Advanced Concurrency

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Excellent Reference on Concurrency

- Reference: “Java Concurrency in Practice” by Brian Goetz
Concurrency without Explicitly Threads

- You can write concurrent applications that don’t use explicit threads or synchronization
- Use built-in abstractions that support coordination and parallel execution
Synchronized Collections

- Achieve thread safety by allowing access to only one thread at a time
- Examples
  - Vector
  - Hashtable
  - Synchronized wrapper classes created by `Collections.synchronizedXxx`
- Example: synchronized set
- [http://docs.oracle.com/javase/6/docs/api/java/util/Collections.html#synchronizedSet(java.util.Set)](http://docs.oracle.com/javase/6/docs/api/java/util/Collections.html#synchronizedSet(java.util.Set))
- Disadvantage of this approach: poor concurrency
Concurrent Collections

- Designed to allow concurrent access by multiple threads
  - Blocking only when they “conflict”
- Higher space overhead
  - Not much time overhead
- Many of the concurrent collections do not allow null keys or values
- Examples
  - `ConcurrentHashMap`
    - Replacement for synchronized hash-based Map implementations
  - `CopyOnWriteArrayList`
    - Replacement for synchronized List implementations (where traversal is the predominant operation)
Concurrent HashMap

• Allows simultaneous reads, and by default up to 16 simultaneous writers
  • Can increase the number of simultaneous writers

• Special Methods
  • V putIfAbsent(K key, V value)
    • Store the value only if the key has no mapping
    • Return old value (null if none)
  • boolean remove(K key, V oldValue)
    • Remove mapping only if it has the specified value
  • boolean replace(K key, V oldValue, V newValue)
    • Update the mapping only if it has the specified value
CopyOnWriteArrayList

- Suitable only if updates rare and iteration occurs often
- Iteration uses a snapshot of the array
- Iterators keep a reference to the backing array current at the beginning of the iteration
- When an update occurs a new array copy is created and published
- Important use case
  - Keeping track of listeners to an Observable
  - While iterating through list of listeners (delivering a notification), one of them might ask to be unsubscribed
Concurrent Skip Lists

• Skip Lists are a probabilistic alternative to balanced trees
  • Stores sorted list of items using layers of linked lists
• Invented in 1988 by Prof. Bill Pugh

Examples

• ConcurrentSkipListMap
  • [http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentSkipListMap.html](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentSkipListMap.html)

• ConcurrentSkipListSet
  • [http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentSkipListSet.html](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentSkipListSet.html)

• Above classes are concurrent replacements for a synchronized SortedMap or SortedSet (e.g., TreeMap, TreeSet wrapped with synchronizedMap)
Waiting for Something to Happen

• We briefly talk about join (waits for another thread to terminate)

• There are lots of ways to have a thread wait until things are right for it to do something
  • wait/notify were the way to do this before Java 5
  • But now we have new ways that are often better: blocking queues and synchronizers
### Blocking Queues

- **BlockingQueue**
  - [http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/BlockingQueue.html](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/BlockingQueue.html)
  - BlockingQueue implementations are thread-safe
  - BlockingQueue implementations designed for used in producer-consumer queues
- BlockingQueue methods can handle in different ways operations that cannot be satisfied immediately. The options are
  - Throwing an exception
  - Returning a special value (null or false)
  - Blocking the thread until the operation can succeed
    - E.g., waiting for space to become available
  - Blocking the thread for a given period of time before giving up

<table>
<thead>
<tr>
<th></th>
<th>throws exception</th>
<th>returns special value</th>
<th>blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>insert</strong></td>
<td>add(e)</td>
<td>offer(e)</td>
<td>put(e)</td>
</tr>
<tr>
<td><strong>remove</strong></td>
<td>remove()</td>
<td>poll()</td>
<td>take()</td>
</tr>
<tr>
<td><strong>examine</strong></td>
<td>element</td>
<td>peek()</td>
<td></td>
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**Synchronizers**

- **Synchronizer**
  - Any object that coordinates control flow of threads
  - They allow threads arriving at synchronizer to pass or to wait

- **Examples**
  - Semaphores
  - Latches
  - Barriers
  - Blocking queues can act as synchronizers
Semaphore

- Controls number of activities accessing a resource or performing an action
- Contains a count of the number of permits available
- You can acquire or release permits
- acquire method - blocks if not enough permits are available
- release method – returns permit to the semaphore
CountDownLatch

- Act as a gate that is open once a set of events have taken place
- Has a counter that can be decremented (never incremented)
- countDown method - decrements counter indicating event has taken place
- await method – wait for the counter to reach zero
  - Blocks until counter reaches zero
Barrier

• Allows set of threads to wait for each other to reach a common point

• await method – blocks until all threads have reached the barrier

• Example: CyclicBarrier
  
  • [http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/CyclicBarrier.html](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/CyclicBarrier.html)
Fairness

• Consider a Blocking queue where you atomically remove multiple elements

• What happens if one person wants to atomically remove 10 elements from a queue that can contain up to 20 elements
  • But there is a constant stream of other threads that want to remove smaller number of elements?

Starvation!
Some Abstractions Have Fair Variants

• For example, fair semaphores and fair reentrant locks
• Generally, fair guarantees first-come, first-served
• But fair almost always reduces throughput
  • Over and above implementation cost
  • Letting running threads run improves throughput
Atomic Classes

- java.util.concurrent.atomic
  - Toolkit of classes that support lock-free thread-safe programming on single variables
- AtomicInteger class
  - Encapsulates an integer
  - Supports atomic operations:
    - int getAndIncrement()
    - int decrementAndGet()
    - boolean compareAndSet(int expect, int update)
- There is an AtomicX class for every primitive type
- The atomic operations are very efficient
  - Most processors provide some kind of atomic compare and swap instruction
Executor

• An object that executes submitted Runnable tasks, rather than starting a thread for each task (e.g., new Thread(new(RunnableTask())).start())

• You ask an executor to do it
  Executor executor = create executor;
  executor.execute(new RunnableTask1());
  executor.execute(new RunnableTask2());

• An executor can be simple or complex
  • The execute method might just run the task
  • Or create and start thread
  • Or do something more complicated

• java.util.concurrent.Executors
  • Provides many factory and utility methods for executors
    • newFixedThreadPool(int nThreads)
    • newCachedThreadPool()
      • Creates threads as needed, reuses them
Why Thread Pools?

• Some overhead to starting a thread
• Running 100,000 threads is a bad idea
  • Unless you have a monster machine