Binary File I/O

Introduction to Programming and Computational Problem Solving: Accelerated Pace

CSE 11

Lecture 18

Announcements

- Assignment 7 is due today, 11:59 PM
  - Upgrade beginning Mar 14, 12:01 AM
- Final assessment is Mar 14-21
- Assignments 5-7 upgrades due Mar 18, 11:59 PM
- Please complete Student Evaluations of Teaching (SET)
- Please complete TA and tutor evaluations

Files

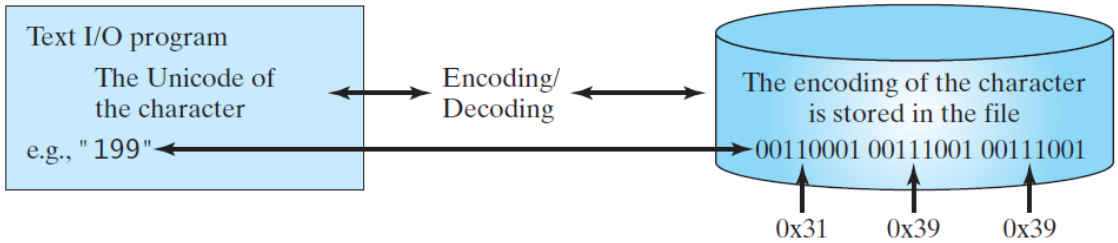
- Files can be classified as either text or binary
  - Human readable files are **text files**
  - All other files are **binary files**
- Java provides many classes for performing text file Input/Output (I/O) and binary file I/O

File I/O

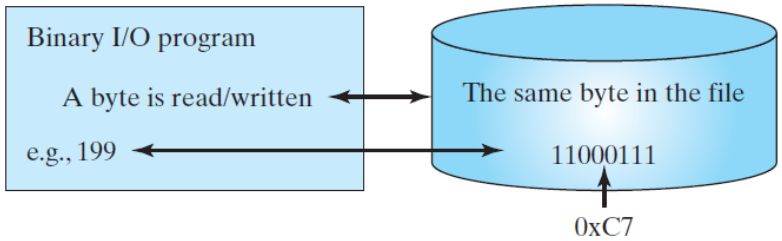
- Remember, a `File` object encapsulates the properties of a file (or directory), *but does not contain the methods for reading/writing data from/to a file*
- In order to perform I/O, you need to create objects using appropriate Java I/O classes
  - The objects contain the methods for reading/writing data from/to a file
- Text file I/O
  - Use the `Scanner` class for reading text data from a file
    - The JVM converts a file specific encoding to Unicode when reading a character
  - Use the `PrintWriter` class for writing text data to a file
    - The JVM converts Unicode to a file specific encoding when writing a character

Binary file I/O

- Binary file I/O does not involve encoding or decoding and thus is more efficient than text file I/O
- Binary files are independent of the encoding scheme on the host machine



(a)

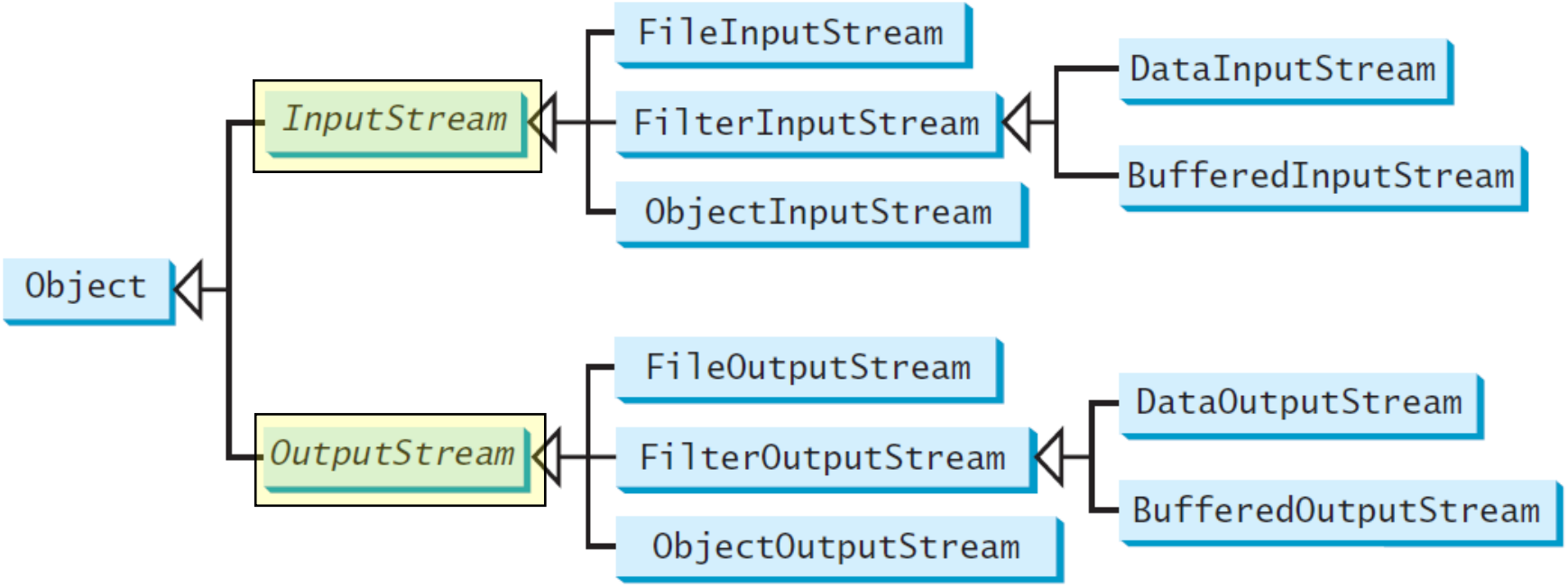


(b)

When you write a byte to a file, the original byte is copied into the file. When you read a byte from a file, the exact byte in the file is returned.

Binary I/O classes

- The abstract `InputStream` is the root class for reading binary data
- The abstract `OutputStream` is the root class for writing binary data



The `InputStream` class

https://docs.oracle.com/javase/8/docs/api/java/io/InputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/InputStream.html

The value returned is a byte as an `int` type

java.io.InputStream	
+read(): int	Reads the next byte of data from the input stream. The value byte is returned as an int value in the range 0 to 255. If no byte is available because the end of the stream has been reached, the value –1 is returned.
+read(b: byte[]): int	Reads up to b.length bytes into array b from the input stream and returns the actual number of bytes read. Returns -1 at the end of the stream.
+read(b: byte[], off: int, len: int): int	Reads bytes from the input stream and stores into b[off], b[off+1], …, b[off+len-1]. The actual number of bytes read is returned. Returns -1 at the end of the stream.
+available(): int	Returns the number of bytes that can be read from the input stream.
+close(): void	Closes this input stream and releases any system resources associated with the stream.
+skip(n: long): long	Skips over and discards n bytes of data from this input stream. The actual number of bytes skipped is returned.
+markSupported(): boolean	Tests if this input stream supports the mark and reset methods.
+mark(readlimit: int): void	Marks the current position in this input stream.
+reset(): void	Repositions this stream to the position at the time the mark method was last called on this input stream.

The `OutputStream` class

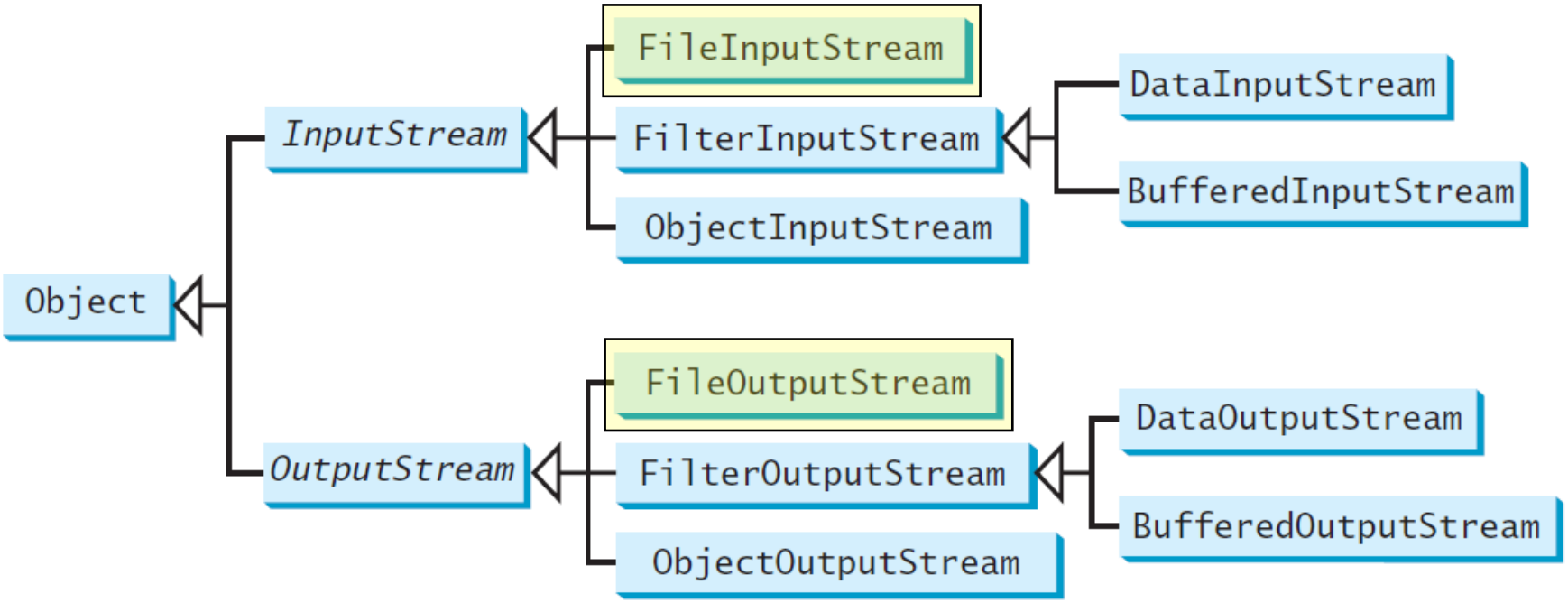
https://docs.oracle.com/javase/8/docs/api/java/io/OutputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/OutputStream.html

The value is a byte as an `int` type

java.io.OutputStream	
+write(int b): void	Writes the specified byte to this output stream. The parameter b is an int value. (byte)b is written to the output stream.
+write(b: byte[]): void	Writes all the bytes in array b to the output stream.
+write(b: byte[], off: int, len: int): void	Writes b[off], b[off+1], …, b[off+len-1] into the output stream.
+close(): void	Closes this output stream and releases any system resources associated with the stream.
+flush(): void	Flushes this output stream and forces any buffered output bytes to be written out.

Binary file I/O classes

- `FileInputStream`/`FileOutputStream` are for reading/writing bytes from/to files
- All the methods in `FileInputStream` and `FileOutputStream` are inherited from their superclasses



The `FileInputStream` class

https://docs.oracle.com/javase/8/docs/api/java/io/FileInputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/FileInputStream.html

- To construct a `FileInputStream` object, use the following constructors

```
public FileInputStream(String filename)
public FileInputStream(File file)
```

- A `java.io.FileNotFoundException` will occur if you attempt to create a `FileInputStream` with a nonexistent file

The `FileOutputStream` class

https://docs.oracle.com/javase/8/docs/api/java/io/FileOutputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/FileOutputStream.html

- To construct a `FileOutputStream` object, use the following constructors

```
public FileOutputStream(String filename)
public FileOutputStream(File file)
public FileOutputStream(String filename, boolean append)
public FileOutputStream(File file, boolean append)
```

- If the file does not exist, a new file will be created
- If the file already exists, the first two constructors will **delete** the current contents in the file
- To retain the current content and **append** new data into the file, use the last two constructors by passing `true` to the append parameter

Binary file I/O using `FileInputStream` and `FileOutputStream`

```
public class TestFileStream {
  public static void main(String[] args) throws IOException {
    try (
      // Create an output stream to the file
      FileOutputStream output = new FileOutputStream("temp.dat");
    ) {
      // Output values to the file
      for (int i = 1; i <= 10; i++)
        output.write(i);
    }

    try (
      // Create an input stream for the file
      FileInputStream input = new FileInputStream("temp.dat");
    ) {
      // Read values from the file
      int value;
      while ((value = input.read()) != -1)
        System.out.print(value + " ");
    }
  }
}
```

Use try-with-resources syntax because classes implement `AutoClosable` interface

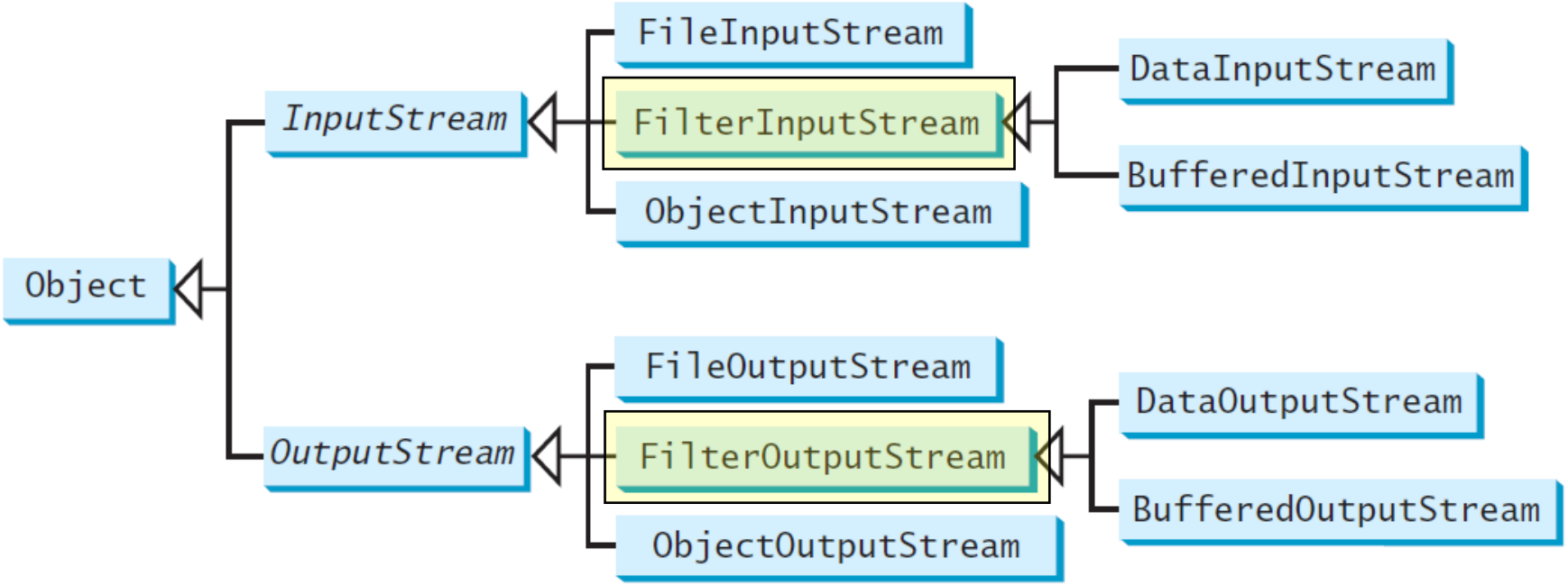
Check for end of file

Filter streams

- `FileInputStream` provides a `read` method that can only be used for reading bytes
  - If you want to read integers, doubles, or strings, you need a filter class to wrap the byte input stream
- *Filter streams* are streams that filter bytes for some purpose
  - Using a filter class enables you to read integers, doubles, and strings instead of bytes and characters

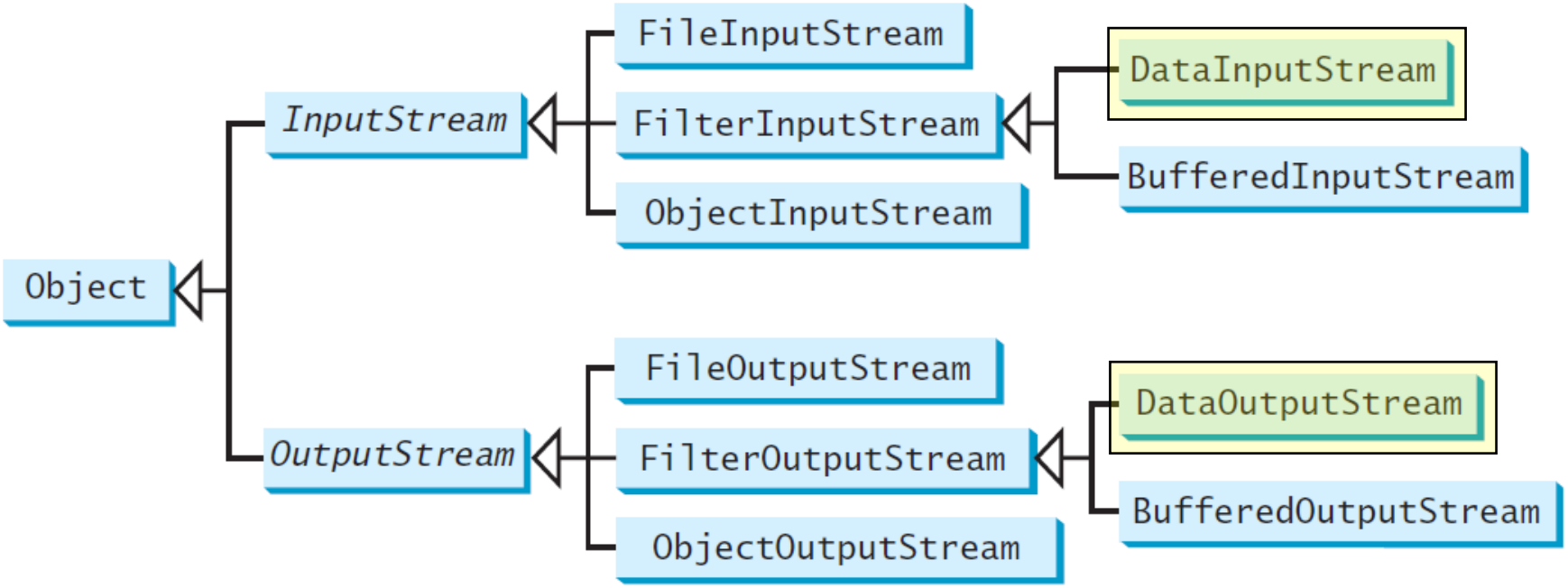
Binary filter I/O classes

- `FilterInputStream` and `FilterOutputStream` are the base classes for filtering data



Binary filter I/O classes

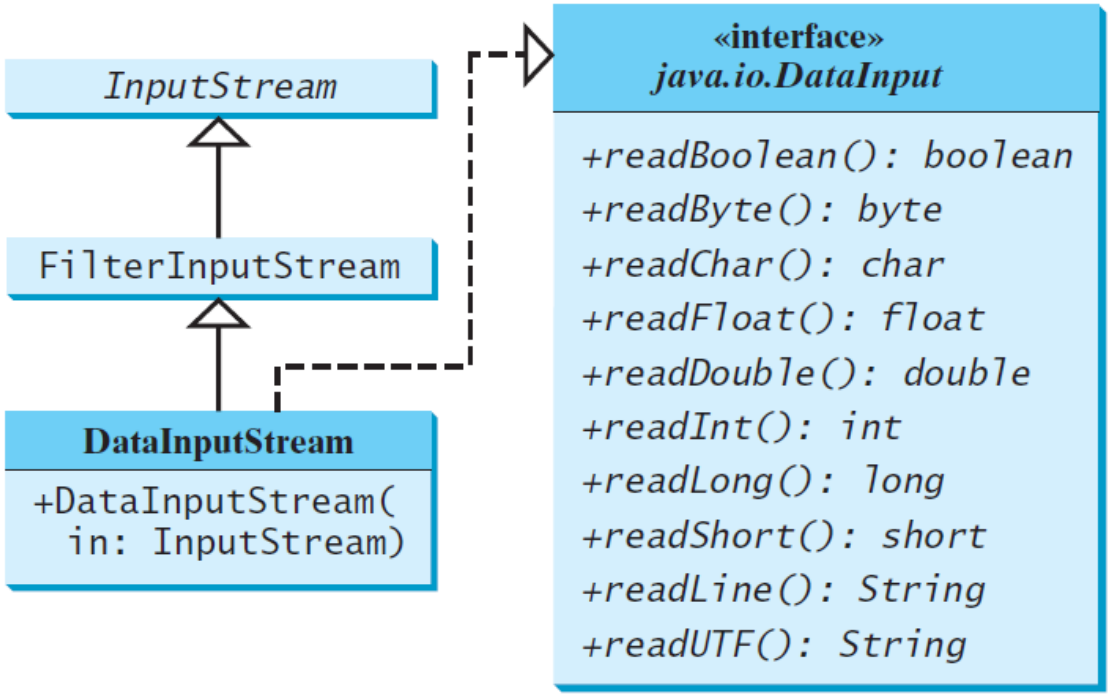
- When you need to process primitive numeric types, use `DataInputStream` and `DataOutputStream` to filter bytes



The `DataInputStream` class

https://docs.oracle.com/javase/8/docs/api/java/io/DataInputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/DataInputStream.html

- `DataInputStream` reads bytes from the stream and converts them into appropriate primitive type values or strings
- `DataInputStream` extends `FilterInputStream` and implements the `DataInput` interface

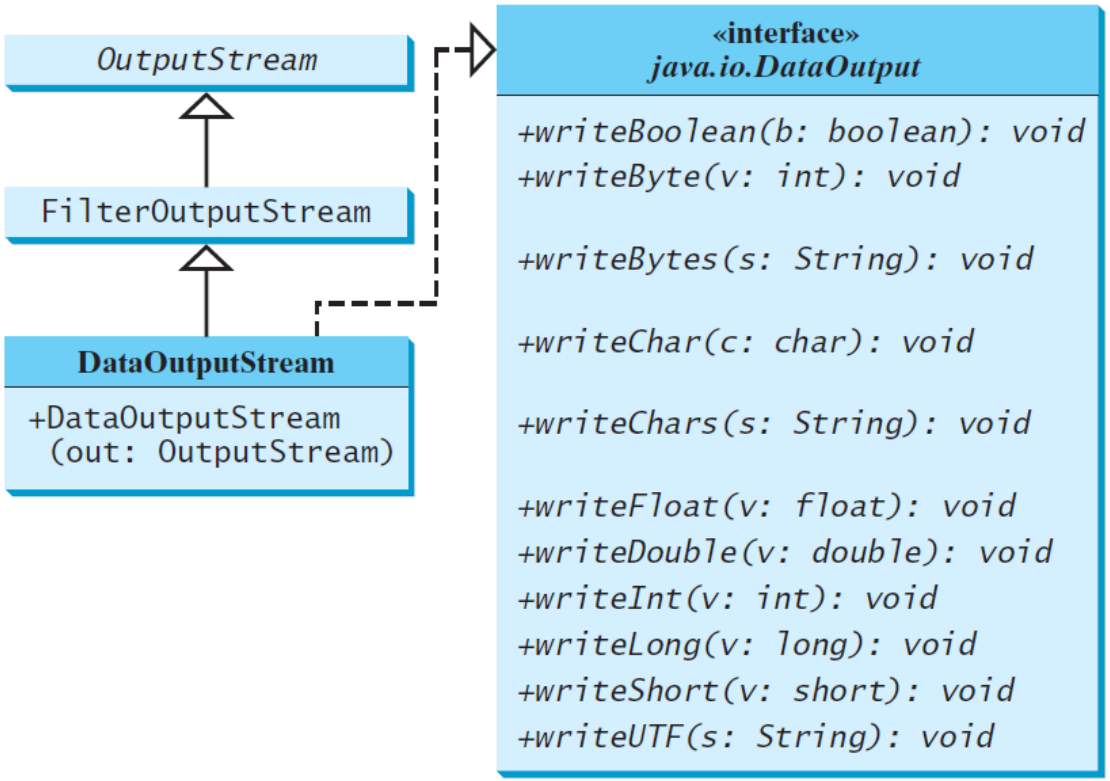


Reads a `Boolean` from the input stream.	
Reads a `byte` from the input stream.	
Reads a character from the input stream.	
Reads a `float` from the input stream.	
Reads a `double` from the input stream.	
Reads an `int` from the input stream.	
Reads a `long` from the input stream.	
Reads a `short` from the input stream.	
Reads a `line` of characters from input.	
Reads a `string` in UTF format.	

The `DataOutputStream` class

https://docs.oracle.com/javase/8/docs/api/java/io/DataOutputStream.html
https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/io/DataOutputStream.html

- `DataOutputStream` converts primitive type values or strings into bytes and output the bytes to the stream
- `DataOutputStream` extends `FilterOutputStream` and implements the `DataOutput` interface



`+writeBoolean(b: boolean): void`	Writes a Boolean to the output stream.
`+writeByte(v: int): void`	Writes the eight low-order bits of the argument `v` to the output stream.
`+writeBytes(s: String): void`	Writes the lower byte of the characters in a string to the output stream.
`+writeChar(c: char): void`	Writes a character (composed of 2 bytes) to the output stream.
`+writeChars(s: String): void`	Writes every character in the string `s` to the output stream, in order, 2 bytes per character.
`+writeFloat(v: float): void`	Writes a `float` value to the output stream.
`+writeDouble(v: double): void`	Writes a `double` value to the output stream.
`+writeInt(v: int): void`	Writes an `int` value to the output stream.
`+writeLong(v: long): void`	Writes a `long` value to the output stream.
`+writeShort(v: short): void`	Writes a `short` value to the output stream.
`+writeUTF(s: String): void`	Writes `s` string in UTF format.

Characters and strings in binary I/O

- Remember, a Unicode character consists of two bytes
  - The `writeChar(char c)` method writes the Unicode of character `c` to the output
  - The `writeChars(String s)` method writes the Unicode for each character in the string `s` to the output
- Remember, an ASCII character consists of one byte, which is stored in the **lower byte** of a Unicode character
  - The `writeByte(int v)` method writes the **lowest byte** of integer `v` to the output (i.e., **the higher three bytes of the integer are discarded**)
  - The `writeBytes(String s)` method writes the **lower byte** of the Unicode of the characters in the string `s` to the output (i.e., **the higher byte of the Unicode of the characters are discarded**)

Characters and strings in binary I/O

- Unicode Transformation Format (UTF)
  - The `writeUTF(String s)` method writes the string `s` in UTF
    - UTF is coding scheme for efficiently compressing a string of Unicode characters

Binary file I/O using DataInputStream and DataOutputStream

```
public class TestDataStream {
  public static void main(String[] args) throws IOException {
    try ( // Create an output stream for file temp.dat
      DataOutputStream output =
        new DataOutputStream(new FileOutputStream("temp.dat"));
    ) {
      // Write student test scores to the file
      output.writeUTF("John");
      output.writeDouble(85.5);
      output.writeUTF("Jim");
      output.writeDouble(185.5);
      output.writeUTF("George");
      output.writeDouble(105.25);
    }

    try ( // Create an input stream for file temp.dat
      DataInputStream input =
        new DataInputStream(new FileInputStream("temp.dat"));
    ) {
      // Read student test scores from the file
      System.out.println(input.readUTF() + " " + input.readDouble());
      System.out.println(input.readUTF() + " " + input.readDouble());
      System.out.println(input.readUTF() + " " + input.readDouble());
    }
  }
}
```

You must read the data in the **same order <u>and</u> same format** in which they are stored

End of file (EOF)

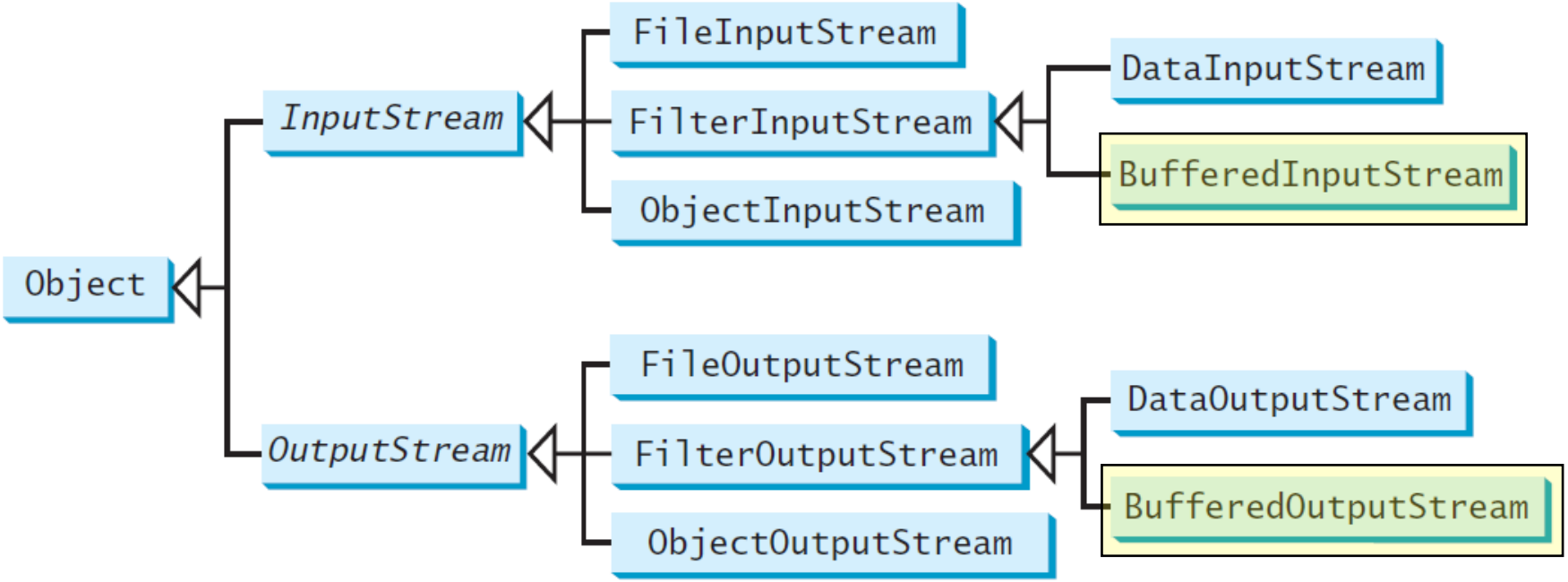
- If you keep reading data at the end of an `InputStream`, then an `EOFException` will occur

```
public class DetectEndOfFile {
  public static void main(String[] args) {
    try {
      try (DataInputStream input =
        new DataInputStream(new FileInputStream("test.dat"))) {
        while (true)
          System.out.println(input.readDouble());
      }
    }
    catch (EOFException ex) {
      System.out.println("All data were read");
    }
    catch (IOException ex) {
      ex.printStackTrace();
    }
  }
}
```

This is just an example to throw `EOFException`. Use `input.available()` to check for EOF (if `input.available() == 0`, then it is EOF).

Binary filter I/O classes

- Use `BufferedInputStream` and `BufferedOutputStream` to speed up input and output by reading ahead and writing later
- All the methods in `BufferedInputStream` and `BufferedOutputStream` are inherited from their superclasses

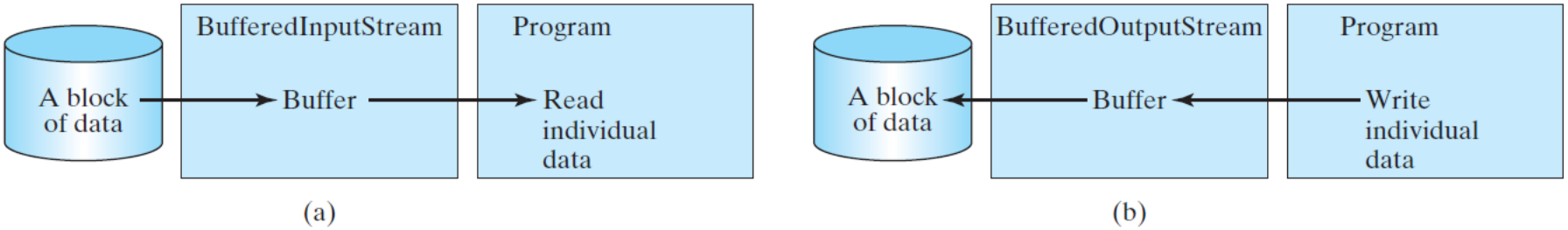


The BufferedInputStream and BufferedOutputStream classes

```
// Create a BufferedInputStream
public BufferedInputStream(InputStream in)
public BufferedInputStream(InputStream in, int bufferSize)

// Create a BufferedOutputStream
public BufferedOutputStream(OutputStream out)
public BufferedOutputStream(OutputStream out, int bufferSize)
```

The default buffer size is 512 bytes



Example

```
public class Copy {
  public static void main(String[] args) throws IOException {
    // Check command-line parameter usage
    if (args.length != 2) {
      System.out.println(
        "Usage: java Copy sourceFile targetfile");
      System.exit(1);
    }

    // Check if source file exists
    File sourceFile = new File(args[0]);
    if (!sourceFile.exists()) {
       System.out.println("Source file " + args[0] + " does not exist");
       System.exit(2);
    }

    // Check if target file exists
    File targetFile = new File(args[1]);
    if (targetFile.exists()) {
      System.out.println("Target file " + args[1] + " already exists");
      System.exit(3);
    }
    ...
```

Example

```
    ...
    try (
      // Create an input stream
      BufferedInputStream input =
        new BufferedInputStream(new FileInputStream(sourceFile));

      // Create an output stream
      BufferedOutputStream output =
        new BufferedOutputStream(new FileOutputStream(targetFile));
    ) {
      // Continuously read a byte from input and write it to output
      int r;
      int numberOfBytesCopied = 0;
      while ((r = input.read()) != -1) {
        output.write((byte)r);
        numberOfBytesCopied++;
      }

      // Display the file size
      System.out.println(numberOfBytesCopied + " bytes copied");
    }
  }
}
```

Check for end of file

Other binary file I/O

- Objects
  - `ObjectInputStream` and `ObjectOutputStream` can be used to read and write serializable objects
- Random access
  - `RandomAccessFile` allows data to be read from and written to any location (not necessarily sequentially) in the file

CSE 11 topics

- Introduction to Java
- Numbers and mathematics
- Characters and strings
- Selections
- Methods
- Loops
- Recursion (simple)
- Arrays

Procedural programming

Object-oriented programming

- Objects and classes
  - Object-oriented thinking
- Inheritance
- Polymorphism
- Abstract classes
- Interfaces
- Introduction to generics
- Exceptions
- Text file input/output
- Binary file input/output
- Assertions

Introduction to Java

- Java is:
  - a high-level programming language
    - Computer-specific details are abstracted
  - an object-oriented programming language
    - Based on classes
  - a strongly typed language
    - **Programmers must explicitly identify the type of every variable, method, and object**
  - a general-purpose programming language
    - Not specialized to a particular application domain
  - platform independent
    - Write a program once and run it on any computer

Numbers and mathematics

- Numerical data types (e.g., an integer)
- Numeric operations (e.g., addition)
- Mathematical functions (e.g., cosine)
- Reading numbers from the console

Characters and strings

- Character data type (i.e., `char`)
- Comparing and testing characters
- String data type (i.e., `String`)
- Simple string methods (e.g., number of characters in a string)
- Reading a character and string from the console

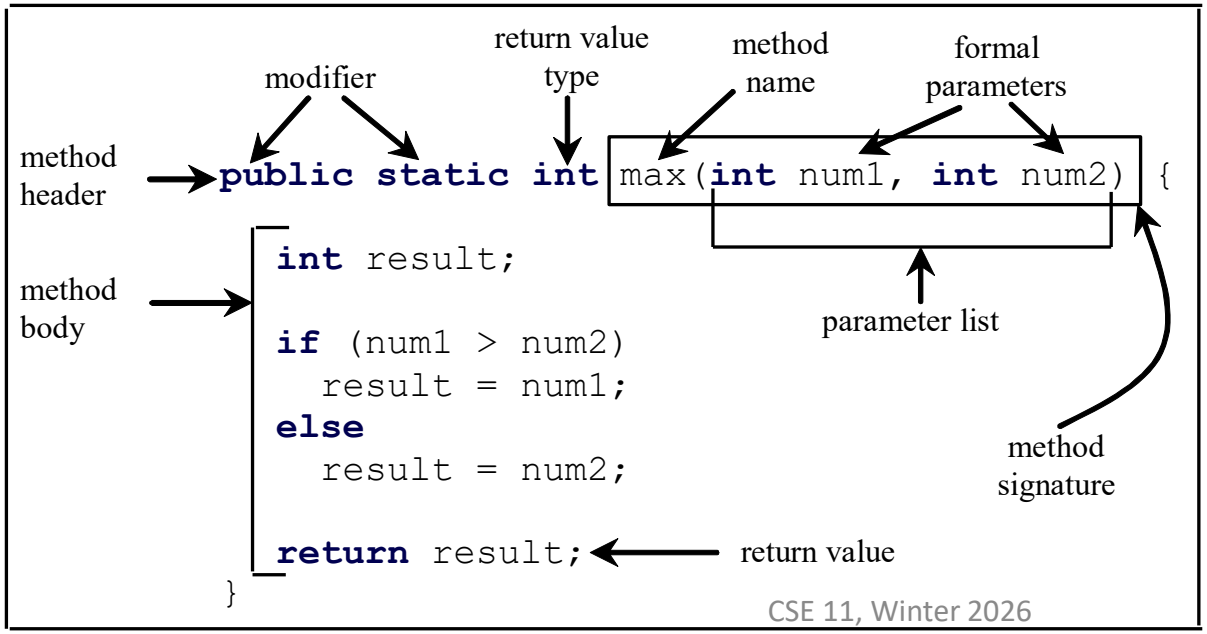
Selections

- Relational operators (e.g., less than, equal to)
- Logical operators (e.g., not, and, or)
- `if` statements
- `if-else` statements
- `switch` statements

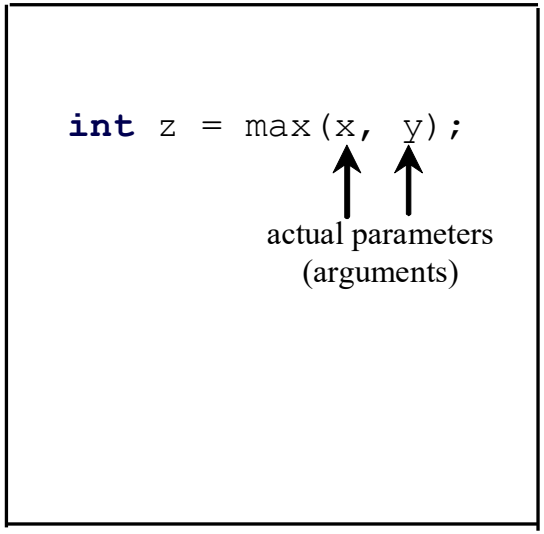
Methods

- A method is a collection of statements that are grouped together to perform an operation
- Write a method once and reuse it anywhere

Define a method



Invoke a method

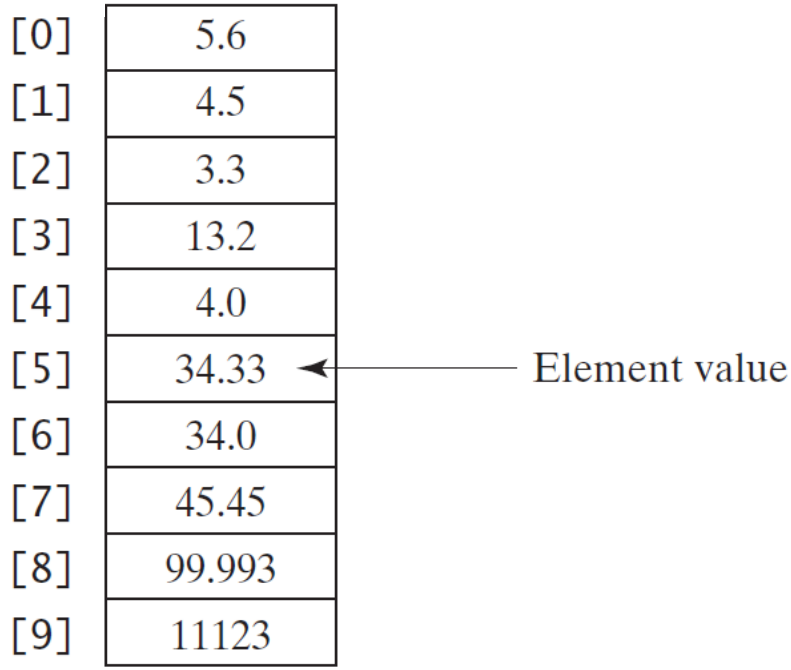


Loops and recursion

- `while` loops
- `do-while` loops
- `for` loops
- Recursion is a technique that leads to elegant solutions to problems that are difficult to program using simple loops
  - A recursive method is one that invokes itself directly or indirectly

Arrays

- Array is a data structure that represents a collection of the same types of data



1-dimensional array

	[0]	[1]	[2]	[3]	[4]
[0]	0	0	0	0	0
[1]	0	0	0	0	0
[2]	0	7	0	0	0
[3]	0	0	0	0	0
[4]	0	0	0	0	0

2-dimensional array

Procedural programming vs object-oriented programming

- Procedural programming
  - Data and operations on data are separate
  - Requires passing data to methods
- Object-oriented programming
  - Data and operations on data are in an object
  - Organizes programs like the real world
    - All objects are associated with both attributes and activities
  - Using objects improves software reusability and makes programs easier to both develop and maintain

Objects and classes

- An object represents an entity in the real world that can be distinctly identified
  - For example, a student, a desk, a circle, a button, and even a loan can all be viewed as objects
  - An object has a unique identity, state, and behaviors
- Classes are constructs that define objects of the same type

Object-oriented thinking

- Classes provide more flexibility and modularity for building reusable software
- Class abstraction and encapsulation
  - Separate class implementation from the use of the class
  - The creator of the class provides a description of the class and let the user know how the class can be used
  - The user of the class does not need to know how the class is implemented
  - The detail of implementation is encapsulated and hidden from the user

Inheritance

- Inheritance enables you to define a general class (i.e., a *superclass*) and later extend it to more specialized classes (i.e., *subclasses*)
- A subclass inherits from a superclass
  - For example, both a circle and a rectangle are geometric objects
    - `GeometricObject` is a superclass
    - `Circle` is a subclass of `GeometricObject`
    - `Rectangle` is a subclass of `GeometricObject`
- Models **is-a** relationships
  - For example
    - `Circle` **is-a** `GeometricObject`
    - `Rectangle` **is-a** `GeometricObject`

Polymorphism

- A class defines a type
- A type defined by a subclass is called a *subtype*, and a type defined by its superclass is called a *supertype*
  - For example
    - `Circle` is a subtype of `GeometricObject`, and `GeometricObject` is a supertype for `Circle`
- *Polymorphism* means that a variable of a supertype can refer to a subtype object
  - Greek word meaning “many forms”

Abstract classes

- Inheritance enables you to define a general class (i.e., a *superclass*) and later extend it to more specialized classes (i.e., *subclasses*)
- Sometimes, a superclass is so general it cannot be used to create objects
  - Such a class is called an *abstract class*
- An abstract class cannot be used to create objects
- An **abstract** class can contain abstract methods that are implemented in **concrete** subclasses
- Just like nonabstract classes, models **is-a** relationships
  - For example
    - `Circle` **is-a** `GeometricObject`
    - `Rectangle` **is-a** `GeometricObject`

Interfaces

- An interface is a class-like construct that contains **only** constants and abstract methods . An interface can also contain default and static methods with implementations.
  - In many ways, an interface is similar to an abstract class, but the intent of an interface is to specify common behavior for objects
    - For example, you can specify that the objects are comparable and/or cloneable using appropriate interfaces
- Interfaces model **is-kind-of** relationships
  - For example
    - `Fruit` **is-kind-of** `Edible`
    - `Fish` **is-kind-of** `Edible`

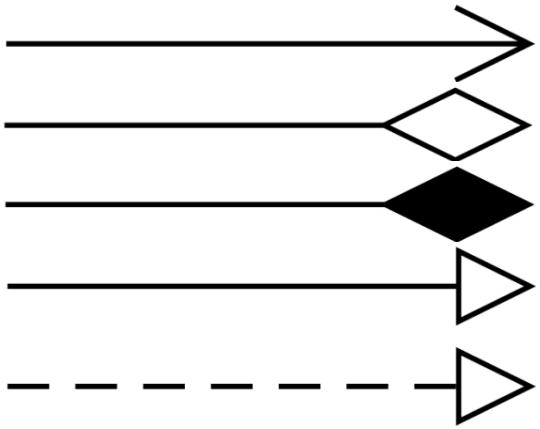
Methods and data fields visibility

Modifiers on Members in a Class	Accessed from Same Class	Accessed from Any Class in Same Package	Accessed from Any Class in Same Package and Any Subclass in Any Package	Accessed from Any Class in Any Package
Public	✓	✓	✓	✓
Protected	✓	✓	✓	
Default (no modifier)	✓	✓		
Private	✓			

Unified Modeling Language (UML)

+ public
# protected
- private

- Static variables and methods are <u>underlined</u>
- Abstract class names and methods are *italicized*
- Interface names and methods are *italicized*
- Open or no arrow is association
- Hollow diamond is aggregation
- Filled diamond is composition
- Hollow triangle is inheritance
- Dashed line with hollow triangle is implementation of interface



Additional topics

- Introduction to generics
- Exceptions
- Text file input/output (I/O)
- Binary file input/output (I/O)
- Assertions

Introduction to generics

- Generics let you parameterize types
  - You can define a method or class with generic types, which are replaced with concrete types

Exceptions

- Exceptions are errors caused by your program and external circumstances
  - These errors can be caught and handled by your program
- Exception handling separates error-handling code from normal programming tasks
  - Makes programs easier to read and to modify
- The **`try`** block contains the code that is executed in **normal** circumstances
- The **`catch`** block contains the code that is executed in **exceptional** circumstances
- A method should **throw** an exception if the error needs to be handled by its caller

Text file input/output (I/O)

- In order to perform I/O, you need to create objects using appropriate Java I/O classes
  - The objects contain the methods for reading/writing data from/to a file

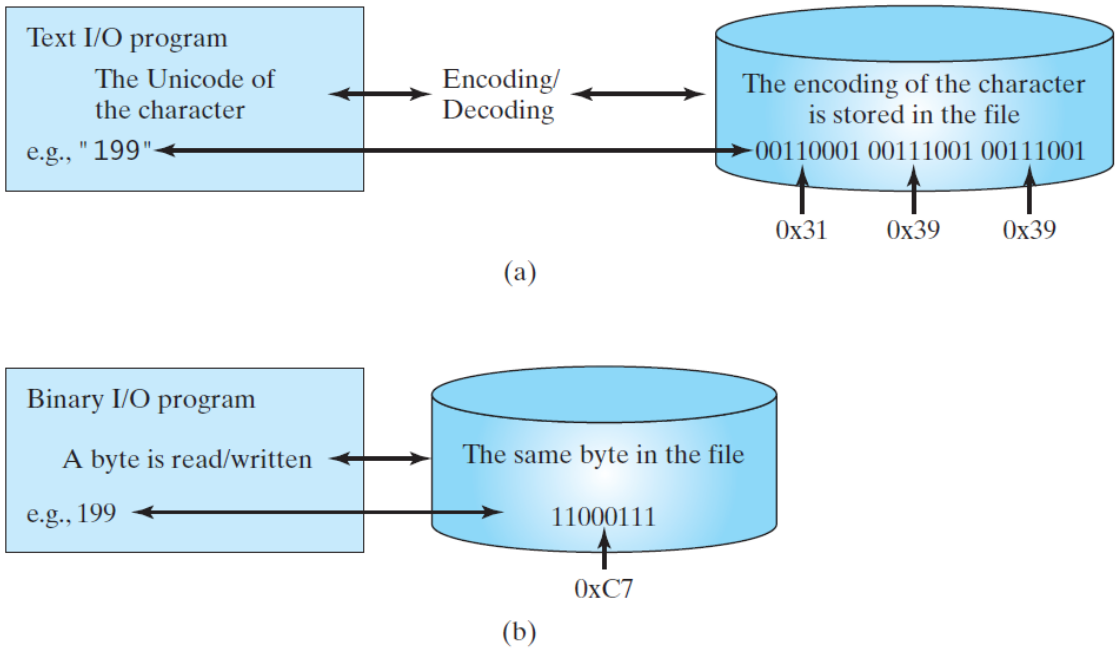
    `File`

    `Scanner`

    `PrintWriter`

Binary file input/output (I/O)

- Binary I/O does not involve encoding or decoding and thus is more efficient than text I/O



Assertions

- An assertion is a Java statement that enables you to assert an assumption about your program
- An assertion contains a Boolean expression that should be true during program execution
- Assertions can be used to assure program correctness and avoid logic errors

CSE 11 topics

- Introduction to Java
- Numbers and mathematics
- Characters and strings
- Selections
- Methods
- Loops
- Recursion (simple)
- Arrays

Procedural programming

Object-oriented programming

- Objects and classes
  - Object-oriented thinking
- Inheritance
- Polymorphism
- Abstract classes
- Interfaces
- Introduction to generics
- Exceptions
- Text file input/output
- Binary file input/output
- Assertions