Modeling

Introduction

What

★★☆☆ Can explain models

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

★★★☆ Can explain how models are used

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

***Model-driven development (MDD)*, also called *Model-driven engineering*, is an approach to software development that strives to exploit models as blueprints.** MDD uses models as primary engineering artifacts when developing software. That is, the system is first created in the form of models. After that, the models are converted to code using code-generation techniques (usually, automated or semi-automated, but can even involve manual translation from model to code). MDD requires the use of a very expressive modeling notation (graphical or otherwise), often specific to a given problem domain. It also requires sophisticated tools to generate code from models and maintain the link between models and the code. One advantage of MDD is that the same model can be used to create software for different platforms and different languages. MDD has a lot of promise, but it is still an emerging technology.

Further reading:

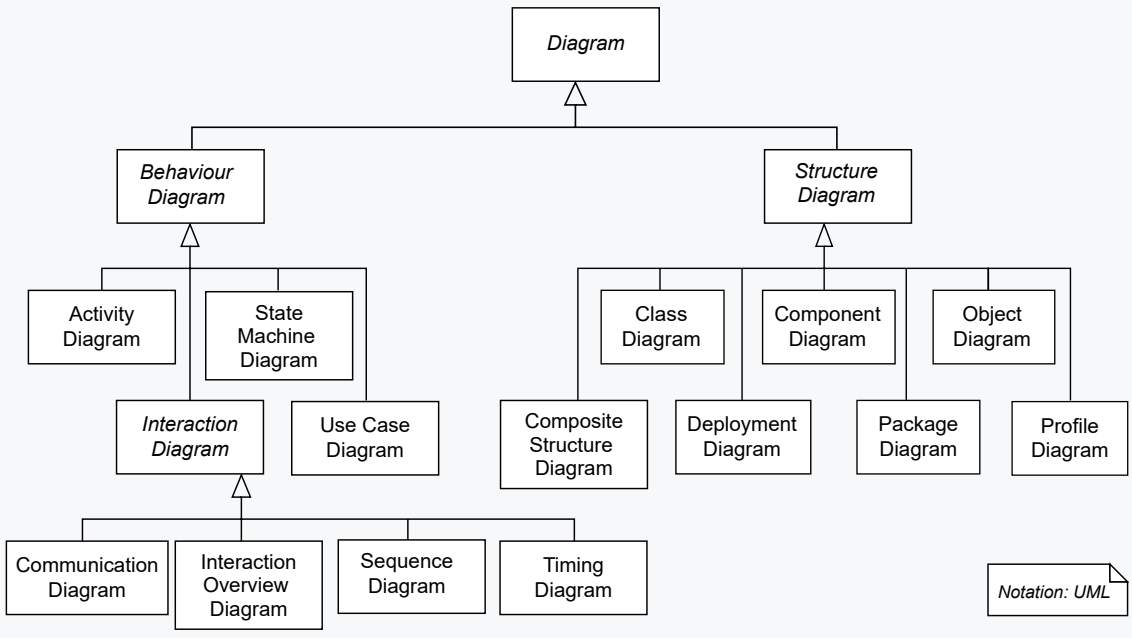
- Martin Fowler's view on MDD - TLDR: he is sceptical
- 5 types of Model Driven Software Development - A more optimistic view, although an old article

Exercises

UML Models

★★★☆ Can identify UML models

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



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

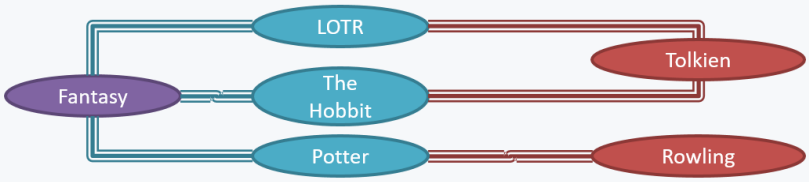
Modeling structures

OO Structures

★☆☆☆ Can explain structure modeling of OO solutions

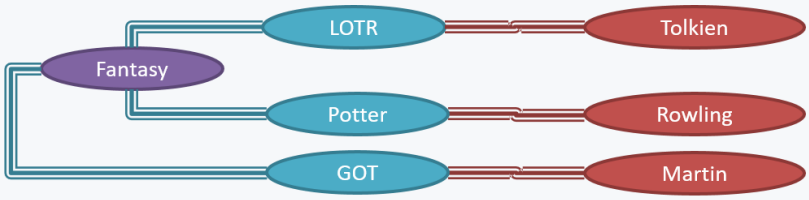
An OO solution is basically a network of objects interacting with each other. Therefore, **it is useful to be able to model how the relevant objects are 'networked' together** inside a software i.e. how the objects are connected together.

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.

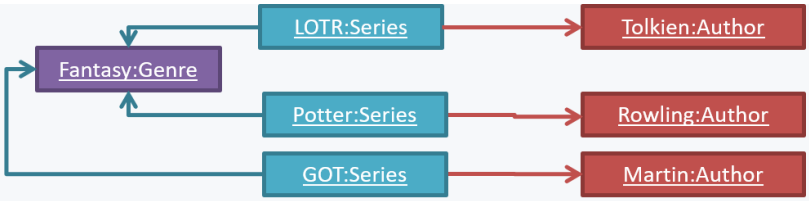


However, object structures do not change at random; they change based on a set of rules, as was decided by the designer of that software. Those **rules that object structures need to follow can be illustrated as a *class structure*** i.e. a structure that exists among the relevant classes.

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)

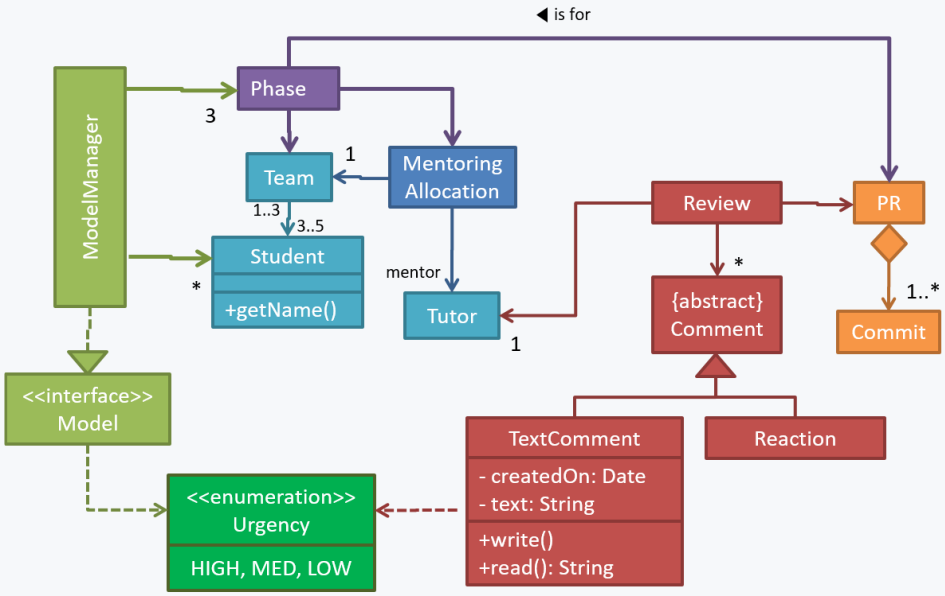
★☆☆☆ Can use basic-level class diagrams

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

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.

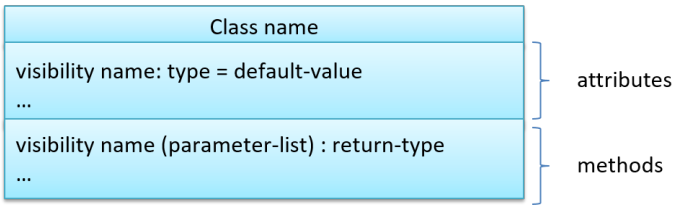
An example class diagram:



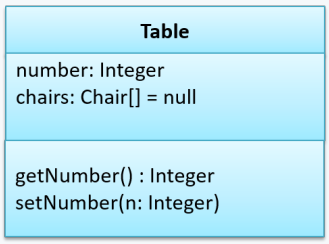
Classes form the basis of class diagrams.

UML Class Diagrams → Classes → What

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

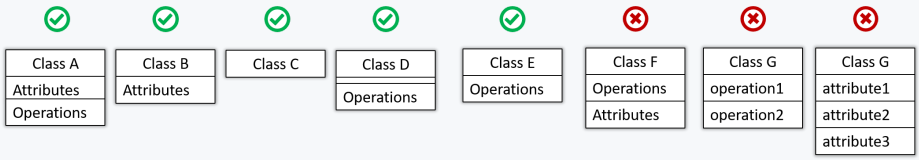


A `Table` class shown in UML notation:



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. Similarly, *some* attributes/operations can be omitted if not relevant. '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.



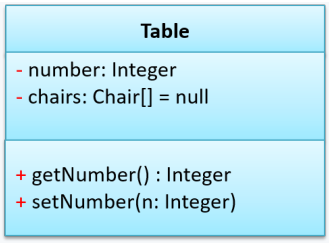
The *visibility* of attributes and operations is used to indicate the level of access allowed for each attribute or operation. The types of visibility and their exact meanings depend on the programming language used. Here are some common visibilities and how they are indicated in a class diagram:

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

How visibilities map to programming language features

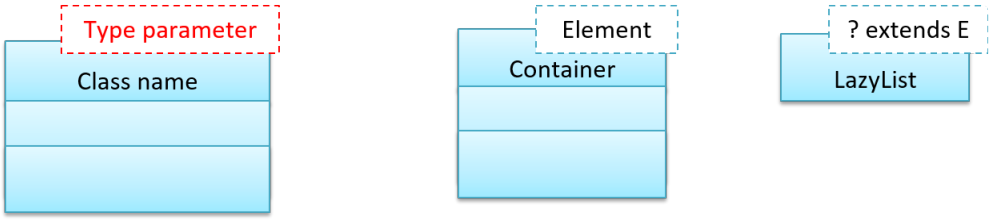
Visibility	Java	Python
`-` private	`private`	at least two leading underscores (and at most one trailing underscores) in the name
`#` protected	`protected`	one leading underscore in the name
`+` public	`public`	all other cases
`~` package private	default visibility	not applicable

`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.

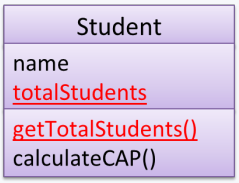


Exercises

UML Class Diagrams → Class-Level Members → What

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

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



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

OOP 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.

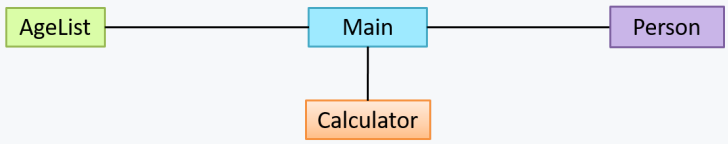
▼ 🎓 UML 🔜 Class Diagrams → Associations → What

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:

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

***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.

▼ 🎓 UML 🔚 Class Diagrams → Associations → Roles

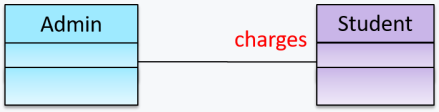
***Association Role* labels are used to indicate the role played by the classes in the association.**

📦 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.

```
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)




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

▼ 🎓 OOP 🔚 Associations → 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();
    ...
}
```

Bidirectional associations require matching variables in both classes.

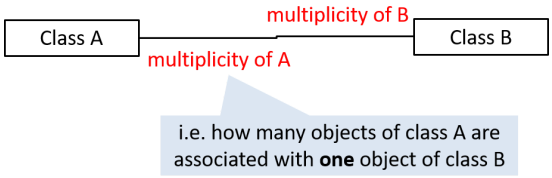
In the code below, the `Foo` class has a variable to hold a `Bar` object and vice versa i.e., each object can have an association with an object of the other type.

```
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;
    ...
}
```



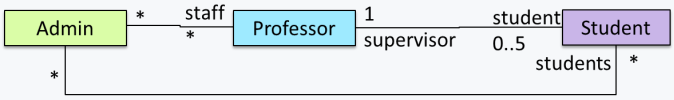
Commonly used multiplicities:

- `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.



Exercises

OOP Associations → Navigability

When two classes are linked by an association, it does not necessarily mean the two objects taking part in an instance of the association *knows about* (i.e., has a reference to) each other. **The concept of which object in the association knows about the other object is called *navigability*.**

Navigability can be *unidirectional* or *bidirectional*. Suppose there is an association between the classes `Box` and `Rope`, and the `Box` object `b` and the `Rope` object `r` is taking part in one instance of that association.

- **Unidirectional**: If the navigability is from `Box` to `Rope`, `b` will have a reference to `r` but `r` will not have a reference to `b`. Similarly, if the navigability is in the other direction, `r` will have a reference to `b` but `b` will not have a reference to `r`.
- **Bidirectional**: `b` will have a reference to `r` and `r` will have a reference to `b` i.e., the two objects will be pointing to each other for the same single instance of the association.

Note that two unidirectional associations in opposite directions do not add up to a single bidirectional association.

In the code below, there is a bidirectional association between the `Person` class and the `Cat` class i.e., if `Person` `p` is the owner of the `Cat` `c`, `p` it will result in `p` and `c` having references to each other.

```
class Person {
    Cat pet;
    //...
}

class Cat{
    Person owner;
    //...
}
```

The code below has two unidirectional associations between the `Person` class and the `Cat` class (in opposite directions) because the breeder is not necessarily the same person keeping the cat as a pet i.e., there are two separate associations here, which rules out it being a bidirectional association.

```
class Person {
    Cat pet;
    //...
}

class Cat{
    Person breeder;
    //...
}
```

UML Class Diagrams → Associations → Navigability

Use arrowheads to indicate the navigability of an association.

In this example, the navigability is unidirectional, and is from the `Logic` class to the `Minefield` class. That means if a `Logic` object `L` is associated with a `Minefield` object `M`, `L` has a reference to `M` but `M` doesn't have a reference to `L`.

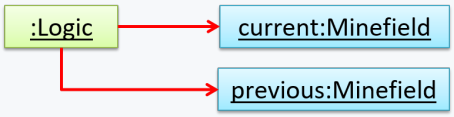

```
class Logic {
    Minefield minefield;
    // ...
}

class Minefield {
    //...
}
```

Here is an example of a bidirectional navigability; i.e., if a `Dog` object `d` is associated with a `Man` object `m`, `d` has a reference to `m` and `m` has a reference to `d`.


```
class Dog {
    Man man;
    // ...
}

class Man {
    Dog dog;
    // ...
}
```

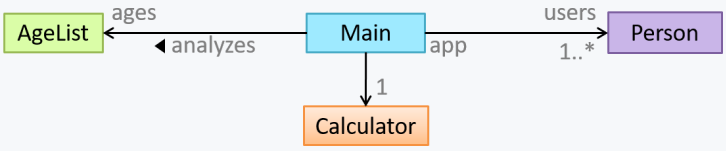
Navigability can be shown in class diagrams as well as object diagrams.

According to this object diagram, the given `Logic` object is associated with and aware of two `MineField` objects.



Exercises

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



Exercises

Which association notations are shown?

Explain Class Diagram

Draw Class Diagram for Box etc.

Adding More Info to UML Models

★★★☆ Can add more info to UML models

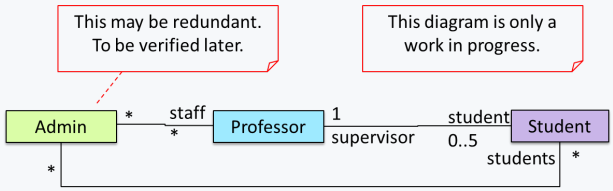
UML notes can be used to add more info to any UML model.

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

★★☆☆ Can use intermediate-level class diagrams

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

Modeling inheritance

OOP → 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.

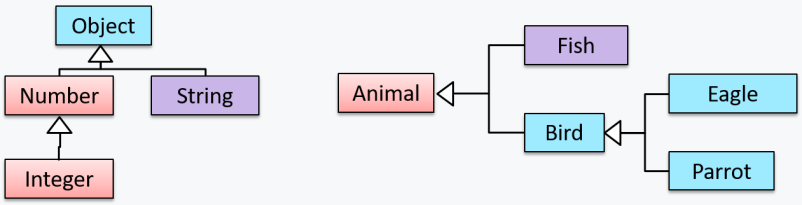
Inheritance does not necessarily mean a sub-type relationship exists. However, the two often go hand-in-hand. For simplicity, at this point let us assume inheritance implies a sub-type relationship.

To continue the previous example,

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

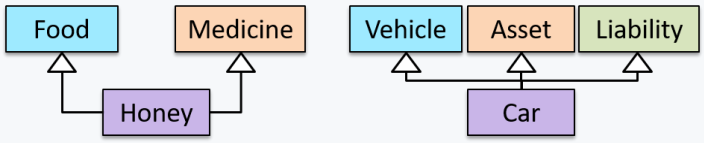
Inheritance relationships through a chain of classes can result in inheritance *hierarchies* (aka inheritance *trees*).

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`.

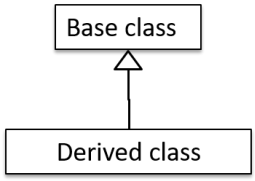


Exercises

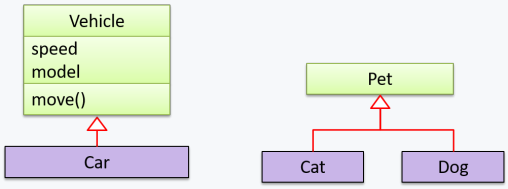
UML → Class Diagrams → Inheritance → What

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.



Modeling composition

🎓 OOP → Associations → 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.

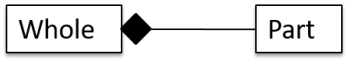
📦 In this code, the `Email` has a composition type relationship with the `Subject` class, in the sense that the subject is part of the email.

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

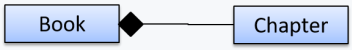
🎓 UML → Class Diagrams → Composition → What

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.



Modeling aggregation

OOP → Associations → 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.

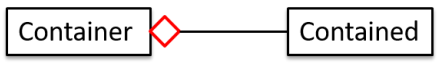
In the code below, there is an aggregation association between the `Team` class and the `Person` class in that a `Team` contains a `Person` object who is the leader of the team.

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

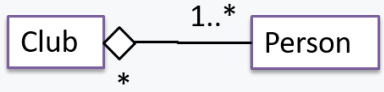
UML → Class Diagrams → Aggregation → What

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.

Exercises

Modeling dependencies

OOP → Associations → Dependencies

In the context of OOP associations, **a *dependency* is a need for one class to depend on another without having a direct association in the same direction.** Reason for the exclusion: If there is an association from class `Foo` to class `Bar` (i.e., navigable from `Foo` to `Bar`), that means `Foo` is *obviously* dependent on `Bar` and hence there is no point in mentioning *dependency* specifically. In other words, we are only concerned about *non-obvious* dependencies here. One cause of such dependencies is interactions between objects that do not have a long-term link between them.

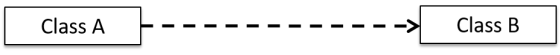
A `Course` class can have a dependency on a `Registrar` class because the `Course` class needs to refer to the `Registrar` class to obtain the the maximum number of students it can support (e.g., `Registrar.MAX_COURSE_CAPACITY`).

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.

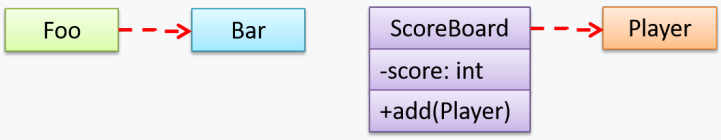
```
class Foo {

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

class Bar {
    int value;

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

UML → Class Diagrams → 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`.

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

Modeling enumerations

▼ 🎓 OOP → Classes → Enumerations

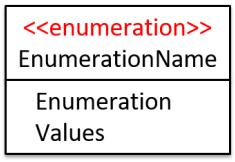
An *Enumeration* is a fixed set of values that can be considered as a data type. An enumeration is often useful when using a regular data type such as `int` or `String` would allow invalid values to be assigned to a variable.

📦 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.

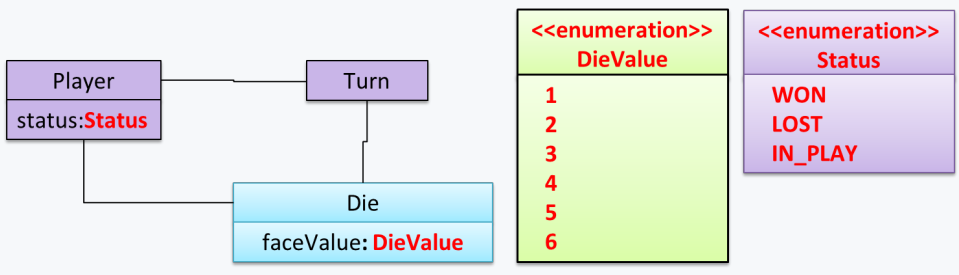
`Priority`: `HIGH`, `MEDIUM`, `LOW`

▼ 🎓 UML → Class Diagrams → Enumerations → What

Notation:



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



Exercises

Define WeekDay Enum

Modeling abstract classes

OOP → Inheritance → 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.

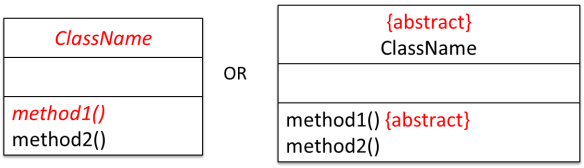
> **Abstract method**: An *abstract method* is a method signature without a method implementation.

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.

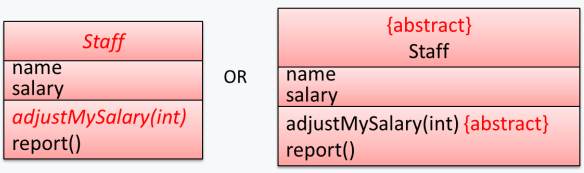
A class that has an abstract method becomes an abstract class because the class definition is incomplete (due to the missing method body) and it is not possible to create objects using an incomplete class definition.

UML → Class Diagrams → Abstract Classes → What

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



Example:



Modeling interfaces

OOP → Inheritance → 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()`.

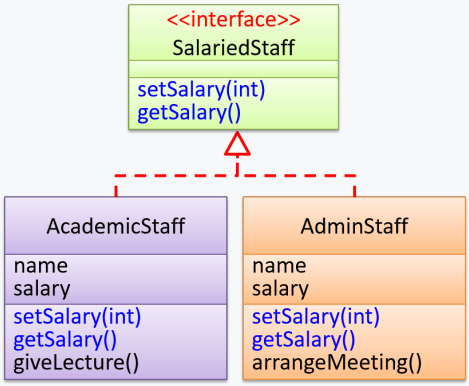
A class implementing an interface results in an *is-a* relationship, just like in class inheritance.

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()`.

UML → Class Diagrams → 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.



Exercises

Statements about class diagram

Explain notations in the class diagram

Draw a Class Diagram for the code (`StockItem`, `Inventory`, `Review`, etc.)

Class Diagrams - Advanced

★★★☆ Can use advanced class diagrams

A class diagram can show association classes too.

OOP → Associations → Association Classes

An *association class* represents additional information about an association. It is a normal class but plays a special role from a design point of view.

A `Man` class and a `Woman` class are linked with a 'married to' association and there is a need to store the date of marriage. However, that data is related to the association rather than specifically owned by either the `Man` object or the `Woman` object. In such situations, an additional association class can be introduced, e.g. a `Marriage` class, to store such information.

Implementing association classes

There is no special way to implement an association class. It can be implemented as a normal class that has variables to represent the endpoint of the association it represents.

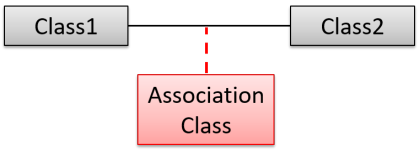
In the code below, the `Transaction` class is an association class that represents a transaction between a `Person` who is the seller and another `Person` who is the buyer.

```
class Transaction {

    //all fields are compulsory
    Person seller;
    Person buyer;
    Date date;
    String receiptNumber;

    Transaction(Person seller, Person buyer, Date date, String receiptNumber) {
        //set fields
    }
}
```

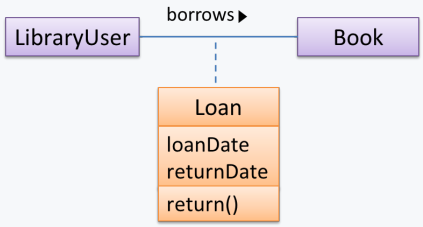
Exercises

UML → Class Diagrams → Association Classes → What

Association classes are denoted as a connection to an association link using a dashed line as shown below.



In this example `Loan` is an association class because it stores information about the `borrows` association between the `User` and the `Book`.



Exercises

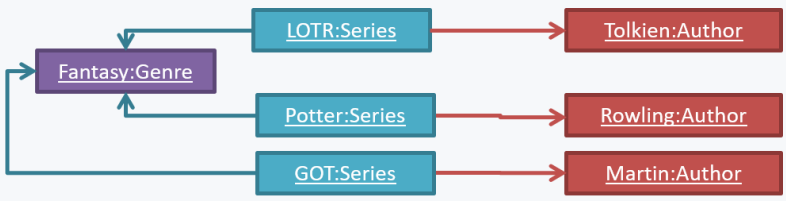
Object Diagrams

★☆☆☆ Can use basic object diagrams

UML → Object Diagrams → Introduction

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

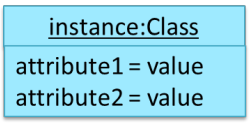
An example object diagram:



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

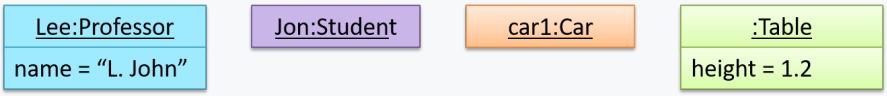
Notation:



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:



Exercises

UML → Object Diagrams → Associations

A solid line indicates an association between two objects.

An example object diagram showing two associations:

Exercises

Draw an Object Diagram for Box etc.

Object Oriented Domain Models

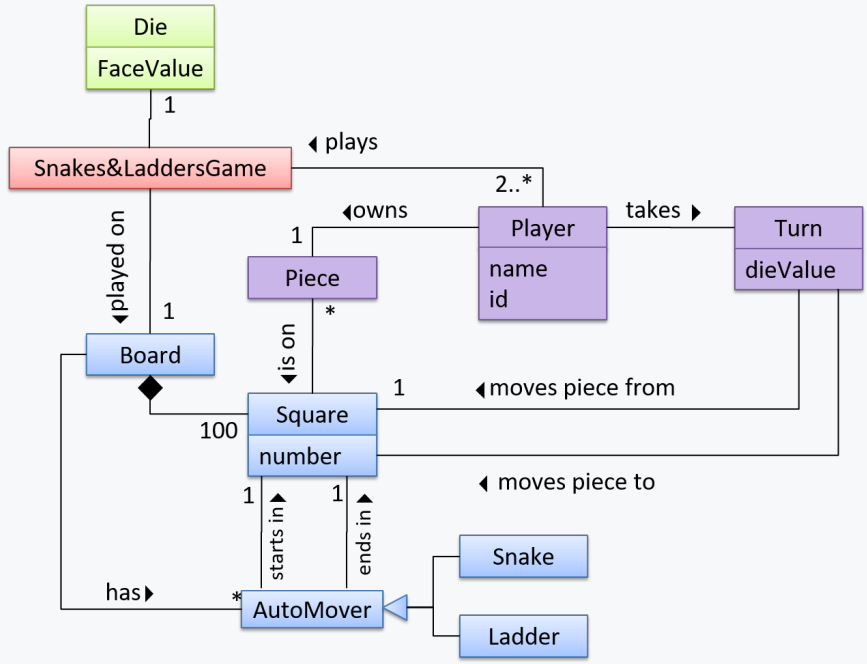
★★★☆ Can explain object oriented domain models

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

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

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

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



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

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

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

Exercises

This diagram is,...

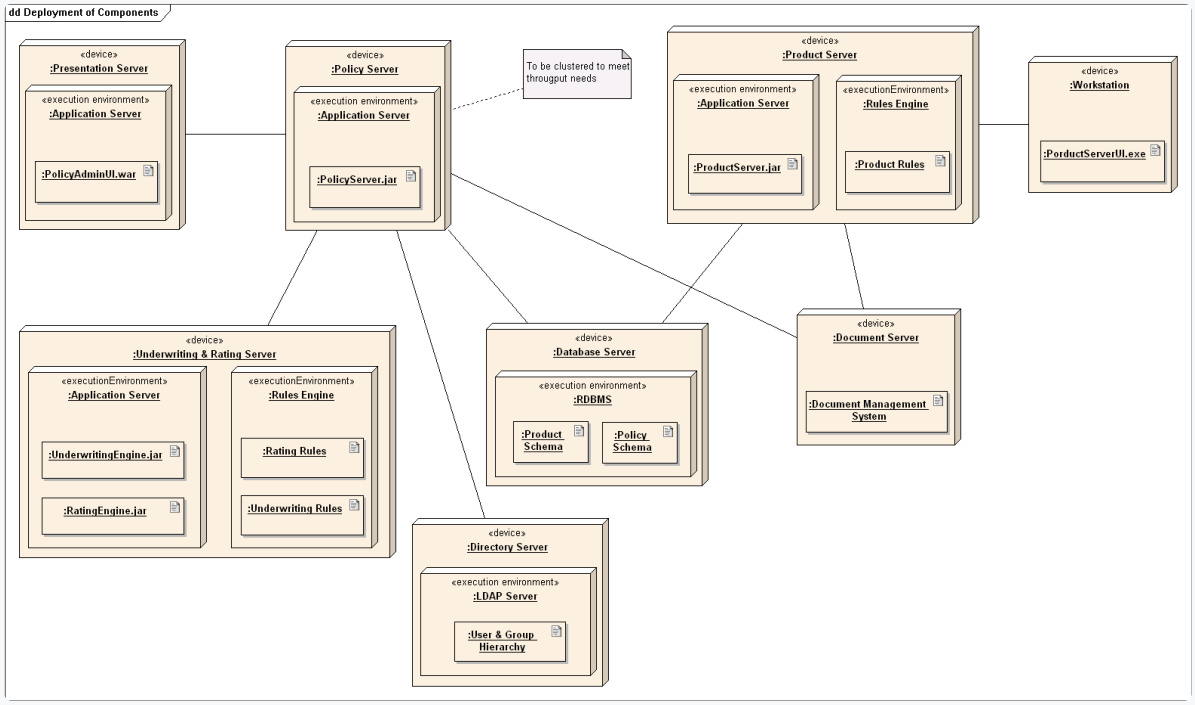
Difference between a class diagram and an OO domain model?

Deployment Diagrams

★★★★ Can explain deployment diagrams

A *deployment diagram* shows a system's physical layout, revealing which pieces of software run on which pieces of hardware.

An example deployment diagram:



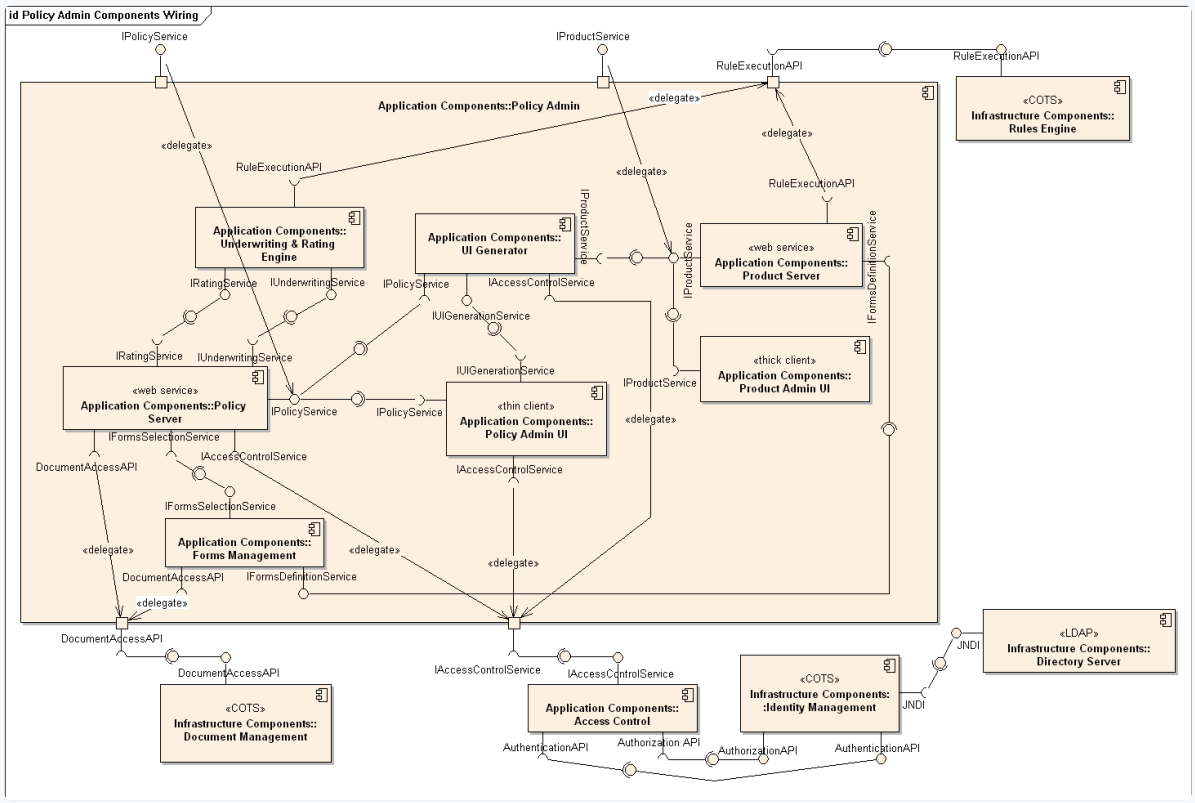
source:https://commons.wikimedia.org

Component Diagrams

★★★★ Can explain component diagrams

A *component diagram* is used to show how a system is divided into components and how they are connected to each other through interfaces.

An example component diagram:



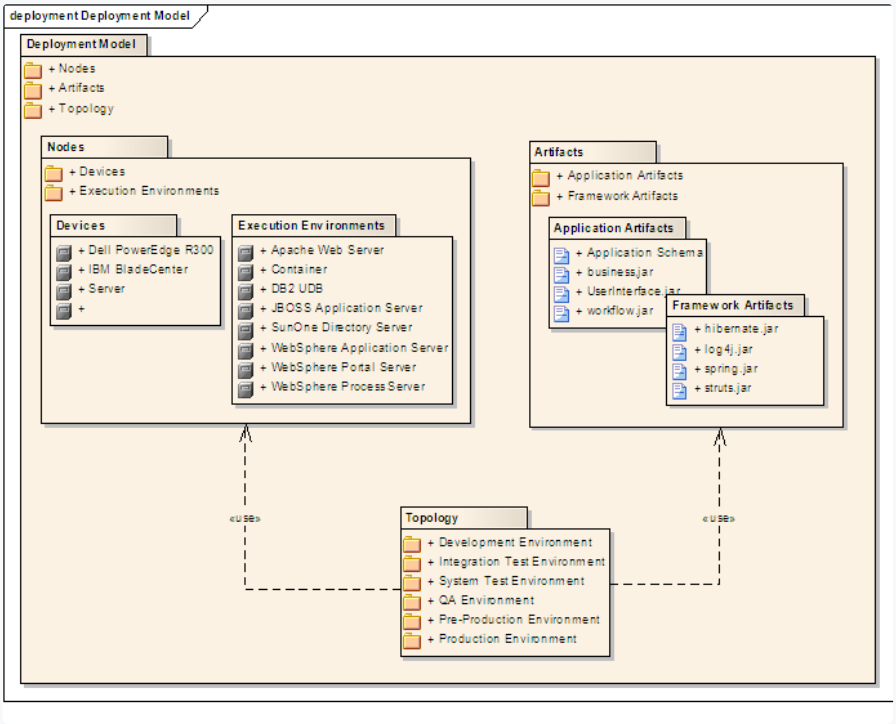
source:https://commons.wikimedia.org

Package Diagrams

★★★★ Can explain package diagrams

A *package diagram* shows packages and their dependencies. A package is a grouping construct for grouping UML elements (classes, use cases, etc.).

Here is an example package diagram:



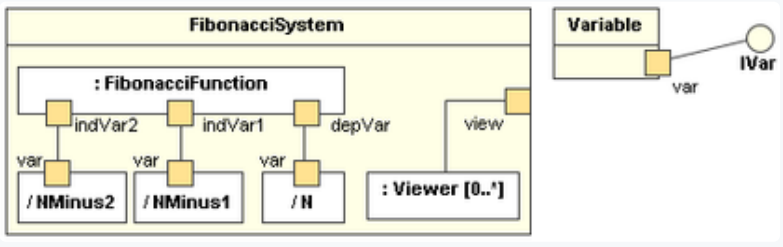
source:https://commons.wikimedia.org

Composite Structure Diagrams

★★★★ Can explain composite structure diagrams

A *composite structure diagram* hierarchically decomposes a class into its internal structure.

Here is an example composite structure diagram:



source:https://commons.wikimedia.org

Modeling behaviors

Activity Diagrams - Basic

★★★☆ Can use basic-level activity diagrams

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

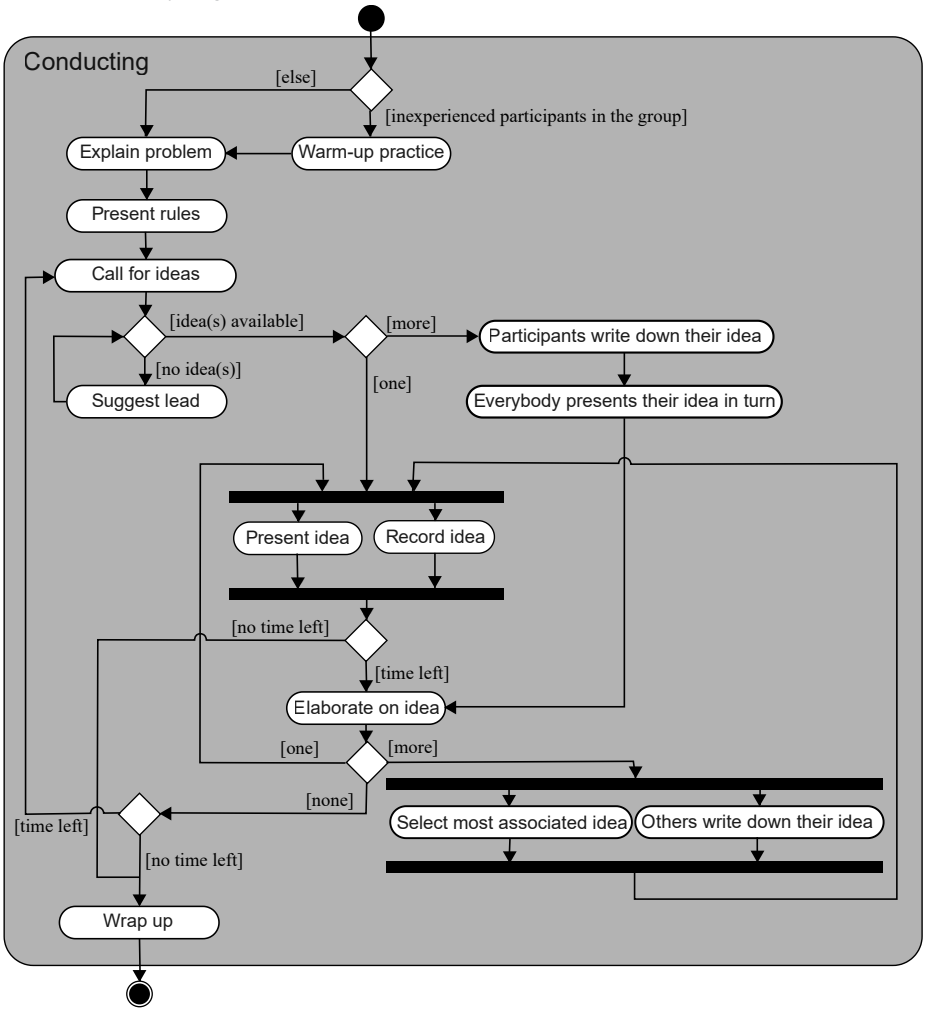
Some examples in which a certain workflow is relevant to software project:

- A software that automates the work of an insurance company needs to take into account the workflow of processing an insurance claim.
- The algorithm of a piece of code represents the workflow (i.e. the execution flow) of the code.

UML Activity Diagrams → Introduction → What

UML *activity diagrams* (AD) can model workflows. *Flow charts* are another type of diagram that can model workflows. Activity diagrams are the UML equivalent of flow charts.

An example activity diagram:



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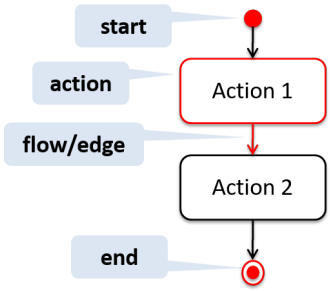
UML Activity Diagrams → Basic Notation → Linear Paths

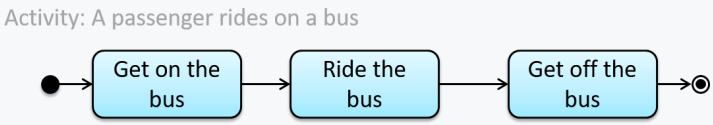
An activity diagram (AD) captures an *activity* through the *actions* and *control flows* that make up the activity.

- An *action* is a single step in an activity. It is shown as a rectangle with rounded corners.
- A *control flow* shows the flow of control from one action to the next. It is shown by drawing a line with an arrow-head to show the direction of the flow.



Note the slight difference between the *start node* and the *end node* which represent the start and the end of the activity, respectively.

This activity diagram shows the action sequence of the activity *a passenger rides the bus*:



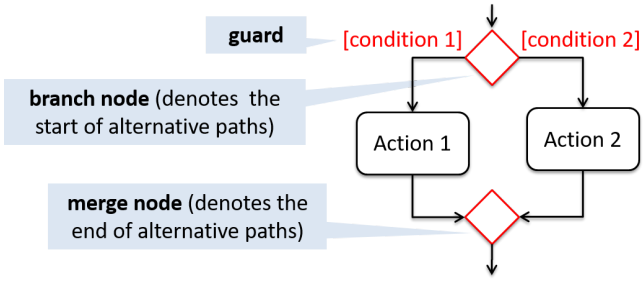
Exercises

UML Activity Diagrams → Basic Notation → Alternate Paths

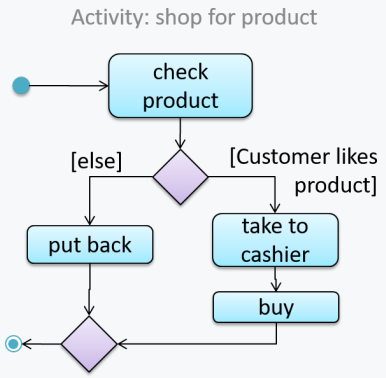
A *branch node* shows the start of alternate paths. Each control flow exiting a branch node has a *guard condition*: a boolean condition that should be true for execution to take that path. ***Exactly one* of the guard conditions should be true** at any given branch node.

A *merge node* shows the end of alternate paths.

Both branch nodes and merge nodes are diamond shapes. Guard conditions must be in square brackets.



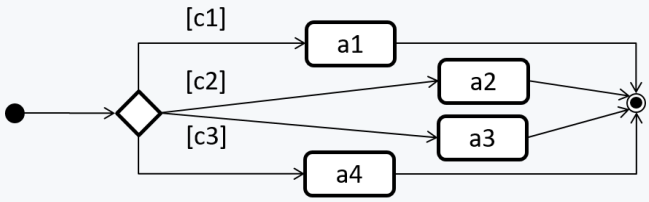
The AD below shows alternate paths involved in the workflow of the activity *shop for product*:



Some acceptable simplifications (by convention):

- Omitting the merge node if it doesn't cause any ambiguities.
- Multiple arrows can starting from the same corner of a branch node.
- Omitting the `[Else]` condition.

The AD below illustrates the simplifications mentioned above:



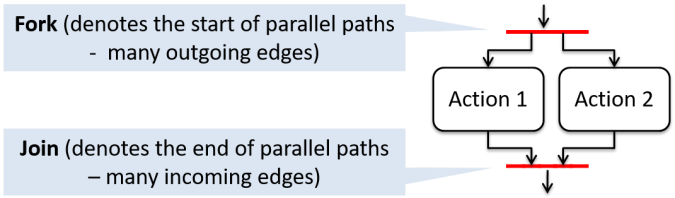
UML Activity Diagrams → Basic Notation → Parallel Paths

***Fork* nodes indicate the start of concurrent flows of control.**

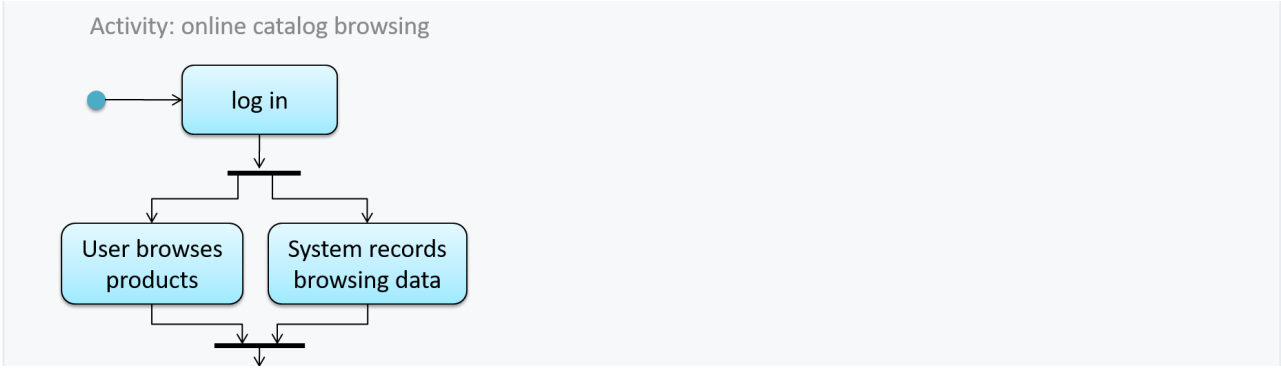
***Join* nodes indicate the end of parallel paths.**

Both have the same notation: a bar.

In a set of parallel paths, execution along **all parallel paths should be complete before the execution can start on the outgoing control flow of the *join*.**



In this activity diagram (from an online shop website) the actions *User browses products* and *System records browsing data* happen in parallel. Both of them need to finish before the *log out* action can take place.



Exercises

Which sequences are not allowed?

Model the algorithms of calculating grades

Model workflow of a Burger shop

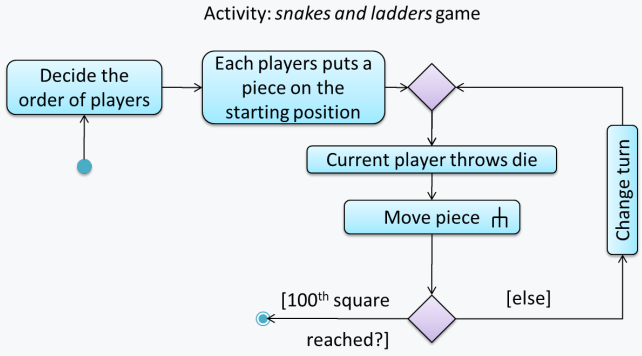
Activity Diagrams - Intermediate

★★★☆ Can use intermediate-level activity diagrams

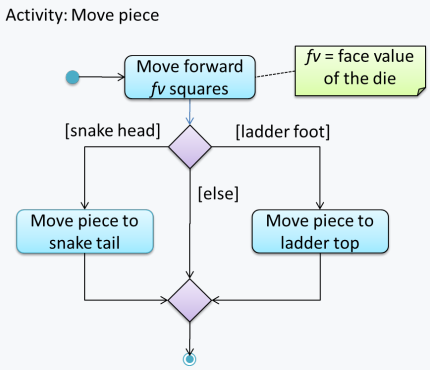
UML Activity Diagrams → Intermediate Notation → Rakes

The rake notation is used to indicate that a part of the activity is given as a separate diagram.

Here is the AD for a game of 'Snakes and Ladders'.



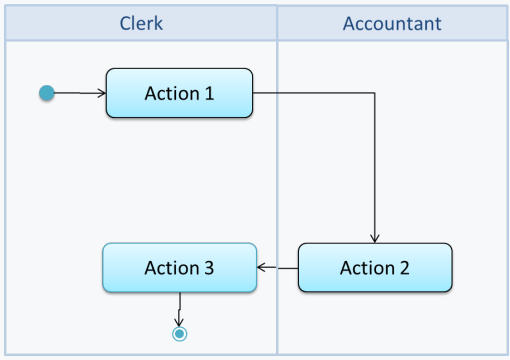
The *rake* symbol (in the `Move piece` action above) is used to show that the action is described in another subsidiary activity diagram elsewhere. That diagram is given below.



UML Activity Diagrams → Intermediate Notation → Swim Lanes

It is possible to *partition* an activity diagram to show who is doing which action. Such partitioned activity diagrams are sometime called *swimlane diagrams*.

A simple example of a swimlane diagram:



Sequence Diagrams - Basic

★★☆☆ Can draw basic sequence diagrams

Sequence diagrams model the interactions between various entities in a system, in a specific scenario. Modelling such scenarios is useful, for example, to verify the design of the internal interactions is able to provide the expected outcomes.

Some examples where a sequence diagram can be used:

📦 To model how components of a system interact with each other to respond to a user action.

📦 To model how objects inside a component interact with each other to respond to a method call it received from another component.

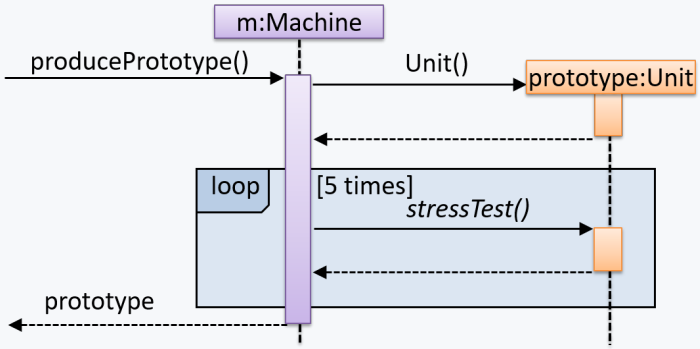
🎓 UML 📲 Sequence Diagrams → Introduction

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

📦 Consider the code below.

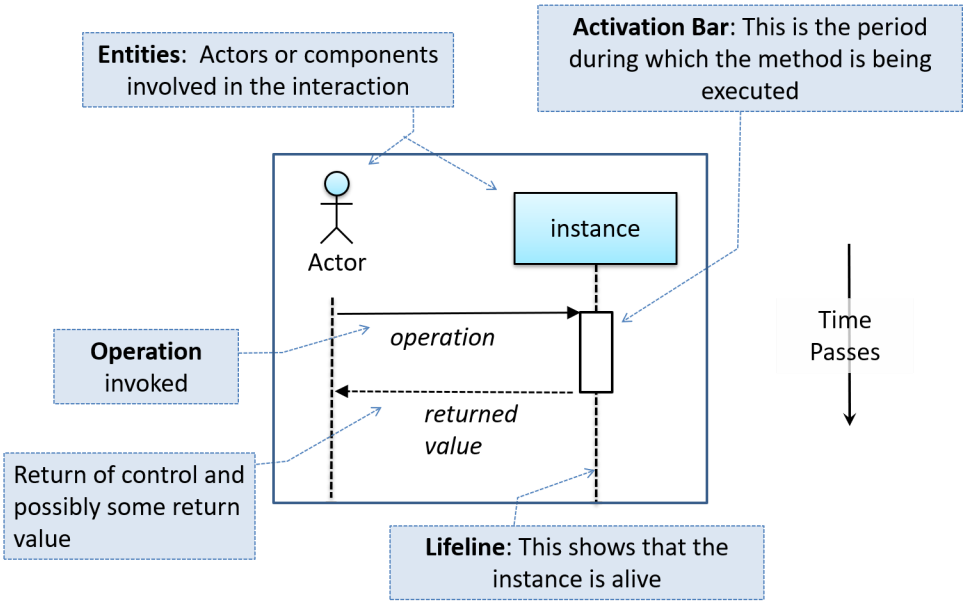
```
class Machine {

    Unit producePrototype() {
        Unit prototype = new Unit();
        for (int i = 0; i < 5; i++) {
            prototype.stressTest();
        }
        return prototype;
    }
}

class Unit {

    public void stressTest() {

    }
}

```

Here is the sequence diagram to model the interactions for the method call `produceProtoype()` on a `Machine` object.

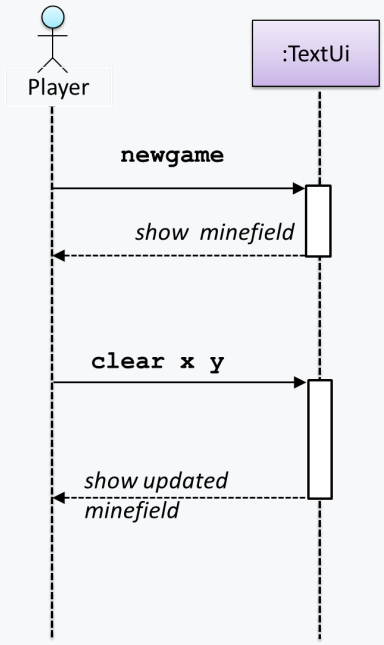


🎓 UML 📲 Sequence Diagrams → Basic Notation

Notation:



This sequence diagram shows some interactions between a human user and the Text UI of a CLI Minesweeper game.



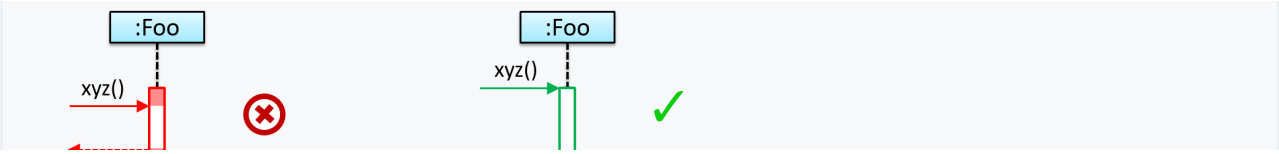
The player runs the `newgame` action on the `TextUi` object which results in the `TextUi` showing the minefield to the player. Then, the player runs the `clear x y` command; in response, the `TextUi` object shows the updated minefield.

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.

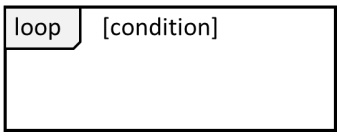
Note that unlike in object diagrams, the **class/object name is not underlined in sequence diagrams**.

✗ **[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.

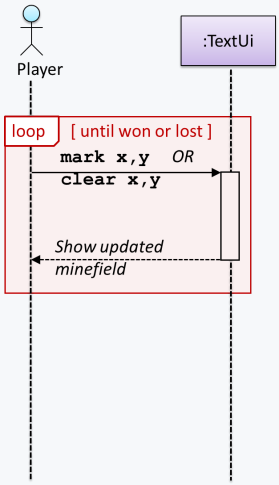


UML Sequence Diagrams → Loops

Notation:

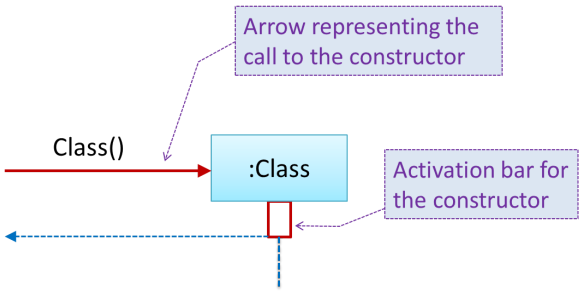


The `Player` calls the `mark x,y` command or `clear x y` command repeatedly until the game is won or lost.



UML Sequence Diagrams → Object Creation

Notation:



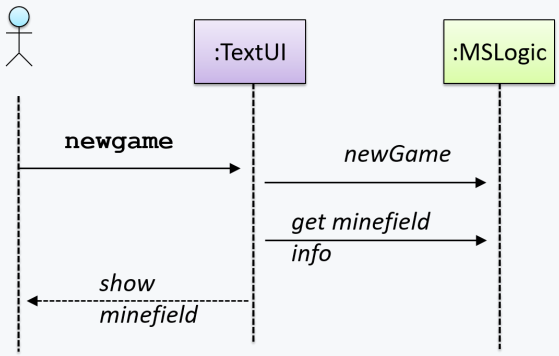
- The arrow that represents the constructor arrives at the side of the box representing the instance.
- The activation bar represents the period the constructor is active.

The `Logic` object creates a `Minefield` object.

UML Sequence Diagrams → Minimal Notation

To reduce clutter, **optional elements (e.g, activation bars, return arrows) may be omitted** if the omission does not result in ambiguities or loss of *relevant* 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



Exercises

Explain Sequence Diagram about Machine

Draw a Sequence Diagram for the code (`PersonList` , `Person` , `Tag`)

Find notation errors in Sequence Diagram

Sequence Diagrams - Intermediate

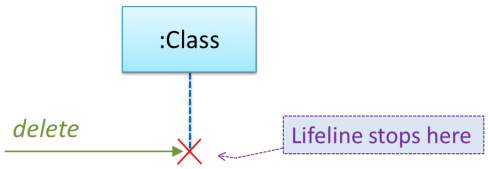
★★★☆ Can draw intermediate-level sequence diagrams

UML Sequence Diagrams → Object Deletion

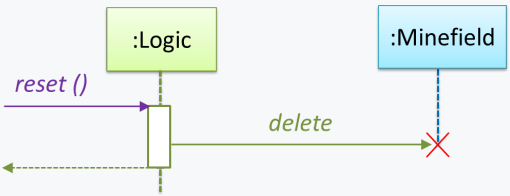
UML uses an `X` at the end of the lifeline of an object to show its deletion.

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:



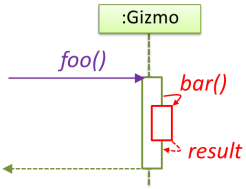
Note how the below diagram shows the deletion of the `Minefield` object.



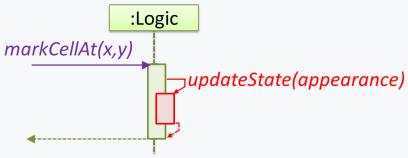
UML Sequence Diagrams → Self-Invocation

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

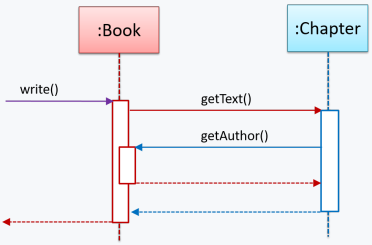
Notation:



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



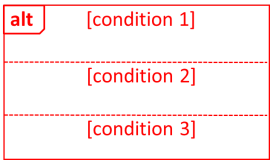
In this variation, the `Book#write()` method is calling the `Chapter#getText()` method which in turn does a *call back* by calling the `getAuthor()` method of the calling object.



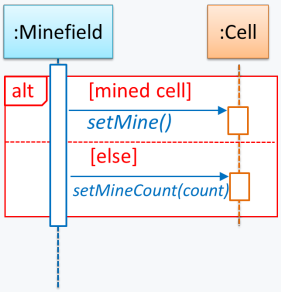
UML Sequence Diagrams → Alternative Paths

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.



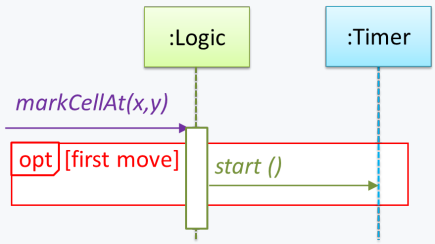
No more than one alternative partitions be executed in an `alt` frame. That is, it is acceptable for none of the alternative partitions to be executed but it is not acceptable for multiple partitions to be executed.

UML Sequence Diagrams → Optional Paths

UML uses `opt` frames to indicate optional paths.

Notation:

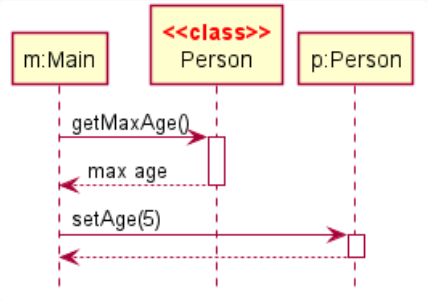
`Logic#markCellAt(...)` calls `Timer#start()` only if it is the first move of the player.



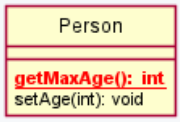
UML Sequence Diagrams → Calls to Static Methods

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:



Exercises

What's going on here?

Explain Sequence Diagram (`ParserFactory`)

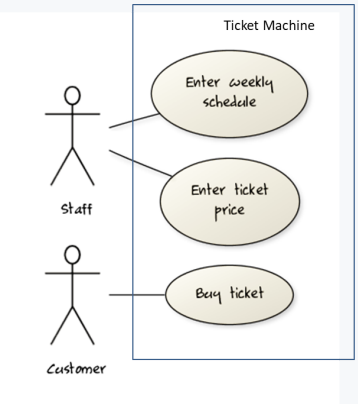
Draw Sequence Diagram for printing a quote

Use Case Diagrams

★★★☆ Can explain use case diagrams

Use case diagrams model the mapping between *features* of a system and its user *roles* i.e., which user roles can perform which tasks using the software.

A simple use case diagram:

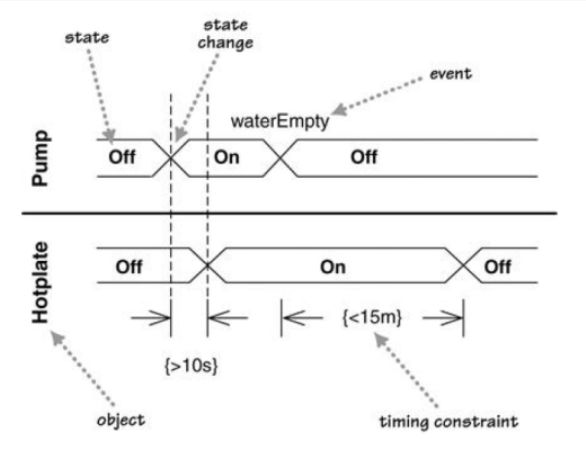


Timing Diagrams

★★★★ Can explain timing diagrams

A *timing diagram* focuses on timing constraints.

Here is an example timing diagram:



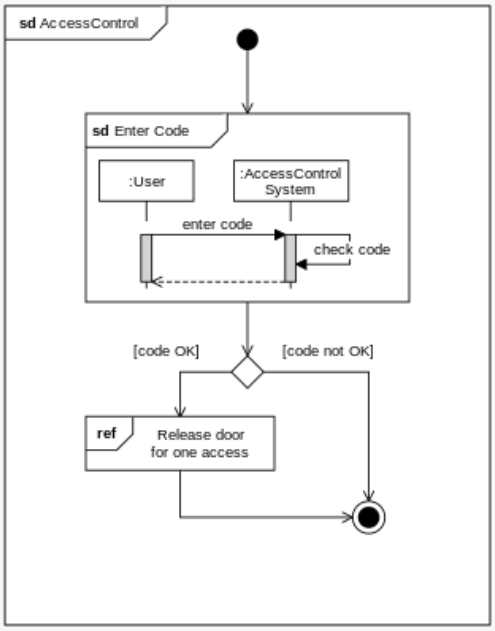
Adapted from: *UML Distilled* by Martin Fowler

Interaction Overview Diagrams

★★★★ Can explain interaction overview diagrams

***Interaction overview* diagrams are a combination of activity diagrams and sequence diagrams**.

An example:



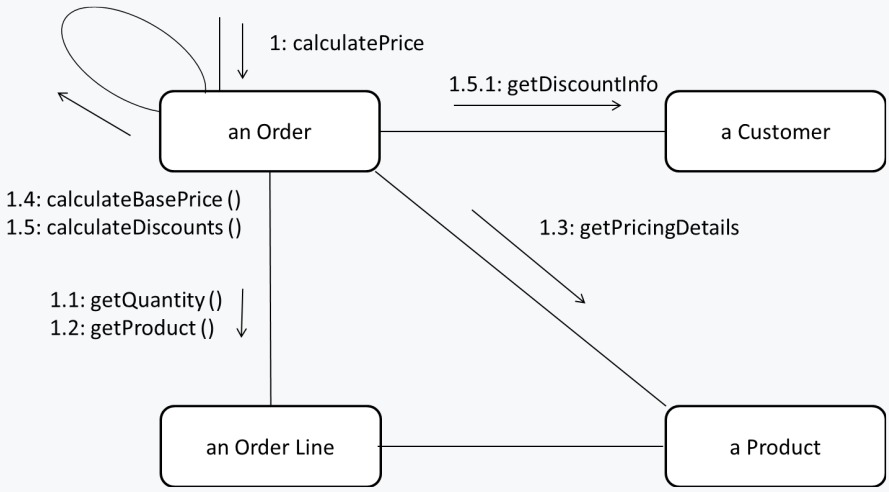
source: https://commons.wikimedia.org

Communication Diagrams

★★★★ Can explain communication diagrams

Communication diagrams **are like sequence diagrams but emphasize the data links between the various participants in the interaction rather than the sequence of interactions.**

An example:



Adapted from: *UML Distilled* by Martin Fowler

State Machine Diagrams

★★★★ Can explain state machine diagrams

A *State Machine Diagram* models state-dependent behavior.

Consider how a CD player responds when the "eject CD" button is pushed:

- If the CD tray is already open, it does nothing.
- If the CD tray is already in the process of opening (opened half-way), it continues to open the CD tray.
- If the CD tray is closed and the CD is being played, it stops playing and opens the CD tray.
- If the CD tray is closed and CD is not being played, it simply opens the CD tray.
- If the CD tray is already in the process of closing (closed half-way), it waits until the CD tray is fully closed and opens it immediately afterwards.

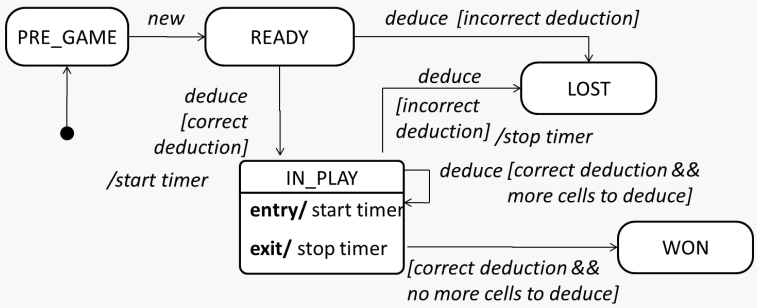
What this means is that the CD player's response to pushing the "eject CD" button depends on what it was doing at the time of the event. More generally, the CD player's response to the event received depends on its internal state. Such a behavior is called a *state-dependent behavior*.

Often, state-dependent behavior displayed by an object in a system is simple enough that it needs no extra attention; such a behavior can be as simple as a *conditional* behavior like `if x > y, then x = x - y`.

Occasionally, objects may exhibit state-dependent behavior that is complex enough such that it needs to be captured in a separate model. Such state-dependent behavior can be modeled using UML *state machine diagrams* (SMD for short, sometimes also called 'state charts', 'state diagrams' or 'state machines').

An SMD views the life-cycle of an object as consisting of a finite number of states where each state displays a unique behavior pattern. SMDs capture information such as the states an object can be in during its lifetime, how the object responds to various events while in each state, and how the object transits from one state to another. In contrast to sequence diagrams that capture object behavior one scenario at a time, SMDs capture the object's behavior over its full life-cycle.

An SMD for the Minesweeper game.



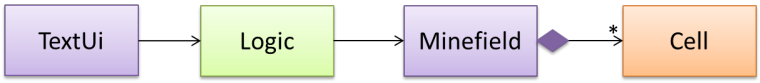
Modeling a solution

Introduction

★★☆☆ Can explain how modeling can be used before implementation

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

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



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

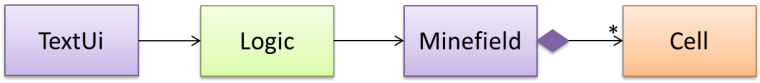
- Is this class structure able to produce the behavior you want?
- What API should each class have?
- Do you need more classes?

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

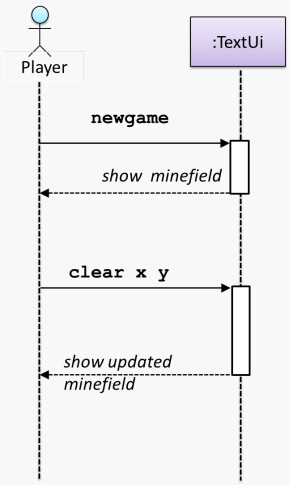
Basic

★★★☆ Can use simple class diagrams and sequence diagrams to model an OO solution

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

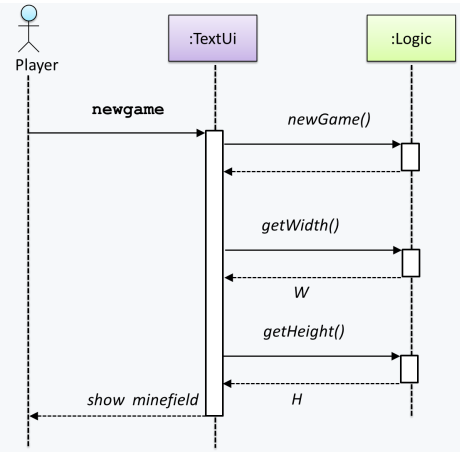


Let us start by modeling a sample interaction between the person playing the game and the `TextUi` object.



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

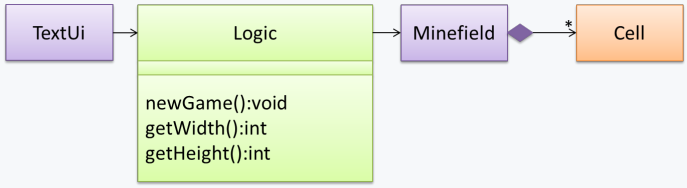
How does the `TextUi` object carry out the requests it has received from the player? It would need to interact with other objects of the system. Because the `Logic` class is the one that controls the game logic, the `TextUi` needs to collaborate with `Logic` to fulfill the `newgame` request. Let us extend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



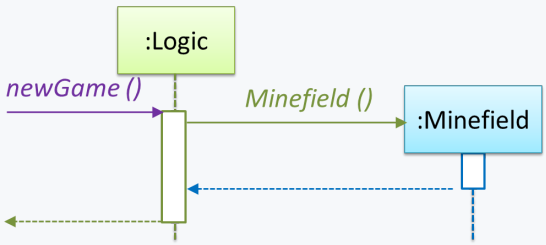
`W` = Width of the minefield; `H` = Height of the minefield

The above diagram assumes that `W` and `H` are the only information `TextUi` requires to display the minefield to the `Player`. Note that there could be other ways of doing this.

The `Logic` methods you conceptualized in our modeling so far are:

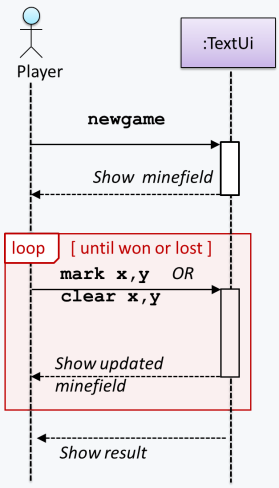


Now, let us look at what other objects and interactions are needed to support the `newGame()` operation. It is likely that a new `Minefield` object is created when the `newGame()` method is called.



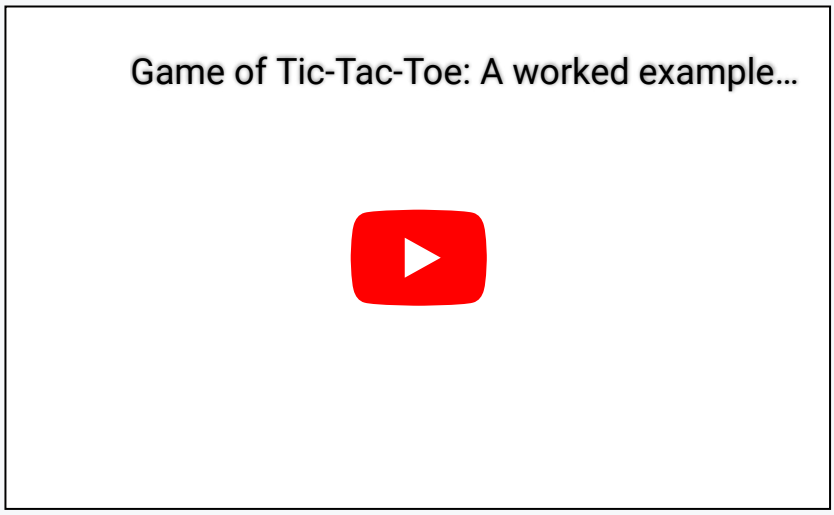
Note that the behavior of the `Minefield` constructor has been abstracted away. It can be designed at a later stage.

Given below are the interactions between the player and the `TextUi` for the whole game.



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

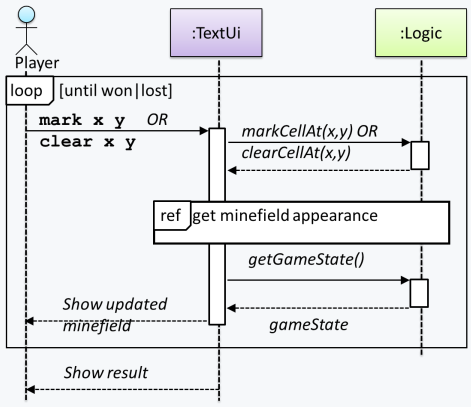
Defining the architecture-level APIs for a small Tic-Tac-Toe game:

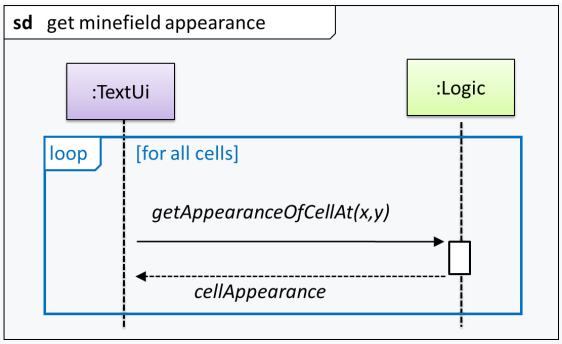


Intermediate

★★★★ Can use intermediate class diagram and sequence diagram concepts to model an OO design

Continuing with the example in [Design → Modeling → Modeling a Solution → Basic], next let us model how the `TextUi` interacts with the `Logic` to support the mark and clear operations until the game is won or lost.





This interaction adds the following methods to the `Logic` class:

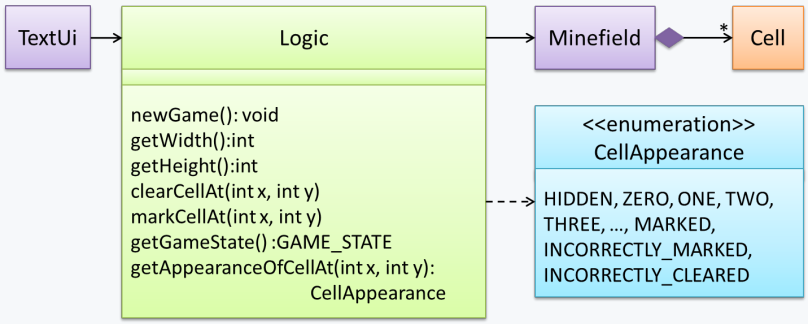
- `clearCellAt(int x, int y)`
- `markCellAt(int x, int y)`
- `getGameState(): GAME_STATE (GAME_STATE: READY, IN_PLAY, WON, LOST, …)`

And it adds the following operation to Logic API:

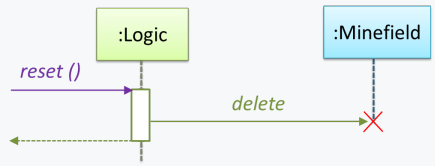
- `getAppearanceOfCellAt(int,int): CELL_APPEARANCE (CELL_APPEARANCE: HIDDEN, ZERO, ONE, TWO, THREE, …, MARKED, INCORRECTLY_MARKED, INCORRECTLY_CLEARED)`

In the above design, `TextUi` does not access `Cell` objects directly. Instead, it gets values of type `CELL_APPEARANCE` from `Logic` to be displayed as a minefield to the player. Alternatively, each cell or the entire minefield can be passed directly to `TextUi`.

Here is the updated class diagram:

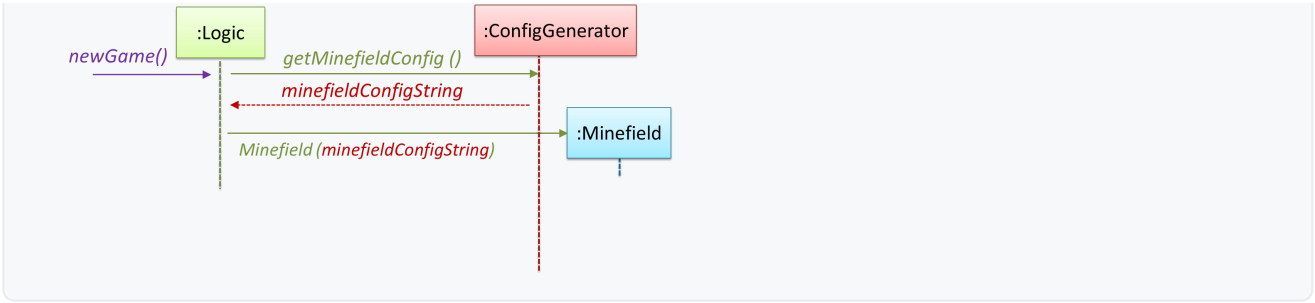


The above is for the case when Actor `Player` interacts with the system using a text UI. Additional operations (if any) required for the GUI can be discovered similarly. Suppose `Logic` supports a `reset()` operation. You can model it like this:

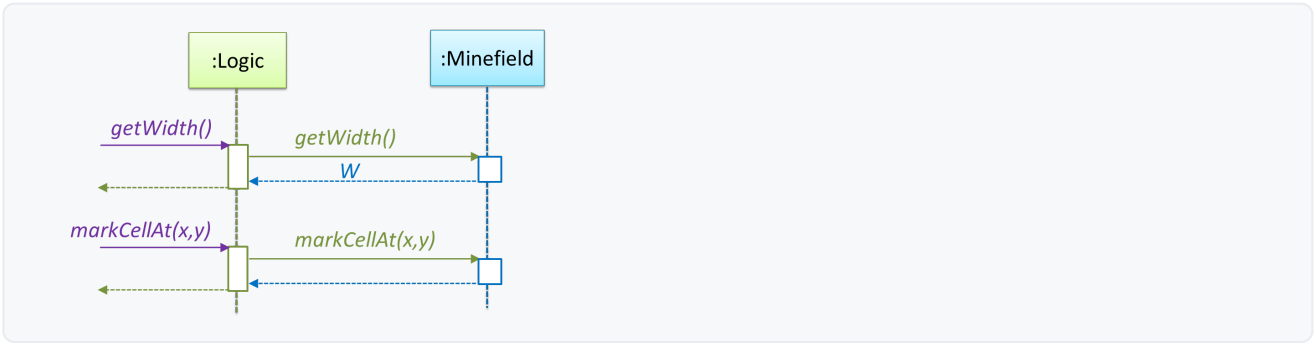


Our current model assumes that the `Minefield` object has enough information (i.e. H, W, and mine locations) to create itself.

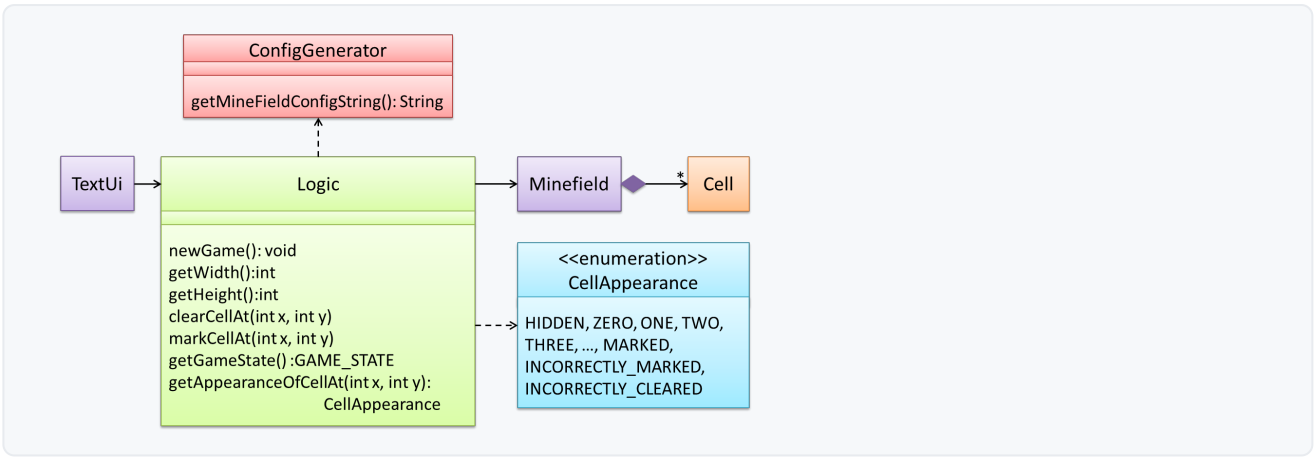
An alternative is to have a `ConfigGenerator` object that generates a string containing the minefield information as shown below.



In addition, `getWidth()`, `getHeight()`, `markCellAt(x,y)` and `clearCellAt(x,y)` can be handled like this.



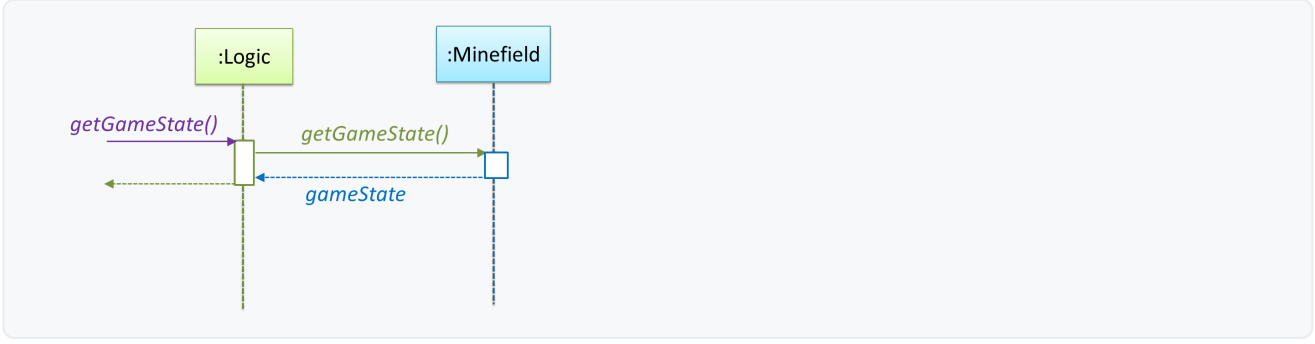
The updated class diagram:



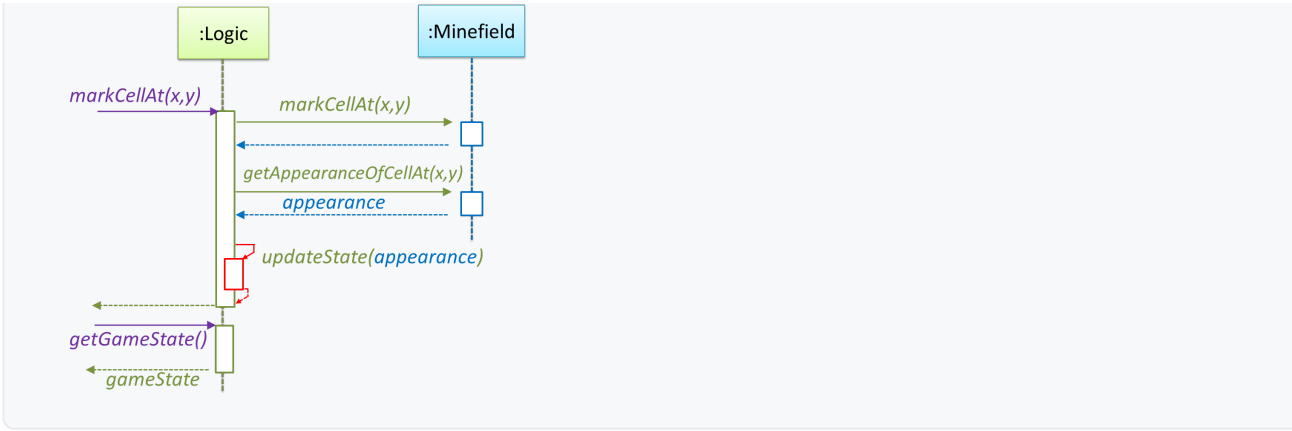
How is the `getGameState()` operation supported? Given below are two ways (there could be other ways):

1. The `Minefield` class knows the state of the game at any time. The `Logic` class retrieves it from the `Minefield` class as and when required.
2. The `Logic` class maintains the state of the game at all times.

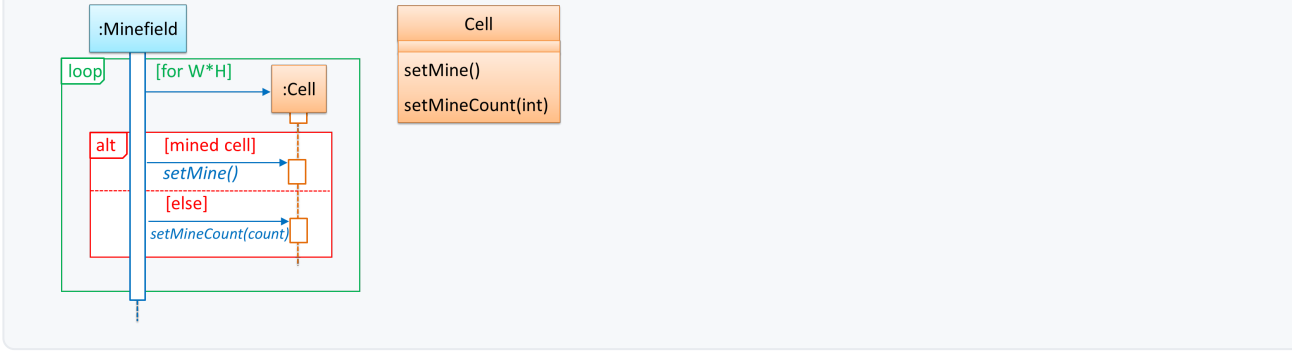
Here's the SD for option 1.



Here's the SD for option 2. Assume that the game state is updated after every mark/clear action.

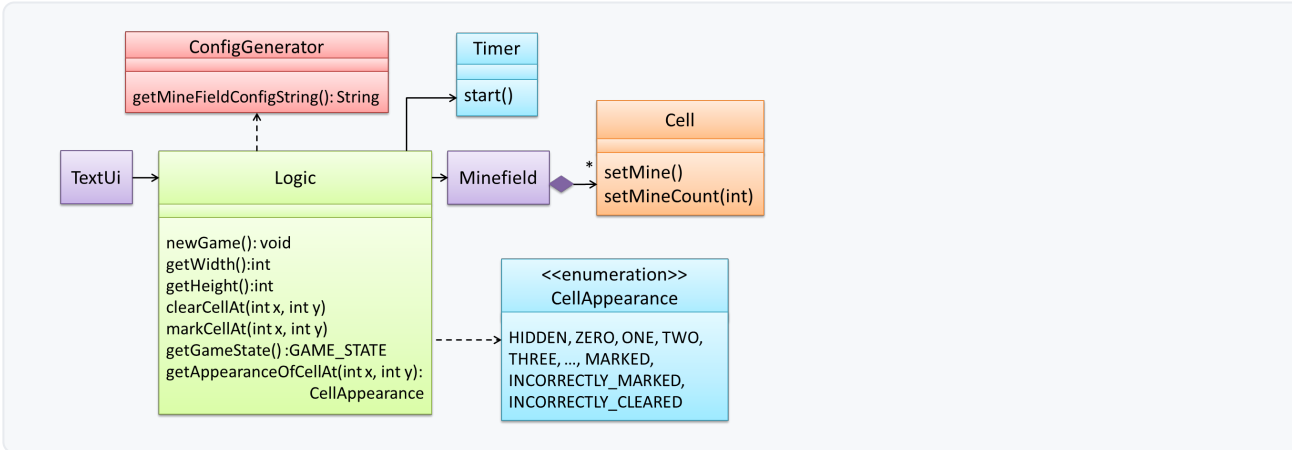


It is now time to explore what happens inside the `Minefield` constructor. One way is to design it as follows.



Now let us assume that `Minesweeper` supports a 'timing' feature.

Updated class diagram:



When designing components, it is not necessary to draw elaborate UML diagrams capturing all details of the design. They can be done as rough sketches. For example, draw sequence diagrams only when you are not sure which operations are required by each class, or when you want to verify that your class structure can indeed support the required operations.