

# Developing for Infinispan 12.1

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# Chapter 1. Configuring the Infinispan Maven Repository

Infinispan Java distributions are available from Maven.

Infinispan artifacts are available from Maven central. See the [org.infinispan](#) group for available Infinispan artifacts.

## 1.1. Configuring Your Infinispan POM

Maven uses configuration files called Project Object Model (POM) files to define projects and manage builds. POM files are in XML format and describe the module and component dependencies, build order, and targets for the resulting project packaging and output.

### *Procedure*

1. Open your project `pom.xml` for editing.
2. Define the `version.infinispan` property with the correct Infinispan version.
3. Include the `infinispan-bom` in a `dependencyManagement` section.

The Bill Of Materials (BOM) controls dependency versions, which avoids version conflicts and means you do not need to set the version for each Infinispan artifact you add as a dependency to your project.

4. Save and close `pom.xml`.

The following example shows the Infinispan version and BOM:

```
<properties>
  <version.infinispan>12.1.8.Final</version.infinispan>
</properties>

<dependencyManagement>
  <dependencies>
    <dependency>
      <groupId>org.infinispan</groupId>
      <artifactId>infinispan-bom</artifactId>
      <version>${version.infinispan}</version>
      <type>pom</type>
      <scope>import</scope>
    </dependency>
  </dependencies>
</dependencyManagement>
```

### *Next Steps*

Add Infinispan artifacts as dependencies to your `pom.xml` as required.

# Chapter 2. Cache Managers

The main entry point to Infinispan is the `CacheManager` interface that lets you:

- Configure and obtain caches.
- Manage and monitor clustered Infinispan nodes.
- Execute code across your cluster.

If you embed Infinispan in your application, then you use an `EmbeddedCacheManager`. If you run Infinispan as a remote server, then you use a `RemoteCacheManager`.

Cache Managers are heavyweight objects so you should instantiate only one `CacheManager` instance per JVM in most cases.

```
EmbeddedCacheManager manager = new DefaultCacheManager(); ①
```

① Starts a local, non-clustered, Cache Manager with no caches.

Cache Managers have lifecycles and the default constructors also call the `start()` method. Overloaded versions of the constructors are available, but they do not start the `CacheManager`. However, you must always start the `CacheManager` before you can create caches.

Likewise, you must call `stop()` when you no longer require a running `CacheManager` so that it releases resources. This also ensures that the Cache Manager safely stops any caches that it controls.

## 2.1. Obtaining caches

After you configure the `CacheManager`, you can obtain and control caches.

Invoke the `getCache(String)` method to obtain caches, as follows:

```
Cache<String, String> myCache = manager.getCache("myCache");
```

The preceding operation creates a cache named `myCache`, if it does not already exist, and returns it.

Using the `getCache()` method creates the cache only on the node where you invoke the method. In other words, it performs a local operation that must be invoked on each node across the cluster. Typically, applications deployed across multiple nodes obtain caches during initialization to ensure that caches are *symmetric* and exist on each node.

Invoke the `createCache()` method to create caches dynamically across the entire cluster, as follows:

```
Cache<String, String> myCache = manager.administration().createCache("myCache",  
"myTemplate");
```



The preceding operation also automatically creates caches on any nodes that subsequently join the cluster.

Caches that you create with the `createCache()` method are ephemeral by default. If the entire cluster shuts down, the cache is not automatically created again when it restarts.

Use the `PERMANENT` flag to ensure that caches can survive restarts, as follows:

```
Cache<String, String> myCache = manager.administration().withFlags(AdminFlag.  
PERMANENT).createCache("myCache", "myTemplate");
```

For the `PERMANENT` flag to take effect, you must enable global state and set a configuration storage provider.

For more information about configuration storage providers, see [GlobalStateConfigurationBuilder#configurationStorage\(\)](#).

## 2.2. Clustering Information

The `EmbeddedCacheManager` has quite a few methods to provide information as to how the cluster is operating. The following methods only really make sense when being used in a clustered environment (that is when a `Transport` is configured).

## 2.3. Member Information

When you are using a cluster it is very important to be able to find information about membership in the cluster including who is the owner of the cluster.

[`getMembers\(\)`](#)

The `getMembers()` method returns all of the nodes in the current cluster.

[`getCoordinator\(\)`](#)

The `getCoordinator()` method will tell you which one of the members is the coordinator of the cluster. For most intents you shouldn't need to care who the coordinator is. You can use [`isCoordinator\(\)`](#) method directly to see if the local node is the coordinator as well.

# Chapter 3. Cache Interface

Infinispan provides a [Cache](#) interface that exposes simple methods for adding, retrieving and removing entries, including atomic mechanisms exposed by the JDK's `ConcurrentMap` interface. Based on the cache mode used, invoking these methods will trigger a number of things to happen, potentially even including replicating an entry to a remote node or looking up an entry from a remote node, or potentially a cache store.

## 3.1. Cache API

For simple usage, using the Cache API should be no different from using the JDK Map API, and hence migrating from simple in-memory caches based on a Map to Infinispan's Cache should be trivial.

### 3.1.1. Performance Concerns of Certain Map Methods

Certain methods exposed in Map have certain performance consequences when used with Infinispan, such as [size\(\)](#) , [values\(\)](#) , [keySet\(\)](#) and [entrySet\(\)](#) . Specific methods on the [keySet](#), [values](#) and [entrySet](#) are fine for use please see their Javadoc for further details.

Attempting to perform these operations globally would have large performance impact as well as become a scalability bottleneck. As such, these methods should only be used for informational or debugging purposes only.

It should be noted that using certain flags with the [withFlags\(\)](#) method can mitigate some of these concerns, please check each method's documentation for more details.

### 3.1.2. Mortal and Immortal Data

Further to simply storing entries, Infinispan's cache API allows you to attach mortality information to data. For example, simply using [put\(key, value\)](#) would create an *immortal* entry, i.e., an entry that lives in the cache forever, until it is removed (or evicted from memory to prevent running out of memory). If, however, you put data in the cache using [put\(key, value, lifespan, timeunit\)](#) , this creates a *mortal* entry, i.e., an entry that has a fixed lifespan and expires after that lifespan.

In addition to *lifespan* , Infinispan also supports *maxIdle* as an additional metric with which to determine expiration. Any combination of lifespans or maxIdles can be used.

### 3.1.3. putForExternalRead operation

Infinispan's [Cache](#) class contains a different 'put' operation called [putForExternalRead](#) . This operation is particularly useful when Infinispan is used as a temporary cache for data that is persisted elsewhere. Under heavy read scenarios, contention in the cache should not delay the real transactions at hand, since caching should just be an optimization and not something that gets in the way.

To achieve this, [putForExternalRead\(\)](#) acts as a put call that only operates if the key is not present in the cache, and fails fast and silently if another thread is trying to store the same key at the same

time. In this particular scenario, caching data is a way to optimise the system and it's not desirable that a failure in caching affects the on-going transaction, hence why failure is handled differently. `putForExternalRead()` is considered to be a fast operation because regardless of whether it's successful or not, it doesn't wait for any locks, and so returns to the caller promptly.

To understand how to use this operation, let's look at basic example. Imagine a cache of Person instances, each keyed by a PersonId , whose data originates in a separate data store. The following code shows the most common pattern of using `putForExternalRead` within the context of this example:

```
// Id of the person to look up, provided by the application
PersonId id = ...;

// Get a reference to the cache where person instances will be stored
Cache<PersonId, Person> cache = ...;

// First, check whether the cache contains the person instance
// associated with with the given id
Person cachedPerson = cache.get(id);

if (cachedPerson == null) {
    // The person is not cached yet, so query the data store with the id
    Person person = dataStore.lookup(id);

    // Cache the person along with the id so that future requests can
    // retrieve it from memory rather than going to the data store
    cache.putForExternalRead(id, person);
} else {
    // The person was found in the cache, so return it to the application
    return cachedPerson;
}
```

Note that `putForExternalRead` should never be used as a mechanism to update the cache with a new Person instance originating from application execution (i.e. from a transaction that modifies a Person's address). When updating cached values, please use the standard `put` operation, otherwise the possibility of caching corrupt data is likely.

## 3.2. AdvancedCache API

In addition to the simple Cache interface, Infinispan offers an `AdvancedCache` interface, geared towards extension authors. The AdvancedCache offers the ability to access certain internal components and to apply flags to alter the default behavior of certain cache methods. The following code snippet depicts how an AdvancedCache can be obtained:

```
AdvancedCache advancedCache = cache.getAdvancedCache();
```

### 3.2.1. Flags

Flags are applied to regular cache methods to alter the behavior of certain methods. For a list of all available flags, and their effects, see the [Flag](#) enumeration. Flags are applied using [AdvancedCache.withFlags\(\)](#). This builder method can be used to apply any number of flags to a cache invocation, for example:

```
advancedCache.withFlags(Flag.CACHE_MODE_LOCAL, Flag.SKIP_LOCKING)
    .withFlags(Flag.FORCE_SYNCHRONOUS)
    .put("hello", "world");
```

## 3.3. Listeners and Notifications

Infinispan offers a listener API, where clients can register for and get notified when events take place. This annotation-driven API applies to 2 different levels: cache level events and cache manager level events.

Events trigger a notification which is dispatched to listeners. Listeners are simple [POJOs](#) annotated with [@Listener](#) and registered using the methods defined in the [Listenable](#) interface.



Both Cache and CacheManager implement Listenable, which means you can attach listeners to either a cache or a cache manager, to receive either cache-level or cache manager-level notifications.

For example, the following class defines a listener to print out some information every time a new entry is added to the cache, in a non blocking fashion:

```
@Listener
public class PrintWhenAdded {
    Queue<CacheEntryCreatedEvent> events = new ConcurrentLinkedQueue<>();

    @CacheEntryCreated
    public CompletionStage<Void> print(CacheEntryCreatedEvent event) {
        events.add(event);
        return null;
    }
}
```

For more comprehensive examples, please see the [Javadocs for @Listener](#).

### 3.3.1. Cache-level notifications

Cache-level events occur on a per-cache basis, and by default are only raised on nodes where the events occur. Note in a distributed cache these events are only raised on the owners of data being affected. Examples of cache-level events are entries being added, removed, modified, etc. These events trigger notifications to listeners registered to a specific cache.

Please see the [Javadocs on the org.infinispan.notifications.cachelistener.annotation package](#) for a comprehensive list of all cache-level notifications, and their respective method-level annotations.



Please refer to the [Javadocs on the org.infinispan.notifications.cachelistener.annotation package](#) for the list of cache-level notifications available in Infinispan.

## Cluster Listeners

The cluster listeners should be used when it is desirable to listen to the cache events on a single node.

To do so all that is required is set to annotate your listener as being clustered.

```
@Listener (clustered = true)
public class MyClusterListener { .... }
```

There are some limitations to cluster listeners from a non clustered listener.

1. A cluster listener can only listen to `@CacheEntryModified`, `@CacheEntryCreated`, `@CacheEntryRemoved` and `@CacheEntryExpired` events. Note this means any other type of event will not be listened to for this listener.
2. Only the post event is sent to a cluster listener, the pre event is ignored.

## Event filtering and conversion

All applicable events on the node where the listener is installed will be raised to the listener. It is possible to dynamically filter what events are raised by using a [KeyFilter](#) (only allows filtering on keys) or [CacheEventFilter](#) (used to filter for keys, old value, old metadata, new value, new metadata, whether command was retried, if the event is before the event (ie. isPre) and also the command type).

The example here shows a simple `KeyFilter` that will only allow events to be raised when an event modified the entry for the key `Only Me`.

```

public class SpecificKeyFilter implements KeyFilter<String> {
    private final String keyToAccept;

    public SpecificKeyFilter(String keyToAccept) {
        if (keyToAccept == null) {
            throw new NullPointerException();
        }
        this.keyToAccept = keyToAccept;
    }

    public boolean accept(String key) {
        return keyToAccept.equals(key);
    }
}

...
cache.addListener(listener, new SpecificKeyFilter("Only Me"));
...

```

This can be useful when you want to limit what events you receive in a more efficient manner.

There is also a [CacheEventConverter](#) that can be supplied that allows for converting a value to another before raising the event. This can be nice to modularize any code that does value conversions.



The mentioned filters and converters are especially beneficial when used in conjunction with a Cluster Listener. This is because the filtering and conversion is done on the node where the event originated and not on the node where event is listened to. This can provide benefits of not having to replicate events across the cluster (filter) or even have reduced payloads (converter).

## Initial State Events

When a listener is installed it will only be notified of events after it is fully installed.

It may be desirable to get the current state of the cache contents upon first registration of listener by having an event generated of type `@CacheEntryCreated` for each element in the cache. Any additionally generated events during this initial phase will be queued until appropriate events have been raised.



This only works for clustered listeners at this time. [ISPN-4608](#) covers adding this for non clustered listeners.

## Duplicate Events

It is possible in a non transactional cache to receive duplicate events. This is possible when the primary owner of a key goes down while trying to perform a write operation such as a put.

Infinispan internally will rectify the put operation by sending it to the new primary owner for the given key automatically, however there are no guarantees in regards to if the write was first replicated to backups. Thus more than 1 of the following write events ([CacheEntryCreatedEvent](#), [CacheEntryModifiedEvent](#) & [CacheEntryRemovedEvent](#)) may be sent on a single operation.

If more than one event is generated Infinispan will mark the event that it was generated by a retried command to help the user to know when this occurs without having to pay attention to view changes.

```
@Listener
public class MyRetryListener {
    @CacheEntryModified
    public void entryModified(CacheEntryModifiedEvent event) {
        if (event.isCommandRetried()) {
            // Do something
        }
    }
}
```

Also when using a [CacheEventFilter](#) or [CacheEventConverter](#) the [EventType](#) contains a method [isRetry](#) to tell if the event was generated due to retry.

### 3.3.2. Cache manager-level notifications

Cache manager-level events occur on a cache manager. These too are global and cluster-wide, but involve events that affect all caches created by a single cache manager. Examples of cache manager-level events are nodes joining or leaving a cluster, or caches starting or stopping.

See the [org.infinispan.notifications.cachemanagerlistener.annotation](#) package for a comprehensive list of all cache manager-level notifications, and their respective method-level annotations.

### 3.3.3. Synchronicity of events

By default, all async notifications are dispatched in the notification thread pool. Sync notifications will delay the operation from continuing until the listener method completes or the `CompletionStage` completes (the former causing the thread to block). Alternatively, you could annotate your listener as *asynchronous* in which case the operation will continue immediately, while the notification is completed asynchronously on the notification thread pool. To do this, simply annotate your listener such:

Asynchronous Listener

```
@Listener (sync = false)
public class MyAsyncListener {
    @CacheEntryCreated
    void listen(CacheEntryCreatedEvent event) { }
}
```

## Blocking Synchronous Listener

```
@Listener
public class MySyncListener {
    @CacheEntryCreated
    void listen(CacheEntryCreatedEvent event) { }
}
```

## Non-Blocking Listener

```
@Listener
public class MyNonBlockingListener {
    @CacheEntryCreated
    CompletionStage<Void> listen(CacheEntryCreatedEvent event) { }
}
```

### Asynchronous thread pool

To tune the thread pool used to dispatch such asynchronous notifications, use the `<listener-executor />` XML element in your configuration file.

## 3.4. Asynchronous API

In addition to synchronous API methods like `Cache.put()` , `Cache.remove()` , etc., Infinispan also has an asynchronous, non-blocking API where you can achieve the same results in a non-blocking fashion.

These methods are named in a similar fashion to their blocking counterparts, with "Async" appended. E.g., `Cache.putAsync()` , `Cache.removeAsync()` , etc. These asynchronous counterparts return a `CompletableFuture` that contains the actual result of the operation.

For example, in a cache parameterized as `Cache<String, String>`, `Cache.put(String key, String value)` returns `String` while `Cache.putAsync(String key, String value)` returns `CompletableFuture<String>`.

### 3.4.1. Why use such an API?

Non-blocking APIs are powerful in that they provide all of the guarantees of synchronous communications - with the ability to handle communication failures and exceptions - with the ease of not having to block until a call completes. This allows you to better harness parallelism in your system. For example:



```
Set<CompletableFuture<?>> futures = new HashSet<>();
futures.add(cache.putAsync(key1, value1)); // does not block
futures.add(cache.putAsync(key2, value2)); // does not block
futures.add(cache.putAsync(key3, value3)); // does not block

// the remote calls for the 3 puts will effectively be executed
// in parallel, particularly useful if running in distributed mode
// and the 3 keys would typically be pushed to 3 different nodes
// in the cluster

// check that the puts completed successfully
for (CompletableFuture<?> f: futures) f.get();
```

### 3.4.2. Which processes actually happen asynchronously?

There are 4 things in Infinispan that can be considered to be on the critical path of a typical write operation. These are, in order of cost:

- network calls
- marshallng
- writing to a cache store (optional)
- locking

Using the async methods will take the network calls and marshallng off the critical path. For various technical reasons, writing to a cache store and acquiring locks, however, still happens in the caller's thread.

# Chapter 4. Querying Values in Caches

Infinispan lets you perform queries to efficiently and quickly look up values in your data set, both with embedded Infinispan clusters or remote Infinispan server clusters.



You can index and query cache values stored as Plain Old Java Objects (POJOs) or objects encoded as [Protocol Buffers](#) only.

## 4.1. Configuring Infinispan to Index Caches

Create indexes of values in your caches to improve query performance and use full-text search capabilities.



Infinispan uses [Apache Lucene](#) technology to index values in caches.

### Procedure

1. Enable indexing in your cache configuration.

```
<distributed-cache name="my-cache">
  <indexing>
    <!-- Indexing configuration goes here. -->
  </indexing>
</distributed-cache>
```

Adding an `<indexing>` element automatically enables indexing. You do not need to include the `enabled` attribute, even though the default value of the `enabled` attribute is `false` in the configuration schema.

2. Specify each entity that you want to index as a value for the `indexed-entity` element.

```
<distributed-cache name="my-cache">
  <indexing>
    <indexed-entities>
      <indexed-entity>...</indexed-entity>
    </indexed-entities>
  </indexing>
</distributed-cache>
```

### Plain Old Java Objects

For caches that store POJOs, you specify the fully qualified class name that is annotated with `@Indexed`, for example:

```
<indexed-entities>
  <indexed-entity>org.infinispan.sample.Car</indexed-entity>
  <indexed-entity>org.infinispan.sample.Truck</indexed-entity>
</indexed-entities>
```

### Protobuf

For caches that store Protobuf-encoded entries, you specify the **Message** declared in the Protobuf schema.

For example, you use the following Protobuf schema:

```
package book_sample;

/* @Indexed */
message Book {

  /* @Field(store = Store.YES, analyze = Analyze.YES */
  optional string title = 1;

  /* @Field(store = Store.YES, analyze = Analyze.YES */
  optional string description = 2;
  optional int32 publicationYear = 3; // no native Date type available in Protobuf

  repeated Author authors = 4;
}

message Author {
  optional string name = 1;
  optional string surname = 2;
}
```

You should then specify the following value for the **indexed-entity** element:

```
<indexed-entities>
  <indexed-entity>book_sample.Book</indexed-entity>
</indexed-entities>
```

#### 4.1.1. Enabling Cache Indexing Programmatically

Configure indexing for caches programmatically via Infinispan APIs.

##### Procedure

- When using Infinispan as an embedded library, enable and configure indexing for caches with the **IndexingConfigurationBuilder** class, as in the following example:

```
import org.infinispan.configuration.cache.*;

ConfigurationBuilder config=new ConfigurationBuilder();
config.indexing().enable().storage(FILESYSTEM).path("/some/folder").addIndexedEntity(Book.class);
```

#### Reference

- [org.infinispan.configuration.cache.IndexingConfigurationBuilder](#)

### 4.1.2. Index Annotations

When you enable indexing in Infinispan caches, you use the following annotations:

- `@Indexed` denotes a Java object that you want to index.
- `@Field` controls how fields within objects are indexed.

For Infinispan as an embedded library, you add these annotations to your Java classes.

For Infinispan Server, you define Protobuf schemas, `.proto` files, that contain these annotations.

### 4.1.3. Index Configuration

Infinispan configuration controls how indexes are stored and constructed.

#### Index Storage

You can configure how Infinispan stores indexes:

- On the host file system, which is the default and persists indexes between restarts.
- In JVM heap memory, which means that indexes do not survive restarts.  
You should store indexes in JVM heap memory only for small datasets.

#### File system

```
<distributed-cache name="my-cache">
  <indexing storage="filesystem" path="${java.io.tmpdir}/baseDir">
    <!-- Indexing configuration goes here. -->
  </indexing>
</distributed-cache>
```

#### JVM heap memory

```
<distributed-cache name="my-cache">
  <indexing storage="local-heap">
    <!-- Additional indexing configuration goes here. -->
  </indexing>
</distributed-cache>
```

## Index Reader

The index reader is an internal component that provides access to the indexes to perform queries. As the index content changes, Infinispan needs to refresh the reader so that search results are up to date. You can configure the refresh interval for the index reader. By default Infinispan reads the index before each query if the index changed since the last refresh.

```
<distributed-cache name="my-cache">
  <indexing storage="filesystem" path="${java.io.tmpdir}/baseDir">
    <!-- Sets an interval of one second for the index reader. -->
    <index-reader refresh-interval="1000"/>
    <!-- Additional indexing configuration goes here. -->
  </indexing>
</distributed-cache>
```

## Index Writer

The index writer is an internal component that constructs an index composed of one or more segments (sub-indexes) that can be merged over time to improve performance. Fewer segments usually means less overhead during a query because index reader operations need to take into account all segments.

Infinispan uses Apache Lucene internally and indexes entries in two tiers: memory and storage. New entries go to the memory index first and then, when a flush happens, to the configured index storage. Periodic commit operations occur that create segments from the previously flushed data and make all the index changes permanent.



The `index-writer` configuration is optional. The defaults should work for most cases and custom configurations should only be used to tune performance.

```
<distributed-cache name="my-cache">
  <indexing storage="filesystem" path="${java.io.tmpdir}/baseDir">
    <index-writer commit-interval="2000"
      low-level-trace="false"
      max-buffered-entries="32"
      queue-count="1"
      queue-size="10000"
      ram-buffer-size="400"
      thread-pool-size="2">
      <index-merge calibrate-by-deletes="true"
        factor="3"
        max-entries="2000"
        min-size="10"
        max-size="20"/>
    </index-writer>
    <!-- Additional indexing configuration goes here. -->
  </indexing>
</distributed-cache>
```

Table 1. Index writer configuration attributes

Attribute	Description
<code>commit-interval</code>	Amount of time, in milliseconds, that index changes that are buffered in memory are flushed to the index storage and a commit is performed. Because operation is costly, small values should be avoided. The default is 1000 ms (1 second).
<code>max-buffered-entries</code>	Maximum number of entries that can be buffered in-memory before they are flushed to the index storage. Large values result in faster indexing but use more memory. When used in combination with the <code>ram-buffer-size</code> attribute, a flush occurs for whichever event happens first.
<code>ram-buffer-size</code>	Maximum amount of memory that can be used for buffering added entries and deletions before they are flushed to the index storage. Large values result in faster indexing but use more memory. For faster indexing performance you should set this attribute instead of <code>max-buffered-entries</code> . When used in combination with the <code>max-buffered-entries</code> attribute, a flush occurs for whichever event happens first.
<code>thread-pool-size</code>	Number of threads that execute write operations to the index.
<code>queue-count</code>	Number of internal queues to use for each indexed type. Each queue holds a batch of modifications that is applied to the index and queues are processed in parallel. Increasing the number of queues will lead to an increase of indexing throughput, but only if the bottleneck is CPU. For optimum results, do not set a value for <code>queue-count</code> that is larger than the value for <code>thread-pool-size</code> .
<code>queue-size</code>	Maximum number of elements each queue can hold. Increasing the <code>queue-size</code> value increases the amount of memory that is used during indexing operations. Setting a value that is too small can block indexing operations.

Attribute	Description
<code>low-level-trace</code>	Enables low-level trace information for indexing operations. Enabling this attribute substantially degrades performance. You should use this low-level tracing only as a last resource for troubleshooting.

To configure how Infinispan merges index segments, you use the `index-merge` sub-element.

Table 2. Index merge configuration attributes

Attribute	Description
<code>max-entries</code>	Maximum number of entries that an index segment can have before merging. Segments with more than this number of entries are not merged. Smaller values perform better on frequently changing indexes, larger values provide better search performance if the index does not change often.
<code>factor</code>	Number of segments that are merged at once. With smaller values, merging happens more often, which uses more resources, but the total number of segments will be lower on average, increasing search performance. Larger values (greater than 10) are best for heavy writing scenarios.
<code>min-size</code>	Minimum target size of segments, in MB, for background merges. Segments smaller than this size are merged more aggressively. Setting a value that is too large might result in expensive merge operations, even though they are less frequent.
<code>max-size</code>	Maximum size of segments, in MB, for background merges. Segments larger than this size are never merged in the background. Setting this to a lower value helps reduce memory requirements and avoids some merging operations at the cost of optimal search speed. This attribute is ignored when forcefully merging an index and <code>max-forced-size</code> applies instead.

Attribute	Description
<code>max-forced-size</code>	Maximum size of segments, in MB, for forced merges and overrides the <code>max-size</code> attribute. Set this to the same value as <code>max-size</code> or lower. However setting the value too low degrades search performance because documents are deleted.
<code>calibrate-by-deletes</code>	Whether the number of deleted entries in an index should be taken into account when counting the entries in the segment. Setting <code>false</code> will lead to more frequent merges caused by <code>max-entries</code> , but will more aggressively merge segments with many deleted documents, improving query performance.

### Reference

For more information about indexing elements and attributes, refer to the [Infinispan Configuration Schema](#).

## 4.1.4. Rebuilding Indexes

Rebuilding an index reconstructs it from the data stored in the cache. You rebuild indexes when you change things like the definitions of indexed types or analyzers. Likewise, you might also need to rebuild indexes if they are deleted for some reason.

Rebuilding indexes can take a long time to complete because the process takes place for all data in the grid. While the rebuild operation is in progress, queries might also return fewer results.



Infinispan logs the following warning message when you rebuild an index:

```
WARN: Rebuilding indexes also affect queries, that can return less
results than expected.
```

### Procedure

- Rebuild indexes on remote Infinispan servers by calling the `reindexCache()` method as follows:

```
remoteCacheManager.administration().reindexCache("MyCache");
```

- Rebuild indexes when using Infinispan as an embedded library as follows:

```
Indexer indexer = Search.getIndexer(cache);
CompletionStage<Void> future = index.run();
```



## 4.2. Creating Ickle Queries

Infinispan provides an Ickle query language that lets you create relational and full-text queries.

### 4.2.1. Ickle Query Example

To use the API, first obtain a `QueryFactory` to the cache and then call the `.create()` method, passing in the string to use in the query. Each `QueryFactory` instance is bound to the same `Cache` instance as the `Search`, but it is otherwise a stateless and thread-safe object that can be used for creating multiple queries in parallel.

For instance:

```
// Remote Query, using protobuf
QueryFactory qf = org.infinispan.client.hotrod.Search.getQueryFactory(remoteCache);
Query<Transaction> q = qf.create("from sample_bank_account.Transaction where amount > 20");

// Embedded Query using Java Objects
QueryFactory qf = org.infinispan.query.Search.getQueryFactory(cache);
Query<Transaction> q = qf.create("from org.infinispan.sample.Book where price > 20");

// Execute the query
QueryResult<Book> queryResult = q.execute();
```



A query will always target a single entity type and is evaluated over the contents of a single cache. Running a query over multiple caches or creating queries that target several entity types (joins) is not supported.

Executing the query and fetching the results is as simple as invoking the `execute()` method of the `Query` object. Once executed, calling `execute()` on the same instance will re-execute the query.

### Pagination

You can limit the number of returned results by using the `Query.maxResults(int maxResults)`. This can be used in conjunction with `Query.startOffset(long startOffset)` to achieve pagination of the result set.

```
// sorted by year and match all books that have "clustering" in their title
// and return the third page of 10 results
Query<Book> query = queryFactory.create("FROM org.infinispan.sample.Book WHERE title like '%clustering%' ORDER BY year").startOffset(20).maxResults(10)
```

### Number of Hits

The `QueryResult` object has the `.hitCount()` method to return the total number of results of the query, regardless of any pagination parameter. The hit count is only available for indexed queries

for performance reasons.

## Iteration

The `Query` object has the `.iterator()` method to obtain the results lazily. It returns an instance of `CloseableIterator` that must be closed after usage.



The iteration support for Remote Queries is currently limited, as it will first fetch all entries to the client before iterating.

## Named Query Parameters

Instead of building a new `Query` object for every execution it is possible to include named parameters in the query which can be substituted with actual values before execution. This allows a query to be defined once and be efficiently executed many times. Parameters can only be used on the right-hand side of an operator and are defined when the query is created by supplying an object produced by the `org.infinispan.query.dsl.Expression.param(String paramName)` method to the operator instead of the usual constant value. Once the parameters have been defined they can be set by invoking either `Query.setParameter(parameterName, value)` or `Query.setParameters(parameterMap)` as shown in the examples below.

```
QueryFactory queryFactory = Search.getQueryFactory(cache);
// Defining a query to search for various authors and publication years
Query<Book> query = queryFactory.create("SELECT title FROM org.infinispan.sample.Book
WHERE author = :authorName AND publicationYear = :publicationYear").build();

// Set actual parameter values
query.setParameter("authorName", "Doe");
query.setParameter("publicationYear", 2010);

// Execute the query
List<Book> found = query.execute.list();
```

Alternatively, you can supply a map of actual parameter values to set multiple parameters at once:

*Setting multiple named parameters at once*

```
Map<String, Object> parameterMap = new HashMap<>();
parameterMap.put("authorName", "Doe");
parameterMap.put("publicationYear", 2010);

query.setParameters(parameterMap);
```



A significant portion of the query parsing, validation and execution planning effort is performed during the first execution of a query with parameters. This effort is not repeated during subsequent executions leading to better performance compared to a similar query using constant values instead of query parameters.

### 4.2.2. Ickle Query Language Parser Syntax

The Ickle query language is small subset of the [JPQL](#) query language, with some extensions for full-text.

The parser syntax has some notable rules:

- Whitespace is not significant.
- Wildcards are not supported in field names.
- A field name or path must always be specified, as there is no default field.
- **&&** and **||** are accepted instead of **AND** or **OR** in both full-text and JPA predicates.
- **!** may be used instead of **NOT**.
- A missing boolean operator is interpreted as **OR**.
- String terms must be enclosed with either single or double quotes.
- Fuzziness and boosting are not accepted in arbitrary order; fuzziness always comes first.
- **!=** is accepted instead of **<>**.
- Boosting cannot be applied to **>**, **>=**, **<**, **<=** operators. Ranges may be used to achieve the same result.

#### Filtering operators

Ickle support many filtering operators that can be used for both indexed and non-indexed fields.

Operator	Description	Example
in	Checks that the left operand is equal to one of the elements from the Collection of values given as argument.	FROM Book WHERE isbn IN ('ZZ', 'X1234')
like	Checks that the left argument (which is expected to be a String) matches a wildcard pattern that follows the JPA rules.	FROM Book WHERE title LIKE '%Java%'
=	Checks that the left argument is an exact match of the given value	FROM Book WHERE name = 'Programming Java'
!=	Checks that the left argument is different from the given value	FROM Book WHERE language != 'English'
>	Checks that the left argument is greater than the given value.	FROM Book WHERE price > 20
>=	Checks that the left argument is greater than or equal to the given value.	FROM Book WHERE price >= 20

Operator	Description	Example
<	Checks that the left argument is less than the given value.	FROM Book WHERE year < 2012
≤	Checks that the left argument is less than or equal to the given value.	FROM Book WHERE price ≤ 50
between	Checks that the left argument is between the given range limits.	FROM Book WHERE price BETWEEN 50 AND 100

## Boolean conditions

Combining multiple attribute conditions with logical conjunction (**and**) and disjunction (**or**) operators in order to create more complex conditions is demonstrated in the following example. The well known operator precedence rule for boolean operators applies here, so the order of the operators is irrelevant. Here **and** operator still has higher priority than **or** even though **or** was invoked first.

```
# match all books that have "Data Grid" in their title
# or have an author named "Manik" and their description contains "clustering"

FROM org.infinispan.sample.Book WHERE title LIKE '%Data Grid%' OR author.name = '
Manik' AND description like '%clustering%'
```

Boolean negation has highest precedence among logical operators and applies only to the next simple attribute condition.

```
# match all books that do not have "Data Grid" in their title and are authored by
"Manik"
FROM org.infinispan.sample.Book WHERE title != 'Data Grid' AND author.name = 'Manik'
```

## Nested conditions

Changing the precedence of logical operators is achieved with parenthesis:

```
# match all books that have an author named "Manik" and their title contains
# "Data Grid" or their description contains "clustering"
FROM org.infinispan.sample.Book WHERE author.name = 'Manik' AND ( title like '%Data
Grid%' OR description like '% clustering%')
```

## Selecting attributes

In some use cases returning the whole domain object is overkill if only a small subset of the attributes are actually used by the application, especially if the domain entity has embedded entities. The query language allows you to specify a subset of attributes (or attribute paths) to

return - the projection. If projections are used then the `QueryResult.list()` will not return the whole domain entity but will return a `List of Object[]`, each slot in the array corresponding to a projected attribute.

```
# match all books that have "Data Grid" in their title or description
# and return only their title and publication year
SELECT title, publicationYear FROM org.infinispan.sample.Book WHERE title like '%Data
Grid%' OR description like '%Data Grid%'
```

## Sorting

Ordering the results based on one or more attributes or attribute paths is done with the `ORDER BY` clause. If multiple sorting criteria are specified, then the order will dictate their precedence.

```
# match all books that have "Data Grid" in their title or description
# and return them sorted by the publication year and title
FROM org.infinispan.sample.Book WHERE title like '%Data Grid%' ORDER BY
publicationYear DESC, title ASC
```

## Grouping and Aggregation

Infinispan has the ability to group query results according to a set of grouping fields and construct aggregations of the results from each group by applying an aggregation function to the set of values that fall into each group. Grouping and aggregation can only be applied to projection queries (queries with one or more field in the `SELECT` clause).

The supported aggregations are: `avg`, `sum`, `count`, `max`, and `min`.

The set of grouping fields is specified with the `GROUP BY` clause and the order used for defining grouping fields is not relevant. All fields selected in the projection must either be grouping fields or else they must be aggregated using one of the grouping functions described below. A projection field can be aggregated and used for grouping at the same time. A query that selects only grouping fields but no aggregation fields is legal. Example: Grouping Books by author and counting them.

```
SELECT author, COUNT(title) FROM org.infinispan.sample.Book WHERE title LIKE '
%engine%' GROUP BY author
```



A projection query in which all selected fields have an aggregation function applied and no fields are used for grouping is allowed. In this case the aggregations will be computed globally as if there was a single global group.

## Aggregations

You can apply the following aggregation functions to a field:

*Table 3. Index merge attributes*

Aggregation function	Description
<code>avg()</code>	Computes the average of a set of numbers. Accepted values are primitive numbers and instances of <code>java.lang.Number</code> . The result is represented as <code>java.lang.Double</code> . If there are no non-null values the result is <code>null</code> instead.
<code>count()</code>	Counts the number of non-null rows and returns a <code>java.lang.Long</code> . If there are no non-null values the result is <code>0</code> instead.
<code>max()</code>	Returns the greatest value found. Accepted values must be instances of <code>java.lang.Comparable</code> . If there are no non-null values the result is <code>null</code> instead.
<code>min()</code>	Returns the smallest value found. Accepted values must be instances of <code>java.lang.Comparable</code> . If there are no non-null values the result is <code>null</code> instead.
<code>sum()</code>	Computes the sum of a set of Numbers. If there are no non-null values the result is <code>null</code> instead. The following table indicates the return type based on the specified field.

Table 4. Table sum return type

Field Type	Return Type
Integral (other than BigInteger)	Long
Float or Double	Double
BigInteger	BigInteger
BigDecimal	BigDecimal

## Evaluation of queries with grouping and aggregation

Aggregation queries can include filtering conditions, like usual queries. Filtering can be performed in two stages: before and after the grouping operation. All filter conditions defined before invoking the `groupBy()` method will be applied before the grouping operation is performed, directly to the cache entries (not to the final projection). These filter conditions can reference any fields of the queried entity type, and are meant to restrict the data set that is going to be the input for the grouping stage. All filter conditions defined after invoking the `groupBy()` method will be applied to the projection that results from the projection and grouping operation. These filter conditions can either reference any of the `groupBy()` fields or aggregated fields. Referencing aggregated fields that are not specified in the select clause is allowed; however, referencing non-aggregated and non-grouping fields is forbidden. Filtering in this phase will reduce the amount of groups based on their properties. Sorting can also be specified similar to usual queries. The ordering operation is performed after the grouping operation and can reference any of the `groupBy()` fields or aggregated

fields.

### 4.2.3. Using Full-Text Search

#### Fuzzy Queries

To execute a fuzzy query add `~` along with an integer, representing the distance from the term used, after the term. For instance

```
FROM sample_bank_account.Transaction WHERE description : 'coffee'~2
```

#### Range Queries

To execute a range query define the given boundaries within a pair of braces, as seen in the following example:

```
FROM sample_bank_account.Transaction WHERE amount : [20 to 50]
```

#### Phrase Queries

A group of words can be searched by surrounding them in quotation marks, as seen in the following example:

```
FROM sample_bank_account.Transaction WHERE description : 'bus fare'
```

#### Proximity Queries

To execute a proximity query, finding two terms within a specific distance, add a `~` along with the distance after the phrase. For instance, the following example will find the words canceling and fee provided they are not more than 3 words apart:

```
FROM sample_bank_account.Transaction WHERE description : 'canceling fee'~3
```

#### Wildcard Queries

To search for "text" or "test", use the `?` single-character wildcard search:

```
FROM sample_bank_account.Transaction where description : 'te?t'
```

To search for "test", "tests", or "tester", use the `*` multi-character wildcard search:

```
FROM sample_bank_account.Transaction where description : 'test*'
```

## Regular Expression Queries

Regular expression queries can be performed by specifying a pattern between `/`. Ickle uses Lucene's regular expression syntax, so to search for the words `moat` or `boat` the following could be used:

```
FROM sample_library.Book where title : /[mb]oat/
```

## Boosting Queries

Terms can be boosted by adding a `^` after the term to increase their relevance in a given query, the higher the boost factor the more relevant the term will be. For instance to search for titles containing beer and wine with a higher relevance on beer, by a factor of 3, the following could be used:

```
FROM sample_library.Book WHERE title : beer^3 OR wine
```

## 4.3. Embedded Queries

Use embedded queries when you add Infinispan as a library to custom applications.

Protobuf mapping is not required with embedded queries. Indexing and querying are both done on top of Java objects.

### 4.3.1. Embedded Query Example

We're going to store `Book` instances in an Infinispan cache called "books". `Book` instances will be indexed, so we enable indexing for the cache configuration:

*infinispan.xml*

```
<distributed-cache name="books">
  <indexing path="${user.home}/index">
    <indexed-entities>
      <indexed-entity>org.infinispan.sample.Book</indexed-entity>
    </indexed-entities>
  </indexing>
</distributed-cache>
```

Obtaining the cache:

```
import org.infinispan.Cache;
import org.infinispan.manager.DefaultCacheManager;
import org.infinispan.manager.EmbeddedCacheManager;

EmbeddedCacheManager manager = new DefaultCacheManager("infinispan.xml");
Cache<String, Book> cache = manager.getCache("books");
```



Each **Book** will be defined as in the following example; we have to choose which properties are indexed, and for each property we can optionally choose advanced indexing options using the annotations defined in the Hibernate Search project.

#### *Book.java*

```
package org.infinispan.sample;

import java.time.LocalDate;
import java.util.HashSet;
import java.util.Set;

import org.hibernate.search.mapper.pojo.mapping.definition.annotation.*;

// Annotate values with @Indexed to add them to indexes
// Annotate each fields according to how you want to index it
@Indexed
public class Book {
    @FullTextField
    String title;

    @FullTextField
    String description;

    @KeywordField
    String isbn;

    @GenericField
    LocalDate publicationDate;

    @IndexedEmbedded
    Set<Author> authors = new HashSet<Author>();
}
```

#### *Author.java*

```
package org.infinispan.sample;

import org.hibernate.search.mapper.pojo.mapping.definition.annotation.FullTextField;

public class Author {
    @FullTextField
    String name;

    @FullTextField
    String surname;
}
```

Now assuming we stored several **Book** instances in our Infinispan **Cache**, we can search them for any matching field as in the following example.

```
// Get the query factory from the cache
QueryFactory queryFactory = org.infinispan.query.Search.getQueryFactory(cache);

// Create an Ickle query that performs a full-text search using the ':' operator on
the 'title' and 'authors.name' fields
// You can perform full-text search only on indexed caches
Query<Book> fullTextQuery = queryFactory.create("FROM org.infinispan.sample.Book b
WHERE b.title:'infinispan' AND b.authors.name:'sanne'");

// Use the '=' operator to query fields in caches that are indexed or not
// Non full-text operators apply only to fields that are not analyzed
Query<Book> exactMatchQuery=queryFactory.create("FROM org.infinispan.sample.Book b
WHERE b.isbn = '12345678' AND b.authors.name : 'sanne'");

// You can use full-text and non-full text operators in the same query
Query<Book> query=queryFactory.create("FROM org.infinispan.sample.Book b where
b.authors.name : 'Stephen' and b.description : ('dark' -'tower')");

// Get the results
List<Book> found=query.execute().list();
```

### 4.3.2. Mapping Entities

Infinispan relies on the API of [Hibernate Search](#) in order to define fine grained configuration for indexing at entity level. This configuration includes which fields are annotated, which analyzers should be used, how to map nested objects and so on. Detailed documentation is available at [the Hibernate Search manual](#).

#### @DocumentId

Unlike Hibernate Search, using `@DocumentId` to mark a field as identifier does not apply to Infinispan values; in Infinispan the identifier for all `@Indexed` objects is the key used to store the value. You can still customize how the key is indexed using a combination of `@Transformable`, custom types and custom `FieldBridge` implementations.

#### @Transformable keys

The key for each value needs to be indexed as well, and the key instance must be transformed in a `String`. Infinispan includes some default transformation routines to encode common primitives, but to use a custom key you must provide an implementation of `org.infinispan.query.Transformer`.

#### *Registering a key Transformer via annotations*

You can annotate your key class with `org.infinispan.query.Transformable` and your custom transformer implementation will be picked up automatically:

```

@Transformable(transformer = CustomTransformer.class)
public class CustomKey {
    ...
}

public class CustomTransformer implements Transformer {
    @Override
    public Object fromString(String s) {
        ...
        return new CustomKey(...);
    }

    @Override
    public String toString(Object customType) {
        CustomKey ck = (CustomKey) customType;
        return ...
    }
}

```

*Registering a key Transformer via the cache indexing configuration*

Use the `key-transformers` xml element in both embedded and server config:

```

<replicated-cache name="test">
  <indexing auto-config="true">
    <key-transformers>
      <key-transformer key="com.mycompany.CustomKey"
        transformer="com.mycompany.CustomTransformer"/>
    </key-transformers>
  </indexing>
</replicated-cache>

```

Alternatively, use the Java configuration API (embedded mode):

```

ConfigurationBuilder builder = ...
builder.indexing().enable()
    .addKeyTransformer(CustomKey.class, CustomTransformer.class);

```

## Programmatic mapping

Instead of using annotations to map an entity to the index, it's also possible to configure it programmatically.

In the following example we map an object `Author` which is to be stored in the grid and made searchable on two properties but without annotating the class.

```

import org.apache.lucene.search.Query;
import org.hibernate.search.cfg.Environment;
import org.hibernate.search.cfg.SearchMapping;
import org.hibernate.search.query.dsl.QueryBuilder;
import org.infinispan.Cache;
import org.infinispan.configuration.cache.Configuration;
import org.infinispan.configuration.cache.ConfigurationBuilder;
import org.infinispan.configuration.cache.Index;
import org.infinispan.manager.DefaultCacheManager;
import org.infinispan.query.CacheQuery;
import org.infinispan.query.Search;
import org.infinispan.query.SearchManager;

import java.io.IOException;
import java.lang.annotation.ElementType;
import java.util.Properties;

SearchMapping mapping = new SearchMapping();
mapping.entity(Author.class).indexed()
    .property("name", ElementType.METHOD).field()
    .property("surname", ElementType.METHOD).field();

Properties properties = new Properties();
properties.put(Environment.MODEL_MAPPING, mapping);
properties.put("hibernate.search.[other options]", "[...]");

Configuration infinispanConfiguration = new ConfigurationBuilder()
    .indexing().index(Index.NONE)
    .withProperties(properties)
    .build();

DefaultCacheManager cacheManager = new DefaultCacheManager(infinispanConfiguration);

Cache<Long, Author> cache = cacheManager.getCache();
SearchManager sm = Search.getSearchManager(cache);

Author author = new Author(1, "Manik", "Surtani");
cache.put(author.getId(), author);

QueryBuilder qb = sm.buildQueryBuilderForClass(Author.class).get();
Query q = qb.keyword().onField("name").matching("Manik").createQuery();
CacheQuery cq = sm.getQuery(q, Author.class);
assert cq.getResultSize() == 1;

```

## 4.4. Remote Queries

Use remote queries when you set up Infinispan Sever clusters that you access from clients.

To perform remote queries, data in the cache must use [Google Protocol Buffers](#) as an encoding for

both over-the-wire transmission and storage. Additionally, remote queries require Protobuf schemas (**.proto** files) to define the data structure and indexing elements.



The benefit of using Protobuf with remote queries is that it is language neutral and works with Hot Rod Java clients as well as REST, C++, C#, and Node.js clients.

#### 4.4.1. Remote Query Example

An object called **Book** will be stored in a Infinispan cache called "books". Book instances will be indexed, so we enable indexing for the cache:

*infinispan.xml*

```
<replicated-cache name="books">
  <indexing>
    <indexed-entities>
      <indexed-entity>book_sample.Book</indexed-entity>
    </indexed-entities>
  </indexing>
</replicated-cache>
```

Alternatively, if the cache is not indexed, we configure the **<encoding>** as **application/x-protostream** to make sure the storage is queryable:

*infinispan.xml*

```
<replicated-cache name="books">
  <encoding media-type="application/x-protostream"/>
</replicated-cache>
```

Each **Book** will be defined as in the following example: we use **@Protofield** annotations to identify the message fields and the **@ProtoDoc** annotation on the fields to configure indexing attributes:

```

import org.infinispan.protostream.annotations.ProtoDoc;
import org.infinispan.protostream.annotations.ProtoFactory;
import org.infinispan.protostream.annotations.ProtoField;

@ProtoDoc("@Indexed")
public class Book {

    @ProtoDoc("@Field(index=Index.YES, analyze = Analyze.YES, store = Store.NO)")
    @ProtoField(number = 1)
    final String title;

    @ProtoDoc("@Field(index=Index.YES, analyze = Analyze.YES, store = Store.NO)")
    @ProtoField(number = 2)
    final String description;

    @ProtoDoc("@Field(index=Index.YES, analyze = Analyze.YES, store = Store.NO)")
    @ProtoField(number = 3, defaultValue = "0")
    final int publicationYear;

    @ProtoFactory
    Book(String title, String description, int publicationYear) {
        this.title = title;
        this.description = description;
        this.publicationYear = publicationYear;
    }
    // public Getter methods omitted for brevity
}

```

During compilation, the annotations in the preceding example generate the artifacts necessary to read, write and query **Book** instances. To enable this generation, use the `@AutoProtoSchemaBuilder` annotation in a newly created class with empty constructor or interface:

#### RemoteQueryInitializer.java

```

import org.infinispan.protostream.SerializationContextInitializer;
import org.infinispan.protostream.annotations.AutoProtoSchemaBuilder;

@AutoProtoSchemaBuilder(
    includeClasses = {
        Book.class
    },
    schemaFileName = "book.proto",
    schemaFilePath = "proto/",
    schemaPackageName = "book_sample")
public interface RemoteQueryInitializer extends SerializationContextInitializer {
}

```

After compilation, a file `book.proto` file will be created in the configured `schemaFilePath`, along with an implementation `RemoteQueryInitializerImpl.java` of the annotated interface. This concrete class can be used directly in the Hot Rod client code to initialize the serialization context.

Putting all together:

*RemoteQuery.java*

```
package org.infinispan;

import java.nio.file.Files;
import java.nio.file.Path;
import java.nio.file.Paths;
import java.util.List;

import org.infinispan.client.hotrod.RemoteCache;
import org.infinispan.client.hotrod.RemoteCacheManager;
import org.infinispan.client.hotrod.Search;
import org.infinispan.client.hotrod.configuration.ConfigurationBuilder;
import org.infinispan.query.dsl.Query;
import org.infinispan.query.dsl.QueryFactory;
import org.infinispan.query.remote.client.ProtobufMetadataManagerConstants;

public class RemoteQuery {

    public static void main(String[] args) throws Exception {
        ConfigurationBuilder clientBuilder = new ConfigurationBuilder();
        // RemoteQueryInitializerImpl is generated
        clientBuilder.addServer().host("127.0.0.1").port(11222)
            .security().authentication().username("user").password("user")
            .addContextInitializers(new RemoteQueryInitializerImpl());

        RemoteCacheManager remoteCacheManager = new RemoteCacheManager(clientBuilder
            .build());

        // Grab the generated protobuf schema and registers in the server.
        Path proto = Paths.get(RemoteQuery.class.getClassLoader()
            .getResource("proto/book.proto").toURI());
        String protoBufCacheName = ProtobufMetadataManagerConstants
            .PROTOBUF_METADATA_CACHE_NAME;
        remoteCacheManager.getCache(protoBufCacheName).put("book.proto", Files
            .readString(proto));

        // Obtain the 'books' remote cache
        RemoteCache<Object, Object> remoteCache = remoteCacheManager.getCache("books");

        // Add some Books
        Book book1 = new Book("Infinispan in Action", "Learn Infinispan with using it",
            2015);
        Book book2 = new Book("Cloud-Native Applications with Java and Quarkus", "Build
            robust and reliable cloud applications", 2019);
    }
}
```

```

remoteCache.put(1, book1);
remoteCache.put(2, book2);

// Execute a full-text query
QueryFactory queryFactory = Search.getQueryFactory(remoteCache);
Query<Book> query = queryFactory.create("FROM book_sample.Book WHERE
title:'java'");

List<Book> list = query.execute().list(); // Voila! We have our book back from
the cache!
    }
}

```

### 4.4.2. Registering Protobuf Schemas

To query protobuf entities, you must provide the client and server with the relevant metadata about your entities in a Protobuf schema (`.proto` file).

The descriptors are stored in a dedicated `___protobuf_metadata` cache on the server. Both keys and values in this cache are plain strings. Registering a new schema is therefore as simple as performing a `put()` operation on this cache using the schema name as key and the schema file itself as the value.



If caches use authorization, users must have `CREATE` permissions to add entries in the `___protobuf_metadata` cache. Assign users the `deployer` role at minimum if you use default authorization settings.

Alternatively you can use the `schema` command with the Infinispan CLI, Infinispan Console, REST endpoint `/rest/v2/schemas`, or the `ProtobufMetadataManager` MBean via JMX.



Even if indexing is enabled for a cache no fields of Protobuf encoded entries will be indexed unless you use the `@Indexed` and `@Field` inside Protobuf schema documentation annotations (`@ProtoDoc`) to specify what fields need to get indexed.

#### Reference

- [CLI Guide: Querying Caches with Protobuf Metadata](#)

### 4.4.3. Analysis

Analysis is a process that converts input data into one or more terms that you can index and query. While in [Embedded Query](#) mapping is done through [Hibernate Search annotations](#), that supports a rich set of Lucene based analyzers, in client-server mode the analyzer definitions are declared in a platform neutral way.

#### Default Analyzers

Infinispan provides a set of default analyzers for remote query as follows:



Definition	Description
<code>standard</code>	Splits text fields into tokens, treating whitespace and punctuation as delimiters.
<code>simple</code>	Tokenizes input streams by delimiting at non-letters and then converting all letters to lowercase characters. Whitespace and non-letters are discarded.
<code>whitespace</code>	Splits text streams on whitespace and returns sequences of non-whitespace characters as tokens.
<code>keyword</code>	Treats entire text fields as single tokens.
<code>stemmer</code>	Stems English words using the Snowball Porter filter.
<code>ngram</code>	Generates n-gram tokens that are 3 grams in size by default.
<code>filename</code>	Splits text fields into larger size tokens than the <code>standard</code> analyzer, treating whitespace as a delimiter and converts all letters to lowercase characters.

These analyzer definitions are based on Apache Lucene and are provided "as-is". For more information about tokenizers, filters, and CharFilters, see the appropriate Lucene documentation.

## Using Analyzer Definitions

To use analyzer definitions, reference them by name in the `.proto` schema file.

1. Include the `Analyze.YES` attribute to indicate that the property is analyzed.
2. Specify the analyzer definition with the `@Analyzer` annotation.

The following example shows referenced analyzer definitions:

```
/* @Indexed */
message TestEntity {

    /* @Field(store = Store.YES, analyze = Analyze.YES, analyzer =
    @Analyzer(definition = "keyword")) */
    optional string id = 1;

    /* @Field(store = Store.YES, analyze = Analyze.YES, analyzer =
    @Analyzer(definition = "simple")) */
    optional string name = 2;
}
```

If using Java classes annotated with `@ProtoField`, the declaration is similar:

```

@ProtoDoc("@Field(store = Store.YES, analyze = Analyze.YES, analyzer =
@Analyzer(definition = \"keyword\"))")
@ProtoField(number = 1)
final String id;

@ProtoDoc("@Field(store = Store.YES, analyze = Analyze.YES, analyzer =
@Analyzer(definition = \"simple\"))")
@ProtoField(number = 2)
final String description;

```

## Creating Custom Analyzer Definitions

If you require custom analyzer definitions, do the following:

1. Create an implementation of the `ProgrammaticSearchMappingProvider` interface packaged in a `JAR` file.
2. Provide a file named `org.infinispan.query.spi.ProgrammaticSearchMappingProvider` in the `META-INF/services/` directory of your `JAR`. This file should contain the fully qualified class name of your implementation.
3. Copy the `JAR` to the `lib/` directory of your Infinispan Server installation.



Your `JAR` must be available to Infinispan Server during startup. You cannot add it to an already running server.

The following is an example implementation of the `ProgrammaticSearchMappingProvider` interface:

```

import org.apache.lucene.analysis.core.LowerCaseFilterFactory;
import org.apache.lucene.analysis.core.StopFilterFactory;
import org.apache.lucene.analysis.standard.StandardFilterFactory;
import org.apache.lucene.analysis.standard.StandardTokenizerFactory;
import org.hibernate.search.cfg.SearchMapping;
import org.infinispan.Cache;
import org.infinispan.query.spi.ProgrammaticSearchMappingProvider;

public final class MyAnalyzerProvider implements ProgrammaticSearchMappingProvider {

    @Override
    public void defineMappings(Cache cache, SearchMapping searchMapping) {
        searchMapping
            .analyzerDef("standard-with-stop", StandardTokenizerFactory.class)
                .filter(StandardFilterFactory.class)
                .filter(LowerCaseFilterFactory.class)
                .filter(StopFilterFactory.class);
    }
}

```

## 4.5. Continuous Queries

Continuous Queries allow an application to register a listener which will receive the entries that currently match a query filter, and will be continuously notified of any changes to the queried data set that result from further cache operations. This includes incoming matches, for values that have joined the set, updated matches, for matching values that were modified and continue to match, and outgoing matches, for values that have left the set. By using a Continuous Query the application receives a steady stream of events instead of having to repeatedly execute the same query to discover changes, resulting in a more efficient use of resources. For instance, all of the following use cases could utilize Continuous Queries:

- Return all persons with an age between 18 and 25 (assuming the Person entity has an **age** property and is updated by the user application).
- Return all transactions higher than \$2000.
- Return all times where the lap speed of F1 racers were less than 1:45.00s (assuming the cache contains Lap entries and that laps are entered live during the race).

### 4.5.1. Continuous Query Execution

A continuous query uses a listener that is notified when:

- An entry starts matching the specified query, represented by a **Join** event.
- A matching entry is updated and continues to match the query, represented by an **Update** vent.
- An entry stops matching the query, represented by a **Leave** event.

When a client registers a continuous query listener it immediately begins to receive the results currently matching the query, received as **Join** events as described above. In addition, it will receive subsequent notifications when other entries begin matching the query, as **Join** events, or stop matching the query, as **Leave** events, as a consequence of any cache operations that would normally generate creation, modification, removal, or expiration events. Updated cache entries will generate **Update** events if the entry matches the query filter before and after the operation. To summarize, the logic used to determine if the listener receives a **Join**, **Update** or **Leave** event is:

1. If the query on both the old and new values evaluate false, then the event is suppressed.
2. If the query on the old value evaluates false and on the new value evaluates true, then a **Join** event is sent.
3. If the query on both the old and new values evaluate true, then an **Update** event is sent.
4. If the query on the old value evaluates true and on the new value evaluates false, then a **Leave** event is sent.
5. If the query on the old value evaluates true and the entry is removed or expired, then a **Leave** event is sent.



Continuous Queries can use all query capabilities except: grouping, aggregation, and sorting operations.

## 4.5.2. Creating Continuous Queries

To create a continuous query, do the following:

1. Create a Query object.
2. Obtain the ContinuousQuery (`org.infinispan.query.api.continuous.ContinuousQuery` object of your cache by calling the appropriate method:
  - `org.infinispan.client.hotrod.Search.getContinuousQuery(RemoteCache<K, V> cache)` for remote mode
  - `org.infinispan.query.Search.getContinuousQuery(Cache<K, V> cache)` for embedded mode
3. Register the query and a continuous query listener (`org.infinispan.query.api.continuous.ContinuousQueryListener`) as follows:

```
continuousQuery.addContinuousQueryListener(query, listener);
```

The following example demonstrates a simple continuous query use case in embedded mode:

### *Registering a Continuous Query*

```
import org.infinispan.query.api.continuous.ContinuousQuery;
import org.infinispan.query.api.continuous.ContinuousQueryListener;
import org.infinispan.query.Search;
import org.infinispan.query.dsl.QueryFactory;
import org.infinispan.query.dsl.Query;

import java.util.Map;
import java.util.concurrent.ConcurrentHashMap;

[...]

// We have a cache of Persons
Cache<Integer, Person> cache = ...

// We begin by creating a ContinuousQuery instance on the cache
ContinuousQuery<Integer, Person> continuousQuery = Search.getContinuousQuery(cache);

// Define our query. In this case we will be looking for any Person instances under 21
// years of age.
QueryFactory queryFactory = Search.getQueryFactory(cache);
Query query = queryFactory.create("FROM Person p WHERE p.age < 21");

final Map<Integer, Person> matches = new ConcurrentHashMap<Integer, Person>();

// Define the ContinuousQueryListener
ContinuousQueryListener<Integer, Person> listener = new ContinuousQueryListener
<Integer, Person>() {
    @Override
    public void resultJoining(Integer key, Person value) {
```

```

        matches.put(key, value);
    }

    @Override
    public void resultUpdated(Integer key, Person value) {
        // we do not process this event
    }

    @Override
    public void resultLeaving(Integer key) {
        matches.remove(key);
    }
};

// Add the listener and the query
continuousQuery.addContinuousQueryListener(query, listener);

[...]

// Remove the listener to stop receiving notifications
continuousQuery.removeContinuousQueryListener(listener);

```

As Person instances having an age less than 21 are added to the cache they will be received by the listener and will be placed into the `matches` map, and when these entries are removed from the cache or their age is modified to be greater or equal than 21 they will be removed from `matches`.

### 4.5.3. Removing Continuous Queries

To stop the query from further execution just remove the listener:

```
continuousQuery.removeContinuousQueryListener(listener);
```

### 4.5.4. Continuous Query Performance

Continuous queries are designed to provide a constant stream of updates to the application, potentially resulting in a very large number of events being generated for particularly broad queries. A new temporary memory allocation is made for each event. This behavior may result in memory pressure, potentially leading to `OutOfMemoryErrors` (especially in remote mode) if queries are not carefully designed. To prevent such issues it is strongly recommended to ensure that each query captures the minimal information needed both in terms of number of matched entries and size of each match (projections can be used to capture the interesting properties), and that each `ContinuousQueryListener` is designed to quickly process all received events without blocking and to avoid performing actions that will lead to the generation of new matching events from the cache it listens to.

## 4.6. Query Statistics

Infinispan exposes indexing and querying statistics through the **Search** entry point, which you can use programmatically as follows:

```
// Statistics for the local cluster member
SearchStatistics statistics = Search.getSearchStatistics(cache);

// Consolidated statistics for the whole cluster
CompletionStage<SearchStatisticsSnapshot> statistics = Search
    .getClusteredSearchStatistics(cache)
```

### *Statistics via REST*

Infinispan Server also exposes index and query statistics through the REST endpoint.

Use the following invocation: **GET /v2/caches/{cacheName}/search/stats**

## 4.7. Query Performance Tuning

Infinispan exposes statistics for queries and provides configurable attributes so you can monitor and tune queries for optimal performance.

### *Check index usage statistics*

Indexing caches improves query performance. However, in some cases, queries might only partially use an index such as when not all fields in the schema are annotated.

Start tuning query performance by checking the time it takes for each type of query to run. If your queries seem to be slow, you should make sure that queries are using the indexes for caches and that all entities and field mappings are indexed.

### *Indexing performance*

Indexing can degrade write throughput for Infinispan clusters. The **commit-interval** attribute defines the interval, in milliseconds, between which index changes that are buffered in memory are flushed to the index storage and a commit is performed.

This operation is costly so you should avoid configuring an interval that is too small. The default is 1000 ms (1 second).

### *Querying performance*

The **refresh-interval** attribute defines the interval, in milliseconds, between which the index reader is refreshed.

The default value is **0**, which returns data in queries as soon as it is written to a cache.

A value greater than **0** results in some stale query results but substantially increases throughput, especially in write-heavy scenarios. If you do not need data returned in queries as soon as it is written, you should adjust the refresh interval to improve query performance.

# Chapter 5. Clustered Locks

Clustered locks are data structures that are distributed and shared across nodes in a Infinispan cluster. Clustered locks allow you to run code that is synchronized between nodes.

## 5.1. Lock API

Infinispan provides a `ClusteredLock` API that lets you concurrently execute code on a cluster when using Infinispan in embedded mode.

The API consists of the following:

- `ClusteredLock` exposes methods to implement clustered locks.
- `ClusteredLockManager` exposes methods to define, configure, retrieve, and remove clustered locks.
- `EmbeddedClusteredLockManagerFactory` initializes `ClusteredLockManager` implementations.

### *Ownership*

Infinispan supports `NODE` ownership so that all nodes in a cluster can use a lock.

### *Reentrancy*

Infinispan clustered locks are non-reentrant so any node in the cluster can acquire a lock but only the node that creates the lock can release it.

If two consecutive lock calls are sent for the same owner, the first call acquires the lock if it is available and the second call is blocked.

### *Reference*

- [EmbeddedClusteredLockManagerFactory](#)
- [ClusteredLockManager](#)
- [ClusteredLock](#)

## 5.2. Using Clustered Locks

Learn how to use clustered locks with Infinispan embedded in your application.

### *Prerequisites*

- Add the `infinispan-clustered-lock` dependency to your `pom.xml`:

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-clustered-lock</artifactId>
</dependency>
```

### *Procedure*

1. Initialize the `ClusteredLockManager` interface from a Cache Manager. This interface is the entry point for defining, retrieving, and removing clustered locks.
2. Give a unique name for each clustered lock.
3. Acquire locks with the `lock.tryLock(1, TimeUnit.SECONDS)` method.

```
// Set up a clustered Cache Manager.
GlobalConfigurationBuilder global = GlobalConfigurationBuilder.
defaultClusteredBuilder();

// Configure the cache mode, in this case it is distributed and synchronous.
ConfigurationBuilder builder = new ConfigurationBuilder();
builder.clustering().cacheMode(CacheMode.DIST_SYNC);

// Initialize a new default Cache Manager.
DefaultCacheManager cm = new DefaultCacheManager(global.build(), builder.build());

// Initialize a Clustered Lock Manager.
ClusteredLockManager clm1 = EmbeddedClusteredLockManagerFactory.from(cm);

// Define a clustered lock named 'lock'.
clm1.defineLock("lock");

// Get a lock from each node in the cluster.
ClusteredLock lock = clm1.get("lock");

AtomicInteger counter = new AtomicInteger(0);

// Acquire the lock as follows.
// Each 'lock.tryLock(1, TimeUnit.SECONDS)' method attempts to acquire the lock.
// If the lock is not available, the method waits for the timeout period to elapse.
// When the lock is acquired, other calls to acquire the lock are blocked until the lock
// is released.
CompletableFuture<Boolean> call1 = lock.tryLock(1, TimeUnit.SECONDS).whenComplete((r,
ex) -> {
    if (r) {
        System.out.println("lock is acquired by the call 1");
        lock.unlock().whenComplete((nil, ex2) -> {
            System.out.println("lock is released by the call 1");
            counter.incrementAndGet();
        });
    }
});

CompletableFuture<Boolean> call2 = lock.tryLock(1, TimeUnit.SECONDS).whenComplete((r,
ex) -> {
    if (r) {
        System.out.println("lock is acquired by the call 2");
        lock.unlock().whenComplete((nil, ex2) -> {
            System.out.println("lock is released by the call 2");
        });
    }
});
```



```

        counter.incrementAndGet();
    });
}
});

CompletableFuture<Boolean> call3 = lock.tryLock(1, TimeUnit.SECONDS).whenComplete((r,
ex) -> {
    if (r) {
        System.out.println("lock is acquired by the call 3");
        lock.unlock().whenComplete((nil, ex2) -> {
            System.out.println("lock is released by the call 3");
            counter.incrementAndGet();
        });
    }
});

CompletableFuture.allOf(call1, call2, call3).whenComplete((r, ex) -> {
    // Print the value of the counter.
    System.out.println("Value of the counter is " + counter.get());

    // Stop the Cache Manager.
    cm.stop();
});

```

## 5.3. Configuring Internal Caches for Locks

Clustered Lock Managers include an internal cache that stores lock state. You can configure the internal cache either declaratively or programmatically.

### *Procedure*

1. Define the number of nodes in the cluster that store the state of clustered locks. The default value is **-1**, which replicates the value to all nodes.
2. Specify one of the following values for the cache reliability, which controls how clustered locks behave when clusters split into partitions or multiple nodes leave:
  - **AVAILABLE**: Nodes in any partition can concurrently operate on locks.
  - **CONSISTENT**: Only nodes that belong to the majority partition can operate on locks. This is the default value.
  - Programmatic configuration

```

import org.infinispan.lock.configuration.ClusteredLockManagerConfiguration;
import
org.infinispan.lock.configuration.ClusteredLockManagerConfigurationBuilder;
import org.infinispan.lock.configuration.Reliability;
...

GlobalConfigurationBuilder global = GlobalConfigurationBuilder
.defaultClusteredBuilder();

final ClusteredLockManagerConfiguration config = global.addModule
(ClusteredLockManagerConfigurationBuilder.class).numOwner(2).reliability(Reliabi
lity.AVAILABLE).create();

DefaultCacheManager cm = new DefaultCacheManager(global.build());

ClusteredLockManager clm1 = EmbeddedClusteredLockManagerFactory.from(cm);

clm1.defineLock("lock");

```

- Declarative configuration

```

<?xml version="1.0" encoding="UTF-8"?>
<infinispan
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="urn:infinispan:config:12.1
https://infinispan.org/schemas/infinispan-config-12.1.xsd"
  xmlns="urn:infinispan:config:12.1">

  <cache-container default-cache="default">
    <transport/>
    <local-cache name="default">
      <locking concurrency-level="100" acquire-timeout="1000"/>
    </local-cache>
    <clustered-locks xmlns="urn:infinispan:config:clustered-locks:12.1"
      num-owners = "3"
      reliability="AVAILABLE">
      <clustered-lock name="lock1" />
      <clustered-lock name="lock2" />
    </clustered-locks>
  </cache-container>
  <!-- Cache configuration goes here. -->
</infinispan>

```

## Reference

- [ClusteredLockManagerConfiguration](#)
- [Clustered Locks Configuration Schema](#)

# Chapter 6. Clustered Counters

*Clustered counters* are counters which are distributed and shared among all nodes in the Infinispan cluster. Counters can have different consistency levels: strong and weak.

Although a strong/weak consistent counter has separate interfaces, both support updating its value, return the current value and they provide events when its value is updated. Details are provided below in this document to help you choose which one fits best your uses-case.

## 6.1. Installation and Configuration

In order to start using the counters, you need to add the dependency in your Maven `pom.xml` file:

*pom.xml*

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-clustered-counter</artifactId>
</dependency>
```

The counters can be configured in the Infinispan configuration file or on-demand via the `CounterManager` interface detailed later in this document. A counter configured in the Infinispan configuration file is created at boot time when the `EmbeddedCacheManager` is starting. These counters are started eagerly and they are available in all the cluster's nodes.

```

<?xml version="1.0" encoding="UTF-8"?>
<infinispan>
  <cache-container ...>
    <!-- To persist counters, you need to configure the global state. -->
    <global-state>
      <!-- Global state configuration goes here. -->
    </global-state>
    <!-- Cache configuration goes here. -->
    <counters xmlns="urn:infinispan:config:counters:12.1" num-owners="3"
reliability="CONSISTENT">
      <strong-counter name="c1" initial-value="1" storage="PERSISTENT"/>
      <strong-counter name="c2" initial-value="2" storage="VOLATILE">
        <lower-bound value="0"/>
      </strong-counter>
      <strong-counter name="c3" initial-value="3" storage="PERSISTENT">
        <upper-bound value="5"/>
      </strong-counter>
      <strong-counter name="c4" initial-value="4" storage="VOLATILE">
        <lower-bound value="0"/>
        <upper-bound value="10"/>
      </strong-counter>
      <weak-counter name="c5" initial-value="5" storage="PERSISTENT"
concurrency-level="1"/>
    </counters>
  </cache-container>
</infinispan>

```

or programmatically, in the `GlobalConfigurationBuilder`:

```

GlobalConfigurationBuilder globalConfigurationBuilder = ...;
CounterManagerConfigurationBuilder builder = globalConfigurationBuilder.addModule
(CounterManagerConfigurationBuilder.class);
builder.numOwner(3).reliability(Reliability.CONSISTENT);
builder.addStrongCounter().name("c1").initialValue(1).storage(Storage.PERSISTENT);
builder.addStrongCounter().name("c2").initialValue(2).lowerBound(0).storage(Storage.VO
LATILE);
builder.addStrongCounter().name("c3").initialValue(3).upperBound(5).storage(Storage.PE
RSISTENT);
builder.addStrongCounter().name("c4").initialValue(4).lowerBound(0).upperBound(10).sto
rage(Storage.VOLATILE);
builder.addWeakCounter().name("c5").initialValue(5).concurrencyLevel(1).storage(Storag
e.PERSISTENT);

```

On other hand, the counters can be configured on-demand, at any time after the `EmbeddedCacheManager` is initialized.

```
CounterManager manager = ...;
manager.defineCounter("c1", CounterConfiguration.builder(CounterType.UNBOUNDED_STRONG)
    .initialValue(1).storage(Storage.PERSISTENT).build());
manager.defineCounter("c2", CounterConfiguration.builder(CounterType.BOUNDED_STRONG)
    .initialValue(2).lowerBound(0).storage(Storage.VOLATILE).build());
manager.defineCounter("c3", CounterConfiguration.builder(CounterType.BOUNDED_STRONG)
    .initialValue(3).upperBound(5).storage(Storage.PERSISTENT).build());
manager.defineCounter("c4", CounterConfiguration.builder(CounterType.BOUNDED_STRONG)
    .initialValue(4).lowerBound(0).upperBound(10).storage(Storage.VOLATILE).build());
manager.defineCounter("c2", CounterConfiguration.builder(CounterType.WEAK)
    .initialValue(5).concurrencyLevel(1).storage(Storage.PERSISTENT).build());
```



`CounterConfiguration` is immutable and can be reused.

The method `defineCounter()` will return `true` if the counter is successful configured or `false` otherwise. However, if the configuration is invalid, the method will throw a `CounterConfigurationException`. To find out if a counter is already defined, use the method `isDefined()`.

```
CounterManager manager = ...
if (!manager.isDefined("someCounter")) {
    manager.define("someCounter", ...);
}
```

#### Per cluster attributes:

- **num-owners**: Sets the number of counter's copies to keep cluster-wide. A smaller number will make update operations faster but will support a lower number of server crashes. It **must be positive** and its default value is `2`.
- **reliability**: Sets the counter's update behavior in a network partition. Default value is `AVAILABLE` and valid values are:
  - **AVAILABLE**: all partitions are able to read and update the counter's value.
  - **CONSISTENT**: only the primary partition (majority of nodes) will be able to read and update the counter's value. The remaining partitions can only read its value.

#### Per counter attributes:

- **initial-value** [common]: Sets the counter's initial value. Default is `0` (zero).
- **storage** [common]: Sets the counter's behavior when the cluster is shutdown and restarted. Default value is `VOLATILE` and valid values are:
  - **VOLATILE**: the counter's value is only available in memory. The value will be lost when a cluster is shutdown.
  - **PERSISTENT**: the counter's value is stored in a private and local persistent store. The value is kept when the cluster is shutdown and restored after a restart.



On-demand and **VOLATILE** counters will lose its value and configuration after a cluster shutdown. They must be defined again after the restart.

- **lower-bound** [strong]: Sets the strong consistent counter's lower bound. Default value is `Long.MIN_VALUE`.
- **upper-bound** [strong]: Sets the strong consistent counter's upper bound. Default value is `Long.MAX_VALUE`.



If neither the **lower-bound** or **upper-bound** are configured, the strong counter is set as unbounded.



The **initial-value** must be between **lower-bound** and **upper-bound** inclusive.

- **concurrency-level** [weak]: Sets the number of concurrent updates. Its value **must be positive** and the default value is **16**.

### 6.1.1. List counter names

To list all the counters defined, the method `CounterManager.getCounterNames()` returns a collection of all counter names created cluster-wide.

## 6.2. CounterManager interface

The **CounterManager** interface is the entry point to define, retrieve and remove counters.

#### *Embedded deployments*

**CounterManager** automatically listen to the creation of **EmbeddedCacheManager** and proceeds with the registration of an instance of it per **EmbeddedCacheManager**. It starts the caches needed to store the counter state and configures the default counters.

Retrieving the **CounterManager** is as simple as invoke the `EmbeddedCounterManagerFactory.asCounterManager(EmbeddedCacheManager)` as shown in the example below:

```
// create or obtain your EmbeddedCacheManager
EmbeddedCacheManager manager = ...;

// retrieve the CounterManager
CounterManager counterManager = EmbeddedCounterManagerFactory.asCounterManager(
    manager);
```

#### *Server deployments*

For Hot Rod clients, the **CounterManager** is registered in the **RemoteCacheManager** and can be retrieved as follows:

```
// create or obtain your RemoteCacheManager
RemoteCacheManager manager = ...;

// retrieve the CounterManager
CounterManager counterManager = RemoteCounterManagerFactory.asCounterManager(manager);
```

### 6.2.1. Remove a counter via CounterManager

There is a difference between remove a counter via the `Strong/WeakCounter` interfaces and the `CounterManager`. The `CounterManager.remove(String)` removes the counter value from the cluster and removes all the listeners registered in the counter in the local counter instance. In addition, the counter instance is no longer reusable and it may return an invalid results.

On the other side, the `Strong/WeakCounter` removal only removes the counter value. The instance can still be reused and the listeners still works.



The counter is re-created if it is accessed after a removal.

## 6.3. The Counter

A counter can be strong (`StrongCounter`) or weakly consistent (`WeakCounter`) and both is identified by a name. They have a specific interface but they share some logic, namely, both of them are asynchronous ( a `CompletableFuture` is returned by each operation), provide an update event and can be reset to its initial value.

If you don't want to use the async API, it is possible to return a synchronous counter via `sync()` method. The API is the same but without the `CompletableFuture` return value.

The following methods are common to both interfaces:

```
String getName();
CompletableFuture<Long> getValue();
CompletableFuture<Void> reset();
<T extends CounterListener> Handle<T> addListener(T listener);
CounterConfiguration getConfiguration();
CompletableFuture<Void> remove();
SyncStrongCounter sync(); //SyncWeakCounter for WeakCounter
```

- `getName()` returns the counter name (identifier).
- `getValue()` returns the current counter's value.
- `reset()` allows to reset the counter's value to its initial value.
- `addListener()` register a listener to receive update events. More details about it in the [Notification and Events](#) section.
- `getConfiguration()` returns the configuration used by the counter.

- `remove()` removes the counter value from the cluster. The instance can still be used and the listeners are kept.
- `sync()` creates a synchronous counter.



The counter is re-created if it is accessed after a removal.

### 6.3.1. The `StrongCounter` interface: when the consistency or bounds matters.

The strong counter provides uses a single key stored in Infinispan cache to provide the consistency needed. All the updates are performed under the key lock to updates its values. On other hand, the reads don't acquire any locks and reads the current value. Also, with this scheme, it allows to bound the counter value and provide atomic operations like compare-and-set/swap.

A `StrongCounter` can be retrieved from the `CounterManager` by using the `getStrongCounter()` method. As an example:

```
CounterManager counterManager = ...
StrongCounter aCounter = counterManager.getStrongCounter("my-counter");
```



Since every operation will hit a single key, the `StrongCounter` has a higher contention rate.

The `StrongCounter` interface adds the following method:

```
default CompletableFuture<Long> incrementAndGet() {
    return addAndGet(1L);
}

default CompletableFuture<Long> decrementAndGet() {
    return addAndGet(-1L);
}

CompletableFuture<Long> addAndGet(long delta);

CompletableFuture<Boolean> compareAndSet(long expect, long update);

CompletableFuture<Long> compareAndSwap(long expect, long update);
```

- `incrementAndGet()` increments the counter by one and returns the new value.
- `decrementAndGet()` decrements the counter by one and returns the new value.
- `addAndGet()` adds a delta to the counter's value and returns the new value.
- `compareAndSet()` and `compareAndSwap()` atomically set the counter's value if the current value is the expected.



A operation is considered completed when the `CompletableFuture` is completed.





The difference between compare-and-set and compare-and-swap is that the former returns true if the operation succeeds while the latter returns the previous value. The compare-and-swap is successful if the return value is the same as the expected.

### Bounded StrongCounter

When bounded, all the update method above will throw a `CounterOutOfBoundsException` when they reached the lower or upper bound. The exception has the following methods to check which side bound has been reached:

```
public boolean isUpperBoundReached();  
public boolean isLowerBoundReached();
```

### Uses cases

The strong counter fits better in the following uses cases:

- When counter's value is needed after each update (example, cluster-wise ids generator or sequences)
- When a bounded counter is needed (example, rate limiter)

### Usage Examples

```

StrongCounter counter = counterManager.getStrongCounter("unbounded_counter");

// incrementing the counter
System.out.println("new value is " + counter.incrementAndGet().get());

// decrement the counter's value by 100 using the functional API
counter.addAndGet(-100).thenApply(v -> {
    System.out.println("new value is " + v);
    return null;
}).get();

// alternative, you can do some work while the counter is updated
CompletableFuture<Long> f = counter.addAndGet(10);
// ... do some work ...
System.out.println("new value is " + f.get());

// and then, check the current value
System.out.println("current value is " + counter.getValue().get());

// finally, reset to initial value
counter.reset().get();
System.out.println("current value is " + counter.getValue().get());

// or set to a new value if zero
System.out.println("compare and set succeeded? " + counter.compareAndSet(0, 1));

```

And below, there is another example using a bounded counter:

```

StrongCounter counter = counterManager.getStrongCounter("bounded_counter");

// incrementing the counter
try {
    System.out.println("new value is " + counter.addAndGet(100).get());
} catch (ExecutionException e) {
    Throwable cause = e.getCause();
    if (cause instanceof CounterOutOfBoundsException) {
        if (((CounterOutOfBoundsException) cause).isUpperBoundReached()) {
            System.out.println("ops, upper bound reached.");
        } else if (((CounterOutOfBoundsException) cause).isLowerBoundReached()) {
            System.out.println("ops, lower bound reached.");
        }
    }
}

// now using the functional API
counter.addAndGet(-100).handle((v, throwable) -> {
    if (throwable != null) {
        Throwable cause = throwable.getCause();
        if (cause instanceof CounterOutOfBoundsException) {
            if (((CounterOutOfBoundsException) cause).isUpperBoundReached()) {
                System.out.println("ops, upper bound reached.");
            } else if (((CounterOutOfBoundsException) cause).isLowerBoundReached()) {
                System.out.println("ops, lower bound reached.");
            }
        }
        return null;
    }
    System.out.println("new value is " + v);
    return null;
}).get();

```

Compare-and-set vs Compare-and-swap examples:

```

StrongCounter counter = counterManager.getStrongCounter("my-counter");
long oldValue, newValue;
do {
    oldValue = counter.getValue().get();
    newValue = someLogic(oldValue);
} while (!counter.compareAndSet(oldValue, newValue).get());

```

With compare-and-swap, it saves one invocation counter invocation (`counter.getValue()`)

```
StrongCounter counter = counterManager.getStrongCounter("my-counter");
long oldValue = counter.getValue().get();
long currentValue, newValue;
do {
    currentValue = oldValue;
    newValue = someLogic(oldValue);
} while ((oldValue = counter.compareAndSwap(oldValue, newValue).get()) !=
currentValue);
```

### 6.3.2. The **WeakCounter** interface: when speed is needed

The **WeakCounter** stores the counter's value in multiple keys in Infinispan cache. The number of keys created is configured by the **concurrency-level** attribute. Each key stores a partial state of the counter's value and it can be updated concurrently. Its main advantage over the **StrongCounter** is the lower contention in the cache. On the other hand, the read of its value is more expensive and bounds are not allowed.



The reset operation should be handled with caution. It is **not** atomic and it produces intermediate values. These values may be seen by a read operation and by any listener registered.

A **WeakCounter** can be retrieved from the **CounterManager** by using the **getWeakCounter()** method. As an example:

```
CounterManager counterManager = ...
StrongCounter aCounter = counterManager.getWeakCounter("my-counter");
```

#### Weak Counter Interface

The **WeakCounter** adds the following methods:

```
default CompletableFuture<Void> increment() {
    return add(1L);
}

default CompletableFuture<Void> decrement() {
    return add(-1L);
}

CompletableFuture<Void> add(long delta);
```

They are similar to the **StrongCounter**'s methods but they don't return the new value.

#### Uses cases

The weak counter fits best in use cases where the result of the update operation is not needed or

the counter's value is not required too often. Collecting statistics is a good example of such an use case.

## Examples

Below, there is an example of the weak counter usage.

```
WeakCounter counter = counterManager.getWeakCounter("my_counter");

// increment the counter and check its result
counter.increment().get();
System.out.println("current value is " + counter.getValue());

CompletableFuture<Void> f = counter.add(-100);
//do some work
f.get(); //wait until finished
System.out.println("current value is " + counter.getValue().get());

//using the functional API
counter.reset().whenComplete((aVoid, throwable) -> System.out.println("Reset done " +
(throwable == null ? "successfully" : "unsuccessfully"))).get();
System.out.println("current value is " + counter.getValue().get());
```

## 6.4. Notifications and Events

Both strong and weak counter supports a listener to receive its updates events. The listener must implement `CounterListener` and it can be registered by the following method:

```
<T extends CounterListener> Handle<T> addListener(T listener);
```

The `CounterListener` has the following interface:

```
public interface CounterListener {
    void onUpdate(CounterEvent entry);
}
```

The `Handle` object returned has the main goal to remove the `CounterListener` when it is not longer needed. Also, it allows to have access to the `CounterListener` instance that is it handling. It has the following interface:

```
public interface Handle<T extends CounterListener> {
    T getCounterListener();
    void remove();
}
```

Finally, the `CounterEvent` has the previous and current value and state. It has the following interface:

```
public interface CounterEvent {  
    long getOldValue();  
    State getOldState();  
    long getNewValue();  
    State getNewState();  
}
```



The state is always `State.VALID` for unbounded strong counter and weak counter. `State.LOWER_BOUND_REACHED` and `State.UPPER_BOUND_REACHED` are only valid for bounded strong counters.



The weak counter `reset()` operation will trigger multiple notification with intermediate values.

# Chapter 7. Using the CDI Extension

Infinispan provides an extension that integrates with the CDI (Contexts and Dependency Injection) programming model and allows you to:

- Configure and inject caches into CDI Beans and Java EE components.
- Configure cache managers.
- Receive cache and cache manager level events.
- Control data storage and retrieval using JCache annotations.

## 7.1. CDI Dependencies

Update your `pom.xml` with one of the following dependencies to include the Infinispan CDI extension in your project:

*Embedded (Library) Mode*

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-cdi-embedded</artifactId>
</dependency>
```

*Server Mode*

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-cdi-remote</artifactId>
</dependency>
```

## 7.2. Injecting Embedded Caches

Set up CDI beans to inject embedded caches.

*Procedure*

1. Create a cache qualifier annotation.

```
...
import javax.inject.Qualifier;

@Qualifier
@Target({ElementType.FIELD, ElementType.PARAMETER, ElementType.METHOD})
@Retention(RetentionPolicy.RUNTIME)
@Documented
public @interface GreetingCache { ❶
}
```

① Creates a `@GreetingCache` qualifier.

2. Add a producer method that defines the cache configuration.

```
...
import org.infinispan.configuration.cache.Configuration;
import org.infinispan.configuration.cache.ConfigurationBuilder;
import org.infinispan.cdi.ConfigureCache;
import javax.enterprise.inject.Produces;

public class Config {

    @ConfigureCache("mygreetingcache") ①
    @GreetingCache ②
    @Produces
    public Configuration greetingCacheConfiguration() {
        return new ConfigurationBuilder()
            .memory()
            .size(1000)
            .build();
    }
}
```

① Names the cache to inject.

② Adds the cache qualifier.

3. Add a producer method that creates a clustered cache manager, if required

```
...
package org.infinispan.configuration.global.GlobalConfigurationBuilder;

public class Config {

    @GreetingCache ①
    @Produces
    @ApplicationScoped ②
    public EmbeddedCacheManager defaultClusteredCacheManager() { ③
        return new DefaultCacheManager(
            new GlobalConfigurationBuilder().transport().defaultTransport().build();
        }
    }
}
```

① Adds the cache qualifier.

② Creates the bean once for the application. Producers that create cache managers should always include the `@ApplicationScoped` annotation to avoid creating multiple cache managers.

③ Creates a new `DefaultCacheManager` instance that is bound to the `@GreetingCache` qualifier.





Cache managers are heavy weight objects. Having more than one cache manager running in your application can degrade performance. When injecting multiple caches, either add the qualifier of each cache to the cache manager producer method or do not add any qualifier.

4. Add the `@GreetingCache` qualifier to your cache injection point.

```
...
import javax.inject.Inject;

public class GreetingService {

    @Inject @GreetingCache
    private Cache<String, String> cache;

    public String greet(String user) {
        String cachedValue = cache.get(user);
        if (cachedValue == null) {
            cachedValue = "Hello " + user;
            cache.put(user, cachedValue);
        }
        return cachedValue;
    }
}
```

## 7.3. Injecting Remote Caches

Set up CDI beans to inject remote caches.

### Procedure

1. Create a cache qualifier annotation.

```
@Remote("mygreetingcache") ①
@Qualifier
@Target({ElementType.FIELD, ElementType.PARAMETER, ElementType.METHOD})
@Retention(RetentionPolicy.RUNTIME)
@Documented
public @interface RemoteGreetingCache { ②
}
```

① names the cache to inject.

② creates a `@RemoteGreetingCache` qualifier.

2. Add the `@RemoteGreetingCache` qualifier to your cache injection point.

```

public class GreetingService {

    @Inject @RemoteGreetingCache
    private RemoteCache<String, String> cache;

    public String greet(String user) {
        String cachedValue = cache.get(user);
        if (cachedValue == null) {
            cachedValue = "Hello " + user;
            cache.put(user, cachedValue);
        }
        return cachedValue;
    }
}

```

#### *Tips for injecting remote caches*

- You can inject remote caches without using qualifiers.

```

...
@Inject
@Remote("greetingCache")
private RemoteCache<String, String> cache;

```

- If you have more than one Infinispan cluster, you can create separate remote cache manager producers for each cluster.

```

...
import javax.enterprise.context.ApplicationScoped;

public class Config {

    @RemoteGreetingCache
    @Produces
    @ApplicationScoped ①
    public ConfigurationBuilder builder = new ConfigurationBuilder(); ②
        builder.addServer().host("localhost").port(11222);
        return new RemoteCacheManager(builder.build());
    }
}

```

① creates the bean once for the application. Producers that create cache managers should always include the `@ApplicationScoped` annotation to avoid creating multiple cache managers, which are heavy weight objects.

② creates a new `RemoteCacheManager` instance that is bound to the `@RemoteGreetingCache` qualifier.

## 7.4. JCache Caching Annotations

You can use the following JCache caching annotations with CDI managed beans when JCache artifacts are on the classpath:

### **@CacheResult**

caches the results of method calls.

### **@CachePut**

caches method parameters.

### **@CacheRemoveEntry**

removes entries from a cache.

### **@CacheRemoveAll**

removes all entries from a cache.



**Target type:** You can use these JCache caching annotations on methods only.

To use JCache caching annotations, declare interceptors in the `beans.xml` file for your application.

*Managed Environments (Application Server)*

```
<?xml version="1.0" encoding="UTF-8"?>
<beans xmlns="http://xmlns.jcp.org/xml/ns/javaee"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://xmlns.jcp.org/xml/ns/javaee
http://xmlns.jcp.org/xml/ns/javaee/beans_1_1.xsd"
  version="1.2" bean-discovery-mode="annotated">

  <interceptors>
    <class>org.infinispan.jcache.annotation.InjectedExceptionInterceptor</class>
    <class>org.infinispan.jcache.annotation.InjectedExceptionInterceptor</class>
    <class>
org.infinispan.jcache.annotation.InjectedExceptionInterceptor</class>
    <class>org.infinispan.jcache.annotation.InjectedExceptionInterceptor</class>
  </interceptors>
</beans>
```

```
<?xml version="1.0" encoding="UTF-8"?>
<beans xmlns="http://xmlns.jcp.org/xml/ns/javaee"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://xmlns.jcp.org/xml/ns/javaee
http://xmlns.jcp.org/xml/ns/javaee/beans_1_1.xsd"
  version="1.2" bean-discovery-mode="annotated">

  <interceptors>
    <class>org.infinispan.jcache.annotation.CacheResultInterceptor</class>
    <class>org.infinispan.jcache.annotation.CachePutInterceptor</class>
    <class>org.infinispan.jcache.annotation.CacheRemoveEntryInterceptor</class>
    <class>org.infinispan.jcache.annotation.CacheRemoveAllInterceptor</class>
  </interceptors>
</beans>
```

### JCache Caching Annotation Examples

The following example shows how the `@CacheResult` annotation caches the results of the `GreetingService.greet()` method:

```
import javax.cache.interceptor.CacheResult;

public class GreetingService {

    @CacheResult
    public String greet(String user) {
        return "Hello" + user;
    }
}
```

With JCache annotations, the default cache uses the fully qualified name of the annotated method with its parameter types, for example:

`org.infinispan.example.GreetingService.greet(java.lang.String)`

To use caches other than the default, use the `cacheName` attribute to specify the cache name as in the following example:

```
@CacheResult(cacheName = "greeting-cache")
```

## 7.5. Receiving Cache and Cache Manager Events

You can use CDI Events to receive Cache and cache manager level events.

- Use the `@Observes` annotation as in the following example:

```
import javax.enterprise.event.Observes;
import org.infinispan.notifications.cachemanagerlistener.event.CacheStartedEvent;
import org.infinispan.notifications.cachelistener.event.*;

public class GreetingService {

    // Cache level events
    private void entryRemovedFromCache(@Observes CacheEntryCreatedEvent event) {
        ...
    }

    // Cache manager level events
    private void cacheStarted(@Observes CacheStartedEvent event) {
        ...
    }
}
```

# Chapter 8. Locking and Concurrency

Infinispan makes use of multi-versioned concurrency control ([MVCC](#)) - a concurrency scheme popular with relational databases and other data stores. MVCC offers many advantages over coarse-grained Java synchronization and even JDK Locks for access to shared data, including:

- allowing concurrent readers and writers
- readers and writers do not block one another
- write skews can be detected and handled
- internal locks can be striped

## 8.1. Locking implementation details

Infinispan's MVCC implementation makes use of minimal locks and synchronizations, leaning heavily towards lock-free techniques such as [compare-and-swap](#) and lock-free data structures wherever possible, which helps optimize for multi-CPU and multi-core environments.

In particular, Infinispan's MVCC implementation is heavily optimized for readers. Reader threads do not acquire explicit locks for entries, and instead directly read the entry in question.

Writers, on the other hand, need to acquire a write lock. This ensures only one concurrent writer per entry, causing concurrent writers to queue up to change an entry.

To allow concurrent reads, writers make a copy of the entry they intend to modify, by wrapping the entry in an [MVCCEntry](#). This copy isolates concurrent readers from seeing partially modified state. Once a write has completed, [MVCCEntry.commit\(\)](#) will flush changes to the data container and subsequent readers will see the changes written.

### 8.1.1. Clustered caches and locks

In Infinispan clusters, primary owner nodes are responsible for locking keys.

For non-transactional caches, Infinispan forwards the write operation to the primary owner of the key so it can attempt to lock it. Infinispan either then forwards the write operation to the other owners or throws an exception if it cannot lock the key.



If the operation is conditional and fails on the primary owner, Infinispan does not forward it to the other owners.

For transactional caches, primary owners can lock keys with optimistic and pessimistic locking modes. Infinispan also supports different isolation levels to control concurrent reads between transactions.

### 8.1.2. The LockManager

The [LockManager](#) is a component that is responsible for locking an entry for writing. The [LockManager](#) makes use of a [LockContainer](#) to locate/hold/create locks. [LockContainers](#) come in two broad flavours,

with support for lock striping and with support for one lock per entry.

### 8.1.3. Lock striping

Lock striping entails the use of a fixed-size, shared collection of locks for the entire cache, with locks being allocated to entries based on the entry's key's hash code. Similar to the way the JDK's `ConcurrentHashMap` allocates locks, this allows for a highly scalable, fixed-overhead locking mechanism in exchange for potentially unrelated entries being blocked by the same lock.

The alternative is to disable lock striping - which would mean a *new* lock is created per entry. This approach *may* give you greater concurrent throughput, but it will be at the cost of additional memory usage, garbage collection churn, etc.



#### *Default lock striping settings*

lock striping is disabled by default, due to potential deadlocks that can happen if locks for different keys end up in the same lock stripe.

The size of the shared lock collection used by lock striping can be tuned using the `concurrencyLevel` attribute of the `<locking />` configuration element.

#### Configuration example:

```
<locking striping="false|true"/>
```

Or

```
new ConfigurationBuilder().locking().useLockStriping(false|true);
```

### 8.1.4. Concurrency levels

In addition to determining the size of the striped lock container, this concurrency level is also used to tune any JDK `ConcurrentHashMap` based collections where related, such as internal to `DataContainers`. Please refer to the JDK `ConcurrentHashMap` Javadocs for a detailed discussion of concurrency levels, as this parameter is used in exactly the same way in Infinispan.

#### Configuration example:

```
<locking concurrency-level="32"/>
```

Or

```
new ConfigurationBuilder().locking().concurrencyLevel(32);
```

### 8.1.5. Lock timeout

The lock timeout specifies the amount of time, in milliseconds, to wait for a contented lock.

**Configuration example:**

```
<locking acquire-timeout="10000"/>
```

Or

```
new ConfigurationBuilder().locking().lockAcquisitionTimeout(10000);  
//alternatively  
new ConfigurationBuilder().locking().lockAcquisitionTimeout(10, TimeUnit.SECONDS);
```

### 8.1.6. Consistency

The fact that a single owner is locked (as opposed to all owners being locked) does not break the following consistency guarantee: if key **K** is hashed to nodes **{A, B}** and transaction **TX1** acquires a lock for **K**, let's say on **A**. If another transaction, **TX2**, is started on **B** (or any other node) and **TX2** tries to lock **K** then it will fail with a timeout as the lock is already held by **TX1**. The reason for this is the that the lock for a key **K** is always, deterministically, acquired on the same node of the cluster, regardless of where the transaction originates.

## 8.2. Data Versioning

Infinispan supports two forms of data versioning: simple and external. The simple versioning is used in transactional caches for write skew check.

The external versioning is used to encapsulate an external source of data versioning within Infinispan, such as when using Infinispan with Hibernate which in turn gets its data version information directly from a database.

In this scheme, a mechanism to pass in the version becomes necessary, and overloaded versions of `put()` and `putForExternalRead()` will be provided in `AdvancedCache` to take in an external data version. This is then stored on the `InvocationContext` and applied to the entry at commit time.



Write skew checks cannot and will not be performed in the case of external data versioning.



# Chapter 9. Transactions

Infinispan can be configured to use and to participate in JTA compliant transactions.

Alternatively, if transaction support is disabled, it is equivalent to using autocommit in JDBC calls, where modifications are potentially replicated after every change (if replication is enabled).

On every cache operation Infinispan does the following:

1. Retrieves the current [Transaction](#) associated with the thread
2. If not already done, registers [XAResource](#) with the transaction manager to be notified when a transaction commits or is rolled back.

In order to do this, the cache has to be provided with a reference to the environment's [TransactionManager](#). This is usually done by configuring the cache with the class name of an implementation of the [TransactionManagerLookup](#) interface. When the cache starts, it will create an instance of this class and invoke its `getTransactionManager()` method, which returns a reference to the [TransactionManager](#).

Infinispan ships with several transaction manager lookup classes:

## *Transaction manager lookup implementations*

- [EmbeddedTransactionManagerLookup](#): This provides with a basic transaction manager which should only be used for embedded mode when no other implementation is available. This implementation has some severe limitations to do with concurrent transactions and recovery.
- [JBossStandaloneJTAManagerLookup](#): If you're running Infinispan in a standalone environment, or in JBoss AS 7 and earlier, and WildFly 8, 9, and 10, this should be your default choice for transaction manager. It's a fully fledged transaction manager based on [JBoss Transactions](#) which overcomes all the deficiencies of the [EmbeddedTransactionManager](#).
- [WildflyTransactionManagerLookup](#): If you're running Infinispan in WildFly 11 or later, this should be your default choice for transaction manager.
- [GenericTransactionManagerLookup](#): This is a lookup class that locate transaction managers in the most popular Java EE application servers. If no transaction manager can be found, it defaults on the [EmbeddedTransactionManager](#).

WARN: [DummyTransactionManagerLookup](#) has been deprecated in 9.0 and it will be removed in the future. Use [EmbeddedTransactionManagerLookup](#) instead.

Once initialized, the [TransactionManager](#) can also be obtained from the [Cache](#) itself:

```
//the cache must have a transactionManagerLookupClass defined
Cache cache = cacheManager.getCache();

//equivalent with calling TransactionManagerLookup.getTransactionManager();
TransactionManager tm = cache.getAdvancedCache().getTransactionManager();
```

## 9.1. Configuring transactions

Transactions are configured at cache level. Below is the configuration that affects a transaction behaviour and a small description of each configuration attribute.

```
<locking
  isolation="READ_COMMITTED"/>
<transaction
  locking="OPTIMISTIC"
  auto-commit="true"
  complete-timeout="60000"
  mode="NONE"
  notifications="true"
  reaper-interval="30000"
  recovery-cache="__recoveryInfoCacheName__"
  stop-timeout="30000"
  transaction-manager-lookup=
"org.infinispan.transaction.lookup.GenericTransactionManagerLookup"/>
```

or programmatically:

```
ConfigurationBuilder builder = new ConfigurationBuilder();
builder.locking()
    .isolationLevel(IsolationLevel.READ_COMMITTED);
builder.transaction()
    .lockingMode(LockingMode.OPTIMISTIC)
    .autoCommit(true)
    .completedTxTimeout(60000)
    .transactionMode(TransactionMode.NON_TRANSACTIONAL)
    .useSynchronization(false)
    .notifications(true)
    .reaperWakeUpInterval(30000)
    .cacheStopTimeout(30000)
    .transactionManagerLookup(new GenericTransactionManagerLookup())
    .recovery()
    .enabled(false)
    .recoveryInfoCacheName("__recoveryInfoCacheName__");
```

- **isolation** - configures the isolation level. Check section [Isolation Levels](#) for more details. Default is **REPEATABLE\_READ**.
- **locking** - configures whether the cache uses optimistic or pessimistic locking. Check section [Transaction Locking](#) for more details. Default is **OPTIMISTIC**.
- **auto-commit** - if enable, the user does not need to start a transaction manually for a single operation. The transaction is automatically started and committed. Default is **true**.
- **complete-timeout** - the duration in milliseconds to keep information about completed transactions. Default is **60000**.

- **mode** - configures whether the cache is transactional or not. Default is **NONE**. The available options are:
  - **NONE** - non transactional cache
  - **FULL\_XA** - XA transactional cache with recovery enabled. Check section [Transaction recovery](#) for more details about recovery.
  - **NON\_DURABLE\_XA** - XA transactional cache with recovery disabled.
  - **NON\_XA** - transactional cache with integration via [Synchronization](#) instead of XA. Check section [Enlisting Synchronizations](#) for details.
  - **BATCH** - transactional cache using batch to group operations. Check section [Batching](#) for details.
- **notifications** - enables/disables triggering transactional events in cache listeners. Default is **true**.
- **reaper-interval** - the time interval in millisecond at which the thread that cleans up transaction completion information kicks in. Defaults is **30000**.
- **recovery-cache** - configures the cache name to store the recovery information. Check section [Transaction recovery](#) for more details about recovery. Default is **recoveryInfoCacheName**.
- **stop-timeout** - the time in millisecond to wait for ongoing transaction when the cache is stopping. Default is **30000**.
- **transaction-manager-lookup** - configures the fully qualified class name of a class that looks up a reference to a **javax.transaction.TransactionManager**. Default is **org.infinispan.transaction.lookup.GenericTransactionManagerLookup**.

For more details on how Two-Phase-Commit (2PC) is implemented in Infinispan and how locks are being acquired see the section below. More details about the configuration settings are available in [Configuration reference](#).

## 9.2. Isolation levels

Infinispan offers two isolation levels - [READ\\_COMMITTED](#) and [REPEATABLE\\_READ](#).

These isolation levels determine when readers see a concurrent write, and are internally implemented using different subclasses of **MVCCEntry**, which have different behaviour in how state is committed back to the data container.

Here's a more detailed example that should help understand the difference between **READ\_COMMITTED** and **REPEATABLE\_READ** in the context of Infinispan. With **READ\_COMMITTED**, if between two consecutive read calls on the same key, the key has been updated by another transaction, the second read may return the new updated value:

```

Thread1: tx1.begin()
Thread1: cache.get(k) // returns v
Thread2:
Thread2: tx2.begin()
Thread2: cache.get(k) // returns v
Thread2: cache.put(k, v2)
Thread2: tx2.commit()
Thread1: cache.get(k) // returns v2!
Thread1: tx1.commit()

```

With **REPEATABLE\_READ**, the final get will still return **v**. So, if you're going to retrieve the same key multiple times within a transaction, you should use **REPEATABLE\_READ**.

However, as read-locks are not acquired even for **REPEATABLE\_READ**, this phenomena can occur:

```

cache.get("A") // returns 1
cache.get("B") // returns 1

Thread1: tx1.begin()
Thread1: cache.put("A", 2)
Thread1: cache.put("B", 2)
Thread2:
Thread2: tx2.begin()
Thread2: cache.get("A") // returns 1
Thread1: tx1.commit()
Thread2: cache.get("B") // returns 2
Thread2: tx2.commit()

```

## 9.3. Transaction locking

### 9.3.1. Pessimistic transactional cache

From a lock acquisition perspective, pessimistic transactions obtain locks on keys at the time the key is written.

1. A lock request is sent to the primary owner (can be an explicit lock request or an operation)
2. The primary owner tries to acquire the lock:
  - a. If it succeed, it sends back a positive reply;
  - b. Otherwise, a negative reply is sent and the transaction is rollback.

As an example:

```

transactionManager.begin();
cache.put(k1,v1); //k1 is locked.
cache.remove(k2); //k2 is locked when this returns
transactionManager.commit();

```

When `cache.put(k1,v1)` returns, `k1` is locked and no other transaction running anywhere in the cluster can write to it. Reading `k1` is still possible. The lock on `k1` is released when the transaction completes (commits or rollbacks).



For conditional operations, the validation is performed in the originator.

### 9.3.2. Optimistic transactional cache

With optimistic transactions locks are being acquired at transaction prepare time and are only being held up to the point the transaction commits (or rollbacks). This is different from the 5.0 default locking model where local locks are being acquire on writes and cluster locks are being acquired during prepare time.

1. The prepare is sent to all the owners.
2. The primary owners try to acquire the locks needed:
  - a. If locking succeeds, it performs the write skew check.
  - b. If the write skew check succeeds (or is disabled), send a positive reply.
  - c. Otherwise, a negative reply is sent and the transaction is rolled back.

As an example:

```
transactionManager.begin();
cache.put(k1,v1);
cache.remove(k2);
transactionManager.commit(); //at prepare time, K1 and K2 is locked until
committed/rolled back.
```



For conditional commands, the validation still happens on the originator.

### 9.3.3. What do I need - pessimistic or optimistic transactions?

From a use case perspective, optimistic transactions should be used when there is *not* a lot of contention between multiple transactions running at the same time. That is because the optimistic transactions rollback if data has changed between the time it was read and the time it was committed (with write skew check enabled).

On the other hand, pessimistic transactions might be a better fit when there is high contention on the keys and transaction rollbacks are less desirable. Pessimistic transactions are more costly by their nature: each write operation potentially involves a RPC for lock acquisition.

## 9.4. Write Skews

Write skews occur when two transactions independently and simultaneously read and write to the same key. The result of a write skew is that both transactions successfully commit updates to the same key but with different values.

Infinispan automatically performs write skew checks to ensure data consistency for **REPEATABLE\_READ** isolation levels in optimistic transactions. This allows Infinispan to detect and roll back one of the transactions.

When operating in **LOCAL** mode, write skew checks rely on Java object references to compare differences, which provides a reliable technique for checking for write skews.

### 9.4.1. Forcing write locks on keys in pessimistic transactions

To avoid write skews with pessimistic transactions, lock keys at read-time with **Flag.FORCE\_WRITE\_LOCK**.



- In non-transactional caches, **Flag.FORCE\_WRITE\_LOCK** does not work. The **get()** call reads the key value but does not acquire locks remotely.
- You should use **Flag.FORCE\_WRITE\_LOCK** with transactions in which the entity is updated later in the same transaction.

Compare the following code snippets for an example of **Flag.FORCE\_WRITE\_LOCK**:

```
// begin the transaction
if (!cache.getAdvancedCache().lock(key)) {
    // abort the transaction because the key was not locked
} else {
    cache.get(key);
    cache.put(key, value);
    // commit the transaction
}
```

```
// begin the transaction
try {
    // throws an exception if the key is not locked.
    cache.getAdvancedCache().withFlags(Flag.FORCE_WRITE_LOCK).get(key);
    cache.put(key, value);
} catch (CacheException e) {
    // mark the transaction rollback-only
}
// commit or rollback the transaction
```

## 9.5. Dealing with exceptions

If a **CacheException** (or a subclass of it) is thrown by a cache method within the scope of a JTA transaction, then the transaction is automatically marked for rollback.

## 9.6. Enlisting Synchronizations

By default Infinispan registers itself as a first class participant in distributed transactions through

**XAResource**. There are situations where Infinispan is not required to be a participant in the transaction, but only to be notified by its lifecycle (prepare, complete): e.g. in the case Infinispan is used as a 2nd level cache in Hibernate.

Infinispan allows transaction enlistment through **Synchronization**. To enable it just use **NON\_XA** transaction mode.

**Synchronizations** have the advantage that they allow **TransactionManager** to optimize 2PC with a 1PC where only one other resource is enlisted with that transaction (**last resource commit optimization**). E.g. Hibernate second level cache: if Infinispan registers itself with the **TransactionManager** as a **XAResource** than at commit time, the **TransactionManager** sees two **XAResource** (cache and database) and does not make this optimization. Having to coordinate between two resources it needs to write the tx log to disk. On the other hand, registering Infinispan as a **Synchronization** makes the **TransactionManager** skip writing the log to the disk (performance improvement).

## 9.7. Batching

Batching allows atomicity and some characteristics of a transaction, but not full-blown JTA or XA capabilities. Batching is often a lot lighter and cheaper than a full-blown transaction.



Generally speaking, one should use batching API whenever the only participant in the transaction is an Infinispan cluster. On the other hand, JTA transactions (involving **TransactionManager**) should be used whenever the transactions involves multiple systems. E.g. considering the "Hello world!" of transactions: transferring money from one bank account to the other. If both accounts are stored within Infinispan, then batching can be used. If one account is in a database and the other is Infinispan, then distributed transactions are required.



You *do not* have to have a transaction manager defined to use batching.

### 9.7.1. API

Once you have configured your cache to use batching, you use it by calling **startBatch()** and **endBatch()** on **Cache**. E.g.,

```

Cache cache = cacheManager.getCache();
// not using a batch
cache.put("key", "value"); // will replicate immediately

// using a batch
cache.startBatch();
cache.put("k1", "value");
cache.put("k2", "value");
cache.put("k2", "value");
cache.endBatch(true); // This will now replicate the modifications since the batch was
started.

// a new batch
cache.startBatch();
cache.put("k1", "value");
cache.put("k2", "value");
cache.put("k3", "value");
cache.endBatch(false); // This will "discard" changes made in the batch

```

### 9.7.2. Batching and JTA

Behind the scenes, the batching functionality starts a JTA transaction, and all the invocations in that scope are associated with it. For this it uses a very simple (e.g. no recovery) internal `TransactionManager` implementation. With batching, you get:

1. Locks you acquire during an invocation are held until the batch completes
2. Changes are all replicated around the cluster in a batch as part of the batch completion process. Reduces replication chatter for each update in the batch.
3. If synchronous replication or invalidation are used, a failure in replication/invalidation will cause the batch to roll back.
4. All the transaction related configurations apply for batching as well.

## 9.8. Transaction recovery

Recovery is a feature of XA transactions, which deal with the eventuality of a resource or possibly even the transaction manager failing, and recovering accordingly from such a situation.

### 9.8.1. When to use recovery

Consider a distributed transaction in which money is transferred from an account stored in an external database to an account stored in Infinispan. When `TransactionManager.commit()` is invoked, both resources prepare successfully (1st phase). During the commit (2nd) phase, the database successfully applies the changes whilst Infinispan fails before receiving the commit request from the transaction manager. At this point the system is in an inconsistent state: money is taken from the account in the external database but not visible yet in Infinispan (since locks are only released during 2nd phase of a two-phase commit protocol). Recovery deals with this situation to make sure



data in both the database and Infinispan ends up in a consistent state.

### 9.8.2. How does it work

Recovery is coordinated by the transaction manager. The transaction manager works with Infinispan to determine the list of in-doubt transactions that require manual intervention and informs the system administrator (via email, log alerts, etc). This process is transaction manager specific, but generally requires some configuration on the transaction manager.

Knowing the in-doubt transaction ids, the system administrator can now connect to the Infinispan cluster and replay the commit of transactions or force the rollback. Infinispan provides JMX tooling for this - this is explained extensively in the [Transaction recovery and reconciliation](#) section.

### 9.8.3. Configuring recovery

Recovery is *not* enabled by default in Infinispan. If disabled, the `TransactionManager` won't be able to work with Infinispan to determine the in-doubt transactions. The [Transaction configuration](#) section shows how to enable it.

NOTE: `recovery-cache` attribute is not mandatory and it is configured per-cache.



For recovery to work, `mode` must be set to `FULL_XA`, since full-blown XA transactions are needed.

#### Enable JMX support

In order to be able to use JMX for managing recovery JMX support must be explicitly enabled.

### 9.8.4. Recovery cache

In order to track in-doubt transactions and be able to reply them, Infinispan caches all transaction state for future use. This state is held only for in-doubt transaction, being removed for successfully completed transactions after when the commit/rollback phase completed.

This in-doubt transaction data is held within a local cache: this allows one to configure swapping this info to disk through cache loader in the case it gets too big. This cache can be specified through the `recovery-cache` configuration attribute. If not specified Infinispan will configure a local cache for you.

It is possible (though not mandated) to share same recovery cache between all the Infinispan caches that have recovery enabled. If the default recovery cache is overridden, then the specified recovery cache must use a [TransactionManagerLookup](#) that returns a different transaction manager than the one used by the cache itself.

### 9.8.5. Integration with the transaction manager

Even though this is transaction manager specific, generally a transaction manager would need a reference to a `XAResource` implementation in order to invoke `XAResource.recover()` on it. In order to obtain a reference to an Infinispan `XAResource` following API can be used:

```
XAResource xar = cache.getAdvancedCache().getXAResource();
```

It is a common practice to run the recovery in a different process from the one running the transaction.

### 9.8.6. Reconciliation

The transaction manager informs the system administrator on in-doubt transaction in a proprietary way. At this stage it is assumed that the system administrator knows transaction's XID (a byte array).

A normal recovery flow is:

- **STEP 1:** The system administrator connects to an Infinispan server through JMX, and lists the in doubt transactions. The image below demonstrates JConsole connecting to an Infinispan node that has an in doubt transaction.

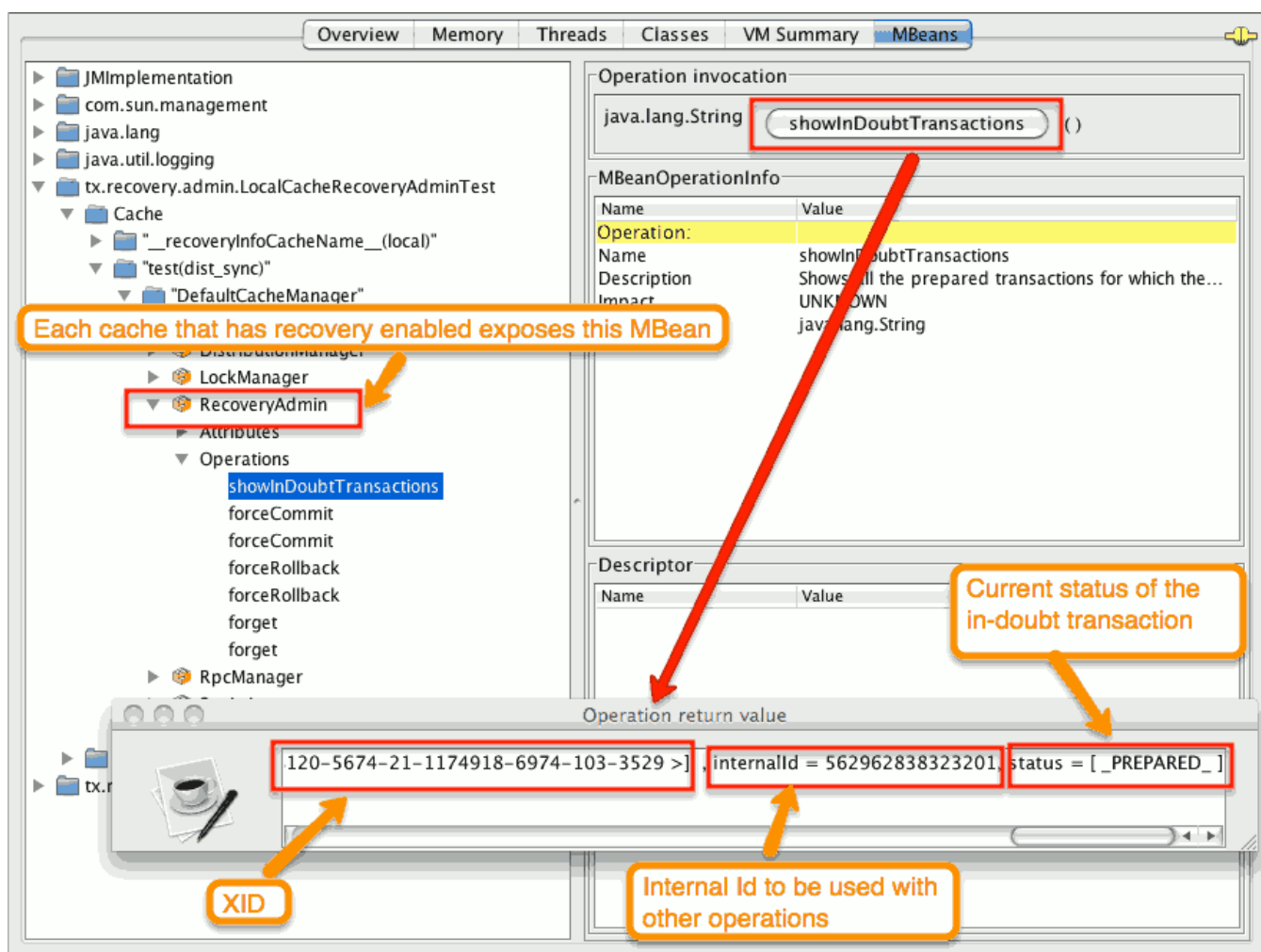


Figure 1. Show in-doubt transactions

The status of each in-doubt transaction is displayed (in this example " *PREPARED* "). There might be multiple elements in the status field, e.g. "PREPARED" and "COMMITTED" in the case the transaction committed on certain nodes but not on all of them.

- **STEP 2:** The system administrator visually maps the XID received from the transaction manager

to an Infinispan internal id, represented as a number. This step is needed because the XID, a byte array, cannot conveniently be passed to the JMX tool (e.g. JConsole) and then re-assembled on Infinispan's side.

- **STEP 3:** The system administrator forces the transaction's commit/rollback through the corresponding jmx operation, based on the internal id. The image below is obtained by forcing the commit of the transaction based on its internal id.

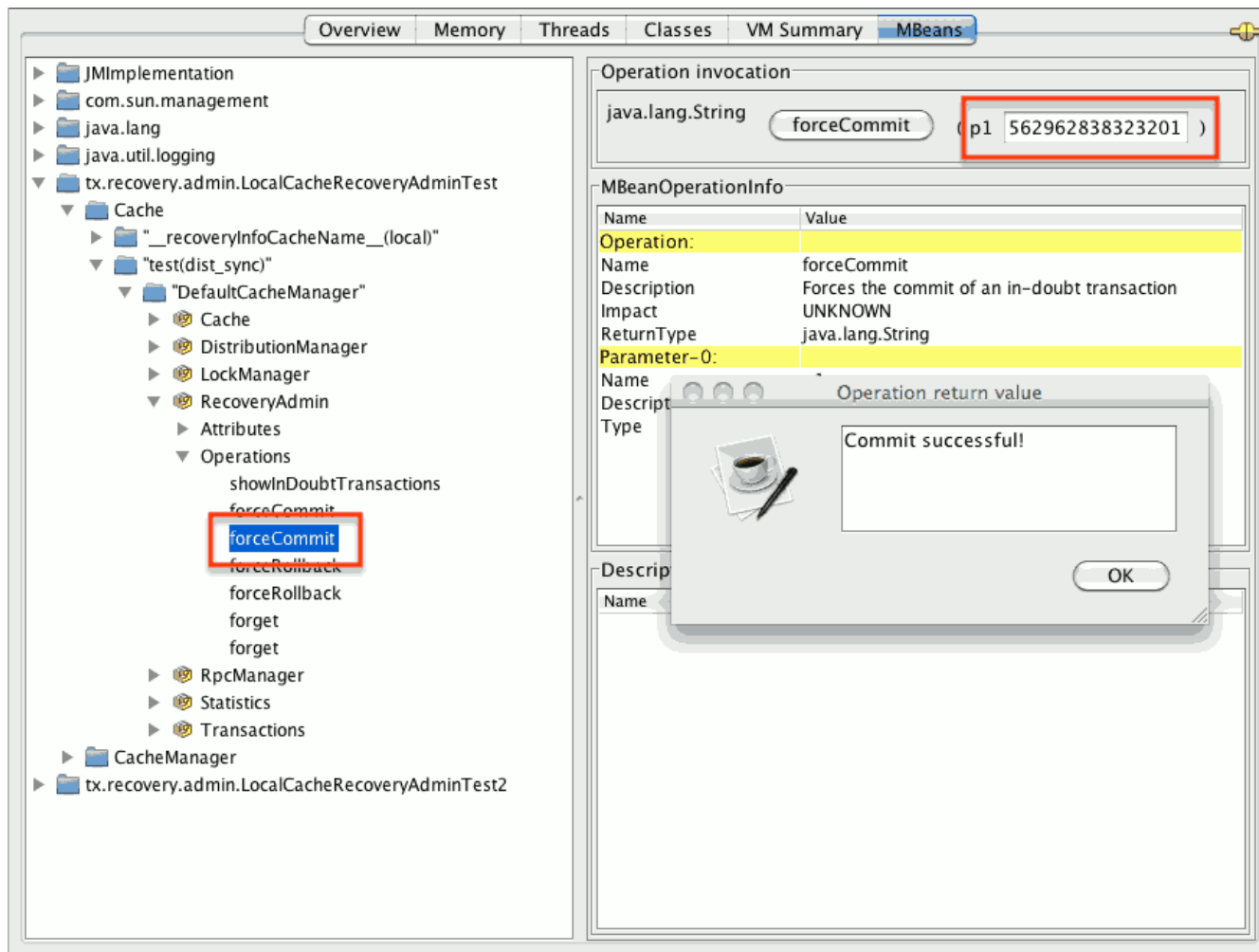


Figure 2. Force commit



All JMX operations described above can be executed on any node, regardless of where the transaction originated.

### Force commit/rollback based on XID

XID-based JMX operations for forcing in-doubt transactions' commit/rollback are available as well: these methods receive byte[] arrays describing the XID instead of the number associated with the transactions (as previously described at step 2). These can be useful e.g. if one wants to set up an automatic completion job for certain in-doubt transactions. This process is plugged into transaction manager's recovery and has access to the transaction manager's XID objects.

# Chapter 10. Functional Map API

Infinispan provides an experimental API for interacting with your data which takes advantage of the functional programming additions and improved asynchronous programming capabilities available in Java 8.

Infinispan's [Functional Map API](#) is a distilled map-like asynchronous API which uses functions to interact with data.

## 10.1. Asynchronous and Lazy

Being an asynchronous API, all methods that return a single result, return a `CompletableFuture` which wraps the result, so you can use the resources of your system more efficiently by having the possibility to receive callbacks when the `CompletableFuture` has completed, or you can chain or compose them with other `CompletableFuture`.

For those operations that return multiple results, the API returns instances of a [Traversable](#) interface which offers a lazy pull-style API for working with multiple results.

[Traversable](#), being a lazy pull-style API, can still be asynchronous underneath since the user can decide to work on the traversable at a later stage, and the [Traversable](#) implementation itself can decide when to compute those results.

## 10.2. Function transparency

Since the content of the functions is transparent to Infinispan, the API has been split into 3 interfaces for read-only ( [ReadOnlyMap](#) ), read-write ( [ReadWriteMap](#) ) and write-only ( [WriteOnlyMap](#) ) operations respectively, in order to provide hints to the Infinispan internals on the type of work needed to support functions.

## 10.3. Constructing Functional Maps

To construct any of the read-only, write-only or read-write map instances, an Infinispan [AdvancedCache](#) is required, which is retrieved from the Cache Manager, and using the [AdvancedCache](#) , static method factory methods are used to create [ReadOnlyMap](#) , [ReadWriteMap](#) or [WriteOnlyMap](#)

```
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.impl.*;
import org.infinispan.AdvancedCache;

AdvancedCache<String, String> cache = ...

FunctionalMapImpl<String, String> functionalMap = FunctionalMapImpl.create(cache);
ReadOnlyMap<String, String> readOnlyMap = ReadOnlyMapImpl.create(functionalMap);
WriteOnlyMap<String, String> writeOnlyMap = WriteOnlyMapImpl.create(functionalMap);
ReadWriteMap<String, String> readWriteMap = ReadWriteMapImpl.create(functionalMap);
```



At this stage, the Functional Map API is experimental and hence the way `FunctionalMap`, `ReadOnlyMap`, `WriteOnlyMap` and `ReadWriteMap` are constructed is temporary.

## 10.4. Read-Only Map API

Read-only operations have the advantage that no locks are acquired for the duration of the operation. Here's an example on how to the equivalent operation for `Map.get(K)`:

```
import org.infinispan.functional.EntryView.ReadEntryView;
import org.infinispan.functional.FunctionalMap.ReadOnlyMap;

ReadOnlyMap<String, String> readOnlyMap = ...
CompletableFuture<Optional<String>> readFuture = readOnlyMap.eval("key1",
ReadEntryView::find);
readFuture.thenAccept(System.out::println);
```

Read-only map also exposes operations to retrieve multiple keys in one go:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.Traversable;

ReadOnlyMap<String, String> readOnlyMap = ...

Set<String> keys = new HashSet<>(Arrays.asList("key1", "key2"));
Traversable<String> values = readOnlyMap.evalMany(keys, ReadEntryView::get);
values.forEach(System.out::println);
```

Finally, read-only map also exposes methods to read all existing keys as well as entries, which include both key and value information.

### 10.4.1. Read-Only Entry View

The function parameters for read-only maps provide the user with a [read-only entry view](#) to interact with the data in the cache, which include these operations:

- `key()` method returns the key for which this function is being executed.
- `find()` returns a Java 8 `Optional` wrapping the value if present, otherwise it returns an empty optional. Unless the value is guaranteed to be associated with the key, it's recommended to use `find()` to verify whether there's a value associated with the key.
- `get()` returns the value associated with the key. If the key has no value associated with it, calling `get()` throws a `NoSuchElementException`. `get()` can be considered as a shortcut of `ReadEntryView.find().get()` which should be used only when the caller has guarantees that there's definitely a value associated with the key.

- `findMetaParam(Class<T> type)` allows metadata parameter information associated with the cache entry to be looked up, for example: entry lifespan, last accessed time...etc. See [Metadata Parameter Handling](#) to find out more.

## 10.5. Write-Only Map API

Write-only operations include operations that insert or update data in the cache and also removals. Crucially, a write-only operation does not attempt to read any previous value associated with the key. This is an important optimization since that means neither the cluster nor any persistence stores will be looked up to retrieve previous values. In the main Infinispan Cache, this kind of optimization was achieved using a local-only per-invocation flag, but the use case is so common that in this new functional API, this optimization is provided as a first-class citizen.

Using [write-only map API](#), an operation equivalent to `javax.cache.Cache (JCache)`'s void returning `put` can be achieved this way, followed by an attempt to read the stored value using the read-only map API:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;

WriteOnlyMap<String, String> writeOnlyMap = ...
ReadOnlyMap<String, String> readOnlyMap = ...

CompletableFuture<Void> writeFuture = writeOnlyMap.eval("key1", "value1",
    (v, view) -> view.set(v));
CompletableFuture<String> readFuture = writeFuture.thenCompose(r ->
    readOnlyMap.eval("key1", ReadEntryView::get));
readFuture.thenAccept(System.out::println);
```

Multiple key/value pairs can be stored in one go using `evalMany` API:

```
WriteOnlyMap<String, String> writeOnlyMap = ...

Map<K, String> data = new HashMap<>();
data.put("key1", "value1");
data.put("key2", "value2");
CompletableFuture<Void> writerAllFuture = writeOnlyMap.evalMany(data, (v, view) ->
    view.set(v));
writerAllFuture.thenAccept(x -> "Write completed");
```

To remove all contents of the cache, there are two possibilities with different semantics. If using `evalAll` each cached entry is iterated over and the function is called with that entry's information. Using this method also results in listeners being invoked.

```
WriteOnlyMap<String, String> writeOnlyMap = ...

CompletableFuture<Void> removeAllFuture = writeOnlyMap.evalAll(WriteEntryView::remove
);
removeAllFuture.thenAccept(x -> "All entries removed");
```

The alternative way to remove all entries is to call `truncate` operation which clears the entire cache contents in one go without invoking any listeners and is best-effort:

```
WriteOnlyMap<String, String> writeOnlyMap = ...

CompletableFuture<Void> truncateFuture = writeOnlyMap.truncate();
truncateFuture.thenAccept(x -> "Cache contents cleared");
```

### 10.5.1. Write-Only Entry View

The function parameters for write-only maps provide the user with a [write-only entry view](#) to modify the data in the cache, which include these operations:

- `set(V, MetaParam.Writable...)` method allows for a new value to be associated with the cache entry for which this function is executed, and it optionally takes zero or more metadata parameters to be stored along with the value. See [Metadata Parameter Handling](#) for more information.
- `remove()` method removes the cache entry, including both value and metadata parameters associated with this key.

## 10.6. Read-Write Map API

The final type of operations we have are readwrite operations, and within this category CAS-like (CompareAndSwap) operations can be found. This type of operations require previous value associated with the key to be read and for locks to be acquired before executing the function. The vast majority of operations within `ConcurrentMap` and `JCache` APIs fall within this category, and they can easily be implemented using the [read-write map API](#). Moreover, with [read-write map API](#), you can make CASlike comparisons not only based on value equality but based on metadata parameter equality such as version information, and you can send back previous value or boolean instances to signal whether the CASlike comparison succeeded.

Implementing a write operation that returns the previous value associated with the cache entry is easy to achieve with the read-write map API:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;

ReadWriteMap<String, String> readWriteMap = ...

CompletableFuture<Optional<String>> readWriteFuture = readWriteMap.eval("key1",
"value1",
    (v, view) -> {
        Optional<V> prev = rw.find();
        view.set(v);
        return prev;
    });
readWriteFuture.thenAccept(System.out::println);
```

`ConcurrentMap.replace(K, V, V)` is a replace function that compares the value present in the map and if it's equals to the value passed in as first parameter, the second value is stored, returning a boolean indicating whether the replace was successfully completed. This operation can easily be implemented using the read-write map API:

```
ReadWriteMap<String, String> readWriteMap = ...

String oldValue = "old-value";
CompletableFuture<Boolean> replaceFuture = readWriteMap.eval("key1", "value1", (v,
view) -> {
    return view.find().map(prev -> {
        if (prev.equals(oldValue)) {
            rw.set(v);
            return true; // previous value present and equals to the expected one
        }
        return false; // previous value associated with key does not match
    }).orElse(false); // no value associated with this key
});
replaceFuture.thenAccept(replaced -> System.out.printf("Value was replaced? %s\n",
replaced));
```



The function in the example above captures `oldValue` which is an external value to the function which is valid use case.

Read-write map API contains `evalMany` and `evalAll` operations which behave similar to the write-only map offerings, except that they enable previous value and metadata parameters to be read.

### 10.6.1. Read-Write Entry View

The function parameters for read-write maps provide the user with the possibility to query the information associated with the key, including value and metadata parameters, and the user can also use this [read-write entry view](#) to modify the data in the cache.



The operations exposed by read-write entry views are a union of the operations exposed by [read-only entry views](#) and [write-only entry views](#).

## 10.7. Metadata Parameter Handling

[Metadata parameters](#) provide extra information about the cache entry, such as version information, lifespan, last accessed/used time...etc. Some of these can be provided by the user, e.g. version, lifespan...etc, but some others are computed internally and can only be queried, e.g. last accessed/used time.

The functional map API provides a flexible way to store metadata parameters along with an cache entry. To be able to store a metadata parameter, it must extend `MetaParam.Writable` interface, and implement the methods to allow the internal logic to extra the data. Storing is done via the `set(V, MetaParam.Writable...)` method in the [write-only entry view](#) or [read-write entry view](#) function parameters.

Querying metadata parameters is available via the `findMetaParam(Class)` method available via [read-write entry view](#) or [read-only entry views](#) or function parameters.

Here is an example showing how to store metadata parameters and how to query them:

```
import java.time.Duration;
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.MetaParam.*;

WriteOnlyMap<String, String> writeOnlyMap = ...
ReadOnlyMap<String, String> readOnlyMap = ...

CompletableFuture<Void> writeFuture = writeOnlyMap.eval("key1", "value1",
    (v, view) -> view.set(v, new MetaLifespan(Duration.ofHours(1).toMillis())));
CompletableFuture<MetaLifespan> readFuture = writeFuture.thenCompose(r ->
    readOnlyMap.eval("key1", view -> view.findMetaParam(MetaLifespan.class).get()));
readFuture.thenAccept(System.out::println);
```

If the metadata parameter is generic, for example `MetaEntryVersion<T>`, retrieving the metadata parameter along with a specific type can be tricky if using `.class` static helper in a class because it does not return a `Class<T>` but only `Class`, and hence any generic information in the class is lost:

```

ReadOnlyMap<String, String> readOnlyMap = ...

CompletableFuture<String> readFuture = readOnlyMap.eval("key1", view -> {
    // If caller depends on the typed information, this is not an ideal way to retrieve
    it
    // If the caller does not depend on the specific type, this works just fine.
    Optional<MetaEntryVersion> version = view.findMetaParam(MetaEntryVersion.class);
    return view.get();
});

```

When generic information is important the user can define a static helper method that coerces the static class retrieval to the type requested, and then use that helper method in the call to `findMetaParam`:

```

class MetaEntryVersion<T> implements MetaParam.Writable<EntryVersion<T>> {
    ...
    public static <T> T type() { return (T) MetaEntryVersion.class; }
    ...
}

ReadOnlyMap<String, String> readOnlyMap = ...

CompletableFuture<String> readFuture = readOnlyMap.eval("key1", view -> {
    // The caller wants guarantees that the metadata parameter for version is numeric
    // e.g. to query the actual version information
    Optional<MetaEntryVersion<Long>> version = view.findMetaParam(MetaEntryVersion.
type());
    return view.get();
});

```

Finally, users are free to create new instances of metadata parameters to suit their needs. They are stored and retrieved in the very same way as done for the metadata parameters already provided by the functional map API.

## 10.8. Invocation Parameter

[Per-invocation parameters](#) are applied to regular functional map API calls to alter the behaviour of certain aspects. Adding per invocation parameters is done using the `withParams(Param<?>...)` method.

`Param.FutureMode` tweaks whether a method returning a `CompletableFuture` will span a thread to invoke the method, or instead will use the caller thread. By default, whenever a call is made to a method returning a `CompletableFuture`, a separate thread will be span to execute the method asynchronously. However, if the caller will immediately block waiting for the `CompletableFuture` to complete, spanning a different thread is wasteful, and hence `Param.FutureMode.COMPLETED` can be passed as per-invocation parameter to avoid creating that extra thread. Example:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.Param.*;

ReadOnlyMap<String, String> readOnlyMap = ...
ReadOnlyMap<String, String> readOnlyMapCompleted = readOnlyMap.withParams(FutureMode
.COMPLETED);
Optional<String> readFuture = readOnlyMapCompleted.eval("key1", ReadEntryView::find)
.get();
```

Param.PersistenceMode controls whether a write operation will be propagated to a persistence store. The default behaviour is for all write-operations to be propagated to the persistence store if the cache is configured with a persistence store. By passing PersistenceMode.SKIP as parameter, the write operation skips the persistence store and its effects are only seen in the in-memory contents of the cache. PersistenceMode.SKIP can be used to implement an `Cache.evict()` method which removes data from memory but leaves the persistence store untouched:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.Param.*;

WriteOnlyMap<String, String> writeOnlyMap = ...
WriteOnlyMap<String, String> skipPersistMap = writeOnlyMap.withParams(PersistenceMode
.SKIP);
CompletableFuture<Void> removeFuture = skipPersistMap.eval("key1", WriteEntryView:
.remove);
```

Note that there's no need for another PersistenceMode option to skip reading from the persistence store, because a write operation can skip reading previous value from the store by calling a write-only operation via the WriteOnlyMap.

Finally, new Param implementations are normally provided by the functional map API since they tweak how the internal logic works. So, for the most part of users, they should limit themselves to using the Param instances exposed by the API. The exception to this rule would be advanced users who decide to add new interceptors to the internal stack. These users have the ability to query these parameters within the interceptors.

## 10.9. Functional Listeners

The functional map offers a listener API, where clients can register for and get notified when events take place. These notifications are post-event, so that means the events are received after the event has happened.

The listeners that can be registered are split into two categories: [write listeners](#) and [read-write listeners](#).

### 10.9.1. Write Listeners

[Write listeners](#) enable user to register listeners for any cache entry write events that happen in either a read-write or write-only functional map.

Listeners for write events cannot distinguish between cache entry created and cache entry modify/update events because they don't have access to the previous value. All they know is that a new non-null entry has been written.

However, write event listeners can distinguish between entry removals and cache entry create/modify-update events because they can query what the new entry's value via `ReadEntryView.find()` method.

Adding a write listener is done via the `WriteListeners` interface which is accessible via both `ReadWriteMap.listeners()` and `WriteOnlyMap.listeners()` method.

A write listener implementation can be defined either passing a function to `onWrite(Consumer<ReadEntryView<K, V>>)` method, or passing a `WriteListener` implementation to `add(WriteListener<K, V>)` method. Either way, all these methods return an [AutoCloseable](#) instance that can be used to de-register the function listener:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.Listeners.WriteListeners.WriteListener;

WriteOnlyMap<String, String> woMap = ...

AutoCloseable writeFunctionCloseHandler = woMap.listeners().onWrite(written -> {
    // `written` is a ReadEntryView of the written entry
    System.out.printf("Written: %s\n", written.get());
});
AutoCloseable writeCloseHanlder = woMap.listeners().add(new WriteListener<String,
String>() {
    @Override
    public void onWrite(ReadEntryView<K, V> written) {
        System.out.printf("Written: %s\n", written.get());
    }
});

// Either wrap handler in a try section to have it auto close...
try(writeFunctionCloseHandler) {
    // Write entries using read-write or write-only functional map API
    ...
}
// Or close manually
writeCloseHanlder.close();
```

## 10.9.2. Read-Write Listeners

[Read-write listeners](#) enable users to register listeners for cache entry created, modified and removed events, and also register listeners for any cache entry write events.

Entry created, modified and removed events can only be fired when these originate on a read-write functional map, since this is the only one that guarantees that the previous value has been read, and hence the differentiation between create, modified and removed can be fully guaranteed.

Adding a read-write listener is done via the `ReadWriteListeners` interface which is accessible via `ReadWriteMap.listeners()` method.

If interested in only one of the event types, the simplest way to add a listener is to pass a function to either `onCreate`, `onModify` or `onRemove` methods. All these methods return an `AutoCloseable` instance that can be used to de-register the function listener:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;

ReadWriteMap<String, String> rwMap = ...
AutoCloseable createClose = rwMap.listeners().onCreate(created -> {
    // `created` is a ReadEntryView of the created entry
    System.out.printf("Created: %s%n", created.get());
});
AutoCloseable modifyClose = rwMap.listeners().onModify((before, after) -> {
    // `before` is a ReadEntryView of the entry before update
    // `after` is a ReadEntryView of the entry after update
    System.out.printf("Before: %s%n", before.get());
    System.out.printf("After: %s%n", after.get());
});
AutoCloseable removeClose = rwMap.listeners().onRemove(removed -> {
    // `removed` is a ReadEntryView of the removed entry
    System.out.printf("Removed: %s%n", removed.get());
});
AutoCloseable writeClose = woMap.listeners().onWrite(written -> {
    // `written` is a ReadEntryView of the written entry
    System.out.printf("Written: %s%n", written.get());
});
...
// Either wrap handler in a try section to have it auto close...
try(createClose) {
    // Create entries using read-write functional map API
    ...
}
// Or close manually
modifyClose.close();
```

If listening for two or more event types, it's better to pass in an implementation of `ReadWriteListener` interface via the `ReadWriteListeners.add()` method. `ReadWriteListener` offers the same `onCreate/onModify/onRemove` callbacks with default method implementations that are empty:

```

import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.functional.Listeners.ReadWriteListeners.ReadWriteListener;

ReadWriteMap<String, String> rwMap = ...
AutoCloseable readWriteClose = rwMap.listeners.add(new ReadWriteListener<String,
String>() {
    @Override
    public void onCreate(ReadEntryView<String, String> created) {
        System.out.printf("Created: %s%n", created.get());
    }

    @Override
    public void onModify(ReadEntryView<String, String> before, ReadEntryView<String,
String> after) {
        System.out.printf("Before: %s%n", before.get());
        System.out.printf("After: %s%n", after.get());
    }

    @Override
    public void onRemove(ReadEntryView<String, String> removed) {
        System.out.printf("Removed: %s%n", removed.get());
    }
});
AutoCloseable writeClose = rwMap.listeners.add(new WriteListener<String, String>() {
    @Override
    public void onWrite(ReadEntryView<K, V> written) {
        System.out.printf("Written: %s%n", written.get());
    }
});

// Either wrap handler in a try section to have it auto close...
try(readWriteClose) {
    // Create/update/remove entries using read-write functional map API
    ...
}
// Or close manually
writeClose.close();

```

## 10.10. Marshalling of Functions

Running functional map in a cluster of nodes involves marshalling and replication of the operation parameters under certain circumstances.

To be more precise, when write operations are executed in a cluster, regardless of read-write or write-only operations, all the parameters to the method and the functions are replicated to other nodes.

There are multiple ways in which a function can be marshalled. The simplest way, which is also the

most costly option in terms of payload size, is to mark the function as `Serializable`:

```
import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;

WriteOnlyMap<String, String> writeOnlyMap = ...

// Force a function to be Serializable
Consumer<WriteEntryView<String>> function =
    (Consumer<WriteEntryView<String>> & Serializable) wv -> wv.set("one");

CompletableFuture<Void> writeFuture = writeOnlyMap.eval("key1", function);
```

Infinispan provides overloads for all functional methods that make lambdas passed directly to the API serializable by default; the compiler automatically selects this overload if that's possible. Therefore you can call

```
WriteOnlyMap<String, String> writeOnlyMap = ...
CompletableFuture<Void> writeFuture = writeOnlyMap.eval("key1", wv -> wv.set("one"));
```

without doing the cast described above.

A more economical way to marshall a function is to provide an Infinispan `Externalizer` for it:

```

import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.commons.marshall.Externalizer;
import org.infinispan.commons.marshall.SerializeFunctionWith;

WriteOnlyMap<String, String> writeOnlyMap = ...

// Force a function to be Serializable
Consumer<WriteEntryView<String>> function = new SetStringConstant<>();
CompletableFuture<Void> writeFuture = writeOnlyMap.eval("key1", function);

@SerializeFunctionWith(value = SetStringConstant.Externalizer0.class)
class SetStringConstant implements Consumer<WriteEntryView<String>> {
    @Override
    public void accept(WriteEntryView<String> view) {
        view.set("value1");
    }

    public static final class Externalizer0 implements Externalizer<Object> {
        public void writeObject(ObjectOutput oo, Object o) {
            // No-op
        }
        public Object readObject(ObjectInput input) {
            return new SetStringConstant<>();
        }
    }
}

```

To help users take advantage of the tiny payloads generated by `Externalizer`-based functions, the functional API comes with a helper class called `org.infinispan.commons.marshall.MarshallableFunctions` which provides marshallable functions for some of the most commonly user functions.

In fact, all the functions required to implement `ConcurrentMap` and `JCache` using the functional map API have been defined in `MarshallableFunctions`. For example, here is an implementation of `JCache`'s `boolean putIfAbsent(K, V)` using functional map API which can be run in a cluster:

```

import org.infinispan.functional.EntryView.*;
import org.infinispan.functional.FunctionalMap.*;
import org.infinispan.commons.marshall.MarshallableFunctions;

ReadWriteMap<String, String> readWriteMap = ...

CompletableFuture<Boolean> future = readWriteMap.eval("key1",
    MarshallableFunctions.setValueIfAbsentReturnBoolean());
future.thenAccept(stored -> System.out.printf("Value was put? %s\n", stored));

```



## 10.11. Use Cases for Functional API

This new API is meant to complement existing Key/Value Infinispan API offerings, so you'll still be able to use `ConcurrentMap` or `JCache` standard APIs if that's what suits your use case best.

The target audience for this new API is either:

- Distributed or persistent caching/inmemorydatagrid users that want to benefit from `CompletableFuture` and/or `Traversable` for async/lazy data grid or caching data manipulation. The clear advantage here is that threads do not need to be idle waiting for remote operations to complete, but instead these can be notified when remote operations complete and then chain them with other subsequent operations.
- Users who want to go beyond the standard operations exposed by `ConcurrentMap` and `JCache`, for example, if you want to do a replace operation using metadata parameter equality instead of value equality, or if you want to retrieve metadata information from values and so on.

# Chapter 11. Executing Code in the Grid

The main benefit of a Cache is the ability to very quickly lookup a value by its key, even across machines. In fact this use alone is probably the reason many users use Infinispan. However Infinispan can provide many more benefits that aren't immediately apparent. Since Infinispan is usually used in a cluster of machines we also have features available that can help utilize the entire cluster for performing the user's desired workload.



This section covers only executing code in the grid using an embedded cache, if you are using a remote cache you should review details about executing code in the remote grid.

## 11.1. Cluster Executor

Since you have a group of machines, it makes sense to leverage their combined computing power for executing code on all of them. The cache manager comes with a nice utility that allows you to execute arbitrary code in the cluster. Note this feature requires no Cache to be used. This [Cluster Executor](#) can be retrieved by calling `executor()` on the [EmbeddedCacheManager](#). This executor is retrievable in both clustered and non clustered configurations.



The `ClusterExecutor` is specifically designed for executing code where the code is not reliant upon the data in a cache and is used instead as a way to help users to execute code easily in the cluster.

This manager was built specifically using Java 8 and such has functional APIs in mind, thus all methods take a functional interface as an argument. Also since these arguments will be sent to other nodes they need to be serializable. We even used a nice trick to ensure our lambdas are immediately Serializable. That is by having the arguments implement both Serializable and the real argument type (ie. Runnable or Function). The JRE will pick the most specific class when determining which method to invoke, so in that case your lambdas will always be serializable. It is also possible to use an Externalizer to possibly reduce message size further.

The manager by default will submit a given command to all nodes in the cluster including the node where it was submitted from. You can control on which nodes the task is executed on by using the [filterTargets](#) methods as is explained in the section.

### 11.1.1. Filtering execution nodes

It is possible to limit on which nodes the command will be ran. For example you may want to only run a computation on machines in the same rack. Or you may want to perform an operation once in the local site and again on a different site. A cluster executor can limit what nodes it sends requests to at the scope of same or different machine, rack or site level.

*SameRack.java*

```
EmbeddedCacheManager manager = ...;
manager.executor().filterTargets(ClusterExecutionPolicy.SAME_RACK).submit(...)
```

To use this topology base filtering you must enable topology aware consistent hashing through Server Hinting.

You can also filter using a predicate based on the **Address** of the node. This can also be optionally combined with topology based filtering in the previous code snippet.

We also allow the target node to be chosen by any means using a **Predicate** that will filter out which nodes can be considered for execution. Note this can also be combined with Topology filtering at the same time to allow even more fine control of where you code is executed within the cluster.

*Predicate.java*

```
EmbeddedCacheManager manager = ...;
// Just filter
manager.executor().filterTargets(a -> a.equals(..)).submit(...)
// Filter only those in the desired topology
manager.executor().filterTargets(ClusterExecutionPolicy.SAME_SITE, a -> a.equals(..))
    .submit(...)
```

### 11.1.2. Timeout

Cluster Executor allows for a timeout to be set per invocation. This defaults to the distributed sync timeout as configured on the Transport Configuration. This timeout works in both a clustered and non clustered cache manager. The executor may or may not interrupt the threads executing a task when the timeout expires. However when the timeout occurs any **Consumer** or **Future** will be completed passing back a **TimeoutException**. This value can be overridden by invoking the **timeout** method and supplying the desired duration.

### 11.1.3. Single Node Submission

Cluster Executor can also run in single node submission mode instead of submitting the command to all nodes it will instead pick one of the nodes that would have normally received the command and instead submit it to only one. Each submission will possibly use a different node to execute the task on. This can be very useful to use the ClusterExecutor as a **java.util.concurrent.Executor** which you may have noticed that ClusterExecutor implements.

*SingleNode.java*

```
EmbeddedCacheManager manager = ...;
manager.executor().singleNodeSubmission().submit(...)
```

## Failover

When running in single node submission it may be desirable to also allow the Cluster Executor handle cases where an exception occurred during the processing of a given command by retrying the command again. When this occurs the Cluster Executor will choose a single node again to resubmit the command to up to the desired number of failover attempts. Note the chosen node could be any node that passes the topology or predicate check. Failover is enabled by invoking the overridden [singleNodeSubmission](#) method. The given command will be resubmitted again to a single node until either the command completes without exception or the total submission amount is equal to the provided failover count.

### 11.1.4. Example: PI Approximation

This example shows how you can use the ClusterExecutor to estimate the value of PI.

Pi approximation can greatly benefit from parallel distributed execution via Cluster Executor. Recall that area of the square is  $S_a = 4r^2$  and area of the circle is  $C_a = \pi r^2$ . Substituting  $r^2$  from the second equation into the first one it turns out that  $\pi = 4 * C_a / S_a$ . Now, imagine that we can shoot very large number of darts into a square; if we take ratio of darts that land inside a circle over a total number of darts shot we will approximate  $C_a / S_a$  value. Since we know that  $\pi = 4 * C_a / S_a$  we can easily derive approximate value of pi. The more darts we shoot the better approximation we get. In the example below we shoot 1 billion darts but instead of "shooting" them serially we parallelize work of dart shooting across the entire Infinispan cluster. Note this will work in a cluster of 1 as well, but will be slower.

```
public class PiAppx {

    public static void main (String [] arg){
        EmbeddedCacheManager cacheManager = ..
        boolean isCluster = ..

        int numPoints = 1_000_000_000;
        int numServers = isCluster ? cacheManager.getMembers().size() : 1;
        int numberPerWorker = numPoints / numServers;

        ClusterExecutor clusterExecutor = cacheManager.executor();
        long start = System.currentTimeMillis();
        // We receive results concurrently - need to handle that
        AtomicLong countCircle = new AtomicLong();
        CompletableFuture<Void> fut = clusterExecutor.submitConsumer(m -> {
            int insideCircleCount = 0;
            for (int i = 0; i < numberPerWorker; i++) {
                double x = Math.random();
                double y = Math.random();
                if (insideCircle(x, y))
                    insideCircleCount++;
            }
            return insideCircleCount;
        }, (address, count, throwable) -> {
            if (throwable != null) {
```

```

        throwable.printStackTrace();
        System.out.println("Address: " + address + " encountered an error: " +
throwable);
    } else {
        countCircle.getAndAdd(count);
    }
});
fut.whenComplete((v, t) -> {
    // This is invoked after all nodes have responded with a value or exception
    if (t != null) {
        t.printStackTrace();
        System.out.println("Exception encountered while waiting:" + t);
    } else {
        double appxPi = 4.0 * countCircle.get() / numPoints;

        System.out.println("Distributed PI appx is " + appxPi +
            " using " + numServers + " node(s), completed in " + (System
.currentTimeMillis() - start) + " ms");
    }
});

// May have to sleep here to keep alive if no user threads left
}

private static boolean insideCircle(double x, double y) {
    return (Math.pow(x - 0.5, 2) + Math.pow(y - 0.5, 2))
        <= Math.pow(0.5, 2);
}
}

```

# Chapter 12. Streams

You may want to process a subset or all data in the cache to produce a result. This may bring thoughts of Map Reduce. Infinispan allows the user to do something very similar but utilizes the standard JRE APIs to do so. Java 8 introduced the concept of a [Stream](#) which allows functional-style operations on collections rather than having to procedurally iterate over the data yourself. Stream operations can be implemented in a fashion very similar to MapReduce. Streams, just like MapReduce allow you to perform processing upon the entirety of your cache, possibly a very large data set, but in an efficient way.



Streams are the preferred method when dealing with data that exists in the cache because streams automatically adjust to cluster topology changes.

Also since we can control how the entries are iterated upon we can more efficiently perform the operations in a cache that is distributed if you want it to perform all of the operations across the cluster concurrently.

A stream is retrieved from the [entrySet](#), [keySet](#) or [values](#) collections returned from the Cache by invoking the [stream](#) or [parallelStream](#) methods.

## 12.1. Common stream operations

This section highlights various options that are present irrespective of what type of underlying cache you are using.

## 12.2. Key filtering

It is possible to filter the stream so that it only operates upon a given subset of keys. This can be done by invoking the [filterKeys](#) method on the [CacheStream](#). This should always be used over a Predicate [filter](#) and will be faster if the predicate was holding all keys.

If you are familiar with the [AdvancedCache](#) interface you may be wondering why you even use [getAll](#) over this [keyFilter](#). There are some small benefits (mostly smaller payloads) to using [getAll](#) if you need the entries as is and need them all in memory in the local node. However if you need to do processing on these elements a stream is recommended since you will get both distributed and threaded parallelism for free.

## 12.3. Segment based filtering



This is an advanced feature and should only be used with deep knowledge of Infinispan segment and hashing techniques. These segments based filtering can be useful if you need to segment data into separate invocations. This can be useful when integrating with other tools such as [Apache Spark](#).

This option is only supported for replicated and distributed caches. This allows the user to operate upon a subset of data at a time as determined by the [KeyPartitioner](#). The segments can be filtered

by invoking `filterKeySegments` method on the `CacheStream`. This is applied after the key filter but before any intermediate operations are performed.

## 12.4. Local/Invalidation

A stream used with a local or invalidation cache can be used just the same way you would use a stream on a regular collection. Infinispan handles all of the translations if necessary behind the scenes and works with all of the more interesting options (ie. `storeAsBinary` and a cache loader). Only data local to the node where the stream operation is performed will be used, for example invalidation only uses local entries.

## 12.5. Example

The code below takes a cache and returns a map with all the cache entries whose values contain the string "JBoss"

```
Map<Object, String> jbossValues = cache.entrySet().stream()
    .filter(e -> e.getValue().contains("JBoss"))
    .collect(Collectors.toMap(Map.Entry::getKey, Map.Entry::getValue));
```

## 12.6. Distribution/Replication/Scattered

This is where streams come into their stride. When a stream operation is performed it will send the various intermediate and terminal operations to each node that has pertinent data. This allows processing the intermediate values on the nodes owning the data, and only sending the final results back to the originating nodes, improving performance.

### 12.6.1. Rehash Aware

Internally the data is segmented and each node only performs the operations upon the data it owns as a primary owner. This allows for data to be processed evenly, assuming segments are granular enough to provide for equal amounts of data on each node.

When you are utilizing a distributed cache, the data can be reshuffled between nodes when a new node joins or leaves. Distributed Streams handle this reshuffling of data automatically so you don't have to worry about monitoring when nodes leave or join the cluster. Reshuffled entries may be processed a second time, and we keep track of the processed entries at the key level or at the segment level (depending on the terminal operation) to limit the amount of duplicate processing.

It is possible but highly discouraged to disable rehash awareness on the stream. This should only be considered if your request can handle only seeing a subset of data if a rehash occurs. This can be done by invoking `CacheStream.disableRehashAware()`. The performance gain for most operations when a rehash doesn't occur is completely negligible. The only exceptions are for `iterator` and `forEach`, which will use less memory, since they do not have to keep track of processed keys.



Please rethink disabling rehash awareness unless you really know what you are doing.

## 12.6.2. Serialization

Since the operations are sent across to other nodes they must be serializable by Infinispan marshallng. This allows the operations to be sent to the other nodes.

The simplest way is to use a `CacheStream` instance and use a lambda just as you would normally. Infinispan overrides all of the various `Stream` intermediate and terminal methods to take `Serializable` versions of the arguments (ie. `SerializableFunction`, `SerializablePredicate`...) You can find these methods at [CacheStream](#). This relies on the spec to pick the most specific method as defined [here](#).

In our previous example we used a `Collector` to collect all the results into a `Map`. Unfortunately the `Collectors` class doesn't produce `Serializable` instances. Thus if you need to use these, there are two ways to do so:

One option would be to use the `CacheCollectors` class which allows for a `Supplier<Collector>` to be provided. This instance could then use the `Collectors` to supply a `Collector` which is not serialized.

```
Map<Object, String> jbossValues = cache.entrySet().stream()
    .filter(e -> e.getValue().contains("Jboss"))
    .collect(CacheCollectors.serializableCollector(() -> Collectors.toMap
(Map.Entry::getKey, Map.Entry::getValue)));
```

Alternatively, you can avoid the use of `CacheCollectors` and instead use the overloaded `collect` methods that take `Supplier<Collector>`. These overloaded `collect` methods are only available via `CacheStream` interface.

```
Map<Object, String> jbossValues = cache.entrySet().stream()
    .filter(e -> e.getValue().contains("Jboss"))
    .collect(() -> Collectors.toMap(Map.Entry::getKey, Map.Entry::getValue)
);
```

If however you are not able to use the `Cache` and `CacheStream` interfaces you cannot utilize `Serializable` arguments and you must instead cast the lambdas to be `Serializable` manually by casting the lambda to multiple interfaces. It is not a pretty sight but it gets the job done.

```
Map<Object, String> jbossValues = map.entrySet().stream()
    .filter(((Serializable & Predicate<Map.Entry<Object, String>>)) e -> e
.getValue().contains("Jboss"))
    .collect(CacheCollectors.serializableCollector(() -> Collectors.toMap
(Map.Entry::getKey, Map.Entry::getValue)));
```

The recommended and most performant way is to use an `AdvancedExternalizer` as this provides the



smallest payload. Unfortunately this means you cannot use lambdas as advanced externalizers require defining the class before hand.

You can use an advanced externalizer as shown below:

```
Map<Object, String> jbossValues = cache.entrySet().stream()
    .filter(new ContainsFilter("Jboss"))
    .collect(() -> Collectors.toMap(Map.Entry::getKey, Map.Entry::getValue)
);

class ContainsFilter implements Predicate<Map.Entry<Object, String>> {
    private final String target;

    ContainsFilter(String target) {
        this.target = target;
    }

    @Override
    public boolean test(Map.Entry<Object, String> e) {
        return e.getValue().contains(target);
    }
}

class JbossFilterExternalizer implements AdvancedExternalizer<ContainsFilter> {

    @Override
    public Set<Class<? extends ContainsFilter>> getTypeClasses() {
        return Util.asSet(ContainsFilter.class);
    }

    @Override
    public Integer getId() {
        return CUSTOM_ID;
    }

    @Override
    public void writeObject(ObjectOutput output, ContainsFilter object) throws
IOException {
        output.writeUTF(object.target);
    }

    @Override
    public ContainsFilter readObject(ObjectInput input) throws IOException,
ClassNotFoundException {
        return new ContainsFilter(input.readUTF());
    }
}
```

You could also use an advanced externalizer for the collector supplier to reduce the payload size even further.

```

Map<Object, String> map = (Map<Object, String>) cache.entrySet().stream()
    .filter(new ContainsFilter("Jboss"))
    .collect(Collectors.toMap(Map.Entry::getKey, Map.Entry::getValue));

class ToMapCollectorSupplier<K, U> implements Supplier<Collector<Map.Entry<K, U>, ?,
Map<K, U>>> {
    static final ToMapCollectorSupplier INSTANCE = new ToMapCollectorSupplier();

    private ToMapCollectorSupplier() { }

    @Override
    public Collector<Map.Entry<K, U>, ?, Map<K, U>> get() {
        return Collectors.toMap(Map.Entry::getKey, Map.Entry::getValue);
    }
}

class ToMapCollectorSupplierExternalizer implements AdvancedExternalizer
<ToMapCollectorSupplier> {

    @Override
    public Set<Class<? extends ToMapCollectorSupplier>> getTypeClasses() {
        return Util.asSet(ToMapCollectorSupplier.class);
    }

    @Override
    public Integer getId() {
        return CUSTOM_ID;
    }

    @Override
    public void writeObject(ObjectOutput output, ToMapCollectorSupplier object)
throws IOException {
    }

    @Override
    public ToMapCollectorSupplier readObject(ObjectInput input) throws IOException,
ClassNotFoundException {
        return ToMapCollectorSupplier.INSTANCE;
    }
}

```

## 12.7. Parallel Computation

Distributed streams by default try to parallelize as much as possible. It is possible for the end user to control this and actually they always have to control one of the options. There are 2 ways these streams are parallelized.

**Local to each node** When a stream is created from the cache collection the end user can choose between invoking `stream` or `parallelStream` method. Depending on if the parallel stream was

picked will enable multiple threading for each node locally. Note that some operations like a rehash aware iterator and `forEach` operations will always use a sequential stream locally. This could be enhanced at some point to allow for parallel streams locally.

Users should be careful when using local parallelism as it requires having a large number of entries or operations that are computationally expensive to be faster. Also it should be noted that if a user uses a parallel stream with `forEach` that the action should not block as this would be executed on the common pool, which is normally reserved for computation operations.

**Remote requests** When there are multiple nodes it may be desirable to control whether the remote requests are all processed at the same time concurrently or one at a time. By default all terminal operations except the iterator perform concurrent requests. The iterator, method to reduce overall memory pressure on the local node, only performs sequential requests which actually performs slightly better.

If a user wishes to change this default however they can do so by invoking the `sequentialDistribution` or `parallelDistribution` methods on the `CacheStream`.

## 12.8. Task timeout

It is possible to set a timeout value for the operation requests. This timeout is used only for remote requests timing out and it is on a per request basis. The former means the local execution will not timeout and the latter means if you have a failover scenario as described above the subsequent requests each have a new timeout. If no timeout is specified it uses the replication timeout as a default timeout. You can set the timeout in your task by doing the following:

```
CacheStream<Map.Entry<Object, String>> stream = cache.entrySet().stream();
stream.timeout(1, TimeUnit.MINUTES);
```

For more information about this, please check the java doc in `timeout` javadoc.

## 12.9. Injection

The `Stream` has a terminal operation called `forEach` which allows for running some sort of side effect operation on the data. In this case it may be desirable to get a reference to the `Cache` that is backing this `Stream`. If your `Consumer` implements the `CacheAware` interface the `injectCache` method be invoked before the `accept` method from the `Consumer` interface.

## 12.10. Distributed Stream execution

Distributed streams execution works in a fashion very similar to map reduce. Except in this case we are sending zero to many intermediate operations (map, filter etc.) and a single terminal operation to the various nodes. The operation basically comes down to the following:

1. The desired segments are grouped by which node is the primary owner of the given segment
2. A request is generated to send to each remote node that contains the intermediate and terminal operations including which segments it should process

- a. The terminal operation will be performed locally if necessary
  - b. Each remote node will receive this request and run the operations and subsequently send the response back
3. The local node will then gather the local response and remote responses together performing any kind of reduction required by the operations themselves.
  4. Final reduced response is then returned to the user

In most cases all operations are fully distributed, as in the operations are all fully applied on each remote node and usually only the last operation or something related may be reapplied to reduce the results from multiple nodes. One important note is that intermediate values do not actually have to be serializable, it is the last value sent back that is the part desired (exceptions for various operations will be highlighted below).

**Terminal operator distributed result reductions** The following paragraphs describe how the distributed reductions work for the various terminal operators. Some of these are special in that an intermediate value may be required to be serializable instead of the final result.

### **allMatch noneMatch anyMatch**

The [allMatch](#) operation is ran on each node and then all the results are logically anded together locally to get the appropriate value. The [noneMatch](#) and [anyMatch](#) operations use a logical or instead. These methods also have early termination support, stopping remote and local operations once the final result is known.

### **collect**

The [collect](#) method is interesting in that it can do a few extra steps. The remote node performs everything as normal except it doesn't perform the final [finisher](#) upon the result and instead sends back the fully combined results. The local thread then [combines](#) the remote and local result into a value which is then finally finished. The key here to remember is that the final value doesn't have to be serializable but rather the values produced from the [supplier](#) and [combiner](#) methods.

### **count**

The [count](#) method just adds the numbers together from each node.

### **findAny findFirst**

The [findAny](#) operation returns just the first value they find, whether it was from a remote node or locally. Note this supports early termination in that once a value is found it will not process others. Note the [findFirst](#) method is special since it requires a sorted intermediate operation, which is detailed in the [exceptions](#) section.

### **max min**

The [max](#) and [min](#) methods find the respective min or max value on each node then a final reduction is performed locally to ensure only the min or max across all nodes is returned.

### **reduce**

The various reduce methods [1](#) , [2](#) , [3](#) will end up serializing the result as much as the accumulator can do. Then it will accumulate the local and remote results together locally, before

combining if you have provided that. Note this means a value coming from the combiner doesn't have to be Serializable.

## 12.11. Key based rehash aware operators

The `iterator`, `splititerator` and `forEach` are unlike the other terminal operators in that the rehash awareness has to keep track of what keys per segment have been processed instead of just segments. This is to guarantee an exactly once (`iterator` & `splititerator`) or at least once behavior (`forEach`) even under cluster membership changes.

The `iterator` and `splititerator` operators when invoked on a remote node will return back batches of entries, where the next batch is only sent back after the last has been fully consumed. This batching is done to limit how many entries are in memory at a given time. The user node will hold onto which keys it has processed and when a given segment is completed it will release those keys from memory. This is why sequential processing is preferred for the `iterator` method, so only a subset of segment keys are held in memory at once, instead of from all nodes.

The `forEach()` method also returns batches, but it returns a batch of keys after it has finished processing at least a batch worth of keys. This way the originating node can know what keys have been processed already to reduce chances of processing the same entry again. Unfortunately this means it is possible to have an at least once behavior when a node goes down unexpectedly. In this case that node could have been processing a batch and not yet completed one and those entries that were processed but not in a completed batch will be ran again when the rehash failure operation occurs. Note that adding a node will not cause this issue as the rehash failover doesn't occur until all responses are received.

These operations batch sizes are both controlled by the same value which can be configured by invoking `distributedBatchSize` method on the `CacheStream`. This value will default to the `chunkSize` configured in state transfer. Unfortunately this value is a tradeoff with memory usage vs performance vs at least once and your mileage may vary.

### Using `iterator` with replicated and distributed caches

When a node is the primary or backup owner of all requested segments for a distributed stream, Infinispan performs the `iterator` or `splititerator` terminal operations locally, which optimizes performance as remote iterations are more resource intensive.

This optimization applies to both replicated and distributed caches. However, Infinispan performs iterations remotely when using cache stores that are both `shared` and have `write-behind` enabled. In this case performing the iterations remotely ensures consistency.

## 12.12. Intermediate operation exceptions

There are some intermediate operations that have special exceptions, these are `skip`, `peek`, sorted 1 2. & `distinct`. All of these methods have some sort of artificial iterator implanted in the stream processing to guarantee correctness, they are documented as below. Note this means these operations may cause possibly severe performance degradation.

### **Skip**

An artificial iterator is implanted up to the intermediate skip operation. Then results are brought locally so it can skip the appropriate amount of elements.

### **Sorted**

WARNING: This operation requires having all entries in memory on the local node. An artificial iterator is implanted up to the intermediate sorted operation. All results are sorted locally. There are possible plans to have a distributed sort which returns batches of elements, but this is not yet implemented.

### **Distinct**

WARNING: This operation requires having all or nearly all entries in memory on the local node. Distinct is performed on each remote node and then an artificial iterator returns those distinct values. Then finally all of those results have a distinct operation performed upon them.

The rest of the intermediate operations are fully distributed as one would expect.

## **12.13. Examples**

### **Word Count**

Word count is a classic, if overused, example of map/reduce paradigm. Assume we have a mapping of key  $\rightarrow$  sentence stored on Infinispan nodes. Key is a String, each sentence is also a String, and we have to count occurrence of all words in all sentences available. The implementation of such a distributed task could be defined as follows:

```

public class WordCountExample {

    /**
     * In this example replace c1 and c2 with
     * real Cache references
     *
     * @param args
     */
    public static void main(String[] args) {
        Cache<String, String> c1 = ...;
        Cache<String, String> c2 = ...;

        c1.put("1", "Hello world here I am");
        c2.put("2", "Infinispan rules the world");
        c1.put("3", "JUDCon is in Boston");
        c2.put("4", "JBoss World is in Boston as well");
        c1.put("12", "JBoss Application Server");
        c2.put("15", "Hello world");
        c1.put("14", "Infinispan community");
        c2.put("15", "Hello world");

        c1.put("111", "Infinispan open source");
        c2.put("112", "Boston is close to Toronto");
        c1.put("113", "Toronto is a capital of Ontario");
        c2.put("114", "JUDCon is cool");
        c1.put("211", "JBoss World is awesome");
        c2.put("212", "JBoss rules");
        c1.put("213", "JBoss division of RedHat ");
        c2.put("214", "RedHat community");

        Map<String, Long> wordCountMap = c1.entrySet().parallelStream()
            .map(e -> e.getValue().split("\\s"))
            .flatMap(Arrays::stream)
            .collect(() -> Collectors.groupingBy(Function.identity(), Collectors.
counting()));
    }
}

```

In this case it is pretty simple to do the word count from the previous example.

However what if we want to find the most frequent word in the example? If you take a second to think about this case you will realize you need to have all words counted and available locally first. Thus we actually have a few options.

We could use a finisher on the collector, which is invoked on the user thread after all the results have been collected. Some redundant lines have been removed from the previous example.

```

public class WordCountExample {
    public static void main(String[] args) {
        // Lines removed

        String mostFrequentWord = c1.entrySet().parallelStream()
            .map(e -> e.getValue().split("\\s"))
            .flatMap(Arrays::stream)
            .collect(() -> Collectors.collectingAndThen(
                Collectors.groupingBy(Function.identity(), Collectors.counting()),
                wordCountMap -> {
                    String mostFrequent = null;
                    long maxCount = 0;
                    for (Map.Entry<String, Long> e : wordCountMap.entrySet()) {
                        int count = e.getValue().intValue();
                        if (count > maxCount) {
                            maxCount = count;
                            mostFrequent = e.getKey();
                        }
                    }
                    return mostFrequent;
                }
            ));
    }
}

```

Unfortunately the last step is only going to be ran in a single thread, which if we have a lot of words could be quite slow. Maybe there is another way to parallelize this with Streams.

We mentioned before we are in the local node after processing, so we could actually use a stream on the map results. We can therefore use a parallel stream on the results.

```

public class WordFrequencyExample {
    public static void main(String[] args) {
        // Lines removed

        Map<String, Long> wordCount = c1.entrySet().parallelStream()
            .map(e -> e.getValue().split("\\s"))
            .flatMap(Arrays::stream)
            .collect(() -> Collectors.groupingBy(Function.identity(), Collectors
                .counting()));
        Optional<Map.Entry<String, Long>> mostFrequent = wordCount.entrySet()
            .parallelStream().reduce(
                (e1, e2) -> e1.getValue() > e2.getValue() ? e1 : e2);
    }
}

```

This way you can still utilize all of the cores locally when calculating the most frequent element.

## Remove specific entries

Distributed streams can also be used as a way to modify data where it lives. For example you may want to remove all entries in your cache that contain a specific word.



```
public class RemoveBadWords {
    public static void main(String[] args) {
        // Lines removed
        String word = ..

        c1.entrySet().parallelStream()
            .filter(e -> e.getValue().contains(word))
            .forEach((c, e) -> c.remove(e.getKey()));
    }
}
```

If we carefully note what is serialized and what is not, we notice that only the word along with the operations are serialized across to other nodes as it is captured by the lambda. However the real saving piece is that the cache operation is performed on the primary owner thus reducing the amount of network traffic required to remove these values from the cache. The cache is not captured by the lambda as we provide a special `BiConsumer` method override that when invoked on each node passes the cache to the `BiConsumer`

One thing to keep in mind using the `forEach` command in this manner is that the underlying stream obtains no locks. The cache remove operation will still obtain locks naturally, but the value could have changed from what the stream saw. That means that the entry could have been changed after the stream read it but the remove actually removed it.

We have specifically added a new variant which is called `LockedStream`.

### Plenty of other examples

The `Streams` API is a JRE tool and there are lots of examples for using it. Just remember that your operations need to be `Serializable` in some way.

# Chapter 13. JCache (JSR-107) API

Infinispan provides an implementation of JCache 1.0 API ( [JSR-107](#) ). JCache specifies a standard Java API for caching temporary Java objects in memory. Caching java objects can help get around bottlenecks arising from using data that is expensive to retrieve (i.e. DB or web service), or data that is hard to calculate. Caching these type of objects in memory can help speed up application performance by retrieving the data directly from memory instead of doing an expensive roundtrip or recalculation. This document specifies how to use JCache with the Infinispan implementation of the specification, and explains key aspects of the API.

## 13.1. Creating embedded caches

### Prerequisites

1. Ensure that `cache-api` is on your classpath.
2. Add the following dependency to your `pom.xml`:

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-jcache</artifactId>
</dependency>
```

### Procedure

- Create embedded caches that use the default JCache API configuration as follows:

```
import javax.cache.*;
import javax.cache.configuration.*;

// Retrieve the system wide cache manager
CacheManager cacheManager = Caching.getCachingProvider().getCacheManager();
// Define a named cache with default JCache configuration
Cache<String, String> cache = cacheManager.createCache("namedCache",
    new MutableConfiguration<String, String>());
```

### 13.1.1. Configuring embedded caches

- Pass the URI for custom Infinispan configuration to the `CachingProvider.getCacheManager(URI)` call as follows:

```
import java.net.URI;
import javax.cache.*;
import javax.cache.configuration.*;

// Load configuration from an absolute filesystem path
URI uri = URI.create("file:///path/to/infinispan.xml");
// Load configuration from a classpath resource
// URI uri = this.getClass().getClassLoader().getResource("infinispan.xml").toURI();

// Create a cache manager using the above configuration
CacheManager cacheManager = Caching.getCachingProvider().getCacheManager(uri, this
    .getClass().getClassLoader(), null);
```



By default, the JCache API specifies that data should be stored as **storeByValue**, so that object state mutations outside of operations to the cache, won't have an impact in the objects stored in the cache. Infinispan has so far implemented this using serialization/marshalling to make copies to store in the cache, and that way adhere to the spec. Hence, if using default JCache configuration with Infinispan, data stored must be marshallable.

Alternatively, JCache can be configured to store data by reference (just like Infinispan or JDK Collections work). To do that, simply call:

```
Cache<String, String> cache = cacheManager.createCache("namedCache",
    new MutableConfiguration<String, String>().setStoreByValue(false));
```

## 13.2. Creating remote caches

### Prerequisites

1. Ensure that **cache-api** is on your classpath.
2. Add the following dependency to your **pom.xml**:

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-jcache-remote</artifactId>
</dependency>
```

### Procedure

- Create caches on remote Infinispan servers and use the default JCache API configuration as follows:

```
import javax.cache.*;
import javax.cache.configuration.*;

// Retrieve the system wide cache manager via
org.infinispan.jcache.remote.JCachingProvider
CacheManager cacheManager = Caching.getCachingProvider(
    "org.infinispan.jcache.remote.JCachingProvider").getCacheManager();
// Define a named cache with default JCache configuration
Cache<String, String> cache = cacheManager.createCache("remoteNamedCache",
    new MutableConfiguration<String, String>());
```

### 13.2.1. Configuring remote caches

Hot Rod configuration files include `infinispan.client.hotrod.cache.*` properties that you can use to customize remote caches.

- Pass the URI for your `hotrod-client.properties` file to the `CachingProvider.getCacheManager(URI)` call as follows:

```
import javax.cache.*;
import javax.cache.configuration.*;

// Load configuration from an absolute filesystem path
URI uri = URI.create("file:///path/to/hotrod-client.properties");
// Load configuration from a classpath resource
// URI uri = this.getClass().getClassLoader().getResource("hotrod-
client.properties").toURI();

// Retrieve the system wide cache manager via
org.infinispan.jcache.remote.JCachingProvider
CacheManager cacheManager = Caching.getCachingProvider(
    "org.infinispan.jcache.remote.JCachingProvider")
    .getCacheManager(uri, this.getClass().getClassLoader(), null);
```

## 13.3. Store and retrieve data

Even though JCache API does not extend neither `java.util.Map` not `java.util.concurrent.ConcurrentMap`, it provides a key/value API to store and retrieve data:

```
import javax.cache.*;
import javax.cache.configuration.*;

CacheManager cacheManager = Caching.getCachingProvider().getCacheManager();
Cache<String, String> cache = cacheManager.createCache("namedCache",
    new MutableConfiguration<String, String>());
cache.put("hello", "world"); // Notice that javax.cache.Cache.put(K) returns void!
String value = cache.get("hello"); // Returns "world"
```

Contrary to standard [java.util.Map](#), [javax.cache.Cache](#) comes with two basic put methods called `put` and `getAndPut`. The former returns `void` whereas the latter returns the previous value associated with the key. So, the equivalent of [java.util.Map.put\(K\)](#) in JCache is [javax.cache.Cache.getAndPut\(K\)](#).



Even though JCache API only covers standalone caching, it can be plugged with a persistence store, and has been designed with clustering or distribution in mind. The reason why [javax.cache.Cache](#) offers two put methods is because standard [java.util.Map](#) `put` call forces implementors to calculate the previous value. When a persistent store is in use, or the cache is distributed, returning the previous value could be an expensive operation, and often users call standard [java.util.Map.put\(K\)](#) without using the return value. Hence, JCache users need to think about whether the return value is relevant to them, in which case they need to call [javax.cache.Cache.getAndPut\(K\)](#), otherwise they can call [java.util.Map.put\(K, V\)](#) which avoids returning the potentially expensive operation of returning the previous value.

## 13.4. Comparing [java.util.concurrent.ConcurrentMap](#) and [javax.cache.Cache](#) APIs

Here's a brief comparison of the data manipulation APIs provided by [java.util.concurrent.ConcurrentMap](#) and [javax.cache.Cache](#) APIs.

Operation	<a href="#">java.util.concurrent.ConcurrentMap&lt;K, V&gt;</a>	<a href="#">javax.cache.Cache&lt;K, V&gt;</a>
store and no return	N/A	<code>void put(K key)</code>
store and return previous value	<code>V put(K key)</code>	<code>V getAndPut(K key)</code>
store if not present	<code>V putIfAbsent(K key, V value)</code>	<code>boolean putIfAbsent(K key, V value)</code>
retrieve	<code>V get(Object key)</code>	<code>V get(K key)</code>
delete if present	<code>V remove(Object key)</code>	<code>boolean remove(K key)</code>
delete and return previous value	<code>V remove(Object key)</code>	<code>V getAndRemove(K key)</code>
delete conditional	<code>boolean remove(Object key, Object value)</code>	<code>boolean remove(K key, V oldValue)</code>

Operation	<code>java.util.concurrent.ConcurrentMap&lt;K, V&gt;</code>	<code>javax.cache.Cache&lt;K, V&gt;</code>
replace if present	<code>V replace(K key, V value)</code>	<code>boolean replace(K key, V value)</code>
replace and return previous value	<code>V replace(K key, V value)</code>	<code>V getAndReplace(K key, V value)</code>
replace conditional	<code>boolean replace(K key, V oldValue, V newValue)</code>	<code>boolean replace(K key, V oldValue, V newValue)</code>

Comparing the two APIs, it's obvious to see that, where possible, JCache avoids returning the previous value to avoid operations doing expensive network or IO operations. This is an overriding principle in the design of JCache API. In fact, there's a set of operations that are present in `java.util.concurrent.ConcurrentMap`, but are not present in the `javax.cache.Cache` because they could be expensive to compute in a distributed cache. The only exception is iterating over the contents of the cache:

Operation	<code>java.util.concurrent.ConcurrentMap&lt;K, V&gt;</code>	<code>javax.cache.Cache&lt;K, V&gt;</code>
calculate size of cache	<code>int size()</code>	N/A
return all keys in the cache	<code>Set&lt;K&gt; keySet()</code>	N/A
return all values in the cache	<code>Collection&lt;V&gt; values()</code>	N/A
return all entries in the cache	<code>Set&lt;Map.Entry&lt;K, V&gt;&gt; entrySet()</code>	N/A
iterate over the cache	use <code>iterator()</code> method on <code>keySet</code> , <code>values</code> or <code>entrySet</code>	<code>Iterator&lt;Cache.Entry&lt;K, V&gt;&gt; iterator()</code>

## 13.5. Clustering JCache instances

Infinispan JCache implementation goes beyond the specification in order to provide the possibility to cluster caches using the standard API. Given a Infinispan configuration file configured to replicate caches like this:

*infinispan.xml*

```
<infinispan>
  <cache-container default-cache="namedCache">
    <transport cluster="jcache-cluster" />
    <replicated-cache name="namedCache" />
  </cache-container>
</infinispan>
```

You can create a cluster of caches using this code:

```

import javax.cache.*;
import java.net.URI;

// For multiple cache managers to be constructed with the standard JCache API
// and live in the same JVM, either their names, or their classloaders, must
// be different.
// This example shows how to force their classloaders to be different.
// An alternative method would have been to duplicate the XML file and give
// it a different name, but this results in unnecessary file duplication.
ClassLoader tccl = Thread.currentThread().getContextClassLoader();
CacheManager cacheManager1 = Caching.getCachingProvider().getCacheManager(
    URI.create("infinispan-jcache-cluster.xml"), new TestClassLoader(tccl));
CacheManager cacheManager2 = Caching.getCachingProvider().getCacheManager(
    URI.create("infinispan-jcache-cluster.xml"), new TestClassLoader(tccl));

Cache<String, String> cache1 = cacheManager1.getCache("namedCache");
Cache<String, String> cache2 = cacheManager2.getCache("namedCache");

cache1.put("hello", "world");
String value = cache2.get("hello"); // Returns "world" if clustering is working

// --

public static class TestClassLoader extends ClassLoader {
    public TestClassLoader(ClassLoader parent) {
        super(parent);
    }
}

```

# Chapter 14. Multimap Cache

MultimapCache is a type of Infinispan Cache that maps keys to values in which each key can contain multiple values.

## 14.1. Installation and configuration

*pom.xml*

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-multimap</artifactId>
</dependency>
```

## 14.2. MultimapCache API

MultimapCache API exposes several methods to interact with the Multimap Cache. These methods are non-blocking in most cases; see [limitations](#) for more information.

```
public interface MultimapCache<K, V> {

    CompletableFuture<Optional<CacheEntry<K, Collection<V>>>> getEntry(K key);

    CompletableFuture<Void> remove(SerializablePredicate<? super V> p);

    CompletableFuture<Void> put(K key, V value);

    CompletableFuture<Collection<V>> get(K key);

    CompletableFuture<Boolean> remove(K key);

    CompletableFuture<Boolean> remove(K key, V value);

    CompletableFuture<Void> remove(Predicate<? super V> p);

    CompletableFuture<Boolean> containsKey(K key);

    CompletableFuture<Boolean> containsValue(V value);

    CompletableFuture<Boolean> containsEntry(K key, V value);

    CompletableFuture<Long> size();

    boolean supportsDuplicates();

}
```



*CompletableFuture<Void> put(K key, V value)*

Puts a key-value pair in the multimap cache.

```
MultimapCache<String, String> multimapCache = ...;

multimapCache.put("girlNames", "marie")
    .thenCompose(r1 -> multimapCache.put("girlNames", "oihana"))
    .thenCompose(r3 -> multimapCache.get("girlNames"))
    .thenAccept(names -> {
        if(names.contains("marie"))
            System.out.println("Marie is a girl name");

        if(names.contains("oihana"))
            System.out.println("Oihana is a girl name");
    });
```

The output of this code is as follows:

```
Marie is a girl name
Oihana is a girl name
```

*CompletableFuture<Collection<V>> get(K key)*

Asynchronous that returns a view collection of the values associated with key in this multimap cache, if any. Any changes to the retrieved collection won't change the values in this multimap cache. When this method returns an empty collection, it means the key was not found.

*CompletableFuture<Boolean> remove(K key)*

Asynchronous that removes the entry associated with the key from the multimap cache, if such exists.

*CompletableFuture<Boolean> remove(K key, V value)*

Asynchronous that removes a key-value pair from the multimap cache, if such exists.

*CompletableFuture<Void> remove(Predicate<? super V> p)*

Asynchronous method. Removes every value that match the given predicate.

*CompletableFuture<Boolean> containsKey(K key)*

Asynchronous that returns true if this multimap contains the key.

*CompletableFuture<Boolean> containsValue(V value)*

Asynchronous that returns true if this multimap contains the value in at least one key.

*CompletableFuture<Boolean> containsEntry(K key, V value)*

Asynchronous that returns true if this multimap contains at least one key-value pair with the value.

*CompletableFuture<Long> size()*

Asynchronous that returns the number of key-value pairs in the multimap cache. It doesn't return

the distinct number of keys.

*boolean supportsDuplicates()*

Asynchronous that returns true if the multimap cache supports duplicates. This means that the content of the multimap can be 'a' → ['1', '1', '2']. For now this method will always return false, as duplicates are not yet supported. The existence of a given value is determined by 'equals' and 'hashCode' method's contract.

## 14.3. Creating a Multimap Cache

Currently the MultimapCache is configured as a regular cache. This can be done either by code or XML configuration. See how to configure a regular Cache in the section link to [\[configure a cache\]](#).

### 14.3.1. Embedded mode

```
// create or obtain your EmbeddedCacheManager
EmbeddedCacheManager cm = ... ;

// create or obtain a MultimapCacheManager passing the EmbeddedCacheManager
MultimapCacheManager multimapCacheManager = EmbeddedMultimapCacheManagerFactory.from(cm);

// define the configuration for the multimap cache
multimapCacheManager.defineConfiguration(multimapCacheName, c.build());

// get the multimap cache
multimapCache = multimapCacheManager.get(multimapCacheName);
```

## 14.4. Limitations

In almost every case the Multimap Cache will behave as a regular Cache, but some limitations exist in the current version, as follows:

### 14.4.1. Support for duplicates

Duplicates are not supported yet. This means that the multimap won't contain any duplicate key-value pair. Whenever put method is called, if the key-value pair already exist, this key-value pair won't be added. Methods used to check if a key-value pair is already present in the Multimap are the `equals` and `hashCode`.

### 14.4.2. Eviction

For now, the eviction works per key, and not per key-value pair. This means that whenever a key is evicted, all the values associated with the key will be evicted too.

### 14.4.3. Transactions

Implicit transactions are supported through the auto-commit and all the methods are non blocking. Explicit transactions work without blocking in most of the cases. Methods that will block are `size`, `containsEntry` and `remove(Predicate<? super V> p)`

# Chapter 15. Anchored Keys module

Infinispan version 11 introduces an experimental module that allows scaling up a cluster and adding new nodes without expensive **state transfer**.

## 15.1. Background

For background, the preferred way to scale up the storage capacity of a Infinispan cluster is to use distributed caches. A distributed cache stores each key/value pair on **num-owners** nodes, and each node can compute the location of a key (aka the key owners) directly.

Infinispan achieves this by statically mapping cache keys to **num-segments** **consistent hash segments**, and then dynamically mapping segments to nodes based on the cache's **topology** (roughly the current plus the historical membership of the cache). Whenever a new node joins the cluster, the cache is **rebalanced**, and the new node replaces an existing node as the owner of some segments. The key/value pairs in those segments are copied to the new node and removed from the no-longer-owner node via **state transfer**.



Because the allocation of segments to nodes is based on random UUIDs generated at start time, it is common (though less so after [ISPN-11679](#) ), for segments to also move from one old node to another old node.

## 15.2. Architecture

The basic idea is to skip the static mapping of keys to segments and to map keys directly to nodes.

When a key/value pair is inserted into the cache, the newest member becomes the **anchor owner** of that key, and the only node storing the actual value. In order to make the anchor location available without an extra remote lookup, all the other nodes store a reference to the anchor owner.

That way, when another node joins, it only needs to receive the location information from the existing nodes, and values can stay on the anchor owner, minimizing the amount of traffic.

## 15.3. Limitations

### Only one node can be added at a time

An external actor (e.g. a Kubernetes/OpenShift operator, or a human administrator) must monitor the load on the current nodes, and add a new node whenever the newest node is close to "full".



Because the anchor owner information is replicated on all the nodes, and values are never moved off a node, the memory usage of each node will keep growing as new entries and nodes are added.

### There is no redundancy

Every value is only stored on a single node. When a node crashes or even stops gracefully, the values stored on that node are lost.

### Transactions are not supported

A later version may add transaction support, but the fact that any node stop or crash loses entries makes transactions a lot less valuable compared to a distributed cache.

### Hot Rod clients do not know the anchor owner

Hot Rod clients cannot use the topology information from the servers to locate the anchor owner. Instead, the server receiving a Hot Rod get request must make an additional request to the anchor owner in order to retrieve the value.

## 15.4. Configuration

The module is still very young and does not yet support many Infinispan features.

Eventually, if it proves useful, it may become another cache mode, just like scattered caches. For now, configuring a cache with anchored keys requires a replicated cache with a custom element `anchored-keys`:

```
<?xml version="1.0" encoding="UTF-8"?>
<infinispan
  xmlns="urn:infinispan:config:12.1"
  xmlns:anchored="urn:infinispan:config:anchored:12.1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="urn:infinispan:config:12.1
    https://infinispan.org/schemas/infinispan-config-12.1.xsd
    urn:infinispan:config:anchored:12.1
    https://infinispan.org/schemas/infinispan-anchored-config-12.1.xsd">

  <cache-container default-cache="default">
    <transport/>
    <replicated-cache name="default">
      <anchored:anchored-keys/>
    </replicated-cache>
  </cache-container>

</infinispan>
```

When the `<anchored-keys/>` element is present, the module automatically enables anchored keys and makes some required configuration changes:

- Disables `await-initial-transfer`
- Enables conflict resolution with the equivalent of

```
<partition-handling when-split="ALLOW_READ_WRITES" merge-policy="PREFER_NON_NULL"/>
```

The cache will fail to start if these attributes are explicitly set to other values, if state transfer is

disabled, or if transactions are enabled.

## 15.5. Implementation status

Basic operations are implemented: `put`, `putIfAbsent`, `get`, `replace`, `remove`, `putAll`, `getAll`.

### 15.5.1. Functional commands

The `FunctionalMap` API is not implemented.

Other operations that rely on the functional API's implementation do not work either: `merge`, `compute`, `computeIfPresent`, `computeIfAbsent`.

### 15.5.2. Partition handling

When a node crashes, surviving nodes do not remove anchor references pointing to that node. In theory, this could allow merges to skip conflict resolution, but currently the `PREFERRED_NON_NULL` merge policy is configured automatically and cannot be changed.

### 15.5.3. Listeners

Cluster listeners and client listeners are implemented and receive the correct notifications.

Non-clustered embedded listeners currently receive notifications on all the nodes, not just the node where the value is stored.

## 15.6. Performance considerations

### 15.6.1. Client/Server Latency

The client always contacts the primary owner, so any read has a  $(N-1)/N$  probability of requiring a unicast RPC from the primary to the anchor owner.

Writes require the primary to send the value to one node and the anchor address to all the other nodes, which is currently done with  $N-1$  unicast RPCs.

In theory we could send in parallel one unicast RPC for the value and one multicast RPC for the address, but that would need additional logic to ignore the address on the anchor owner and with TCP multicast RPCs are implemented as parallel unicasts anyway.

### 15.6.2. Memory overhead

Compared to a distributed cache with one owner, an anchored-keys cache contains copies of all the keys and their locations, plus the overhead of the cache itself.

Therefore, a node with anchored-keys caches should stop accepting new entries when it has less than  $(\text{key size} + \text{per-key overhead}) * \text{number of entries not yet inserted}$  bytes available.



The number of entries not yet inserted is obviously very hard to estimate. In the future we may provide a way to limit the overhead of key location information, e.g. by using a distributed cache.

The per-key overhead is lowest for off-heap storage, around 63 bytes: 8 bytes for the entry reference in `MemoryAddressHash.memory`, 29 bytes for the off-heap entry header, and 26 bytes for the serialized `RemoteMetadata` with the owner's address.

The per-key overhead of the `ConcurrentHashMap`-based on-heap cache, assuming a 64-bit JVM with compressed OOPS, would be around 92 bytes: 32 bytes for `ConcurrentHashMap.Node`, 32 bytes for `MetadataImmutableCacheEntry`, 24 bytes for `RemoteMetadata`, and 4 bytes in the `ConcurrentHashMap.table` array.

### 15.6.3. State transfer

State transfer does not transfer values, only keys and anchor owner information.

Assuming that the values are much bigger compared to the keys, state transfer for an anchored keys cache should also be much faster compared to the state transfer of a distributed cache of a similar size. But for small values, there may not be a visible improvement.

The initial state transfer does not block a joiner from starting, because it will just ask another node for the anchor owner. However, the remote lookups can be expensive, especially in embedded mode, but also in server mode, if the client is not `HASH_DISTRIBUTION_AWARE`.

# Chapter 16. CloudEvents Integration Module (Experimental)

Infinispan version 12 introduces an experimental module that converts Infinispan events to CloudEvents events and sends them to a Kafka topic in structured mode, with the JSON format.

This allows Infinispan be further used as a Knative source.

There are two broad kinds of events, and they can be sent to different Kafka topics:

- Cache entry modifications: created, updated, removed, expired
- Audit events: user login, access denied

## 16.1. Configuration

CloudEvents integration is enabled by adding the module to the global configuration and configuring at least a list of bootstrap Kafka servers and a topic.

```
<?xml version="1.0" encoding="UTF-8"?>
<infinispan
  xmlns="urn:infinispan:config:12.1"
  xmlns:ce="urn:infinispan:config:cloudevents:12.1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="urn:infinispan:config:12.1
    https://infinispan.org/schemas/infinispan-config-12.1.xsd
    urn:infinispan:config:cloudevents:12.1
    https://infinispan.org/schemas/infinispan-cloudevents-config-12.1.xsd">

  <cache-container default-cache="default">
    <transport/>
    <ce:cloudevents bootstrap-servers="127.0.0.1:9092"
      audit-topic="audit"
      cache-entries-topic="cache-events"/>

    <replicated-cache name="default">
      <ce:cloudevents-cache enabled="false"/>
    </replicated-cache>
  </cache-container>

</infinispan>
```



```
GlobalConfigurationBuilder managerBuilder = GlobalConfigurationBuilder
    .defaultClusteredBuilder();
CloudEventsGlobalConfigurationBuilder cloudEventsGlobalBuilder =
    managerBuilder.addModule(CloudEventsGlobalConfigurationBuilder.class);
cloudEventsGlobalBuilder.bootstrapServers("localhost:9092");
cloudEventsGlobalBuilder.cacheEntriesTopic("ispn");
```

Currently only the list of bootstrap servers, the number of acks, and the cache entries/audit topic names are configurable.

## 16.2. Event Format

The events are sent in [Kafka structured mode](#), in the [JSON event format](#)

This is an example of an event:

```
{
  "specversion": "1.0",
  "source": "/infinispan/CLUSTER/testCache",
  "type": "org.infinispan.entry.created",
  "time": "2020-10-29T22:05:08.767950Z",
  "subject": "key-1",
  "id": "key-1:CommandInvocation:Test-NodeA:0",
  "data": {
    "property": "value"
  }
}
```

The **source** field starts with `/infinispan/`, then the cluster name, and ends with the cache name.

The **type** field is a straightforward mapping of the Infinispan cache entry event types, prefixed with `org.infinispan.entry`.

The **data** field is the new entry value (or the old value, for remove events). If the value is Protostream-encoded, a Java object that can be marshalled to Protostream, or a Java primitive wrapper, it is converted to JSON. If the value is not encoded with Protostream or it is a Java object and the cache manager is configured to use another marshaller, the marshalled value is written as a string. If the marshalled value is not a valid UTF-8 string, it is first Base64-encoded.

The **subject** field is the affected cache key, converted to a string using the same mechanism as the values. The only difference is that the resulting JSON is also wrapped in a string.

TODO: The JSON conversion currently adds `\n` and space characters, which are escaped and preserved in the **subject** field value. We may want to Base64-encode protostream keys instead.

The **id** field is composed from the key and a transaction/invoke id. Expiration events do not have an invoke id, so a random id is generated instead.

# Chapter 17. Infinispan Modules for WildFly

To use Infinispan inside applications deployed to WildFly, you should install Infinispan modules that:

- Let you deploy applications without packaging Infinispan JAR files in your WAR or EAR file.
- Allow you to use a Infinispan version that is independent to the one bundled with WildFly.



Infinispan modules are deprecated and planned for removal. These modules provide a temporary solution until WildFly directly manages the `infinispan` subsystem.

## 17.1. Installing Infinispan Modules

Download and install Infinispan modules for WildFly.

### *Prerequisites*

1. JDK 8 or later.
2. An existing WildFly installation.

### *Procedure*

1. Download the ZIP archive for the modules from the [Infinispan software downloads](#).
2. Extract the ZIP archive and copy the contents of `modules` to the `modules` directory of your WildFly installation so that you get the resulting structure:

```
$WILDFLY_HOME/modules/system/add-ons/{moduleprefix}/org/infinispan/ispn-12.1
```

## 17.2. Configuring Applications to Use Infinispan Modules

After you install Infinispan modules for WildFly, configure your application to use Infinispan functionality.

### *Procedure*

1. In your project `pom.xml` file, mark the required Infinispan dependencies as *provided*.
2. Configure your artifact archiver to generate the appropriate `MANIFEST.MF` file.

```

<dependencies>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-core</artifactId>
    <scope>provided</scope>
  </dependency>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-cache-store-jdbc</artifactId>
    <scope>provided</scope>
  </dependency>
</dependencies>
<build>
  <plugins>
    <plugin>
      <groupId>org.apache.maven.plugins</groupId>
      <artifactId>maven-war-plugin</artifactId>
      <configuration>
        <archive>
          <manifestEntries>
            <Dependencies>org.infinispan:ispn-12.1 services</Dependencies>
          </manifestEntries>
        </archive>
      </configuration>
    </plugin>
  </plugins>
</build>

```

Infinispan functionality is packaged as a single module, `org.infinispan`, that you can add as an entry to your application's manifest as follows:

#### *MANIFEST.MF*

```

Manifest-Version: 1.0
Dependencies: org.infinispan:ispn-12.1 services

```

#### *AWS dependencies*

If you require AWS dependencies, such as S3\_PING, add the following module to your application's manifest:

```

Manifest-Version: 1.0
Dependencies: com.amazonaws.aws-java-sdk:ispn-12.1 services

```

# Chapter 18. Custom Interceptors



Custom interceptors are deprecated in Infinispan and will be removed in a future version.

Custom interceptors are a way of extending Infinispan by being able to influence or respond to any modifications to cache. Example of such modifications are: elements are added/removed/updated or transactions are committed.

## 18.1. Adding custom interceptors declaratively

Custom interceptors can be added on a per named cache basis. This is because each named cache have its own interceptor stack. Following xml snippet depicts the ways in which a custom interceptor can be added.

```
<local-cache name="cacheWithCustomInterceptors">
  <!-- Define custom interceptors. -->
  <!-- Custom interceptors should extend
       org.infinispan.interceptors.BaseCustomAsyncInterceptor -->
  <custom-interceptors>
    <interceptor position="FIRST" class="com.mycompany.CustomInterceptor1">
      <property name="attributeOne">value1</property>
      <property name="attributeTwo">value2</property>
    </interceptor>
    <interceptor position="LAST" class="com.mycompany.CustomInterceptor2"/>
    <interceptor index="3" class="com.mycompany.CustomInterceptor1"/>
    <interceptor before="org.infinispan.interceptors.CallInterceptor"
                  class="com.mycompany.CustomInterceptor2"/>
    <interceptor after="org.infinispan.interceptors.CallInterceptor"
                  class="com.mycompany.CustomInterceptor1"/>
  </custom-interceptors>
</local-cache>
```

## 18.2. Adding custom interceptors programmatically

In order to do that one needs to obtain a reference to the `AdvancedCache`. This can be done as follows:

```
CacheManager cm = getCacheManager();//magic
Cache aCache = cm.getCache("aName");
AdvancedCache advCache = aCache.getAdvancedCache();
```

Then one of the `addInterceptor()` methods should be used to add the actual interceptor. For further documentation refer to `AdvancedCache` javadoc.

## 18.3. Custom interceptor design

When writing a custom interceptor, you need to abide by the following rules.

- Custom interceptors must declare a public, empty constructor to enable construction.
- Custom interceptors will have setters for any property defined through property tags used in the XML configuration.

# Chapter 19. Extending Infinispan

Infinispan can be extended to provide the ability for an end user to add additional configurations, operations and components outside of the scope of the ones normally provided by Infinispan.

## 19.1. Custom Commands

Infinispan makes use of a [command/visitor pattern](#) to implement the various top-level methods you see on the public-facing API.

While the core commands - and their corresponding visitors - are hard-coded as a part of Infinispan's core module, module authors can extend and enhance Infinispan by creating new custom commands.

As a module author (such as [infinispan-query](#), etc.) you can define your own commands.

You do so by:

1. Create a `META-INF/services/org.infinispan.commands.module.ModuleCommandExtensions` file and ensure this is packaged in your jar.
2. Implementing `ModuleCommandFactory` and `ModuleCommandExtensions`
3. Specifying the fully-qualified class name of the `ModuleCommandExtensions` implementation in `META-INF/services/org.infinispan.commands.module.ModuleCommandExtensions`.
4. Implement your custom commands and visitors for these commands

### 19.1.1. An Example

Here is an example of an `META-INF/services/org.infinispan.commands.module.ModuleCommandExtensions` file, configured accordingly:

*org.infinispan.commands.module.ModuleCommandExtensions*

```
org.infinispan.query.QueryModuleCommandExtensions
```

### 19.1.2. Preassigned Custom Command Id Ranges

This is the list of `Command` identifiers that are used by Infinispan based modules or frameworks. Infinispan users should avoid using ids within these ranges. (RANGES to be finalised yet!) Being this a single byte, ranges can't be too large.

Infinispan Query:	100 - 119
Hibernate Search:	120 - 139
Hot Rod Server:	140 - 141

## 19.2. Extending the configuration builders and parsers

If your custom module requires configuration, it is possible to enhance Infinispan's configuration builders and parsers. Look at the [custom module tests](#) for a detail example on how to implement this.