BigMemory Go Configuration Guide

Innovation Release

Version 4.3.5

April 2018

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Document ID: BMG-CG-435-20180417

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About BigMemory Go Configuration

BigMemory Go supports declarative configuration via an XML configuration file, as well as programmatic configuration via class-constructor APIs. Choosing one approach over the other can be a matter of preference or a requirement, such as when an application requires a certain run-time context to determine appropriate configuration settings.

If your project permits the separation of configuration from run time use, there are advantages to the declarative approach:

- Cache configuration can be changed more easily at deployment time.
- Configuration can be centrally organized for greater visibility.
- Configuration lifecycle can be separated from application-code lifecycle.
- Configuration errors are checked at startup rather than causing an unexpected runtime error.
- If the configuration file is not provided, a default configuration is always loaded at runtime.

This guide focuses on XML declarative configuration. Programmatic configuration is explored in certain examples and is documented in the Javadoc at "http://www.ehcache.org/apidocs/2.10.1/".

XML Configuration

BigMemory Go uses Ehcache as its user-facing interface and is configured using the Ehcache configuration system.By default, Ehcache looks for an ASCII or UTF8 encoded XML configuration file called ehcache.xml at the top level of the Java classpath. You may specify alternate paths and filenames for the XML configuration file by using the various CacheManager constructors as described in the CacheManager Javadoc at "http://www.ehcache.org/apidocs/2.10.1/".

To avoid resource conflicts, one XML configuration is required for each CacheManager that is created. For example, directory paths and listener ports require unique values. BigMemory Go will attempt to resolve conflicts, and, if one is found, it will emit a warning reminding the user to use separate configurations for multiple CacheManagers.

A sample ehcache.xml file is included in the BigMemory Go distribution. It contains full commentary on how to configure each element. This file can also be downloaded from "http://ehcache.org/ehcache.xml".

ehcache.xsd

Ehcache configuration files must comply with the Ehcache XML schema, ehcache.xsd, which can be downloaded from "http://ehcache.org/ehcache.xsd".

The BigMemory Go distribution also contains a copy of ehcache.xsd.

ehcache-failsafe.xml

If the CacheManager default constructor or factory method is called, Ehcache looks for a file called ehcache.xml in the top level of the classpath. Failing that, it looks for ehcache-failsafe.xml in the classpath. The ehcache-failsafe.xml file is packaged in the Ehcache JAR and should always be found.

ehcache-failsafe.xml provides a simple default configuration to enable users to get started before they create their own ehcache.xml.

When ehcache-failsafe.xml is used, Ehcache will emit a warning, reminding the user to set up a proper configuration. The meaning of the elements and attributes are explained in the section on ehcache.xml.

```
<ehcache>
  <diskStore path="java.io.tmpdir"/>
  <defaultCache
     maxEntriesLocalHeap="10000"
     eternal="false"
     timeToIdleSeconds="120"
     timeToLiveSeconds="120"
     maxEntriesLocalDisk="10000000"
     diskExpiryThreadIntervalSeconds="120"
     memoryStoreEvictionPolicy="LRU">
     <persistence strategy="localTempSwap"/>
  </defaultCache>
</ehcache>
```

About Default Cache

The *defaultCache* configuration is applied to any cache that is not explicitly configured. The defaultCache appears in the ehcache-failsafe.xml file by default, and can also be added to any BigMemory Go configuration file.

While the defaultCache configuration is not required, an error is generated if caches are created by name (programmatically) with no defaultCache loaded.

Dynamically Changing Cache Configuration

While most of the BigMemory Go configuration is not changeable after startup, certain cache configuration parameters can be modified dynamically at runtime. These include the following:

- Expiration settings
  - **timeToLive** – The maximum number of seconds an element can exist in the cache regardless of access. The element expires at this limit and will no longer be returned from the cache. The default value is 0, which means no TTL eviction takes place (infinite lifetime).
  - **timeToIdle** – The maximum number of seconds an element can exist in the cache without being accessed. The element expires at this limit and will no longer be

returned from the cache. The default value is 0, which means no TTI eviction takes place (infinite lifetime).

Note that the `eternal` attribute, when set to "true", overrides `timeToLive` and `timeToIdle` so that no expiration can take place.

- Local sizing attributes
  - `maxEntriesLocalHeap`
  - `maxBytesLocalHeap`
  - `maxEntriesLocalDisk`
  - `maxBytesLocalDisk`.
- memory-store eviction policy.
- CacheEventListeners can be added and removed dynamically

This example shows how to dynamically modify the cache configuration of a running cache:

```
Cache cache = manager.getCache("sampleCache");
CacheConfiguration config = cache.getCacheConfiguration();
config.setTimeToIdleSeconds(60);
config.setTimeToLiveSeconds(120);
config.setmaxEntriesLocalHeap(10000);
config.setmaxEntriesLocalDisk(1000000);
```

Dynamic cache configurations can also be disabled to prevent future changes:

```
Cache cache = manager.getCache("sampleCache");
cache.disableDynamicFeatures();
```

In ehcache.xml, you can disable dynamic configuration by setting the `<ehcache>` element's `dynamicConfig` attribute to "false".

Passing Copies Instead of References

By default, a get() operation on a store returns a reference to the requested data, and any changes to that data are immediately reflected in the memory store. In cases where an application requires a *copy* of data rather than a reference to it, you can configure the store to return a copy. This allows you to change a copy of the data without affecting the original data in the memory store.

This is configured using the `copyOnRead` and `copyOnWrite` attributes of the <cache> and <defaultCache> elements in your configuration, or programmatically as follows:

```
CacheConfiguration config = new CacheConfiguration("copyCache", 1000)
                                  .copyOnRead(true).copyOnWrite(true);
Cache copyCache = new Cache(config);
```

The default configuration is "false" for both options.

To copy elements on put()-like and/or get()-like operations, a copy strategy is used. The default implementation uses serialization to copy elements. You can provide

your own implementation of net.sf.ehcache.store.compound.CopyStrategy using the <copyStrategy> element:

```
<cache name="copyCache"
    maxEntriesLocalHeap="10"
    eternal="false"
    timeToIdleSeconds="5"
    timeToLiveSeconds="10"
    copyOnRead="true"
    copyOnWrite="true">
  <copyStrategy class="com.company.ehcache.MyCopyStrategy"/>
</cache>
```

A single instance of your CopyStrategy is used per cache. Therefore, in your implementation of CopyStrategy.copy(T), T must be thread-safe.

A copy strategy can be added programmatically in the following way:

```
CacheConfiguration cacheConfiguration = new CacheConfiguration("copyCache", 10);
CopyStrategyConfiguration copyStrategyConfiguration = new CopyStrategyConfiguration();
copyStrategyConfiguration.setClass("com.company.ehcache.MyCopyStrategy");
cacheConfiguration.addCopyStrategy(copyStrategyConfiguration);
```

2 Configuring Storage Tiers

About Storage Tiers

BigMemory Go has three storage tiers, summarized here:

- **Memory store** – Heap memory that holds a copy of the hottest subset of data from the off-heap store. Subject to Java GC.
- **Off-heap store** – Limited in size only by available RAM. Not subject to Java GC. Can store serialized data only. Provides overflow capacity to the memory store.
- **Disk store** – Backs up in-memory data and provides overflow capacity to the other tiers. Can store serialized data only.

This document defines the standalone storage tiers and their suitable element types and then details the configuration for each storage tier.

Before running in production, it is strongly recommended that you test the tiers with the actual amount of data you expect to use in production. For information about sizing the tiers, refer to "Sizing Storage Tiers" on page 23.

Configuring Memory Store

The memory store is always enabled and exists in heap memory. For the best performance, allot as much heap memory as possible without triggering garbage collection (GC) pauses, and use the off-heap store to hold the data that cannot fit in heap (without causing GC pauses).

The memory store has the following characteristics:

- Accepts all data, whether serializable or not
- Fastest storage option
- Thread safe for use by multiple concurrent threads

The memory store is the top tier and is automatically used by BigMemory Go to store the data hotset because it is the fastest store. It requires no special configuration to enable, and its overall size is taken from the Java heap size. Since it exists in the heap, it is limited by Java GC constraints.

Memory Use, Spooling, and Expiry Strategy in the Memory Store

All caches specify their maximum in-memory size, in terms of the number of elements, at configuration time.

When an element is added to a cache and it goes beyond its maximum memory size, an existing element is either deleted, if overflow is not enabled, or evaluated for spooling to another tier, if overflow is enabled. The overflow options are `overflowToOffHeap` and `<persistence>` (disk store).

If overflow is enabled, a check for expiry is carried out. If it is expired it is deleted; if not it is spooled. The eviction of an item from the memory store is based on the optional `MemoryStoreEvictionPolicy` attribute specified in the configuration file. Legal values are LRU (default), LFU and FIFO:

- **Least Recently Used (LRU)**—LRU is the default setting. The last-used timestamp is updated when an element is put into the cache or an element is retrieved from the cache with a get call.
- **Least Frequently Used (LFU)** —For each get call on the element the number of hits is updated. When a put call is made for a new element (and assuming that the max limit is reached for the memory store) the element with least number of hits, the Less Frequently Used element, is evicted.
- **First In First Out (FIFO)** — Elements are evicted in the same order as they come in. When a put call is made for a new element (and assuming that the max limit is reached for the memory store) the element that was placed first (First-In) in the store is the candidate for eviction (First-Out).

For all the eviction policies there are also putQuiet() and getQuiet() methods which do not update the last used timestamp.

When there is a get() or a getQuiet() on an element, it is checked for expiry. If expired, it is removed and null is returned. Note that at any point in time there will usually be some expired elements in the cache. Memory sizing of an application must always take into account the maximum size of each cache.

Tip: calculateInMemorySize() is a convenient method that can provide an estimate of the size (in bytes) of the memory store. It returns the serialized size of the cache, providing a rough estimate. Do not use this method in production as it is has a negative effect on performance.

An alternative is to have an expiry thread. This is a trade-off between lower memory use and short locking periods and CPU utilization. The design is in favor of the latter. For those concerned with memory use, simply reduce the tier size. For more information, refer to "Sizing Storage Tiers" on page 23.

Configuring Off-Heap Store

The off-heap store extends the in-memory store to memory outside the of the object heap. This store, which is not subject to Java garbage collection (GC), is limited only by the amount of RAM available.

Because off-heap data is stored in bytes, only data that is Serializable is suitable for the off-heap store. Any non serializable data overflowing to the OffHeapMemoryStore is simply removed, and a WARNING level log message emitted.

Since serialization and deserialization take place on putting and getting from the off-heap store, it is theoretically slower than the memory store. This difference, however, is mitigated when GC involved with larger heaps is taken into account.

Allocating Direct Memory in the JVM

The off-heap store uses the direct-memory portion of the JVM. You must allocate sufficient direct memory for the off-heap store by using the JVM property `MaxDirectMemorySize`.

For example, to allocate 2GB of direct memory in the JVM:

```
java -XX:MaxDirectMemorySize=2G ...
```

Since direct memory may be shared with other processes, allocate at least 256MB (or preferably 1GB) more to direct memory than will be allocated to the off-heap store.

Note the following about allocating direct memory:

- If you configure off-heap memory but do not allocate direct memory with `-XX:MaxDirectMemorySize`, the default value for direct memory depends on your version of your JVM. Oracle HotSpot has a default equal to maximum heap size (-Xmx value), although some early versions may default to a particular value.
- `MaxDirectMemorySize` must be added to the local node's startup environment.
- Direct memory, which is part of the Java process heap, is separate from the object heap allocated by -Xmx. The value allocated by `MaxDirectMemorySize`must not exceed physical RAM, and is likely to be less than total available RAM due to other memory requirements.
- The amount of direct memory allocated must be within the constraints of available system memory and configured off-heap memory.
- The maximum amount of direct memory space you can use depends on the process data model (32-bit or 64-bit) and the associated operating system limitations, the amount of virtual memory available on the system, and the amount of physical memory available on the system.

Using Off-Heap Store with 32-bit JVMs

The amount of heap-offload you can achieve is limited by addressable memory. 64-bit systems can allow as much memory as the hardware and operating system can handle, while 32-bit systems have strict limitations on the amount of memory that can be effectively managed.

For a 32-bit process model, the maximum virtual address size of the process is typically 4GB, though most 32-bit operating systems have a 2GB limit. The maximum heap size available to Java is lower still due to particular operating-system (OS) limitations, other operations that may run on the machine (such as mmap operations used by certain APIs), and various JVM requirements for loading shared libraries and other code. A useful rule to observe is to allocate no more to off-heap memory than what is left over after -Xmx is set. For example, if you set -Xmx3G, then off-heap should be no more than 1GB. Breaking this rule may not cause an OutOfMemoryError on startup, but one is likely to occur at some point during the JVM's life.

If Java GC issues are afflicting a 32-bit JVM, then off-heap store can help. However, note the following:

- Everything has to fit in 4GB of addressable space. If 2GB of heap is allocated (with -Xmx2g) then at most are 2GB left for off-heap data.
- The JVM process requires some of the 4GB of addressable space for its code and shared libraries plus any extra Operating System overhead.
- Allocating a 3GB heap with -Xmx, as well as 2047MB of off-heap memory, will not cause an error at startup, but when it's time to grow the heap an OutOfMemoryError is likely.
- If both -Xms3G and -Xmx3G are used with 2047MB of off-heap memory, the virtual machine will start but then complain as soon as the off-heap store tries to allocate the off-heap buffers.
- Some APIs, such as java.util.zip.ZipFile on a 1.5 JVM, may <mmap> files in memory. This will also use up process space and may trigger an OutOfMemoryError.

Configuring the Off-Heap Store

If an off-heap store is configured, the corresponding memory store overflows to that off-heap store. Configuring an off-heap store can be done either through XML or programmatically. With either method, the off-heap store is configured on a per-cache basis.

Declarative Configuration

The following XML configuration creates an off-heap cache with an in-heap store (`maxEntriesLocalHeap`) of 10,000 elements which overflow to a 1-gigabyte off-heap area.

```
<ehcache updateCheck="false" monitoring="off" dynamicConfig="false">
  <defaultCache maxEntriesLocalHeap="10000"
              eternal="true"
              memoryStoreEvictionPolicy="LRU"
              statistics="false" />
  <cache name="sample-offheap-cache"
       maxEntriesLocalHeap="10000"
       eternal="true"
       memoryStoreEvictionPolicy="LRU"
       overflowToOffHeap="true"
       maxBytesLocalOffHeap="1G"/>
</ehcache>
```

The configuration options are:

overflowToOffHeap

Values may be true or false. When set to true, enables the cache to utilize off-heap memory storage to improve performance. Off-heap memory is not subject to Java GC cycles and has a size limit set by the Java property `MaxDirectMemorySize`. The default value is false.

maxBytesLocalOffHeap

Sets the amount of off-heap memory available to the cache and is in effect only if `overflowToOffHeap` is true. The minimum amount that can be allocated is 1MB. There is no maximum.

For more information on sizing data stores, see "Sizing Storage Tiers" on page 23.

Note: You should set `maxEntriesLocalHeap` to at least 100 elements when using an off-heap store to avoid performance degradation. Lower values for `maxEntriesLocalHeap` trigger a warning to be logged.

Programmatic Configuration

The equivalent cache can be created using the following programmatic configuration:

```
public Cache createOffHeapCache()
{
  CacheConfiguration config = new CacheConfiguration("sample-offheap-cache", 10000)
  .overflowToOffHeap(true).maxBytesLocalOffHeap("1G");
  Cache cache = new Cache(config);
  manager.addCache(cache);
  return cache;
}
```

Off-Heap Configuration Examples

These examples show how to allocate 8GB of machine memory to different stores. It assumes a data set of 7GB - say for a cache of 7M items (each 1kb in size).

Those who want minimal application response-time variance (or minimizing GC pause times), will likely want all the cache to be off-heap. Assuming that 1GB of heap is needed for the rest of the application, they will set their Java config as follows:

```
java -Xms1G -Xmx1G -XX:maxDirectMemorySize=7G
```

And their Ehcache config as:

```
<cache
 maxEntriesLocalHeap=100
 overflowToOffHeap="true"
 maxBytesLocalOffHeap="6G"
... />
```

Note: To accommodate server communications layer requirements, the value of `maxDirectMemorySize` must be greater than the value of `maxBytesLocalOffHeap`. The exact amount greater depends upon the size of `maxBytesLocalOffHeap`. The minimum is 256MB, but if you allocate 1GB more to the `maxDirectMemorySize`, it will certainly be sufficient. The server will only use what it needs and the rest will remain available.

Those who want best possible performance for a hot set of data, while still reducing overall application response time variance, will likely want a combination of on-heap and off-heap. The heap will be used for the hotset, the off-heap for the rest. So, for

example if the hot set is 1M items (or 1GB) of the 7GB data. They will set their Java config as follows

```
java -Xms2G -Xmx2G -XX:maxDirectMemorySize=6G
```

And their Ehcache config as:

```
<cache
  maxEntriesLocalHeap=1M
  overflowToOffHeap="true"
  maxBytesLocalOffHeap="5G"
  ...>
```

This configuration will compare *very* favorably against the alternative of keeping the less-hot set in a database (100x slower) or caching on local disk (20x slower).

Where the data set is small and pauses are not a problem, the whole data set can be kept on heap:

```
<cache
  maxEntriesLocalHeap=1M
  overflowToOffHeap="false"
  ...>
```

Where latency isn't an issue, the disk can be used:

```
<cache
  maxEntriesLocalHeap=1M
  <persistence strategy="localTempSwap"/>
  ...>
```

Tuning Off-Heap Store Performance

Memory-related or performance issues that arise during operations can be related to improper allocation of memory to the off-heap store. If performance or functional issues arise that can be traced back to the off-heap store, see the suggested tuning tips in this section.

General Memory allocation

Committing too much of a system's physical memory is likely to result in paging of virtual memory to disk, quite likely during garbage-collection operations, leading to significant performance issues. On systems with multiple Java processes, or multiple processes in general, the sum of the Java heaps and off-heap stores for those processes should also not exceed the size of the physical RAM in the system. Besides memory allocated to the heap, Java processes require memory for other items, such as code (classes), stacks, and PermGen.

Note that MaxDirectMemorySize sets an upper limit for the JVM to enforce, but does not actually allocate the specified memory. Overallocation of direct memory (or buffer) space is therefore possible, and could lead to paging or even memory-related errors. The limit on direct buffer space set by MaxDirectMemorySize should take into account the total physical memory available, the amount of memory that is allotted to the JVM object heap, and the portion of direct buffer space that other Java processes may consume.

In addition, be sure to allocate at least 15 percent more off-heap memory than the size of your data set. To maximize performance, a portion of off-heap memory is reserved for meta-data and other purposes.

Note also that there could be other users of direct buffers (such as NIO and certain frameworks and containers). Consider allocating additional direct buffer memory to account for that additional usage.

Compressed References

For 64-bit JVMs running Java 6 Update 14 or higher, consider enabling compressed references to improve overall performance. For heaps up to 32GB, this feature causes references to be stored at half the size, as if the JVM is running in 32-bit mode, freeing substantial amounts of heap for memory-intensive applications. The JVM, however, remains in 64-bit mode, retaining the advantages of that mode.

For the Oracle HotSpot, compressed references are enabled using the option `-XX:+UseCompressedOops`. For IBM JVMs, use `-Xcompressedrefs`.

Slow Off-Heap Allocation

Based configuration, usage, and memory requirements, BigMemory could allocate off-heap memory multiple times. If off-heap memory comes under pressure due to over-allocation, the host OS may begin paging to disk, thus slowing down allocation operations. As the situation worsens, an off-heap buffer too large to fit in memory can quickly deplete critical system resources such as RAM and swap space and crash the host OS.

To stop this situation from degrading, off-heap allocation time is measured to avoid allocating buffers too large to fit in memory. If it takes more than 1.5 seconds to allocate a buffer, a warning is issued. If it takes more than 15 seconds, the JVM is halted with System.exit() (or a different method if the Security Manager prevents this).

To prevent a JVM shutdown after a 15-second delay has occurred, set the `net.sf.ehcache.offheap.DoNotHaltOnCriticalAllocationDelay` system property to true. In this case, an error is logged instead.

Swappiness and Huge Pages

An OS could swap data from memory to disk even if memory is not running low. For the purpose of optimization, data that appears to be unused may be a target for swapping. Because BigMemory can store substantial amounts of data in RAM, its data may be swapped by the OS. But swapping can degrade overall cluster performance by introducing thrashing, the condition where data is frequently moved forth and back between memory and disk.

To make heap memory use more efficient, Linux, Microsoft Windows, and Oracle Solaris users should review their configuration and usage of swappiness as well as the size of the swapped memory pages. In general, BigMemory benefits from lowered swappiness and the use of *huge pages* (also known as *big pages*, *large pages*, and *superpages*).

Settings for these behaviors vary by OS and JVM. For Oracle HotSpot, `-XX:+UseLargePages` and `-XX:LargePageSizeInBytes=<size>` (where <size> is a value allowed by the OS for specific CPUs) can be used to control page size. However, note that this setting does *not* affect how off-heap memory is allocated. Over-allocating huge pages while also configuring substantial off-heap memory *can starve off-heap allocation and lead to memory and performance problems*.

Maximum Serialized Size of an Element

This section applies when using BigMemory through the Ehcache API.

Unlike the memory and the disk stores, by default the off-heap store has a 4MB limit for classes with high quality hashcodes, and 256KB limit for those with pathologically bad hashcodes. The built-in classes such as String and the java.lang.Number subclasses Long and Integer have high quality hashcodes. This can issues when objects are expected to be larger than the default limits.

To override the default size limits, set the system property `net.sf.ehcache.offheap.cache_name.config.idealMaxSegmentSize` to the size you require.

For example,

```
net.sf.ehcache.offheap.com.company.domain.State.config.idealMaxSegmentSize=30M
```

Reducing Faulting

While the memory store holds a hotset (a subset) of the entire data set, the off-heap store should be large enough to hold the entire data set. The frequency of misses (get operations that fail to find the data in memory) begins to rise when the data is too large to fit into off-heap memory, forcing gets to fetch data from the disk store (called *faulting*). More misses in turn raise latency and lower performance.

For example, tests with a 4GB data set and a 5GB off-heap store recorded no misses. With the off-heap store reduced to 4GB, 1.7 percent of cache operations resulted in misses. With the off-heap store at 3GB, misses reached 15 percent.

Configuring Disk Store

The disk store provides a thread-safe disk-spooling facility that can be used for either additional storage or persisting data through system restarts.

This section describes local disk usage. You can find additional information about configuring the disk store in "Configuring Fast Restart (FRS)" on page 39.

Serialization

Only data that is Serializable can be placed in the disk store. Writes to and from the disk use ObjectInputStream and the Java serialization mechanism. Any non-serializable data overflowing to the disk store is removed and a NotSerializableException is thrown.

Serialization speed is affected by the size of the objects being serialized and their type. It has been found that:

- The serialization time for a Java object consisting of a large Map of String arrays was 126ms, where the serialized size was 349,225 bytes.
- The serialization time for a byte[] was 7ms, where the serialized size was 310,232 bytes.

Byte arrays are 20 times faster to serialize, making them a better choice for increasing disk-store performance.

Configuring the Disk Store

Disk stores are configured on a per CacheManager basis. If one or more caches requires a disk store but none is configured, a default directory is used and a warning message is logged to encourage explicit configuration of the disk store path.

Configuring a disk store is optional. If all caches use only memory and off-heap stores, then there is no need to configure a disk store. This simplifies configuration, and uses fewer threads. This also makes it unnecessary to configure multiple disk store paths when multiple CacheManagers are being used.

Two disk store options are available:

- Temporary store (`localTempSwap`)
- Persistent store (`localRestartable`)

localTempSwap

The `localTempSwap` persistence strategy allows the memory and off-heap stores to overflow to disk when they become full. This option makes the disk a temporary store because overflow data does not survive restarts or failures. When the node is restarted, any existing data on disk is cleared because it is not designed to be reloaded.

If the disk store path is not specified, a default path is used, and the default will be auto-resolved in the case of a conflict with another CacheManager.

The localTempSwap disk store creates a data file for each cache on startup called "<*cache_name*> .data".

localRestartable

This option implements a restartable store for all in-memory data. After any restart, the data set is automatically reloaded from disk to the in-memory stores.

The path to the directory where any required disk files will be created is configured with the `<diskStore>` sub-element of the Ehcache configuration. In order to use the restartable store, a unique and explicitly specified path is required.

The diskStore Configuration Element

Files are created in the directory specified by the `<diskStore>` configuration element. The `<diskStore>` element has one attribute called `path`.

```
<diskStore path="/path/to/store/data"/>
```

Legal values for the path attribute are legal file system paths. For example, for Unix:

```
/home/application/cache
```

The following system properties are also legal, in which case they are translated:

- `user.home` - User's home directory
- `user.dir`- User's current working directory
- `java.io.tmpdir` - Default temp file path
- `ehcache.disk.store.dir`- A system property you would normally specify on the command line—for example, `java -Dehcache.disk.store.dir=/u01/myapp/diskdir`.

Subdirectories can be specified below the system property, for example:

```
user.dir/one
```

To programmatically set a disk store path:

```
DiskStoreConfiguration diskStoreConfiguration = new DiskStoreConfiguration();
diskStoreConfiguration.setPath("/my/path/dir");
// Already created a configuration object ...
configuration.addDiskStore(diskStoreConfiguration);
CacheManager mgr = new CacheManager(configuration);
```

Note: A CacheManager's disk store path cannot be changed once it is set in configuration. If the disk store path is changed, the CacheManager must be recycled for the new path to take effect.

Disk Store Expiry and Eviction

Expired elements are eventually evicted to free up disk space. The element is also removed from the in-memory index of elements.

One thread per cache is used to remove expired elements. The optional attribute `diskExpiryThreadIntervalSeconds` sets the interval between runs of the expiry thread.

Important: Setting `diskExpiryThreadIntervalSeconds` to a low value can cause excessive disk-store locking and high CPU utilization. The default value is 120 seconds.

If a cache's disk store has a limited size, Elements will be evicted from the disk store when it exceeds this limit. The LFU algorithm is used for these evictions. It is not configurable or changeable.

Note: With the `localTempSwap` strategy, you can use `maxEntriesLocalDisk` or `maxBytesLocalDisk` at either the Cache or CacheManager level to control the size of the disk tier.

Turning off Disk Stores

To turn off disk store path creation, comment out the `diskStore` element in ehcache.xml.

The default Ehcache configuration, ehcache-failsafe.xml, uses a disk store. To avoid use of a disk store, specify a custom ehcache.xml with the `diskStore` element commented out.

3 Sizing Storage Tiers

The Sizing Attributes

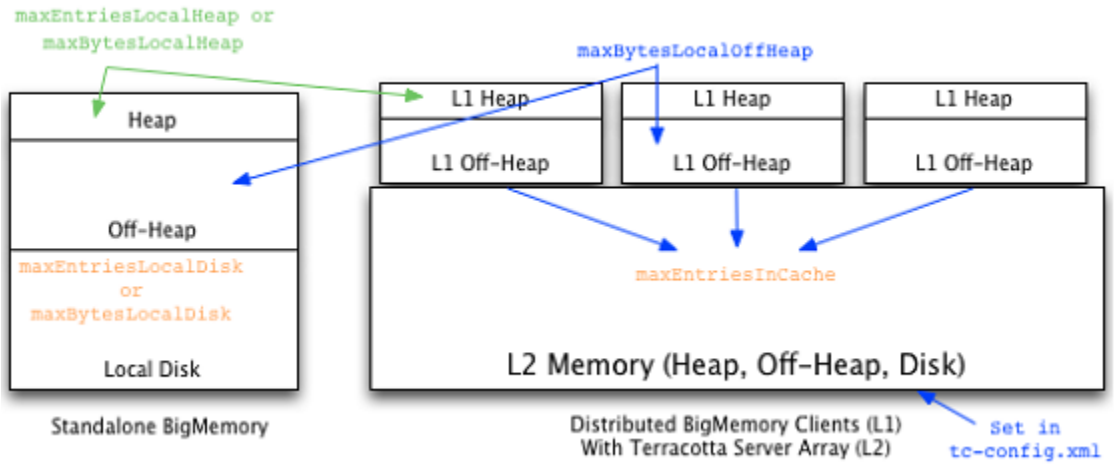
Tuning BigMemory Go often involves sizing the data storage tiers appropriately. You can size the different data tiers in a number of ways using simple sizing attributes. These sizing attributes affect memory and disk resources.

The following table summarizes the sizing attributes you can use.

Tier	Attribute	Description
Memory Store (Heap)	`maxEntriesLocalHeap` `maxBytesLocalHeap`	The maximum number of entries or bytes a data set can use in local heap memory, or when set at the CacheManager level (maxBytesLocalHeap only), as a pool available to all data sets under that CacheManager. This setting is required for every cache or at the CacheManager level. Pooling is available at the CacheManager level using `maxBytesLocalHeap` only.
Off-heap Store	`maxBytesLocalOffHeap`	The maximum number of bytes a data set can use in off-heap memory, or when set at the CacheManager level, as a pool available to all data sets under that CacheManager. Pooling is available at the CacheManager level.
Disk Store	`maxEntriesLocalDisk` `maxBytesLocalDisk`	The maximum number of entries or bytes a data set can use on the local disk, or when set at the CacheManager level (maxBytesLocalDisk only), as a pool available to all data sets under that CacheManager. Note that these settings apply to temporary disk usage (`localTempSwap`); these settings do not apply to disk persistence. Pooling is available at the CacheManager level using `maxBytesLocalDisk` only.

Attributes that set a number of entries or elements take an integer. Attributes that set a memory size (bytes) use the Java -Xmx syntax (for example: "500k", "200m", "2g") or percentage (for example: "20%"). Percentages, however, can be used only in the case where a CacheManager-level pool has been configured.

The following diagram illustrates the tiers and their effective sizing attributes.



Pooling Resources Versus Sizing Individual Data Sets

You can constrain the size of any data set on a specific tier in that data set's configuration. You can also constrain the size of all of a CacheManager's data sets in a specific tier by configuring an overall size at the CacheManager level.

If there is no CacheManager-level pool specified for a tier, an individual data set claims the amount of that tier specified in its configuration. If there is a CacheManager-level pool specified for a tier, an individual data set claims that amount *from the pool*. In this case, data sets with no size configuration for that tier receive an equal share of the remainder of the pool (after data sets with explicit sizing configuration have claimed their portion).

For example, if a CacheManager with eight data sets pools one gigabyte of heap, and two data sets each explicitly specify 200MB of heap while the remaining data sets do not specify a size, the remaining data sets will share 600MB of heap equally. Note that data sets must use bytes-based attributes to claim a portion of a pool; entries-based attributes such as `maxEntriesLocal` cannot be used with a pool.

On startup, the sizes specified by data sets are checked to ensure that any CacheManager-level pools are not over-allocated. If over-allocation occurs for any pool, an InvalidConfigurationException is thrown. Note that percentages should not add up to more than 100% of a single pool.

If the sizes specified by data sets for any tier take exactly the entire CacheManager-level pool specified for that tier, a warning is logged. In this case, data sets that do not specify a size for that tier cannot use the tier, as nothing is left over.

Memory Store (Heap)

A size must be provided for the heap, either in the CacheManager (`maxBytesLocalHeap` only) or in each individual cache (`maxBytesLocalHeap` or `maxEntriesLocalHeap`). Not doing so causes an InvalidConfigurationException.

If a pool is configured, it can be combined with a heap setting in an individual cache. This allows the cache to claim a specified portion of the heap setting configured in the pool. However, in this case the cache setting must use `maxBytesLocalHeap` (same as the CacheManager).

In any case, every cache *must* have a heap setting, either configured explicitly or taken from the pool configured in the CacheManager.

Off-Heap Store

Off-heap sizing can be configured in bytes only, never by entries.

If a CacheManager has a pool configured for off-heap, your application cannot add caches dynamically that have off-heap configuration — doing so generates an error. In addition, if any caches that used the pool are removed programmatically or through the Terracotta Management Console (TMC), other caches in the pool cannot claim the unused portion. To allot the entire off-heap pool to the remaining caches, remove the unwanted cache from the Ehcache configuration and then reload the configuration.

To use off-heap as a data tier, a cache must have `overflowToOffHeap` set to "true". If a CacheManager has a pool configured for using off-heap, the `overflowToOffHeap` attribute is automatically set to "true" for all caches. In this case, you can prevent a specific cache from overflowing to off-heap by explicitly setting its `overflowToOffHeap` attribute to "false".

Note that an exception is thrown if any cache using an off-heap store attempts to put an element that will cause the off-heap store to exceed its allotted size. The exception will contain a message similar to the following:

```
The element '[ key = 25274, value=[B@3ebb2a91, version=1, hitCount=0,
CreationTime = 1367966069431, LastAccessTime = 1367966069431 ]'
is too large to be stored in this offheap store.
```

Local Disk Store

The local disk can be used as a data tier, either for temporary storage or for disk persistence, but not both at once.

To use the disk as a temporary tier during BigMemory operation, set the `persistenceStrategy` to "localTempSwap", and use the `maxBytesLocalDisk` setting to configure the size of this tier. For more information about using the disk as a temporary tier, see "Configuring Disk Store" on page 19.

For information about using the disk store for data persistence, see "Data Persistence Implementation" on page 40.

Sizing Examples

The following examples illustrate both pooled and individual cache-sizing configurations.

Note: Some of the following examples include allocations for off-heap storage. Off-heap data storage (i.e., the off-heap tier) is only available with the Terracotta BigMemory products.

Pooled Resources

The following configuration sets pools for all of this CacheManager's caches:

```
<ehcache xmlns...
        Name="CM1"
        maxBytesLocalHeap="100M"
        maxBytesLocalOffHeap="10G"
        maxBytesLocalDisk="50G">
...
<cache name="Cache1" ... </cache>
<cache name="Cache2" ... </cache>
<cache name="Cache3" ... </cache>
</ehcache>
```

CacheManager CM1 automatically allocates these pools equally among its three caches. Each cache gets one third of the allocated heap, off-heap, and local disk. Note that at the CacheManager level, resources can be allocated in bytes only.

Explicitly Sizing Caches

You can explicitly allocate resources to specific caches:

```
<ehcache xmlns...
        Name="CM1"
        maxBytesLocalHeap="100M"
        maxBytesLocalOffHeap="10G"
        maxBytesLocalDisk="60G">
...
<cache name="Cache1" ...
        maxBytesLocalHeap="50M"
        ...
  </cache>
<cache name="Cache2" ...
       maxBytesLocalOffHeap="5G"
       ...
  </cache>
<cache name="Cache3" ... </cache>
</ehcache>
```

In the example above, Cache1 reserves 50Mb of the 100Mb local-heap pool; the other caches divide the remaining portion of the pool equally. Cache2 takes half of the local off-heap pool; the other caches divide the remaining portion of the pool equally. Cache3 receives 25Mb of local heap, 2.5Gb of off-heap, and 20Gb of the local disk.

Caches that reserve a portion of a pool are not required to use that portion. Cache1, for example, has a fixed portion of the local heap but may have any amount of data in heap up to the configured value of 50Mb.

Note that caches must use the same sizing attributes used to create the pool. Cache1, for example, cannot use `maxEntriesLocalHeap` to reserve a portion of the pool.

Mixed Sizing Configurations

If a CacheManager does not pool a particular resource, that resource can still be allocated in cache configuration, as shown in the following example.

```
<ehcache xmlns...
        Name="CM2"
        maxBytesLocalHeap="100M">
...
<cache name="Cache4" ...
        maxBytesLocalHeap="50M"
        maxEntriesLocalDisk="100000"
        ...
  </cache>
<cache name="Cache5" ...
       maxBytesLocalOffHeap="10G"
       ...
  </cache>
<cache name="Cache6" ... </cache>
</ehcache>
```

CacheManager CM2 creates one pool (local heap). Its caches all use the local heap and are constrained by the pool setting, as expected. However, cache configuration can allocate other resources as desired. In this example, Cache4 allocates disk space for its data, and Cache5 allocates off-heap space for its data. Cache6 gets 25Mb of local heap only.

Using Percents

The following configuration sets pools for each tier:

```
<ehcache xmlns...
        Name="CM1"
        maxBytesLocalHeap="1G"
        maxBytesLocalOffHeap="10G"
        maxBytesLocalDisk="50G">
...
<!-- Cache1 gets 400Mb of heap, 2.5Gb of off-heap, and 5Gb of disk. -->
<cache name="Cache1" ...
maxBytesLocalHeap="40%">
</cache>
<!-- Cache2 gets 300Mb of heap, 5Gb of off-heap, and 5Gb of disk. -->
<cache name="Cache2" ...
maxBytesLocalOffHeap="50%">
</cache>
<!-- Cache2 gets 300Mb of heap, 2.5Gb of off-heap, and 40Gb of disk. -->
<cache name="Cache3" ...
maxBytesLocalDisk="80%">
</cache>
</ehcache>
```

Note: You can use a percentage of the total JVM heap for the CacheManager maxBytesLocalHeap. The CacheManager percentage, then, is a portion of the total JVM heap, and in turn, the Cache percentage is the portion of the CacheManager pool for that tier.

Sizing Without a Pool

The CacheManager in this example does not pool any resources.

```
<ehcache xmlns...
        Name="CM3"
       ... >
...
<cache name="Cache7" ...
        maxBytesLocalHeap="50M"
        maxEntriesLocalDisk="100000"
        ...
  </cache>
<cache name="Cache8" ...
       maxEntriesLocalHeap="1000"
       maxBytesLocalOffHeap="10G"
       ...
  </cache>
<cache name="Cache9" ...
       maxBytesLocalHeap="50M"
...
</cache>
</ehcache>
```

Caches can be configured to use resources as necessary. Note that every cache in this example must declare a value for local heap. This is because no pool exists for the local heap; implicit (CacheManager configuration) or explicit (cache configuration) local-heap allocation is required.

Pinning and Size Limitations

Pinned caches can override the limits set by cache-configuration sizing attributes, potentially causing OutOfMemory errors. This is because pinning prevents flushing of cache entries to lower tiers. For more information on pinning, see "Pinning Data" on page 35.

Built-In Sizing Computation and Enforcement

Internal BigMemory Go mechanisms track data-element sizes and enforce the limits set by CacheManager sizing pools.

Sizing of Elements

Elements put in a memory-limited cache will have their memory sizes measured. The entire Element instance added to the cache is measured, including key and value, as well as the memory footprint of adding that instance to internal data structures. Key and

value are measured as object graphs – each reference is followed and the object reference also measured. This goes on recursively.

Shared references will be measured by each class that references it. This will result in an overstatement. Shared references should therefore be ignored.

Ignoring for Size Calculations

For the purposes of measurement, references can be ignored using the `@IgnoreSizeOf` annotation. The annotation may be declared at the class level, on a field, or on a package. You can also specify a file containing the fully qualified names of classes, fields, and packages to be ignored.

This annotation is not inherited, and must be added to any subclasses that should also be excluded from sizing.

The following example shows how to ignore the `Dog` class.

```
@IgnoreSizeOf
public class Dog {
  private Gender gender;
  private String name;
}
```

The following example shows how to ignore the `sharedInstance` field.

```
public class MyCacheEntry {
  @IgnoreSizeOf
  private final SharedClass sharedInstance;
    ...
}
```

Packages may be also ignored if you add the @IgnoreSizeOf annotation to appropriate package-info.java of the desired package. Here is a sample package-info.java for and in the com.pany.ignore package:

```
@IgnoreSizeOf
package com.pany.ignore;
import net.sf.ehcache.pool.sizeof.filter.IgnoreSizeOf;
```

Alternatively, you may declare ignored classes and fields in a file and specify a `net.sf.ehcache.sizeof.filter` system property to point to that file.

```
# That field references a common graph between all cached entries
com.pany.domain.cache.MyCacheEntry.sharedInstance
# This will ignore all instances of that type
com.pany.domain.SharedState
# This ignores a package
com.pany.example
```

Note that these measurements and configurations apply only to on-heap storage. Once Elements are moved to off-heap memory ordisk, they are serialized as byte arrays. The serialized size is then used as the basis for measurement.

Configuration for Limiting the Traversed Object Graph

As noted above, sizing caches involves traversing object graphs, a process that can be limited with annotations. This process can also be controlled at both the CacheManager and cache levels.

Size-Of Limitation at the CacheManager Level

Control how deep the size-of engine can go when sizing on-heap elements by adding the following element at the CacheManager level:

```
<sizeOfPolicy maxDepth="100" maxDepthExceededBehavior="abort"/>
```

This element has the following attributes

- `maxDepth` – Controls how many linked objects can be visited before the size-of engine takes any action. This attribute is required.
- `maxDepthExceededBehavior` – Specifies what happens when the max depth is exceeded while sizing an object graph:
  - "continue" – (DEFAULT) Forces the size-of engine to log a warning and continue the sizing operation. If this attribute is not specified, "continue" is the behavior used.
  - "abort" – Forces the SizeOf engine to abort the sizing, log a warning, and mark the cache as not correctly tracking memory usage. With this setting, `Ehcache.hasAbortedSizeOf()` returns true.

The SizeOf policy can be configured at the CacheManager level (directly under `<ehcache>`) and at the cache level (under `<cache>` or `<defaultCache>`). The cache policy always overrides the CacheManager if both are set.

Size-Of Limitation at the Cache level

Use the `<sizeOfPolicy>` as a sub-element in any `<cache>` block to control how deep the size-of engine can go when sizing on-heap elements belonging to the target cache. This cache-level setting overrides the CacheManager size-of setting.

Debugging of Size-Of Related Errors

If warnings or errors appear that seem related to size-of measurement (usually caused by the size-of engine walking the graph), generate more log information on sizing activities:

- Set the `net.sf.ehcache.sizeof.verboseDebugLogging` system property to true.
- Enable debug logs on `net.sf.ehcache.pool.sizeof` in your chosen implementation of SLF4J.

Eviction When Using CacheManager-Level Storage

When a CacheManager-level storage pool is exhausted, a cache is selected on which to perform eviction to recover pool space. The eviction from the selected cache is performed using the cache's configured eviction algorithm (LRU, LFU, etc...). The cache from which eviction is performed is selected using the "minimal eviction cost" algorithm described below:

```
eviction-cost = mean-entry-size * drop-in-hit-rate
```

Eviction cost is defined as the increase in bytes requested from the underlying SOR (System of Record, e.g., database) per unit time used by evicting the requested number of bytes from the cache.

If we model the hit distribution as a simple power-law then:

```
P(hit n'th element) ~ 1/n^{alpha}
```

In the continuous limit, this means the total hit rate is proportional to the integral of this distribution function over the elements in the cache. The change in hit rate due to an eviction is then the integral of this distribution function between the initial size and the final size. Assuming that the eviction size is small compared to the overall cache size, we can model this as:

```
drop ~ access * 1/x^{alpha} * Delta(x)
```

where "access" is the overall access rate (hits + misses), and x is a unit-less measure of the "fill level" of the cache. Approximating the fill level as the ratio of hit rate to access rate, and substituting in to the eviction-cost expression, we get:

```
eviction-cost = mean-entry-size * access * 1/(hits/access)^{alpha}
                    * (eviction / (byteSize / (hits/access)))
```

Simplifying:

```
eviction-cost = (byteSize / countSize) * access * 1/(h/A)^{alpha}
                    * (eviction * hits)/(access * byteSize)
eviction-cost = (eviction * hits) / (countSize * (hits/access)^{alpha})
```

Removing the common factor of "eviction", which is the same in all caches, lead us to evicting from the cache with the minimum value of:

```
eviction-cost = (hits / countSize) / (hits/access)^{alpha}
```

When a cache has a zero hit-rate (it is in a pure loading phase), we deviate from this algorithm and allow the cache to occupy 1/nth of the pool space, where "n" is the number of caches using the pool. Once the cache starts to be accessed, we re-adjust to match the actual usage pattern of that cache.

4 Managing Data Life

Configuration Options that Affect Data Life

This topic covers managing the life of the data in each of the data-storage tiers, including the pinning features of Automatic Resource Control (ARC).

You use the options to manage data life within the data-storage tiers:

- **Flush** – To move an entry to a lower tier. Flushing is used to free up resources while still keeping data in BigMemory Go .
- **Fault** – To copy an entry from a lower tier to a higher tier. Faulting occurs when data is required at a higher tier but is not resident there. The entry is not deleted from the lower tiers after being faulted.
- **Eviction** – To remove an entry from BigMemory Go. The entry is deleted; it can only be reloaded from an outside source. Entries are evicted to free up resources.
- **Expiration** – A status based on Time-To-Live and Time-To-Idle settings. To maintain performance, expired entries may not be immediately flushed or evicted.
- **Pinning** – To keep data in memory indefinitely.

Setting Expiration

Data entries expire based on parameters with configurable values. When eviction occurs, expired elements are the first to be removed. Having an effective expiration configuration is critical to optimizing the use of resources such as heap and maintaining overall performance.

To add expiration, specify values for the following `<cache>` attributes, and tune these values based on results of performance tests:

- `timeToIdleSeconds` – The maximum number of seconds an element can exist in the BigMemory data store without being accessed. The element expires at this limit and will no longer be returned from BigMemory Go . The default value is 0, which means no TTI eviction takes place (infinite lifetime).
- `timeToLiveSeconds` – The maximum number of seconds an element can exist in the BigMemory data store regardless of use. The element expires at this limit and will no longer be returned from BigMemory Go . The default value is 0, which means no TTL eviction takes place (infinite lifetime).
- `eternal` – If the cache's `eternal` flag is set, it overrides any finite TTI/TTL values that have been set. Individual cache elements may also be set to eternal. Eternal elements and caches do not expire, however they may be evicted.

For information about how configuration can impact eviction, see "How Configuration Affects Element Flushing and Eviction" on page 36.

Pinning Data

Without pinning, expired cache entries can be flushed and eventually evicted, and even most non-expired elements can also be flushed and evicted as well, if resource limitations are reached. Pinning gives per-cache control over whether data can be evicted from BigMemory Go .

Data that should remain in memory can be pinned. You cannot pin individual entries, only an entire cache. As described in the following topics, there are two types of pinning, depending upon whether the pinning configuration should take precedence over resource constraints or the other way around.

Configuring Pinning

Entire caches can be pinned using the `pinning` element in the Ehcache configuration. This element has a required attribute (`store`) to specify how the pinning will be accomplished.

The `store` attribute can have either of the following values:

- inCache – Data is pinned in the cache, in any tier in which cache data is stored. The tier is chosen based on performance-enhancing efficiency algorithms. Unexpired entries can never be evicted.
- localMemory – Data is pinned to the memory store or the off-heap store. Entries are evicted only in the event that the store's configured size is exceeded.

For example, the following cache is configured to pin its entries:

```
<cache name="Cache1" ... >
     <pinning store="inCache" />
</cache>
```

The following cache is configured to pin its entries to heap or off-heap only:

```
<cache name="Cache2" ... >
     <pinning store="localMemory" />
</cache>
```

Pinning and Cache Sizing

The interaction of the pinning configuration with the cache sizing configuration depends upon which pinning option is used.

For `inCache` pinning, the pinning setting takes priority over the configured cache size. Elements resident in a cache with this pinning option cannot be evicted if they have not expired. This type of pinned cache is not eligible for eviction at all, and `maxEntriesInCache` should not be configured for this cache.

Important: Potentially, pinned caches could grow to an unlimited size. Caches should never be pinned unless they are designed to hold a limited amount of data (such as reference data) or their usage and expiration characteristics are understood well enough to conclude that they cannot cause errors.

For `localMemory` pinning, the configured cache size takes priority over the pinning setting. `localMemory` pinning should be used for optimization, to keep data in heap or off-heap memory, unless or until the tier becomes too full. If the number of entries surpasses the configured size, entries will be evicted. For example, in the following cache the `maxEntriesLocalHeap` and `maxBytesLocalOffHeap` settings override the pinning configuration. (Off-heap storage is only available in the Terracotta BigMemory products.)

```
<cache name="myCache"
     maxEntriesLocalHeap="10000"
     maxBytesLocalOffHeap="8g"
     ... >
    <pinning store="localMemory" />
</cache>
```

Scope of Pinning

Pinning achieved programmatically will not be persisted — after a restart the pinned entries are no longer pinned.

Explicitly Removing Data from a Pinned Cache

To unpin all of a cache's pinned entries, clear the cache. Specific entries can be removed from a cache using Cache.remove(). To empty the cache, Cache.removeAll(). If the cache itself is removed (Cache.dispose() or CacheManager.removeCache()), then any data still remaining in the cache is also removed locally. However, that remaining data is *not* removed from disk (if localRestartable).

How Configuration Affects Element Flushing and Eviction

The following example shows a cache with certain expiration settings:

```
<cache name="myCache"
      eternal="false" timeToIdleSeconds="3600"
      timeToLiveSeconds="0" memoryStoreEvictionPolicy="LFU">
</cache>
```

Note the following about the myCache configuration:

- If a client accesses an entry in myCache that has been idle for more than an hour (`timeToIdleSeconds`), that element is evicted.
- If an entry expires but is not accessed, and no resource constraints force eviction, then the expired entry remains in place until a periodic evictor removes it.
- Entries in myCache can live forever if accessed at least once per 60 minutes (`timeToLiveSeconds`). However, unexpired entries may still be flushed based on other limitations. For details, see "Sizing Storage Tiers" on page 23.

Data Freshness and Expiration

Databases and other systems of record (SORs) that were not built to accommodate caching outside of the database do not normally come with any default mechanism for notifying external processes when data has been updated or modified.

When using BigMemory Go as a caching system, the following strategies can help to keep the data in the cache in sync:

- **Data Expiration** Use the eviction algorithms included with Ehcache, along with the `timeToIdleSeconds` and `timetoLiveSeconds` settings, to enforce a maximum time for elements to live in the cache (forcing a re-load from the database or SOR).
- **Message Bus**: Use an application to make all updates to the database. When updates are made, post a message onto a message queue with a key to the item that was updated. All application instances can subscribe to the message bus and receive messages about data that is updated, and can synchronize their local copy of the data accordingly (for example by invalidating the cache entry for updated data)
- **Triggers**: Using a database trigger can accomplish a similar task as the message bus approach. Use the database trigger to execute code that can publish a message to a message bus. The advantage to this approach is that updates to the database do not have to be made only through a special application. The downside is that not all database triggers support full execution environments and it is often inadvisable to execute heavy-weight processing such as publishing messages on a queue during a database trigger.

The Data Expiration method is the simplest and most straightforward. It gives you the most control over the data synchronization, and doesn't require cooperation from any external systems. You simply set a data expiration policy and let Ehcache expire data from the cache, thus allowing fresh reads to re-populate and re-synchronize the cache.

If you choose the Data Expiration method, you can read more about the cache configuration settings in "Cache Eviction Algorithms" in the *Developer Guide* for BigMemory Go and review the timeToIdle and timeToLive configuration settings in "Setting Expiration." The most important consideration when using the expiration method is balancing data freshness with database load. The shorter you make the expiration settings - meaning the more "fresh" you try to make the data - the more load you will place on the database.

Try out some numbers and see what kind of load your application generates. Even modestly short values such as five or ten minutes will produce significant load reductions.

5 Configuring Fast Restart (FRS)

About Fast Restart (FRS)

BigMemory's Fast Restart (FRS) feature provides enterprise-ready crash resilience by keeping a fully consistent, real-time record of your in-memory data. After any kind of shutdown — planned or unplanned — the next time your application starts up, all of the data that was in BigMemory is still available and very quickly accessible.

The advantages of the Fast Restart feature include:

- In-memory data survives crashes and enables fast restarts. Because your in-memory data does not need to be reloaded from a remote data source, applications can resume at full speed after a restart.
- A real-time record of your in-memory data provides true fault tolerance. Fast Restart provides the equivalent of a local "hot mirror," which guarantees full data consistency.
- A consistent record of your in-memory data opens many possibilities for business innovation, such as arranging data sets according to time-based needs or moving data sets around to different locations. The uses of the Fast Restart store can range from a simple key-value persistence mechanism with fast read performance, to an operational store with in-memory speeds during operation for both reads and writes.

Data Persistence Implementation

The BigMemory Fast Restart feature works by creating a real-time record of the in-memory data, which it persists in a Fast Restart store on the local disk. After any restart, the data that was last in memory (both heap and off-heap stores) automatically loads from the Fast Restart store back into memory.

Data persistence is configured by adding the `<persistence>` sub-element to a cache configuration. The `<persistence>` sub-element includes two attributes: `strategy` and `synchronousWrites`.

Strategy Options

The options for the `strategy` attribute are:

- `"localRestartable"` — Enables the Fast Restart feature which automatically logs all BigMemory data. This option provides fast restartability with fault-tolerant data persistence.
- `"localTempSwap"` — Enables temporary local disk usage. This option provides an extra tier for data storage during operation, but this store is not persisted. After a restart, the disk is cleared of any BigMemory data.
- `"none"` — Does not offload data to disk. With this option, all of the working data is kept in memory only. This is the default mode.

Synchronous Writes Options

If the `strategy` attribute is set to "localRestartable", then the `synchronousWrites` attribute can be configured. The options for `synchronousWrites` are:

- **synchronousWrites="false"** — This option specifies that an eventually consistent record of the data is kept on disk at all times. Writes to disk happen when efficient, and cache operations proceed without waiting for acknowledgement of writing to disk. After a restart, the data is recovered as it was when last synced. This option is faster than `synchronousWrites="true"`, but after a crash, the last 2-3 seconds of written data may be lost.

  If not specified, the default for `synchronousWrites` is "false".

- **synchronousWrites="true"** — This option specifies that a fully consistent record of the data is kept on disk at all times. As changes are made to the data set, they are synchronously recorded on disk. The write to disk happens before a return to the caller. After a restart, the data is recovered exactly as it was before shutdown. This option is slower than `synchronousWrites="false"`, but after a crash, it provides full data consistency.

For transaction caching with `synchronousWrites`, soft locks are used to protect access. If there is a crash in the middle of a transaction, then upon recovery the soft locks are cleared on next access.

DiskStore Path

The path to the directory where any required disk files will be created is configured with the `<diskStore>` sub-element of the Ehcache configuration.

- For "localRestartable", a unique and explicitly specified path is required.
- For "localTempSwap", if the disk store path is not specified, a default path is used for the disk tier, and the default path will be auto-resolved in the case of a conflict with another CacheManager.

Note: The Fast Restart feature does not use the disk tier in the same way that conventional disk persistence does. Therefore, when configured for "localRestartable," disk store size measures such as Cache.getDiskStoreSize() or Cache.calculateOnDiskSize() are not applicable and will return zero. On the other hand, when configured for "localTempSwap", these measures will return size values.

Configuration Examples

This section presents possible disk usage configurations for BigMemory Go.

Options for Crash Resilience

The following configuration provides fast restartability with fully consistent data persistence:

```
<ehcache>
  <diskStore path="/path/to/store/data"/>
  <cache>
    <persistence strategy="localRestartable" synchronousWrites="true"/>
  </cache>
</ehcache>
```

The following configuration provides fast restartability with eventually consistent data persistence:

```
<ehcache>
  <diskStore path="/path/to/store/data"/>
  <cache>
    <persistence strategy="localRestartable" synchronousWrites="false"/>
  </cache>
</ehcache>
```

Temporary Disk Storage

The "localTempSwap" persistence strategy create a local disk tier for in-memory data during BigMemory operation. The disk storage is temporary and is cleared after a restart.

```
<ehcache>
  <diskStore path="/auto/default/path"/>
  <cache>
    <persistence strategy="localTempSwap"/>
  </cache>
</ehcache>
```

Note: With the "localTempSwap" strategy, you can use `maxEntriesLocalDisk` or `maxBytesLocalDisk` at either the Cache or CacheManager level to control the size of the disk tier.

In-memory Only Cache

When the persistence strategy is "none", all cache stays in memory (with no overflow to disk nor persistence on disk).

```
<cache>
  <persistence strategy="none"/>
</cache>
```

Programmatic Configuration Example

The following is an example of how to programmatically configure cache persistence on disk:

```
Configuration cacheManagerConfig = new Configuration()
    .diskStore(new DiskStoreConfiguration()
    .path("/path/to/store/data"));
CacheConfiguration cacheConfig = new CacheConfiguration()
    .name("my-cache")
    .maxBytesLocalHeap(16, MemoryUnit.MEGABYTES)
    .maxBytesLocalOffHeap(256, MemoryUnit.MEGABYTES)
```

```
    .persistence(new PersistenceConfiguration().strategy(Strategy.LOCALRESTARTABLE));
cacheManagerConfig.addCache(cacheConfig);
CacheManager cacheManager = new CacheManager(cacheManagerConfig);
Ehcache myCache = cacheManager.getEhcache("my-cache");
```

Fast Restart Performance

When configured for fast restartability ("localRestartable" persistence strategy), BigMemory becomes active on restart after all of the in-memory data is loaded. The amount of time until BigMemory is restarted is proportionate to the amount of in-memory data and the speed of the underlying infrastructure. Generally, recovery can occur as fast as the disk speed. With an SSD, for example, if you have a read throughput of 1 GB per second, you will see a similar loading speed during recovery.

Fast Restart Limitations

The following recommendations should be observed when configuring BigMemory for fast restartability:

- The size of on-heap or off-heap stores should not be changed during a shutdown. If the amount of memory allocated is reduced, elements will be evicted upon restart.
- Restartable caches should not be removed from the CacheManager during a shutdown.
- If a restartable cache is disposed, the reference to the cache is deleted, but the cache contents remain in memory and on disk. After a restart, the cache contents are once again recovered into memory and on disk. The way to safely dispose of an unused restartable cache, so that it does not take any space in disk or memory, is to call clear on the cache and then dispose.

A System Properties

Special System Properties

net.sf.ehcache.disabled

Setting this system property to `true` (using `java -Dnet.sf.ehcache.disabled=true` in the Java command line) disables caching in ehcache. If disabled, no elements can be added to a cache (puts are silently discarded).

net.sf.ehcache.use.classic.lru

When LRU is selected as the eviction policy, set this system property to `true` (using `java -Dnet.sf.ehcache.use.classic.lru=true` in the Java command line) to use the older LruMemoryStore implementation. This is provided for ease of migration.