Input & Output Classes

Java’s Hierarchy of Input/Output Classes and Their Purpose

Introduction

- Java has a hierarchy of input classes for different purposes.
- The base class is InputStream, which reads input as bytes. It has many subclasses, like FileInputStream and DataInputStream.
- Other input classes convert the input into characters, strings, or primitive data types.
  - Those classes (almost) all get the bytes they need from in InputStream.
- Java's output classes use a similar design.

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Sources of Input

An application can read input from:

- console or terminal
- file on disk, USB drive, etc.
- URL on the internet
- a sensor, using its device driver
- a microphone or camera, using its device driver
- another process (output of another application)
- other sources

What's in a File?

A file contains **bytes**, grouped into blocks (usually 512 bytes per block).

Only bytes -- 0's and 1's.

Not text, characters, or images.

Only Bytes.

What about Text Files? PNG?

Text, images, sound, etc. depend on how the application interprets the bytes in a file.

JPEG, PNG, GIF - a standard for how to read and write **bytes** that represent an image.

MP3 - a standard for how to interpret **bytes** so they can be rendered (by software) as sound.

TXT - **bytes** represent codes for characters, using a standard character encoding. Depending on the encoding, one character may be more than one byte in a file.

Text File Example

Suppose we want to write this to a file:

```
cat
```

What data is actually written to the file?

If we use ASCII or Unicode UTF-8 *encoding* for the characters, the file would contain:

binary

```
0110001101100001
0111010000001010
```

hexadecimal

```
6361740A
```

Hex 63 is the code for 'c'. The last byte (hex 0A) is a *newline*. It is added by a text editor or Java's System.out.println().
Each **hex digit** represents 4 bits, e.g. 3=0011, 6=0110, A=1010,

Text File Example Explained

1. "encode" each character according to a character set and encoding. For ASCII, UTF-8, and many others:

   `'c'` = x63 (hexadecimal 63, or binary 0110 0001)

   `'a'` = x61

   `'t'` = x74

2. at the end of each "line" of text is a line-end character. This is usually newline (hex 0A). Old MacOS apps use a "carriage return" (hex 0D) instead.

Numerical Example

How can we save the value of Math.PI to a file?

3.14159265358979 3

If we write it as *text (characters)* the result would be:

hexadecimal view of file (spaces added for clarity):

```
34312e33 32393531 35333536 39373938
00000a33
```

20 bytes. But this is a waste!

Math.PI is a **double** value using 8 bytes in memory.

If we write the actual binary value (as in memory) to file, it would only need 8-bytes, and no data lost in converting to decimal digits.

Writing Binary Values

Java has a DataOutputStream class for writing primitive values (byte, int, long, double) directly to a file in binary form without converting to text form.

Writing Math.PI to a file in binary form, the file contains:

hexadecimal view of file:

```
0940 fb21 4454 182d
```

Only 8 bytes! (2 hexadecimal digits = 1 byte)

MP3, JPEG, PNG, MPEG all contain data in binary format, as in the example above. It is faster and smaller than writing numeric data as text.

The Important Lesson

Data on computers is read and written as bytes.

"Text" is an interpretation of those bytes as characters.

"Text" requires use of a *character set* and *character encoding* to translate chars to bytes or bytes to chars.

"Binary format" refers to a file where the data is stored directly in a binary encoding, without converting to text.

Classes for Input

InputStream	read input as bytes
Reader, InputStreamReader	read input as characters
BufferedReader	read entire lines as Strings
DataInputStream	read data as primitive values (byte, int, float, double)

InputStream

Reads input as bytes. **`read()`** returns 1 byte.

If no more data, read() returns -1.

```
buffer = new StringBuffer( );
while ( true ) {
    int c = inputStream.read( );
    if ( c < 0 ) break; // end of input
    buffer.append( (char)c );
}
```

InputStream with array of byte

Reading 1 byte at a time is slow.

It is usually faster to read many bytes into an array.

```
byte[] buff = new byte[1024];
while ( true ) {
  int count = inputStream.read( buff );
  if ( count <= 0 ) break; // end
  // process buff[0] ... buff[count-1]
}
```

Why byte[1024]?

You can make the byte array any size you like.

However, at a lower level the operating system reads and "buffers" input in "blocks".

1 block is usually 512, 1024, 2048, or 4096 bytes.

So, its efficient to write code that matches this.

```
int BUFF_SIZE = 512; // or 1024, 2048, 4196, or 8*1024
byte[] buff = new byte[BUFF_SIZE];
int count = in.read(buff);
```

Do & test programming Idiom

This kind of code is common in C.

It calls read(), sets the value of c, then tests the result.

When there is no more input, read() returns -1.

```
buffer = new StringBuffer( );
int c = 0;
while ( (c=inputStream.read( )) >=0 ) {
   buffer.append( (char)c );
}
```

InputStream with array error

read(byte[]) may not fill the entire array (buff)!

Always check **`count`** of bytes read.

Do not assume that count == buff.length !

```
byte[] buff = new byte[512];
count = inputStream.read(buff);

// ERROR! buff may contain junk
String data = new String(buff);
```

FileInputStream

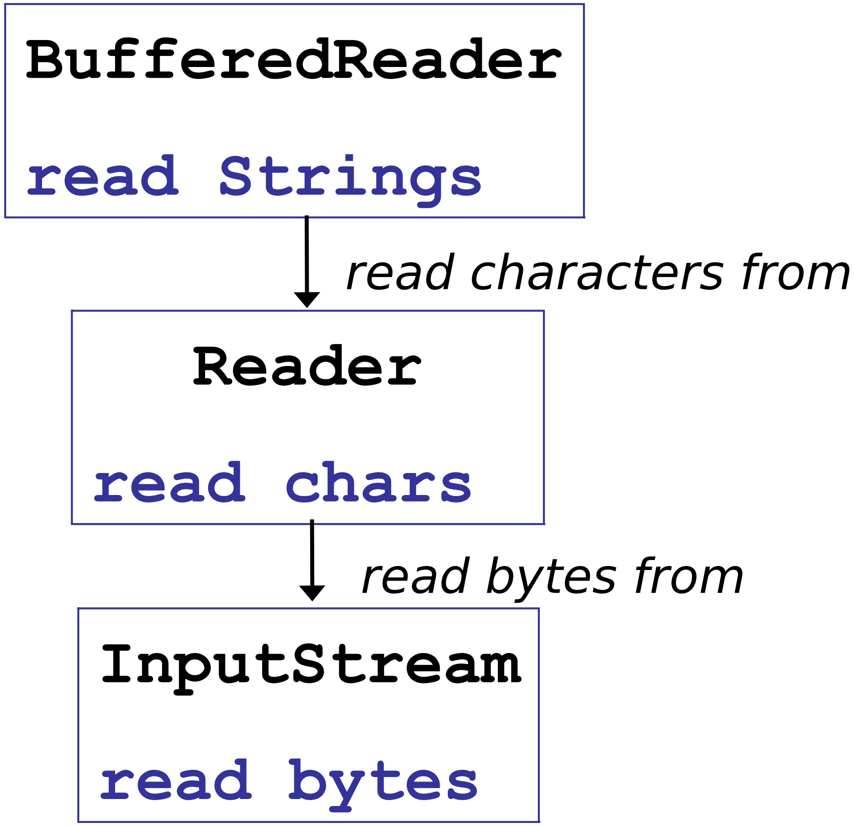
- An InputStream connected to a file.
- Has many constructors.
- Works just like InputStream! (its a subclass)

```
InputStream inputStream =
    new FileInputStream("c:/test.dat");

while ( true ) {
    int c = inputStream.read( );
    if ( c < 0 ) break; // end of input
    buffer.append( (char)c );
}
inputStream.close( );
```

Text Input Class Hierarchy

- Each layer "**adapts**" a lower layer to provide a different interface.



BufferedReader

read Strings

read characters from

Reader

read chars

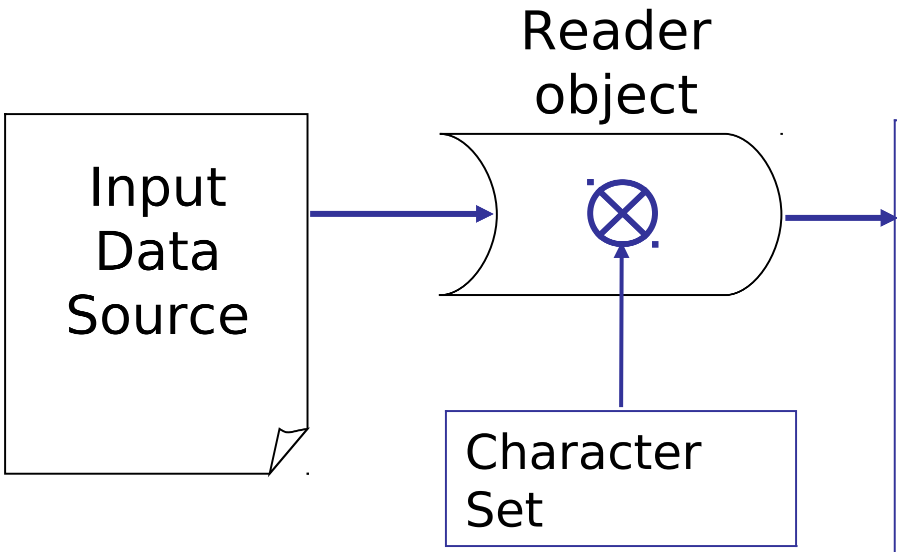
read bytes from

InputStream

read bytes

Reader

- Reader: reads bytes and converts to chars.
- Interprets bytes using a Character Set Encoding.
- Usually uses an InputStream as input source.



Reader object

Input Data Source

Character Set

```
InputStreamReader reader =
    new InputStreamReader(
      System.in, "MS874" );
// read one character
int  c = reader.read( );
// read array of chars
int n = reader.read(char[] c);
```

InputStreamReader class

InputStreamReader is a kind of Reader.

It gets data from an InputStream (*any* InputStream object)

```
InputStream in = new FileInputStream( "test" );
// InputStreamReader "wraps" an InputStream
InputStreamReader reader =
        new InputStreamReader(in);
// read a character
char b = (char)reader.read( );
// read several characters together
char[] buff = new char[1024];
int nchars = reader.read(buff, 0, buff.length);
// close the input stream
reader.close( );
```

Shortcut: FileReader

FileReader opens a file and creates InputStreamReader for it. (Automatically creates a FileInputStream.)

```
InputStreamReader reader =
            new FileReader("filename");
// read a character
char b = (char) reader.read( );
```

BufferedReader class

BufferedReader reads input as Strings.

It uses a Reader to read characters.

1. Read from System.in

```
BufferedReader br = new BufferedReader(
         new InputStreamReader( System.in ) );
// read a line
String s = br.readLine( );
```

2. Read from a file.

```
InputStream in = new FileInputStream("file");
Reader reader = new InputStreamReader( in );
BufferedReader br = new BufferedReader(reader);
// read a line (removes newline char)
String s = br.readLine( );
```

BufferedReader methods

Buffered Reader methods:

`int read()` - read next char

`int read(char[], start, count)` - read chars into array

`String readLine()` - return a string containing rest of the line

`close()` - close the reader

`ready()` - inquire if there is data ready to be read (avoid blocking)

BufferedReader for File Input

To read from a file, create a BufferedReader around a FileReader. The ready() method returns true if (a) the input buffer contains data or (b) underlying data source is not empty (when reading from file). ready() is used to avoid "blocking" the application during a read.

```
String filename = "mydata.txt";
BufferedReader br = new BufferedReader(
        new FileReader( filename ) );
// read lines as long as more data
while( br.ready() )
{
   String s = br.readLine();
   // do something with the string
}
br.close( );
```

BufferedReader and End-of-Data

The `readLine( )` method returns **`null`** if the end of input stream is encountered. Use this to detect the end of input or file.

```java
String filename = "mydata.txt";
BufferedReader br = new BufferedReader(
                     new FileReader(filename));
// read all data
String line;
while((line=br.readLine()) != null)
{
   // process the data
   System.out.println( line.toUpperCase() );
}
br.close( );
```

Character Sets

There are many language-specific character sets:

Extended ASCII - encoding for English, 1 byte per char

ISO-8859-11 - one-byte encoding for Thai chars

TIS-620 - another one-byte encoding for Thai chars

- Having many character sets and encodings means its hard to know what a file contains.
- You have to know the character set and encoding that was used to write text the file.

Character Sets

Java API docs list names of character sets.

```
InputStreamReader reader
            = new InputStreamReader( inputStream, "charset" );
```

Charset Name	Description
`ASCII`	ASCII 7-bit encoding
`ISO8859_1`	ISO 8859-1 Latin alphabet No. 1
`Cp874`	IBM (DOS) Thai encoding
`MS874`	MS Windows Thai encoding
`TIS620`	TIS-620, Thai encoding
`UTF-8`	8-bit UTF encoding
`UTF-16`	16-bit UTF encoding

Unicode and UTF-8

UNIcode is a universal standard that includes character codes for all alphabets. See them all at:

`https://unicode.org`

Most languages use a variable-length encoding of Unicode to save space.

By default, Java reads/writes using UTF-8 encoding.

UTF-8 needs 1 byte per char for English alphabet,

but 2-3 bytes per char for Thai alphabet.

Unicode Text Example

Write this string to a file (use Java code or a text editor).

If you use a text editor, verify that it uses UTF-8 encoding.

สวัสดี

If you 'type' or 'cat' the file on a terminal it will show "สวัสดี", because the console also understands UTF-8.

If you look at the bytes in the file, it contains:

hexadecimal (2 hex chars = 1 byte)

```
e0b8aae0 b8a7e0b8 b1e0b8aa e0b894e0 b8b5
```

18 bytes! Why?

Using 2-byte per Unicode character, you would expect it to be 12 bytes. UTF-8 makes Thai text longer.

Input Streams & Reader Summary

Java has a Reader class for common InputStream classes.

InputStream	Reader
InputStream	InputStreamReader
	StringBufferReader
FilterInputStream	FilterReader
FileInputStream	FileReader
PipedInputStream	PipedReader

Read Primitive Values in Binary Form

DataInputStream

Scanner

java.util.Scanner is a general parser for text files. It also provides data conversion (int, double, String, etc).

Scanner reads from an InputStream or a String.

```
// scanner to read an InputStream
InputStream in = new FileInputStream(...);
Scanner scanner = new Scanner( in );

// scanner to parse a String
String s = "Peanuts 10.0 Baht";
Scanner scan = new Scanner( s );
```

Using Scanner

Convert next token into any primitive or get a line as String.

```
Scanner scanner = new Scanner("3 dogs .5");
if ( scanner.hasNextInt() )
     n = scanner.nextInt();  // 3
if ( scanner.hasNext() )
     word = scanner.next();  // "dogs"
if ( scanner.hasNextDouble() )
     x = scanner.nextDouble(); // 0.5
// read and discard rest of this line
scanner.nextLine();
```

Output

Classes for Output

`OutputStream`	write output as bytes

`Writer,`
`OutputStreamWriter`
	write characters and strings to an OutputStream

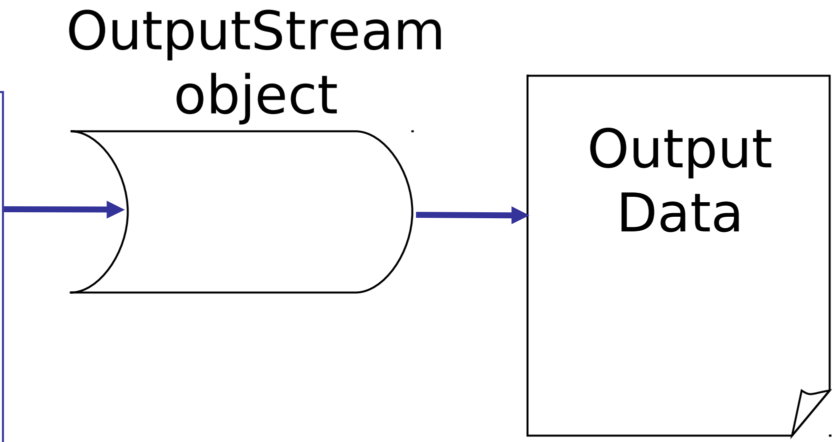
`BufferedWriter`	writes text (Strings) to an OutputStream
`PrintStream`	like Writer but adds methods to convert other data types to string, and create formatted output.
`DataOutputStream`	write primitive values (byte, int, float, double) in binary format, in a portable way

The hierarchy of output classes is similar to Java's input classes

OutputStream

- OutputStream writes bytes to some output destination
- No interpretation of characters.
- Has several subclasses, such as FileOutputStream.

```
OutputStream out = ... ;
// write 1 byte
out.write( b );
// write array of bytes
out.write( byte[ ] b );
// flush buffered data
out.flush( );
// close output stream
out.close( );
```



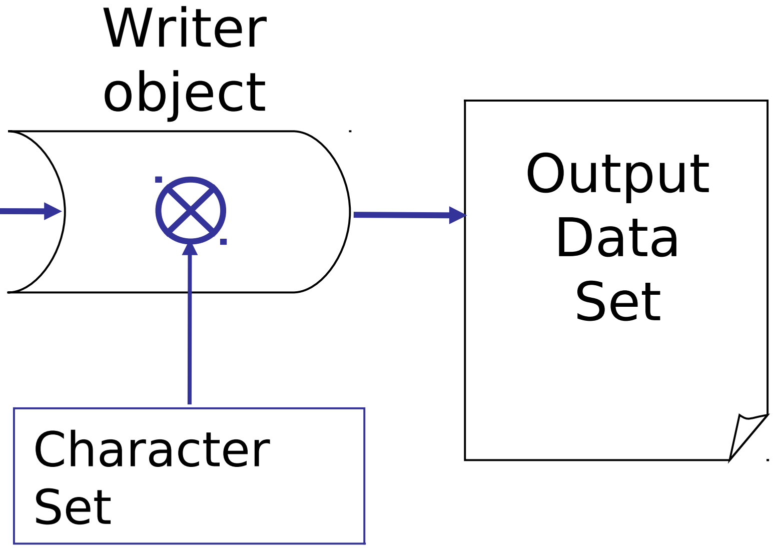
OutputStream object

Output Data

Writer

- Writer converts characters and strings to bytes.
- Interprets chars according to character set encoding.
- Uses an OutputStream to "output" the bytes.

```
OutputStreamWriter out =
    new OutputStreamWriter(
      System.out, "MS874");
// write one character
out.write( c );
// write array of characters
char [] ca = ...;
out.write( ca );
```



PrintStream

PrintStream is a convenience class for writing to text files.

It is a subclass of OutputStream, but methods do not throw IOException (so you don't need try - catch).

System.out is a PrintStream object.

`print(int n)` - print primitives in text form, e.g. 10, -5

`print(float f)`

`etc.`

`println(n)` - same as print() but appends newline

`printf`("format", arg1, arg2, ...) - formatted output

`format`("format", arg1, arg2, ...) - same as `printf`

Output Streams and Writers

Java has several classes derived from OutputStream and Writer. Each class handles a particular output sink.

OutputStream	**Writer**
OutputStream	OutputStreamWriter
FilterOutputStream	FilterWriter
FileOutputStream	FileWriter
PipedOutputStream	PipedWriter
	StringWriter

Writing Binary Data

DataOutputStream

Handling Exceptions

Two common exceptions thrown by I/O methods:

`IOException` - cannot perform a read or write

`FileNotFoundException` - file not found, or you don't have permission to access the file.

Less common, but may occur...

`SecurityException` - Java's security manager denies access to the file.

Handling Exceptions

Your code must deal with these exceptions in one of two ways:

1. Declare that method may throw exception:

```
public void myMethod(params) throws IOException{
    // body of method
}
```

2. Catch the exception and take some action. See next slide.

Catching an Exception

```
BufferedReader reader = null;
try {
   reader = new BufferedReader(
         new FileReader( filename ) );
} catch (FileNotFoundException ex) {
   System.out.println(
         "Couldn't open file " + filename);
   return;
}
// read a line from file
try {
   String s = reader.readLine( );
   // do something with string
} catch (IOException ex) {
   System.out.println(
      "Exception reading file: " +ex);
}
```

Using Files

Many I/O classes operate on File objects.

Create a File object by specifying the filename and optional path:

```
File file1 = new File("input.txt");  // in "current" directory

File file2 = new File("/temp/input.txt");  // in temp dir

File file3 = new File("\\temp\\input.txt"); // same thing

File file4 = new File("/temp", "input.txt"); // same thing

File dir = new File("/temp");    // open directory as a file
```

These commands **do not create** a file in the computer's file system. They only create a File object in Java.

Testing Files

`File` has methods to:

- test file existence and permissions (can read?)
- create a file, delete a file
- get file properties, such as path

```
File file = new File( "/temp/input.txt" );  // file object

if ( file.exists( ) && file.canRead( ) )       // OK to read?
     FileInputStream fin = new FileInputStream(file);

if ( ! file.exists( ) ) file.createNewFile( );  // create a file!
if ( file.canWrite( ) )                  // OK to write?
     FileOutputStream fout = new FileOutputStream(file);
```

More File Operations

File objects can tell you their size, location (path), modification time, etc.   See the Java API.

```
File file = new File("/temp/something.txt"); // file object

if ( file.isFile() ) {
     /* this is an ordinary file (not a directory or link) */
     long length = file.length( );
     long date = file.lastModified( );
}

if ( file.isDirectory() ) {
     /* this is a directory */
     File[] files = file.listFiles();  // files in the directory
}
```

File Copy Example

Example of how to use a File, but not good code.

You also must catch IOException.

```
File infile = new File("/temp/old.txt");
File outfile = new File("/temp/new.txt");
if ( outfile.exists() ) outfile.delete( );
outfile.createNewFile();

FileReader in = new FileReader( infile );
FileWriter out = new FileWriter( outfile );
// reading 1 char at a time is inefficient
int c;
while ( (c = in.read()) >= 0 ) out.write(c);
in.close();
out.flush();  // flush any data from buffer
out.close();
```

Extra Topics (Optional)

1. Reading & Writing Binary Format Data
2. Read without blocking (waiting for input)
3. Random Access versus Sequential Access
4. Using a Pipe - you write data to one end and read it from the other end
5. Unicode for Thai

Reading Binary Data

Examples: MP3 file, image file

Advantages:

- smaller size, faster, less loss of precision in numbers

Has methods for reading primitive values.

```
InputStream in = new FileInputStream( "mydata" );
DataInputStream data = new DataInputStream( in );
try {
   int n = data.readInt( );          // 4 byte integer
   double x = data.readDouble( ); // 8 byte double
   char c = data.readChar( );      // 2 byte unicode
}
catch ( IOException e ) { ... }
```

End-of-File for DataInputStream

- Throws EOFException if end of input encountered while reading.

```
InputStream in = new FileInputStream( "mydata" );
DataInputStream data = new DataInputStream( in );

// read doubles until end of file
double sum = 0;
while( true ) {
   try {
      double x = data.readDouble( ); // read 8 bytes
      sum += x;
   } catch ( IOException e ) { ... }
   catch ( EOFException e ) { break; } // End of File
}
data.close( );
```

Writing Binary Data

DataOutputStream methods similar to DataInputStream

```
OutputStream out = new FileInputStream( "mydata" );
DataInputStream data = new DataInputStream( out );
long studentId = 6010541234L;
double score = 90.3;
char grade = 'A';
try {
    data.writeLong(studentId); // 8 byte long
    data.writeDouble(score);   // 8 byte double
    data.writeChar(grade);     // 2 byte char
}
catch ( IOException e ) { ... }
```

How to Read without Blocking

InputStream has an `available()` method that returns the number of bytes waiting to be read.

Use this to read without blocking (waiting for input).

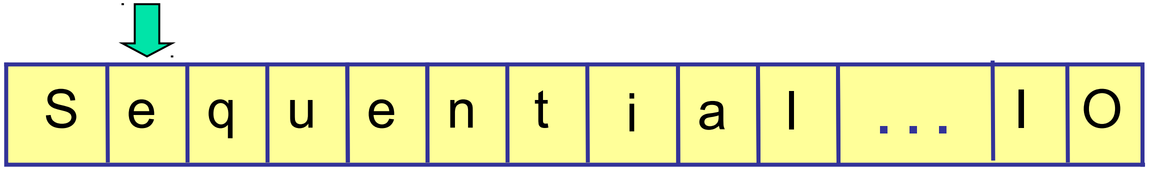
Reader classes have a **`ready()`** method.

```
InputStream in = System.in;  // any InputStream

// read whatever bytes are available
int size = in.available();
if ( size > 0 ) {
   byte[] b = new byte[size];
   in.read( b ); // this should not block
}
```

Sequential Access

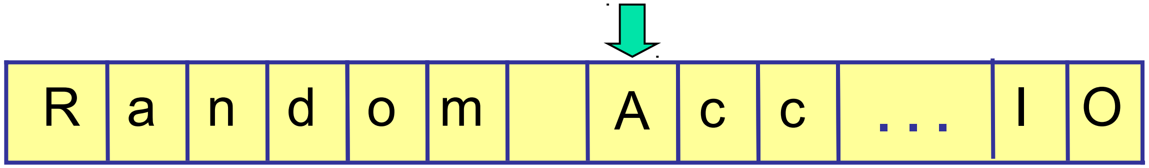
- Read/write sequentially starting from the beginning.
  - Cannot "back up" and reread or rewrite something.
  - Cannot "jump" to arbitrary location in stream.
- InputStream and OutputStream use sequential I/O.
- InputStream has a **`skip(n)`**, but it is still sequential.



```
int a = instream.read( );        // read a = 'S'
byte[] b = new byte[10];
int count = instream.read(b);   // read next 10 bytes
```

Random Access

- Can move to any location using **seek( )** method.
- Can move forward and backward.
- Only makes sense for files.



R	a	n	d	o	m		A	c	c	. . .	I	O

```
File file = new File( "c:/data/myfile.txt" );
RandomAccessFile rand =
            new RandomAccessFile(file, "r");
rand.seek( 7L );          // goto byte 7 ('A')
int b = rand.read();      // read one byte ('A')
```

RandomAccessFile

- Random Access I/O means you can move around in the file, reading/writing at any place you want.
- For output, you can even write *beyond* the end of file.
- Use **`seek()`** to move current position.

```
RandomAccessFile ra = new RandomAccessFile("name", "rw");
ra.seek( 100000L );  // go to byte #100000
byte[] b = new byte[1000];
// all "read" methods are binary, like DataInputStream
ra.readFully( b );   // read 1000 bytes
ra.seek( 200000L );  // go to byte #200000
ra.write( b );
```

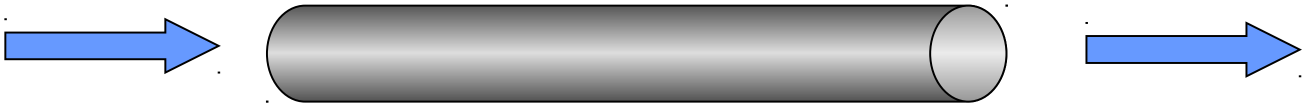
Reading and Writing Pipes

One object writes data into the pipe, another object reads data from the pipe.

Useful for multi-threaded applications.

```
PipedOutputStream pout =
 new PipedOutputStream();
```

```
PipedInputStream pin =
 new PipedInputStream(pout);
```



```
PipedOutputStream pout = new PipedOutputStream();

PipedInputStream pin = new PipedInputStream( pout );

PrintStream out = new PrintStream( pout );

BufferedInputStream in = new BufferedInputStream( pin );

out.println("data into the pipe");  // write to the pipe

String s = in.readLine( );  // read from the pipe
```

Unicode For สวัสดี

The Unicode for the Thai chars used in the example are (with vowels list after the consonant):

ส = 0E2A

วั = 0E27 0E31

ส = 0E2A

ดี = 0E14 0E35

Print Unicode in Java:

```
String s = "\u0e2a\u0e27\u0e31\u0e2a\u0e14\u0e35";
System.out.println( s );
```

More Information

Oracle Java Tutorials (online)

Basic I/O
https://docs.oracle.com/javase/tutorial/essential/io/

Handling Exceptions
https://docs.oracle.com/javase/tutorial/essential/exceptions/