want.

4. Indicate which repo:branch contains your proposed code, using the `head repository` and `compare` dropdowns. e.g.,
   head repository: **myrepo/samplerepo-pr-practice** compare: **master**

6. Verify the proposed code: Verify that the diff view in the page shows the exact change you intend to propose. If it doesn't, update the branch as necessary.

7. Submit the PR:

1. Click the Create pull request button.
2. Fill in the PR name and description e.g.,
   Name: `Add an introduction to the README.md`
   Description:

   ```
   Add some paragraph to the README.md to explain ...
   Also add a heading ...
   ```

3. If you want to indicate that the PR you are about to create is 'still work in progress, not yet ready', click on the dropdown arrow in the Create pull request button and choose `Create draft pull request` option.
4. Click the Create pull request button to create the PR.
5. Go to the receiving repo to verify that your PR appears there in the `Pull requests` tab.

The next step of the PR life cycle is the PR *review*. The members of the repo that received your PR can now review your proposed changes.

- If they like the changes, they can *merge* the changes to their repo, which also closes the PR automatically.
- If they don't like it at all, they can simply close the PR too i.e., they reject your proposed change.
- In most cases, they will add comments to the PR to suggest further changes. When that happens, GitHub will notify you.

You can update the PR along the way too. Suppose PR reviewers suggested a certain improvement to your proposed code. To update your PR as per the suggestion, you can simply modify the code in your local repo, commit the updated code to the same `master` branch, and push to your fork as you did earlier. The PR will auto-update accordingly.

Sending PRs using the `master` branch is less common than sending PRs using separate branches. For example, suppose you wanted to propose two bug fixes that are not related to each other. In that case, it is more appropriate to send two separate PRs so that each fix can be reviewed, refined, and merged independently. But if you send PRs using the `master` branch only, both fixes (and any other change you do in the `master` branch) will appear in the PRs you create from it.

To create another PR while the current PR is still under review, create a new branch (remember to switch back to the `master` branch first), add your new proposed change in that branch, and create a new PR following the steps given above.

It is possible to create PRs within the same repo e.g., you can create a PR from branch `feature-x` to the `master` branch, within the same repo. Doing so will allow the code to be reviewed by other developers (using PR review mechanism) before it is merged.

Resources

- GitHub's own documentation on creating a PR

Reviewing PRs ★★☆☆

The *PR review* stage is a dialog between the PR author and members of the repo that received the PR, in order to refine and eventually merge the PR.

Given below are some steps you can follow when reviewing a PR.

1. Locate the PR:

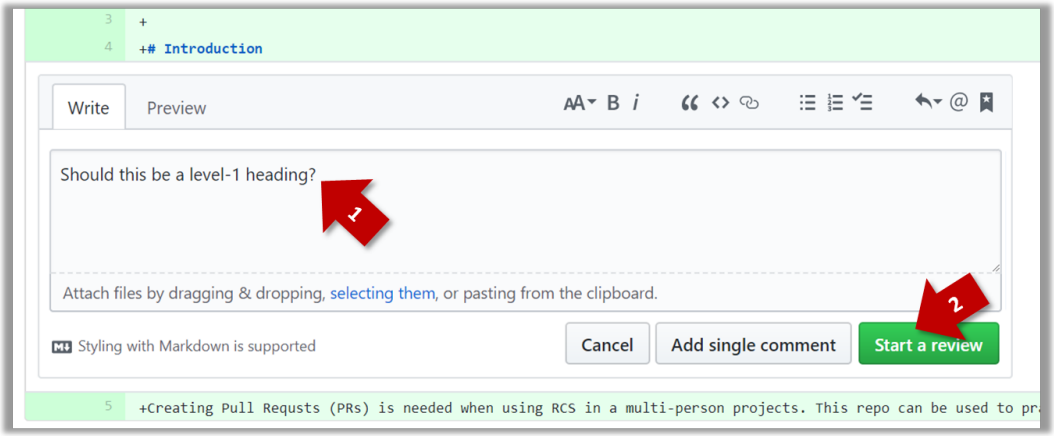
1. Go to the GitHub page of the repo.
2. Click on the `Pull requests` tab.
3. Click on the PR you want to review.

2. Read the PR description. It might contain information relevant to reviewing the PR.

3. Click on the `Files changed` tab to see the *diff* view.

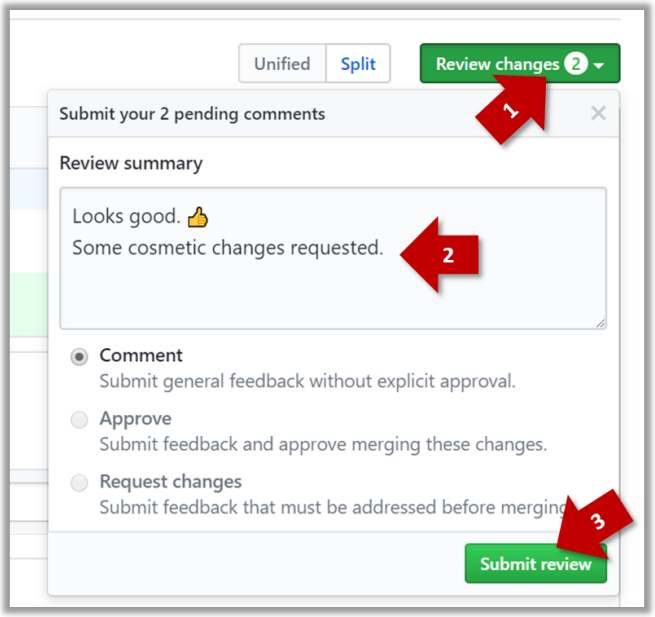
4. Add review comments:

1. 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.
   💡 To mark multiple lines, click-and-drag the ➕ icon.
2. Enter your comment.
   📎 This page @SE-EDU/guides has some best practices PR reviewers can follow.
3. After typing in the comment, click on the Start a review button (not the Add single comment button. This way, your comment is saved but not visible to others yet. It will be visible to others only when you have finished the entire review.



4. Repeat the above steps to add more comments.

5. Submit the review:



1. When there are no more comments to add, click on the Review changes button (on the top right of the diff page).
2. Type in an overall comment about the PR, if any. e.g.,

```
Overall, I found your code easy to read for the most part except a few places
where the nesting was too deep. I noted a few minor coding standard violations
too. Some of the classes are getting quite long. Consider splitting into smaller
classes if that makes sense.
```

   `LGTM` is often used in such overall comments, to indicate `Looks good to merge`.
   `nit` is another such term, used to indicate minor flaws e.g., `LGTM, almost. Just a few nits to fix.`.
3. Choose `Approve`, `Comment`, or `Request changes` option as appropriate and click on the Submit review button.

Merging PRs ★★☆☆

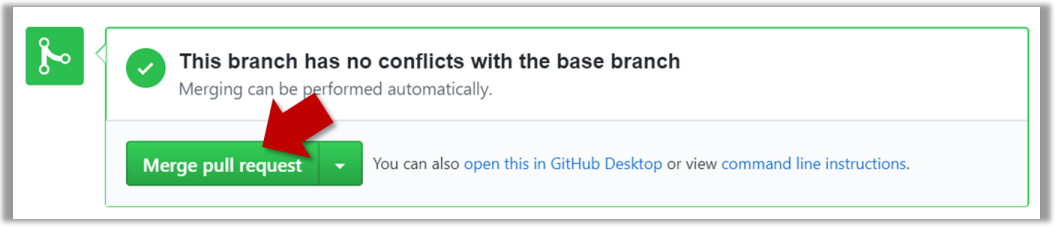
Let's look at the steps involved in merging a PR, assuming the PR has been reviewed, refined, and approved for merging already.

Preparation: If you would like to try merging a PR yourself, you can create a dummy PR in the following manner.

1. Fork any repo (e.g., samplerepo-pr-practice).
2. Clone in to your computer.
3. Create a new branch e.g., (`feature1`) and add some commits to it.
4. Push the new branch to the fork.
5. Create a PR from that branch to the `master` branch in your fork. Yes, it is possible to create a PR within the same repo.

1. Locate the PR to be merged in your repo's GitHub page.

2. Click on the `Conversation` tab and scroll to the bottom. You'll see a panel containing the PR status summary.



3. If the PR is not merge-able in the current state, the Merge pull request will not be green. Here are the possible reasons and remedies:

- **Problem: The PR code is out-of-date**, indicated by the message **This branch is out-of-date with the base branch**. That means the repo's `master` branch has been updated since the PR code was last updated.
  - If the PR author has allowed you to update the PR and you have sufficient permissions, GitHub will allow you to update the PR simply by clicking the Update branch on the right side of the 'out-of-date' error message. If that option is not available, post a message in the PR requesting the PR author to update the PR.

- **Problem: There are merge conflicts**, indicated by the message **This branch has conflicts that must be resolved**. That means the repo's `master` branch has been updated since the PR code was last updated, in a way that the PR code conflicts with the current `master` branch. Those conflicts must be resolved before the PR can be merged.
  - If the conflicts are simple, GitHub might allow you to resolve them using the Web interface.
  - If that option is not available, post a message in the PR requesting the PR author to update the PR.

3. Merge the PR by clicking 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.

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to Git and GitHub, the `Create merge commit` options are recommended.

Next, sync your local repos (and forks). Merging a PR simply merges the code in the upstream remote repository in which it was merged. The PR author (and other members of the repo) needs to pull the merged code from the upstream repo to their local repos and push the new code to their respective forks to sync the fork with the upstream repo.

Forking Workflow ★★★☆

You can follow the steps in the simulation of a forking workflow given below to learn how to follow such a workflow.

ℹ This activity is best done as a team.

Step 1. One member: set up the team org and the team repo.

1. **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.
2. **Add a team** called `developers` to your team org.
3. **Add team members** to the `developers` team.
4. **Fork** se-edu/samplerepo-workflow-practice to your team org. We'll refer to this as the *team repo*.
5. **Add the forked repo to the `developers` team.** Give write access.

Step 2. Each team member: create PRs via own fork.

1. **Fork that repo** from your team org to your own GitHub account.
2. **Create a branch** named `add-{your name}-info` (e.g. `add-johnTan-info`) in the local repo.
3. **Add a file** `yourName.md` into the `members` directory (e.g., `members/jonhTan.md`) containing some info about you into that branch.
4. **Push that branch to your fork**.
5. **Create a PR** from that branch to the `master` branch of the team repo.

Step 3. For each PR: review, update, and merge.

1. **[A team member (not the PR author)] Review the PR** by adding comments (can be just dummy comments).
2. **[PR author] Update the PR** by pushing more commits to it, to simulate updating the PR based on review comments.
3. **[Another team member] Approve and merge** the PR using the GitHub interface.
4. **[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.

Step 4. Create conflicting PRs.

1. **[One member]: Update README:** In the `master` branch, remove John Doe and Jane Doe from the `README.md`, commit, and push to the main repo.
2. **[Each team member] Create a PR** to add yourself under the `Team Members` section in the `README.md`. Use a new branch for the PR e.g., `add-johnTan-name`.

Step 5. Merge conflicting PRs one at a time. Before merging a PR, you'll have to resolve conflicts.

1. [Optional] A member can inform the PR author (by posting a comment) that there is a conflict in the PR.
2. **[PR author] Resolve the conflict locally**:
   1. Pull the `master` branch from the repo in your team org.

    2. Merge the pulled `master` branch to your PR branch.
    3. Resolve the merge conflict that crops up during the merge.
    4. Push the updated PR branch to your fork.
3. **[Another member or the PR author]: Merge the de-conflicted PR**: When GitHub does not indicate a conflict anymore, you can go ahead and merge the PR.