Introduction to Java

Volatile Variables

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Learning Objectives in this Part of the Lesson

• Understand how Java volatile variables provide concurrent programs with thread-safe mechanisms to read from & write to single variables
Overview of Java
Volatile Variables
Overview of Java Volatile Variables

- When a concurrent program is not written correctly, the errors tend to fall into three categories: *atomicity*, *visibility*, or *ordering*

See earlier lesson on "Overview of Atomic Operations"
Overview of Java Volatile Variables

- Volatile ensures that changes to a variable are always consistent & visible to other threads atomically

See tutorials.jenkov.com/java-concurrency/volatile.html
Overview of Java Volatile Variables

- Volatile ensures that changes to a variable are always consistent & visible to other threads atomically.
- Reads & writes go directly to main memory (not registers/cache) to avoid *read/write conflicts* on Java fields storing shared mutable data.

![GO TO JAIL]
Overview of Java Volatile Variables

- Volatile ensures that changes to a variable are always consistent & visible to other threads atomically
  - Reads & writes go directly to main memory (not registers/cache) to avoid *read/write conflicts* on Java fields storing shared mutable data
- Volatile reads/writes cannot be reordered
Overview of Java Volatile Variables

- Volatile ensures that changes to a variable are always consistent & visible to other threads atomically
  - Reads & writes go directly to main memory (not registers/cache) to avoid *read/write conflicts* on Java fields storing shared mutable data
- Volatile reads/writes cannot be reordered
  - The Java compiler automatically transforms reads & writes on a volatile variable into atomic acquire & release pairs
Overview of Java Volatile Variables

- Volatile is *not* needed in sequential programs for several reasons
Overview of Java Volatile Variables

- Volatile is *not* needed in sequential programs for several reasons, e.g.
  - Reads & writes of (most) Java primitive variables are atomic

*If the main thread writes a value to a non-volatile (nv) field the next read of that field will get that value*
Overview of Java Volatile Variables

- Volatile is *not* needed in sequential programs for several reasons, e.g.
  - Reads & writes of (most) Java primitive variables are atomic
  - Although multiple-step operations are performed at the machine code level for variables of types long & double, these operations aren’t interleaved in a single-threaded program

See [docs.oracle.com/javase/specs/jls/se7/html/jls-17.html#jls-17.7](https://docs.oracle.com/javase/specs/jls/se7/html/jls-17.html#jls-17.7)
Overview of Java Volatile Variables

- Volatile is needed in concurrent Java programs

See en.wikipedia.org/wiki/Volatile_variable
Overview of Java Volatile Variables

- Volatile *is* needed in concurrent Java programs
- One thread may not see the latest value of a variable changed by another thread due to caching
Overview of Java Volatile Variables

- Volatile is needed in concurrent Java programs
- One thread may not see the latest value of a variable changed by another thread due to caching

Thread$_1$ writes a value to a non-volatile field nv, which is cached locally in the core for efficiency
Overview of Java Volatile Variables

- Volatile *is* needed in concurrent Java programs
- One thread may not see the latest value of a variable changed by another thread due to caching

When Thread₂ subsequently reads the value of field nv it gets a different result due to caching
Overview of Java Volatile Variables

- Java defines the `volatile` keyword to address these problems.

**In Java** [edit]

The Java programming language also has the `volatile` keyword, but it is used for a somewhat different purpose. When applied to a field, the Java qualifier `volatile` guarantees that:

- In all versions of Java, there is a global ordering on the reads and writes to a volatile variable. This implies that every thread accessing a volatile field will read its current value before continuing, instead of (potentially) using a cached value. (However, there is no guarantee about the relative ordering of volatile reads and writes with regular reads and writes, meaning that it's generally not a useful threading construct.)

- In Java 5 or later, volatile reads and writes establish a **happens-before relationship**, much like acquiring and releasing a mutex. [9]

Using `volatile` may be faster than a `lock`, but it will not work in some situations. [citation needed] The range of situations in which volatile is effective was expanded in Java 5; in particular, double-checked locking now works correctly. [10]

See [en.wikipedia.org/wiki/Volatile_variable#In_Java](en.wikipedia.org/wiki/Volatile_variable#In_Java)
Overview of Java Volatile Variables

- Java defines the volatile keyword to address these problems
- A value written to a volatile variable will *always* be stored in main memory
Overview of Java Volatile Variables

- Java defines the volatile keyword to address these problems
- A value written to a volatile variable will *always* be stored in main memory
- A volatile write “happens-before” all following reads of the same variable

See [en.wikipedia.org/wiki/Happened-before](en.wikipedia.org/wiki/Happened-before)
Overview of Java Volatile Variables

- Java defines the volatile keyword to address these problems
  - A value written to a volatile variable will *always* be stored in main memory
  - An access to a volatile variable will be read from main memory

**volatile reads are cheap & volatile writes are cheaper than synchronized statements**
Overview of Java Volatile Variables

- Volatile guarantees *atomicity*

```java
volatile long foo;
final long A = 0xffffffffffffffffl;
final long B = 0;

new Thread(() -> {
    for (int i;; i++) {
        foo = i % 2 == 0 ? A : B;
    }
}).start();

new Thread(() -> {
    long fooRead = foo;
    if (fooRead != A && fooRead != B)
        System.err.println("foo incomplete write "+ Long.toHexString(fooRead));
}).start();
```

*If volatile is removed here then incomplete writes may occur (especially on 32 bit machines)*

See [stackoverflow.com/questions/3038203/is-there-any-point-in-using-a-volatile-long](https://stackoverflow.com/questions/3038203/is-there-any-point-in-using-a-volatile-long)
Overview of Java Volatile Variables

- Volatile guarantees *atomicity*
  - Reads & writes are *atomic* for all variables declared volatile

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**Atomic Access**

In programming, an *atomic* action is one that effectively happens all at once. An atomic action cannot stop in the middle: it either happens completely, or it doesn't happen at all. No side effects of an atomic action are visible until the action is complete.

We have already seen that an increment expression, such as `c++`, does not describe an atomic action. Even very simple expressions can define complex actions that can decompose into other actions. However, there are actions you can specify that are atomic:

- Reads and writes are atomic for reference variables and for most primitive variables (all types except `long` and `double`).
- Reads and writes are atomic for all variables declared *volatile* *(including long and double variables).*

Atomic actions cannot be interleaved, so they can be used without fear of thread interference. However, this does not eliminate all need to synchronize atomic actions, because memory consistency errors are still possible. Using volatile variables reduces the risk of memory consistency errors, because any write to a volatile variable establishes a happens-before relationship with subsequent reads of that same variable. This means that changes to a volatile variable are always visible to other threads. What's more, it also means that when a thread reads a volatile variable, it sees not just the latest change to the volatile, but also the side effects of the code that led up the change.

See [docs.oracle.com/javase/tutorial/essential/concurrency/atomic.html](https://docs.oracle.com/javase/tutorial/essential/concurrency/atomic.html)
Overview of Java Volatile Variables

• Volatile guarantees *atomicity*
  • Reads & writes are *atomic* for all variables declared volatile
  • Reads & writes are *always* atomic for Java references

Atomic Access

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We have already seen that an increment expression, such as `++`, does not describe an atomic action. Even very simple expressions can define complex actions that can decompose into other actions. However, there are actions you can specify that are atomic:

• **Reads and writes are atomic for reference variables** and for most primitive variables (all types except long and double).
  • Reads and writes are atomic for all variables declared volatile (*including* long and double variables).

Atomic actions cannot be interleaved, so they can be used without fear of thread interference. However, this does not eliminate all need to synchronize atomic actions, because memory consistency errors are still possible. Using volatile variables reduces the risk of memory consistency errors, because any write to a volatile variable establishes a happens-before relationship with subsequent reads of that same variable. This means that changes to a volatile variable are always visible to other threads. What's more, it also means that when a thread reads a volatile variable, it sees not just the latest change to the volatile, but also the side effects of the code that led up the change.

See [docs.oracle.com/javase/tutorial/essential/concurrency/atomic.html](docs.oracle.com/javase/tutorial/essential/concurrency/atomic.html)
Overview of Java Volatile Variables

- Volatile guarantees *visibility*  

```java
public class MyRunnable implements Runnable {
    private volatile boolean mIsStopped = false;
    
    public void stopMe() {
        mIsStopped = true;
    }
    
    public void run() {
        while (mIsStopped != true) {  // a long-running operation
            ...
        }
    }
}

Overview of Java Volatile Variables

- Volatile guarantees visibility
- If an action in thread T1 is visible to thread T2, the result of that action can be observed by thread T2

```java
public class MyRunnable implements Runnable {
    private volatile boolean mIsStopped = false;

    public void stopMe() {
        mIsStopped = true; // T1 write
    }

    public void run() { // T2 read
        while (mIsStopped != true) {
            // a long-running operation
        }
    }

    ...}
```

volatile write is visible to "happens-after" reads
Overview of Java Volatile Variables

- Volatile guarantees *ordering*

```java
public class MyRunnable
    implements Runnable {
    private volatile boolean mIsStopped = false;

    public void stopMe() {
        mIsStopped = true;
    }

    public void run() {
        while (mIsStopped != true) {
            // a long-running operation
        }
    }

    ...
```

Overview of Java Volatile Variables

- Volatile guarantees *ordering*
- *Ordering* constraints describe what order operations are seen to occur in different threads

```java
public class MyRunnable implements Runnable {
    private volatile boolean mIsStopped = false;

    public void stopMe() {
        mIsStopped = true; // T1 write
    }

    public void run() { // T2 read
        while (mIsStopped != true) {
            // a long-running operation
        }
        ...
    }
}
```

The write to `mIsStopped` in T1 must happen before the T2 read completes.
Overview of Java Volatile Variables

- Incrementing a volatile is *not* atomic

<table>
<thead>
<tr>
<th>Thread\textsubscript{1}</th>
<th>Thread\textsubscript{2}</th>
<th>volatile value</th>
</tr>
</thead>
<tbody>
<tr>
<td>initialized</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>read value</td>
<td>← 0</td>
<td></td>
</tr>
<tr>
<td>read value</td>
<td>← 0</td>
<td></td>
</tr>
<tr>
<td>increase value by 2</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>increase value by 1</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>write back</td>
<td>write back</td>
<td>→ 2 or 1?</td>
</tr>
</tbody>
</table>
Overview of Java Volatile Variables

- Incrementing a volatile is *not* atomic
- If multiple threads try to increment a volatile at the same time, an update might get lost

<table>
<thead>
<tr>
<th></th>
<th>Thread₁</th>
<th>Thread₂</th>
</tr>
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<tr>
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<tr>
<td>increase value by 2</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>increase value by 1</td>
<td></td>
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</tr>
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Consider using the java.util.concurrent.atomic package, which supports atomic increment/decrement & compare-and-swap (CAS) operations
End of Introduction to Volatile Variables