HW 4: Data Processing with Boston's Open Datasets

- Choose one of those datasets and implement 3 types of data processing with it.
  - https://data.boston.gov/
- Requirements
  - Use Stream API to perform data processing.

Tips

- You can parse a CSV file to `List<List<String>>` this way:
  - By stripping commas and double quotations.

```
Path path = Paths.get(...);
try( Stream<String> lines = Files.lines(path) ){
  List<List<String>> matrix =
      lines.map( line -> {
        return Stream.of( line.split(",") )
                     .map(value->value.substring(...))
                     .collect( Collectors.toList() ); })
           .collect( Collectors.toList() );
} catch (IOException ex) {}
```



```
// Stream to array conversion
//
String[] arr = stream.toArray(String[]::new);

// Array to stream conversion
//
Stream<String> stream = Arrays.stream(arr);

// Stream to list conversion
//
List<String> list = stream.collect(Collectors.toList());

// List to stream conversion
//
Stream<String> stream = list.stream();

// List to array conversion
//
String[] arr = list.toArray(new String[0]);

// Array to list conversion
//
List<String> list = Arrays.asList(arr);
```


HW 5

- You worked on 3 types of data processing in HW 4.
- Run those data processing with 3 extra threads.
  - One data processing with one extra thread.
  - No need to do anything new, in terms of data processing
    - Reuse data processing code from HW 4.
- Have the main thread
  - wait for 3 data processing threads to be terminated with join()
  - collect data processing results from runnable objects.
- This is the last one in the first half of HWs.
  - They will be due on ~~Oct 31~~ Nov 7 .

Race Conditions (Data Races)

Thread Safety

- Threads are a powerful tool to make your code more efficient and responsive/available.
- However, multi-threaded code can cause "thread safety" issues when it is poorly written.
- 2 major thread safety issues
  - Race condition (data race)
    - Messes up the consistency of data shared among threads
    - Breaks the shared data
  - Deadlock
    - Makes code execution stuck forever.
- "Thread-safe" code is free from these 2 issues.

Race Conditions (a.k.a. Data Races)

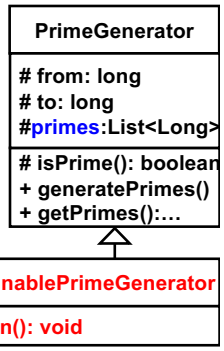
- Threads run *independently*.
  - They NEVER coordinate with each other (by default) regarding their task execution.
    - They don't know if other threads exist and run.
    - They don't know what other threads are doing.
    - They cannot control when their tasks are executed and completed.
    - They cannot control the order of their task execution.
    - c.f. `MCTest`, `RunnablePrimeGenerator`, `RunnablePrimeFactorizer`
- Exception: `Thread.join()` (a.k.a. "after you" operation)
  - allows threads to coordinate with each other to some extent.
    - A thread (caller of `join()`) can wait for doing something until another thread (callee of `join()`) is terminated.

- Threads can share variables (i.e., data fields).
  - Exception: Local variables are NEVER shared among threads.
- They can mess up the consistency of the shared data.
  - A thread can write some data to a variable when another thread is reading data from the variable.
  - A thread can write some data to a variable when another thread is writing different data to the variable.

Example 1: `RunnablePrimeGenerator`

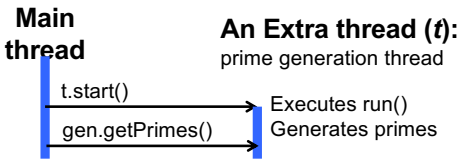
```
class RunnablePrimeGenerator extends PrimeGenerator
                             implements Runnable {
  public RunnablePrimeGenerator(long from, long to){
    super(from, to); }

  public void run(){
    generatePrimes(); }
```



- Multi-threaded client code

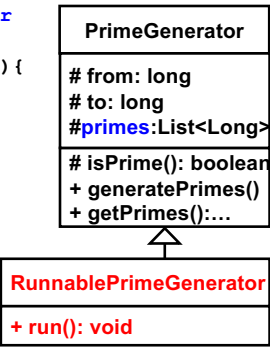
```
RunnablePrimeGenerator gen =
          new RunnablePrimeGenerator(...);
Thread t = new Thread(gen);
t.start();
gen.getPrimes().forEach(...); //join() is not called!
```



What variable is shared by the two threads?


```
Class RunnablePrimeGenerator extends PrimeGenerator
                             implements Runnable {
  public RunnablePrimeGenerator(long from, long to){
    super(from, to); }

  public void run(){
    generatePrimes(); }
```



- Multi-threaded client code

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RunnablePrimeGenerator gen =
          new RunnablePrimeGenerator(...);
Thread t = new Thread(gen);
t.start();
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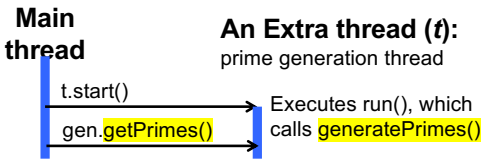


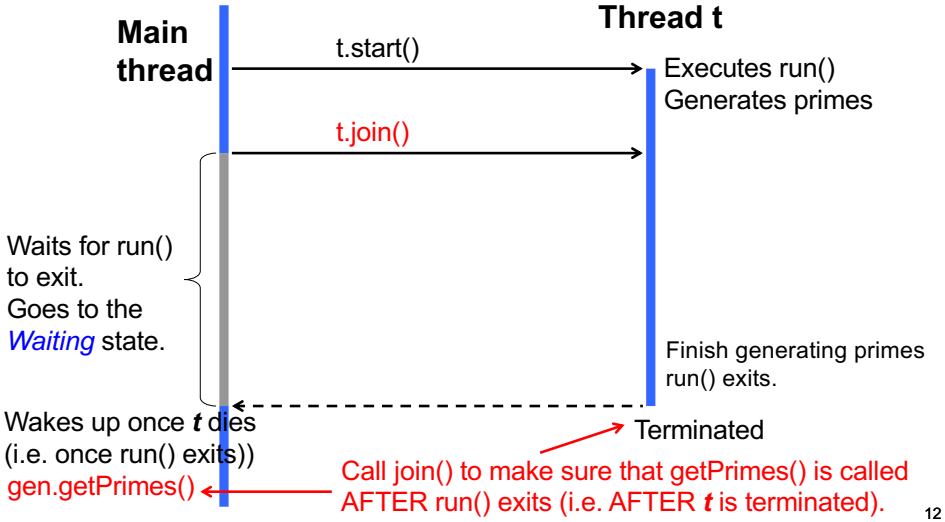
The two threads share `primes`.

- The best-case (lucky) scenario
  - The main thread obtains the complete set of primes
    - if it happens to call **`getPrimes()`** after the prime generation thread is terminated.

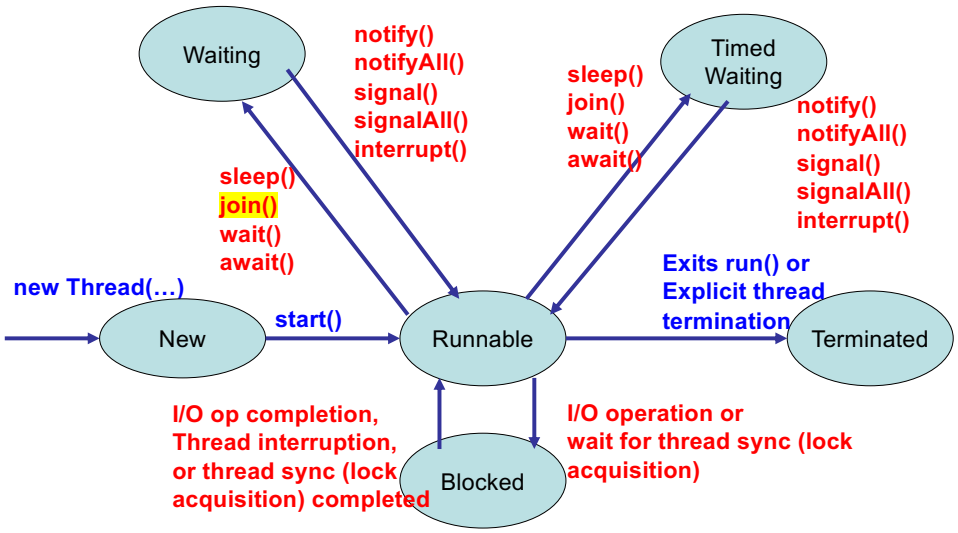
- Race condition scenario
  - The main thread obtains an incomplete set of primes
    - if it happens to call **`getPrimes()`** before the prime generation thread is terminated.

Thread.join()

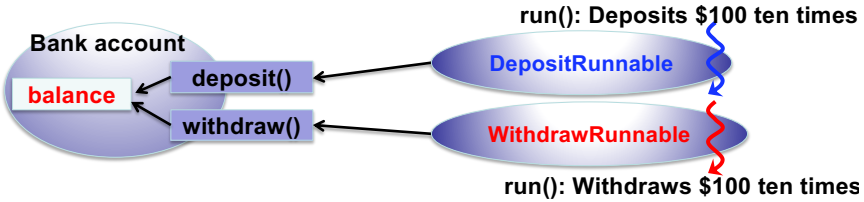
- The main thread has to call `join()` to obtain the complete set of primes for sure.



States of a Thread



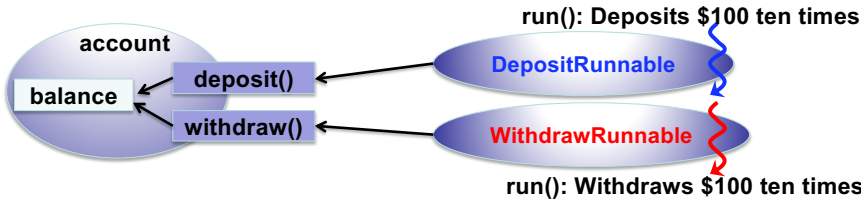
Example 2: `ThreadUnsafeBankAccount`



- The variable "balance" is shared by 2 threads.
- They access the variable independently.

```
public void deposit(double amount){
    System.out.print("Current balance (d): " + balance);
    balance = balance + amount;
    System.out.println(", New balance (d): " + balance); }
```

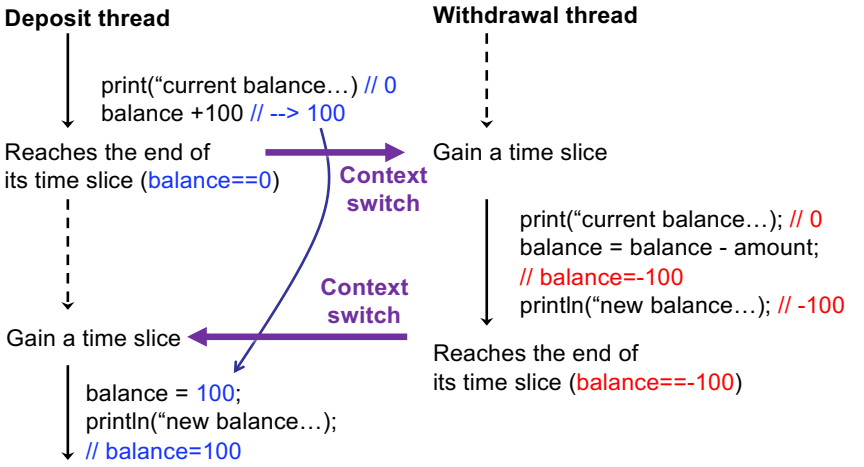
```
public void withdraw(double amount){
    System.out.print("Current balance (w): " + balance);
    balance = balance - amount;
    System.out.println(", New balance (w): " + balance); }
```

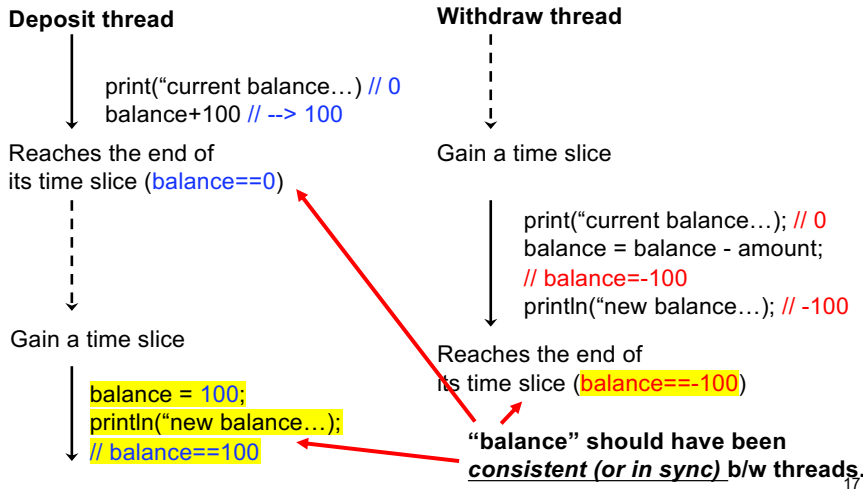
- Desirable output:
  - `Current balance (d): 0.0, New balance (d): 100.0`
  - `Current balance (w): 100.0, New balance (w): 0.0`
  - `Current balance (d): 0.0, New balance (d): 100.0`
  - `Current balance (w): 100.0, New balance (w): 0.0`
  - `...`
- In reality:
  - `Current balance (d): 0.0Current balance (w): 0.0, New balance (w): -100.0 , New balance (d): 100.0`

How Can This Happen?

`Current balance (d): 0.0Current balance (w): 0.0, New balance (w): -100.0 , New balance (d): 100.0`



```
Current balance (d): 0.0Current balance (w): 0.0, New balance (w): -100.0
, New balance (d): 100.0
```

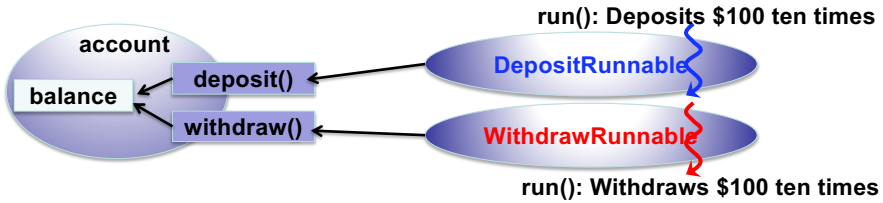


Source of the Problem: Visibility

- `ThreadUnsafeBankAccount` is NOT thread-safe.
  - Race conditions (data races) can occur.
- Race conditions occur due to visibility issue.
  - The most up-to-date value of the shared variable `balance` is *not visible* for all threads.

Where can a Context Switch Occur?

- To analyze thread safety, it is important to know where/when a context switch can occur in your code.
- A context switch can occur across *atomic operations*.
  - `intValue = 1;`
    - Sequence of 2 atomic operations
  - `balance = balance + amount;`
    - Sequence of 5 atomic operations
  - `balance += amount;`
    - Syntactic sugar for `balance = balance + amount;`




```
public void deposit(double amount){
            balance = balance + amount;  }
public void withdraw(double amount){
            balance = balance - amount;  }
```

- Race conditions can occur in the following cases:
  - Has read `balance`, but hasn't read `amount` yet.
    Context switch occurs, followed by a balance change by another thread
  - Has read `balance` and `amount`, but hasn't done addition/subtraction yet.
    Context switch occurs, followed by a balance change by another thread
  - Has read `balance` and `amount` and finished addition/subtraction, but hasn't updated `balance` yet
    Context switch occurs, followed by a balance change by another thread

Atomicity of Operations for Primitive Types

- The read and write operations for primitive data types, except double and long (64-bit) types, are atomic.
  - An atomic operation is transformed to a single bytecode instruction for a JVM.
  - No context switches occur during the execution of a byte code instruction.

- The read and write operations for primitive data types, except double and long (64-bit) types, are atomic.
  - Given `int x;`, Thread A does: `x=1;` Thread B does: `x=2;`
    - An assignment of an int value (write operation) is atomic.
    - **x** has 1 or 2 in the end, depending on which thread performs assignment earlier.
    - **x** never contain other values (e.g., 0 and 3) or corrupted data.
      - An example of corrupted data
        - » The first 16-bit of **x** is assigned by Thread A and the remaining part is assigned by Thread B.

Compound Operations

- A *compound* of atomic operations is NOT atomic.
  - `int i; boolean done;`
  - `done = true;` // 2 steps
  - `i = 1;` // 2 steps
  - `if(done==true)` // 3 steps
  - `if(done)` // 3 steps
  - `i = j;` // 2 steps
  - `j = i + 1;` // 5 steps
    - Reading the value of i, reading/loading the value of 1, summing up i and 1, storing the sum to a certain memory space, and assigning it to j.
  - `i = i + 1;` // 5 steps
  - `i++;` // 5 steps
  - `return i;` // 2 steps
  - A context switch can occur *in between* atomic operations/steps.
  - A race condition may occur due to the context switch.

What about 64-bit Types?

- The read and write operations for double and long variables are NOT atomic.
  - Given `long x`, Thread A does: `x=1L;` Thread B does: `x=2L;`
    - No guarantee that **x** has 1L or 2L in the end.
    - **x** can contain another value (e.g., 3L) or corrupted data.
      - An example of corrupted data
        - » The first 32-bit of **x** is assigned by Thread A and the remaining part is assigned by Thread B.
  - `aLongVar = 100L;` // More than 2 (~4) steps
  - `if(aLongVar==100)` // More than 3 (~6) steps
  - `aLongVar++` // More than 5 (~10) steps

Atomicity of Operations for Reference Types

- The read and write operations for reference types are atomic.
  - Given `String s`, Thread A does `s="a"` Thread B does `s="b"`
    - `s` has "a" or "b" in the end, depending on which thread performs assignment earlier.
    - `s` never contain other values (e.g., "x") or corrupted data.

Compound Operations

- A *compound* of atomic operations is NOT atomic.
  - ```
    Account account1 = ...;
    Account account2 = ...;
    Account sourceOfWireTransfer = account1;       // 2 steps
    Account destinationOfWireTransfer = account2;  // 2 steps
    ```
  - ```
    ArrayList<Car> cars = ...;
    Car car = cars.get(0);          // Many steps
                                    // ArrayList is NOT thread-safe.
                                    // All of its public methods are not.
                                    // Assignment is atomic/1-step though.
    ```

Atomicity of Constructors

- Only one thread can run a constructor on a class instance that is being created and initialized.

```
class Account{
  double balance;                   // Shared variable

  public Account(double initAmount){// Assigns a value to the shared
    balance = initAmount;           // variable thru 2+ steps...
  }                                 // but...THREAD-SAFE!

  public deposit(float amount){ ... }
  public withdraw(float amount){ ... }}
```

  - Until a thread returns/completes a constructor on a class instance, no other threads can call any public methods on that instance.

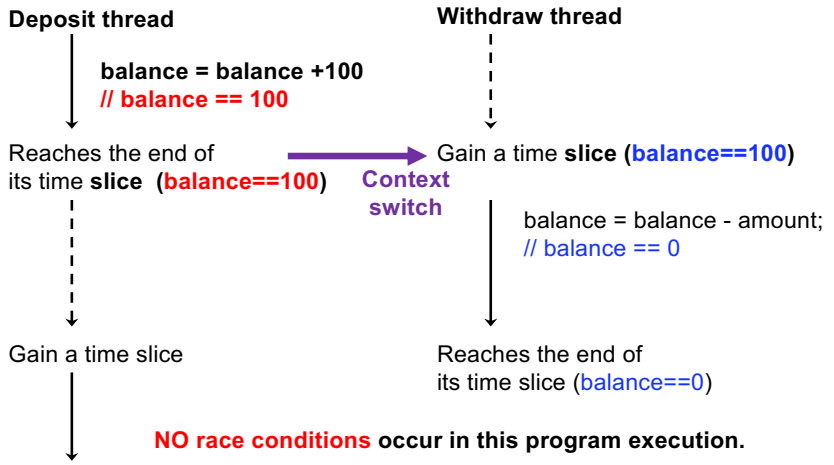
- ```
  Account account = new Account(0);
                  // Account's constructor is thread-safe (kinda atomic).
                  // Assignment is atomic (1-step).
                  // However, a compound of the two 2 ops is NOT atomic.
  ```
- ```
  Student student = new Student ("John", "Smith");
  ```
- ```
  Car car = new Car ("Honda", "CR-V", 2010, ...);
  ```
- ```
  String s = "umb";             // This is a syntactic sugar of:
  ```
- ```
  String s = new String("umb");
                  // String's constructor is thread-safe.
                  // Assignment is atomic (1-step).
                  // However, a compound of the two ops is NOT atomic.
  ```
- ```
  Integer i = 10;             // This is a syntactic sugar of:
  ```
- ```
  Integer i = Integer.valueOf(10);
                  // valueOf() calls Integer's constructor internally.
                  // Integer's constructor is thread-safe.
                  // Assignment is atomic (1-step).
                  // However, a compound of the two ops is NOT atomic.
  ```
  ```

What's Tricky in Multi-threading

- Your test code may or may not be able to detect race conditions
  - even if you run/test it a lot of times.

Consider this "Lucky" Case

- `public void deposit(double amount){ balance = balance + amount; }`



- `public void deposit(double amount){ balance = balance + amount; }`
- `public void withdraw(double amount){ balance = balance - amount; }`

- No race conditions occur if the "deposit" thread:
  - Has't read `balance`.
    Context switch, followed by a balance update by another thread.
  - Has completed to update `balance`
    Context switch, followed by a balance update by another thread.

Race Conditions (a.k.a. Data Races)

- All threads
  - Run in their *race* to complete their tasks.
  - Manipulate a shared object/data independently.
- The end result depends on which of them happens to win the race.
  - No guarantees on the order of thread execution.
  - No guarantees on how much task a thread can perform in a single CPU time slice/quota.
  - No guarantees on the end result on shared data.

Note: Thread States

- The state of a thread has nothing to do with…
  - whether the thread is "actively running" on a CPU core or it is "inactively waiting" for its next turn.
- Both "active" and "inactive" threads can be in the *Runnable* state.
- The *Waiting* or *Blocked* state does NOT mean that a thread is "inactive."
- Threads
  - change their states by themselves or via thread-to-thread interactions.
  - Has no control over active-inactive cycles (i.e., context switches).

States of a Thread