Object Oriented Design

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Inheritance

What is it?

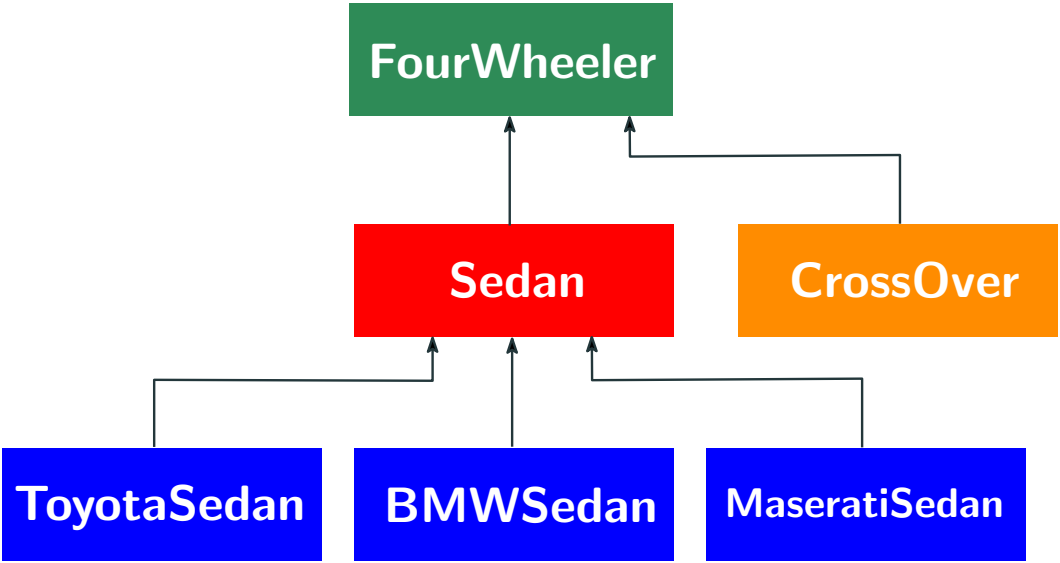
It is a mechanism by which a class can **inherit** some properties (variables and methods) of another related (coder decides) class or classes

☞ Helps to establish **meaningful relations** between various objects in a problem and also **reduces redundancy** in code

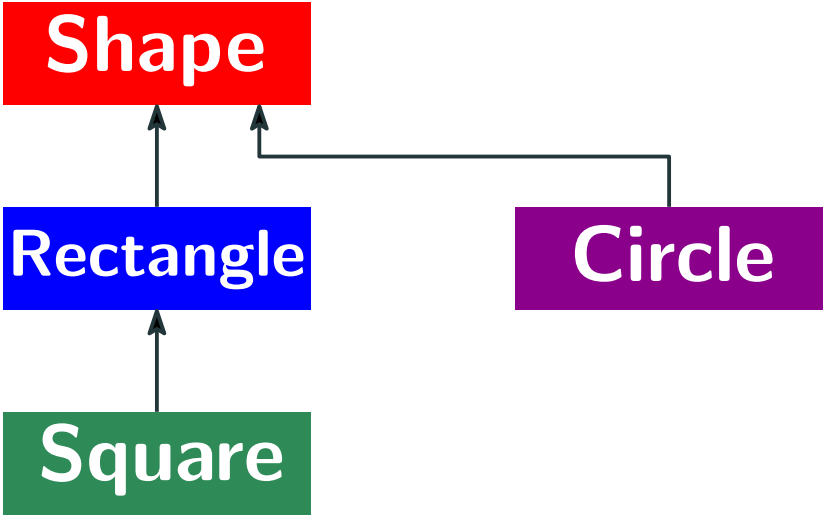
Parent and subclasses

If a class `X` **inherits** (can use) some properties (variables and methods) of another class `Y`, then with respect to this relationship, `X` is the **subclass/child class** and `Y` is the **parent** class

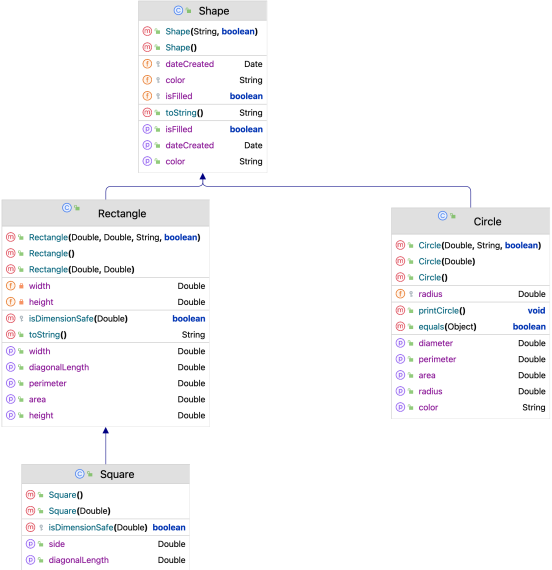
An example of inheritance



Another example



UML (Unified Modeling Language) diagram generated using IntelliJ



Generating UML diagrams in IntelliJ

1. Select a class or a package from the left pane
2. Right click on it
3. Click on `Diagrams`
4. Then, click on `Show Diagram`

IntelliJ Ultimate Version (free for students) is needed to enable this feature

The Shape class

```java
public class Shape {

   protected String color;
   protected boolean isFilled;
   protected final Date dateCreated; // once an object is created we cannot change its date of creation

   public Shape() {
      color = "black";
      isFilled = false;
      dateCreated = new Date();
      System.out.println("No arg contructor in Shape is being executed.");
   }

   public Shape(String color, boolean filled) {
      this.color = color;
      isFilled = filled;
      dateCreated = new Date();
      System.out.println("Shape(String color, boolean filled) contructor in Shape is being executed.");
   }

   public String getColor() {
      System.out.println("getColor() from Shape class is being executed");
      return color;
   }
   // continued on the next slide ...
}
```

The Shape class

```java
public class Shape {

   // continued from the previous slide

   public void setColor(String color) { this.color = color; }

   public boolean isFilled() { return isFilled; }

   public void setFilled(boolean filled) {   this.isFilled = filled; }

   final public Date getDateCreated() { // a child class cannot redefine this method since it is declared as final
      return dateCreated;
   }

   public String toString() {
      String str = "";
      str += "COLOR: " + this.color + ", IS_FILLED: ";
      str += this.isFilled + ", DATE_CREATED: ";
      str += this.dateCreated;
      return str;
   }
}
```

The Rectangle class

```java
public class Rectangle extends Shape { // a child class of the Shape class
   private Double height, width; // not accessible to any other class

   public Rectangle() {
      super("dark green",true);
      System.out.println("No arg contructor in Rectangle is being executed.");
      height = 1.0;
      width = 2.0;
   }

   public Rectangle(Double height, Double width, String color, boolean filledOrNot) {
      super(color,filledOrNot);
      System.out.println("Rectangle(Double height, Double width, String color, boolean filled) contructor in Circle
                          is being executed.");
      if(!isDimensionSafe(height) || !isDimensionSafe(width) )
         throw new IllegalArgumentException("Impermissible side-length.");

      this.height = height;
      this.width = width;
   }
   // continued on the next slide ...
}
```

The Rectangle class

```java
public class Rectangle extends Shape {
   // continued from the previous slide

   public Rectangle(Double height, Double width) {
      System.out.println("Rectangle(Double height, Double width) contructor in Circle is being executed.");
      if(!isDimensionSafe(height) || !isDimensionSafe(width) )
         throw new IllegalArgumentException("Impermissible side-length.");

      this.height = height;
      this.width = width;
   }

   public Double getWidth() {    return width; }

   public void setWidth(Double width) {
      if(!isDimensionSafe(width) )
         throw new IllegalArgumentException("Impermissible side-length.");

      this.width = width;
   }
   // continued on the next slide ...
}
```

The Rectangle class

```java
public class Rectangle extends Shape {
   // continued from the previous slide
   public Double getHeight() { return height; }

   public void setHeight(Double height) {
      if(!isDimensionSafe(height)) throw new IllegalArgumentException("Critical runtime failure.");
      this.height = height;
   }

   public Double getArea() { return height * width; }
   public Double getPerimeter() { return 2 * (height + width); }

   public String toString() {
      String str = super.toString();
      str += ", HEIGHT: " + height + ", ";
      str += "WIDTH: " + width;
      return str;
   }

   protected boolean isDimensionSafe(Double length) { return length <= 100; }

   public Double getDiagonalLength() {
      System.out.println("getDiagonalLength from Rectangle");
      return Math.sqrt( Math.pow(height, 2) + Math.pow(width, 2) );
   }
}
```

The Square class

```java
public class Square extends Rectangle { // a child class of the Rectangle; this class does not have any instance variable!
   public Square() {
      super(1.0,1.0);
      System.out.println("No arg contructor in Square is being executed.");
   }
   public Square(Double side) {
      System.out.println("Square(Double side) contructor in Square is being executed.");
      if(!isDimensionSafe(side))
         throw new IllegalArgumentException("Impermissible side-length.");
      super.setHeight(side);    super.setWidth(side);
   }
   public void setSide(Double side) {
      if(!isDimensionSafe(side))
         throw new IllegalArgumentException("Impermissible side-length.");
      super.setHeight(side);    super.setWidth(side);
   }
   public Double getSide() { return super.getHeight(); }

   @Override
   protected boolean isDimensionSafe(Double side) { return side <= 50; }

   @Override
   public Double getDiagonalLength() {
      System.out.println("getDiagonalLength from Square");
      return Math.sqrt(2) * getSide();
   }
}
```

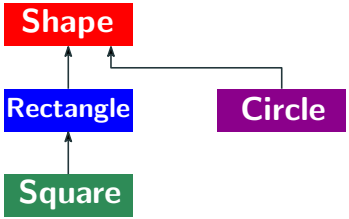
The Circle class

```java
public class Circle extends Shape {
   protected Double radius;

   public Circle() {
      this(1.0);
      System.out.println("No arg contructor in Circle is being executed.");
   }

   public Circle(Double radius) {
      if(radius < 0)
         throw new IllegalArgumentException("Radius cannot be negative.");

      this.radius = radius;
      System.out.println("Circle(Double radius) contructor in Circle is being executed.");
   }

   public Circle(Double radius, String color, boolean filled) {
      this.radius = radius;
      this.color = color;
      isFilled = filled;
      System.out.println("Circle(Double radius, String color, boolean filled) contructor in Circle is being executed.");
   }

   public Double getRadius() { return radius; }
   // continued on the next slide ...
}
```

The Circle class

```java
public class Circle extends Shape {
   // continued from the previous slide
   public void setRadius(Double radius) { this.radius = radius; }

   @Override
   public String getColor() {
      System.out.println("getColor() from Circle class is being executed");
      return color;
   }

   public Double getArea() { return Math.PI * radius * radius; }
   public Double getPerimeter() { return 2 * Math.PI * radius; }
   public Double getDiameter() { return 2 * radius; }

   // Gives compilation error since this method is already declared to be final in the superclass Shape
   //public Date getDateCreated() { return dateCreated; }

   public void printCircle() {
      System.out.println("This circle this created on " + getDateCreated() +    " having radius " + radius);
   }

   public boolean equals(Object ob) {
      if (ob instanceof Circle) return Math.abs(radius - ((Circle) ob).radius) < 0.000001;
      else return false;
   }
}
```

Fun fact



When an object of type `Square` is created, first a constructor of the `Shape` class is invoked, then a constructor from `Rectangle`, and finally a constructor from `Square`

Access modifers

Modifier	Class	Package	Subclass	Outside Package
`public`	Y	Y	Y	Y
`protected`	Y	Y	Y	***N***
none used	Y	Y	***N***	***N***
`private`	Y	***N***	***N***	***N***

https://docs.oracle.com/javase/tutorial/java/javaOO/accesscontrol.html

Important things in inheritance

- `extends` keyword: used to define a child class
- the 3 access modifier keywords are – `public`, `protected`, `private`
- if X is a child class of class Y, then when an object of type X is created, first, a constructor from the Y class is invoked
- `super` constructor: used to invoke a constructor from parent class
- for invoking a constructor from the same class use the `this` constructor
- `instanceof` operator: used to check whether an object is of a specified type (note that the left operand, which is a reference variable, must be initialized)
- the `@Override` annotation: an optional annotation used by developers to declare that a certain method is redefined/overridden in some child class
- define a method using the `final` keyword if you do not the method to be overridden by a child class

The `Object` class

`Object` class

It is a parent class of every other Java class in this universe! This means no matter which Java class you are working with, **inheritance** is always present.

☞ https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/Object.html

`println(Object x)` and `print(Object x)`

These two methods call the **`toString()`** method from the class of **`x`** for printing. In case, a `toString` method has not been defined inside the class, the **`toString()`** method from the **`Object`** class is called that creates some string representation of the object from printing purposes. Such representations look like **`introduction.Point@36baf30c`** and usually are not very useful to users.

`equals()` method

Checks if two objects have the exact same content. If the `equals()` method is not defined inside a class, the `equals()` method from the `Object` class is used whenever needed for equality checks.

Inheritance examples from Java's library

The `Number` class

Class Number

java.lang.Object
    java.lang.Number

All Implemented Interfaces:

Serializable

Direct Known Subclasses:

AtomicInteger, AtomicLong, BigDecimal, BigInteger, Byte, Double, DoubleAccumulator, DoubleAdder, Float, Integer, Long, LongAccumulator, LongAdder, Short

Classes such as `Double`, `Integer`, etc are child classes of the `Number` class, which is again a child class of the `Object` class

Reference. `https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/Number.html`

Inheritance examples from Java's library

The `IllegalArgumentException` class

```java
public double findSquareRootOf(double i) {
   if(i < 0) throw new IllegalArgumentException("Hey, i cannot be negative!");
   ....
}
```

Class IllegalArgumentException

java.lang.Object
  java.lang.Throwable
    java.lang.Exception
      java.lang.RuntimeException
        java.lang.IllegalArgumentException

All Implemented Interfaces:

Serializable

Direct Known Subclasses:

IllegalChannelGroupException, IllegalCharsetNameException, IllegalFormatException, IllegalSelectorException, IllegalThreadStateException, InvalidKeyException, InvalidOpenTypeException, InvalidParameterException, InvalidPathException, InvalidStreamException, KeyAlreadyExistsException, NumberFormatException, PatternSyntaxException, ProviderMismatchException, UnresolvedAddressException, UnsupportedAddressTypeException, UnsupportedCharsetException

Reference. https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/IllegalArgumentException.html

Other exceptions you should be aware of in this course

- **`ArithmeticException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/ArithmeticException.html
- **`NumberFormatException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/NumberFormatException.html
- **`IllegalArgumentException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/IllegalArgumentException.html
- **`NullPointerException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/NullPointerException.html
- **`IOException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/io/IOException.html
- **`IndexOutOfBoundsException`**
  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/IndexOutOfBoundsException.html
- **`IllegalStateException`**

  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/IllegalStateException.html

Good programmers usually can anticipate the possible exceptions in advance and they take care of those in their code by writing a few extra lines of code for exception handling

Generic classes

A **generic class** is a class that is parameterized over types

- The built-data structures in Java are all generic
- For instance, the `ArrayList` class is generic.

  https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/util/ArrayList.html
- `public class ArrayList<E> ... { ... }`
- This means one can declare an `ArrayList` of any data type
- ```
  ArrayList<Point> myPoints = new ArrayList<>();
  ArrayList<Double> myDoubles = new ArrayList<>();
  ```
- We cannot use the primitive types such as `int`, `double`, etc. for defining an object of a generic class. Instead, the wrapper classes, `Integer`, `Double`, etc. must be used.

☞ In this course, we will design generic classes for building the data structures
  ```

Interfaces

What is it?

An interface is a group of **related** methods with empty bodies; basically a starving class with no method bodies and possibly with no variables. They are used to design new classes.

```java
public interface SuperStoreSellableItem {
   String getDescription();
   double getListPrice();
   String findWhoSupplies();
}
```

```java
public class Photograph implements SuperStoreSellableItem{
   final private String description, supplier;
   final private double listPrice;

   public Photograph(String description, double listPrice, String supplier) {
      this.description = description;
      this.listPrice = listPrice;
      this.supplier = supplier;
   }

   public String getDescription() { return description; }
   public double getListPrice() { return listPrice; }
   public String findWhoSupplies() { return supplier; }
}
```

Interfaces

```java
import java.util.ArrayList;

public class TestPhotograph {
   public static void main(String[] args) {

      ArrayList<Photograph> wareHouse = new ArrayList<>();
      wareHouse.add(new Photograph("Dali Painting (Print)", 8753.67, "JAX Paintings"));
      wareHouse.add(new Photograph("Local Painting (Original)", 625.99, "Independent Painter"));

      System.out.print(wareHouse.get(0).getListPrice());
   }
}
```

Output

```
8753.67
```

Multiple inheritance and interfaces

```java
public interface SuperStoreSellableItem {
    String getDescription();
    double getListPrice();
    String findWhoSupplies();
}
```

```java
public interface Transportable {
    double weight();
    boolean isHazardous();
}
```

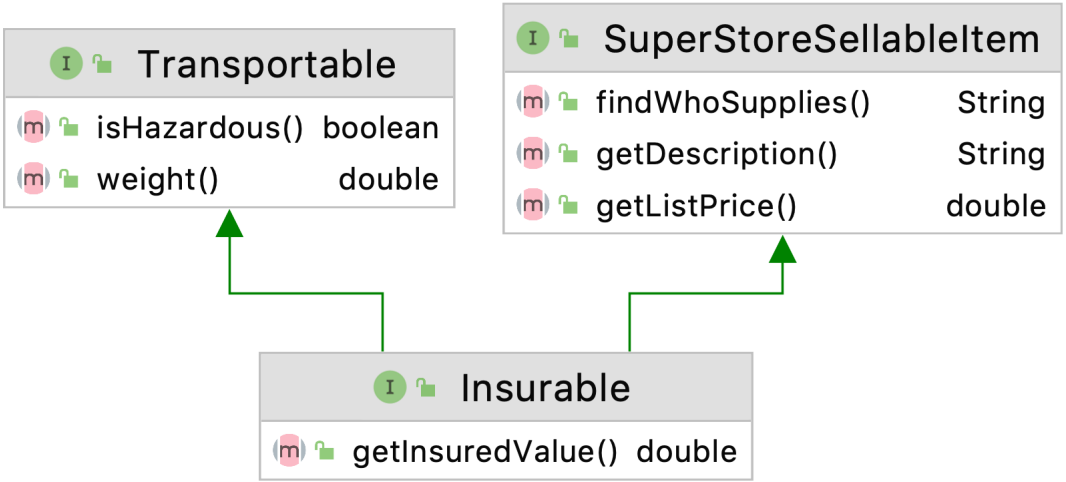
```java
public interface Insurable extends SuperStoreSellableItem, Transportable {
    double getInsuredValue();
}
```

Although not possible just with classes, one can inherit an interface from multiple interfaces

Multiple inheritance and interfaces

```java
public class BoxedItem implements Insurable {
   private String description, supplier;
   private double listPrice, weight;
   private boolean haz;

   public String getDescription() { return description; }
   public double getListPrice() { return listPrice; }
   public String findWhoSupplies() { return supplier; }

   public double weight() { return weight; }
   public boolean isHazardous() { return haz; }

   public double getInsuredValue() { return listPrice * 1.5; }
}
```

UML


Transportable
isHazardous() boolean
weight() double
SuperStoreSellableItem
findWhoSupplies() String
getDescription() String
getListPrice() double
Insurable
getInsuredValue() double

Interfaces

- We can declare variables inside an interface but they must be initialized; they are `static` and `final` by default
- We **cannot** define any method inside an interface
- Since an interface is not a class, we cannot create any object of its type

Abstract classes

```java
public abstract class AbstractSuperStoreSellableItem {
   String description;

   public String getDescription() { return description; }
   public abstract double getListPrice();
   public abstract String findWhoSupplies();
}
```

- Like interfaces, abstract classes are used to define new classes
- Unlike interfaces, normal variable declarations are allowed
- The undefined methods must have the keyword `abstract` in their signature
- Akin to interfaces, we **cannot** create an object of an abstract class

Abstract classes

```java
public abstract class AbstractSuperStoreSellableItem {
   String description;

   public String getDescription() { return description; }
   public abstract double getListPrice();
   public abstract String findWhoSupplies();
}
```

```java
public class StoreSellablePhotograph extends AbstractSuperStoreSellableItem {
   private String supplier;
   private double listPrice;

   public StoreSellablePhotograph(String description, double listPrice, String supplier) {
      this.description = description;
      this.listPrice = listPrice;
      this.supplier = supplier;
   }
   public String getDescription() { return description; }
   public double getListPrice() { return listPrice; }
   public String findWhoSupplies() { return supplier; }
}
```

Abstract classes

```java
public class TestStoreSellablePhotograph {
   public static void main(String[] args) {
      ArrayList<StoreSellablePhotograph> wareHouse = new ArrayList<>();
      wareHouse.add(new StoreSellablePhotograph("Dali Painting (Print)", 8753.67, "JAX Paintings"));
      wareHouse.add(new StoreSellablePhotograph("Local Painting (Original)", 625.99, "Independent Painter"));

      System.out.print(wareHouse.get(0).getDescription());
   }
}
```

Output

```
Dali Painting (Print)
```

Generic interfaces and abstract classes

Note

Interfaces and abstract classes can be generic too

☞ The popular `List` interface in Java is generic. See `https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/util/List.html`.

A list is an ordered collection (also known as a sequence). The user of this interface has precise control over where in the list each element is inserted. The user can access elements by their integer index (position in the list), and search for elements in the list.

☞ Generic abstract classes can be defined in the usual way like other non-abstract generic classes.

Interfaces vs abstract classes

- **Multiple inheritance** needed? Use interface, classes cannot help you
- **Want to write bodies** of some methods? Use an abstract class, interface won't you allow to do this
- **Working with unrelated classes**? Use interface, otherwise use an abstract class

Iterators

for-each loops

- ```
  ArrayList<Point> points = new ArrayList<>();
  for( Point p : points )
      System.out.println(p);
  ```
- Unlike the traditional loops (`for`, `while`, `do-while`), a `for-each` loop does not require a loop variable and is thus very easy to use
- Syntax is short and sweet; no worries about updating loop variables
- For the built-in data structures such `ArrayList`, such loops works since those classes iterable
- But what if you design your own data structure? How to make it iterable? The `for-each` loop won't know how to iterate over its data items
- **Solution.** make your class iterable by implementing the `Iterable` interface
  ```

An example

- `for-each` loop does not work on `String` objects
- **Reason.** the `String` class is not iterable
- So, let us design our own string class and make it iterable using the **`Iterable`** and **`Iterator`** interfaces that are already included in Java

`Iterable` interface in Java

https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/lang/Iterable.html

`Iterator` interface in Java

https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/util/Iterator.html

Code

```java
public class IterableString implements Iterable<Character>{
   String str;
   public IterableString(String str) { this.str = str; }
   public Character getCharAt(int position) { return str.charAt(position); }
   public int length() { return str.length(); }

   public Iterator<Character> iterator() { return new IterableStringIterator(this); }

   public static class IterableStringIterator implements Iterator<Character> {
      int position;
      IterableString s;
      public IterableStringIterator(IterableString s) {
         this.s = s;
         position = 0;
      }

      public boolean hasNext() { return position < s.length(); }

      public Character next() {
         Character c = s.getCharAt(position);
         position++;
         return c;
      }
      public String toString(){ return str; }
   }
}
```

Code

Now for-each loop works!

```
var str = new IterableString("Data Structures"); // 'var' keyword can auto-detect the type of the variables in most cases
for( var c : str )
      System.out.print(c);
```

Another way to iterate

```
Iterator<Character> it = str.iterator();
while(it.hasNext())
    System.out.print(it.next());
```

Built-in iterable string class in Java

StringBuilder

An authentic and short Java tutorial

https://docs.oracle.com/javase/tutorial/index.html