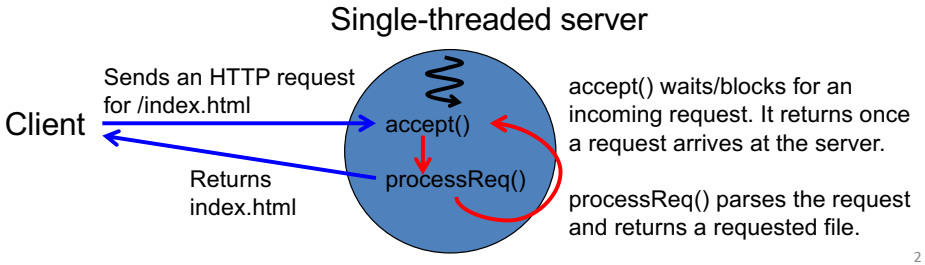
Race Conditions

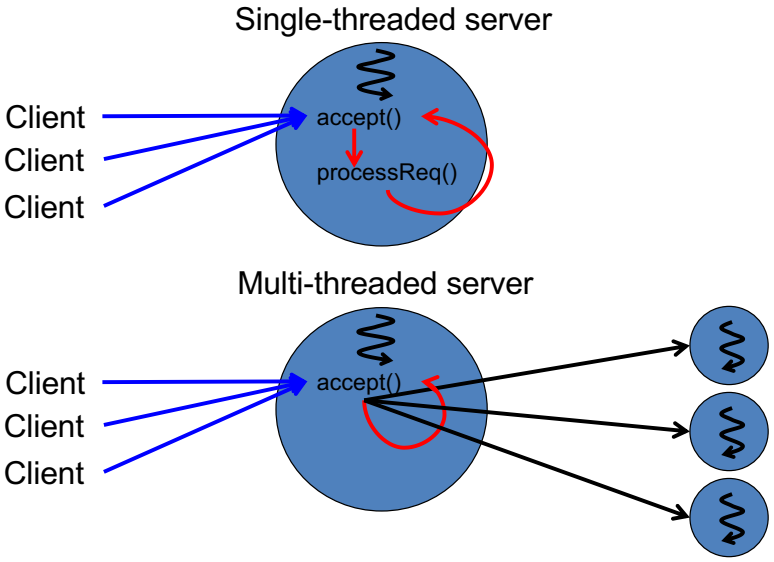
- Race conditions can occur if…
  - Multiple threads share and access a variable (data field).
    - Solution to eliminate race conditions
      - Define a lock in the variable's enclosing class
      - Use the lock to access the variable
        - » Surround every read/write logic on the variable with lock() and unlock()
  - Multiple threads call an API method that is NOT thread-safe.
    - You cannot define a lock in the method's enclosing class (i.e., API class)
    - You need to perform thread synchronization in your client code that uses the API method.

Exercise: Access Counter for a Web Server

- Suppose you are developing a web server.
  - Receives a HTTP request that a client (browser) transmits to request an HTML file.
  - Returns the requested file to the client.
- What if the server receives multiple requests from multiple clients simultaneously?
  - If the server is single-threaded, it processes requests *sequentially*.

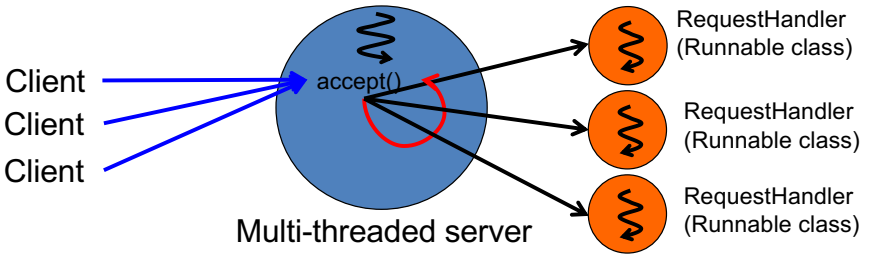


Concurrent (Multi-threaded) Web Server



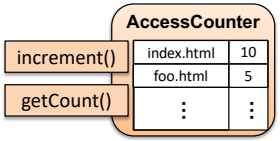
Thread-per-Request Concurrency

- Once the web server receives a request from a client, it creates a new thread.
  - The thread parses the incoming request and returns a requested file.
  - The thread terminates once the requested file is returned to the client.



Access Counter in a Concurrent Web Server

- **AccessCounter**
  - Contains a map that pairs a relative file path and its access count.
    - Assume `java.util.HashMap<java.nio.file.Path, Integer>`
  - `void increment(Path path)`
    - accepts a file path and increments its access count.
  - `int getCount(Path path)`
    - accepts a file path and returns its access count.



Access Counter in a Concurrent Web Server

- **AccessCounter**
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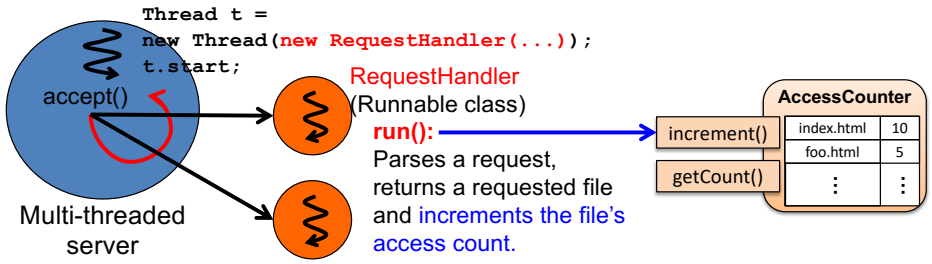
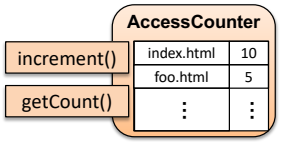
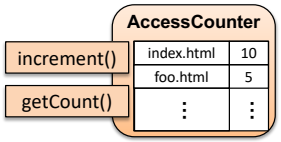


Concurrent Access Counter

- `HashMap` is NOT thread-safe.
  - All of its public methods never perform thread synchronization.
    - `containsKey()`, `put()`, `get()`, `putIfAbsent()`, `replace()`, etc.
    - C.f. API doc: "Note that this implementation is not synchronized."
  - Race conditions can occur in those public methods.
- Client code of those public methods need to perform thread synchronization.
  - `AccessCounter`'s `increment()` and `getCount()`
    - `increment()`
      - if(A requested path is in AC){
        increment the path's access count. }
        else{
        add the path and the access count of 1 to AC. }
    - `getCount()`
      - if(A requested path is in AC){
        get the path's access count and return it. }
        else{
        return 0. }



- Client code of those public methods need to perform thread synchronization.
  - `AccessCounter`'s `increment()` and `getCount()`
    - `increment()`
      - lock.lock();
        if(A requested path is in AC){
        increment the path's access count. }
        else{
        add the path and the access count of 1 to AC. }
        lock.unlock();
    - `getCount()`
      - lock.lock();
        if(A requested path is in AC){
        get the path's access count and return it. }
        else{
        return 0. }
        lock.unlock();



HW 11

- Implement **`AccessCounter`** as a thread-safe *Singleton* class.
  - Define a **`HashMap<java.nio.file.Path, Integer>`**
  - Define a regular (non-static) lock and use the lock in **`increment()`** and **`getCount()`**
  - Define another (static) lock and use the lock in **`getInstance()`**
- Place some test/dummy files
  - **`AccessCounter.java`**
    `RequestHandler.java`
    `a.html`
    `b.html`
    `...`
- **`RequestHandler`**: A Runnable class
  - **`run()`**: Picks up one of the files at random, calls **`increment()`** and **`getCount()`** for that file, and sleeps for a few seconds. Repeats this forever with an infinite loop.
- **`main()`**: Test code
  - Creates 10+ instances of **`RequestHandler`** and use 10+ threads to execute **`RequestHandler`**'s **`run()`**.
- Implement 2-step thread termination in **`RequestHandler`**.
  - Have the main thread terminate those 10+ threads in 2 steps.

- Deadline: April 9 (Tue) midnight

Concurrency and Immutability

Immutable Classes

- Classes that never change the state of each instance
  - Getter methods only; no setter methods available.
- All public methods are thread-safe because they never need thread synchronization.
  - No need to worry about race conditions.
  - No performance loss.
- An example: **`java.lang.String`**
  - ```
    char[] str = {'u', 'm', 'b'};
    String string = new String(str);
    ```
  - ```
    String string = "umb";      // Syntactic sugar for the above code
    ```
  - A series of constructors to initialize string data.
  - All non-constructor methods never change the initialized string data.
  - No setter methods are available.

Example Methods in `String`

```
String str = "umb";
System.out.println( str );                  // umb

System.out.println( str.replace("b","l"));// uml
                        // Creates a new String instance that
                        // contains "uml" and returns it.
System.out.println( str );                  // umb

System.out.println( str.toUpperCase() );  // UMB
                        // Creates a new String instance
                        // that contains "UMB" and returns it.
System.out.println( str );                  // umb

System.out.println( str.substring(1,2) ); // mb
                        // Creates a new String instance that contains
                        // "mb" and returns it.
System.out.println( str );                  // umb
```

- Some methods of `String` look like setter methods, but they are actually NOT.
  - They never change the initialized string data ("umb").

`String`

- Final class, which cannot be extended (sub-classed)
  - `public final class String{…}`
  - Prevents its sub-classes from updating the initialized string data.
- Maintains the initialized string data (e.g., "umb") in a private and final data field.
  -
```
public final class String{
    private final char value[];

    ... }
```
  - Once a value is assigned to a final variable, the value cannot be changed afterward.
    - No methods of `String` can change the value.

- Each "setter-like" method of `String` creates another `String` instance that contains another string data.

```
public final class String{
    private final char[] value;            // Immutable
    ...
    public String toUpperCase(){
        int length = value.length;         // Local variable
        char[] result = new char[length];  // Local variable

        for( int i = 0; i < length; i++ ){ // Local variable
            result[i] = ... // Transform value[i] to an upper case
        }
        return new String(result);
    } }
```

  - This is actually NOT a setter method! It is thread-safe.

Benefits of Immutability

- For API designers
  - An immutable class never require thread synchronization in its methods.
    - No need to guard its data field (e.g., `value` in `String`) with a lock
      - The data field's value never changes.
      - All threads simply read "fixed" (or "finalized") data from the data field.
  - Its methods are free from race conditions.
    - Makes it easier to do debugging.

- For API users
  - Immutable classes are free from potential performance loss due to thread synchronization.
    - Thread synchronization forces every thread to acquire a lock.
      - There is some overhead to acquire a lock.
    - If the lock is not available, the thread needs to be in the "blocked" state until it becomes available.
      - It cannot do anything to make progress.

Note That…

- An immutable class's methods are thread-safe, but…
- Client code of those methods may or may not be thread-safe.
  - The code below is NOT thread-safe; it requires thread synchronization.

```
public class Person {
 private String firstName, lastName; // Shared variables
 ...
 public void setFirstName(String first){
   firstName = first;                 // 2 steps. Not thread-safe  }

 public void setLastName(String last){
   lastName = last;                   // 2 steps. Not thread-safe  }

 public String getLastName(){
   return lastName;                   // 2 Steps. Not thread-safe  }

 public String getFullName(){
   return firstName + " " + lastName; // Multi-steps. Not thread-safe.
   // Syntax sugar for new StringBuilder().append(firstName).append(" ")
   //                                     .append(lastName).toString()
   // An instance of StringBuilder is local for each thread though } }
```

- An immutable class's methods are thread-safe, but…
- Client code of those methods may or may not be thread-safe.
  - The code below is thread-safe.

```
public class ErrorMsgGenerator {
 ...
 public String getFileNotFoundErrorMsg(String path){
   return "The requested file " + path + " was not found.";

     // Syntax sugar for new StringBuilder().append("...")
     //                                     .append(path.toString())
     //                                     ....toString();
     // Multiple steps, but thread-safe!
     // Local variables are not sharable by threads.
     // Reads and writes on a local variable are thread-safe.
     // "path" is a local variable.
     // An instance of StringBuilder is local for each thread.
 } }
```

Other Immutable Classes

- Wrapper classes for primitive types

Primitive type	Wrapper class
boolean	Boolean
byte	Byte
char	Character
float	Float
int	Integer
long	Long
short	Short
double	Double

- `java.nio.file.Path`
- `java.util.regex.Pattern`
- Some classes in `java.net`
  - e.g., `URL`, `URI`, `Inet4Address` and `Inet6Address`
- Date and Time API (`java.time`)
  - All the classes are immutable and thread-safe.

Appendix:
NIO-based File/Path Handling and Try-with-resources Statement

(1) Dealing with File/Directory Paths in NIO

- `java.nio.file.Paths`
  - A utility class (i.e., a set of static methods) to create a path in the file system.
    - Path: A sequence of directory names
      - Optionally with a file name in the end.
  - A path can be *absolute* or *relative*.
    - `Path absolute = Paths.get("/Users/jxs/temp/test.txt");`
    - `Path relative = Paths.get("temp/test.txt");`
- `java.nio.file.Path`
  - Represents a path in the file system.
  - Given a path, *resolve* (or determine) another path.
    - `Path absolute = Paths.get("/Users/jxs/");`
      `Path another = absolute.resolve("temp/test.txt");`
    - `Path relative = Paths.get("src");`
      `Path another = relative.resolveSibling("bin");`

Just in Case: Passing a Variable # of Parameters to a Method

- `Paths.get()` can receive a variable number of parameter values (1 to many values)
  - c.f. Java API documentation
  - `Paths.get(String first, String... more)`
    - `Paths.get("temp/test.txt");` // relative path
    - `Paths.get("temp", "test.txt");` // relative path
    - `Paths.get("/", "Users", "jxs");` // absolute path
  - `String... More` → Can receive zero to many String values.
  - Introduced in Java 5 (JDK 1.5)

- Parameter values are handled with an array.
  -
```
class Foo{
    public void varParamMethod(String... strings){
        for(int i = 0; i < strings.length; i++){
            System.out.println(strings[i]); } } }
```
  -
```
Foo foo = new Foo();
foo.varParamMethod("U", "M", "B");
```
- **`String... Strings`** is a syntactic sugar for **`String[] strings`**.
  - Your Java compiler transforms the above code to:
    -
```
class Foo{
    public void varParamMethod(String[] Strings){
        for(int i = 0; i < strings.length; i++){
            System.out.println(strings[i]); } } }
```
    -
```
Foo foo = new Foo();
String[] strs = {"U", "M", "B"};
foo.varParamMethod(strs);
```

Reading and Writing into a File w/ NIO

- `java.nio.file.Files`
  - A utility class (i.e., a set of static methods) to process a file/directory.
  - Reading a byte sequence and a char sequence from a file

```
Path path = Paths.get("/Users/jxs/temp/test.txt");
byte[] bytes = Files.readAllBytes(path);
String content = new String(bytes);
```

```
List<String> lines = Files.readAllLines(path);
for(String line: lines){
  System.out.println(line); }
```

  - Writing into a file

```
Files.write(path, bytes);
Files.write(path, content.getBytes());
Files.write(path, bytes, StandardOpenOption.CREATE);
Files.write(path, lines);
Files.write(path, lines, StandardOpenOption.WRITE);
```

```
StandardOpenOption: CREATE, WRITE, APPEND, DELETE_ON_CLOSE, etc.
```


NIO (java.nio) v.s. Traditional I/O (java.io)

- NIO provides simpler or easier-to-use APIs.
  - Client code can be more concise and easier to understand.
- NIO:

```
Path path = Paths.get("/Users/jxs/temp/test.txt");
byte[] bytes = Files.readAllBytes(path);
String content = new String(bytes);
```

- java.io:

```
File file = ...;
FileInputStream fis = new FileInputStream(file);
int len = (int)file.length();
byte[] bytes = new byte[len];
fis.read(bytes);
fis.close();
String content = new String(bytes);
```


NIO (java.nio) v.s. Traditional I/O (java.io)

- NIO:

```
Path path = Paths.get("/Users/jxs/temp/test.txt");
List<String> lines = Files.readAllLines(path);
```

- java.io:

```
int ch=-1, i=0;
ArrayList<String> contents = new ArrayList<String>();
StringBuffer strBuff = new StringBuffer();
File file = ...;
InputStreamReader reader = new InputStreamReader(
                                new FileInputStream(file));
while( (ch=reader.read()) != -1 ){
    if( (char)ch == '\n' ){       //**line break detection
        contents.add(i, strBuff.toString());
        strBuff.delete(0, strBuff.length());
        i++;
        continue;
    }
    strBuff.append((char)ch);
}
reader.close();
```

** The perfect (platform independent) detection of a line break should be more complex.
Unix: '\n', Mac: '\r', Windows: '\r\n' c.f. BufferedReader.read()

NIO (java.nio) v.s. Traditional I/O (java.io)

- NIO:

```
Path path = Paths.get("/Users/jxs/temp/test.txt");
List<String> lines = Files.readAllLines(path);
```

- java.io (a bit simplified version):

```
int ch=-1, i=0;
ArrayList<String> contents = new ArrayList<String>();
StringBuffer strBuff = new StringBuffer();
File file = ...;
FileReader reader = new FileReader(file); //***
while( (ch=reader.read()) != -1 ){
    if( (char)ch == '\n' ){  //** Line break detection
        contents.add(i, strBuff.toString());
        strBuff.delete(0, strBuff.length());
        i++;
        continue;
    }
    strBuff.append((char)ch);
}
reader.close();
```

*** FileReader: A convenience class for reading character files.

Files in Java NIO

- readAllBytes(), readAllLines()
  - Read the whole data from a file without buffering.
- write()
  - Write a set of data to a file without buffering.
- When using a large file, it makes sense to use **`BufferedReader`** and **`BufferedWriter`** with **`Files`**.
  - ```
    Path path = Paths.get("/Users/jxs/temp/test.txt");
    BufferedReader reader = Files.newBufferedReader(path);
    while( (line=reader.readLine()) != null ){
        // do something
    }
    reader.close();
    ```
  - ```
    BufferedWriter writer = Files.newBufferedWriter(path);
    writer.write(...);
    writer.close();
    ```


Just in case: Buffering

- At the lowest level, read/write operations deal with data *byte by byte*, or *char by char*.
  - File access occurs *byte by byte*, or *char by char*.
- Inefficient if you read/write a lot of data.
- Buffering allows read/write operations to deal with data in a coarse-grained manner.
  - Chunk by chunk, not byte by byte or char by char
  - Chunk = a set of bytes or a set of chars
    - The size of a chunk: 512 bytes by default, but configurable

Getting Input/Output Streams from `Files`

- Input and output streams can be obtained from **`Files`**.
  - ```
    Path path = Paths.get("/Users/jxs/temp/test.txt");
    InputStream is = Files.newInputStream(path);
    ```
    - `is` contains an instance of ChannelInputStream, which is a subclass of InputStream.
    - Make sure to call `is.close()` in the end.
- Can decorate the input/output stream with filters.
  - ```
    ZipInputStream zis = new ZipInputStream(
                                Files.newInputStream(path) );
    ```
    - Make sure to call `zis.close()` in the end.

Never Forget to Call close()

- Need to call `close()` on each input/output stream (or its filer) in the end.
  - Must-do: Follow the *Before/After* design pattern.
    - In Java, use a *try-catch-finally* or *try-finally* statement.
      - ```
        Open a file here.
        try{
            Do something with the file here.
            Throw an exception if an error occurs.
        }catch(...){
            Error-handling code here.
        }finally{
            Close the file here.
        }
        ```
  - Note: No need to call `close()` when using **`readAllBytes()`**, **`readAllLines()`** and **`write()`** of **`Files`**.
        ```

```
– Path path = Paths.get("/Users/jxs/temp/test.txt");
  BufferedReader reader = Files.newBufferedReader(path);
  try{
    while( (line=reader.readLine()) != null ){
        // do something
    }
  }catch(IOException ex){
    ... // Error handling
  }finally{
    reader.close();
  }
```


(2) Try-with-resources Statement

- Allows you to skip calling close() explicitly in the finally block.
  - *Try-catch-finally*

```
– Open a file here.
  try{
      Do something with the file here.
  }catch(...){
      Handle errors here.
  }finally{
      Close the file here.
  }
```

  - *Try-with-resources*

```
• try ( Open a file here ){
      Do something with the file here.
  }
```


- `close()` is automatically called on a resource used for reading or writing to a file, when exiting a try block.

```
• try( BufferedReader reader =
          Files.newBufferedReader( Paths.get("test.txt")) ){
      while( (line=reader.readLine()) != null ){
          // do something }
  }
```

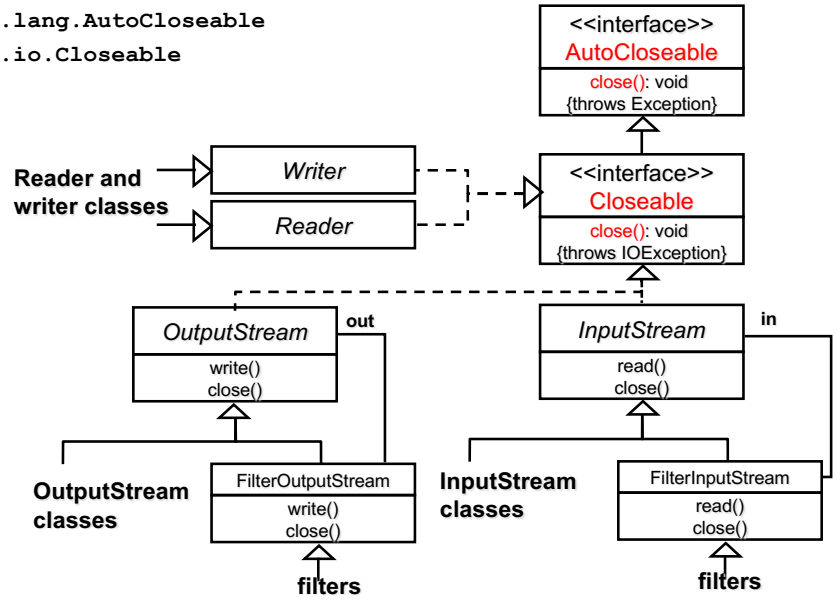
  - No explicit call of close() on `reader` in the finally block. `reader` is expected to implement the `AutoCloseable` interface.

```
• try( BufferedReader reader = Files.newBufferedReader(...);
       PrintWriter writer = new PrintWriter(...) ){
      while( (line=reader.readLine()) != null ){
          // do something
          writer.println(...); }
  }
```

  - Can specify multiple resources in a try block. close() is automatically called on all of them. They all need to implement `AutoCloseable`.

AutoCloseable Interface

- `java.lang.AutoCloseable`
- `java.io.Closeable`



- Recap: No need to call `close()` when using `readAllBytes()`, `readAllLines()` and `write()` of `Files`.
  - Those methods internally use the try-with-resources statement to read and write to a file.

Try-with-resources-Catch-Finally

- Catch and finally blocks can be attached to a try-with-resources statement.

```
try( BufferedReader reader =
        Files.newBufferedReader( Paths.get("test.txt")) ){
    while( (line=reader.readLine()) != null ){
        // do something. This part may throw an exception.}
}catch(...){
    //This block runs if the try block throws an exception.
}finally{
    ...
    //No need to do reader.close() here.
}
```

  - The catch and finally blocks run (if necessary) AFTER close() is called on `reader`.