Object Oriented Programming

I/O Streams

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Learning outcomes

After this lecture and the related practical students should...

- understand the concept of streams in Java
- be able to create and use text and data streams

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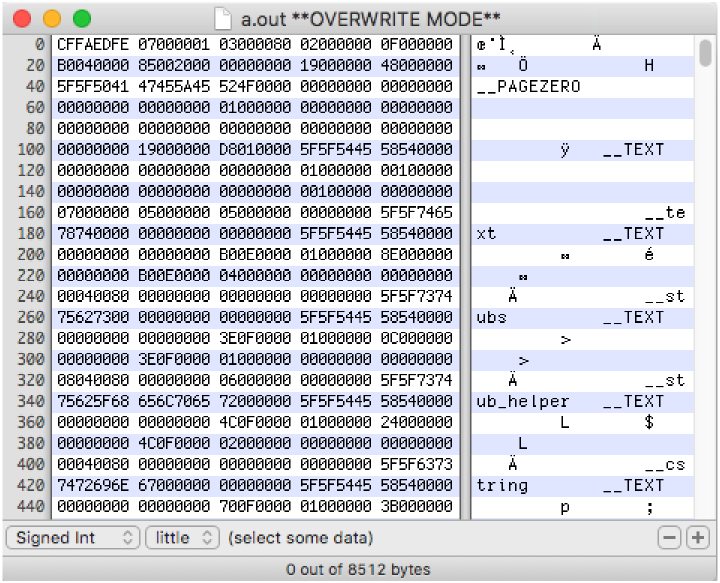
Files

- We usually distinguish between two different types of files
  - Data Files
  - Text Files
- Both store data in binary
- Text files store it in a way most programs can understand

Data Files

- These types of files contain only data in binary
- If we try to look at these all we will see is numbers (usually in hex)
- It may not be possible to understand the meaning of the data
  - Two int values will look the same as one long value or eight bytes

Data File



a.out **OVERWRITE MODE**

```
  0  CFFAEDFE 07000001 03000080 02000000 0F000000   œ˙Ì˛       Ä
 20  B0040000 85002000 00000000 19000000 48000000   ∞   Ö           H
 40  5F5F5041 47455A45 524F0000 00000000 00000000   __PAGEZERO
 60  00000000 00000000 01000000 00000000 00000000
 80  00000000 00000000 00000000 00000000 00000000
100  00000000 19000000 D8010000 5F5F5445 58540000           ÿ   __TEXT
120  00000000 00000000 00000000 01000000 00100000
140  00000000 00000000 00000000 00100000 00000000
160  07000000 05000000 05000000 00000000 5F5F7465                   __te
180  78740000 00000000 00000000 5F5F5445 58540000   xt          __TEXT
200  00000000 00000000 B00E0000 01000000 8E000000           ∞       é
220  00000000 B00E0000 04000000 00000000 00000000       ∞
240  00040080 00000000 00000000 00000000 5F5F7374      Ä            __st
260  75627300 00000000 00000000 5F5F5445 58540000   ubs         __TEXT
280  00000000 00000000 3E0F0000 01000000 0C000000           >
300  00000000 3E0F0000 01000000 00000000 00000000       >
320  08040080 00000000 06000000 00000000 5F5F7374      Ä            __st
340  75625F68 656C7065 72000000 5F5F5445 58540000   ub_helper   __TEXT
360  00000000 00000000 4C0F0000 01000000 24000000           L       $
380  00000000 4C0F0000 02000000 00000000 00000000       L
400  00040080 00000000 00000000 00000000 5F5F6373      Ä            __cs
420  7472696E 67000000 00000000 5F5F5445 58540000   tring       __TEXT
440  00000000 00000000 700F0000 01000000 3B000000           p       ;
```

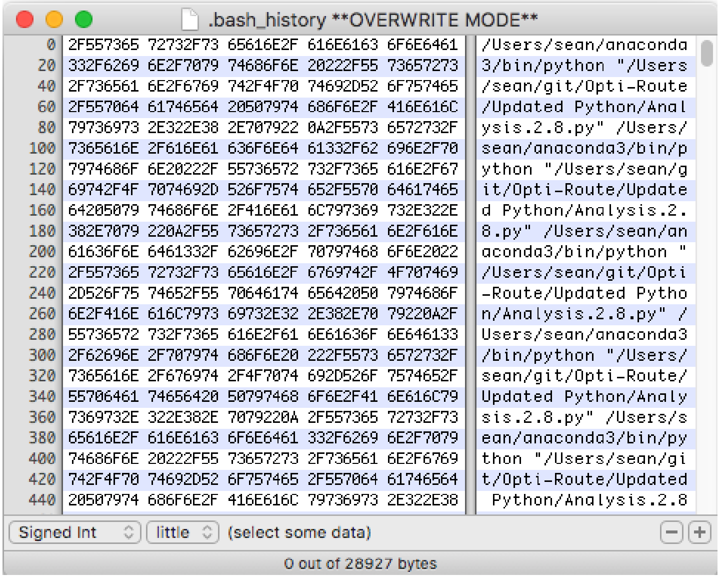
Signed Int | little | (select some data)

0 out of 8512 bytes

Text Files

- These files are used only to store text information
- This data is also stored in binary, but it is represented using ASCII codes
- All text editors understand how to convert this binary information to text for us to view and change

Text File



```
  0  2F557365 72732F73 65616E2F 616E6163 6F6E6461  /Users/sean/anaconda
 20  332F6269 6E2F7079 74686F6E 20222F55 73657273  3/bin/python "/Users
 40  2F736561 6E2F6769 742F4F70 74692D52 6F757465  /sean/git/Opti-Route
 60  2F557064 61746564 20507974 686F6E2F 416E616C  /Updated Python/Anal
 80  79736973 2E322E38 2E707922 0A2F5573 6572732F  ysis.2.8.py" /Users/
100  7365616E 2F616E61 636F6E64 61332F62 696E2F70  sean/anaconda3/bin/p
120  7974686F 6E20222F 55736572 732F7365 616E2F67  ython "/Users/sean/g
140  69742F4F 7074692D 526F7574 652F5570 64617465  it/Opti-Route/Update
160  64205079 74686F6E 2F416E61 6C797369 732E322E  d Python/Analysis.2.
180  382E7079 220A2F55 73657273 2F736561 6E2F616E  8.py" /Users/sean/an
200  61636F6E 6461332F 62696E2F 70797468 6F6E2022  aconda3/bin/python "
220  2F557365 72732F73 65616E2F 6769742F 4F707469  /Users/sean/git/Opti
240  2D526F75 74652F55 70646174 65642050 7974686F  -Route/Updated Pytho
260  6E2F416E 616C7973 69732E32 2E382E70 79220A2F  n/Analysis.2.8.py" /
280  55736572 732F7365 616E2F61 6E61636F 6E646133  Users/sean/anaconda3
300  2F62696E 2F707974 686F6E20 222F5573 6572732F  /bin/python "/Users/
320  7365616E 2F676974 2F4F7074 692D526F 7574652F  sean/git/Opti-Route/
340  55706461 74656420 50797468 6F6E2F41 6E616C79  Updated Python/Analy
360  7369732E 322E382E 7079220A 2F557365 72732F73  sis.2.8.py" /Users/s
380  65616E2F 616E6163 6F6E6461 332F6269 6E2F7079  ean/anaconda3/bin/py
400  74686F6E 20222F55 73657273 2F736561 6E2F6769  thon "/Users/sean/gi
420  742F4F70 74692D52 6F757465 2F557064 61746564  t/Opti-Route/Updated
440  20507974 686F6E2F 416E616C 79736973 2E322E38   Python/Analysis.2.8
```

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IO Streams

- This lecture focuses on the use of I/O streams in Java by using the examples of file reading
- However, most of the examples can be applied to streams that are connected to another source or destination such as a network location
- Investigating this will be left for you to do in your own time

I/O Stream

- An I/O stream represents an input source and an output destination
- This means that an I/O stream is really just a way to get data from one location to another
- There are many different kinds of sources and destinations
  - Files, devices, other programs, network resources, memory locations
- Streams can carry different types of data
  - Bytes, characters and other primitive types, objects

Sequence of Data

- A stream can be viewed as a sequence of data
  - A program can use an input stream to read data from a source
  - A program can use an output stream to write data to a destination
- When we describe it as a sequence of data, what is really meant is that the data will have some order
- If the source is a file it will be stored one piece of data after another, if the destination is a file we can only add one piece of data at a time

Streams

- There are many different types of streams
    - Byte streams
    - Character streams
    - Buffered streams
    - Data streams
    - Object streams

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Byte Streams

- The most basic type of stream is a byte stream
- These streams only read or write data one byte at a time
- When a program needs to understand the meaning of the data, a byte stream is not very good
- If we wish to read an `int`, it is 4 bytes of information
- To correctly read this int we would need to read all 4 bytes and then perform the correct operations to calculate the original value based on the 4 bytes

Why Have Byte Streams?

- Given that these streams are not very useful, why are we bothering to learn about them at all?
- The reason is that this basic functionality is used by other more complex streams
- The more complex streams are capable or reading the 4 bytes and automatically converting them into an int for us
- But internally they operate in this same basic way of reading a single byte at a time and then combing the data into the correct format

Types of Byte Streams

- There are many different types of byte streams, all of them extend the classes `InputStream` and `OutputStream` in the package `java.io`
- We will skip the information of reading and writing with byte streams

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Character Streams

- Java stores character values using Unicode
- Character streams automatically translates this internal format to and from the local character set
- This means a program to read some text from a file will automatically adjust to read characters correctly for the user

Types of Character Streams

- There are different character streams, all of them extend the classes `Reader` and `Writer` in the package `java.io`

- Our examples will be using the `FileReader` and `FileWriter`

FileReader API

`read`

```
public int read() throws IOException
```

Reads a single character.

Returns: The character read, as an integer in the range 0 to 65535 (0x00-0xffff), or -1 if the end of the stream has been reached

Throws: `IOException` - if an I/O error occurs.

FileWriter API

write

```
public void write(int c) throws IOException
```

Writes a single character. The character to be written is contained in the 16 low-order bits of the given integer value; the 16 high-order bits are ignored.

Parameters: c - int specifying a character to be written.

Throws: `IOException` - if an I/O error occurs.

Reading Some Data

- Here we can see that the methods are generally simple to use, however both methods might throw an `IOException`
- `IOException` is a checked exception
- Even though the method reads a single character, the actual return type of the method is `int`
- This allows the special example of returning -1 when the end of the file has been reached

Reading Some Characters

- Our example will read 30 characters from a file, converts each character to upper case and store them in an array
- The name of the file we are reading from is `"chars.txt"`
- We will assume that the file is in the same folder as the program

Reading Some Characters

```
public static void main(String[] args) {
  FileReader fr = null;
  char[]  chars  = new char[30];
  try{
    fr = new FileReader("chars.txt");
    for (int i = 0; i < chars.length; i++) {
      char c = (char) fr.read();
      chars[i] = Character.toUpperCase(c);
    }
  } catch (IOException e){
    e.printStackTrace();
  }
  System.out.print(characters);
}
```

Example Explained

- The code above is quite simple, but it is complicated because we must include error-recovery code
- All of the work in this code is completed in the four lines from 6 to 9
- There are several things that we should note about this code.
  - Our variables are declared before the try section of the try-catch statement.
  - We use read in a loop to read all the characters
  - The return value of the read method must be typecast before it is stored in the array

Writing Some Characters

```java
public static void main(String[] args) {
   String sos = "Hello darkness, my old
    friend\nI've come to talk with you again";
   FileWriter fw = null;
   try{
      fw = new FileWriter("lChars.txt")
      for (int i = 0; i < data.length; i++) {
         char c = sos.charAt(i); // get
    character
         fw.write(c); // write character
      }
      fw.close();
   } catch (IOException e){
      e.printStackTrace();
   }
}
```

Example Explained

- Here again, the code is quite simple but complicated by error recovery

- The part of the code we should note is a statement on line 10 called `close`.

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Closing Streams

- Whenever we create a stream in Java, a number of objects are created in memory to help
- If we do not correctly deal with streams, these will continue to waste memory in our program, causing it to run more slowly or crash
- The JVM limits the amount of memory available to each program
- After we have finished using a stream we should close it

Closing Streams

- This is done using the method called `close`
- This is something that we should always do
- There are a number of strategies for choosing where to do this
- In the example above, it is done when we are finished writing to the file
- However, if there is a problem before we have finished writing, the close method will not be executed and therefore the stream is not closed

Close in Finally

- Alternatively, we can use the finally section to close the stream we are using
- However, because the close method might throw `IOException`, we must include another try-catch statement
- Additionally, because the stream may be null (if there is an exception before or during its creation), we must first check that it is not null before trying to close it
- This can make our code look much more complicated

Close in Finally

```
try{
   ...
} catch (IOException e){
   e.printStackTrace();
} finally {
   if(fw != null){
      try { fw.close(); } catch (Exception e2) {
         System.out.println("Steam could not be closed");
      }
   }
}
```

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Try With Resources

- That example is very messy and difficult to understand
- In Java 7, a new feature was added to simplify this
- The try with resources statement, will automatically close streams when we are finished
- Java will then automatically close the stream for us when the try section is finished **or** an exception happens

Try With Resources

```
try(declare and construct stream){
  // use stream
} catch (expected exception){
  // handle expected exception
}
```

- This allows us to declare and construct our stream
- If we look at the write character example again, we can see that the code is much shorter and the easier to understand

Writing some Characters

```java
public static void main(String[] args) {
  String sos = "Hello darkness, my old friend\nI've come to talk with you again";

  try(FileWriter fw = new FileWriter("1Chars.txt")){
    for (int i = 0; i < sos.length(); i++) {
      char c = sos.charAt(i); // get character
      fw.write(c); // write character
    }
  } catch (IOException e){
    e.printStackTrace();
  }
}
```

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Reading and Writing Lines

- Reading and writing characters is useful, but characters are small pieces of information
- Generally, we are used to working with larger pieces of information such as strings
- When reading and writing strings, generally work one line at a time
- So we will look at some classes that allow us to read and write data using strings.

Buffered Streams

- These classes are known as **buffered** streams
- These streams are designed to be more efficient
- When using normal I/O streams, every time we call the read or write method the functionality is performed by the operating system
- This causes the OS to have to access a file or a network resource, which is very slow
- When we use a buffered stream, data is read from or written to an area of memory called a **buffer** each time we use the read or write methods

The Buffer

- When the buffer is full (for writing) all of the data in the buffer is written to the file
- When the buffer is empty (for reading) more data is read from the file
- This is done in a single operation for larger amounts of data and is much faster

The Buffer

- However, if we use a buffered stream nothing is written to the disk until the buffer is full
- Because of the way hard drives work (separated into sectors of between 512 and 4096 bytes), it takes the same amount of time to write one byte as to write 100
- The reverse is also true for reading

Stream Wrapping

- Any stream can be converted into a buffered stream
- We take a stream that will write data to a source and we place it inside a buffered stream
- When the buffer needs to be filled or emptied, it then calls the read or write method of the inner stream
- This means that in order to create a buffered stream, first we have to a stream to pass as a parameter
- This process is referred to as **stream wrapping**.

Types of Buffered Streams

- There are different types of buffered streams for different types of data
- For example to create a buffered byte stream we would use the `BufferedInputStream` or `BufferedOutputStream`
- For character streams we would use the `BufferedReader` and `BufferedWriter`

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Constructing a Buffered Stream

- To create a buffered character stream, we first need to create the character stream
- If we are reading a file `"ex.txt"`, first we would create `FileReader fr = new FileReader("ex.txt");`
- Once this is created, we can use it to create a BufferedReader object
- `BufferedReader br = new BufferedReader(fr);`
- These statements can be combined into a single statement by passing the result of the constructor of the first into the constructor of the second
- E.g. `BufferedReader br = new BufferedReader(new FileReader("chars.txt"))`

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Flushing Streams

- When writing data using a buffered stream, the data is only written when the buffer is full
- But what if the buffer is not full and we want the data to be written now?
- Java provides a method that we can use at any time to write any data that is currently in the buffer into the destination
- This method is called `flush`
- Whenever the flush method is executed, all data in the buffer will be written even if it is only a single byte

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Reading and writing with buffered streams

- The buffered streams provide the methods `read` and `write` which work exactly the same way as in the character and byte streams that we have seen already
- However, they also add methods that are much easier to use when reading or writing data in larger amounts
- Lets look at the methods of the `BufferedReader` and `BufferedWriter`

BufferedReader API

`readLine`

`public String readLine() throws IOException`

Reads a line of text. A line is considered to be terminated by any one of a line feed ('\n'), a carriage return ('\r'), or a carriage return followed immediately by a linefeed.

Returns: A String containing the contents of the line, not including any line-termination characters, or null if the end of the stream has been reached

Throws: `IOException` - if an I/O error occurs.

BufferedWriter API

write

`public void write(String str) throws IOException`

Writes a string.

Parameters: str - String to be written

Throws: `IOException` - if an I/O error occurs.

Reading Some Lines

- Lets look at an example where we read 7 lines from a file and store them in an array to be printed later.

```java
public static void main(String[] args) {
  String[] lyrics = new String[7];
  try(BufferedReader br = new BufferedReader(new
    FileReader("chars.txt"))){
     for (int i = 0; i < lyrics.length; i++) {
        lyrics[i] = br.readLine();
     }
  }catch(IOException e){
     e.printStackTrace();
  }
  for (int i = 0; i < lyrics.length; i++) {
     System.out.println(lyrics[i]);
  }
}
```

Writing Some Lines

- And another example where we write every string in an array into a file, each as a separate line.

```java
public static void main(String[] args) {
  String[] words = new String[] {"Hi", "my", "name",
    "is", "Sean"};

  try (BufferedWriter bw = new BufferedWriter(new
    FileWriter("words.txt"))) {
    for (int i = 0; i < words.length; i++) {
      bw.write(words[i] + "\n");
    }
  } catch (IOException e) {
    e.printStackTrace();
  }
}
```

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Processing Strings

- Chapter 9 in the book covered some basic string processing
- This can be easily applied to strings that have been read from files
- Consider an example of a program that reads lyrics of a song from one file and replaces some of the words before writing it into another file
- In this example we will use the `replace` method in the String class to achieve our aim

Knowing When to Stop

- The biggest problem that we face is that we do not know how many lines that there are in the file
- We could check and read that much information, but every time we want to use the program on a different file, we would need to find the number of lines
- Instead, it is easier to check every time if we have reached the end of the file
- In the API documentation of the `readLine` method, it states that null is returned when the end of the stream is reached
- So we try to read a line and loop as long as the variable is not null

Example

```java
public static void main(String[] args) {
  try (BufferedReader br = new BufferedReader(new
    FileReader("chars.txt"));
        BufferedWriter bw = new BufferedWriter(new
    FileWriter("words.txt"))) {
     String line = br.readLine();
     while(line != null){
        bw.write(line.replace("silence", "music") +
    "\n");
        line = br.readLine();
     }
  } catch (IOException e) {
     e.printStackTrace();
  }
}
```

Why add \n?

- It should be noted, that because the readLine method does not include any new line characters in the strings it returns when writing these strings to the file the must be added

- This is why every time we write a line of text, we add a new line character too

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Data Representation

- Data is represented differently in the computer than the way it is presented to us
- For example when we print the number 123456789 we see this in the console as 9 characters, however in the computer internally it is represented as `00000111 01011011 11001101 00010101`
- This is convenient because the second is very difficult to understand for humans
- If we were to write this number into a file using a character stream the information will require 9 bytes to be represented, while the second version takes on 4 bytes to be represented inside the computer

Data Streams

- Data streams allow us to store primitive data type values and strings in the same format as they are stored in memory in the computer
- This means that the files are in a format the the computer can easily understand, but to a human will often not make any sense
- This makes the operating with files more efficient, because we are no longer required to convert between the human version and the computer version

Types of Data Streams

- For writing and reading data we will use the `DataInputStream` and `DataOutputStream`
- These streams are constructed in the same way as the buffered streams
- In fact they are usually constructed **using** buffered streams
- This means that if we want our program to be efficient we need to create a total of three streams to read or write data

Constructing Data Streams

- First we need to construct a `FileInputStream`, then using that we construct a `BufferedInputStream` and finally using that we construct a `DataInputStream`
- It is acceptable to not use the buffered input stream and instead simply pass the file input stream to the data input stream, however this will result in a program that is less efficient
- The process is similar for the data output stream

Constructing Data Input Stream

```
FileInputStream fis = new
   FileInputStream("grades.dat");
BufferedInputStream bis = new
   BufferedInputStream(fis);
DataInputStream dis = new
   DataInputStream(bis);

OR

DataInputStream dis = new
   DataInputStream(new
   BufferedInputStream(new
   FileInputStream("grades.dat")));
```

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Different Data

- Because we can store different types of data and each will be stored in the same format as in memory, we need a method for each of these types of data
- For example, if I want to write an integer into a file I cannot use the same method that writes a double because these types are stored in different ways
- For example to write data we have the methods
  - `writeInt` for ints
  - `writeChar` for chars
  - `writeDouble` for doubles
- We the same for other primitive types
- To write a string we use the method `writeUTF`
- There are also similar methods for reading the same information

DataInputStream - readInt

`public int readInt() throws IOException`
Reads four input bytes and returns an int value. Let a-d be the first through fourth bytes read. The value returned is: `(((a & 0xff) << 24) | ((b & 0xff) << 16) | ((c & 0xff) << 8) | (d & 0xff)))`
Returns: the next four bytes of this input stream, interpreted as an int.
Throws: `EOFException` - if this input stream reaches the end before reading four bytes.
`IOException` - the stream has been closed and the contained input stream does not support reading after close, or another I/O error occurs.

DataInputStream - readUTF

`public final String readUTF() throws IOException`
Reads in a string that has been encoded using a modified UTF-8 format. The general contract of readUTF is that it reads a representation of a Unicode character string encoded in modified UTF-8 format;
Returns: a Unicode string.
Throws: `EOFException` - if this input stream reaches the end before reading four bytes.
`IOException` - the stream has been closed and the contained input stream does not support reading after close, or another I/O error occurs.
`UTFDataFormatException` - if the bytes do not represent a valid modified UTF-8 encoding of a string.

Reading Example

- Assume that we have a file that contains the names, student numbers (as ints) and three grades for a number of students
- Lets write a program to read the information about the first student stored in the file and then print the information to the screen
- Just like with the scanner and user input, the order that we write our statements must match the order that the data appears in the file

Reading Example

```java
public static void main(String[] args) {
  String name = "";
  int studentNumber = -1;
  double[] grades = new double[3];
  try{
    DataInputStream dis = new DataInputStream(new
   BufferedInputStream(new
   FileInputStream("grades.dat")));
    name = dis.readUTF();
    studentNumber = dis.readInt();
    for (int i = 0; i < grades.length; i++) {
      grades[i] = dis.readDouble();
    }
```

Reading Example

```
    } catch (IOException e){
        e.printStackTrace();
    }
    System.out.print("Student " + name + " Number: "+
      studentNumber +" got grades ");
    for (int i = 0; i < grades.length; i++) {
        System.out.print(grades[i] + " ");
    }
}
```

Reading Example Notes

- Note here that first we read the name of the student using the `readUTF` method, then the student number and then the three grades
- Because each of these pieces of information is stored in a different way, mixing up the order would result in data that does not make any sense and might crash the program
- Now lets look at an example of using the `DataOutputStream` to write the same data into a file for a single student

DataOutputStream - writeInt

`public final void writeInt(int v) throws IOException`

Writes an int to the underlying output stream as four bytes, high byte first.

Parameters: v - an int to be written.

Throws: `IOException` - if an I/O error occurs.

DataOutputStream - writeUTF

`public final void writeUTF(String str) throws IOException`

Writes a string to the underlying output stream using modified UTF-8 encoding in a machine-independent manner. First, two bytes are written to the output stream as if by the `writeShort` method giving the number of bytes to follow. This value is the number of bytes actually written out, not the length of the string. Following the length, each character of the string is output, in sequence, using the modified UTF-8 encoding for the character.

Parameters: str - a string to be written.

Throws: `IOException` - if an I/O error occurs.

Writing Example

```
public static void main(String[] args) {
  String name = "Sean Russell";
  int sn = 12345678;
  double[] grades = new double[] { 100, 95, 77.7 };

  try (DataOutputStream dos = new
   DataOutputStream(new BufferedOutputStream(new
   FileOutputStream("grades.dat")))) {
    dos.writeUTF(name);
    dos.writeInt(sn);
    for (int i = 0; i < grades.length; i++) {
      dos.writeDouble(grades[i]);
    }
  } catch (IOException e) {
    e.printStackTrace();
  }
}
```